नेपाल सरकार
सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालय

स्थानीय विकास प्रशिक्षण प्रतिष्ठान
Local Development Training Academy

प्रशिक्षकका लागि

स्थानीय तहका लागि तयार पारिएको प्रशिक्षण सामग्री

चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

प्रशिक्षण सामग्रीको बनावटः
१. प्रशिक्षण मार्गदर्शन
२. प्रशिक्षण योजना
३. सत्र योजना (अभ्यास पत्र समेत)
४. प्रस्तुति सामग्री (पावरप्वाइन्ट स्लाइड)
५. सहभागीका लागि अध्ययन सामग्री
६. मूल्याङ्कनका औजारहरू

मोड्युल २१

नेपाल सरकार
सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालय

स्थानीय विकास प्रशिक्षण प्रतिष्ठान
(स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)
Local Development Training Academy
(Established under the Local Development Training Academy Act, 2049)
"An Autonomous, Professional, Client Centered, Gender Responsive National Institute of Excellence in the area of Local-Self Governance."
LDTA>>>

प्रशिक्षकका लागि

स्थानीय तहका लागि तयार पारिएको प्रशिक्षण सामग्री

चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

२०७८ असार

मोड्युल २१

प्रकाशकः

सर्वाधिकारः

प्रकाशनः २०७८ असार

प्रशिक्षण सामग्री निर्माणमा संलग्न सदस्यहरू

श्री पीतकुमार श्रेष्ठ, स्थानीय विकास प्रशिक्षण प्रतिष्ठान, ललितपुर

श्री जयकृष्ण श्रेष्ठ, स्थानीय विकास प्रशिक्षण प्रतिष्ठान, ललितपुर

श्री योग माया सापकोटा, स्थानीय विकास प्रशिक्षण प्रतिष्ठान, ललितपुर

प्राविधिक सहयोग

डा. श्रीराम शर्मा, परामर्शदाता

भाषा सम्पादनः

सम्पर्कका लागिः

मन्तव्य

दुई शब्द

स्थानीय विकास प्रशिक्षण प्रतिष्ठानले चट्याङ्गबाट हुने मानविय क्षति, वस्तुभाउको क्षति, भौतिक संरचना, विद्युतीय सामाग्री तथा अन्य क्षतिको परिमाण र प्रकृतिको बारेमा स्थानीय तहहरुको क्षमता अभिबृद्धि गर्ने उद्देश्यले **चट्टयाङ्ग र विद्युतीय लेखा परीक्षण** विषयक तीन दिने प्रशिक्षणको पाठ्यक्रम तयार गरेको छ। यस पाठ्यक्रमको उपयोग गरी स्थानीय तहहरुमा भौतिक संरचनामा चट्याङ्ग प्रतिरक्षी प्रणाली जडान गर्ने प्रविधिको उपयोग गर्ने क्षमता विकास हुने र विद्युतीय गडबडीका कारण हुने दुर्घटना न्यूनीकरण भएर मानवीय तथा भौतिक क्षति कम हुने अपेक्षा गरिएको छ।

प्रतिष्ठानलाई उक्त कार्यको महत्वपूर्ण जिम्मेवारी दिनुहुने सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालयका सचिवज्यू, सह–सचिवज्यूहरू, उप–सचिवज्यूहरूलगायत सम्पूर्ण मन्त्रालय परिवारप्रति हार्दिक आभार व्यक्त गर्दछु। प्रतिष्ठानलाई वर्तमान स्थितिमा ल्याइपुऱ्याउनमा प्रतिष्ठानमा कार्यरत कर्मचारीहरूको लगनशीलता, मिहिनेत, दूरदृष्टि पनि उत्तिकै महत्वपूर्ण छ, म यसका लागि प्रतिष्ठानका सम्पूर्ण कर्मचारीहरूलाई धन्यवाद दिन्छु। सङ्घीय संरचनाअन्तर्गत स्थानीय तहको क्षमता अभिवृद्धि गर्न प्रतिष्ठान सधैं प्रतिबद्ध रहने र मागमा आधारित उपयोगी कार्यक्रमहरूका साथ निरन्तर अगाडि बढ्ने कुरामा विश्वास दिलाउँदै प्रतिष्ठानले पाएको स्नेह, सहयोग र सद्भाव निरन्तर रूपमा सबै क्षेत्रबाट पाइरहने अपेक्षा गरेको छु।

अन्त्यमा, यो पाठ्क्रम निर्माण गर्न उल्लेख्य भूमिका खेल्नुहुने विज्ञ डा. श्रीराम शर्मा र स्थानीय विकास प्रशिक्षण प्रतिष्ठानका निर्देशक श्री जयकृष्ण श्रेष्ठ र व्यवस्थापन अधिकृत श्री योग माया सापकोटालगायत अन्य सहयोगी कर्मचारीहरुलाई हार्दिक धन्यवाद व्यक्त गर्दै प्रशिक्षणको सफलता, प्रशिक्षण सामग्रीको सार्थकता र लक्ष्य प्राप्तिका लागि समेत हार्दिक शुभकामना व्यक्त गर्दछु।

पीतकुमार श्रेष्ठ
कार्यकारी निर्देशक
स्थानीय विकास प्रशिक्षण प्रतिष्ठान

विषयसूची

प्रशिक्षण मार्गदर्शन

प्रशिक्षण सामग्रीबारे

स्थानीय विकासको कार्यसँग सम्बन्धित स्थानीय तहहरूको प्रशासनिक एवं व्यवस्थापनसम्बन्धी दक्षता अभिवृद्धि गर्ने उद्देश्यले त्यस्ता निकायहरूमा संलग्न जनप्रतिनिधिहरू एवम् कार्यरत कर्मचारीहरूलाई योजनाबद्ध तरिकाले उच्चस्तरीय प्रशिक्षणको व्यवस्था गरी स्थानीय स्तरमा ती निकायहरूको संस्थागत विकासमा सघाउ पुऱ्याउन स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन २०४९ अन्तर्गत वि.सं. २०५० सालमा स्थापना भएको यो एक स्वशासित र सङ्गठित संस्थाका रूपमा रहेको छ। प्रतिष्ठानको मुख्य उद्देश्य प्रशिक्षण स्थानीय विकास कार्यसँग सम्बन्धित स्थानीय तहका व्यक्तिहरूका लागि आवश्यक पर्ने प्रशिक्षणको व्यवस्था गर्ने, प्रशिक्षण केन्द्रद्वारा सञ्चालन गरिने प्रशिक्षण कार्यक्रमसम्बन्धी अनुसन्धान गर्ने र प्रशिक्षण केन्द्रद्वारा सञ्चालन गरिने प्रशिक्षण कार्यक्रमलाई बढी उपयोगी तुल्याउन तथा प्रशिक्षण सामग्री तयार गर्नका लागि समस्यामूलक अनुसन्धान, परामर्श सेवा तथा सूचना सेवासम्बन्धी कार्यक्रमहरू सञ्चालन गर्ने रहेको छ।

यो प्रशिक्षण सामग्री सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालयको निर्देशनमा स्थानीय विकास प्रशिक्षण प्रतिष्ठानबाट तयार पारिएको हो । यस **तीन दिने** प्रशिक्षण सामग्रीले **चट्टयाङ्ग र विद्युतीय लेखा परीक्षण** प्रशिक्षणलाई प्रभावकारी बनाउन प्रशिक्षकहरूलाई महत्त्वपूर्ण मार्गदर्शन हुने अपेक्षा गरिएको छ।

प्रशिक्षण सामग्रीको उद्देश्य

यस प्रशिक्षण सामग्रीको उद्देश्य गाउँपालिका/नगरपालिकाहरूमा कार्यान्वयन गरिने **चट्टयाङ्ग र विद्युतीय लेखा परीक्षण** प्रशिक्षण कार्यलाई प्रभावकारी र गुणस्तरीय बनाउनुका साथै प्रशिक्षण कार्यमा एकरूपता ल्याई प्रशिक्षणलाई सहभागितामूलक बनाउनु हो।

प्रशिक्षण सामग्रीको बनावट

यस प्रशिक्षण सामग्रीलाई चार खण्डमा विभाजन गरिएको छ। पहिलो खण्डमा प्रशिक्षण सामग्री र यसको प्रयोग गर्ने तरिका (Instsruction to user) उल्लेख गरिएको छ। दोस्रो खण्डमा प्रशिक्षण योजना, प्रशिक्षण तालिका समावेश गरिएको छ । तेस्रो खण्डमा प्रशिक्षणका प्रत्येक सत्रका विषयवस्तुहरूको पाठयोजना, पावरप्वाइन्ट स्लाइडहरू र विषयवस्तुसँग सम्बन्धित अध्ययन सामग्री समेटिएको छ भने अन्तिम खण्डमा प्रशिक्षण मूल्याङ्कनका औजारहरू समावेश गरिएको छ। यसका विषयवस्तुहरूलाई सङ्क्षिप्तमा तल उल्लेख गरिएको छ।

१. प्रशिक्षण सामग्रीको प्रयोग गर्ने तरिका

यसमा प्रशिक्षण सामग्रीको पृष्ठभूमि, यसको उद्देश्य, प्रशिक्षण सामग्रीमा समावेश गरिएका विषयवस्तुहरू, प्रशिक्षण सामग्री प्रयोग गर्ने तरिका, प्रशिक्षणका विधिहरू र तिनको सञ्चालन प्रक्रिया, अध्ययन सामग्री, प्रशिक्षण मूल्याङ्कनका औजारहरू, प्रशिक्षणका प्रयोगकर्ता आदि समावेश गरिएको छ।

२. प्रशिक्षण योजना

प्रशिक्षण योजना प्रशिक्षण सञ्चालनका लागि तयार पारिएको प्रशिक्षणको समग्र खाका हो। यसमा प्रशिक्षणका साधारण र निर्दिष्ट उद्देश्य, प्रशिक्षणका विषयवस्तु, प्रशिक्षण सञ्चालन विधि र प्रशिक्षण सामग्री उल्लेख गरिएको छ।

३. प्रशिक्षण दैनिक तालिका

प्रशिक्षण दैनिक तालिकामा हरेक दिनका क्रियाकलाप र विषयवस्तु र तिनका लागि आवश्यक समय उल्लेख गरिएको छ ।

४. पाठयोजना

पाठयोजना हरेक सत्र सञ्चालनका लागि मार्गदर्शन हो । यसमा सत्रका साधारण र निर्दिष्ट उद्देश्य, सत्रका विषयवस्तु, प्रशिक्षण क्रियाकलापको विस्तृत विवरण, प्रशिक्षण विधि, प्रशिक्षण सामग्री र आवश्यक समय उल्लेख गरिएको छ । यसमा सत्रका निर्दिष्ट उद्देश्य हासिल भए वा भएनन् थाहा पाउनका लागि सत्र मूल्याङ्कन विधिसमेत उल्लेख गरिएको छ ।

५. पावरप्वाइन्ट स्लाइड

प्रशिक्षण सत्र सञ्चालनका लागि आवश्यक पावरप्वाइन्ट स्लाइडहरू यस सामग्रीमा क्रमबद्ध रूपमा समावेश गरिएका छन् । सत्रका साधारण र निर्दिष्ट उद्देश्य, सत्रका विषयवस्तुहरू, समूह कार्य वा अभ्यास र सो अभ्यास सञ्चालनका लागि गर्नुपर्ने क्रियाकलाप पनि पावरप्वाइन्ट स्लाइडमा उल्लेख गरिएको छ ।

६. अध्ययन सामग्री

प्रशिक्षणका विषयवस्तु र प्रस्तुतीकरणसँग सम्बन्धित सामग्रीहरूको विस्तृत विवरण अध्ययनसामग्रीका रूपमा यस सामग्रीभित्र समावेश गरिएको छ । यी सामग्रीहरूलाई प्रशिक्षण सत्रका आधारमा छुट्याई क्रमबद्ध रूपमा व्यवस्थित गरिएको छ ।

७. प्रशिक्षण मूल्याङ्कनका औजारहरू

प्रशिक्षणको प्रभावकारिता मापनका लागि निम्नलिखित औजारहरू समावेश गरिएका छन् ।

(क) प्रशिक्षणपूर्व र प्रशिक्षणपश्चात् जानकारी

यसअन्तर्गत प्रशिक्षणका विषयवस्तुहरूमा सहभागीहरूको बुझाइको अवस्था थाहा पाउन प्रशिक्षणका विषयवस्तुहरूसँग सम्बन्धी प्रश्नहरू निर्धारण गरी प्रशिक्षणको सुरुमा पूर्व जानकारी र अन्तमा पश्चात् जानकारी लिइन्छ। यसले प्रशिक्षणका कारण सहभागीहरूको ज्ञान र सिपमा आएको परिवर्तन मापन गर्न सहयोग गर्दछ ।

(ख) दैनिक पृष्ठपोषण फाराम

हरेक दिनको अन्तमा दिनभरि भएका छलफलहरूमा सहभागीहरूको सिकाइ थाहा पाउन दैनिक पृष्ठपोषण फारामको प्रयोग गरिन्छ । यसबाट सहभागीहरूले सिकेका र सिकेका कुरालाई कहाँ र कसरी प्रयोग गर्ने भन्ने बारेमा र प्रशिक्षणलाई अझ प्रभावकारी सुधार गर्नुपर्ने सुझाव पाउन सकिन्छ ।

(ग) प्रशिक्षण सुधारका लागि प्रश्नावली

यो प्रश्नावली प्रशिक्षणको अन्त्यमा सहभागीलाई वितरण गरी उनीहरूको प्रतिक्रिया लिन प्रयोग गरिन्छ। यसबाट (१) प्रशिक्षणको समग्र मूल्याङ्कन, (२) सहजकर्ताप्रतिको दृष्टिकोण, (३) प्रशिक्षणमा उपलब्ध गराइएका पाठ्यसामग्रीको प्रभावकारिता, (४) प्रशिक्षणका विषयवस्तुको उपयुक्तता र (५) प्रशिक्षणमा प्रयोग भएका प्रशिक्षण विधिहरूको सान्दर्भिकता जाँच गरिन्छ।

प्रशिक्षण कार्यक्रमको मूल्याङ्कन

प्रशिक्षण कार्यक्रमको प्रभावकारितालाई मुख्यतः चारवटा तहमा मूल्याङ्कन गरिनुपर्दछ । सहभागीहरूको प्रशिक्षणप्रतिको प्रतिक्रिया, उनीहरूको सिकाइको स्तर, प्रशिक्षण कार्यक्रमले सहभागीहरूको दैनिक व्यवहार र उनीहरूको दैनिक कार्यसम्पादनमा ल्याएको परिवर्तन र सो परिवर्तनको परिणामस्वरूप समग्र संस्थाको कार्यसम्पादनमा आएको परिवर्तनलाई प्रशिक्षण प्रभावकारिता मूल्याङ्कनका आधार बनाइनु पर्दछ।

प्रशिक्षण सामग्रीको प्रयोग विधि

चट्टयाङ्ग र विद्युतीय लेखा परीक्षण प्रशिक्षणको प्रस्तुतिलाई व्यवस्थित र पूर्ण गराउनका लागि पाठयोजनाको अनुसरण गर्नुपर्दछ। यस सामग्रीमा व्यवस्था गरिएको पाठयोजनालाई अनुसरण गरी सहज तरिकाले सत्र सञ्चालन गर्न क्रियाकलाप शीर्षकअन्तर्गत विषयवस्तुलाई विस्तृत रूपमा प्रस्तुत गरिएको छ । विषयप्रस्तुति अगाडि विषयप्रति रुचि जगाउने, विषयको महत्त्व दर्साउने जस्ता कार्य प्रशिक्षक आफैँले विकास गरी सत्र सञ्चालन गर्न सक्ने छन्। प्रशिक्षकले विषयवस्तुको अध्ययन सामग्री राम्रोसँग अध्ययन गरी विषयको प्रभावकारी प्रस्तुतीकरणका लागि आवश्यक दृश्य सामग्रीको तयारी/सङ्कलनसमेत गर्न सक्ने छन्। यसका साथै प्रशिक्षकले प्रशिक्षण सामग्रीमा उल्लेख गरिएका पावरप्वाइन्ट स्लाइड र अध्ययन सामग्रीमा समावेश गरिएका चित्र, चार्ट, ग्राफ आदिलाई आवश्यकताअनुसार तिनको आकार विस्तार गरी प्रस्तुत गर्न सक्ने छन्। सत्रहरूको प्रस्तुतीकरणका लागि सिलसिलेबार रूपमा पावरप्वाइन्ट स्लाइडहरू समावेश गरिएको छ । प्रशिक्षणको प्रभावकारिता र प्रशिक्षण प्रभावकारिताको मापनका लागि प्रशिक्षण मूल्याङ्कनका औजारहरूसमेत सामग्रीमा समावेश गरिएका छन्। तिनलाई उपयुक्त तरिकाले प्रयोग गरिनु आवश्यक छ ।

अध्ययन सामग्री

प्रस्तुत सामग्रीमा समावेश गरिएका अध्ययन सामग्रीहरू **चट्टयाङ्ग र विद्युतीय लेखा परीक्षण** प्रशिक्षणसँग सम्बन्धित विभिन्न निकायहरूका प्रकाशन, प्रशिक्षण सामग्री, नेपाल सरकारले गरेका नीतिगत व्यवस्थाहरू आदिलाई आधार मानी तयार गरिएको छ । यी अध्ययन सामग्रीहरू केवल सन्दर्भ सामग्री मात्र हुन्। यिनलाई समय समयमा अद्यावधिक गराउनु पर्दछ।

प्रशिक्षण सामग्रीको प्रयोगकर्ता

यो प्रशिक्षण सामग्री **चट्टयाङ्ग र विद्युतीय लेखा परीक्षण** प्रशिक्षणमा रुचि राख्ने जोसुकैका लागि उपयोगी हुने छ । यो विशेष गरी **चट्टयाङ्ग र विद्युतीय लेखा परीक्षण** प्रशिक्षण सहजकर्ताहरूलाई ध्यानमा राखी तयार पारिएको छ तर यस सामग्रीको उपयुक्तताको ठहर गर्ने जोसुकैले पनि यसको प्रयोग गर्न सक्ने छन् । यसका प्रयोगकर्ताले यसमा उल्लिखित विधि, प्रक्रिया, समय, सामग्री जस्ता पक्षहरूलाई हुबहु उतार्नुभन्दा यसमा उल्लिखित मार्गदर्शन र स्थानीय परिवेशअनुसार यसलाई सहयोगी सामग्रीका रूपमा बुझेर प्रयोग गर्नु उपयुक्त हुने छ । स्थानीय परिवेशअनुसार यस निर्देशिकाको म ूल मर्मलाई ध्यानमा राखी सहजकर्ता/प्रशिक्षकले अन्य रचनात्मक गतिविधिसमेत अँगाल्न सक्ने छन् ।

प्रशिक्षण विधि र प्रयोग तरिका

प्रशिक्षकको सहजीकरणलाई व्यवस्थित गर्नका लागि पाठयोजनामा प्रशिक्षण विधिहरू उल्लेख गरिएका छन् । प्रशिक्षण कार्यक्रमलाई सहभागितामूलक र प्रभावकारी बनाउन निम्न विधिहरू प्रयोग गर्न सकिने छ ।

क) समूह छलफल

सहभागितामूलक प्रक्रियाबाट प्रशिक्षण सञ्चालन गर्नका लागि समूह छलफल एक महत्त्वपूर्ण विधि हो । समूह छलफलका लागि निम्न प्रक्रिया अपनाउनुपर्ने हुन्छः

- समूह विभाजन गर्दा सकभर सहभागी सङ्ख्या बराबर बनाउने, सहभागीको स्तरलाई ध्यान दिने ।
- समूह छलफलका लागि विषयवस्तु किटानी गर्ने ।
- छलफलको विषयअनुसार स्थान र समय निर्धारण गर्ने ।
- सहजकर्ताले छलफल प्रक्रिया बताउने । जस्तैः
    - समूहमा संयोजक, प्रतिवेदक चयन गर्ने ।
    - समूहमा सबैको भनाइ समेटिनुपर्ने ।
    - समूहको निचोड ठुलो कागजमा तयार गर्ने ।
    - संयोजकले समूहकार्य प्रस्तुत गर्ने आदि ।
- समूहमा खुल्ला छलफल चलाउन प्रेरित गर्ने ।
- सहजकर्ताले छलफलको सन्दर्भ र विषयवस्तुलाई आधार मानी आफ्नो निष्कर्ष दिने ।

ख) खेल

खेल विधिले विषयवस्तुलाई सजिलै प्रस्ट पार्न सहयोग गर्दछ । खेल विधिबाट सिकेका सिकाइहरू चिरस्थायी हुन्छन् ।

सञ्चालन प्रक्रिया

- खेलको प्रकृतिअनुसार सहभागी सङ्ख्या छनोट गर्ने । शारीरिक शक्ति प्रयोग गर्नुपर्ने खेल भए शारीरिक रूपमा अशक्त व्यक्तिलाई उसको अनुमतिमा बाहिर राख्ने ।
- लैङ्गिक संवेदनशीलताका पक्षमा ध्यान दिने ।
- समय निर्धारण गर्ने । खेललाई २० मिनेटभन्दा बढी समय दिनु उपयुक्त हुँदैन ।
- खेलमा पालना गर्नुपर्ने नीतिनियम प्रस्ट पार्ने ।
- खेलका लागि आवश्यक सामग्री तयार गर्ने ।
- खेल सकिएपछि खेलबाट भएका सिकाइहरू छलफल गर्ने ।
- खेलका लागि सबैलाई धन्यवाद दिने ।

ग) प्रश्नोत्तर

कुनै विषयवस्तुबारे सहभागीहरूको बुझाइ थाहा पाउनका लागि प्रश्न गर्ने, उत्तर लिने र सोअनुसार सहजकर्ताले विषयवस्तु प्रस्ट पार्ने प्रक्रिया नै प्रश्नोत्तर विधि हो । यसले सहभागीहरूको ध्यान विषयवस्तुप्रति आकर्षित गर्न मदत गर्दछ । सहजकर्ताले प्रश्नोत्तर सिपमा विशेष ध्यान पुर्याउनु पर्दछ ।

घ) साना समूह छलफल

यो विधि प्रशिक्षण कार्यका सन्दर्भमा छिट्टै छलफल गरी तत्कालै विषयवस्तुको निष्कर्षमा पुऱ्याउन उपयोगी हुन्छ । २/३ जना सहभागीबिच बसेकै स्थानमा आमनेसामने भई यो विधिमार्फत विषयवस्तुको निचोड निकाल्न सकिन्छ । यस विधिले सिकाइलाई मूर्त रूप दिन मदत गर्दछ ।

सञ्चालन प्रक्रिया

- सहजकर्ताले छलफलको विषय र समय निर्धारण गर्ने ।
- नजिकैका २/३ जना सहभागीलाई आमनेसामने बस्न भन्ने ।
- छलफल गर्न लगाउने । छलफलका मुख्य कुरा टिपोट गर्न भन्ने ।
- छलफलको निचोडलाई मेटाकार्ड दिई लेख्न लगाउने ।
- छलफल सकिएपछि क्रमिक रूपमा सहभागी समूहलाई आफ्नो निचोड प्रस्तुत गर्न लगाउने, छलफल गर्ने, कार्ड सफ्ट बोर्डमा टास्ने ।
- सहभागीको प्रस्तुतिपश्चात् सहजर्ताले विषयवस्तुको सन्दर्भ र तात्पर्य मिलाई निष्कर्ष निकाल्ने ।

ङ) मस्तिष्क मन्थन

सहभागीले आफ्नो विचार मन्थन गरी विषयवस्तुलाई निर्णयमा पुऱ्याउने विधि नै मस्तिष्क मन्थन विधि (Brainstorming) हो ।

सञ्चालन प्रक्रिया

- छलफलको विषय / प्रश्न प्रस्ट रूपमा राख्ने ।
- सोच्नका लागि समय दिने ।
- सहभागीहरूका विचारलाई सङ्गठित गर्दै टिपोट गर्ने, छलफल चलाउने ।
- भनाइलाई निष्कर्षमा पुऱ्याउने ।

च) अभ्यास

सहभागीको प्रत्यक्ष संलग्नतामा सिकाइ आर्जन गर्न यो विधि महत्त्वपूर्ण हुन्छ । यो विधि जीवन र जगतसँग सम्बन्धित घटनामा आधारित कुराहरू प्रस्ट पार्न प्रयोग गरिन्छ ।

सञ्चालन प्रक्रिया

- सहजकर्ताले घटना वा सवाल समूहबिच राख्ने ।
- विषयअनुसार समय निर्धारण गर्ने ।
- सवालका निष्कर्ष निकाल्न लगाउने ।
- अभ्यासबाट निकालिएको निष्कर्षलाई सहजकर्ताले छलफल चलाई अन्तिम निष्कर्ष निकाल्ने ।

ज) लघु प्रवचन

यो प्रशिक्षणको सबैभन्दा महत्त्वपूर्ण विधि हो । यसमार्फत विषयवस्तुलाई सहभागीहरूसमक्ष सहज रूपमा प्रस्तुत गर्न सकिन्छ । नामअनुसार नै यो विधिमार्फत गरिने प्रस्तुतीकरण छोटो र सहभागितामूलक हुनु पर्दछ । प्रशिक्षकले एकोहोरो रूपमा लामो समयसम्म प्रस्तुतीकरण गर्नु हुँदैन । प्रस्तुतीकरणका सिलसिलामा सहभागीहरूलाई पनि संलग्न गराउँदै जानु पर्दछ ।

प्रशिक्षकलाई प्रश्नः

१. सत्रका विषयवस्तुको राम्ररी अध्ययन गर्नुभएको छ ?
२. सत्र सञ्चालनका लागि पाठयोजनाको अध्ययन गर्नुभएको छ ?
३. सहभागीहरूको पृष्ठभूमि तथा स्तरका बारेमा सोच्नुभएको छ ?
४. सत्रका लागि चाहिने आवश्यक प्रशिक्षण सामग्रीहरू जुटाउनुभएको छ ?
५. प्रस्तुतीकरणका बुँदाहरूको राम्ररी अध्ययन गर्नुभएको छ ?
६. प्रस्तुतीकरणमा बढी महत्त्व दिनुपर्ने बुँदाहरूको निर्क्योल गर्नुभएको छ ?
७. प्रस्तुतीकरणमा विशेष जोड दिनका लागि आवश्यक उदाहरणहरूको चयन गर्नुभएको छ ?
८. प्रशिक्षण सारांशका बुँदाहरू तय गर्नुभएको छ ?
९. सत्रप्रति रुचि जगाउन तथा सहभागिता बढाउन आवश्यक पर्ने विधिहरूको चयन गर्नुभएको छ ?
१०. समयभित्र सत्र पूरा गर्न राम्ररी योजना गर्नुभएको छ ?
११. सत्र सञ्चालनका लागि आवश्यक पर्ने भौतिक सामग्रीहरू, जस्तैः सेतो पाटी, फ्लिपचार्ट, खैरो कागज, मेटाकार्ड, मार्कर, मास्किङ टेप, कागज, कलम, कैँची, चित्रहरूको व्यवस्था गर्नुभएको छ ?
१२. प्रशिक्षण हल, बसाइ व्यवस्थापन, कोठाको तापक्रम, हावा, प्रकाश इत्यादिका बारेमा सोच्नुभएको छ ?

प्रशिक्षण योजना

प्रशिक्षण योजना

मोड्युल/विषय	**चट्टयाङ्ग र विद्युतीय लेखा परीक्षण**
मिति	
स्थान	नगरपालिका वा गाउँपालिका
सहजकर्ता	

लक्षित सहभागीहरु

- गाउँपालिका तथा नगरपालिकाका प्राविधिक कर्मचारीहरू

साधारण उद्देश्य

- सहभागीहरुको बढ्दो शहरीकरणको अवस्थामा विद्युतीय र चट्टयाङ्गजन्य दुर्घटनाहरुको उल्लेखिय बृद्धि कारणले उक्त दुर्घटनाको न्यूनीकरण गर्न सक्ने ज्ञान र सीपमा अभिबृद्धि हुनेछ।

निर्दिष्ट उद्देश्यहरू यस प्रशिक्षणको अन्तमा सहभागीहरूले

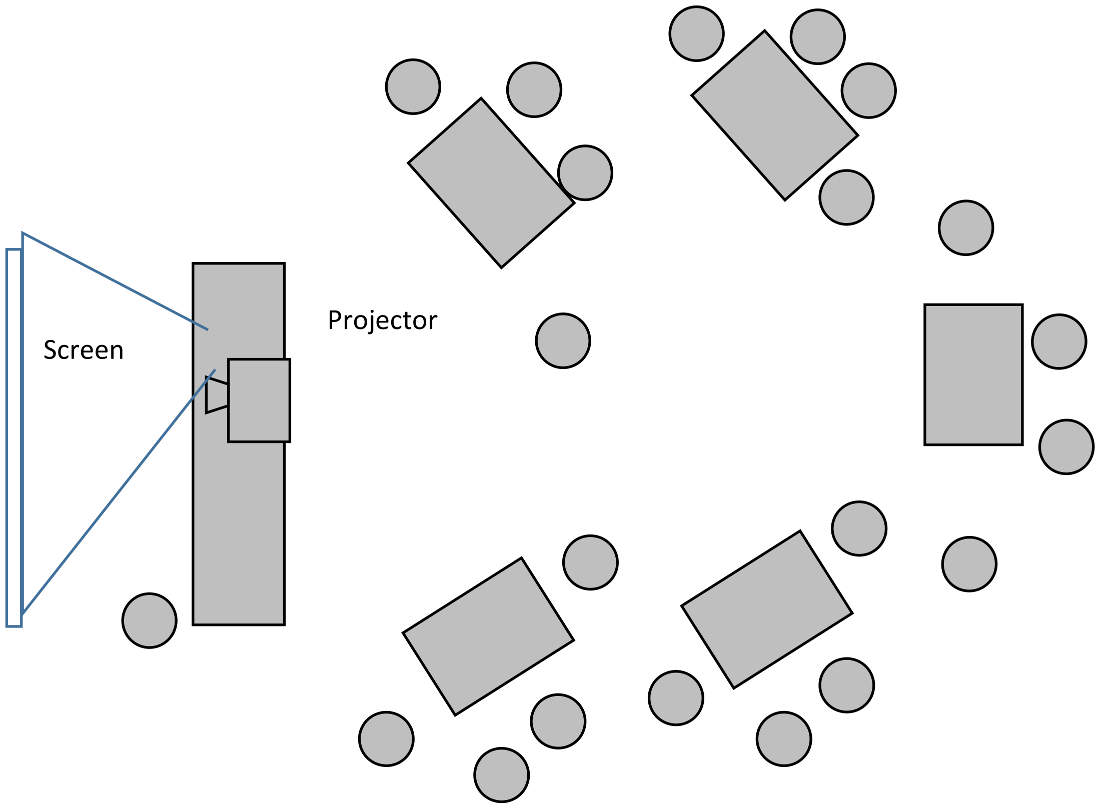
- चट्याङ्गबाट हुने मानविय क्षति, वस्तुभाउको क्षति, भौतिक संरचना, विद्युतीय सामाग्री तथा अन्य क्षतिको परिमाण र प्रकृतिको बारेमा बताउन सक्ने छन्।
- भौतिक संरचनामा चट्याङ्ग प्रतिरक्षी प्रणाली जडान गर्ने प्रविधिको विस्तृत जानकारी दिलाउने सक्ने छन्।
- चट्यांगबाट हुने विद्युतीय सामग्रीहरुको सुरक्षा गर्ने विधि बारे बिस्तृत जानकारी दिनसक्ने छन्।
- अन्तर्राष्ट्रिय मापदण्डका अरेस्टरको जानकारी गराई बजारमा व्याप्त गैरमापदण्डका अरेस्टरहरुको भ्रामक प्रचार प्रति सचेतना हुन सक्ने छन्।
- विद्युतीय गडबडीका कारण हुने विविध दुर्घटनाहरु र विभिन्न आयामहरु तथा दुर्घटना न्यूनीकरणका उपायको बारेमा बिस्तृत रुपमा बताउन सक्ने छन्।
- विद्युतीय गडबडीका कारण हुने दुर्घटना न्यूनीकरणका लागि लेखापरीक्षण गर्ने विधिको बारेमा जानकारी दिने।
- सहभागीहरुको सिकाईलाई व्यवहारिक बनाउनका लागि प्रयोगात्मक प्रशिक्षण दिने र सहभागीहरूलाई भवनहरूमा भएका विद्युतीय कमजोरीका अवस्थाबारे स्थलगतरूपमा व्यवहारिक जानकारी गराउने।

विधिः

- मस्तिष्क मन्थन, समूह अभ्यास, खेल, लघु प्रवचन, प्रश्नोत्तर, चित्र छलफल, मामिला अध्ययन, श्रव्यदृश्य आदि । हरेक दिनको अन्तमा दिनभर छलफल भएका विषयवस्तुको सङ्क्षेपीकरण गर्ने।
- दोस्रो दिन पहिलो दिन सञ्चालन भएका गतिविधिको पुनरवलोकनबाट सत्र सुरुआत गर्ने।
- व्यावहारिक अभ्यासका लागि आवश्यक फाराम अभ्यास सिटहरू तयार गर्ने।

आवश्यक सामग्री, उपकरण र स्रोतसाधनः

ल्यापटप, प्रोजेक्टर, ह्वाइटबोर्ड, स्क्रिन, प्वाइन्टर, पिनबोर्ड, क्यामरा, प्रिन्टर, फारामहरू, हाजिरी रजिस्टर, ब्राउनसिट, न्युजप्रिन्ट, बोर्डमार्कर, परमानेन्ट मार्कर, मेटा कार्ड, मास्किङ टेप, कैँची, स्केल, स्ट्यापलर, थमपिन, पेपर क्लिप, सादाकागज, चक्लेट आदि।

सहभागीहरूका लागि आवश्यक सामग्रीः   नोटबुक, डटपेन, रेकर्ड फाइल, सिसा कलम, मेटाउ, पेन्सिल कटर
सहभागीहरूको प्रशिक्षण हलमा बसाइ व्यवस्था:   
विविध: १. प्रशिक्षण कोठाको उपलब्धता र सहभागी सङ्ख्याका आधारमा सहभागीहरूको बसाइ व्यवस्था मिलाउने।   २. पहिलो दिन सञ्चालन भएका गतिविधिको पुनरवलोकनबाट दोस्रो दिनको सत्र सुरुआत गर्ने।   ३. व्यावहारिक अभ्यासका लागि आवश्यक फाराम/सिटहरू तयार गर्ने।   ४. हरेक दिनको अन्त्यमा दिनभर छलफल भएका विषयवस्तुको सङ्क्षेपीकरण गर्ने।   ५. प्रशिक्षणका अन्त्यमा प्रशिक्षण अवधिभर छलफल भएका विषयवस्तुहरूको सारसङ्क्षेप प्रस्तुत गर्ने।

चट्याङ्ग र विद्युतीय लेखा परीक्षण प्रशिक्षण

कार्यतालिका

समय मिति	पहिलो सत्र ०९०० – १०३०	१०३० – १०४५	दोश्रो सत्र १०४५ – १२१५	१२१५ – १३१५	तेश्रो सत्र १३१५ – १४४५	१४४५ – १५००	चौथो सत्र १५०० – १६३०
पहिलो दिन	प्रशिक्षण कार्यक्रम शुभारम्भ, परिचय, समूह मान्यता निर्धारण, अपेक्षा संकलन, प्रशिक्षण विधि, उद्देश्य र विषयवस्तुको स्पष्टता पूर्व जानकारी	चिया	**चट्याङ्ग: एक परिचय** ▪ चट्याङ्ग को भौतिकी ▪ बादल तथा बिद्युतीय चार्ज उत्पन्न हुने भौतिक प्रक्रिया ▪ चट्याङ्ग पर्न का लागि आवश्यक वातावरण चट्याङ्ग पर्ने प्रक्रिया ▪ चट्याङ्ग संग सम्बन्धित विविध भौतिक क्रियाकलाप र तिनका परिमाणहरु	खाना	**चट्याङ्गका विनाशकारी प्रभावहरु** ▪ चट्याङ्ग: मिथक, भ्रम, वास्तविकताहरु ▪ चट्याङ्गले नेपालमा परेको क्षतिको तथ्याँक ▪ चट्याङ्गका कारण नेपालमा प्रतिवर्ष हुने मानवीय तथा पशुपन्छीको क्षति ▪ चट्याङ्गजन्य क्षतिका दृष्टिकोणबाट विश्व मानचित्रमा नेपालको स्थान ▪ नेपालमा बढी जोखिमयुक्त क्षेत्रहरु	चिया	**चट्याङ्ग प्रतिरक्षी प्रणाली (बाह्य)** ▪ प्रतिरक्षी प्रणालीका आधारभूत सिद्धान्तहरु ▪ बाह्य प्रतिरक्षी प्रणालीका घटकहरु ▪ राष्ट्रिय तथा अन्तर्राष्ट्रिय मापदण्डहरु ▪ बाह्य प्रतिरक्षी प्रणालीका घटकहरु ▪ प्रतिरक्षी प्रणालीका विविध तहहरु
दोश्रो दिन	**चट्याङ्ग प्रतिरक्षी प्रणाली (बाह्य)... निरन्तर** ▪ प्रतिरक्षी सामाग्री का मापदण्डहरु ▪ Air termination system का प्रकार, मापदण्ड तथा जडान		**आन्तरिक प्रतिरक्षा (बिद्युतीय सामाग्रीहरुको सुरक्षा)** ▪ बिद्युतीय overvoltage तथा surge (सर्ज) को परिचय ▪ बिद्युतीय overvoltage तथा		**अन्तर्राष्ट्रिय मापदण्ड IEC अनुरुप तथा गैरमापदण्डका अरेस्टरहरु** ▪ अरेस्टर: एक परिचय ▪ के छ IEC तथा अन्य राष्ट्रिय		**बिद्युतीय गडबडीका कारण हुने दुर्घटनाहरु** ▪ बिधयुतीय दुर्घटना का बिबिध उदाहरणरू

	गर्ने बिधिहरु ■ Down conductor system, का मापदण्ड ■ Earth termination system का प्रकार तथा मापदण्ड तथा जडान गर्ने बिधि		surge का कारण हुने क्षतिहरु ■ सर्जबाट बचाउने उपकरणहरू (SPD) का परिचय तथा प्रकारहरु ■ SPD जडान गर्ने बिधि ■ बन्धनिकरण तथा समानभोल्टेजिकरण (Bonding and equipotentialization)		मापदण्डमा ? ■ गैरमापदण् का अरेस्टरहरुको समस्या के हो ? ■ समाधानका उपायहरु		■ बिद्युतीय दुर्घटनाका कारक तत्वहरु ■ बिद्युतीय दुर्घटना जोखिम न्यूनीकरणका आयाम ■ बिद्युतीय दुर्घटना जोखिम न्यूनीकरणका उपायहरु
तेश्रो दिन	**बिद्युतीय लेखापरीक्षण** (Auditing) ■ सदृश्य निरीक्षण (Visual Inspection) ■ निरन्तरता परिक्षण (Continuity testing) ■ Fault loop impedance testing (अर्थिंगको अबरोधता परिक्षण) ■ ध्रुवीकरण परिक्षण (Polarity testing) ■ चेक लिस्ट तयारी र भर्ने तरिका		**व्यवहारिक / प्रयोगात्मक प्रशिक्षण** ■ प्रशिक्षण स्थलको भवन वा छिमेकमा रहेका भवनहरुको अनुगन निरीक्षण		**व्यवहारिक / प्रयोगात्मक प्रशिक्षण ... निरन्तर** ■ Earth resistance meter, multimeter आदि प्रयोग गरि विविध तारहरूको सुचालाकता,अर्थिंगको अवस्था, आदि मापन र निरीक्षण		**समापन सत्र** ■ प्रशिक्षण मूल्याँकनः लिखित / बहुविकल्प प्रश्नहरू ■ शिकाइलाई आफ्नो कार्यक्षेत्रमा लागू गर्ने योजना निर्माण ■ केही सहभागीहरूको शिकाइ अनुभूती प्रस्तूती ■ पश्चात जानकारी र प्रशिक्षण समापन

सत्र योजना

सत्र योजना

मोडुलः चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्रः १

समयः ९० मिनेट

सत्र विषयः शुभारम्भ

साधारण उद्देश्यः कार्यक्रम को उपादेयितामा प्रकाश

निर्दिष्ट उद्देश्यहरुः सहभागीहरुले यस सत्रको अन्त्यमा,

- प्रशिक्षणको महत्व बारे सुसुचित हुनेछन
- बिषय वस्तु को गहिराई को आंकलन गर्नेछन
- बिबिध चुनौती हरु को जानकारी पाउने छन्
- बिषय वस्तु को ज्ञान को आत्म समीक्षा गर्ने छन्

सत्रका मुख्य विषयवस्तुः

- प्रशिक्षण कार्यक्रम शुभारम्भ,
- परिचय,
- समूह मान्यता निर्धारण,
- अपेक्षा संकलन,
- प्रशिक्षण विधि,
- उद्देश्य र विषयवस्तुको स्पष्टता पूर्व जानकारी

प्रशिक्षण – सिकाई क्रियाकलाप	**अवधि मिनेटमा**	**प्रशिक्षण – सिकाई सामाग्री**	**कैफियत**
क्रियाकलाप १ सत्रको परिचय तथा उद्देश्यहरु र प्रारुपको जानकारी गराउने ▪ उद्घाटन मन्तब्य सहित कार्यक्रम को उद्देश्य को जानकारी गराउने	१०	मौखिक प्रस्तुति,	सहजकर्ताले पहिला नै तयार गरी राख्ने
क्रियाकलाप २ः सहभागीको ध्यानाकर्षण गर्न /सहभागी को ब्यग्तिगत तथा ब्यबसायिक परिचय सहित दैनिक जीवन मा अनुभव गरेका घटनाहरु को बारेमा अन्तरक्रिया गरि, **छलफल गर्ने ।**	१५	मौखिक अन्तरक्रिया	सहजकर्ताले पहिला नै तयार गरी राख्ने

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप ३: विषयवस्तु सम्वन्धी सहभागीलाई जानकारी भएमा भन्न लगाउने	१०	मौखिक अन्तरक्रिया	सहजकर्ताले पहिला नै तयार गरी राख्ने
क्रियाकलाप ४: समूह मान्यता निर्धारण	१५	भौतिक क्रियाकलाप	तत्काल तयारी गर्ने
क्रियाकलाप ५: अपेक्षा संकलन	१०	प्रश्नावली तथा प्रत्रिकृया फारम	पूर्व तयारी गर्ने
क्रियाकलाप ६: प्रशिक्षण विधि	१०	पावर प्वाइटमा देखाउने मल्टिमेडिया	सहज कर्ता ले पूर्व तयारी गर्ने
क्रियाकलाप ७ : उद्देश्य र विषयवस्तुको स्पष्टता पूर्व जानकारी	१०	मौखिक	सहजकर्ताले पहिला नै तयार गरी राख्ने
सत्र संक्षेपीकरण सत्र मूल्याङ्कन पश्चात् सत्रको छोटकरीमा छलफल भएका विषयवस्तु स्पष्ट गर्दै अब यस पछाडिको सत्र **को बा**रेमा छलफल गरिनेछ भनिसत्रको अन्त गर्ने ।	१०		

सत्र योजना

मोडुलः चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्रः २

समयः ९० मिनेट

सत्र विषयः चट्याङ्गको परिचय

साधारण उद्देश्यः चट्याङ्ग को भौतिक प्रक्रिया का बारेमा जानकारी गराउने

निर्दिष्ट उद्देश्यहरुः सहभागीहरुले यस सत्रको अन्त्यमा, निम्न बिषय वस्तु बुझ्ने छन् ।

- चट्याङ्ग किन पर्छ
- चट्याङ्ग कसरि पर्छ
- चट्याङ्ग पर्न का लागि कस्तो वातावरण हुनु पर्दछ
- चट्याङ्ग मा कति परिमाण को करेन्ट, ताप, तथा उर्जा उत्पन्न हुन्छ
- चट्याङ्ग ले क्षति पुर्याउन का लागि कुन भौतिक क्रियाकलाप ले भूमिका खेल्छ
- प्रतिरक्षा का लागि ध्यान दिनु पर्ने मुख्य प्यारामीटर के हो

सत्रका मुख्य विषयवस्तुः

- चट्याङ्ग: एक परिचय
- चट्याङ्ग को भौतिकी
- बादल तथा बिद्युतीय चार्ज उत्पन्न हुने भौतिक प्रक्रिया
- चट्याङ्ग पर्न का लागि आवश्यक वातावरण
- चट्याङ्ग पर्ने प्रक्रिया
- चट्याङ्ग संग सम्बन्धित विविध भौतिक क्रियाकलाप र तिनका परिमाणहरु

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप १ः सहभागीको ध्यानाकर्षण गर्न चट्याङ्ग सम्बन्धी सहभागीहरुको अनुभव तथा बुझाई का बारे अन्तरक्रिया गरि **छलफल गर्ने ।**	५	अन्तरक्रिया	सहजकर्ताले पहिला नै प्रश्नहरु तयार गर्ने
क्रियाकलाप २ः सत्रको परिचय तथा उद्देश्यहरु र प्रारुपको जानकारी गराउने	५	मेटाकार्ड र चार्ट पेपर र मार्कर	सहजकर्ताले पहिला नै तयार गरी राख्ने
क्रियाकलाप ३ः विषयवस्तु सम्वन्धी सहभागीलाई जानकारी भएमा भन्न लगाउने	५	अन्तरक्रियात्मक	

प्रशिक्षण – सिकाई क्रियाकलाप	**अवधि मिनेटमा**	**प्रशिक्षण – सिकाई सामाग्री**	**कैफियत**
क्रियाकलाप ४: भीडियो प्रश्तुति ▪ चट्याङ्ग को भीडियो देखाउने ▪ भिडियो माथि छलफल गर्ने	१५	मल्टीमेडिया मा देखाउने	सहजकर्ताले पहिला नै भिडियो तयारगर्ने
क्रियाकलाप ५ : पावर प्वााइट प्रश्तुति : ▪ बादलमा बिधयुतीय चार्ज को उत्पत्ति को जानकारी	३०	पावर प्वााइट. एनिमेसन भिडियो, मेटाकार्ड र चार्ट पेपर मार्कर	सहजकर्ताले पहिला नै पावर प्वााइट तथा अनिमेशन भिडियो **(**नमुना प्रस्तुति: Lightning video 0**2_d**1**)**तयार गर्ने
क्रियाकलाप ६: पावर प्वााइट प्रश्तुति ▪ चट्याङ्ग पर्ने प्रक्रिया	१५	पावर प्वाइटमा देखाउने मल्टिमेडिया	सहजकर्ताले पहिला नै पावर प्वााइट तथा अनिमेशन भिडियो तयार गर्ने (नमुना प्रस्तुति: Lightning video 0**2_d**1**)**
क्रियाकलाप ७: पावर प्वााइट प्रश्तुति ▪ चट्याङ्ग संग सम्बन्धित विविध भौतिक क्रियाकलाप र तिनका परिमाणहरु	१०	पावर प्वाइन्टमा देखाउने मल्टिमेडिया	सहजकर्ताले पहिला नै पावर प्वााइट तथा अनिमेशन भिडियो तयार गर्ने

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप ८ः सत्रको मूल्याङ्कन तथा संक्षेपीकरण **सत्र मूल्याङ्कन** ▪ चट्याङ्ग को भौतिकी को बारेमा ○ सहभागी लाई सोध्ने ○ कुनै ३ जना सहभागी लाई १ -१ मि बोल्न लगाउने ○ …….. ? **सत्र संक्षेपीकरण** ▪ सत्र मूल्याङ्कन पश्चात् सत्रको छोटकरीमा छलफल भएका विषयवस्तु स्पष्ट गर्दै अब यस पछाडिको सत्र **०२_०३ को बा**रेमा छलफल गरिनेछ भनिसत्रको अन्त गर्ने ।	५	मौखिक अन्तरक्रिया	

सत्र योजना

मोडुलः चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्रः ३

समयः ९० मिनेट

सत्र विषयः चट्याङ्गका विनाशकारी प्रभावहरु

साधारण उद्देश्यः चट्याङ्ग बाट हुने मानविय क्षति, बस्तुभाउ को क्षति, भौतिक संरचना, बिधयुतीय सामाग्री तथा अन्य क्षति को परिमाण र प्रकृति को जानकारी गराउने

निर्दिष्ट उद्देश्यहरुः सहभागीहरुले यस सत्रको अन्त्यमा,

- चट्याङ्ग बाट हुने बिबिध क्षति को जानकारी प्राप्त गर्ने छन्
- क्षतिका आयामहरु को आंकलन गर्ने छन्
- प्रत्यक्ष तथा परोक्ष रुपमा चट्याङ्ग पार्ने क्षति को जानकारी प्राप्त गर्ने छन्

सत्रका मुख्य विषयवस्तुः

- **चट्याङ्गका विनाशकारी प्रभावहरु**
- चट्याङ्ग: मिथक, भ्रम, वास्तविकताहरु
- चट्याङ्गले नेपालमा पारेको क्षतिको तथ्याँक
- चट्याङ्गका कारण नेपालमा प्रतिवर्ष हुने मानवीय तथा पशुपन्छीको क्षति
- चट्याङ्गजन्य क्षतिका दृष्टिकोणबाट विश्व मानचित्रमा नेपालको स्थान
- नेपालमा बढी जोखिमयुक्त क्षेत्रहरु

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप १: सहभागीको ध्यानाकर्षण गर्न सहभागीहरु ले अनुभव गरेका घटना हरु, सुनेका, देखेका मिथकहरुका बारेमा सुन्ने र छलफल गर्ने ।	१०	मौखिक अन्तरक्रिया	सहजकर्ताले वातावरण तयार गर्ने.

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप २: सत्रको परिचय तथा उद्देश्यहरु र प्रारुपको जानकारी गराउने ▪ चट्यांग ले गरेका मानवीय तथा भौतिक क्षति को भिडिओ प्रदर्शन गर्ने ▪ भिडियोमा प्रदर्शित क्षति का बिबिध आयाम मा छलफल गर्ने	२०	भिडिओ, अनिमेशन	सहजकर्ताले पहिला नै तयार गरी राख्न नमुना भिडिओ **(**Lightning video 03_**d**1**)**
क्रियाकलाप ३: नेपाल मा भएका मानवीय क्षति, चौपाया को क्षति, आदि को तथ्यांक प्रस्तुत गर्ने, नेपाल मा चट्यांग को नक्शा प्रस्तुत गर्ने र अति जोखिम युक्त क्षेत्र को पहिचान गर्न लगाउने	३०	पावर प्वाइटमा देखाउने	सहजकर्ताले पहिला नै पावर प्वाइट तयार गर्ने (नमुना पावर प्वाइट प्रस्तुति Presentation 03_**d**1)
क्रियाकलाप ४: पावर प्वाइट प्रस्तुति ▪ विश्व मानचित्रमा नेपालको स्थान ▪ नेपालमा को नक्शा मा चट्यांग र नेपाल मा बढी जोखिमयुक्त क्षेत्रहरु को पहिचान	२०	पावर प्वाइटमा देखाउने मल्टीमेडिया	▪ सहजकर्ताले पहिला नै पावर प्वाइट प्रस्तुति तयार गर्ने (नमुना पावर प्वाइट प्रस्तुति Presentation 03_**d**1)

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप ५ : सत्रको मूल्याङ्कन तथा संक्षेपीकरण **सत्र मूल्याङ्कन** ▪ .... ○ बिबिध प्रश्नहरु सोध्ने ○ चट्यांग ले गर्न सक्ने क्षति को अनुमान गर्न लगाउने **सत्र संक्षेपीकरण** ▪ सत्र मूल्याङ्कन पश्चात् सत्रको छोटकरीमा छलफल भएका विषयवस्तु स्पष्ट गर्दै अब यस पछाडिको सत्र **०१_०४ को बा**रेमा छलफल गरिनेछ भनिसत्रको अन्त गर्ने ।	१०		सहजकर्ताले पहिला नै प्रश्नहरु मेटाकार्डमा तयार गरी राख्ने

सत्र योजना

मोडुलः चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्रः ४

समयः ९० मिनेट

सत्र विषयः चट्याङ्ग प्रतिरक्षी प्रणाली (बाह्य_०१)
साधारण उद्देश्यः भौतिक संरचनामा चट्याङ्ग प्रतिरक्षी प्रणाली जडान गर्ने प्रबिधि को बिस्तृत जानकारी दिलाउने
निर्दिष्ट उद्देश्यहरुः सहभागीहरुले यस सत्रको अन्त्यमा**,**

- चट्याङ्ग प्रतिरक्षी प्रणालीका आधारभूत सिद्धान्तहरु को जानकारी प्राप्त गर्ने छन्
- बाह्य प्रतिरक्षी प्रणालीका घटकहरु को बारेमा जानकारी प्राप्त गर्ने छन्
- प्रतिरक्षी प्रणालीका बारेमा राष्ट्रिय तथा अन्तर्राष्ट्रिय मापदण्डहरु
- बाह्य प्रतिरक्षी प्रणालीका विविध तहहरु को बारेमा बुझ्ने छन्
- प्रतिरक्षी प्रणालीका मापदण्ड अनुरुप का सामाग्री को बारेमा जानकारी प्राप्त गर्ने छन्

सत्रका मुख्य विषयवस्तुः

- प्रतिरक्षी प्रणालीका आधारभूत सिद्धान्तहरु
- राष्ट्रिय तथा अन्तर्राष्ट्रिय मापदण्डहरु
- बाह्य प्रतिरक्षी प्रणालीका घटकहरु
- प्रतिरक्षी प्रणालीका विविध तहहरु

प्रशिक्षण – सिकाई क्रियाकलाप	**अवधि मिनेटमा**	**प्रशिक्षण – सिकाई सामाग्री**	**कैफियत**
क्रियाकलाप १: सहभागीको ध्यानाकर्षण गर्न नेपाल मा प्रचलित चट्यांग प्रतिरक्षी प्रणाली को बारेमा प्रश्न सोधिने छ, सहभागी को ज्ञान का बारेमा **छलफल गर्ने ।**	१०	मौखिक अन्तरक्रिया	सहजकर्ताले प्रश्न पहिला नै तयार गरि छलफल को को वातावरण तयार गर्ने]
क्रियाकलाप २: सत्रको परिचय तथा उद्देश्यहरु र प्रारुपको जानकारी गराउने	५	पावर प्वाइट प्रस्तुति	सहजकर्ताले पहिला नै प्रस्तुतिका बिषय वस्तु तयार गरी राख्ने
क्रियाकलाप ३: पावर प्वाइन्ट प्रस्तुति ▪ प्रतिरक्षी प्रणालीका आधारभूत सिद्धान्तहरु ▪ राष्ट्रिय तथा अन्तर्राष्ट्रिय मापदण्डहरु को बारेमा छलफल ▪ बाह्य प्रतिरक्षी प्रणालीका घटकहरु	४५	पावर प्वाइन्टमा देखाउने मल्टीमेडिया	सहजकर्ताले पहिला नै पावर प्वाइन्ट प्रस्तुति तयार गर्ने (नमुना प्रस्तुति **Presentation** 01**_d2)**

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप ४: भिडियो र पावर प्वाइन्ट प्रस्तुति बाह्य प्रतिरक्षी प्रणाली जडान गर्ने बिधि र अन्य अव्यव हरु	१५	पावर प्वाइन्टमा देखाउने मल्टीमेडिया	सहजकर्ताले पहिला नै पावर प्वाइन्ट प्रस्तुति तयार गर्ने (नमुना प्रस्तुति **Presentation** 01**_d**2**)**
क्रियाकलाप ५ : पावर प्वाइन्ट प्रस्तुति र छलफल ■ बाह्य प्रतिरक्षी प्रणाली जडानका लागि ध्यान दिनु पर्ने कुरा हरु; बिशेष गरि सामाग्री हरु को भौतिक सामाग्री का आकार र प्रकृति को बारेमा प्रस्तुति तथा छलफल	१०	पावर प्वाइटमा देखाउने मल्टिमेडिया	सहजकर्ताले पहिला नै पावर प्वाइन्ट प्रस्तुति तयार गर्ने (नमुना प्रस्तुति **Presentation** 01**_d**2**)**
क्रियाकलाप ६ : सत्रको मूल्याङ्कन तथा संक्षेपीकरण **सत्र मूल्याङ्कन** ▪ सहभागी अनुभूत गरेका र बजार मा पाईने सामाग्री को जानकारी लिन प्रश्नोत्तर गर्ने , जस्तै ○ बजारमा पाइने अरेस्टर को मोटाई कति हुन्छ ? ○ अरेस्टर वा अन्य सामाग्री कुन कुन धातु ले बनेका हुन्छन ? **सत्र संक्षेपीकरण** ■ सत्र मूल्याङ्कन पश्चात् सत्रको छोटकरीमा छलफल भएका विषयवस्तु स्पष्ट गर्दै अब यस पछाडिको सत्र ०१ (दोश्रो दिन) **को बा**रेमा छलफल गरिनेछ भनिसत्रको अन्त गर्ने ।	५		सहजकर्ताले पहिला नै प्रश्नहरु मेटाकार्डमा तयार गरी राख्ने

सत्र योजना

मोडुलः चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्रः ५

समयः ९० मिनेट

सत्र विषयः चट्याङ्ग प्रतिरक्षी प्रणाली (बाह्य_०२)
साधारण उद्देश्यः भौतिक संरचनामा चट्याङ्ग प्रतिरक्षी प्रणाली जडान गर्ने प्रबिधि को बिस्तृत जानकारी दिलाउने
निर्दिष्ट उद्देश्यहरुः सहभागीहरुले यस सत्रको अन्त्यमा,

- प्रतिरक्षी सामाग्री का मापदण्डहरु का बारेमा जानकार हुने छन्
- Air termination system (अरेस्टर) हरु जडान गर्ने बिधि र प्रयोग गरिने सामाग्री का बारेमा जानकारी प्राप्त गर्ने छन्
- संरचना अनुशार प्रतिरक्षा को तह को जानकारी प्राप्त गर्ने छन्
- प्रतिरक्षी सामाग्री जडान गर्न प्रयोग गरिने वैज्ञानिक फर्मुला प्रयोग गरि हिसाब गर्न सक्नेछन
- Down conductor system, जडान गर्ने तरिका, सामाग्री र तह को बारेमा जानकार हुनेछन
- Earth termination (अर्थिंग) system का प्रकार, मापदण्ड तथा जडान गर्ने बिधि का बारेमा तह र संरचना का बारेमा जानकारी प्राप्त गर्ने छन्

सत्रका मुख्य विषयवस्तुः

- प्रतिरक्षी सामाग्री का मापदण्डहरु
- Air termination system (अरेस्टर) का प्रकार, मापदण्ड तथा जडान गर्ने बिधि
- Down conductor system, का मापदण्ड
- Earth termination (अर्थिंग) system का प्रकार, मापदण्ड तथा जडान गर्ने बिधि

प्रशिक्षण – सिकाई क्रियाकलाप	**अवधि मिनेटमा**	**प्रशिक्षण – सिकाई सामाग्री**	**कैफियत**
क्रियाकलाप १ः सहभागीको ध्यानाकर्षण गर्न बजार मा पाइने अरेस्टर र अन्य सामाग्रीका मापदण्ड बारेमा सहभागी संग जानकारी लिने र **छलफल गर्ने ।**	१०	मौखिक अन्तरक्रिया	सहजकर्ताले पहिला नै तयार गरी राख्ने
क्रियाकलाप २ः सत्रको परिचय तथा उद्देश्यहरु र प्रारुपको जानकारी गराउने	५	पावर प्वाइन्ट, मेटाकार्ड र चार्ट पेपर र मार्कर	सहजकर्ताले पहिला नै तयार गरी राख्ने

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
▪ **क्रियाकलाप ३** : पावर प्वाइन्ट प्रस्तुति ▪ अरेस्टर का प्रकार ▪ जडान गर्ने बिबिध बिधिहरु (protective angle method, rolling sphere method, mesh method) ▪ अरेस्टर का लागि चाहिने सामाग्री का आकार तथा धातु का सामाग्री को विवरण र मापदण्ड ▪ Down conductor system, का मापदण्ड, जडान गर्ने सामाग्री को आकार, तह अनुशार जडान गर्ने बिधि ▪ Earth termination (अर्थिंग)system का प्रकार , मापदण्ड तथा जडान गर्ने बिधि	५०	पावर प्वाइन्टमा देखाउने मल्टीमेडिया प्रयोग गर्ने	सहजकर्ताले पहिला नै पावर प्वाइन्ट तयार गर्ने (नमुना पावर प्वाइन्ट Presentation 01_d2)
क्रियाकलाप ४ : भिडियो एनिमेशन प्रस्तुति तथा छलफल	१५	भिडियो एनिमेशन	सहजकर्ताले पहिला नै भिडियो तयार गर्ने (Video 01_02_Lightning Protection)
क्रियाकलाप ५ : सत्रको मूल्याङ्कन तथा संक्षेपीकरण **सत्र मूल्याङ्कन** ○ जडान को बिधि को बारेमा सहभागी संग फिडब्याक लिने ? ○ पुनरावलोकन गर्ने ? **सत्र संक्षेपीकरण** ▪ सत्र मूल्याङ्कन पश्चात् सत्रको छोटकरीमा छलफल भएका विषयवस्तु स्पष्ट गर्दै अब यस पछाडिको सत्र ०२ (दोश्रो दिन) **को बा**रेमा छलफल गरिनेछ भनिसत्रको अन्त गर्ने ।	१०		सहजकर्ताले पहिला नै प्रश्नहरु मेटाकार्डमा तयार गरी राख्ने

सत्र योजना

मोडुलः चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्रः ६

समयः ९० मिनेट

सत्र विषयः चट्यांगबाट आन्तरिक प्रतिरक्षा (बिद्युतीय सामाग्रीहरुको सुरक्षा)
साधारण उद्देश्यः चट्यांग हुने बिद्युतीय सामाग्रीहरुको सुरक्षा गर्ने बिधि बारे बिस्तृत जानकारी दिने
निर्दिष्ट उद्देश्यहरुः सहभागीहरुले यस सत्रको अन्त्यमा,

- बिधयुतीय सर्ज को बारेमा जानकारी प्राप्त गर्ने छन्
- बिधयुतीय सर्ज का श्रोत तथा तिनले पुर्याउने क्षति का बारेमा जानकारी प्राप्त गर्ने छन्
- सर्ज तथा ओवरभोल्टेज बाट बचाउने उपकरण हरु को प्रकार, प्रतिरक्षा का प्रक्रिया आदि का बारेमा जानकारी
- सर्ज प्रतिरक्षी उपकरण (SPD) जडान गर्ने तरिका
- बन्धनिकरण तथा समानभोल्टेजिकरण (Bonding and equipotentialization) को जानकारी

सत्रका मुख्य विषयवस्तुः

- बिद्युतीय overvoltage तथा surge (सर्ज) को परिचय
- बिद्युतीय overvoltage तथा surge का कारण हुने क्षतिहरु
- सर्जबाट बचाउने उपकरणहरू (SPD) का परिचय तथा प्रकारहरु
- SPD जडान गर्ने बिधि
- बन्धनिकरण तथा समानभोल्टेजिकरण (Bonding and equipotentialization)

प्रशिक्षण – सिकाई क्रियाकलाप	**अवधि मिनेटमा**	**प्रशिक्षण – सिकाई सामाग्री**	**कैफियत**
क्रियाकलाप १ः सहभागीको ध्यानाकर्षण गर्न सर्ज का बारेमा सहभागीको ज्ञान को बारेमा अन्तरक्रिया गर्ने **छलफल गर्ने ।**	१०	मौखिक अन्तरक्रिया	सहजकर्ताले पहिला नै प्रश्न तयार गरी राख्ने
क्रियाकलाप २ः सत्रको परिचय तथा उद्देश्यहरु र प्रारुपको जानकारी गराउने	५	पावर प्वाइन्ट प्रस्तुति	सहजकर्ताले पहिला नै तयार गरी राख्ने
क्रियाकलाप ३ : भिडिओ प्रस्तुति ▪ बिधयुतीय सर्ज तथा सर्ज प्रतिरक्षी उपकरण को जानकारी	१०	मल्टीमेडिया	सहजकर्ताले पहिला नै तयार गरी राख्ने (**नमुना** Video 02_02_surge protection)

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप ४ : पावर प्वाइन्ट प्रस्तुति ▪ बिधयुतीय सर्ज तथा सर्ज प्रतिरक्षी उपकरण को जानकारी ▪ सर्ज के हो, कसरि उत्पन्न हुन्छ, चट्यांग ले उत्पन्न गर्ने सर्ज को प्रकृति कस्तो हुन्छ ▪ सर्ज प्रतिरक्षी सामाग्री कति किसिम का हुनछन ▪ जडान गर्ने तरिका के हो ▪ कुन ठाउँ मा कसो सर्ज प्रतिरक्षी सामाग्री कसरी जोडिन्छ	४५	पावर प्वाइन्टमा देखाउने मेटाकार्ड र चार्ट पेपर र मार्कर	सहजकर्ताले पहिला नै पावर प्वाइन्टमा प्रस्तुति तयार गरी राख्ने **नमुना प्रस्तुति** - (Presentation 02_d2)
क्रियाकलाप ५ : पावर प्वाइन्टमा प्रस्तुति ▪ बन्धनिकरण तथा समानभोल्टेजिकरण (Bonding and equipotentialization) ▪ बन्धनिकरण महत्व के हो	१५	पावर प्वाइन्टमा देखाउने	सहजकर्ताले पहिला नै पावर प्वाइन्टमा प्रस्तुति तयार गरी राख्ने **नमुना प्रस्तुति** - (Presentation 02_d2)
क्रियाकलाप ६ : सत्रको मूल्याङ्कन तथा संक्षेपीकरण **सत्र मूल्याङ्कन** ○ सहभागी लाई सर्ज उपकरण का बारेमा प्रस्तुत गर्न लगाउने ○ सहजकर्ताले सहभागी लाई सहयोग गर्ने **सत्र संक्षेपीकरण** ▪ सत्र मूल्याङ्कन पश्चात् सत्रको छोटकरीमा छलफल भएका विषयवस्तु स्पष्ट गर्दै अब यस पछाडिको सत्र ०३ (दोश्रो दिन).**को बा**रेमा छलफल गरिनेछ भनिसत्रको अन्त गर्ने ।	५	अन्तरक्रिया	सहजकर्ताले वातावरण बनाउने र प्रोत्साहन गर्ने

सत्र योजना

मोडुल: चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्र: ७

समय: ९० मिनेट

सत्र विषय: अन्तर्राष्ट्रिय मापदण्ड **IEC** अनुरुप तथा गैरमापदण्डका अरेस्टरहरु

साधारण उद्देश्य: सहभागी लाई अन्तर्राष्ट्रिय मापदण्ड का अरेस्टर को जानकारी गराई बजार मा ब्याप्त गैरमापदण्डका अरेस्टरहरु को भ्रामक प्रचार प्रति सचेतना दिलाउने

निर्दिष्ट उद्देश्यहरु: सहभागीहरुले यस सत्रको अन्त्यमा,

- राष्ट्रिय तथा अन्तर्राष्ट्रिय बजार मा पाइने विभिन्न किसिम का अरेस्टर को बारे मा जानकारी प्राप्त गर्ने छन्
- **IEC** मापदण्ड अनुरुपका अरेस्टर को पहिचान गर्न सक्ने छन्
- भ्रामक प्रचार गरेर बिक्रि गरिने सामाग्री हरु को यथार्थता जान्ने छन्
- गलत सामाग्री जडान गर्न र गराउन बाट सचेत गरुन सक्ने छन्

सत्रका मुख्य विषयवस्तु:

- अरेस्टर: एक परिचय
- के छ IEC तथा अन्य राष्ट्रिय मापदण्डमा ?
- गैरमापदण्ड का अरेस्टरहरुको समस्या के हो **?**
- समाधानका उपायहरु

प्रशिक्षण – सिकाई क्रियाकलाप	**अवधि मिनेटमा**	**प्रशिक्षण – सिकाई सामाग्री**	**कैफियत**
क्रियाकलाप १: सहभागीको ध्यानाकर्षण गर्न सहभागी ले बजार मा देखेका अथवा प्रचार प्रसार गरिने अरेस्टर को बारेमा सोध्ने र उनीहरुको धरान उक्त सामाग्री को बारेमा बुझ्ने	१०	अन्तरक्रिया	सहजकर्ताले वातावरण तयार गर्ने र प्रश्न सोधी टिपोट गर्न लगाउने
क्रियाकलाप २: सत्रको परिचय तथा उद्देश्यहरु र प्रारुपको जानकारी गराउने	१०	पावर प्वाइन्टमा देखाउने	सहजकर्ताले पहिला नै पावर प्वाइन्ट तयार गरी राख्ने

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप ३ : पावर प्वाइन्ट प्रस्तुति ▪ अरेस्टरहरु को परिचय ▪ IEC तथा अन्य राष्ट्रिय मापदण्डमा अरेस्टर को अवधारणा ▪ गैर मापदण्ड का अरेस्टर हरु वैज्ञानिकता के हो ▪ गैर मापदण्डका अरेस्टर को समस्या के हो	५०	पावर प्वाइन्टमा देखाउने मल्टीमेडिया	सहजकर्ताले पहिला नै पावर प्वाइन्टमा तयार गर्ने
क्रियाकलाप ४ : पावर प्वाइन्ट र भिडिओ प्रस्तुति NFC (French standard) गलत ब्याख्या नेपाली बजार मा गरिने भ्रामक प्रचार	१५	पावर प्वाइन्टमा देखाउने मल्टीमेडिया	सहजकर्ताले पहिला नै पावर प्वाइन्ट र मल्टीमेडिया तयार गर्ने
क्रियाकलाप ५: सत्रको मूल्याङ्कन तथा संक्षेपीकरण **सत्र मूल्याङ्कन** ▪ अन्तरक्रिया गर्ने ○ अरेस्टर को बास्तबिकता को बारेमा पुन सोध्ने ? ○ **NFC** को समस्या को बारेमा सोध्ने ? **सत्र संक्षेपीकरण** ▪ सत्र मूल्याङ्कन पश्चात् सत्रको छोटकरीमा छलफल भएका विषयवस्तु स्पष्ट गर्दै अब यस पछाडिको सत्र ०४ (दोश्रो दिन) **को बा**रेमा छलफल गरिनेछ भनिसत्रको अन्त गर्ने ।	५	अन्तरक्रिया	सहजकर्ताले वातावरण बनाई अन्तरक्रिया गर्ने

सत्र योजना

मोडुलः चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्रः ८

समयः ९० मिनेट

सत्र विषयः बिद्युतीय गडबडीका कारण हुने दुर्घटनाहरु

साधारण उद्देश्यः बिद्युतीय गडबडीका कारण हुने बिबिध दुर्घटनाहरु, र विभिन्न आयाम हरु तथा दुर्घटना न्यूनीकरण का उपाय को बारेमा बिस्तृत जानकारी गराउने

निर्दिष्ट उद्देश्यहरुः सहभागीहरुले यस सत्रको अन्त्यमा,

- बिद्युतीय गडबडीका कारण हुने दुर्घटना को बिस्तृत जानकारी प्राप्त गर्ने छन्
- बिद्युतीय गडबडीका कारण हुने दुर्घटना का विभिन्न कारक तत्व हरु का बारेमा जानकारी प्राप्त गर्ने छन्
- बिद्युतीय दुर्घटना जोखिम न्यूनीकरणका उपाय हरु को जानकारी प्राप्त गर्ने छन्
- बिद्युतीय दुर्घटना मा उल्लेख्य कमि ल्याउन का भूमिका खेल्न सक्षम हुने छन्

सत्रका मुख्य विषयवस्तुः

- बिद्युतीय गडबडीका कारण हुने दुर्घटनाहरु
- बिधयुतीय दुर्घटना का बिबिध उदाहरणरू
- बिद्युतीय दुर्घटनाका कारक तत्वहरु
- बिद्युतीय दुर्घटना जोखिम न्यूनीकरणका आयाम
- बिद्युतीय दुर्घटना जोखिम न्यूनीकरणका उपायहरु

प्रशिक्षण – सिकाई क्रियाकलाप	**अवधि मिनेटमा**	**प्रशिक्षण – सिकाई सामाग्री**	**कैफियत**
क्रियाकलाप १ः सहभागीको ध्यानाकर्षण गर्न बिद्युतीय दुर्घटना का बारेमा सहभागी हरुको ज्ञान को बारेमा प्रतिक्रिया गर्ने र **छलफल गर्ने ।**	१०	अन्तरक्रिया	सहजकर्ताले पहिला नै प्रश्न हरु तयार तयार गरी राख्ने
क्रियाकलाप २ः सत्रको परिचय तथा उद्देश्यहरु र प्रारुपको जानकारी गराउने	५	मेटाकार्ड र चार्ट पेपर र मार्कर	सहजकर्ताले पहिला नै तयार गरी राख्ने
क्रियाकलाप ३ः विषयवस्तु सम्वन्धी केहि सहभागीलाई जानकारी भएमा भन्न लगाउने	५	मौखिक अन्तरक्रिया	

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप ४: भिडियो प्रदर्शन ▪ बिद्युतीय गडबडीका कारण हुने दुर्घटना केहि झलक हरु	१०	मल्टीमेडिया भिडिओ प्रदर्शन	सहजकर्ताले पहिला नै भिडिओ अनिमेशन तयार गर्ने
क्रियाकलाप ५: .पावर प्वाईन्ट प्रस्तुति ▪ बिधयुतीय दुर्घटना का बिबिध उदाहरणरू ▪ बिद्युतीय दुर्घटनाका कारक तत्वहरु ▪ बिद्युतीय दुर्घटना जोखिम न्यूनीकरणका आयाम ▪ बिद्युतीय दुर्घटना जोखिम न्यूनीकरणका उपायहरु	५०	पावर प्वाईन्ट प्रस्तुति	सहजकर्ताले पहिला नै पावर प्वाईन्ट प्रस्तुति तयार गरी राख्ने
क्रियाकलाप ६ : सत्रको मूल्याङ्कन तथा संक्षेपीकरण **सत्र मूल्याङ्कन** ▪ .सहभागी ले प्राप्त गरेको ज्ञान को परिक्षण गर्ने ○ बिद्युतीय दुर्घटनाका कारक तत्वहरु को बारेमा सोध्ने ? ○ बिद्युतीय दुर्घटना जोखिम न्यूनीकरणका उपायहरु को बारेमा दोहोर्याउन लगाउने ? **सत्र संक्षेपीकरण** ▪ सत्र मूल्याङ्कन पश्चात् सत्रको छोटकरीमा छलफल भएका विषयवस्तु स्पष्ट गर्दै अब यस पछाडिको सत्र ०१ (तेश्रो दिन) **को बारेमा** छलफल गरिनेछ भनिसत्रको अन्त गर्ने ।	१०	अन्तरक्रिया	सहजकर्ताले पहिला नै प्रश्नहरु मेटाकार्डमा तयार गरी राख्ने

सत्र योजना

मोडुलः चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्रः ९

समयः ९० मिनेट

सत्र विषयः बिद्युतीय लेखापरीक्षण **(Electrical Auditing)**

साधारण उद्देश्यः बिद्युतीय गडबडी का कारण हुने दुर्घटना न्युनिन्करण का लागि लेखापरीक्षण गर्ने बिधि को बारेमा जानकारी दिने

निर्दिष्ट उद्देश्यहरुः सहभागीहरुले यस सत्रको अन्त्यमा,

- सदृश्य निरीक्षण (Visual Inspection) गर्ने तरिका को बारेमा बुझ्ने छन्
- निरन्तरता परिक्षण गर्ने तरिका र चाहिने उपकरण का बारेमा जानकारी प्राप्त गर्ने छन्
- Fault loop impedance testing (अर्थिंगको अबरोधता परिक्षण) को तरिका का र प्रयोग गरिने उपकरण को बारेमा जानकारी प्राप्त गर्ने छन्
- ध्रुवीकरण परिक्षण (Polarity testing) को जानकारी प्राप्त गर्ने छन्
- चेक लिस्ट तयारी र भर्ने तरिका को ज्ञान प्राप्त गर्ने छन्

सत्रका मुख्य विषयवस्तुः

- सदृश्य निरीक्षण (Visual Inspection)
- निरन्तरता परिक्षण (Continuity testing)
- Fault loop impedance testing (अर्थिंगको अबरोधता परिक्षण)
- ध्रुवीकरण परिक्षण (Polarity testing)
- चेक लिस्ट तयारी र भर्ने तरिका

प्रशिक्षण – सिकाई क्रियाकलाप	**अवधि मिनेटमा**	**प्रशिक्षण – सिकाई सामाग्री**	**कैफियत**
क्रियाकलाप १: सहभागीको ध्यानाकर्षण गर्न सहभागी को लेखा परिक्षण सम्बन्धि अनुभव रहेको खण्ड मा सो बारे **छलफल गर्ने ।**	१०	अन्तरक्रिया	सहजकर्ताले वातावरण तयार गर्ने
क्रियाकलाप २: सत्रको परिचय तथा उद्देश्यहरु र प्रारुपको जानकारी गराउने	५	मेटाकार्ड र चार्ट पेपर र मार्कर	सहजकर्ताले पहिला नै तयार गरी राख्ने

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप ३ : पावर प्वाईन्ट प्रस्तुति ▪ सदृश्य निरीक्षण (Visual Inspection) ▪ निरन्तरता परिक्षण (Continuity testing) ▪ Fault loop impedance testing (अर्थिंगको अबरोधता परिक्षण) ▪ ध्रुवीकरण परिक्षण (Polarity testing) ▪ चेक लिस्ट तयारी र भर्ने तरिका	५०	पावर प्वाइटमा देखाउने मल्टीमेडिया	सहजकर्ताले पहिला नै पावर प्वाईन्ट प्रस्तुति तयार गर्ने
क्रियाकलाप ४ : अभ्यास ▪ सहभागी चेकक लिस्ट भर्न का लागि कक्षा कार्य दिने ▪ कुनै सहभागी लाई समस्या रहेमा सहजकर्ता ले सहयोग गरिदिने	२०	मेटाकार्ड र चार्ट पेपर र मार्कर	सहजकर्ताले पहिला नै मेटाकार्डहरु क्रमसंग तयार गरी राख्ने
क्रियाकलाप ५ : सत्रको मूल्याङ्कन तथा संक्षेपीकरण **सत्र मूल्याङ्कन** ▪ फिडब्याक प्रश्न सोध्ने ○ लेखापरिक्षण किन गर्ने, यसका फाइदा के हुन् ? **सत्र संक्षेपीकरण** ▪ सत्र मूल्याङ्कन पश्चात् सत्रको छोटकरीमा छलफल भएका विषयवस्तु स्पष्ट गर्दै अब यस पछाडिको सत्र ०२ र ०३ (तेश्रो दिन)..**को** ब्यबहारिक सिकाई को **बा**रेमा छलफल गरिनेछ भनिसत्रको अन्त गर्ने ।	५	अन्तरक्रिया	सहजकर्ताले पहिला नै प्रश्नहरु मेटाकार्डमा तयार गरी राख्ने

सत्र योजना

मोडुलः चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्रः १०

समयः ९० मिनेट

सत्र विषयः व्यवहारिक / प्रयोगात्मक प्रशिक्षण

साधारण उद्देश्यः सहभागीहरुको सिकाई लाई ब्यबहारिक बनाउन का लागि प्रयोगात्मक प्रशिक्षण दिने हभागीहरूलाई भवनहरूमा भएका विद्युतीय कमजोरीका अवस्थाबारे स्थलगतरूपमा व्यवहारिक जानकारी गराउने ।

निर्दिष्ट उद्देश्यहरुः सहभागीहरुले यस सत्रको अन्त्यमा,

- विद्युतीय सुरक्षा का दृष्टिकोण ले विभिन्न हिस्सा को जांच पड्ताल गर्न सक्ने छन्
- तार तथा अन्य सुचालक सामग्रीको सुचालाकता मापन गर्न सक्ने छन्
- अर्थिंग को सुचालाकता मापन गर्न सक्ने छन्
- मल्टिमिटर तथा भोल्टमीटर जस्ता उपकरण चलाउन सक्ने छन् वनहरूमा विद्युतीय सुरक्षा र कमजोरीको अवस्था थाहा पाउन मुख्य के के कुरा हेर्ने र नाप्ने भन्ने कुरा व्यवहारिक रूपमा नै

सत्रका मुख्य विषयवस्तुः

- प्रशिक्षण स्थलको भवन वा छिमेकमा रहेका भवनहरुको अनुगन निरीक्षण
- ल्टेज र रेजिस्ट्यान्स मापन

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप १ः सहभागीहरुलाई प्रशिक्षण भवन वा छिमेकमा रहेका भवनहरुको **निरिक्षण गर्न लगाउनु अघि के के कमजोरी हुन्छन् र कसरी थाहा पाउने सोधेर छलफल गर्ने ।**	५	अन्तरक्रिया	कुन भवनमा को जाने पहिले नै तय गरिराख्ने र त्यसको बारेमा जानकारी दिने
क्रियाकलाप २ः सत्रको परिचय तथा उद्देश्यहरु र प्रारुपको जानकारी गराउने ▪ के के हेर्ने र नाप्ने	५	मेटाकार्ड र चार्ट पेपर र मार्कर	सहजकर्ताले पहिला नै तयार गरी राख्ने

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप ३: सहभागीलाई भवनको स्थलगत भ्रमण गराइ के के कमजोरीहरु छन् अवलोकन गर्न लगाउने र भन्न लगाउने	२०	स्थलगत भ्रमण र अवलोकन र अन्तरक्रिया	
क्रियाकलाप ४: क्रियाकलाप ३ का कमजोरीहरुलाई नापेर पुष्टि गर्ने ▪ करेण्ट नाप्ने ▪ भोल्टेज नाप्ने ▪ अवरोध नाप्ने	३०	मल्टिमिटर	नाप्ने उपकरण तयार राख्ने
क्रियाकलाप ५: प्रशिक्षण हलमा पुगेर अवलोकन गरेका कुराहरुको समिक्षा गर्ने ▪ ▪	३०	अन्तरक्रिया	

सत्र योजना

मोडुलः चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्रः ११

समयः ९० मिनेट

सत्र विषयः व्यवहारिक / प्रयोगात्मक प्रशिक्षण

साधारण उद्देश्यः सहभागीहरुको सिकाईलाई ब्यबहारिक बनाउन का लागि प्रयोगात्मक प्रशिक्षण दिने विद्युती परिमाणहरू नाप्न जान्ने

निर्दिष्ट उद्देश्यहरुः सहभागीहरुले यस सत्रको अन्त्यमा,

- विद्युतीय सुरक्षा का दृष्टिकोण ले विभिन्न हिस्सा को जांच पड्ताल गर्न सक्ने छन्
- तार तथा अन्य सुचालक सामग्रीको सुचालाकता मापन गर्न सक्ने छन्
- अर्थिंग को सुचालाकता मापन गर्न सक्ने छन्
- मल्टिमिटर तथा भोल्टमीटर Earth resistance meter, जस्ता उपकरण चलाउन सक्ने छन् ध नाप्न जान्नेछन् हरूको परिमाण कति कम वा धेरै भन्ने सुरक्षाका मापदण्ड जान्नेछन्

सत्रका मुख्य विषयवस्तुः

- Earth resistance meter, multimeter आदि प्रयोग गरि विविध तारहरूको सुचालाकता, अर्थिंगको अवस्था, आदि मापन र निरीक्षण

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप १ः सहभागीको ध्यानाकर्षण गर्न अघिल्लो शत्रमा देखेका कुराहरुबारे छलफल गर्ने ।	५		
क्रियाकलाप २ः सत्रको परिचय तथा उद्देश्यहरु र प्रारुपको जानकारी गराउने ▪ ▪ ▪	५	मेटाकार्ड र चार्ट पेपर र मार्कर	सहजकर्ताले पहिला नै तयार गरी राख्ने

प्रशिक्षण – सिकाई क्रियाकलाप	अवधि मिनेटमा	प्रशिक्षण – सिकाई सामाग्री	कैफियत
क्रियाकलाप ४: विभिन्न तारहरुको सुचालकता र अवरोधहरु नाप्ने ▪ हरेक सहभागीहरुलाई Earth resistance meter, multimeter आदि प्रयोग गर्न सिकाउने	७०	प्रयोगात्मक सामग्री तथा उपकरण	सहजकर्ताले पहिला नै चेक गरी सामग्रीहरू तयार गरी राख्ने
क्रियाकलाप ५: सत्रको मूल्याङ्कन तथा संक्षेपीकरण **सत्र मूल्याङ्कन** ▪ मल्टिमिटर प्रयोग सम्बन्धी केही प्रश्नहरू सोध्ने ○ .... ? ○ .... ? **सत्र संक्षेपीकरण** ▪ सत्र मूल्याङ्कन पश्चात् सत्रको छोटकरीमा छलफल भएका विषयवस्तु स्पष्ट गर्दै शत्र अन्त्यको बारेमा जानकारी दिने	१०		सहजकर्ताले पहिला नै प्रश्नहरु मेटाकार्डमा तयार गरी राख्ने

सत्र योजना

मोडुलः चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

सत्रः १२

समयः ९० मिनेट

सत्र विषयः समापन सत्र

साधारण उद्देश्यः प्रशिक्षण मूल्याँकन गर्ने र शिकाइको उपयोग योजना बनाउने

निर्दिष्ट उद्देश्यहरुः सहभागीहरुले यस सत्रको अन्त्यमा,

- प्रशिक्षणको उपलव्धि जान्नेछन् र व्यक्त गर्नेछन्
- शिकाइ उपयोगको योजना बनाउनेछन् र कार्यान्वयनको प्रतिबद्धता जनाउनेछन्

सत्रका मुख्य विषयवस्तुः

- प्रशिक्षण मूल्याँकनः लिखित / बहुविकल्प प्रश्नहरू
- सिकाइलाई आफ्नो कार्यक्षेत्रमा लागू गर्ने योजना निर्माण
- केही सहभागीहरूको शिकाइ अनुभूती प्रस्तूती
- पश्चात जानकारी र प्रशिक्षण समापन

प्रशिक्षण – सिकाई क्रियाकलाप	**अवधि मिनेटमा**	**प्रशिक्षण – सिकाई सामाग्री**	**कैफियत**
क्रियाकलाप १: प्रशिक्षण मूल्याँकनः लिखित / बहुविकल्प प्रश्नहरूको उत्तर लेख्न लगाउने	१५	लिखित	सहजकर्ताले पहिला नै तयार गरी राख्ने
क्रियाकलाप २ : शिकाइलाई आफ्नो कार्यक्षेत्रमा लागू गर्ने योजना निर्माण **सहभागीहरूलाई सामुहिक रूपमा योजना तयार गर्न लगाउने र प्रस्तूत गर्न लगाउने**	२०	सामुहिक अभ्यासका लागि न्यूजप्रीण्ट र साइनपेनहरू	सहजकर्ताले पहिला नै तयार गरी राख्ने
क्रियाकलाप ३: केही सहभागीहरूको शिकाइ अनुभूती प्रस्तूती	१०	मौखिक प्रस्तूती	
क्रियाकलाप ४: पश्चात जानकारी र प्रशिक्षण समापन	४५	मन्तव्य प्रस्तूतीको व्यवस्था र प्रमाणमत्रहरू	तत्काल तयारी गर्ने

प्रस्तुति सामग्री (पावरप्वाइन्ट स्लाइड)

स्थानीय विकास प्रशिक्षण प्रतिष्ठान (स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित) "An Autonomous, Professional, Client Centered, Gender Responsive National Institute of Excellence in the area of Local-Self Governance."
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चट्टयाङ्ग र विद्युतीय लेखा परीक्षण प्रशिक्षण

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प्रशिक्षण औपचारिकता

- परिचय
- नाम:
- ठेगाना:
- पद:
- कार्य अनुभव:

साधारण उद्देश्य

- सहभागीहरुको बढ्दो शहरीकरणको अवस्थामा विद्युतीय र चट्टयाङ्गजन्य दुर्घटनाहरुको उल्लेखिय बृद्धि कारणले उक्त दुर्घटनाको न्यूनीकरण गर्न सक्ने ज्ञान र सीपमा अभिबृद्धि हुनेछ।

निर्दिष्ट उद्देश्यहरु

यस प्रशिक्षणको अन्तमा सहभागीहरुले

- चट्याङ्गबाट हुने मानविय क्षति, वस्तुभाउको क्षति, भौतिक संरचना, विद्युतीय सामाग्री तथा अन्य क्षतिको परिमाण र प्रकृतिको बारेमा बताउन सक्ने छन्।
- भौतिक संरचनामा चट्याङ्ग प्रतिरक्षी प्रणाली जडान गर्ने प्रविधिको विस्तृत जानकारी दिलाउने सक्ने छन्।
- चट्यांगबाट हुने विद्युतीय सामग्रीहरुको सुरक्षा गर्ने विधि बारे बिस्तृत जानकारी दिनसक्ने छन्।
- अन्तर्राष्ट्रिय मापदण्डका अरेस्टरको जानकारी गराई बजारमा व्याप्त गर□ापदण्डका अरेस्टरहरुको भ्रामक प्रचार प्रति सचेतना हुन सक्ने छन्।

निर्दिष्ट उद्देश्यहरु

यस प्रशिक्षणको अन्तमा सहभागीहरुले

- विद्युतीय गडबडीका कारण हुने विविध दुर्घटनाहरु र विभिन्न आयामहरु तथा दुर्घटना न्यूनीकरणका उपायको बारेमा बिस्तृत रुपमा बताउन सक्ने छन्।
- विद्युतीय गडबडीका कारण हुने दुर्घटना न्यूनीकरणका लागि लेखापरीक्षण गर्ने विधिको बारेमा जानकारी दिने।
- सहभागीहरुको सिकाईलाई व्यवहारिक बनाउनका लागि प्रयोगात्मक प्रशिक्षण दिने र सहभागीहरूला□भवनहरूमा भएका विद्युतीय कमजोरीका अवस्थाबारे स्थलगतरूपमा व्यवहारिक जानकारी गराउने।

अपेक्षा संकलन

प्रशिक्षणका विषयवस्तु

- **चट्याङ्ग: एक परिचय**
- **चट्याङ्गका विनाशकारी प्रभावहरु**
- **चट्याङ्ग प्रतिरक्षी प्रणाली**
- **आन्तरिक प्रतिरक्षा (बिद्युतीय सामाग्रीहरुको सुरक्षा)**
- **अन्तर्राष्ट्रिय मापदण्ड IEC अनुरुप तथा गैरमापदण्डका अरेस्टरहरु**
- **बिद्युतीय गडबडीका कारण हुने दुर्घटनाहरु**
- **बिद्युतीय लेखापरीक्षण** (Auditing)
- **व्यवहारिक / प्रयोगात्मक प्रशिक्षण**

प्रशिक्षण विधि

- मष्तिस्क मन्थन, समुह अभ्यास, लघुप्रवचन, प्रश्नोत्तर आदि। हरेक दिनको अन्तमा दिनभर छलफल भएका विषयवस्तुको संक्षेपीकरण गर्ने।
- दोस्रो दिन पहिलो दिन संचालन भएका गतिविधिको पुनरावलोकनबाट सत्र शुरुवात गर्ने।
- व्यवहारिक अभ्यासको लागि आवश्यक फाराम अभ्यास सिटहरु तयार गर्ने।

समय तालिका

०७३० – ०८३०	१ घण्टा	चिया र नास्ता
०८३० – ०९००	३० मि	अघिल्लो दिनको पुनरावलोकन
०९०० – १०३०	१ घ ३० मि	पहिलो सत्र
१०३० – १०४५	१५ मि	चिया विश्राम
१०४५ – १२१५	१ घ ३० मि	दोश्रो सत्र
१२१५ – १३१५	१ घण्टा	दिवा भोजन विश्राम
१३१५ – १४४५	१ घ ३० मि	तेश्रो सत्र
१४४५ –१५००	१५ मि	चिया विश्राम
१५०० – १६३०	१ घ ३० मि	चौथो सत्र

समूह मान्यता

- समय तालिकाको पालना ....
- मोबाईल साईलेन्ट मोडमा ....
- ....
-

पूर्व जानकारी

धन्यवाद

13

स्थानीय विकास प्रशिक्षण प्रतिष्ठान
(स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)
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चट्याङ्ग: एक परिचय..

साधारण उद्देश्य: **चट्याङ्ग को भौतिक प्रक्रिया का बारेमा जानकारी गराउने**

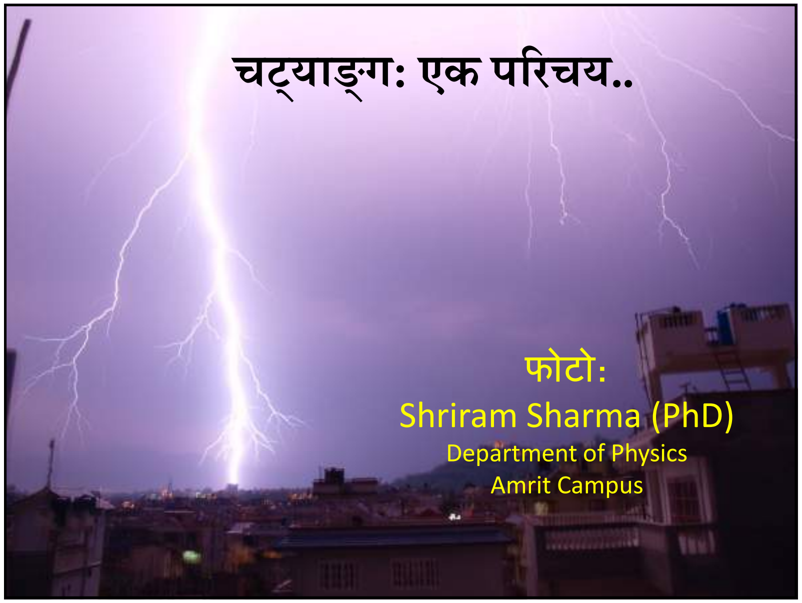
निर्दिष्ट उद्देश्यहरु : सहभागीहरुले यस सत्रको अन्त्यमा निम्न बिषय वस्तु बुझ्ने छन्

- **चट्याङ्ग किन पर्छ**
- **चट्याङ्ग कसरि पर्छ**
- **चट्याङ्ग पर्न का लागि कस्तो वातावरण हुनु पर्दछ**
- **चट्याङ्ग मा कति परिमाण को करेन्ट, ताप, तथा उर्जा उत्पन्न हुन्छ**
- **चट्याङ्ग ले क्षति पुर्याउन का लागि कुन भौतिक क्रियाकलाप ले भूमिका खेल्छ प्रतिरक्षा का लागि ध्यान दिनु पर्ने मुख्य प्यारामीटर के हो**

चट्याङ्ग: एक परिचय..

सत्रका मुख्य विषयवस्तु:

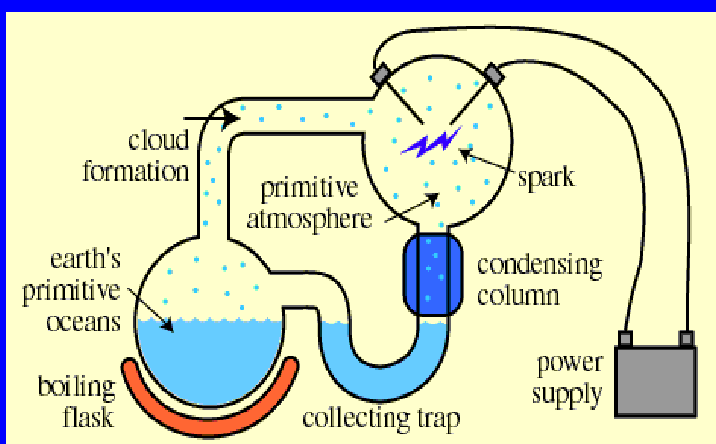
- **चट्याङ्ग: एक परिचय**
- चट्याङ्ग को भौतिकी
- बादल तथा बिद्युतीय चार्ज उत्पन्न हुने भौतिक प्रक्रिया
- चट्याङ्ग पर्न का लागि आवश्यक वातावरण
- चट्याङ्ग पर्ने प्रक्रिया
- चट्याङ्ग संग सम्बन्धित विविध भौतिक क्रियाकलाप र तिनका परिमाणहरु



- *Beginning of the lightning flash*

Introduction

- *Lightning is believed to have been occuring on earth long before the existence of life on it.*
- *Lightning is attributed to be responsible for the production of the biochemical molecule of life.*



Lightning may have created the first building blocks of life on Earth

Beginning of the lightning flash

- *Every civilization of human kind on earth has observed lightning activity right from the beginning.*
- *The human civilizations have always had a wholesome respect and fear for the power of the lightning flash.*
- *Our ancestors believed that the unpredictable power of the thunderbolt lay in the hands of divine powers.*

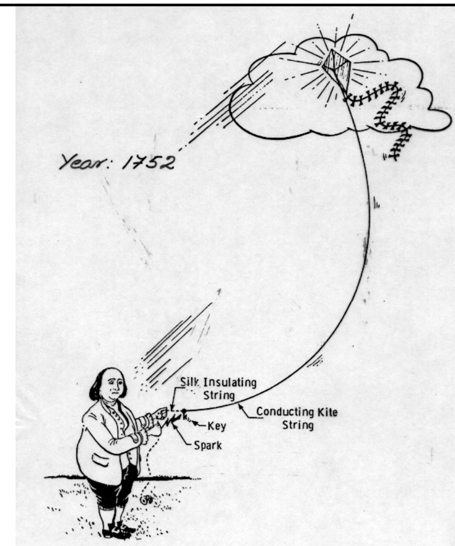
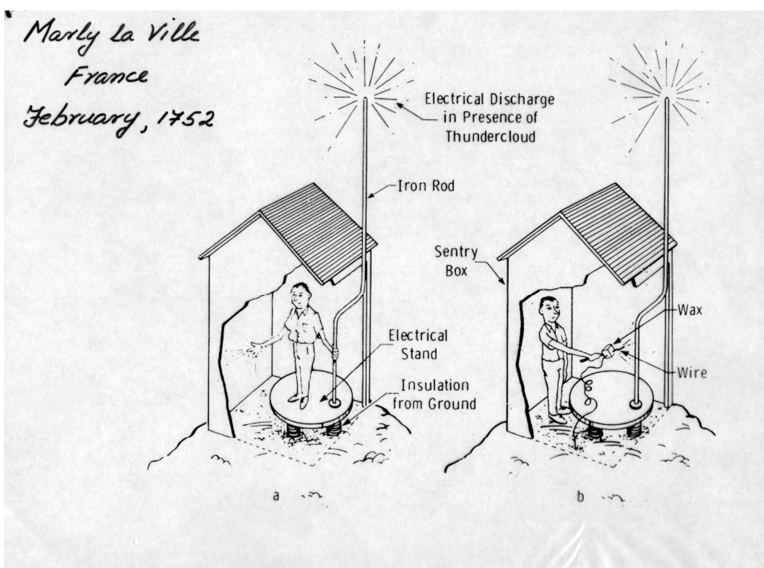


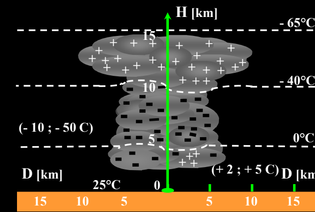
Fig. 1.2. Franklin's electrical kite experiment: Sparks jump from the electrified key at the end of the electrified kite string to Franklin's hand.



Benjamin Franklin looking at electrostatic
bells he used to
study cloud electricity. Two chimes,
separated from each other by a
small gap, are connected to rods that go u
through the roof and to
ground. A thundercloud charges the right-
hand bell, either by induction
or point discharge; the bell then alternatel
attracts or repels a small
ball suspended between the chimes on a s
thread. The ball rattles
between the bells, ringing an alarm when
storm approaches. The electroscope
hanging from the right-hand bell was used
to measure the
cloud's polarity. A grounded rod of Franklin
1762 design can be
seen through the window on the right

Thunderstorms

Cumulonimbus cloud



diameter : ~ 10 km

height to top (anvil) : ~ 10 to 15 km

height to base : ~ 1 to 2 km

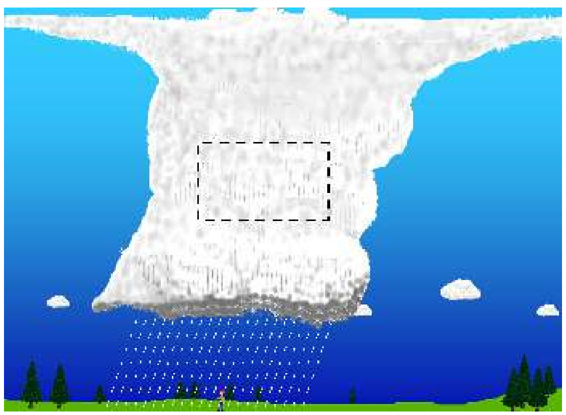
mass of water : ~ 10^8 kg

electric charge : ~ 100 C

electric potential (CG) : ~ 100 MV

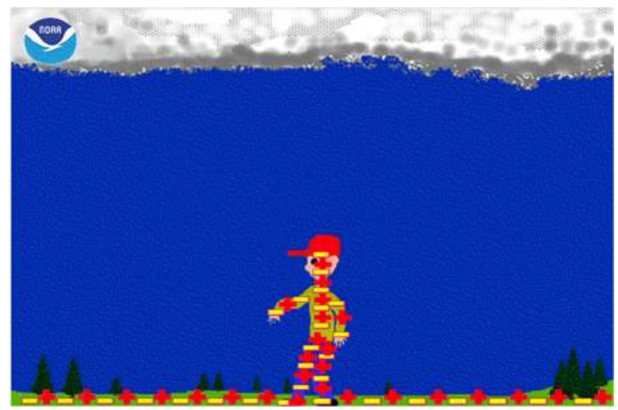
duration : ~ 1 hour

Getting All Charged Up



The main charging area of the thunderstorm cloud is in the central part of the storm where temperatures are between -10 and -25 degrees Celsius.

Charging on the ground



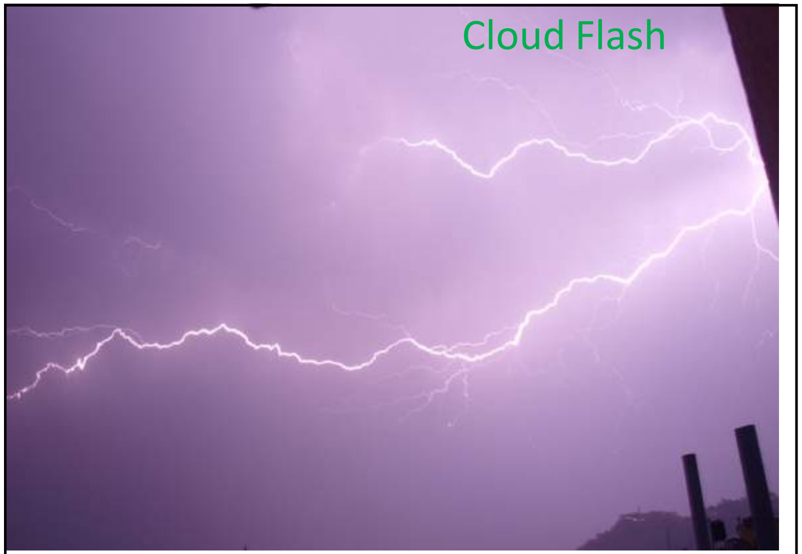
The cloud charges also affect objects on the ground. The negative charges in the cloud not only repel the negative charges in the ground, but, if you're outside, also in you. This could cause you to become positively charged.

Under the charged thunderstorm

If you become "charged up," you could be struck and killed at any moment. Signs that you are becoming "charged" include hair standing on end or a tingling sensation. Don't wait for these signs to happen as it may be too late to avoid getting struck. Seek shelter as soon as there are any signs of a developing or approaching thunderstorm.

Cloud to ground flash

Cloud Flash



Cloud to the air upward

The Lightning Flash

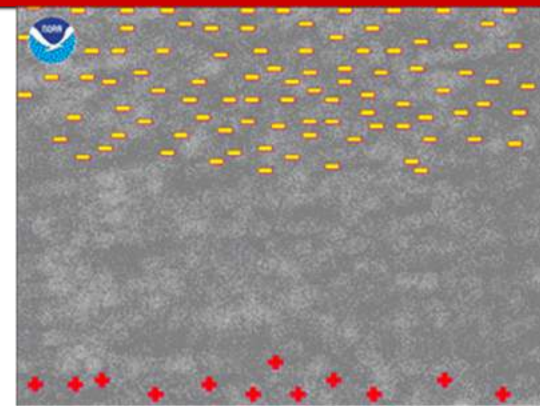
The most common cloud-to-ground lightning flash* consists of:

1. A stepped leader
2. A return stroke
3. Dart leader(s)
4. Return stroke(s)

Now we'll take a look at the science of the lightning flash.

* The most common cloud-to-ground lightning flash is the "negative" cloud-to-ground flash.

Charges on the Move



Air is normally a poor conductor of electricity. However, if the charge difference (electrical potential) between the oppositely charged areas within the cloud becomes too large, the air loses its ability to stop charge movement and negative charges start to move toward the ground.

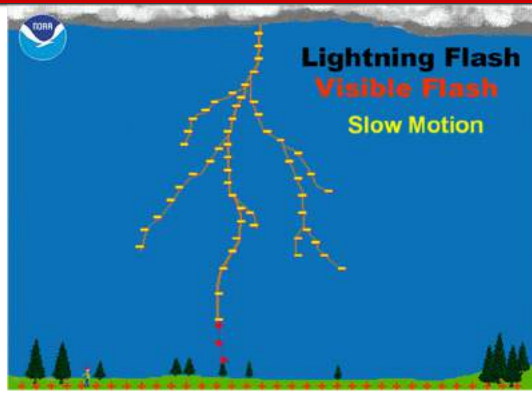
Charges Emerge from the Cloud

The negative charge emerges from the base of the cloud as the "stepped leader." Although the stepped leader doesn't initially sense objects on the ground, it moves toward the ground and often branches outward as it attempts to make a connection.

Stepping Its Way to the Ground

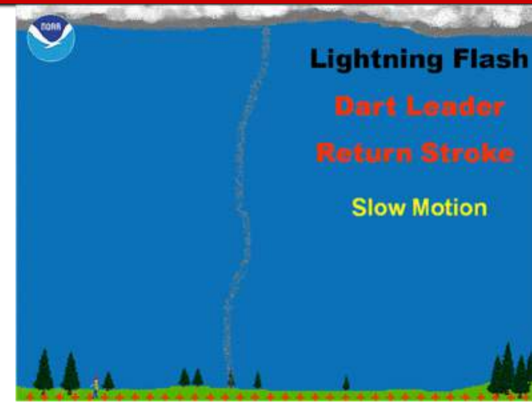
The stepped leader jumps in little steps of about 150 feet (50 meters) as it moves toward the ground (which is why it's called a stepped leader). Between each step, it pauses for a very short moment. Each little step creates a very small flash.

The Visible Flash



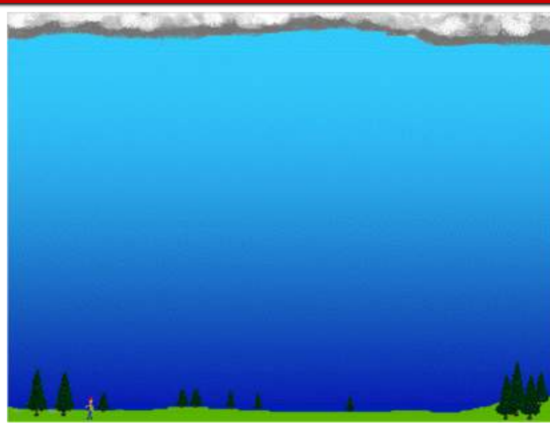
Once the stepped leader connects with an upward streamer, the channel starts discharging rapidly to the ground. The actual discharge begins near the ground and works its way through the entire channel. As it does, the discharge creates a very bright flash of light called the "return stroke" which moves upward through the channel at about 200 million miles per hour.

Dart Leaders and Return Strokes



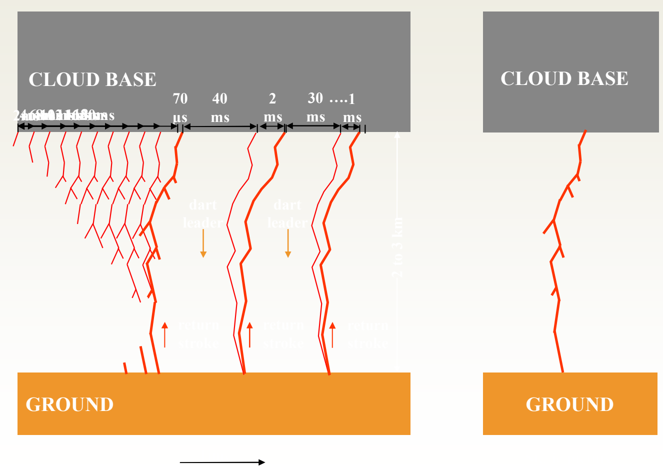
The initial flash momentarily leaves an ionized channel in the atmosphere. If additional charges in the cloud are immediately available to the channel, another negatively charged leader will start moving toward the ground. We call this a "dart leader." Once it reaches the ground, it will discharge via another return stroke.

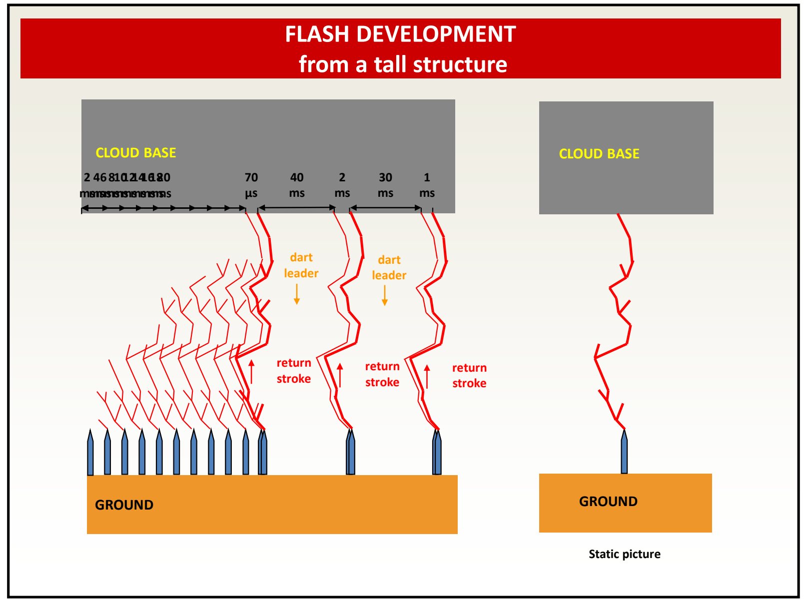
The Lightning Flash at Normal Speed



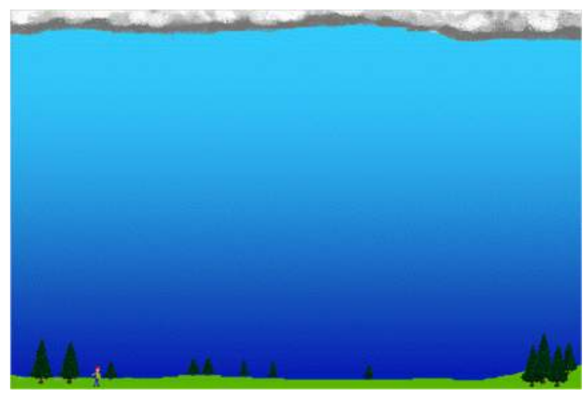
Here's a look at the lightning flash at near normal speed. The stepped leader and dart leaders happen so quickly that we can't see them. All we see are the bright return strokes.

FLASH DEVELOPEMENT
from a flat ground

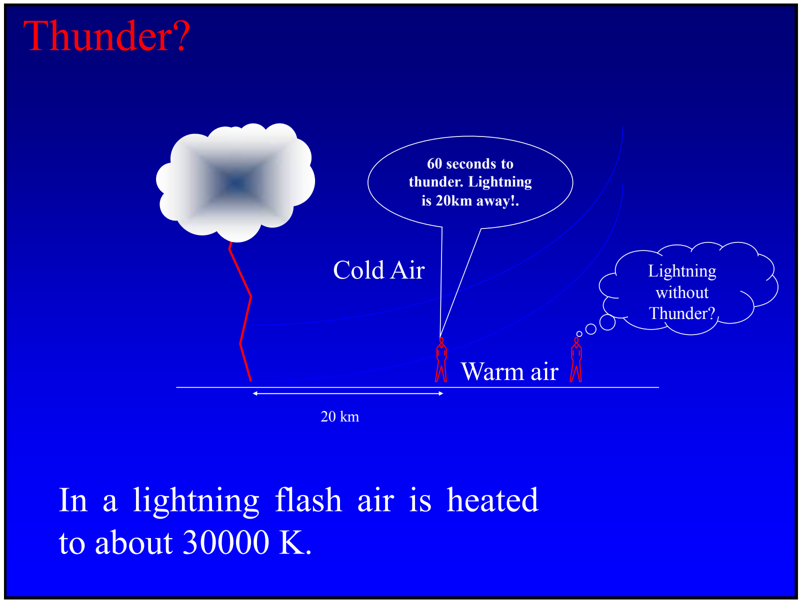


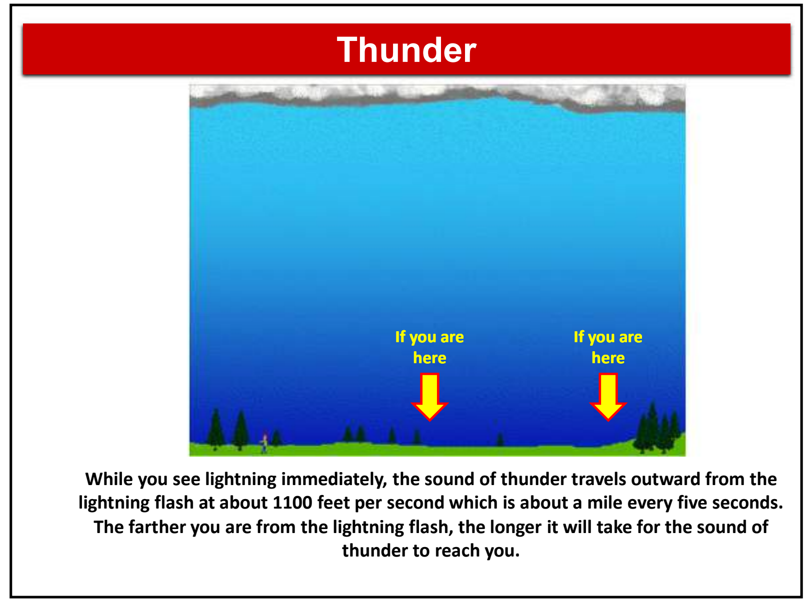


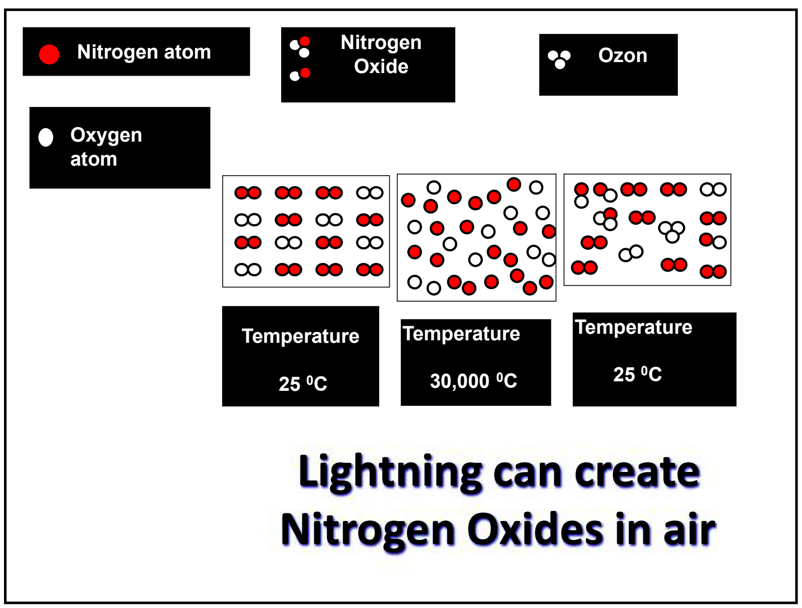
Thunder



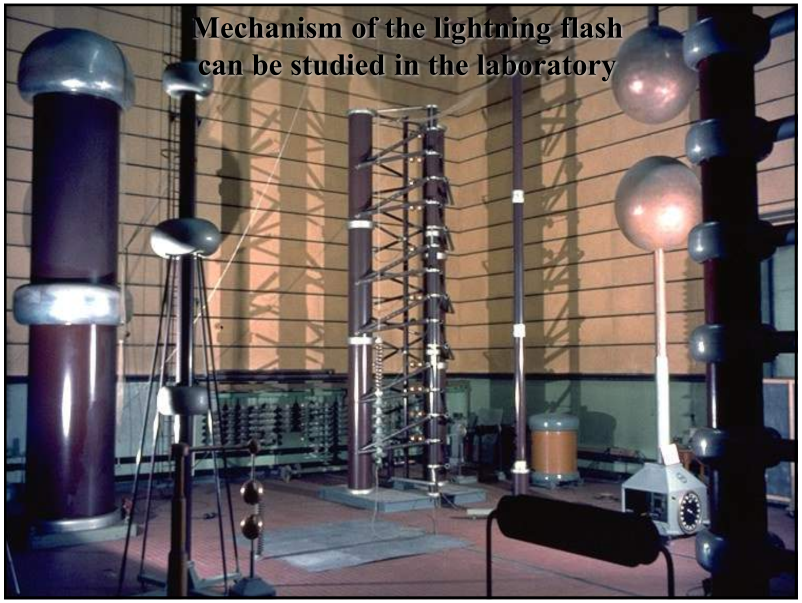
When lightning passes through the air, it heats the air very rapidly and causes it to expand. Immediately after the flash, the air cools and contracts quickly. This rapid expansion and contraction creates a sound wave that we call thunder.


Thunder?
60 seconds to thunder. Lightning is 20km away!.
Cold Air
Lightning without Thunder?
Warm air
20 km
In a lightning flash air is heated to about 30000 K.

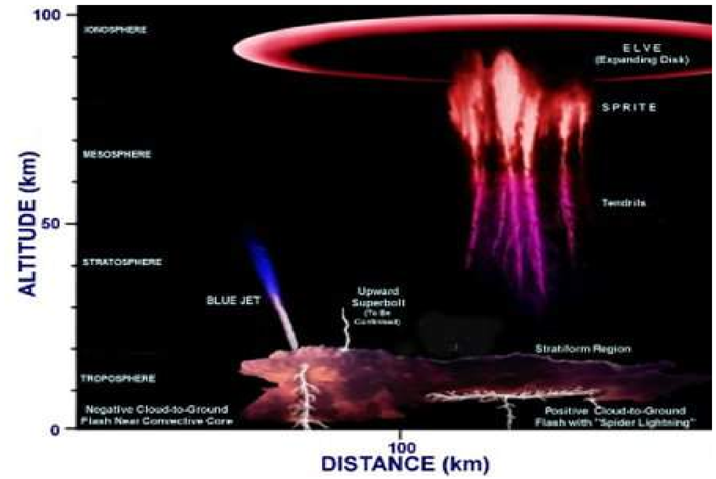

Thunder
If you are here
If you are here
While you see lightning immediately, the sound of thunder travels outward from the lightning flash at about 1100 feet per second which is about a mile every five seconds. The farther you are from the lightning flash, the longer it will take for the sound of thunder to reach you.


Nitrogen atom
Nitrogen Oxide
Ozon
Oxygen atom
Temperature 25 °C
Temperature 30,000 °C
Temperature 25 °C
Lightning can create Nitrogen Oxides in air


Natural Lightning
Natural and triggered lightning
Triggered Lightning



Blue jets and sprites



धन्यवाद

51

स्थानीय विकास प्रशिक्षण प्रतिष्ठान
(स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)

"An Autonomous, Professional, Client Centered, Gender Responsive National Institute of Excellence in the area of Local-Self Governance."

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नेपाल सरकार
सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालय

चट्याङ्गका विनाशकारी प्रभावहरु

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चट्याङ्गका विनाशकारी प्रभावहरु...

साधारण उद्देश्य:

चट्याङ्ग बाट हुने मानविय क्षति, बस्तुभाउ को क्षति, भौतिक संरचना, बिधयुतीय सामाग्री तथा अन्य क्षति व
परिमाण र प्रकृति को जानकारी गराउने

निर्दिष्ट उद्देश्यहरु: सहभागीहरुले यस सत्रको अन्त्यमा,

- चट्याङ्ग बाट हुने बिबिध क्षति को जानकारी प्राप्त गर्ने छन्
- क्षतिका आयामहरु को आंकलन गर्ने छन्
- प्रत्यक्ष तथा परोक्ष रुपमा चट्याङ्ग पार्ने क्षति को जानकारी प्राप्त गर्ने छन्

चट्याङ्गका विनाशकारी प्रभावहरु...

सत्रका मुख्य विषयवस्तु:

- **चट्याङ्गका विनाशकारी प्रभावहरु**
- चट्याङ्ग: मिथक, भ्रम, वास्तविकताहरु
- चट्याङ्गले नेपालमा पारेको क्षतिको तथ्याँक
- चट्याङ्गका कारण नेपालमा प्रतिवर्ष हुने मानवीय तथा पशुपन्छीको क्षति
- चट्याङ्गजन्य क्षतिका दृष्टिकोणबाट विश्व मानचित्रमा नेपालको स्थान

नेपालमा बढी जोखिमयुक्त क्षेत्रहरु

पृथ्वीमा चट्यांग को उपस्थिति

- *Lightning is believed to have been occuring on earth long before the existence of life on it.*

जन विश्वास

Hinduism

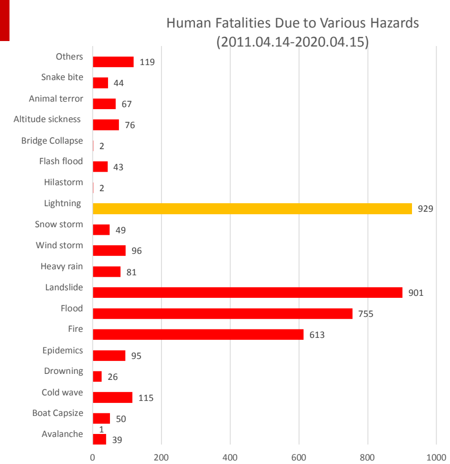
Buddhism

Early statues of Buddha show him carrying in his right hand a double headed Vajra or Dorje, a thunderbolt with prongs at each end, like a pointed dumb-bell (similar to that of Indra's Vajra).

Scandinavian (Thor)

विनाश को एक झलक

Fatalities

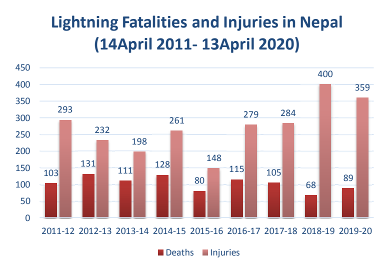


Lightning

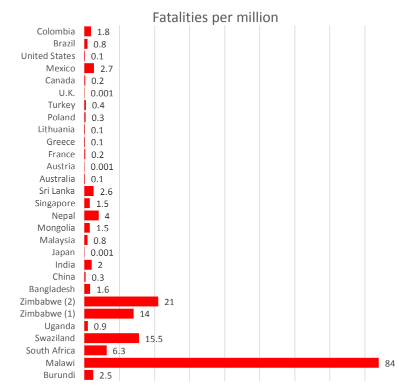
- Kills 24,000 people/yr
- Injures 240,000 people /yr (Cooper and Holle, 2019)
- Kills 100+ people/yr (in Nepal alone)
- Injures ~300 people /yr (As per DRR portal)

Background..

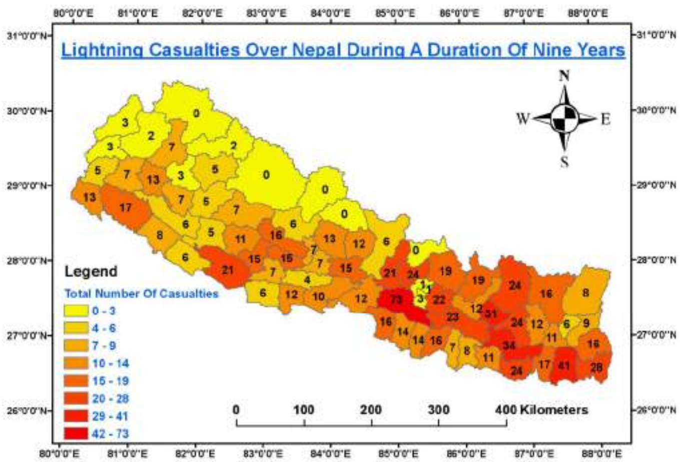
Fatalities per year



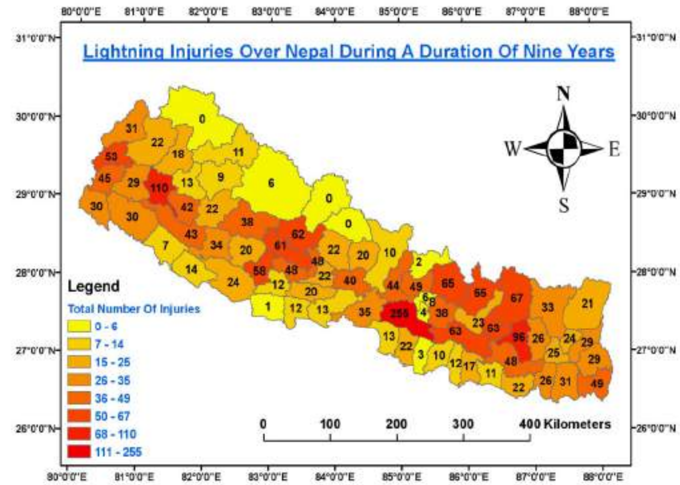
Nepal's status



District-wise Lightning fatalities



District-wise Lightning Injuries



खतराहरु

मानवीय क्षति

All 11 members of a football team were killed by a single bolt of lightning that left the other team unhurt in Congo in 1998. Thirty other people received burns at the match

घाइतेहरु

चट्याङले सताएको गाउँ

- जब आकाशमा कालो बादल मडारिन थाल्छ यहाँको एक गाउँका बासिन्दा ज्यान जोगाउनका लागि हतारहतार घरभित्र पस्न थाल्छन्।
- वर्षेनी चट्याङका कारण मानवीय र पशु चौपायाको क्षति हुन थालेपछि पर्वतको महाशीला गाउँपालिका–६ फलामखानीका बासिन्दा त्रसित हुने गरेका छन्।
- वर्षेनी चट्याङका कारण एकदेखि तीनसम्मको ज्यान जाने गरेको छ भने धेरै पशुधनकोसमेत क्षति हुने
- 'चड्केनीले मानवीय क्षति नभएको वर्ष नै छैन
- यो पर्वतको सबैभन्दा बढी चट्याङ पर्ने गाउँको रुपमा परिचित छ ।
- **स्थानीय जीतबहादुर विकका अनुसार चट्याङगबाट बच्ने कुनै उपाय नभएपछि गाउँलेहरू मेघगर्जन सुरू हुनासाथ घर वरिपरि मदिरा छर्केर भित्र बस्ने गर्छन्।**
- मदिरा घर वरिपरि छर्केपछि दैवीप्रकोप हट्ने विश्वासले मदिरा छर्कने गरिएको विकले बताए।
- सेतोपाटी संवाददातापर्वत, वैशाख १३

चट्याङले एकैठाउँमा ५२ भेडा मरे

3 months ago newsofnepal

नेपाल समाचारपत्र

बाजुरा, चट्याङ लागेर आज यहाँ ५२ भेडा मरेका छन् । जिल्लाको बडिमालिका नगरपालिका–७

त्यस्तै चट्याङकै कारण रेडियो बार्जुको स्टेशनमा पनि ठूलो क्षति भएको छ । रेडियोमा रहेको ट्रान्समिटर, मिक्चर, दुई थान कम्प्युटर सहितका मेशिनरी सामानमा क्षति भएको

बाजुरा, चट्याङ लागेर आज यहाँ ५२ भेडा मरेका छन् । जिल्लाको बडिमालिका नगरपालिका–७ चुथीको जङ्गलमा चराउन लगिरहेका बेला परेको चट्याङ लागेर एकै दिन ५२ भेडा मरेको जिल्ला प्रहरी कार्यालयले जनाएको छ । भेडा बूढीनन्दा नगरपालिका–४ का राजेन्द्र रोकाया र दीपक धामीका रहेको प्रहरी नायब उपरीक्षक उद्धवसिंह भाटले बताउनुभयो । चुथीको जङ्गलमा एकै साथ चरिरहेका १२३ वटा भेडामध्ये चट्याङ लागेर ५२ भेडा घटनास्थलमा नै मरेको प्रमुख भाटको भनाइ छ ।

रुकुम पश्चिममा चट्याङ लागेर एकै परिवारका ६ जना घाइते

- धनवीर दाहाल, रुकुम । रुकुम पश्चिमको मुसिकोट नगरपालिका ३ माछमीमा चट्याङ लागेर एकै परिवारका ६ जना घाइते भएका छन् । बुधबार मुसिकोट नगरपालिका–३, माछमिका जीतबहादुर ओलीको घरमा बिहान ६ बजे परेको चट्याङ लागेर ४ बालबालिका र २ महिला घाइते भएको प्रहरीले जनाएको छ ।
- 23/01/2019 (Nepal Samachar Patra)

पांचथरमा चट्याङ आतंक एकको मृत्यु, १० घाइते

पाँचथर ।शनिबार पाँचथरका छुट्टाछुट्टै स्थानमा चट्याङ लागेर एकको मृत्यु भएको छ भने १० घाइते भएका छन् ।
दिउँसोको समयमा झरीसँगै परेको चट्याङ लागेर फाल्गुनन्द गाउँपालिका–३ पौवासारतापका १७ वर्षीय भगेन्द्र तामाङको मृत्यु भएको हो । चट्याङ लागेर उनकै भाइ ११ वर्षीय मनकुमार तामाङ घाइते भएका छन् । घाइते तामाङको पाँचथर अस्पतालमा प्राथमिक उपचारपछि झापा सिफारिश गरिएको छ
17/02/2019 (Nepal Samachar Patra)

अभिनेत्रि करिश्मा मानन्धरको घरमा पर्यो चट्याङ ,चट्याङले चिरियो रुख

- काठमाडौं – चर्चित अभिनेत्रि करिश्मा मानन्धरको घरमा चट्याङ परेको छ । गोदावरीस्थित अभिनेत्री करिश्मा मानन्धरको घरमा चट्याङ परेको बताइएको छ । आइतबार दिउँसो उनको घर अगाडि रहेको बगैंचाको रुखमा चट्याङ परेको हो ।चट्याङबाट उनको घर अगाडिको रुख चिरा परेको बताइएको छ । अभिनेत्रि करिश्मा मानन्धरले चट्याङ पर्दा उनकी छोरी कविता मानान्धर तर्सिएको उनले बताएकी छिन् । May 7, 2019

Taja Khabar

चट्याङले २८ भेडा मारिए

जेष्ठ २, २०७६कान्तिपुर संवाददाता

लमजुङ — दूधपोखरी गाउँपालिका-१ मलेयाडाँडा लेकको घुम्ती गोठमा चट्याङ पर्दा २८ वटा भेडा मरेका छन् । गत बैशाख २८ परेको चट्याङले रुख ढाल्नुका साथै भेडा मारेको किसानले बताएका छन । घटनामा साढे ५ लाख रुपैयाँ बराबरको क्षति भएको छ ।

चट्याङले ६ जनाको मृत्यु

चट्याङबाट दुई दिनमा १० जनाको मृत्यु, कसरी जोगिने

सेतोपाटी संवाददाता

चट्याङ लागेर पछिल्लो दुई दिनमा १० जनाको मृत्यु भएको छ।
मंगलबार रूपन्देहीमा तीन जना र दाङमा तीन गरी छ जनाको चट्याङ लागेर मृत्यु भएको हो।
मंगलबार साँझ घरखेतमा काम गरिरहेको बेला चट्याङ परेर उनीहरुको मृत्यु भएको हो। जिल्ला प्रहरी कार्यालय रुपन्देहीका अनुसार मृत्यु हुनेमा गैडहवा गाउँपालिका-७ का २५ वर्षीय भगवानदास लोध, कञ्चन गाउँपालिका-२ का ६० वर्षीय नन्दराम अर्याल र सैनामैना नगरपालिका-७ का ६२ वर्षीय चन्द्रबहादुर विक छन्।
दाङमा पनि चट्याङ लागेर तीन जना बालकको मृत्यु भएको छ। मंगलबार बेलुकी ६:२५ बजे परेको चट्याङ लागेर राप्ती गाउँपालिका-३ मौरीघाटका साजन चौधरी (१३), रमित चौधरी (११), विनाश चौधरी (११)को मृत्यु भएको दाङ प्रहरीले जनाएको छ।
त्यसैगरी, चट्याङ लागेर मृतक विनाशका भाइ अविनाश चौधरी (८) गम्भीर घाइते भएका छन्। उनको राप्ती स्वास्थ्य विज्ञान प्रतिष्ठान घोराहीमा उपचार भइरहेको छ।
दाङ प्रहरी प्रमुख एसपी बेलबहादुर पाण्डेका अनुसार चारै जना बालक जामुनाको रूखमा चढेका चढेका थिए। उनीहरू रूखमा चढेका बेला परेको चट्याङले केहीको मृत्यु भएको हो।
बुधबार प्रदेश नम्बर १ का छुट्टाछुट्टै स्थानमा चट्याङ लागेर चार जनाको मृत्यु भएको छ। तीन जना घाइते भएका छन्। १ नम्बर प्रदेश प्रहरीका अनुसार बुधबार दिउँसो पौने ३ बजे मोरङको रंगेली नगरपालिका-९ दोहमना बजारछेउमा चट्याङ लागेर सोही स्थानका १४ वर्षीय बालक अभत ऋषिदेव र १५ वर्षीय अनिल ऋषिदेवको मृत्यु भएको छ।
चट्याङ लागेर बेहोस भएका दुवै बालकको उपचारको क्रममा रंगेली अस्पतालमा मृत्यु भएको प्रहरीले जनाएको छ।
झापाको बाह्रदशी गाउँपालिका-५ का ६० वर्षीय पर्शुराम पाठक ओलीको मृत्यु भएको छ। घरमा बसिरहेका दुबै चट्याङ लागेर उनी गम्भीर घाइते भएका थिए। उपचारका लागि बिएण्डसी अस्पताल लगिएकोमा मृत्यु भएको प्रहरीले जनाएको छ। घाइते भएका सोही ठाउँका ५२ वर्षीय दुर्गाप्रसाद ओलीको उपचार भइरहेको छ।
झापाकै कचनकवल गाउँपालिका-२ बस्ने ३१ वर्षीया भूमा गाइने घर नजिकै बारीमा काम गरिरहेको अवस्थामा चट्याङ लागि घाइते भएकी छन्। उनको मेची अञ्चल अस्पताल भद्रपुरमा उपचार भइरहेको छ।
सुनसरीको बराहा नगरपालिका-९ श्रीलंका टापुमा चट्याङ लागेर ६ वर्षीय बालक अभिषेक उराँवको घटनास्थलमा नै मृत्यु भएको छ। ४ वर्षीया बालिका पुष्पा उराँव घाइते भएकी छिन्।
गत वर्ष चट्याङ लागेर ६८ जनाको मृत्यु भएको थियो भने ४ सय जना घाइते थिए। यस वर्ष पनि चट्याङ लागेर ३१ जनाको मृत्यु भइसकेको छ भने एक सय ३८ जना घाइते भएको प्रहरीले जनाएको छ।

पश्चिम मकवानपुरको राक्सिराङ गाउँपालिका वडा नम्बर ८ माइसिराङ एकसाताका बीचमा एउटै घरमा दुईपटक चट्याङ परेर तीन आमाछोरीसहित सातजना घाइते भएका छन् । सोमबार साँझ परेको चट्याङले ९ वर्षीया उपासना प्रजा र ६ वर्षीया आस्था प्रजा घाइते भएकी हुन् । यस्तै, केहीदिन अघि परेको चट्याङबाट गर्भवती महिला दिलकुमारी प्रजासहित पाँच जना घाइते भएका थिए ।सोमबार घाइते भएकी उपासना र आस्था दिलकुमारीकी छोरी हुन् । चट्याङबाट दिलकुमारीसँगै गर्भवतीश्रीमाया, अञ्जना, विन्दुमाया र शितल प्रजा घाइते भएका थिए । **Source: Herald Magazine**

Animals being killed by a flash.

- 153 pigs being killed by lightning in China

- 143 goats being killed by lightning in China

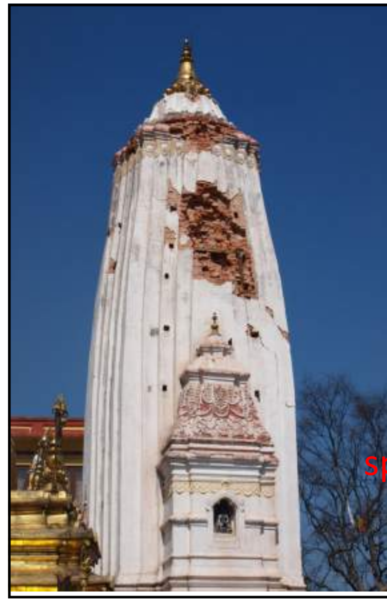
Sheep

- 173 sheep being killed by lightning in China

गाईहरु पनि

- 23 cows were killed in China in 2012
- 16 cows in Philadelphia 1995

Lightning Threats



Pratappur Temple damaged by a strike in February 2011.

The UNESCO world heritage site was capriciously struck, sparing the taller structure in the close vicinity

Damage to the Structures

It spared the tallest structure and struck the dwarf one. These archeological buildings are under severe threat.

Damages to the property

Damage to Wind mills

Lightning Destroying Oil refinery in Venezuela

Trees are often struck

It ignites forest fire

- Arizona Forest fire ignited by lightning.

Buildings too

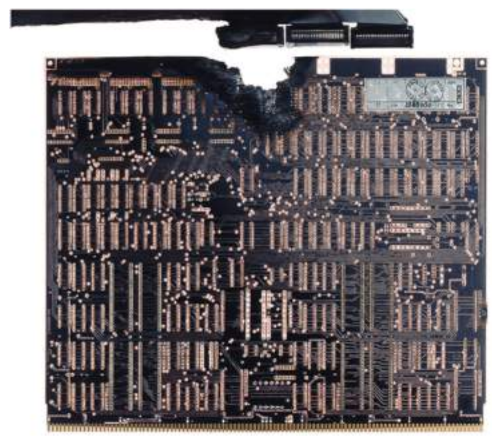
- A House gutted by lightning strike in Malaysia.

poors too!!!

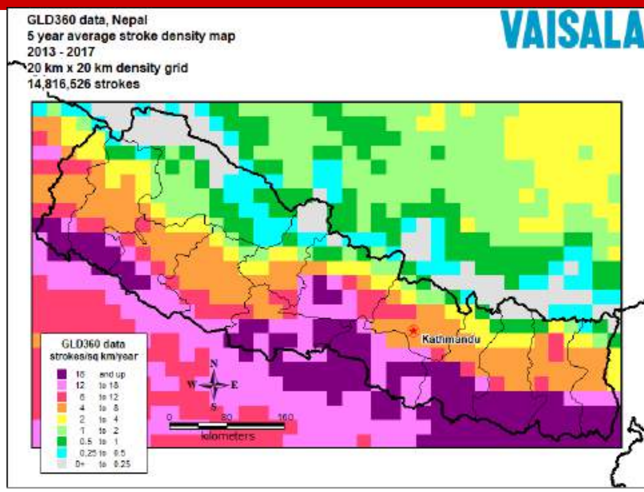
A hut gutted in Zambia (2013)

Today's House/ A digital house

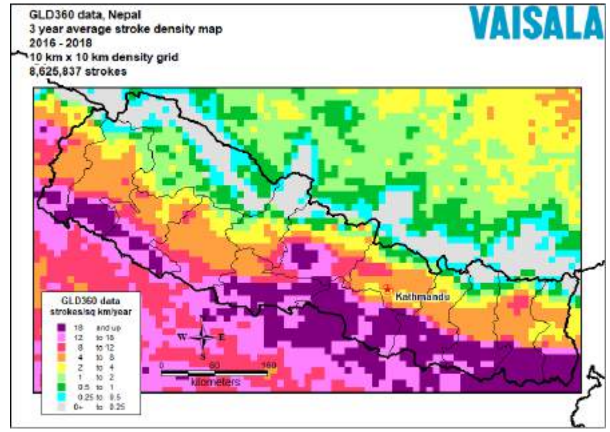
Effects on Electronics



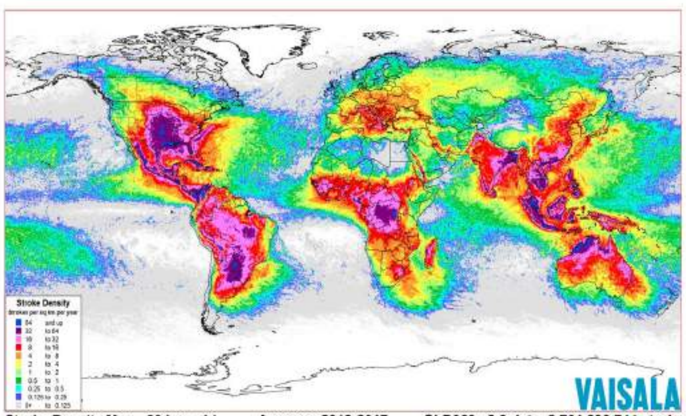
Lightning Density (5 Years)



Lightning Density (recent 3 yrs)



Global scenario



Stroke Density Map - 20 km grid Average: 2013-2017 GLD360 v2.0 data: 8,761,390,744 strokes

Awareness in Developed countries

Awareness works!!!

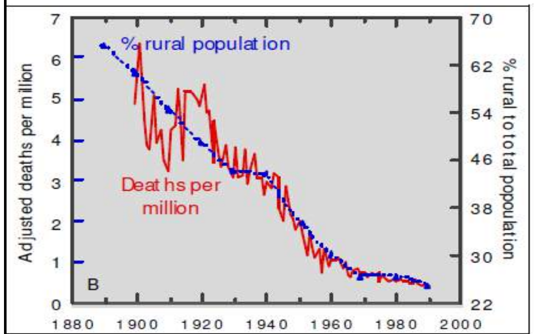


FIGURE 1. Annual time series for the US from 1900 to 1991. Solid line shows lightning deaths per million people, and dashed line shows percent rural population (López

About 300 people died per year before the 1940s. At the end of November of 2012, 28 deaths had been reported for the year.

Develop world

Awareness in Nepal

In Nepal

African Centres for Lightning and Electromagnetics Network

ACLENet

Thank you!! Question?

धन्यवाद

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स्थानीय विकास प्रशिक्षण प्रतिष्ठान (स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)

"An Autonomous, Professional, Client Centered, Gender Responsive National Institute of Excellence in the area of Local-Self Governance."

Local Development Training Academy (Established by Local Development Training Academy Act, 2049)

LDTA >>>

नेपाल सरकार
सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालय

चट्याङ्ग प्रतिरक्षी प्रणाली (बाह्य_०१)

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चट्याङ्ग प्रतिरक्षी प्रणाली (बाह्य_०१)

साधारण उद्देश्य:
भौतिक संरचनामा चट्याङ्ग प्रतिरक्षी प्रणाली जडान गर्ने प्रबिधि को बिस्तृत जानकारी दिलाउने

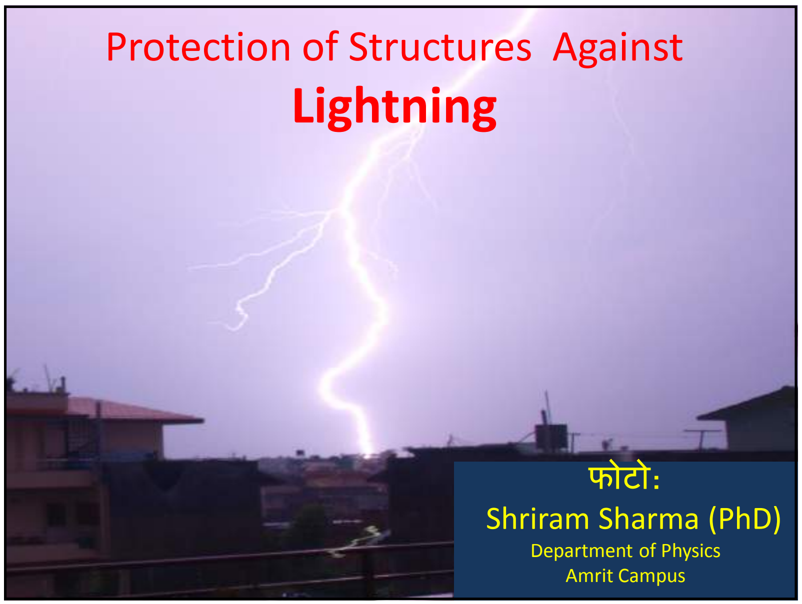
निर्दिष्ट उद्देश्यहरु : सहभागीहरुले यस सत्रको अन्त्यमा,

- चट्याङ्ग प्रतिरक्षी प्रणालीका आधारभूत सिद्धान्तहरु को जानकारी प्राप्त गर्ने छन्
- बाह्य प्रतिरक्षी प्रणालीका घटकहरु को बारेमा जानकारी प्राप्त गर्ने छन्
- प्रतिरक्षी प्रणालीका बारेमा राष्ट्रिय तथा अन्तर्राष्ट्रिय मापदण्डहरु
- बाह्य प्रतिरक्षी प्रणालीका विविध तहहरु को बारेमा बुझ्ने छन्
- प्रतिरक्षी प्रणालीका मापदण्ड अनुरुप का सामाग्री को बारेमा जानकारी प्राप्त गर्ने छन्

चट्याङ्ग प्रतिरक्षी प्रणाली (बाह्य_०१)

सत्रका मुख्य विषयवस्तु:

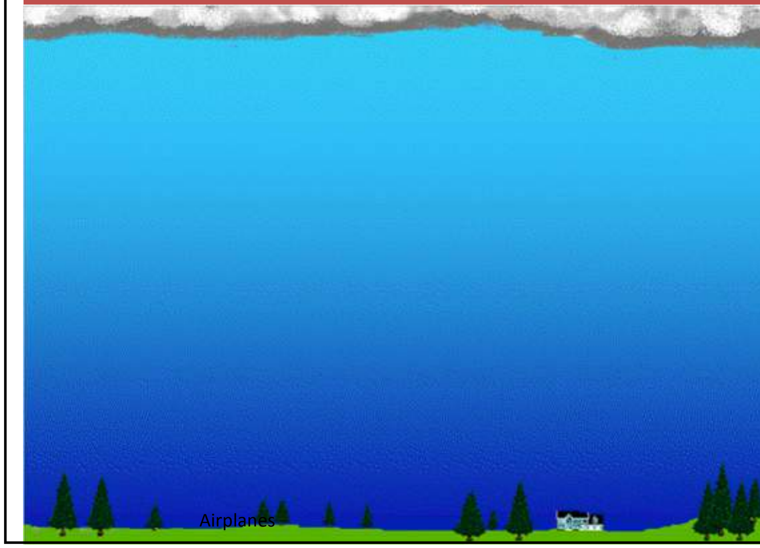
- प्रतिरक्षी प्रणालीका आधारभूत सिद्धान्तहरु
- राष्ट्रिय तथा अन्तर्राष्ट्रिय मापदण्डहरु
- बाह्य प्रतिरक्षी प्रणालीका घटकहरु
- प्रतिरक्षी प्रणालीका विविध तहहरु



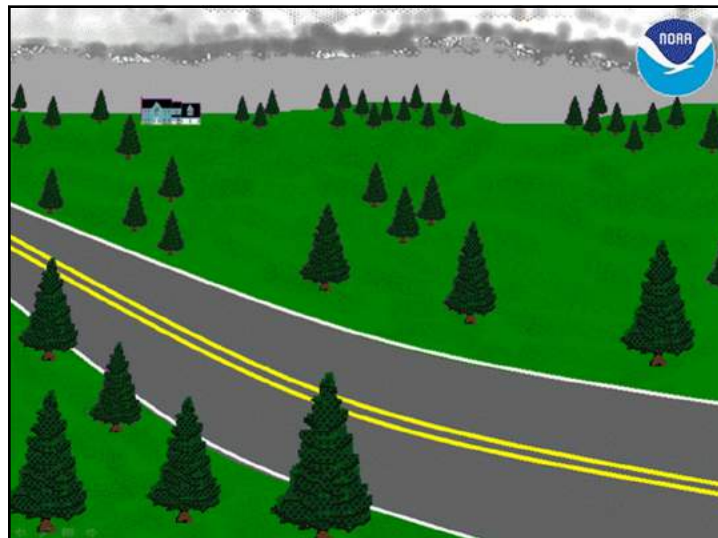
- *In appreciation of the work of a merciful God*

Can we survive a lightning stroke??

Can we survive a lightning stroke??



Can we survive a lightning stroke??



Cars

Lightning Protection System

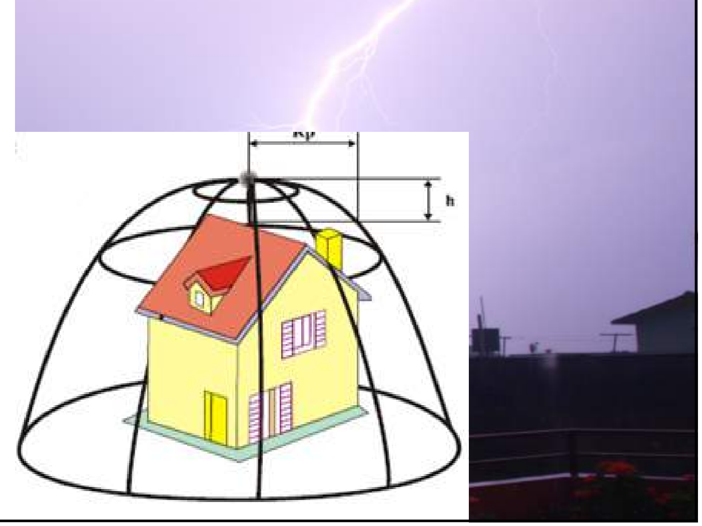
Lightning Protection system

A personal lightning protection system proposed to Benjamin Franklin by Jacques Barbue Dubourg in a letter dated 1773.

Lightning Protection

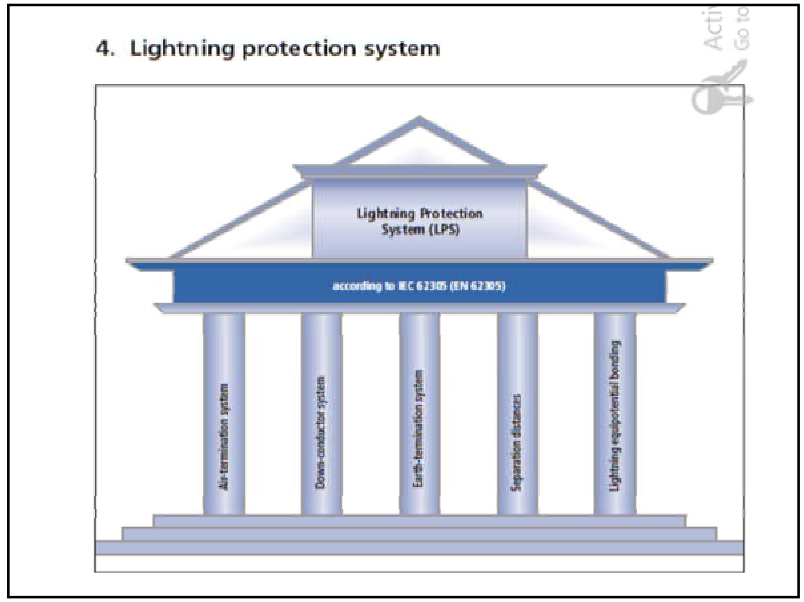
- Buiding Protection
- Surge Protection

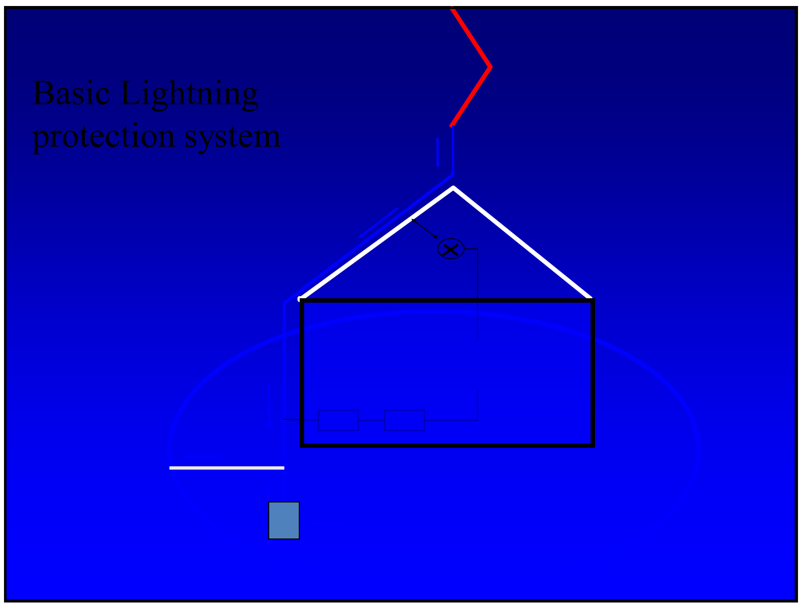
BUILDING PROTECTION

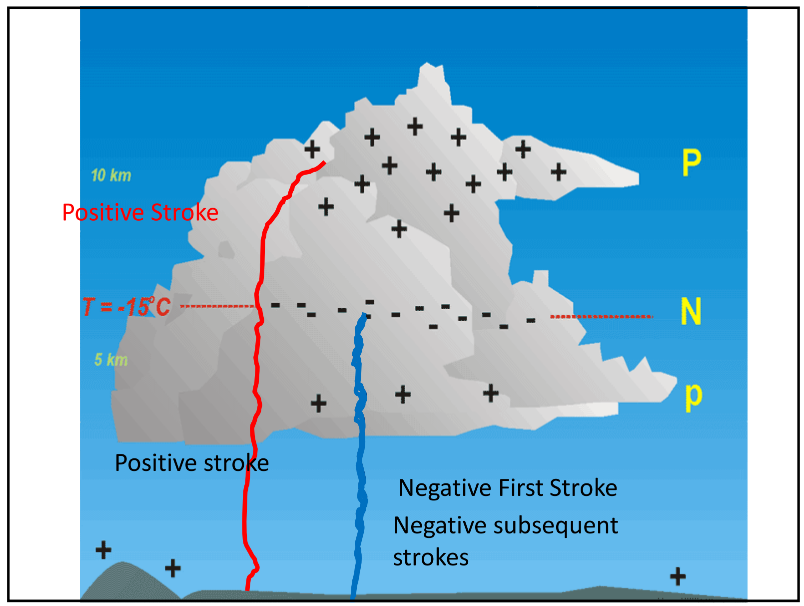


Structural Protection

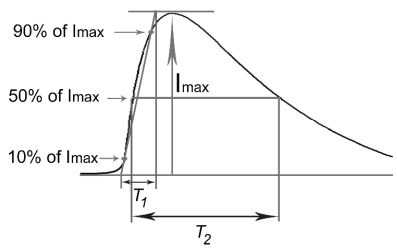
- **A structural protection system consists of two parts**
- **External Protection system**
- a) intercept a direct lightning flash to the structure (with an air-termination system)
- b) conduct the lightning current safely towards earth (using a down-conductor system)
- c) disperse the lightning current into the earth (using an earth-termination system)
- **Internal protection system**
- a) prevents dangerous sparking within the structure using either equipotential bonding or a separation distance (and hence electrical insulation) between the external LPS components and other electrically conducting elements internal to the structure.



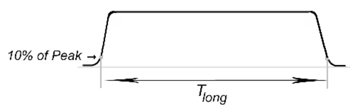




Lightning Current most often contains two parts



Short stroke



Long stroke

T_1 : 10 µs for PS/ 1.0 µs for NFS / 0.25 µs for NSS
T_2 : 350 µs for PS/ 200 µs for NFS / 100 µs for NSS

Duration: 0.5 ms
Current: 0.2 - 1 kA

I_{peak} (kA)

TYPE OF STROKE	95%	50%	5%
Positive	4.6	35	250
Negative first	4.0	20	90
Negative sub.	4.9	11.8	28.6

STANDARDS

IEC 62305-1 (2010): Protection against lightning - General principles
(International Electrotechnical Commission)
IEC 62305-2 (2010): Protection against lightning - Risk management

IEC 62305-3 (2010): Protection against lightning - Physical damage and life hazard

IEC 62305-4 (2010): Protection against lightning - Electrical and electronics systems

IEC 62305-5 (2010): Protection against lightning - supply lines

NFPA 780 (2014): Standard for the installation of lightning protection systems
(National Fire Protection Association)

AS/NZS 1768 (2007): Lightning protection
SANS 10313 (2010): Protection against lightning — Physical damage to structures and life hazard

NF C 17-102 (1995): Lightning Protection- Protection of structures and open areas against lightning using ESE devices
UNE-21186 (1996): Protección contra el rayo: Pararrayos con dispositivo de cebado

Structural Protection is given under 4 Levels of Protection (Classes of Protection)

Class I or Level I : **Highest level of Protection**

Class II or Level II

Class III or Level III

Class IV or Level IV : **Lowest level of protection**

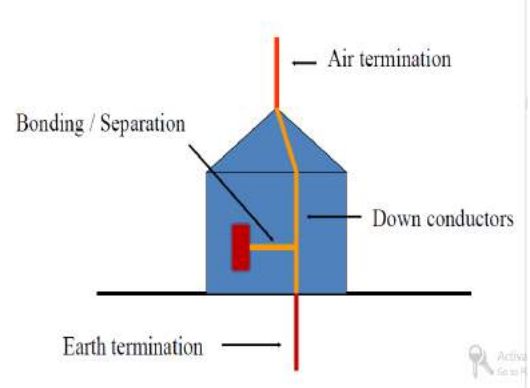
Level of Protection

Limiting Currents (kA)	LPL			
	I	II	III	IV
Maximum	200	150	100	100
Minimum	3	5	10	16

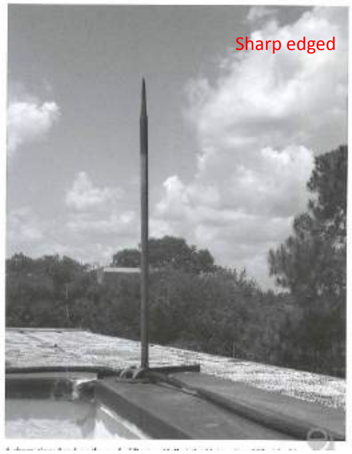
Maximum value of current determines the withstanding capacity of the components of LPS

Minimum value of current determines the probability of lightning stepped leader bypassing the LPS

Main components of a Lightning Protection System (LPS)

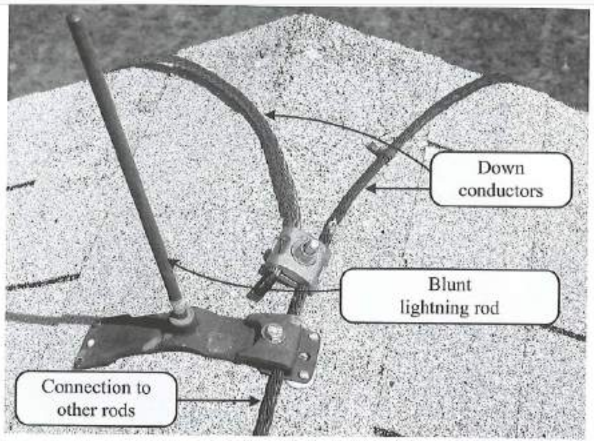


Air Terminals



Air terminals

Air terminals and down conductors



Dimensions and materials of air terminals

Material	Configuration	Cross-sectional area in [mm²]
Copper, tin-plated copper	Solid tape	50
	Solid round [b]	50
	Stranded [b]	50
	Solid round [c]	176
Aluminium	Solid tape	70
	Solid round	50
	Stranded	50
Aluminium alloy	Solid tape	50
	Solid round	50
	Stranded	50
	Solid round	176
Copper coated aluminium alloy	Solid round	50
Hot-dipped galvanised steel	Solid tape	50
	Solid round	50
	Stranded	50
	Solid round [c]	176
Copper-coated steel	Solid round	50
	Solid tape	50
Stainless steel	Solid tape [d]	50
	Solid round [d]	50
	Stranded	50

[a] Mechanical and electrical properties as well as corrosion resistance properties must meet the requirements of the future IEC 62561 series.
[b] 50 mm² (diameter of 8 mm) may be reduced to 25 mm² in certain applications where the mechanical strength is not an essential requirement. In this case, consideration should be given to reduce the spacing between the fasteners.
[c] Applicable for air-termination rods and earth entry rods. For air-termination rods where mechanical stress such as wind load is not critical, an at least 1 m long rod with a diameter of 9.5 mm may be used.
[d] If thermal and mechanical considerations are important, these values should be increased to 75 mm².

Material, configuration and minimum cross-sectional area of air-termination according to Table 6 of IEC 62305-3

धन्यवाद

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स्थानीय विकास प्रशिक्षण प्रतिष्ठान
(स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)
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Local Development Training Academy
(Established by Local Development Training Academy Act, 2049)
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नेपाल सरकार
सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालय

चट्याङ्ग प्रतिरक्षी प्रणाली (बाह्य_०२)

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चट्याङ्ग प्रतिरक्षी प्रणाली (बाह्य_०२)

साधारण उद्देश्य: भौतिक संरचनामा चट्याङ्ग प्रतिरक्षी प्रणाली जडान गर्ने प्रबिधि को बिस्तृत जानकारी दिलाउने

निर्दिष्ट उद्देश्यहरु : सहभागीहरुले यस सत्रको अन्त्यमा,

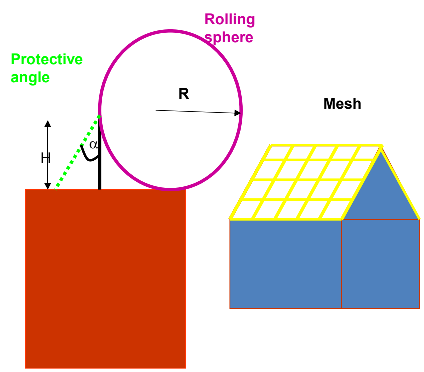
- प्रतिरक्षी सामाग्री का मापदण्डहरु का बारेमा जानकार हुने छन्
- Air termination system (अरेस्टर) हरु जडान गर्ने बिधि र प्रयोग गरिने सामाग्री का बारेमा जानकारी प्राप्त गर्ने छन्
- संरचना अनुशार प्रतिरक्षा को तह को जानकारी प्राप्त गर्ने छन्
- प्रतिरक्षी सामाग्री जडान गर्न प्रयोग गरिने वैज्ञानिक फर्मुला प्रयोग गरि हिसाब गर्न सक्नेछन
- Down conductor system, जडान गर्ने तरिका, सामाग्री र तह को बारेमा जानकार हुनेछन
- Earth termination (अर्थिंग) system का प्रकार, मापदण्ड तथा जडान गर्ने बिधि का बारेमा तह र संरचना का बारेमा जानकारी प्राप्त गर्ने छन्

चट्याङ्ग प्रतिरक्षी प्रणाली (बाह्य_०२)

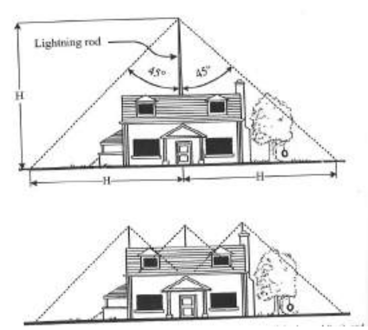
सत्रका मुख्य विषयवस्तु:

- प्रतिरक्षी सामाग्री का मापदण्डहरु
- Air termination system (अरेस्टर) का प्रकार, मापदण्ड तथा जडान गर्ने बिधि
- Down conductor system, का मापदण्ड
- Earth termination (अर्थिंग) system का प्रकार, मापदण्ड तथा जडान गर्ने बिधि

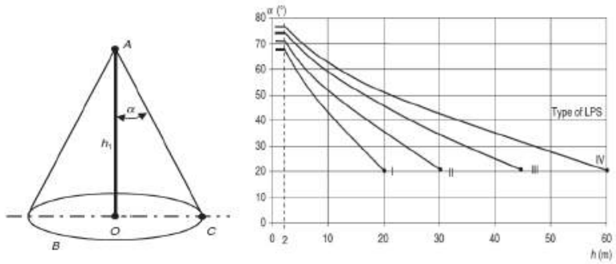
Three Methods to install the air termination



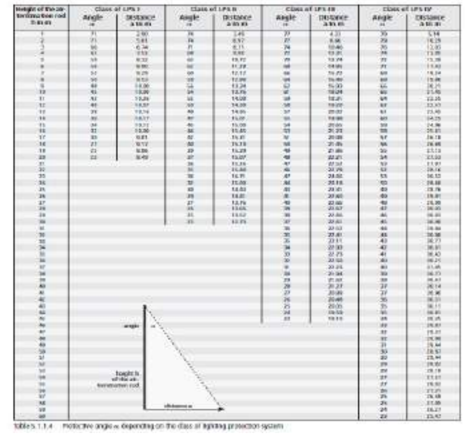
Protection Angle Method



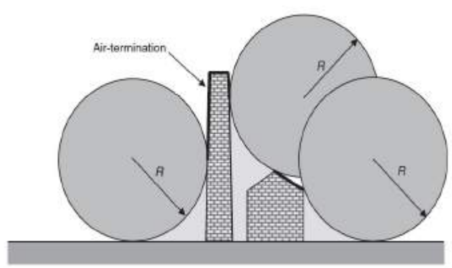
Level of Protection (Angle of Protection)



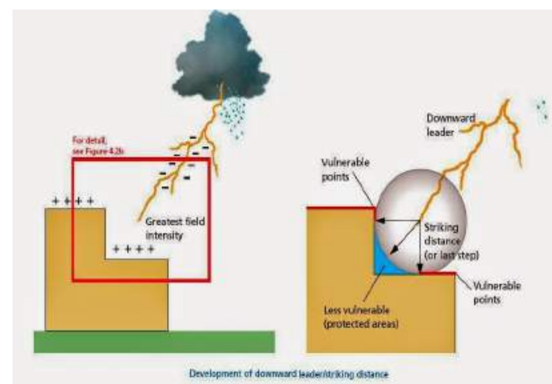
Volume protected by a vertical air-termination rod. A is the tip of the air-termination rod, B is the reference plane, OC is the radius of the protected area, and h_1 is the height of the air-termination rod above the reference plane of protection.



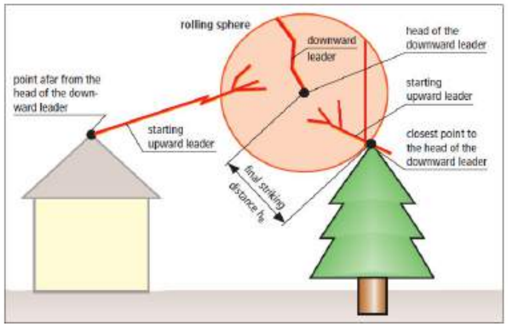
Rolling Sphere Method



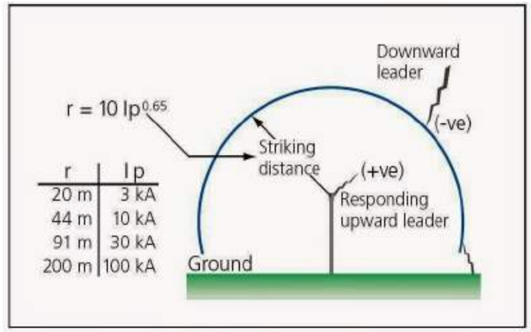
Striking Distance on a house



Striking Distance, radius of the sphere



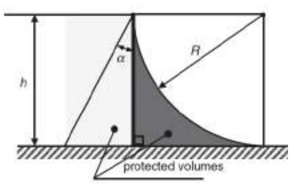
Striking Distance and radius of the sphere



Striking Distance.

- **Notes to the above formulas:**
- The larger the amount of charge carried by the lightning leader, the larger the resulting lightning current, the greater will be the distance at which this happens.
- The head of the downward leader approaches the objects on the ground, unaffected by anything, until it reaches the final striking distance.
- It is more difficult for an air-terminal to intercept a smaller lightning flash than a larger flash, as the smaller flash must approach closer to the air-terminal before the upward leader is launched.
- To protect the structure against smaller lightning flashes, air-terminals must be spaced closer together. For smaller lightning flashes there is a risk that an air terminal may not be close enough to intercept the down leader, thus a closer structural point releases an upward leader which intercepts the flash (i.e. the building is struck).

Level of Protection



Class of LPS	Protection method	
	Rolling sphere radius R (m)	Mesh size W (m)
I	20	5 × 5
II	30	10 × 10
III	45	15 × 15
IV	60	20 × 20

Protection level, striking distance and peak current

Lightning protection level LPL	Probabilities for the limit values of the lightning current parameters		Radius of the rolling sphere (final striking distance h_B) r in m	Min. peak value of current I in kA
	< Max. values acc. to Table 5 IEC 62305-1 (EN 62305-1)	> Min. values acc. to Table 6 IEC 62305-1 (EN 62305-1)		
IV	0.84	0.97	60	16
III	0.91	0.97	45	10
II	0.97	0.98	30	5
I	0.99	0.99	20	3

$$r = 10 \cdot I^{0.65}$$

r in m
I in kA

Rolling sphere method

The horizontal ground safety radius R_g, for height of lightning rod h_1 and striking distance S (radius of rolling sphere) is governed by

$$R_g = \sqrt{2 \times S \times h_1 - h_1^2}$$

The lightning object safety radius R_o, for height of object h_2, is given by using

$$R_o = R_g \times \left[1 - \sqrt{\frac{2 \times S \times h_2 - h_2^2}{2 \times S \times h_1 - h_1^2}}\right]$$

Relation between Lightning Protection Levels and Rolling Sphere Radius

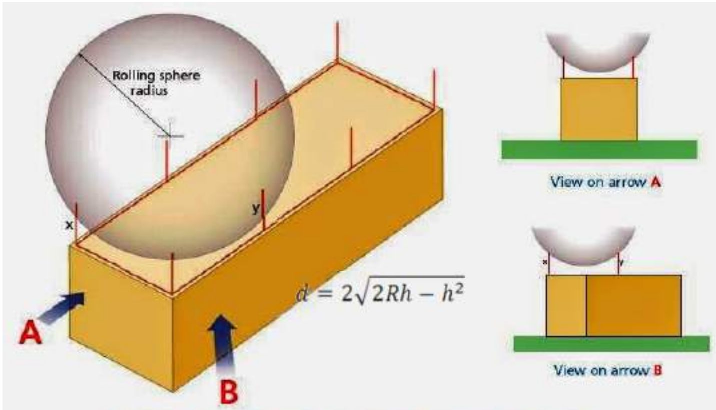
	LPL I	LPL II	LPL III	LPL IV
Minimum current (kA)	3	5	10	16
Probability current is greater than minimum (%)	99	97	91	84
Rolling sphere radius (m)	20	30	45	60

Minimum current levels (related to interception efficiency) for lightning protection levels I to IV.

Note:

- Suppose that a lightning protection system to provide LPL I such that 99% of all lightning flashes are intercepted (all those of 3 kA or greater). There is only a 1% probability that lightning may be smaller than the 3 kA minimum, and may not be close enough to an air-terminal to be intercepted. It should be noted that flashes of less than 3 kA are rare, and typically would not be expected to cause damage to the structure. Protection greater than LPL I (99%) would require significantly more material, is not covered by the standard and generally is not required for commercial construction.

Separation of Air terminals



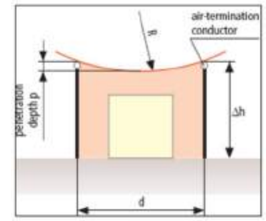
Application of the rolling sphere to air rods in a non-isolated system

The following formula can be used to calculate the penetration depth p of the rolling sphere when the rolling sphere rolls "on rails", for example .

$$p = R - \sqrt{R^2 - \left(\frac{d}{2}\right)^2}$$

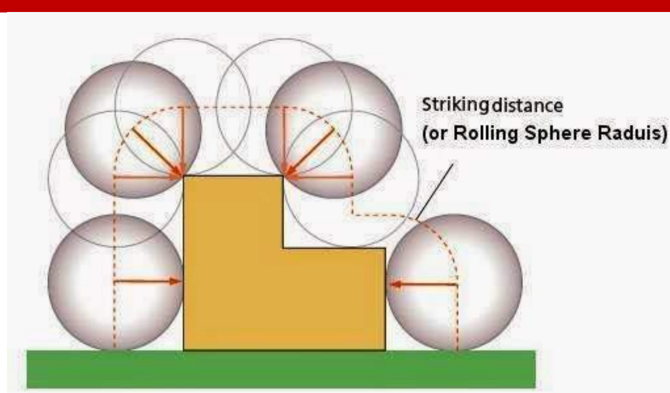
R : Radius of the rolling sphere

d : Distance between two air-termination rods or two parallel air-termination conductors



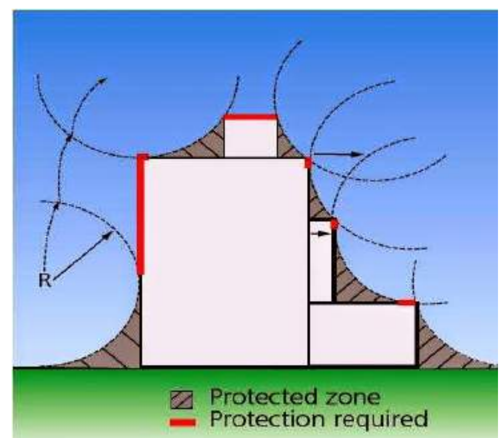
Penetration depth p of the rolling sphere

Applying The Rolling Sphere Method for Lightning Protection Design

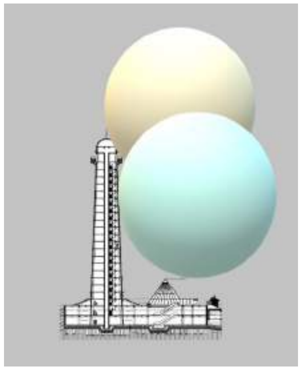


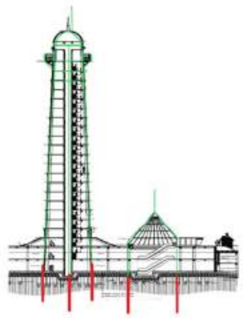
Circular Path around the building (dotted line)

A Schematic Diagram for rolling sphere method



Rolling sphere on Dharahara





Mesh Method

Principles of Mesh method

- Air-termination conductors are positioned on roof edge lines, on roof overhangs and on roof ridge lines if the slope of the roof exceeds 10 per cent, in which case parallel air-termination conductors, instead of a mesh, may be used providing their distance is not greater than the required mesh width.
- The mesh dimensions of the air-termination network are not greater than the values of mesh sizes, for the required protection level

Mesh Method

- The network of the air-termination system is constructed in such a way that the lightning current will always encounter at least two distinct metal routes to the earth-termination system. There are no metal installation protrusions outside the volume protected by the air-termination system, and if there are, these protrusions must be electrically connected to the mesh or to the network of the air-termination system.
- The air-termination conductors must follow, as far as possible, the shortest and most direct route

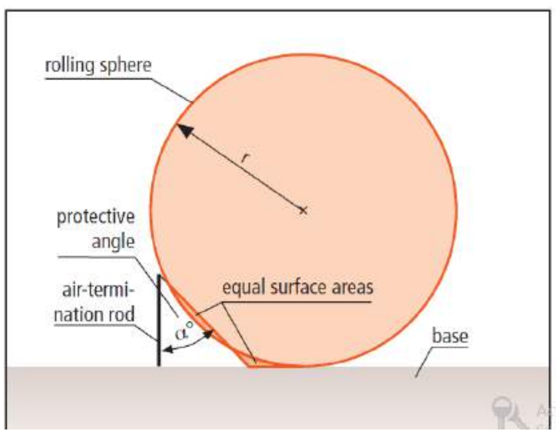
Mesh method

Types of Lightning Protection System	Mesh Size (m)
I	5 x 5
II	10 x 10
III	15 x 15
IV	20 x 20

Comparison of the three methods

- The protection angle method is only suitable for simple common structures or for small parts of bigger structures. It is not suitable for structures higher than the radius of the rolling sphere relevant to the selected protection level of the lightning protection system.
- The mesh method is suitable for general purposes and particularly for the protection of plane surfaces (flat roofs).
- The rolling sphere method is always suitable, even for complex shaped structures.

Protective angle and comparable radius of the rolling sphere



Air terminals of metal sheets

Table 6.1 Table of minimum thicknesses of metal sheets for air-termination [illegible]s (see IEC 62305-3 [2])

Class of LPS	Material	Thickness, t (mm)	Thickness, t' (mm)
I to IV	Lead	–	2.0
	Stainless steel or galvanized steel	4	0.5
	Titanium	4	0.5
	Copper	5	0.5
	Aluminium	7	0.65
	Zinc	–	0.7

Down conductor system

- The down-conductor system is the second part of an external LPS and is intended to conduct the lightning current from the air-termination system to the earth-termination system.
- In order to reduce the probability of damage due to lightning current flowing in the lightning protection system, several equally spaced down-conductors of minimum length are installed and an equipotential bonding to conducting parts of the structure is performed

Down Conductor System

- The down-conductor system is the electrically conductive connection between the air-termination system and the earth-termination system.
- The function of down-conductor systems is to conduct the intercepted lightning current to the earth-termination system without intolerable temperature rises.

LPS Down conductor on a simple of house

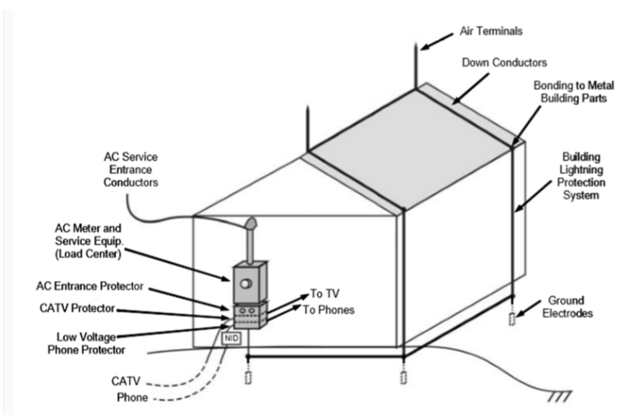


Table 4 – Typical values of the distance between down-conductors and between ring conductors according to the class of LPS

Class of LPS	Typical distances m
I	10
II	10
III	15
IV	20

Material, configuration and min. cross sections of air-termination conductors, air-termination rods and down conductors according to IEC 62305-3

Material	Configuration	Min. cross-section mm^2	Remarks[10]
Copper	solid flat material	50[8]	min. thickness 2 mm
	solid round material[7]	50[8]	diameter 8 mm
	cable	50[8]	min. diameter each wire 1.7 mm
	solid round material[3], [4]	200[8]	diameter 16 mm
Tin plated copper[1]	solid flat material	50[8]	min. thickness 2 mm
	solid round material[7]	50[8]	diameter 8 mm
	cable	50[8]	min. diameter each wire 1.7 mm
Aluminium	solid flat material	70	min. thickness 3 mm
	solid round material	50[8]	diameter 8 mm
	cable	50[8]	min. diameter each wire 1.7 mm
Aluminium alloy	solid flat material	50[8]	min. thickness 2.5 mm
	solid round material	50	diameter 8 mm
	cable	50[8]	min. diameter each wire 1.7 mm
	solid round material[3]	200[8]	diameter 16 mm
Hot dipped galvanised steel[2]	solid flat material	50[8]	min. thickness 2.5 mm
	solid round material[9]	50	diameter 8 mm
	cable	50[8]	min. diameter each wire 1.7 mm
	solid round material[3], [4], [9]	200[8]	diameter 16 mm
Stainless steel[5]	solid flat material[6]	50[8]	min. thickness 2 mm
	solid round material[6]	50	min. thickness 8 mm
	cable	70[8]	min. diameter each wire 1.7 mm
	solid round material[3], [4]	200[8]	diameter 16 mm

Specifications

1) Hot dipped or electroplated, minimum thickniss of the coating 1 µm.

2) The coating should be smooth, continuous and free of residual flux, minimum thickness 50 µm.

3) For air-termination rods. For applications where mechanical loads, like wind loads are not critical, a max. 1 m long air-termination rod with a diameter of 10 mm with an additional fixing may be used.

4) For lead-in earth rods.

5) Chromium ≥ 16 %, nickel ≥ 8 %, carbon ≤ 0.03 %

6) For stainless steel in concrete and/or in direct contact with flammable material, the min. cross section for solid round material has to be increased to 78 mm^2 (10 mm diameter) and for solid flat material to 75 mm^2 (3 mm thickness).

7) For certain applications where the mechnical strength is not important, 28 mm^2 (6 mm diameter) material may be used instead of 50 mm^2 (8 mm diameter). Then distance of the fixing elements has to be reduced.

8) If thermal and mechanical requirements are important, the min. cross section for solid flat material can be increased to 60 mm^2 and for solid round material to 78 mm^2.

9) At a specific energy of 10,000 kJ/Ω the min. cross section to prevent from melting is 16 mm^2 (copper), 25 mm^2 (aluminium), 50 mm^2 (steel) and 50 mm^2 (stainless steel). For further information see Annex E.

10) Thickness, width and diameter are defined at a tolerance of ± 10 %.

Down conductor

- The materials used for a lightning protection system should have an excellent electrical conductivity to allow the flowing of the lightning current, sufficient mechanical strength to withstand the electrodynamic stresses caused by the high lightning current peak values, and a suitable resistance to corrosion in aggressive environments.

Down conductor

Down Conductors

- In order to reduce the possibility of occurrence of dangerous sparking, the sown-conductors are to be arranged in such a way that from point of strike to earth:
- a) several parallel current paths exist;
- b) the length of the current paths is kept to a minimum.
- The down-conductors shall be so arranged that they become, as far as possible, the direct continuation of the air-termination conductors.

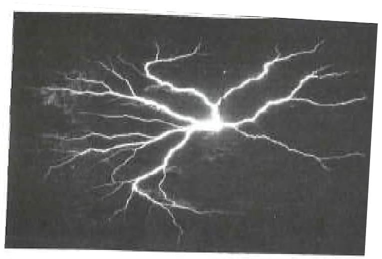
Earth Termination system/Grounding

- Why is Earthing Needed??

Earth Termination System

- The earth-termination system is the third part of an external LPS that is intended to conduct and disperse the lightning current into the earth, without causing any danger to people or damage to installations inside the structure to be protected.
- In general, a low earthing resistance, if possible, lower than 10 Ohm when measured at low frequency, is recommended

Surface arcing



Photograph of surface arcing of about 4 m radius from the point of current injection via a ground rod into soil in a laboratory experiment (Wang *et al.* 2005). Courtesy of Liew Ah Choy.

Surface arcing

Photograph showing evidence of electrical breakdown across the Earth's surface from the current of natural lightning injected into a grounding electrode, in this case the pole on a golf course green. Courtesy of E. Philip Krider.

Earthing/Grounding

Material, configuration and min. dimensions of earth electrodes according to IEC 62305-3 (EN 62305-3) Table 7

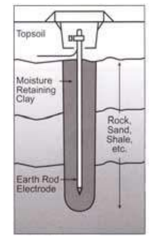
Material	Configuration	Min. dimensions: Earth rod Ø mm	Min. dimensions: Earth conductor	Min. dimensions: Earth plate mm	Notes
Copper	stranded[3]		50 mm²		min. diameter of each strand 1.7 mm
	solid round material[3]		50 mm²		diameter 8 mm
	solid flat material[3]		50 mm²		min. thickness 2 mm
	solid round material	15[8]			
	pipe	20			min. wall thickness 2 mm
	solid plate			500 x 500	min. thickness 2 mm
	grid-type plate			600 x 600	section 25 mm x 2 mm, min. length of grid construction: 4.8 m
Steel	galvanised solid round material[1, 2]	16[9]	diameter 10 mm		
	galvanised pipe[1, 2]	25			min. wall thickness 2 mm
	galvanised solid flat material[1]		90 mm²		min. thickness 3 mm
	galvanised solid plate[1]			500 x 500	min. thickness 3 mm
	galvanised grid-type plate[1]			600 x 600	section 30 mm x 3 mm
	copper-plated solid round material[4]	14			min. 250 µm coating with 99.9 % copper
	bare solid round material[5]		diameter 10 mm		
	bare or galvanised solid flat material[5, 6]		75 mm²		min. thickness 3 mm
	galvanised cable[5, 6]		70 mm²		min. diameter of every wire 1.7 mm
Stainless Steel[7]	solid round material	15	diameter 10 mm		
	solid flat material		100 mm²		min. thickness 2 mm

1) The coating must be smooth, continuous and free of residual flux, mean value 50 µm for round and 70 µm for flat material.
2) Threads must be tapped before galvanising.
3) Can also be tin-coated.
4) The copper must be connected unresolvably with the steel.
5) Only permitted, if embedded completely in concrete.
6) Only permitted for the part of the foundation in contact with the earth, if connected safely with the reinforcement every 5 m.
7) Chrome ≥ 16 %, nickel ≥ 5 %, molybdenum ≥ 2 %, carbon ≤ 0,08 %.
8) In some countries 12 mm are permitted.
9) Some countries require earth lead-in rods to connect down conductor and earth electrode.

Earth Electrodes

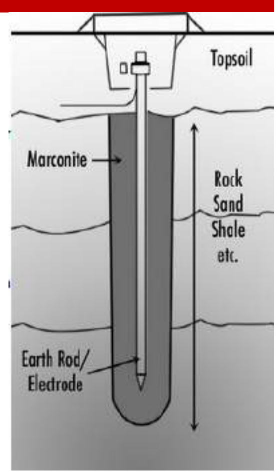
अर्थिंग सामाग्री गर्दा कस्तो सामाग्री राख्ने-अर्थिंग केमिकल

अर्थिंग सामाग्री मा परिमार्जन



Earthing and Backfill

Bentonite Compound
Bentonite is a moisture retaining clay used as an earth electrode back-fill to help lower soil resistivity. The Bentonite clay is a sodium activated montmorillonite which when mixed with water swells to many times its original volume
Marconite Compound
Marconite is a granulated electrically conductive aggregate which replaces sand in mixes with cement, thereby providing electrically conductive concrete.
Electrodes (including copper earth rods) can be encased in Marconite mixture to greatly increase their surface area, lowering the resistance to earth.



हुनु पर्ने के हो ?

धन्यवाद

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स्थानीय विकास प्रशिक्षण प्रतिष्ठान
(स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)

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सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालय

चट्यांग बाट आन्तरिक प्रतिरक्षा (बिद्युतीय सामाग्रीहरुको सुरक्षा)

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साधारण उद्देश्य: चट्यांग हुने बिद्युतीय सामाग्रीहरुको सुरक्षा गर्ने बिधि बारे बिस्तृत जानकारी दिने

निर्दिष्ट उद्देश्यहरु: सहभागीहरुले यस सत्रको अन्त्यमा,

- बिधयुतीय सर्ज को बारेमा जानकारी प्राप्त गर्ने छन्
- बिधयुतीय सर्ज का श्रोत तथा तिनले पुर्याउने क्षति का बारेमा जानकारी प्राप्त गर्ने छन्
- सर्ज तथा ओवरभोल्टेज बाट बचाउने उपकरण हरु को प्रकार, प्रतिरक्षा का प्रक्रिया आदि का बारेमा जानकारी
- सर्ज प्रतिरक्षी उपकरण (SPD) जडान गर्ने तरिका
- बन्धनिकरण तथा समानभोल्टेजिकरण (Bonding and equipotentialization) को जानकारी

चट्यांग बाट आन्तरिक प्रतिरक्षा (बिद्युतीय सामाग्रीहरुको सुरक्षा)

सत्रका मुख्य विषयवस्तु:

- बिद्युतीय overvoltage तथा surge (सर्ज) को परिचय
- बिद्युतीय overvoltage तथा surge का कारण हुने क्षतिहरु
- सर्जबाट बचाउने उपकरणहरू (SPD) का परिचय तथा प्रकारहरु
- SPD जडान गर्ने बिधि
- बन्धनिकरण तथा समानभोल्टेजिकरण (Bonding and equipotentialization)

Internal Protection and Installation concerns of Surge Protective Devices (SPDs)

Internal Protection and Bonding

The functions of the **external LPS** are
• to attract direct lightning strikes into an air termination
• to safely conduct the lightning current to earth by means of a down-conductor system, and
• to distribute the lightning current in the earth via an earth-termination system

The function of the **internal lightning protection** is
• to prevent hazardous sparking inside the building or structure.

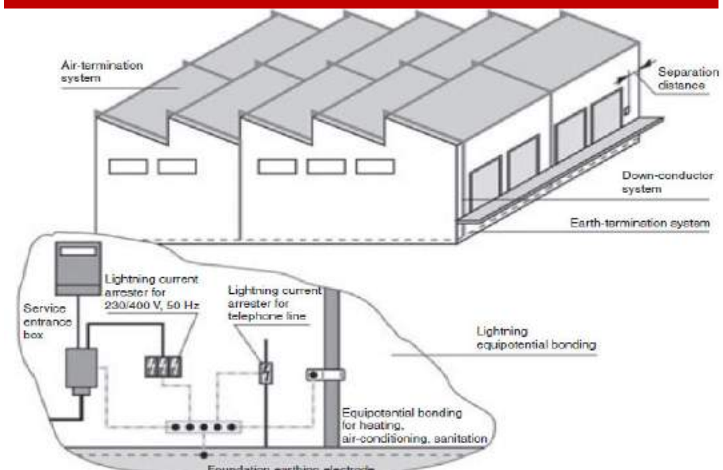
- ***Lightning and Surge Protection according to IEC 62305***

Internal Protection and Bonding

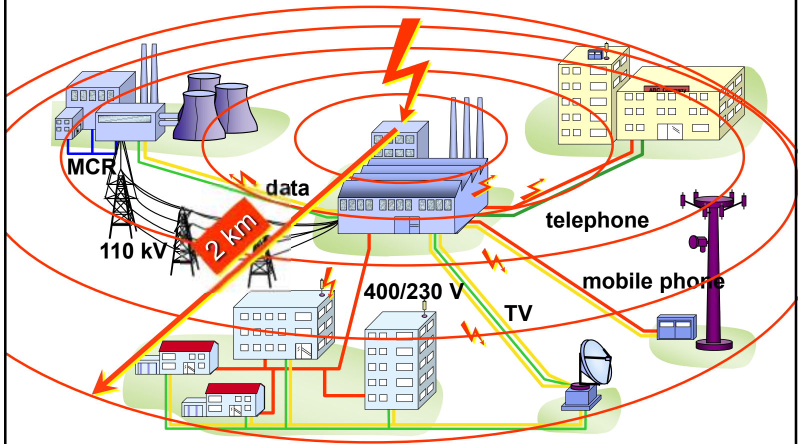
This is achieved by means of equipotential bonding or a safety distance between

- components of the LPS and other conductive elements inside the building or structure.
- The protection equipotential bonding reduces the potential drops caused by the lightning current.
- This is achieved by connecting all separate, conductive parts of the installation directly by means of conductors or SPDs (SPDs)

Internal Protection and Bonding



Danger due to Lightning Strokes



Lightning threat within a range of 2 km

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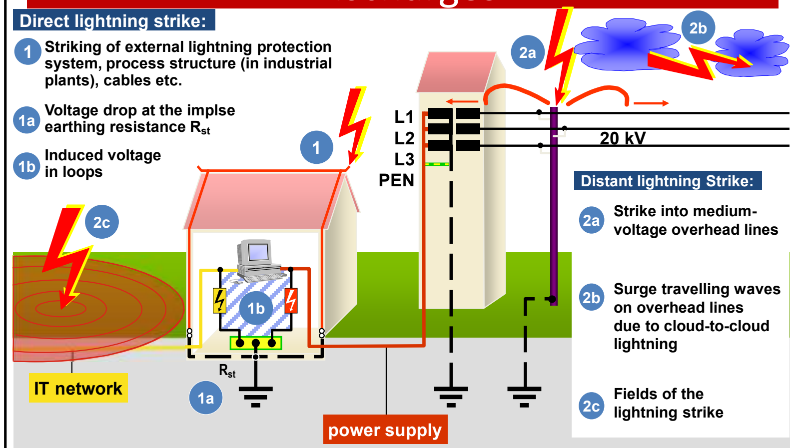
Causes of Surges due to Lightning Discharges



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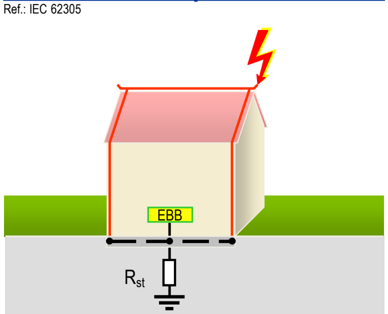
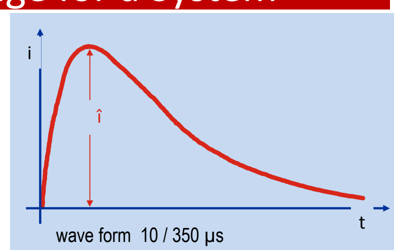
Galvanic Coupling
Lightning Voltage for a System

Lightning Prot. Level	Current amplitude kA
I	200
II	150
III - IV	100

Ref.: IEC 62305





$$\hat{u}_E = \hat{\imath} \cdot R_{st}$$

Example:
$\hat{u}_E$ = 100 kA · 1 Ω = 100 kV

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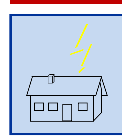
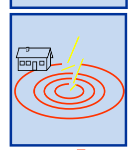
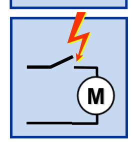
Influences on Electrical Installations
Causes of Surges



Direct lightning strike (LEMP)
- Galvanic coupling
- Inductive / Capacitive coupling



Indirect lightning strike
- Conducted partial lightning currents
- Inductive / Capacitive coupling



Surges (SEMP)
- Switching operations
- Earth faults / Short circuits
- Tripping fuses
- Parallel installation of power and IT conductor systems

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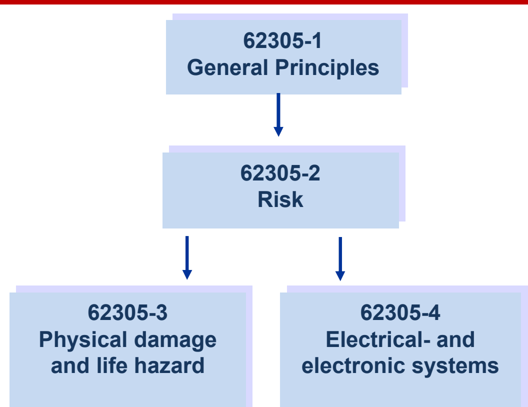
Lightning Current Parameters according to IEC 62305

Parameters	Lightning Protection Level		
	I	II	III-IV
I (kA)	200	150	100
W/R (MJ/Ω)	10	5.6	2.5
Q_s (As)	100	75	50
Q_{long} (As)	200	150	100

IEC 62305 International lightning protection standard

IEC 62305-1	General Principles
IEC 62305-2	Risk Management
IEC 62305-3	Physical Damage to Structures and Life Hazard
IEC 62305-4	Electrical and Electronic Systems

IEC 62305 International lightning protection standard



IEC 62305-3 Physical damage to structures and life hazard

Introduction

a) External LPS (air termination system, down contuctor's, earth termination system).

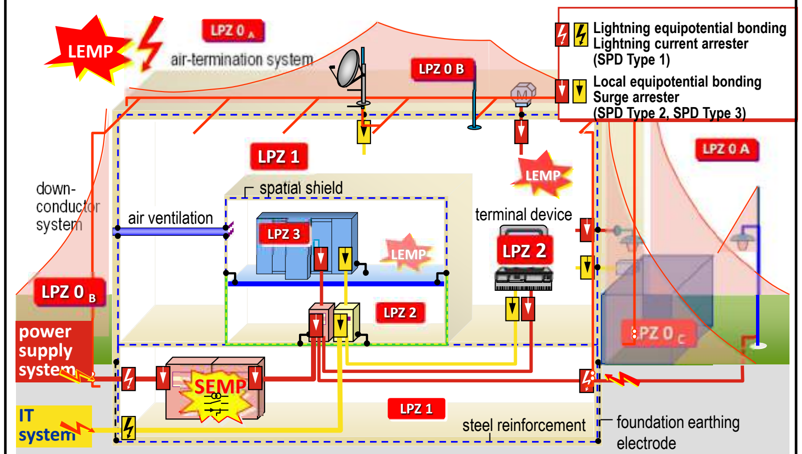
b) An internal LPS (preventing dangerous sparking using equipotential bonding or separation distance (hence electrical insulation) between external LPS and internal metal work.

Standardisation of Surge Protective Devices

IEC 61643-1
Performance Requirements of Surge Protective Devices for Low-Voltage Power Supply Systems

Class I	Class II	Class III
Protection Against Direct Lightning Currents (Lightning Current Arrester)	Protection Against Indirect Lightning Effects (Surge Arrester)	Protection Against Switching Overvoltages (Surge Arrester)
(10/350 µs)	(8/20 µs)	(1.2/50 µs; 8/20 µs)

EMC-Orientated Lightning Protection Zones Concept



INTERNAL LIGHTNING PROTECTION

Lightning Equipotential Bonding

Surge Protection

Coordination

Internal Lightning Protection System

Based on IEC 62305-4

- **Equipotential Bonding at the Boundary of LPZ**
  - Equipotential bonding for all metal parts and supply lines (e.g. metal pipes, electrical power or data lines) which are entering at the boundary of an internal LPZ shall be carried out at equipotential bonding bars which are installed as closely as possible to the point of entry.
  - SPDs with suitable power carrying capacity for electrical power and data lines at the point of entry into the LPZ have always to be installed.

Internal Lightning Protection
Surge Protective Devices

Based on IEC 62305-4

Surge protective devices for lightning equipotential bonding must be capable of safely controlling the partial lightning currents to be expected to flow through them.
For this purpose, surge protective devices are chosen according to the requirements on site and installed in accordance with IEC 60364-5-53

The residual voltage at the surge protective device installed into the building, has to be coordinated with the impulse withstand capability of the installation.

Surge protective devices Class I to be installed at the entry of the building, keep a significant part of the power of lightning currents away from the inside of the building.

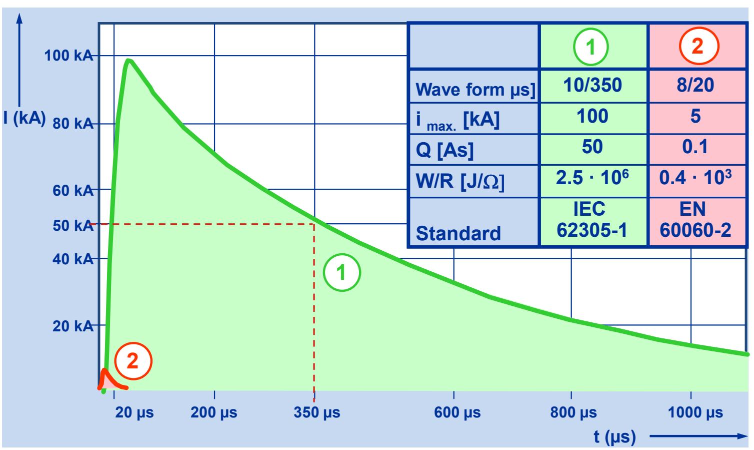
201

What is a Lightning Current Arrester installed into a Power Supply System supposed to perform?

- **Discharging of lightning currents several times without desctruction of the equipment.**
  = Discharge capacity 100 kA (10/350 µs)
- **Providing of a lower voltage protection level than the voltage strength of the downstream installation.**
- **Extinguishing or limiting of mains follow currents.**
- **Ensuring of the energy coordination to downstream surge protective devices and/or terminal equipment.**

202

1 Test Impulse Curent for Lightning Current Arresters
2 Test Impulse Current for Surge Arresters



	1	2
Wave form µs]	10/350	8/20
$i_{max.}$ [kA]	100	5
Q [As]	50	0.1
W/R [J/Ω]	$2.5 \cdot 10^6$	$0.4 \cdot 10^3$
Standard	IEC 62305-1	EN 60060-2

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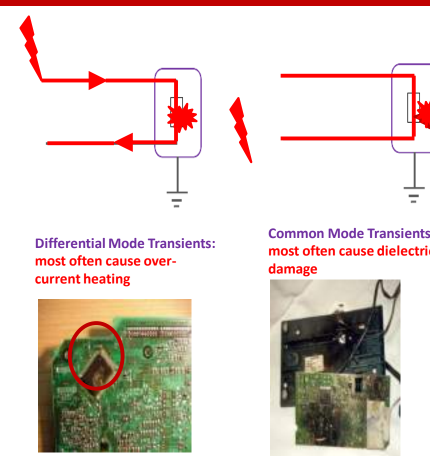
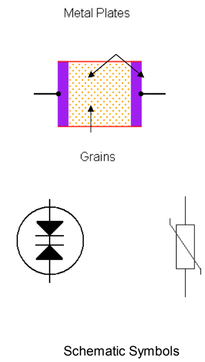
क्षति का किसिम



सर्ज प्रतिरक्षी उपकरणहरु र कार्य प्रक्रिया

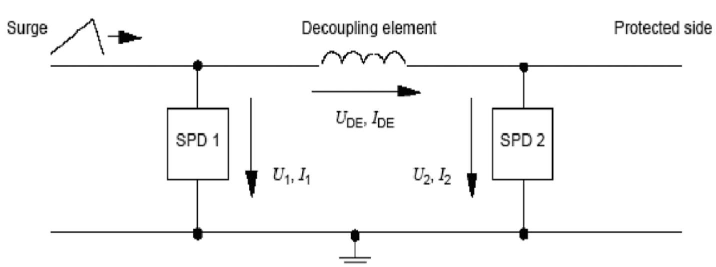
Metal Oxide Varistors (MOV) 	Contains a ceramic mass of zinc oxide grains, combined with other metal oxides sandwiched between two metal plates forming a network of back-to-back diode pairs
Silicon Junction Diode 	The diode is installed reverse-biased under normal conditions. When the voltage rises above normal conditions the diode becomes forward-biased
Spark Gap 	If a voltage surge is experienced a spark ignites gases creating an arc across the gap
Gas Tube Arrestor 	Commonly used for telephone lines as they enter a building Sophisticated spark gap that safely shunts the surge to ground

मेटल अक्साइड भेरिस्टर (MOV) प्रबिधि

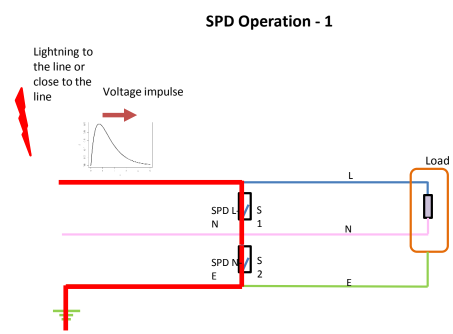


- Contains a ceramic mass of zinc oxide grains combined with small quantities of bismuth, cobalt and manganese sandwiched between two metal plates
- The boundary between each grain and its neighbor forms a diode junction, allowing current to only flow in one direction
- Equivalent to a mass of back-to-back diode pairs, each in parallel

विद्युतिय सर्ज लाई प्रतिरोध गर्ने प्रबिधि

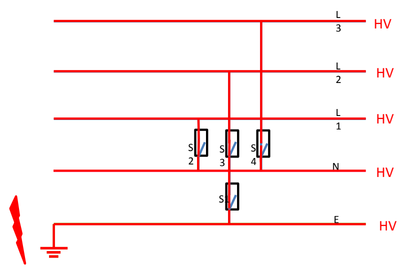


कार्य प्रक्रिया



कार्य प्रक्रिया

SPD Operation - 2

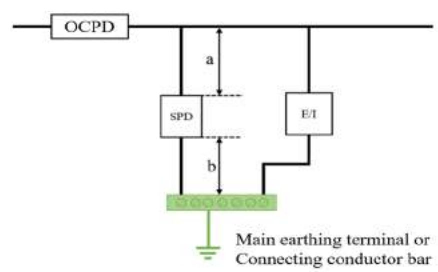


सर्ज प्रतिरक्षी उपकरण का नमुना

अन्तरक्रिया

- सहभागी संग सर्ज प्रतिरक्षी उपकरण को ज्ञान बारे जानकारी लिने
- सर्ज प्रतिरक्षी उपकरण को नमुना देखाउने,
- उक्त उपकरण का विभिन्न भाग को प्रदर्शन गर्ने

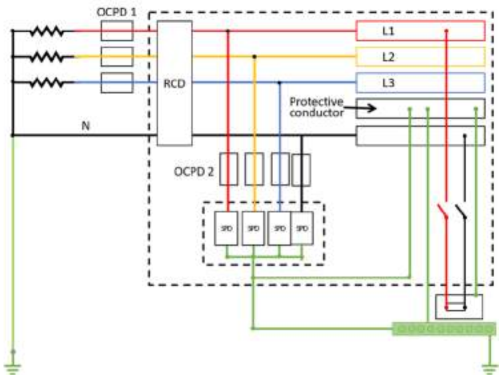
सर्ज प्रतिरक्षी उपकरण जडान गर्ने तरिका



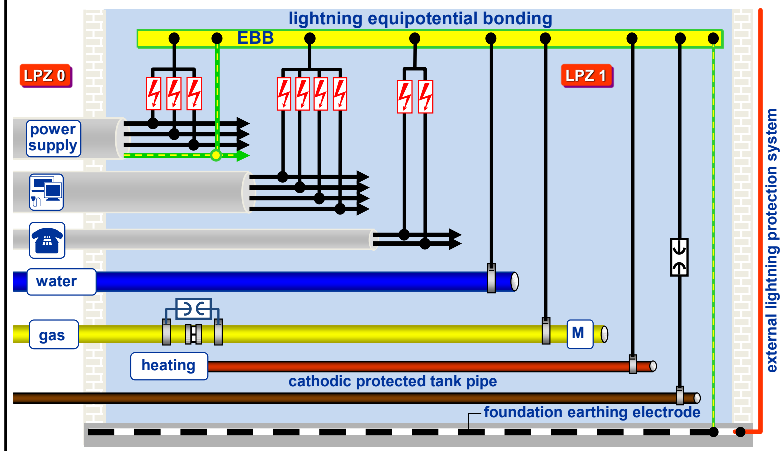
OCPD- Over Current Protective device (उच्च करेन्ट प्रतिरक्षी उपकरण)
SPD- Surge Protective Device (सर्ज प्रतिरक्षी उपकरण)
E/I- Equipment or Installation to be protected (सुरक्षित राख्नु पर्ने सामाग्री वा उपकरण)

Single phase system

सर्ज प्रतिरक्षी उपकरण जडान गर्ने तरिका



Lightning Equipotential Bonding for incoming Lines



214

What is a Surge Arrester installed into a Power Supply System supposed to perform?

- **Discharging of impulse currents (8/20 µs) several times without destroying the terminal equipment**

  = 20 x nominal discharge capacity 5 - 20 kA (8/20 µs)

- **Voltage protection level lower than the electrical strength of the downstream terminal devices**

  = Voltage protection level ≤ 1,500 V

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धन्यवाद

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स्थानीय विकास प्रशिक्षण प्रतिष्ठान
(स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)

"An Autonomous, Professional, Client Centered, Gender Responsive National Institute of Excellence in the area of Local-Self Governance."

Local Development Training Academy
(Established by Local Development Training Academy Act, 2049)

LDTA >>>

नेपाल सरकार
सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालय

अन्तर्राष्ट्रिय मापदण्ड IEC अनुरुप तथा गैरमापदण्डका अरेस्टरहरु

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अन्तर्राष्ट्रिय मापदण्ड IEC अनुरुप तथा गैरमापदण्डका अरेस्टरहरु

साधारण उद्देश्यः **सहभागी लाई अन्तर्राष्ट्रिय मापदण्ड का अरेस्टर को जानकारी गराई बजार मा ब्याप्त गैरमापदण्डका अरेस्टरहरु को भ्रामक प्रचार प्रति सचेतना दिलाउने**

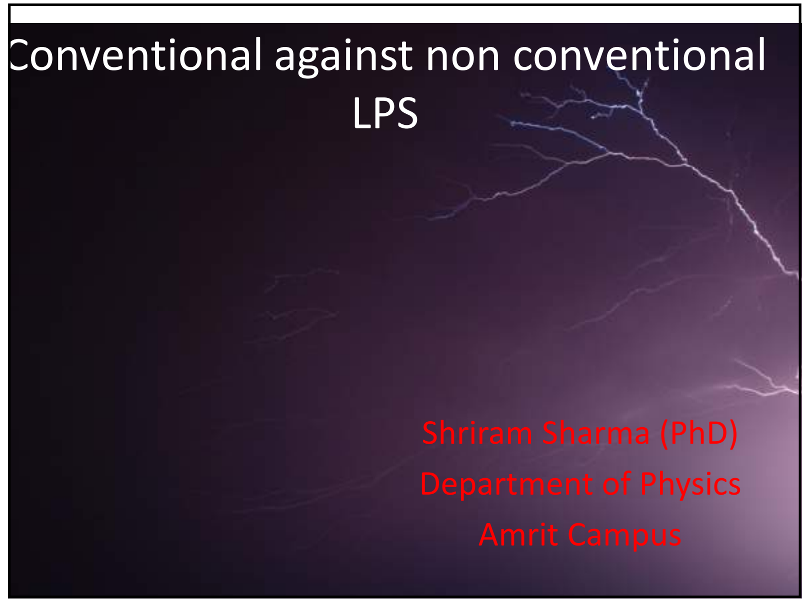
निर्दिष्ट उद्देश्यहरु : सहभागीहरुले यस सत्रको अन्त्यमा,

- राष्ट्रिय तथा अन्तर्राष्ट्रिय बजार मा पाइने विभिन्न किसिम का अरेस्टर को बारे मा जानकारी प्राप्त गर्ने छन्
- **IEC मापदण्ड अनुरुपका अरेस्टर को पहिचान गर्न सक्ने छन्**
- **भ्रामक प्रचार गरेर बिक्रि गरिने सामाग्री हरु को यथार्थता जान्ने छन्**
- **गलत सामाग्री जडान गर्न र गराउन बाट सचेत गरुन सक्ने छन्**

अन्तर्राष्ट्रिय मापदण्ड IEC अनुरुप तथा गैरमापदण्डका अरेस्टरहरु

सत्रका मुख्य विषयवस्तुः

- अरेस्टरः एक परिचय
- के छ IEC तथा अन्य राष्ट्रिय मापदण्डमा ?
- गैरमापदण्ड का अरेस्टरहरुको समस्या के हो **?**
- समाधानका उपायहरु



Conventional air terminals

Conventional Practices

Conventional Practices

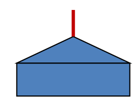
Conventional air terminals

- In the 60s and 70s, due to the higher price of copper and other metals used in lightning protection, people thought they could develop a technique that would reduce the number of air-terminations and down conductors that were prescribed in the international standards.
- The ESE concept was developed based on a premise that some form of a sophisticated device connected to the air termination system could launch an upward streamer/leader much earlier than the conventional Franklin Rod.
- In effect, the rod would act as if it were 'taller' than it actually was by sending off this answering leader.

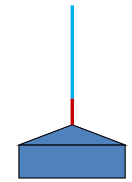
225

The inventors believed that the early initiation of the answering leader (streamer) by the ESE rod made the rod have a greater 'virtual' or effective height.

- Franklin Rod - Only the physical height of the rod is considered



- Early Streamer Emitters (ESE) - 'Effective height' is considered



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Non conventional system

- **The lightning attracting systems**
- The initial lightning attracting system came in the form of the radioactive air terminal in the 1970s and the later system came in the form of the Early Streamer Emission (ESE) air terminal in the late 1980s.
- The **principle** behind the lightning attracting system lay in the existence of the upward streamer. **It is a low current electrical discharge phenomenon that exists when a lightning bolt is about to occur in the immediate vicinity.**

Varieties of ESE developed to induce the streamer at the tip

* Radioactive sources
* Electronic device that injects voltage pulses
* Piezo-electric device that generates voltage pulses
* Complex electrode system that acts as a switch
* Electric field modified by the shape of the tip

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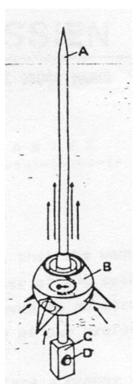
Lightning attracting system

Lightning attracting system

- **Radioactive air terminals**
- The various types of radioactive air terminals were constructed like the Franklin air terminal except that they had radioactive isotopes added to the terminal. The radioactive isotopes were claimed to be able to ionize the terminal which can assist in the launch of the streamers.
- In this method, the inventors claimed that the radioactive air terminal can attract lightning up to 100 m away, hence providing large protection coverage of about the same radial distance.

Lightning attracting system



Some of the radioactive air terminals that banned in most of the countries

ESE Devices

- **Early Streamer Emission (ESE) air terminals**
- When the radioactive air terminals were banned worldwide, the manufacturers rapidly introduced new air terminals which used non-radioactive means to launch the streamers.
- The ESE air terminal made use of proprietary designed metal enclosures around the ordinary lightning rods to create the ionization that can generate the artificial streamers earlier than the natural ones.
- Manufacturer claim: ESE air terminals can launch the streamers earlier, by a few micro seconds i.e. 10^6 ms^{-1}
- However, the scientists observed the speed to be 10^4 to 10^5 ms^{-1}

The lightning elimination systems

- There are two basic types of lightning elimination (i.e. prevention) systems in the market.
- One is claimed by its vendor to be able to eliminate lightning strikes while the other is claimed to be able to drastically reduce the magnitude of the lightning strike current.

The lightning elimination systems

- **The Dissipative Array System (DAS)**
- claimed to be able to prevent lightning from striking the facility it was installed on. Were found to be false claims.

Lightning elimination air terminals

Lightning elimination air terminals

- **Semiconductor Lightning Eliminator (SLE)**
- The SLE was invented in China and is claimed by its inventor to be able to reduce the lightning current by 99%, hence making it safe for installation on buildings which contained sensitive electronic systems.
- a very recent study by two scientists from the Chinese Academy of Sciences show that the lightning reduction properties of the SLE have not been observed when exposed to rocket triggered lightning.

Lightning elimination air terminals

Testing of ESE devices

ESE Air terminals

Those who sell Alternative Air Terminals claim their technology can:

1. Produce an electric field at the tip of the terminal that will make them effectively taller
2. Because of this height, they can use fewer air terminals and their use will produce a larger effective area of protection.
3. Some, who understand very little of the physics, will claim that ESE's ***avert or prevent*** lightning strikes by 'discharging the electric field in the thundercloud'

Early Streamer Emitter Devices

What are they?

Paraton@ir®

Early Streamer Emitter lightning rods

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Typical ESE Air-terminals

What is the real protection radius of the ESE air terminal, even if their method is correct (with reasonable parameters)?

244

Against their claim

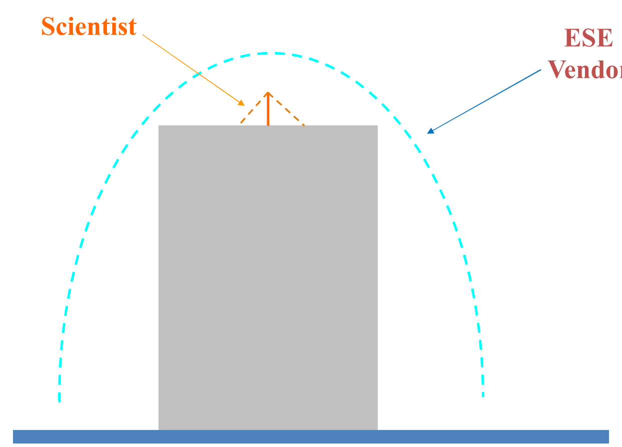
The French Standards specify a high voltage testing to determine the effective height of an ESE rod.

Thus, let us assume that the effective height claimed by ESE manufacturers is correct and look at some systems.

246

Some lab evidence of non-superiority of ESE

247



Lightning struck within few meters from ESE….!

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Other ESE failures -

250

ESE fails itself

251

ESE fails itself

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The view of the international scientific community on ESE devices

In a settlement the NFPA agreed to have ESE technology re-evaluated by an outside panel.

The panel confirmed that there was no scientific basis for NFPA 781

The view of the international scientific community on ESE devices

ESE devices were included into the French National Standards (NF C17-102) in the mid 90s. Spain followed France and adopted ESE concept in their standards as well.

As a result, the French and Spanish codes are NOT accepted standards

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Scientists views on alternative system

''Very little has been done to improve classical air-termination systems. However, the ambitions and potential earnings involved in the design of more effective lightning receptors have been an obvious motivation for the invention and presentation of a lot of different lightning protection systems and items.

The claimed advantages have often been widely advertised, unfortunately without verification of their functions and validation of their effect. So far, parallel tests with simple Franklin rods and various ESE (early streamer emission) devices, lightning repellers, charge transfer systems, ion plasma generators and so on exposed to natural lightning have shown no significant difference in the attraction distance nor in the number of strokes to the different types of air-terminals.

Scientists ...

Hopefully, in the future, more effective lightning protection components and systems will be developed. Until such systems are proven in a scientific sense their use should not be allowed for structures to be protected. Let us remain reasonable and careful when issuing new standards and guides. Of course the IEC 62305 international standard, following the opinion of confirmed scientists, does not advertise such devices because the international scientific community disregards them. Unfortunately, some manufacturers continue to promote and install these fancy devices. Hence the struggle against non-conventional and non-verified systems or models is far from over. These manufacturers will probably continue to produce such devices as long as awful national standards promoting them exist. A new standard could even be published each time a new device appeared on the market. A main target of the international scientific community should be to succeed in withdrawing misleading national standards and the copies made by others blindly following these nations''

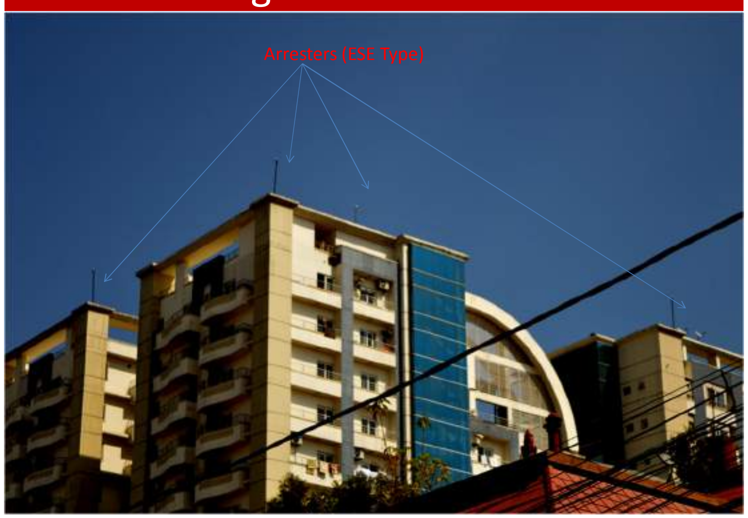
What the standards warn

Radioactive air-terminals shall not be allowed. Any other kind of air-terminal like dissipation system/ESE air-terminal/CSE air-terminal shall not be acceptable

----**NATIONAL BUILDING CODE OF INDIA 2016 Vol B Page 88**

Some wrong Practices in Kathmandu

Some wrong Practices in Kathmandu



Conventional Vs Non conventional


Some wrong Practices in Kathmandu

Some wrong Practices in Kathmandu

Is this LPS correct!?

धन्यवाद

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स्थानीय विकास प्रशिक्षण प्रतिष्ठान
(स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)

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(Established by Local Development Training Academy Act, 2049)

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नेपाल सरकार
सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालय

बिद्युतीय गडबडीका कारण हुने दुर्घटनाहरु

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W>>> www.ldta.org.np

उद्देश्यहरु

साधारण उद्देश्य: बिद्युतीय गडबडीका कारण हुने बिबिध दुर्घटनाहरु, र विभिन्न आयाम हरु तथा दुर्घटना न्यूनीकरण का उपाय को बारेमा बिस्तृत जानकारी गराउने

निर्दिष्ट उद्देश्यहरु: सहभागीहरुले यस सत्रको अन्त्यमा,

- बिद्युतीय गडबडीका कारण हुने दुर्घटना को बिस्तृत जानकारी प्राप्त गर्ने छन्
- बिद्युतीय गडबडीका कारण हुने दुर्घटना का विभिन्न कारक तत्व हरु का बारेमा जानकारी प्राप्त गर्ने छन्
- बिद्युतीय दुर्घटना जोखिम न्यूनीकरणका उपाय हरु को जानकारी प्राप्त गर्ने छन्
- बिद्युतीय दुर्घटना मा उल्लेख्य कमि ल्याउन का भूमिका खेल्न सक्षम हुने छन्

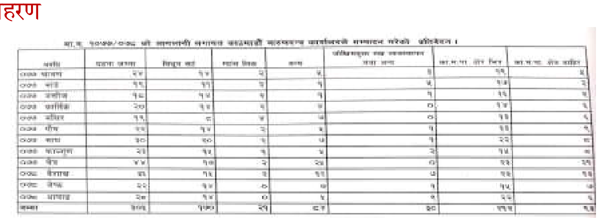
बिद्युतीय गडबडीका कारण हुने दुर्घटनाहरु

सत्रका मुख्य विषयवस्तु:

- **बिद्युतीय गडबडीका कारण हुने दुर्घटनाहरु**
- बिधयुतीय दुर्घटना का बिबिध उदाहरणरू
- बिद्युतीय दुर्घटनाका कारक तत्वहरु
- बिद्युतीय दुर्घटना जोखिम न्यूनीकरणका आयाम
- बिद्युतीय दुर्घटना जोखिम न्यूनीकरणका उपायहरु

प्रशिक्षण को भूमिका

- विद्युतीय आगलागी का कारण हरु का बारेमा प्रशिक्षार्थी का अनुभव र ज्ञान का सम्बन्धि अन्तरक्रिया
- नेपाल मा अनुमानित कति प्रतिशत आगलागी विद्युतीय गडबडी का कारण हुन्छन बारे प्रशिक्षार्थी को अनुमान तथा केहि प्रतिनिधि घटना को वर्णन
- समाचार माध्यम वा अन्य श्रोत बाट संकलित केहि आगलागी का घटना का उदाहरण



विद्युतीय आगलागी का केहि प्रतिनिधि घटनाहरु

MASSIVE FIRE AT MYANGLUNG, DEUDI BAZAR

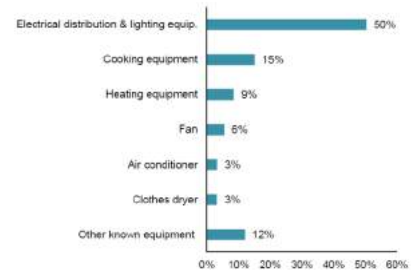
32 houses destroyed by fire out in Sankranti Bazaar, Tehrathum due to electrical short circuit –Dec 16, 2016

Feb 10, 2020

Fire breaks out at Soaltee City Jan 18, 2021

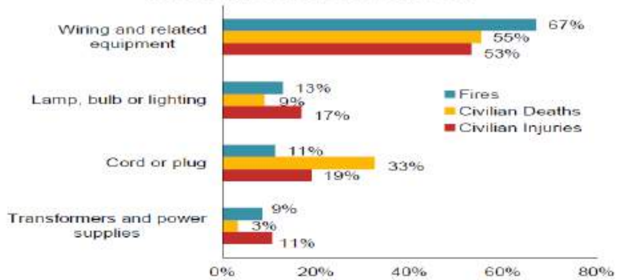
बिकशित मुलुक अमेरिका स्थिति कस्तो छ त?

(50%) of home fires involving electrical failure or malfunction, followed by cooking equipment (15%), heating equipment (9%), fans (6%), air conditioners (3%), and clothes dryers (3%)



घटनाका कारक तत्व के रह्छिन ?

Figure 8. Types of Electrical Distribution or Lighting Equipment Involved in Home Fires, 2012-2016*



*All data in this section are non-confined fires only.

विविध कारणको ब्याख्या

- विद्युतीय आगलागी का लागि पुराना तथा जिर्ण सामाग्री को प्रयोग का हुन सक्ने क्षति
- किन र कसरि ?
- लामो समय प्रयोग पछी गुणस्तर मा आउने ह्राश तथा केहि समय करेन्ट बग्दा तात्ने समस्या परिणाम स्वरूप आगलागी का दुर्घटना
- विद्युतीय उपकरण का प्लग हरुलाई अर्थिंग नगर्दा हुने गडबडी
- प्लग हरुलाई अर्थिंग नगर्दा भोल्टेज गडबडी का कारण हुने दुर्घटना

विविध कारणको ब्याख्या क्रमश:....

अधिक भार ले गर्दा हुने दुर्घटना

किन र कसरि?

विविध कारणको ब्याख्या क्रमश:....

ज्वलनशील पदार्थ विद्युतीय प्लग आदिको नजिक मा भण्डार गर्दा हुने दुर्घटना

विविध कारणको ब्याख्या क्रमश:....

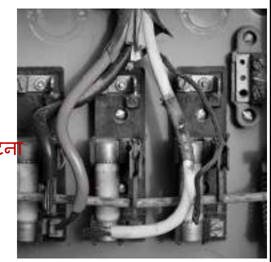
Extension प्लग दुरुपयोग का कारण हुने दुर्घटना

Heater (हिटर) तथा अन्य उपकरण का कारण

विविध कारणको ब्याख्या क्रमश:....

पुरानो वायरिंग का कारण हुने समस्या

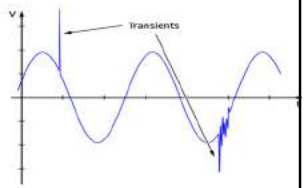
कमसल गुणस्तर का तार वा उपकरण का कारण हुने दुर्घटना

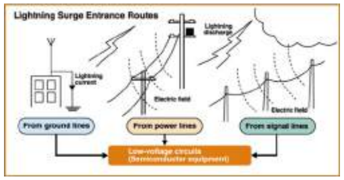


Firemen extinguish the fire by throwing water under pressure

विविध कारणको ब्याख्या क्रमशः....

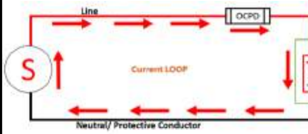
विद्युतीय सर्ज र ति बाट कसरि दुर्घटना हुन सक्छ

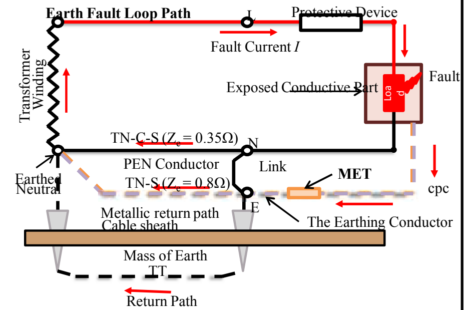




विविध कारणको ब्याख्या क्रमशः....

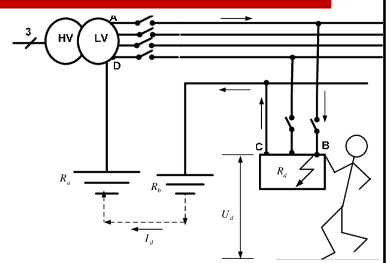
Fault loop अवरोध (impedance) के हो र उक्त कारण दुर्घटना कसरि हुन सक्छन ?

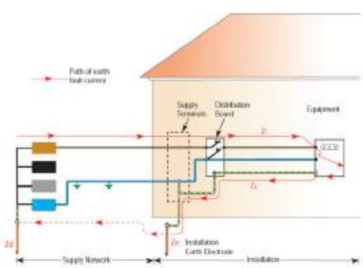




विविध कारणको ब्याख्या क्रमशः....

Fault loop अवरोध (impedance) के हो र उक्त कारण दुर्घटना कसरि हुन सक्छन



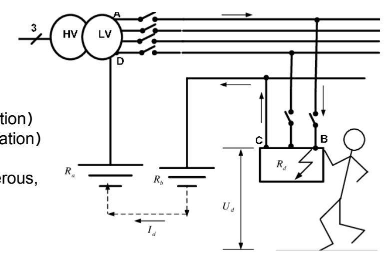


सामान्यतया सुरक्षा का उपकरण हरु एम सी बी अथवा ई एल सी बी को उल्लेखित करेन्ट को मात्रा अनुसार ट्रीप हुन्छन र दुर्घटना हुन बाट बचाउछन: उदाहरण का लागि TT system मा यदि rated करेन्ट $I_{\Delta n}$ छ भने

$$I_{\Delta n} \leq \frac{50}{R_A}$$

जहाँ R_A भनेको अर्थिंग को अवरोध को मान हो,

Fault loop अवरोध (impedance)



मानौं :

-R_a = 10 Ω (resistance of the earth electrode of substation)
-R_b = 20 Ω (resistance of the earth electrode of installation)
-earth-fault loop current I_d = 7.7 A.
-fault voltage $U_f = I_d \times R_A$ = 154 V and therefore dangerous,
तर,
$I_{\Delta n} \leq 50/20 = 2.5$ A

तेसैले, standard 300 mA RCD ले 30 ms मा ट्रीप हुन्छ र दुर्घटना हुन बाट जोगाउछ

तर, तार वा सुचालक तातेको खण्डमा अवरोध बढ्न गई करेन्ट को मात्रा घटछ परिणाम स्वरूप एम सी बी वा आर सी डी ट्रीप गर्दैन, फल आगलागी वा दुर्घटना

Fault loop अवरोध (impedance)

सामान्यतया प्राबिधिक हरु को ध्यान नपुगेको एउटा पाटो तार को गुणस्तर हो, जसका कारण fault loop impedance अवरोध उत्पन्न हुन्छ, यसमा तार लम्बाई ले पनि भूमिका खेल्छ

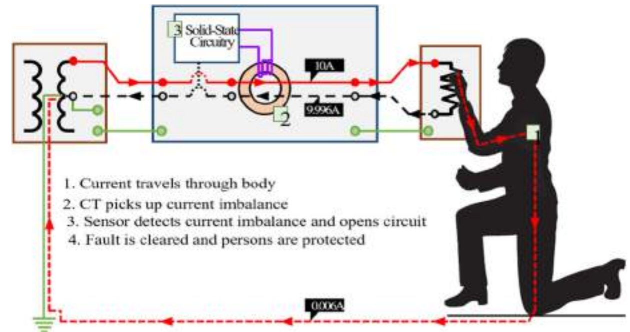
नेपाल मा प्रयोग गरिने तार हरु सामान्यतया ४ किसिम का हुन्छन्; class 1 (Solid conductor), class 2 (multi strand conductor), class 5 (highly flexible wire generally used in panel board) and class 6 (welding wire). The resistances of class 5 and class 6 copper conductors नेपाल मा बढी प्रयोग हुन्छन, जसको अवरोधकता IEC 60364-6 ले तोकेको मापदण्ड भन्दा बढी हुन्छ.

PVC flexible तार हरु class 5 र 6 सुचालक (conductors) ले बढी ताप उत्पन्न गर्छन फलस्वरूप fault loop impedance पनि बढ्न जान्छ र (1) उच्च भोल्टेज को गिरावट (higher voltage drop) हुन्छ, (2) तार मा प्रयोग गरिएको कुचालक आवरण को गुणस्तर मा छिटो ह्राश आउछ (faster degradation of insulation reducing life), (3) साथै सुरक्षा का उपकरण हरु काम गर्दैनन् (non-disconnection of protective device due to increased fault loop impedance results to an accident) र आगलागी को सम्भावना बढेर जान्छ.

Most of the fire accidents that happen in the final circuit is due to the use of low grade class 5 wires. More importantly, it is the higher fault loop impedance and non-disconnection of supply that is more responsible for the ignition of fire (this is because, if the fault loop impedance is higher, there will be a drop in current through the circuit due to which the protective device say MCB, will not trip.

Tool: One should use micro-ohm meter for the continuity test.

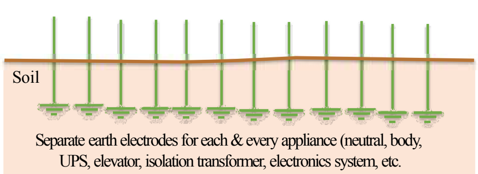
कसरि सुरक्षा उपकरणले सुरक्षित तुल्याउछन्



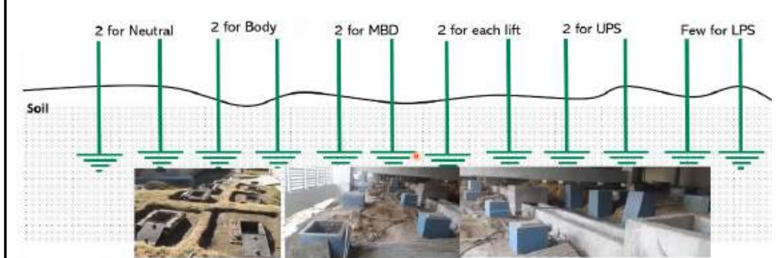
विविध कारणको ब्याख्या क्रमशः.

अबैज्ञानिक अर्थिंग का कारण हुने दुर्घटना हरु

Separate earth electrodes in soil.

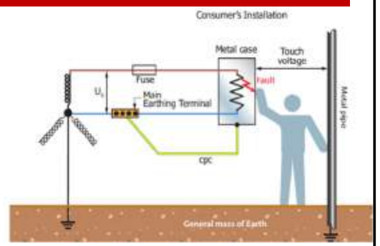


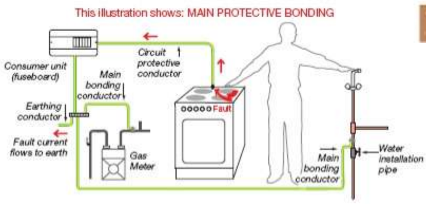
अबैज्ञानिक अर्थिंगका कारण हुने दुर्घटनाहरु



विविध कारणको ब्याख्या क्रमशः.

समान बन्धकिकरण नगर्दा हुने दुर्घटना हरु





समान भोल्टेज

धन्यवाद

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स्थानीय विकास प्रशिक्षण प्रतिष्ठान
(स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)
"An Autonomous, Professional, Client Centered, Gender Responsive National Institute of Excellence in the area of Local-Self Governance."
Local Development Training Academy
(Established by Local Development Training Academy Act, 2049)
LDTA >>>

नेपाल सरकार
सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालय

बिद्युतीय लेखापरीक्षण (Auditing)

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W>>> www.ldta.org.np

बिद्युतीय लेखापरीक्षण (Auditing)

साधारण उद्देश्य: बिद्युतीय गडबडी का कारण हुने दुर्घटना न्युनिन्करण का लागि लेखापरीक्षण गर्ने बिधि को बारेमा जानकारी दिने

निर्दिष्ट उद्देश्यहरु : सहभागीहरुले यस सत्रको अन्त्यमा,

- सदृश्य निरीक्षण (Visual Inspection) गर्ने तरिका को बारेमा बुझ्ने छन्
- निरन्तरता परिक्षण गर्ने तरिका र चाहिने उपकरण का बारेमा जानकारी प्राप्त गर्ने छन्
- Fault loop impedance testing (अर्थिंगको अबरोधता परिक्षण) को तरिका का र प्रयोग गरिने उपकरण को बारेमा जानकारी प्राप्त गर्ने छन्
- ध्रुवीकरण परिक्षण (Polarity testing) को जानकारी प्राप्त गर्ने छन्
- चेक लिस्ट तयारी र भर्ने तरिका को ज्ञान प्राप्त गर्ने छन्

विद्युतीय कोड र बिद्युतीय लेखापरीक्षण

समग्र उद्देश्यः बिद्युतका राष्ट्रिय र अन्तर्राष्ट्रिय मापदण्डहरू तथा विद्युतीय कोडहरूका साथै विद्युतीय लेखापरिक्षणबारे जानकारी दिने ।

विशिष्ट उद्देश्यहरूः सहभागीहरूले यस शत्रको अन्त्यमा,

- बिद्युतका राष्ट्रिय र अन्तर्राष्ट्रिय मापदण्डहरू तथा विद्युतीय कोडहरूबारे जानकारी पाउनेछन्

विद्युतीय लेखापरिक्षणबारे जानकारी पाउनेछन्

सत्रका मुख्य विषयवस्तुहरूः

- बिद्युतका राष्ट्रिय र अन्तर्राष्ट्रिय मापदण्डहरू तथा विद्युतीय कोडहरू
- विद्युतीय लेखापरिक्षण

विद्युतीय कोड र बिद्युतीय लेखापरीक्षण

सत्रका मुख्य विषयवस्तु:

- सदृश्य निरीक्षण (Visual Inspection)
- निरन्तरता परिक्षण (Continuity testing)
- Fault loop impedance testing (अर्थिंगको अबरोधता परिक्षण)
- ध्रुवीकरण परिक्षण (Polarity testing)
- चेक लिस्ट तयारी र भर्ने तरिका

अन्तर्राष्ट्रिय तथा राष्ट्रिय मापदण्डहरु

International Organization for Standardization

INTERNATIONAL ELECTROTECHNICAL COMMISSION

Established in 1962 under Technical committee -64 (TC-64) as IEC 364 and is currently known by IEC-60364

British code 7671 brought into action in 1882 published by the Institution of Electrical Engineers (IEE). Updating every 3 yrs

NFPA was brought into force in 1897, upgrading or updating every 3-5 years since then

VDE 0100 and published by the Association of Electrical Engineers (VDE).

राष्ट्रिय मापदण्ड

1993

Upgraded in 2003, does not cover much on the safety measures and the upgraded electrical code has not been brought into effect as of today.

1937

National Building Code (NBC as IS732) that was upgraded in 2019

Electrical Auditing (विद्युतीय लेखापरिक्षण)

वियुतीय लेखापरीक्षण को मुख्य उद्देश्य, सम्भावित वियुतीय दुर्घटनाको अन्वेषण गर्ने र दुर्घटना लाई रोक्न का लागि सुधार गर्नु पर्ने विधि का बारेमा सुझाव तयार गर्ने हो .

(The purpose of an electrical safety inspection or audit is **to identify potentially hazardous electrical situations and provide corrective actions for these situations**, review and provide corrective actions for electrical safety work processes.)

वियुतीय लेखापरीक्षण का लागि सामान्यतया दुई विधि अपनाउने गरिन्छ

- निरीक्षण (Inspection)
- परिक्षण (Testing)

- निरीक्षण (Inspection)

१. भवन वा संरचना मा (OCPD,MCB,MCCB) जस्ता सुरक्षा उपकरण जडान छ छैन

निरीक्षण (Inspection) क्रमश .....

२. भवन वा संरचना मा प्रमुख बन्धनिकरण सुचालक (main bonding conductors) जडान छ, छैन

३. भवन वा संरचना मा सहायक बन्धनिकरण सुचालक (supplementary bonding conductors) जडान छ, छैन

४. भवन वा संरचना मा अर्थिंग सुचालक (earthing conductor) जडान छ, छैन

५. भवन वा संरचना मा प्रतिरक्षी सुचालक (protective conductor) जडान छ, छैन

६. भवन वा संरचना मा प्रतिरक्षी सुचालक (main earthing terminal) जडान छ, छैन

७ . भवन वा संरचना मा बाह्य चट्यांग प्रतिरक्षी प्रणाली (external lightning protection system) जडान छ, छैन

८. भवन वा संरचना मा सर्ज प्रतिरक्षी उपकरण (Surge Protective Devices) जडान छ, छैन

९. भवन वा संरचना मा सर्ज प्रतिरक्षी सुचालक (protective bonding conductors) जडान छ, छैन

निरीक्षण (Inspection) क्रमश .....

१०. भवन वा संरचना मा सर्ज प्रतिरक्षी उपकरण (Surge Protective Devices) जडान भए कुन प्रकार का र कतिवटा जडान गरिएका छन् के तिनीहरु स्वस्थ छन् ?

११. भवन वा संरचना मा जडान गरिएको अर्थिंग कस्तो किसिम को हो

❑ TT ❑ TN-S ❑ TN-CS ❑ IT

१२. भवन वा संरचना मा जडान भएको एम सी बी को रेटिंग (Rating) के हो

❑ 6A ❑ 16A ❑ 32A ❑ 63A

परिक्षण (Testing)

1. Cross sectional area of Main bonding conductor ……….mm

   (REF > 6mm (Cu) / 6mm (Al) / 30mm (Steel))

2. Cross sectional area of Protective Earthing conductor ……….mm

   (REF > 25mm (Cu) / 35mm (Al))

3. Cross sectional area of Supplementary bonding conductors mm

   (REF > 25mm (Cu) / 16mm (Al) Protection against mechanical damage is provided)

   (REF > 4mm (Cu) / 16mm (Al) Protection against mechanical damage is not provided)

4. Cross sectional area of Earthing conductor mm

   (REF > 16mm (Cu) / 50mm (Steel) Without ELPS)

   (REF > 16mm (Cu) / 50mm (Steel) With ELPS)

परिक्षण (Testing)

5. Cross sectional area of Earthing conductor in soil mm

   (REF > 15 mm dia (Cu) vertical / 17mm dia for copper coated steel)

6. Continuity test :

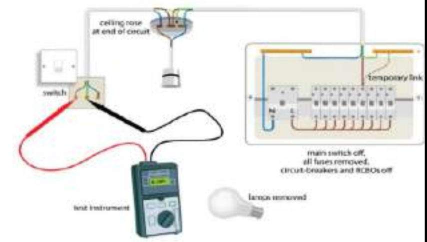
   Resistance of conductor

   (i) ……... Ω

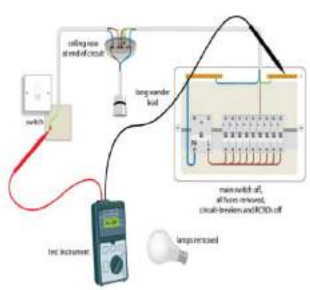
   (ii) …………Ω

   (iii) …………Ω

   (iv) …………Ω



परिक्षण (Testing)



Reference table for resistance for continuity testing	
Cross sectional area 'S' in mm²	Conductor resistance 'R', at 30°C Ω/m
1.5	12.5755
2.5	7.5661
4	4.7392
6	3.1491
10	1.8811
16	1.1858
25	0.7525
35	0.5467
50	0.4043
70	0.2817
95	0.2047
120	0.1632
150	0.1341
185	0.1091

For other temperatures the conductor resistance R_θ can be calculated using

$$R_\theta = R_{30}\cdot[1 + \propto (\theta - 30)]$$

where, θ is the desired temperature at which resistance is to be computed.

$\propto$ is the temperature coefficient (for copper $\propto = 0.00393/K$

परिक्षण (Testing)

Insulation resistance of LV, ELV and electrical separation.

The insulation resistance shall be measured between:

- Live conductors,
- Live conductors and earthing arrangement
- Non-earthed protective conductors and earth

Recommended test voltage and minimum values of insulation resistance.

Nominal voltage (V)	Test Voltage DC (V)	Minimum insulation resistance (MΩ)
SELV and PELV	250	0.5
≤ 500 V or FELV	500	1
˃500 V	1000	1

परिक्षण (Testing)

Test for ELV:

- SELV: live parts from those of other circuits and from earth
- PELV: Live parts from other circuits
- Protection of electrical separation: live parts from those of other circuits and from earth. (the values should satisfy the above table).

Insulation resistance/impedance of floors and walls

This test is required in non-conducting locations, intended to prevent simultaneous contact with parts which may be at different potential during failure of the basic insulation

Polarity:

The polarity of the supply at the origin of the installation shall be verified before the installation is energized. Where single pole switching devices are not permitted in the neutral conductor, a test shall be made to verify that such devices are connected in the line conductor(s) only. It should be verified that:

परिक्षण (Testing)

Voltage drop: It shall be evaluated by measurement of the following.

- The difference between the voltage with and without the designed load
- The difference between the voltage with and without any known load and calculate the designed load
- By calculation of circuit impedance values

Fault loop impedance testing

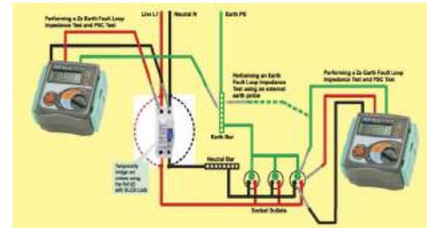
The formula for determining the fault loop impedance `Zs is

Zs=Ze + (R1+R2)

Zs - earth fault loop impedance of the circuit tested

Ze - earth fault loop impedance external to the supply

(R1+R2) - Sum of the resistance of Line and Earth for the tested circuit.



परिक्षण (Testing)

The External Earth Fault Loop test sequence (Ze)

(This is a live test so extra care should be taken!)

Step 1. Use an Earth Fault Loop Tester or select the Earth Fault Loop Test option on a multifunctional tester

Step 2. Test on the incoming side of the installation. Connect one test lead to the Line terminal, the second test lead to the Neutral terminal and the third (usually green) test lead to the incoming Earth conductor.

Step 3. Press the TEST button. The measurement should be a low reading ohm value.

The Earth Fault Loop test sequence (R1+R2):

(This is a live test so extra care should be taken!)

Step 1. Locate the furthest point on the circuit to be tested (such as the furthest socket)

Step 2. With the appropriate Earth Fault Loop Tester, connect the test leads to the Line, Neutral and Earth terminals.

Step 3. Measure and write down the test results on the Schedule of Test Results.

Note: If the circuit is RCD protected than one has to select the "No trip" function of the tester (say Megger 1553) to avoid nuisance tripping of the RCD. If tester does not have this option, then one will have to link out the RCD.

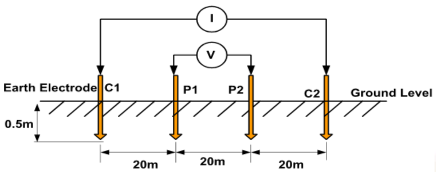
परिक्षण (Testing)

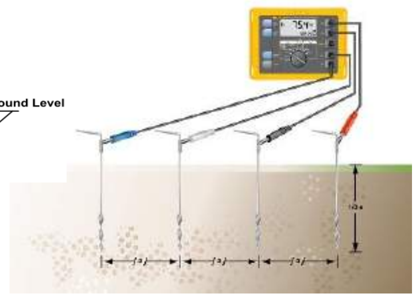
MAXIMUM VALUES OF EARTH FAULT-LOOP IMPEDANCE FOR THE TOTAL CIRCUIT INCLUDING THE SUPPLY TRANSFORMER (Z_s AT 230 V) VALUES RELATING TO OPERATION OF PROTECTIVE DEVICES ON THE FINAL SUBCIRCUIT

Protective device rating Amps	MCBs on the final subcircuit			Fuses on the final subcircuit	
	Type B	Type C	Type D		
	Disconnection times				
	0.4 s			0.4 s	5 s
	Maximum earth fault-loop impedance Z_s Ω				
6	9.6	5.1	3.1	11.5	15.3
10	5.8	3.1	1.8	6.4	9.2
16	3.6	1.9	1.2	3.1	5.0
20	2.9	1.5	0.9	2.1	3.6
25	2.3	1.2	0.7	1.6	2.7
32	1.8	1.0	0.6	1.3	2.2
40	1.4	0.8	0.5	1.0	1.6
50	1.2	0.6	0.4	0.7	1.3
63	0.9	0.5	0.3	0.6	0.9
80	0.7	0.4	0.2	0.4	0.7
100	0.6	0.3	0.2	0.3	0.5
125	0.5	0.2	0.1	0.2	0.4
160	0.4	0.2	0.1	0.2	0.3
200	0.3	0.2	0.1	0.1	0.2

परिक्षण (Testing)

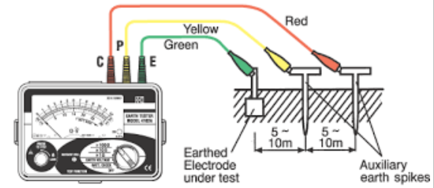
माटो परिक्षण Soil resistivity measurement

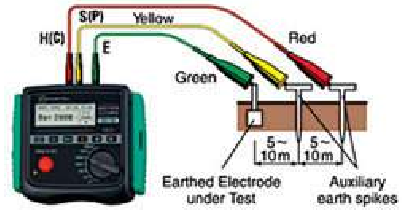




परिक्षण (Testing)

अर्थिंग को सुचालकता परिक्षण





लेखा परिक्षण नमुना चेक लिस्ट

S.N	Inspection	YES	NO
1	Does the electrical installation have overcurrent protective devices (OCPD,MCB,MCCB)?		
2	Does the installation have properly installed Earth leakage circuit breakers (ELCB)?		
3	Does the electrical installation have main bonding conductors ?		
4	Does the electrical installation have supplementary bonding conductors ?		
5	Does the electrical installation have an earthing conductor ?		
6	Does the electrical installation have a protective conductor ?		
7	Does the electrical installation have a main earthing terminal ?		
8	Does the structure have an external lightning protection system ?		
9	Does the installation have Surge Protective Devices ?		
10	Does the installation have earthing conductors (MET to earth pit in TT /IT or MET to Source Earthing as per TN System) ?		
11	Does the installation have a functional earthing (FE) conductor (MET to electronic system) ?		
12	Does the installation have protective bonding conductors in place ?		
13	Does the installation have earthing conductors ?		

लेखा परिक्षण नमुना चेक लिस्ट

TESTING

1. Cross sectional area of Main bonding conductor ....mm^2 (REF > 6mm^2 (Cu) / 6mm^2 (Al) / 30mm^2 (Steel))
2. Cross sectional area of Protective Earthing conductor ....mm^2 (REF > 25mm^2 (Cu) / 35mm^2 (Al))
3. Cross sectional area of Supplementary bonding conductors …..mm^2 (i) (REF > 2.5mm^2 (Cu) / 16mm^2 (Al) Protection against mechanical damage is provided) (ii) (REF > 4mm^2 (Cu) / 16mm^2 (Al) Protection against mechanical damage is not provided)
4. Cross sectional area of Earthing conductor …….. mm^2 (REF > 16mm^2 (Cu) / 50mm^2 (Steel) Without ELPS) (REF > 16mm^2 (Cu) / 50mm^2 (Steel) With ELPS)
5. Cross sectional area of Earthing conductor in soil mm^2 (REF > 15 mm dia (Cu) vertical / 17mm dia for copper coated steel)
6. Continuity test :
   Resistance of conductor (i) .... Ω (ii) ....Ω (iii) ....Ω (iv) ....Ω
7. Insulation resistance between conductors Ω.
8. Impedance of floor ....Ω.
9. Impedance of walls ....Ω.
10. Resistance of SELV ....Ω.
11. Resistance of PELV ....Ω.
12. Value of fault loop impedance.........Ω.
13. Contact resistance of earth electrode......Ω.
14. Soil resistivity(ρ) …………Ωm.

धन्यवाद

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स्थानीय विकास प्रशिक्षण प्रतिष्ठान
(स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)
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Local Development Training Academy
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W>>> www.ldta.org.np

यस सत्रको समग्र उद्देश्य

विद्युतीय लेखा परिक्षण का लागि चाहिने आधारभूत परिक्षण उपकरण को उपयोग र परिक्षण बिधि को जानकारी गराउने

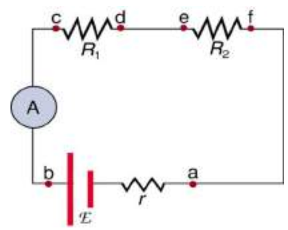
यस सत्रको विशिष्ट उद्देश्यहरू

सहभागीहरूले यस सत्रको अन्त्यमा,

- **विद्युतजन्य पदार्थ हरु को मापन गर्ने विविध उपकरण हरु को बारेमा जानकारी प्राप्त गर्ने छन्**
- **उपकरण हरु को प्रयोग र उपयोगिता का बारेमा जानकारी प्राप्त गर्ने छन्**
- **ब्यबहारिक अभ्यास गर्ने क्रममा सम्बन्धित भवन को विद्युतीय स्वास्थ्य अवस्था को ज्ञान प्राप्त गर्ने छन्**
- **विद्युतीय गडबडी का प्रमुख कारक तत्व र न्यूनीकरण का उपाय का विभिन्न अवयव का बारेमा ज्ञान हाशिल गर्ने छन्**

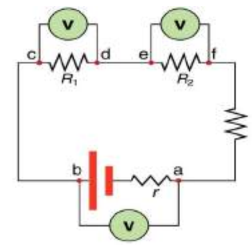
विद्युत सम्बन्धि Physical Quantities र मापन गर्ने उपकरणहरु

Ammeter



विद्युत सम्बन्धि Physical Quantities र मापन गर्ने उपकरण हरु......

Voltmeter

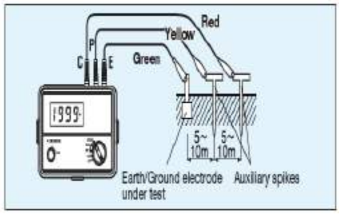


विद्युत सम्बन्धि Physical Quantities र मापन गर्ने उपकरण हरु

Multimeter

विद्युत सम्बन्धि Physical Quantities र मापन गर्ने उपकरण हरु......

Earth-resistance Meter



विद्युत सम्बन्धि Physical Quantities र मापन गर्ने उपकरण हरु......

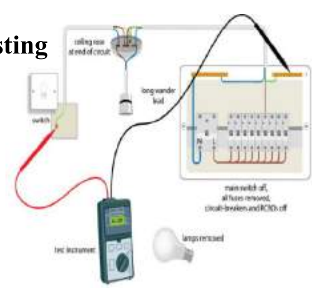
soil resistivity tester

विद्युत सम्बन्धि Physical Quantities र मापन गर्ने उपकरण हरु......

Insulation test meter

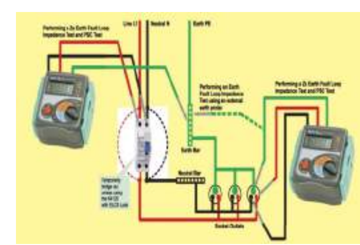
विद्युत सम्बन्धि Physical Quantities र मापन गर्ने उपकरण हरु......

Continuity testing



विद्युत सम्बन्धि Physical Quantities र मापन गर्ने उपकरण हरु......

Fault loop impedance testing



विद्युत सम्बन्धि Physical Quantities र मापन गर्ने उपकरण हरु......

Continuity tester

विद्युत सम्बन्धि Physical Quantities र मापन गर्ने उपकरण हरु......

Vernier Callipers

विद्युत सम्बन्धि Physical Quantities र मापन गर्ने उपकरण हरु......

Micrometer Screw gauge

धन्यवाद

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स्थानीय विकास प्रशिक्षण प्रतिष्ठान
(स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)

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E >>> ldta.org.np@gmail.com
W>>> www.ldta.org.np

नमुना कार्य योजना

क्र स	क्रियाकलापहरु	कहिले गर्ने	जिम्मेवारी कसको	सहयोगी निकाय	कसरी गर्ने
१					
२					
३					

पश्चात जानकारी

मूल्याङ्कन

समापन

धन्यवाद

330

सहभागीका लागि अध्ययन सामग्री
(प्रशिक्षण प्रयोजनका लागि)

Lightning, the Science

Vladimir A. Rakov

Abstract Lightning can be defined as a transient, high-current (typically tens of kiloamperes) electric discharge in air whose length is measured in kilometers. As for any discharge in air, lightning channel is composed of ionized gas, that is, of plasma, whose peak temperature is typically 30,000 K, about five times higher than the temperature of the surface of the Sun. Lightning was present on Earth long before human life evolved and it may even have played a crucial role in the evolution of life on our planet. The global lightning flash rate is some tens to a hundred per second or so. Each year, some 25 million cloud-to-ground lightning discharges occur in the United States, and this number is expected to increase by about 50% due to global warming over the twenty-first century. Lightning initiates many forest fires, and over 30% of all electric power line failures are lightning related. Each commercial aircraft is struck by lightning on average once a year. A lightning strike to an unprotected object or system can be catastrophic. In this chapter, an overview of thunderclouds and their charge structure is given, basic lightning terminology is introduced, and different types of lightning (including the so-called rocket-triggered lightning) are described. For the most common negative cloud-to-ground lightning, main lightning processes are identified and the existing hypotheses of lightning initiation in thunderclouds are reviewed. Additionally, current and electromagnetic field signatures of lightning are characterized and the techniques to measure lightning electric and magnetic fields are discussed.

Keywords Thunderstorm · Return stroke · Ground flash · Stepped leader · Positive lightning

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1 Thunderclouds and Their Charge Structure

The primary source of lightning is the cloud type termed cumulonimbus, commonly referred to as the thundercloud. Sometimes the term "thunderstorm" is used as a synonym for thundercloud, although thunderstorm is usually a system of thunderclouds rather than a single thundercloud. Lightning-like electrical discharges can also be generated in the ejected material above volcanoes, in sandstorms, and in nuclear explosions.

Before reviewing the electrical structure of thunderclouds it is worth outlining their meteorological characteristics. In effect, thunderclouds are large atmospheric heat engines with the input energy coming from the Sun and with water vapor as the primary heat-transfer agent [17]. The principal outputs of such an engine include (but are not limited to) (1) the mechanical work of the vertical and horizontal winds produced by the storm, (2) an outflow of condensate in the form of rain and hail from the bottom of the cloud and of small ice crystals from the top of the cloud, and (3) electrical discharges inside, below, and above the cloud, including corona, lightning, sprites, halos, elves, blue starters, blue jets, and gigantic jets. The processes that operate in a thundercloud to produce these actions are many and complex, most of them being poorly understood. A thundercloud develops from a small, fair-weather cloud called a cumulus which is formed when parcels of warm, moist air rise and cool by adiabatic expansion; that is, without the transfer of heat or mass across the boundaries of the air parcels. When the relative humidity in the rising and cooling parcel exceeds saturation, moisture condenses on airborne particulate matter to form the many small water particles that constitute the visible cloud. The height of the condensation level, which determines the height of the visible cloud base, increases with decreasing relative humidity at ground. This is why cloud bases in Florida are generally lower than in arid locations, such as New Mexico or Arizona. Parcels of warm, moist air can only continue to rise to form a cumulus and eventually a cumulonimbus if the atmospheric temperature lapse rate, the decrease in the temperature with increasing height, is larger than the moist-adiabatic lapse rate of about 0.6 °C per 100 m. The atmosphere is then referred to as unstable since rising moist parcels remain warmer than the air around them and thus remain buoyant. When a parcel rises above the 0 °C isotherm, some of the water particles begin to freeze, but others (typically smaller particles) remain liquid at temperatures lower than 0 °C. These are called supercooled water particles. At temperatures lower than about −40 °C all water particles will be frozen. In the temperature range from 0 to −40 °C liquid water and ice particles coexist forming a mixed phase region where most electrification is thought to occur.

Convection of buoyant moist air is usually confined to the troposphere, the layer of the atmosphere that extends from the Earth's surface to the tropopause. The latter is the boundary between the troposphere and the stratosphere, the layer which extends from the tropopause to a height of approximately 50 km. In the troposphere the temperature decreases with increasing altitude, while in the stratosphere the temperature at first becomes roughly independent of altitude and then increases with altitude. A zero or positive temperature gradient in the stratosphere serves to suppress convection and, therefore, hampers the penetration of cloud tops into the stratosphere. The height of the tropopause varies from approximately 18 km in the tropics in the summer to 8 km or so in high latitudes in the winter. In the case of vigorous updrafts, cloud vertical growth continues into the lower portion of the stratosphere. Convective surges can overshoot the tropopause up to 5 km in severe storms.

Although the primary thunderstorm activity occurs in the lower latitudes, thunderclouds are occasionally observed in the polar regions. Thunderstorms commonly occur over warm coastal regions when breezes from the water are induced to flow inland after sunrise when the land surface is warmed by solar radiation to a temperature higher than that of the water. Similarly, because mountains are heated before valleys, they often aid the onset of convection in unstable air. Further, horizontal wind blowing against a mountain will be directed upward and can aid in the vertical convection of air parcels, a process which is referred to as the "orographic effect." While relatively-small-scale convective thunderstorms (also called air-mass thunderstorms) develop in the spring and summer months when the potential for convection is usually the greatest and an adequate water vapor is available, larger-scale storms associated with frontal activity are observed in temperate latitudes at all times throughout the year.

Lightning is usually associated with convective cloud systems ranging from 3 to 20 km in vertical extent. The horizontal dimensions of active air-mass thunderstorms range from about 3 km to greater than 50 km. Seemingly merged thunderstorms may occur in lines along cold fronts extending for hundreds of kilometers. Ordinary thunderstorms are composed of units of convection, typically some kilometers in diameter, characterized by relatively strong updrafts ($\geq$10 m/s). These units of convection are referred to as cells. The lifetime of an individual cell is of the order of 1 h. Thunderstorms can include a single isolated cell, several cells, or a long-lived cell with a rotating updraft, called a supercell. At any given time, a typical multicell storm consists of a succession of cells at different stages of evolution. Large frontal systems have been observed to persist for more than 48 h and to move more than 2000 km. Thunderstorms over flat terrain tend to move at an average speed of 20–30 km/h. Further information on thunderstorm morphology and evolution can be found in the book by MacGorman and Rust [16] and in the book chapter by Williams [34].

The distribution and motion of thunderstorm electric charges, most residing on hydrometeors (various liquid or frozen water particles in the atmosphere) but with some free ions, is complex and changes continuously as the cloud evolves. Hydrometeors whose motion is predominantly influenced by gravity (fall speed $\geq$ 0.3 m/s) are called precipitation. All other hydrometeors are called cloud particles. In calculating remote electric fields due to cloud charges and lightning-caused field changes, the typical gross thundercloud charge structure is often approximated by an idealized model in which three vertically stacked point charges (or spherically symmetrical charged volumes): main positive at the top, main negative in the middle, and lower positive at the bottom (see Fig. 1). This charge configuration is assumed to be located in an insulating atmosphere above a perfectly conducting ground. The magnitudes of the main positive and negative charges are typically some tens of coulombs, while the lower positive charge is probably about 10 C or less.

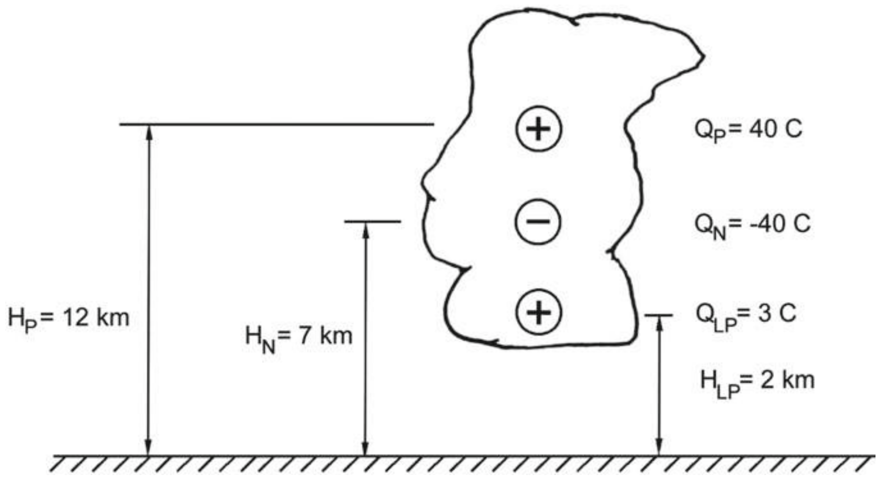

Fig. 1 A vertical tripole representing the idealized gross charge structure of a thundercloud

It has been inferred from a combination of remote and in-situ measurements that, regardless of the stage of storm development, location, and season, negative charge is typically found in the same relatively narrow temperature range, roughly −10 to −25 °C, where the clouds contain both supercooled water and ice. This feature has important implication for the dominant cloud electrification mechanism and is illustrated in Fig. 2.

Many cloud electrification theories have been proposed. There is growing consensus that the so-called graupel-ice mechanism is the dominant one, at least at the initial stages of cloud electrification. In this mechanism, the electric charges are produced by collisions between graupel (millimeter-size soft hail or snow pellet) particles and small ice crystals in the presence of water droplets, and the large-scale separation of charged particles is provided by the action of gravity. The presence of water droplets is necessary for significant charge transfer, as shown by the laboratory experiments. A simplified illustration of this mechanism is given in Fig. 3. The heavy graupel particles (two of which are shown in Fig. 3) fall through a suspension of smaller ice crystals (hexagons) and supercooled water droplets (dots). The droplets remain in a supercooled liquid state until they contact an ice/grouped surface, whereupon they freeze and stick to the surface in a process called riming. Laboratory experiments (e.g., Jayaratne et al. [11]) show that when the temperature is below a critical value called the reversal temperature, T_R, the falling graupel particles acquire a negative charge in collisions with the ice crystals. At temperatures above T_R they acquire a positive charge. The charge sign reversal temperature T_R is generally thought to be between −10 and −20 °C, the temperature range characteristic of the main negative charge region found in thunderclouds. The graupel which picks up positive charge when it falls below the altitude of T_R could explain the existence of the lower positive charge region in the cloud. It is believed that the polarity of the charge that is

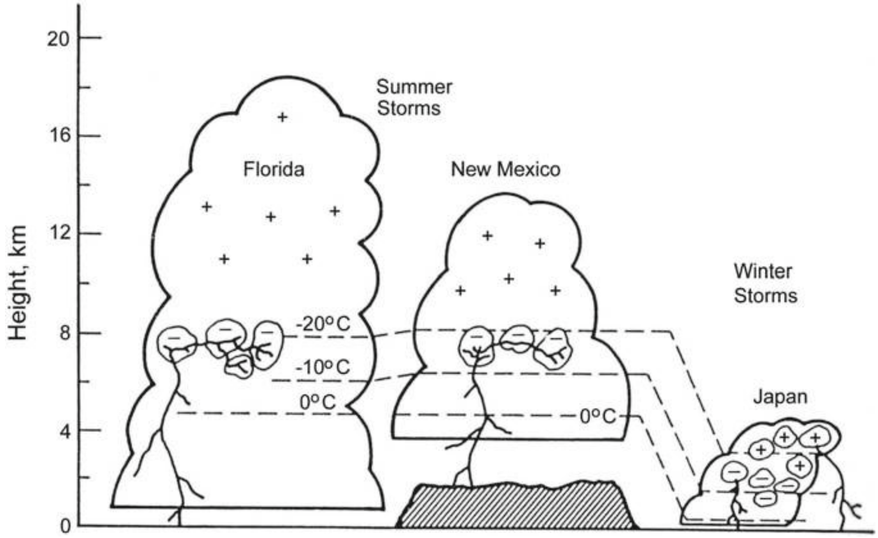

Fig. 2 The locations, shown by the small irregular contours inside the cloud boundaries, of ground-flash charge sources observed in summer thunderstorms in Florida and New Mexico and in winter thunderstorms in Japan using simultaneous measurements of electric field at a number of ground stations. Adapted from Krehbiel [12]

separated in ice-graupel collisions is determined by the rates at which the ice and graupel surfaces are growing. The surface that is growing faster acquires a positive charge.

It appears that the graupel-ice mechanism is capable of explaining the "classical" tripolar cloud charge structure shown in Fig. 1 and the location of the negative charge region in the −10 to −20 °C temperature range seen in Fig. 2.

2 Initiation, Propagation, and Attachment

The lightning discharge in its entirety, whether it strikes ground or not, is usually termed a "lightning flash" or just a "flash." A lightning discharge that involves an object on ground or in the atmosphere is referred to as a "lightning strike." A commonly used nontechnical term for a lightning discharge is a "lightning bolt." About three-quarters of lightning discharges do not involve ground. They include intracloud, intercloud, and cloud-to-air discharges and are collectively referred to as cloud discharges or cloud flashes (see Fig. 4) and sometimes as ICs. Lightning discharges between cloud and Earth are termed cloud-to-ground (or just ground) discharges and sometimes referred to as CGs. The latter constitute about 25% of global lightning activity.

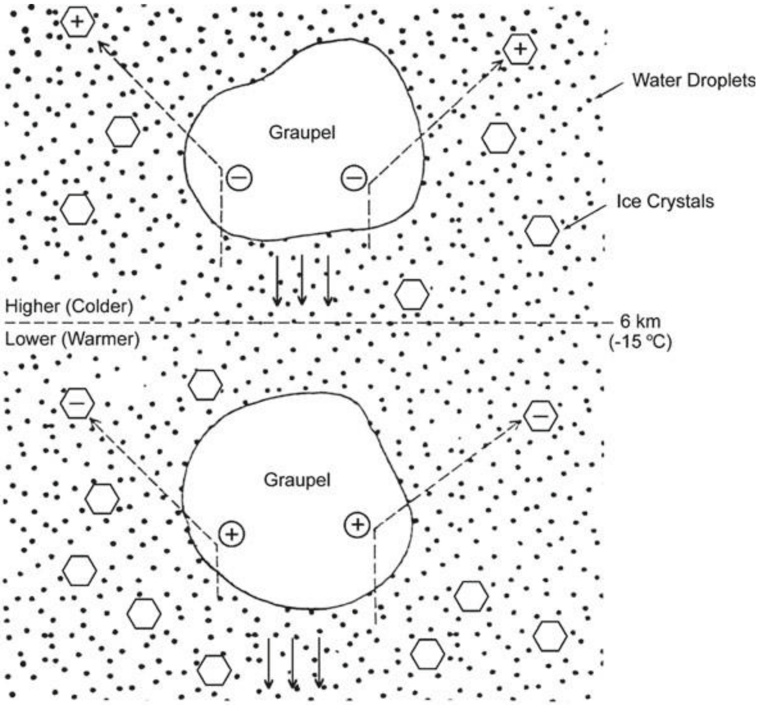

Fig. 3 Schematic representation of the graupel-ice mechanism of cloud electrification, in which the charge transfer occurs via collision of graupel with small ice crystals in the presence of supercooled water droplets. It is assumed that the reversal temperature T_R is -15 °C, and that it occurs at a height of 6 km

About 90% or more of global cloud-to-ground lightning is accounted for by downward (the initial process begins in the cloud and develops in the downward direction) negative (negative charge is effectively transported to the ground) lightning. The term “effectively” is used to indicate that individual charges are not transported all the way from the cloud to ground during the lightning processes. Rather the flow of electrons (the primary charge carriers) in one part of the lightning channel results in the flow of other electrons in other parts of the channel. Other types of cloud-to-ground lightning include downward positive, upward negative, and upward positive discharges (see Fig. 5). Downward flashes exhibit downward branching, while upward flashes are branched upward. Upward lightning discharges [types (b) and (d) in Fig. 5] are thought to occur only from tall objects (higher than 100 m or so) or from objects of moderate height located on mountain tops. There are also bipolar lightning discharges (not shown in Fig. 5) sequentially transferring both positive and negative charges during the same flash. Bipolar lightning discharges are usually initiated from tall objects (are of upward type). Downward bipolar lightning discharges do exist, but appear to be rare.

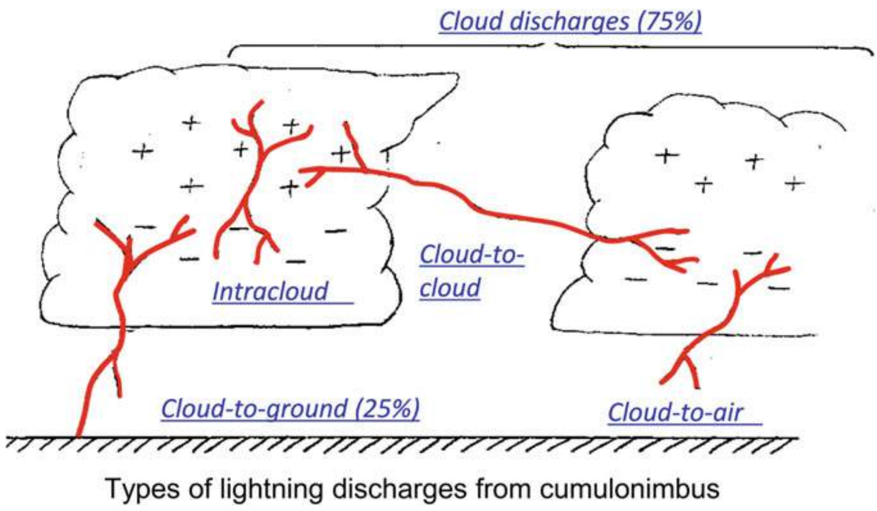

Fig. 4 General classification of lightning discharges from cumulonimbus (thunderstorm clouds). Cloud discharges constitute 75% and cloud-to-ground discharges 25% of global lightning activity

We first introduce, referring to Fig. 6a, b, the basic elements of the negative downward lightning discharge, termed component strokes or just strokes. Then, we will introduce, referring to Fig. 7, the two major lightning processes comprising a stroke, the leader and the return stroke, which occur as a sequence with the leader preceding the return stroke.

Two photographs of the same negative cloud-to-ground discharge are shown in Fig. 6a and b. The image in Fig. 6a was obtained using a stationary camera, while the image in Fig. 6b was captured with a separate camera that was moved horizontally during the time of the flash. As a result, the latter image is time resolved showing several distinct luminous channels between the cloud and ground separated by dark gaps. The distinct channels are associated with individual strokes, and the time intervals corresponding to the dark gaps are typically of the order of tens of milliseconds. These dark time intervals between strokes explain why lightning often appears to the human eye to "flicker." In Fig. 6b, time advances from right to left, so that the first stroke is on the far right. The first two strokes are branched, and the downward direction of branches indicates that this is a downward lightning flash.

Now, we consider sketches of still and time-resolved (much better than in Fig. 6b) optical images of the three-stroke lightning flash shown in Fig. 7a, b, respectively. A sketch of the corresponding current at the channel base is shown in Fig. 7c. In Fig. 7b, time advances from left to right, and the time scale is not continuous. Each of the three strokes in Fig. 7b, represented by its luminosity as a function of height above ground and time, is composed of a downward-moving process, termed a leader, and an upward-moving process, termed a return stroke. The leader creates a conducting path between the cloud charge source region and ground and distributes negative charge from the cloud source region along this path, and the return stroke traverses

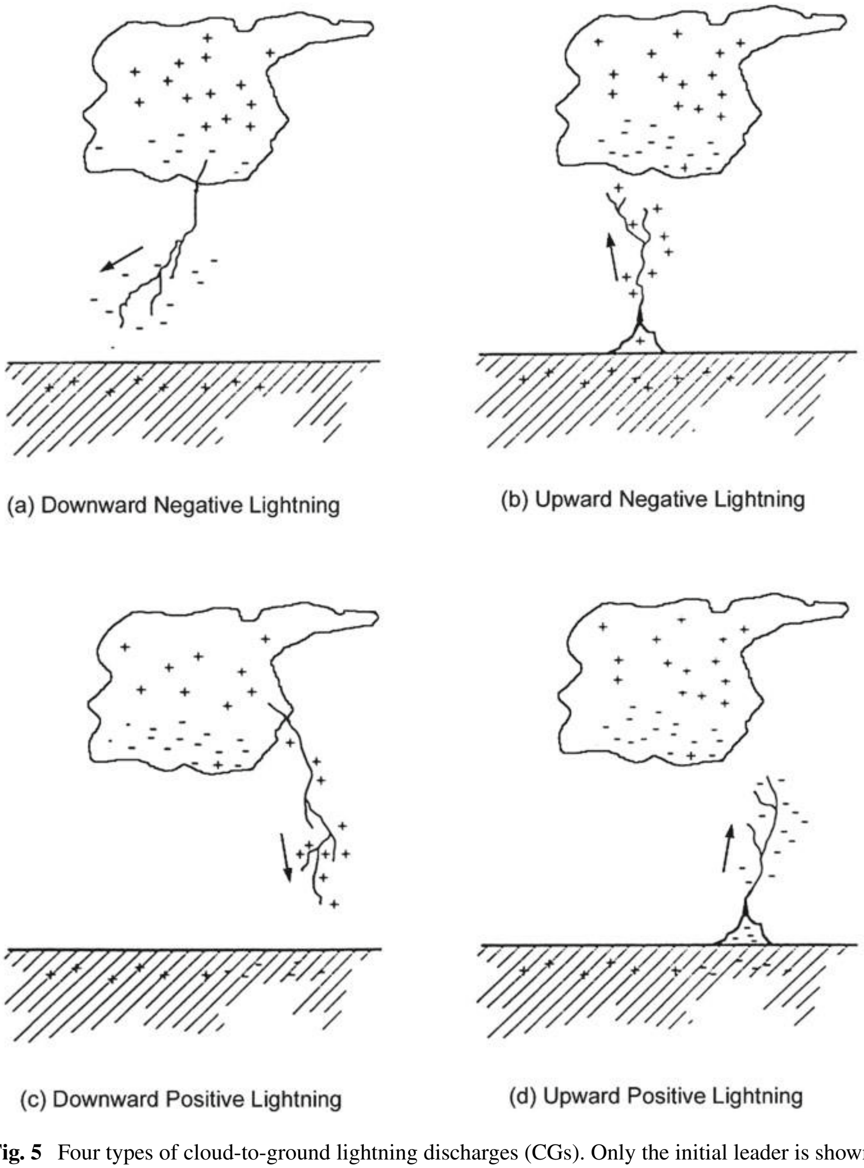

Fig. 5 Four types of cloud-to-ground lightning discharges (CGs). Only the initial leader is shown for each type. For each lightning-type name given below the sketch, direction (downward or upward) indicates the direction of propagation of the initial leader and polarity (negative or positive) refers to the polarity of the cloud charge effectively lowered to ground. In **a**, **c**, the polarity of charge lowered to ground is the same as the leader polarity, while in **b**, **d** those polarities are opposite

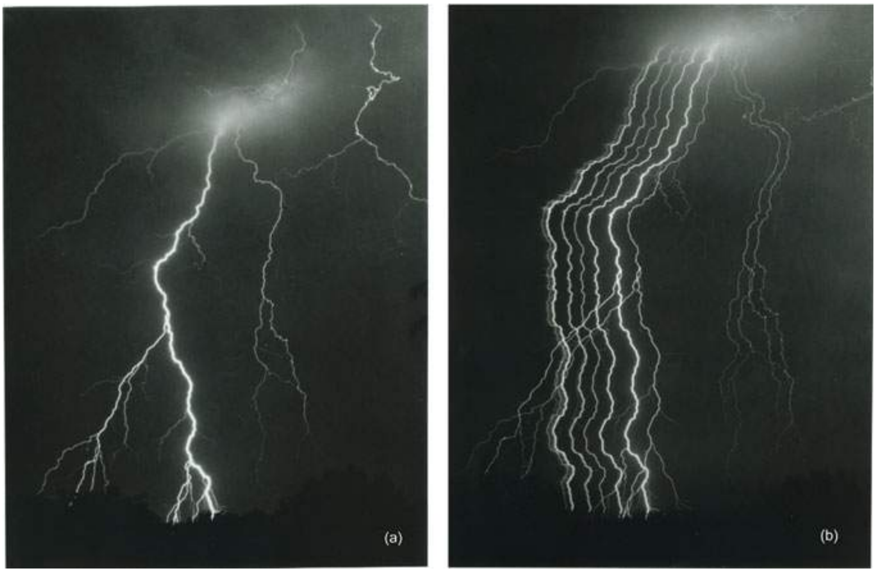

Fig. 6 Lightning flash which appears to have at least 7 (perhaps as many as 10) separate ground strike points: **a** still-camera photograph, **b** moving-camera photograph. Some of the strike points are associated with the same stroke having separate branches touching ground, while others are associated with different strokes taking different paths to ground. Adapted from Hendry [9]

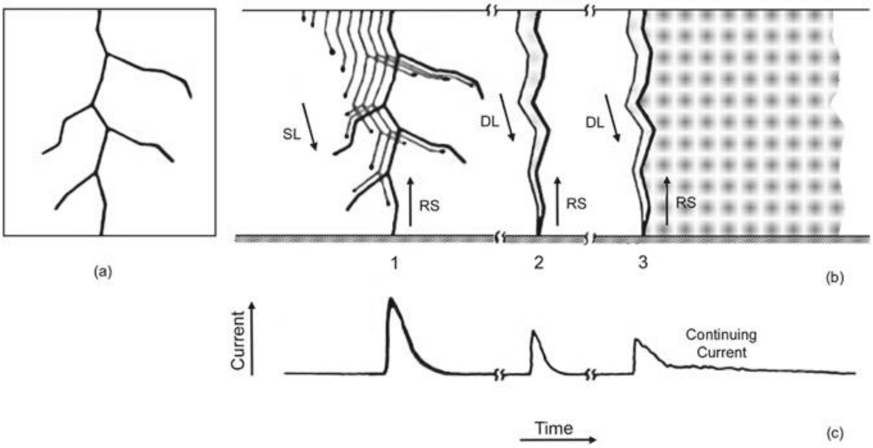

Fig. 7 Schematic diagram showing the luminosity of a three-stroke downward negative flash and the corresponding current at the channel base: **a** still-camera image, **b** streak-camera image, and **c** channel-base current. Stroke 3 is followed by continuing current whose luminosity in (**b**) is represented by an array of dark spots

that path moving from ground toward the cloud charge source region and neutralizes the negative leader charge. Thus, both leader and return-stroke processes serve to effectively transport negative charge from the cloud to ground. As seen in Fig. 7b, the leader initiating the first return stroke differs from the leaders initiating the two subsequent return strokes (all strokes other than first are termed subsequent strokes). In particular, the first-stroke leader appears optically to be an intermittent process, hence the term stepped leader, while the tip of a subsequent-stroke leader appears to move continuously. The continuously moving subsequent-stroke leader tip appears on streak photographs as a downward-moving "dart," hence the term dart leader. The apparent difference between the two types of leaders is related to the fact that the stepped leader develops in virgin air, while the dart leader follows the "pre-conditioned" path of the preceding stroke or strokes.

The electric potential difference between a downward-moving stepped-leader tip and ground is probably some tens of megavolts, comparable to or a considerable fraction of that between the cloud charge source and ground. The magnitude of the potential difference between two points, one at the cloud charge source and the other on ground, is the line integral of electric field intensity between those points. The upper and lower limits for the potential difference between the lower boundary of the main negative charge region and ground can be estimated by multiplying, respectively, the typical observed electric field in the cloud, 10^5 V/m, and the expected electric field at ground under a thundercloud immediately prior to the initiation of lightning, 10^4 V/m, by the height of the lower boundary of the negative charge region above ground. The resultant range is 50–500 MV, if the height is assumed to be 5 km.

When the descending stepped leader attaches to the ground, the first return stroke begins. The first return-stroke current measured at ground rises to an initial peak of about 30 kA in some microseconds and decays to half-peak value in some tens of microseconds. The return stroke effectively lowers to ground the several coulombs of charge originally deposited on the stepped-leader channel including all the branches. Once the bottom of the dart leader channel is connected to the ground, the second (or any subsequent) return-stroke wave is launched upward, which again serves to neutralize the leader charge. The subsequent return-stroke current at ground typically rises to a peak value of 10–15 kA in less than a microsecond and decays to half-peak value in a few tens of microseconds.

The high-current return-stroke wave rapidly heats the channel to a peak temperature near or above 30,000 K and creates a channel pressure of 10 atm (1 megapascal) or more, resulting in channel expansion, intense optical radiation, and an outward propagating shock wave that eventually becomes the thunder (sound wave) we hear at a distance. Each cloud-to-ground lightning flash involves an energy of roughly 10^9–10^{10} J (one to ten gigajoules). Lightning energy is approximately equal to the energy required to operate five 100 W light bulbs continuously for one month. Note that not all the lightning energy is available at the strike point, only 10^{-2}–10^{-3} of the total energy, since most of the energy is spent for producing thunder, hot air, light, and radio waves.

Given above is only basic information about downward negative lightning. In the following, referring to Fig. 8, we present a more complete sequence of processes involved in a typical downward negative lightning flash.

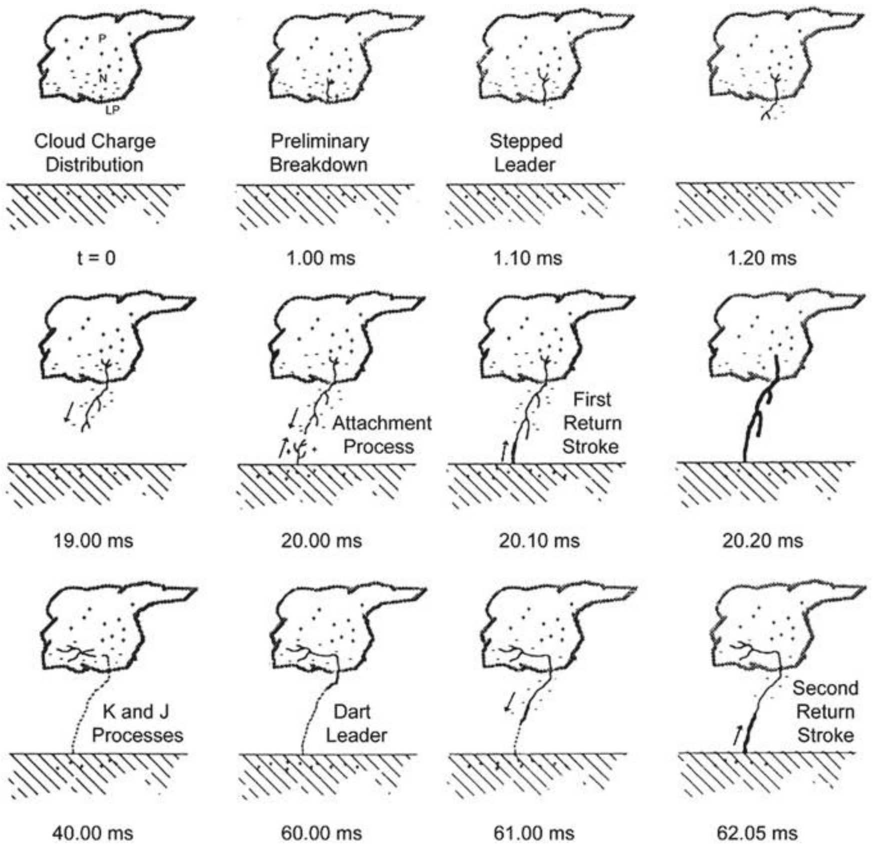

Fig. 8 Various processes comprising a two-stroke negative cloud-to-ground lightning flash. Time labels below the sketches can be used to roughly estimate typical durations of the processes and time intervals between them ($t = 0$ corresponds to the beginning of preliminary breakdown process which ends at $t = 1$ ms). Continuing current and M-components are not illustrated in this figure. Adapted from Uman [29, 30]

The source of lightning is usually a cumulonimbus (see Sect. 1), whose idealized charge structure is shown in Fig. 8 at t = 0 as three vertically stacked regions labeled “P” and “LP” for main positive and lower positive charge regions, respectively, and “N” for main negative charge region. The stepped leader is preceded by an in-cloud process called the preliminary or initial breakdown. It may be a discharge bridging the main negative and the lower positive charge regions, as shown in Fig. 8. The initial breakdown serves to provide conditions for the formation of the stepped leader. The latter is a negatively charged plasma channel extending toward the ground at an average speed of 2×10^5 m/s in a series of discrete steps. Each step produces a current pulse that originates at the tip of the downward-extending leader channel and propagates upward, like a mini return stroke, as schematically shown in Fig. 9. Krider et al. [13] inferred that the peak step current is at least 2–8 kA close to the

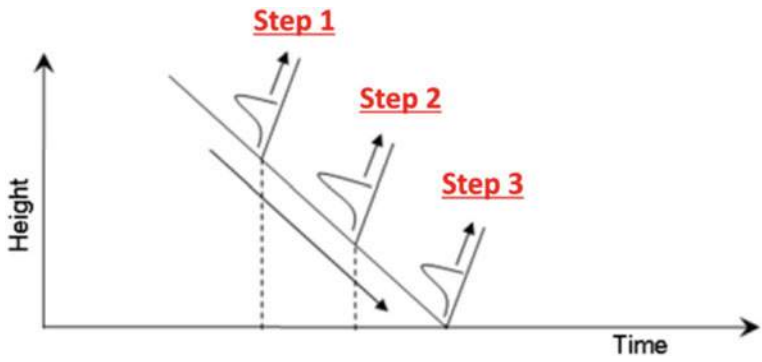

Fig. 9 Schematic representation of the downward leader stepping process. Negatively-sloped arrow indicates the overall downward extension of the leader channel. Three consecutive steps giving rise to current (and light) pulses are shown. Each step-current pulse originates at the tip of the downward-extending channel and propagates upward (as indicated by a positively-sloped arrow), like a mini return stroke. Adapted from Nag and Rakov [18]

ground and the minimum charge involved in the formation of a step is 1–4 mC. From high-speed time-resolved photographs, each step is typically 1 μs in duration and tens of meters in length, with the time interval between steps being 20–50 μs. The stepped leader serves to form a conducting path or channel between the cloud charge region and ground. Several coulombs of negative charge are distributed along this path, including downward branches. The leader may be viewed as a process removing negative charge from the cloud charge region and depositing this charge onto the downward extending channel. The stepped-leader duration is typically some tens of milliseconds, the total charge is about 5 coulombs, and the average leader current is some hundreds of amperes.

As the leader approaches ground, the electric field at the ground surface, particularly at objects or relief features protruding above the surrounding terrain, increases until it exceeds the critical value for the initiation of one or more upward leaders, one of which will become the upward connecting leader. It is usually assumed that the initiation of upward connecting leader (UCL) from ground in response to the descending stepped leader marks the beginning of the attachment process. The attachment process includes the so-called breakthrough phase that is assumed to begin when the relatively low conductivity streamer zones developing ahead of the two propagating leader tips meet to form a common streamer zone. The subsequent accelerated extension of the two relatively high conductivity plasma channels toward each other takes place inside the common streamer zone (see Rakov and Tran [22] and references therein). The attachment process ends when contact is made between the hot channels of the downward and upward moving leaders, probably some tens of meters above ground (more above a tall structure), where the first return stroke begins (see Fig. 10 where the attachment process is schematically shown). The return stroke serves to neutralize the leader charge or, equivalently, to transport the negative charges stored on the leader channel to the ground. It is worth noting that the

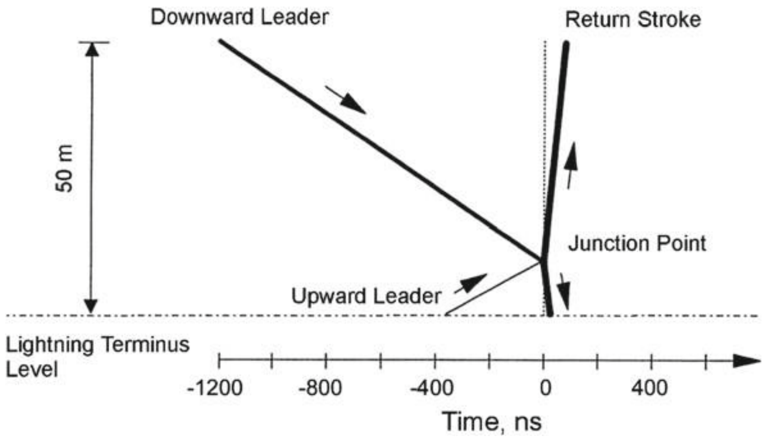

Fig. 10 Schematic representation of the attachment process followed by the bidirectional return-stroke process observed in a rocket-triggered lightning stroke. Rocket-triggered lightning strokes are similar to subsequent strokes in natural lightning. Adapted from Wang et al. [32]

return-stroke process may not neutralize all the leader charge and is likely to deposit some excess positive charge onto the upper part of the leader channel and into the cloud charge source region. The speed of the return stroke, averaged over the visible channel, is typically between one-third and one-half of the speed of light. There is no consensus about whether or how the first return-stroke speed changes over the bottom 100 m or so, but over the entire channel, the speed decreases with increasing height, dropping abruptly after passing each major branch. At the same time, a transient enhancement of the main channel luminosity below the branching point, termed a branch component, is often observed.

When the first return stroke, including any associated in-cloud discharge activity (discussed later), ceases the flash may end. In this case, the lightning is called a single-stroke flash. However, more often the residual first-stroke channel is traversed by a leader that appears to move continuously, a dart leader. During the time interval between the end of the first return stroke and the initiation of a dart leader, J (for junction) and K processes occur in the cloud. K processes can be viewed as transients occurring during the slower J process. The J processes amount to a redistribution of cloud charge on a tens of milliseconds time scale in response to the preceding return stroke. There is controversy as to whether these processes, which apparently act to extend the return-stroke channel further into the cloud, are necessarily related to the initiation of a following dart leader. The J process is often viewed as a relatively slow positive leader extending from the flash origin into the negative charge region, with the K process being a relatively fast "recoil process" that begins at the tip of the positive leader or in a decayed positive leader branch and propagates toward the flash origin. Both the J processes and the K processes in cloud-to-ground discharges serve to transport additional negative charge into and along the existing channel (or its remnants), although not all the way to the ground. In this respect, K processes may be viewed as attempted dart leaders. The processes that occur after the only stroke in single-stroke flashes and after the last stroke in multiple-stroke flashes are sometimes termed F (for final) processes. These are similar, if not identical, to J processes.

The dart leader progresses downward at a typical speed of 10^7 m/s, typically ignores the remnants of first stroke branches, and deposits along the channel a total charge of the order of 1 C. The dart-leader current peak is about 1 kA. Some leaders exhibit stepping near ground while propagating along the path traversed by the preceding return stroke; these leaders being termed dart-stepped leaders. Additionally, some dart or dart-stepped leaders deflect from the previous return-stroke path, become stepped leaders, and form a new termination on the ground.

When a dart leader or dart-stepped leader approaches the ground, an attachment process similar to that described for the first stroke takes place, although it occurs over a shorter distance and consequently takes less time, with the upward connecting leader length being of the order of some meters. Once the bottom of the dart or dart-stepped leader channel is connected to the ground, the second (or any subsequent) return-stroke wave is launched upward, which again serves to neutralize the leader charge. The upward propagation speed of subsequent return strokes is similar to that of first return strokes, although due to the absence of branches the speed variation along the channel does not exhibit abrupt drops.

Wang et al. [32], using the digital optical imaging system ALPS with 3.6-m spatial and 100-ns time resolution, observed the attachment process in one rocket-triggered-lightning stroke (see Sect. 5 of this chapter). A sketch of the time-resolved image for that event is shown in Fig. 10, in which the return stroke begins at $t = 0$. Note that the return stroke was initially a bidirectional process that involved both upward- and downward-moving waves which originated from the junction point of the downward negative dart leader and the upward positive connecting leader.

The impulsive component of the current in a subsequent return stroke is often followed by a continuing current which has a magnitude of tens to hundreds of amperes and a duration up to hundreds of milliseconds (median duration is 6 ms). Continuing currents with a duration in excess of 40 ms are traditionally termed long continuing currents. Between 30 and 50% of all negative cloud-to-ground flashes contain long continuing currents. The source for continuing current is the cloud charge, as opposed to the charge distributed along the leader channel, the latter charge contributing to at least the initial few hundred microseconds of the return-stroke current observed at ground. Continuing current typically exhibits a number of superimposed surges that rise to peak and fall off to the background current level in some hundreds of microseconds, with the peak being generally in the hundreds of amperes range but occasionally in the kiloamperes range. These current surges are associated with enhancements in the relatively faint luminosity of the continuing-current channel and are called M components. Note that continuing current and M-component processes are not shown in Fig. 8.

The time interval between successive return strokes in a flash is usually several tens of milliseconds, although it can be as large as many hundreds of milliseconds if a long continuing current is involved and as small as one millisecond or less. Note that interstroke intervals are usually measured between the peaks of current or electromagnetic field pulses. The total duration of a flash is typically some hundreds of milliseconds, and the total charge lowered to ground is some tens of coulombs. The average number of strokes per flash is 3 to 5. The overwhelming majority (typically about 80%) of negative cloud-to-ground flashes contain more than one stroke.

One-third to one-half of all lightning discharges to earth, both single- and multiple-stroke flashes, strike ground at more than one point with the spatial separation between the channel terminations being up to many kilometers. The average number of channels per flash is 1.5 to 1.7. In most cases, multiple ground terminations within a given flash are associated not with an individual multi-grounded leader but rather with the deflection of a subsequent leader from the previously formed channel.

The salient properties of downward negative lightning discharges are summarized in Table 1.

Lightning initiation in thunderclouds remains a mystery. Indeed, maximum electric fields typically measured in thunderclouds (see Table 3.2 of Rakov and Uman [23] and references therein) are 1–2 $\times$ 10^5 V/m (the highest measured value is 4 $\times$ 10^5 V/m), which is lower than the expected conventional breakdown field, of the order of 10^6 V/m. Two general mechanisms of lightning initiation have been suggested. One relies on the emission of positive streamers from hydrometeors when the electric field exceeds 2.5–9.5 $\times$ 10^5 V/m, and the other involves high-energy cosmic ray particles and the so-called runaway breakdown that occurs in a critical field, calculated to be about 10^5 V/m at an altitude of 6 km. Either of these two mechanisms permits, in principle, creation of an ionized region ("lightning seed") in the cloud that is capable of locally enhancing the electric field at its extremities. Such field enhancement is likely to be the main process leading to the formation (via conventional breakdown) of a hot, self-propagating lightning channel.

3 Current and Electromagnetic Field Signatures

The most complete characterization of the return stroke in negative downward flashes is due to Karl Berger and co-workers (e.g., Berger [3], Berger et al. [4]). The data of Berger were derived from oscillograms of current measured using resistive shunts installed at the tops of two 70 m high towers on the summit of Monte San Salvatore in Lugano, Switzerland. The summit of the mountain is 915 m above sea level and 640 m above the level of Lake Lugano, located at the base of the mountain. The towers are of moderate height, but because the mountain contributed to the electric field enhancement near the tower tops, the effective height of each tower was a few hundred meters. As a result, the majority of lightning strikes to the towers were of the upward type. Here we only consider return strokes in negative downward flashes. A total of 101 are included in the summary by Berger et al. [4]. Berger's data were additionally analyzed by Anderson and Eriksson (1980).

The results of Berger et al. [4] are still used to a large extent as the primary reference source for both lightning protection and lightning research. These results are presented in Figs. 11 and 12 and in Table 2.

Table 1 Characterization of negative cloud-to-ground lightning

Parameter	Typical value[a]
Stepped leader	
Step length, m	50
Time interval between steps, μs	20–50
Step current, kA	>1
Step charge, mC	>1
Average propagation speed, m s^{-1}	2×10^5
Overall duration, ms	35
Average current, A	100–200
Total charge, C	5
Electric potential, MV	~50
Channel temperature, K	~10,000
First return stroke[b]	
Peak current, kA	30
Maximum current rate of rise, kA μs^{-1}	10–20
Current risetime (10–90%), μs	5
Current duration to half-peak value, μs	70–80
Charge transfer, C	5
Propagation speed, m s^{-1}	$(1–2) \times 10^8$
Channel radius, cm	~1–2
Channel temperature, K	~30,000
Dart leader	
Speed, m s^{-1}	$(1–2) \times 10^7$
Duration, ms	1–2
Charge, C	1
Current, kA	1
Electric potential, MV	~15
Channel temperature, K	~20,000
Dart-stepped leader	
Step length, m	10
Time interval between steps, μs	5–10
Average propagation speed, m s^{-1}	$(1–2) \times 10^6$
Subsequent return stroke[b]	
Peak current, kA	10–15
Maximum current rate of rise, kA μs^{-1}	100
10–90% current rate of rise, kA μs^{-1}	30–50
Current risetime (10–90%), μs	0.3–0.6
Current duration to half-peak value, μs	30–40

(continued)

Table 1 (continued)

Parameter	Typical value[a]
Charge transfer, C	1
Propagation speed, m s^{-1}	(1–2) $\times$ 10^8
Channel radius, cm	~1–2
Channel temperature, K	~30,000
Continuing current (longer than 40 ms or so)[c]	
Magnitude, A	100–200
Duration, ms	~100
Charge transfer, C	10–20
M component[b]	
Peak current, A	100–200
Current risetime (10–90%), μs	300–500
Charge transfer, C	0.1–0.2
Overall flash	
Duration, ms	200–300
Number of strokes per flash[d]	3–5
Interstroke interval, ms	60
Charge transfer, C	20
Energy, J	10^9–10^{10}

Adapted from Rakov and Uman [23]
[a]Typical values are based on a comprehensive literature search and unpublished experimental data acquired by the University of Florida Lightning Research Group
[b]All current characteristics for return strokes and M components are based on measurements at the lightning channel base
[c]About 30–50% of lightning flashes contain continuing currents longer than 40 ms or so
[d] About 15–20% of lightning flashes are composed of a single stroke

Figure 11 shows, on two time scales, A and B, the average current wave shapes for negative first and subsequent strokes. The averaging procedure involved the normalization of waveforms from many strokes to their respective peak currents (so that all have peaks equal to unity) and subsequent alignment using the 0.5 peak point on the initial rising portion of the waveforms. The overall duration of the current waveforms is some hundreds of microseconds. The rising portion of the first-stroke waveform has a characteristic concave shape. The averaging procedure masked secondary maxima typically observed in first-stroke waveforms and generally attributed to major branches.

Figure 12 shows the cumulative statistical distributions (solid-line curves) of return-stroke peak currents for (1) negative first strokes, (2) negative subsequent strokes, and (3) positive strokes (each was the only stroke in a flash). These empirical distributions are approximated by log-normal distributions (dashed lines) and shown on cumulative probability distribution graph paper, on which a Gaussian (normal)

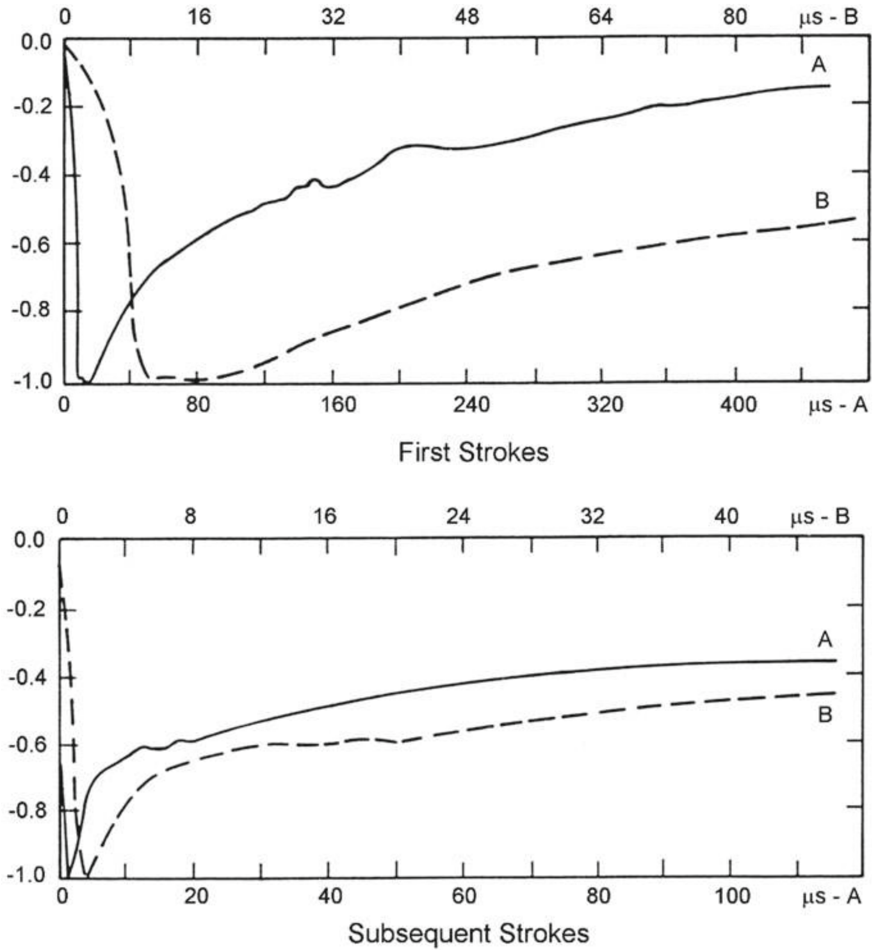

Fig. 11 Average negative first- and subsequent-stroke wave shapes each shown on two time scales, A and B. The lower time scales (A) correspond to solid curves, while the upper time scales (B) correspond to broken curves. The vertical (amplitude) scales are in relative units, the peak values being equal to negative unity. Adapted from Berger et al. [4]

cumulative distribution appears as a slanted straight line, with the horizontal (peak current) scale being logarithmic (base 10). The vertical scale gives the percentage of peak currents exceeding a given value on the horizontal axis. The vertical scale is symmetrical with respect to the 50% value and does not include the 0 and 100% values; it only asymptotically approaches those. For a log normal distribution, the 50% (median) value is equal to the geometric mean value.

The lightning peak current distributions for negative first and subsequent strokes shown in Fig. 12 are also characterized by their 95, 50, and 5% values based on the log normal approximations in Table 2, which contains a number of other parameters

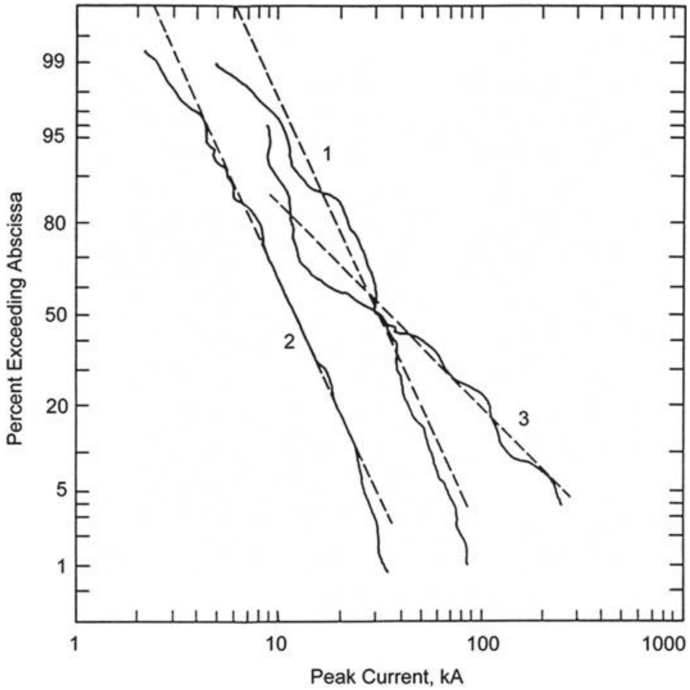

Fig. 12 Cumulative statistical distributions of return-stroke peak current (solid curves) and their log-normal approximations (broken lines) for (1) negative first strokes, (2) negative subsequent strokes, and (3) positive first (and only) strokes, as reported by Berger et al. [4]

derived from the current oscillograms. The minimum peak current value included in the distributions is 2 kA, although no first strokes (of either polarity) with peak currents below 5 kA were observed.

Berger's peak current distributions for first and subsequent negative strokes are generally confirmed by more recent direct current measurements, particularly those with larger sample sizes obtained in Japan (first strokes, N = 120; Takami and Okabe [27]), Austria (subsequent strokes, N = 615, Diendorfer et al. [6]), and Florida (subsequent strokes, N = 165, Schoene et al. [26]). At the same time, direct current measurements in Brazil [28] yielded 50% higher median peak currents for both first (N = 38) and subsequent (N = 71) strokes.

It follows from Fig. 12 and Table 2 that the median return-stroke current peak for first strokes is 2–3 times higher than that for subsequent strokes. Also, negative first strokes transfer about a factor of four larger charge than do negative subsequent strokes. On the other hand, subsequent return strokes are characterized by 3 to 4 times higher current maximum steepness (current maximum rate of rise or maximum dI/dt). It is important to note that the maximum dI/dt reported by Berger et al. [4] and given in Table 2 is an underestimate of the actual value due to the limited time resolution of oscillographic data. [The mean value of maximum dI/dt reported for

Table 2 Parameters of downward negative lightning derived from channel-base current measurements

Parameter	Unit	Sample size	Percent exceeding tabulated value		
			95%	50%	5%
Peak current (minimum 2 kA)	kA				
First strokes		101	14	30	80
Subsequent strokes		135	4.6	12	30
Charge (total charge)	C				
First strokes		93	1.1	5.2	24
Subsequent strokes		122	0.2	1.4	11
Complete flash		94	1.3	7.5	40
Impulse charge (excluding continuing current)	C				
First strokes		90	1.1	4.5	20
Subsequent strokes		117	0.22	0.95	4
Front duration (2 kA to peak)	μs				
First strokes		89	1.8	5.5	18
Subsequent strokes		118	0.22	1.1	4.5
Maximum dI/dt	kA μs^{-1}				
First strokes		92	5.5	12	32
Subsequent strokes		122	12	40	120
Stroke duration (2 kA to half peak value on the tail)	μs				
First strokes		90	30	75	200
Subsequent strokes		115	6.5	32	140
Action integral ($\int I^2 dt$)	A^2s				
First strokes		91	6.0×10^3	5.5×10^4	5.5×10^5
Subsequent strokes		88	5.5×10^2	6.0×10^3	5.2×10^4
Time interval between strokes	ms	133	7	33	150
Flash duration	ms				
All flashes		94	0.15	13	1100
Excluding single-stroke flashes		39	31	180	900

Adapted from Berger et al. [4]

rocket-triggered-lightning strokes (see Sect. 5 of this chapter) by Leteinturier et al. [14] is 110 kA/μs.] As seen in Fig. 12, only a few percent of negative first strokes are expected to exceed 100 kA, while about 20% of positive strokes have been observed to do so. On the other hand, the 50% (median) values of the current distributions for negative first and positive strokes are similar. The action integral (also referred to as specific energy) in Table 2 represents the energy that would be dissipated in a 1 Ω resistor if the lightning current were to flow through it. It is thought that the heating of electrically conducting materials and the explosion of nonconducting materials is, to a first approximation, determined by the value of the action integral. Note that the interstroke interval in Table 2 is likely mislabeled by Berger et al. [4] and is actually the no-current interval, that is, the interstroke interval excluding any continuing current.

Next, we will discuss typical electric and magnetic field waveforms produced by both first and subsequent return strokes at ground level at distances ranging from 1 to 200 km. These waveforms, which are drawings based on many measurements acquired in Florida by Lin et al. [15], are reproduced in Fig. 13.

The electric fields of strokes observed within a few kilometers of the flash are, after the first few tens of microseconds, dominated by the electrostatic component (marked "Ramp" in Fig. 13) of the total electric field, the only field component which is nonzero after the stroke current has ceased to flow. The close magnetic fields at similar times are dominated by the magnetostatic component of the total magnetic field, the component that produces the magnetic field humps marked in Fig. 13. Distant electric and magnetic fields have essentially identical waveshapes and are usually bipolar, as illustrated in Fig. 13. The data of Lin et al. [15] suggest that at a distance of 50 km and beyond, both electric and magnetic field waveshapes are dominated by their respective radiation components.

The initial field peak (marked in some of the waveforms of Fig. 13) is the dominant feature of the electric and magnetic field waveforms beyond about 10 km; this initial peak also is a significant feature of waveforms from strokes between a few and about 10 km and can be identified, with some effort, in waveforms for strokes as close as a kilometer. The initial field peak is due to the radiation component of the total field and, hence, decreases inversely with distance in the absence of significant propagation effects. The field peaks produced by different return strokes at known distances can be range normalized for comparison, for example, to 100 km by multiplying the measured field peaks by $r/10^5$, where r is the stroke distance in meters. The geometric mean of the electric field initial peak value, normalized to 100 km, is typically about 6 V/m for first strokes and 3 V/m for subsequent strokes. Since the initial electric field peak appears to obey a log-normal distribution, the geometric mean value (equal to the median value for a log-normal distribution) is probably a better characteristic of the statistical distribution of this parameter than the mean (arithmetic mean) value. Note that the geometric mean value for a log-normal distribution is lower than the corresponding mean value and higher than the modal (most probable) value.

Lightning peak currents can be estimated from measured electric or magnetic fields, for which a field-to-current conversion procedure (a model-based or empirical

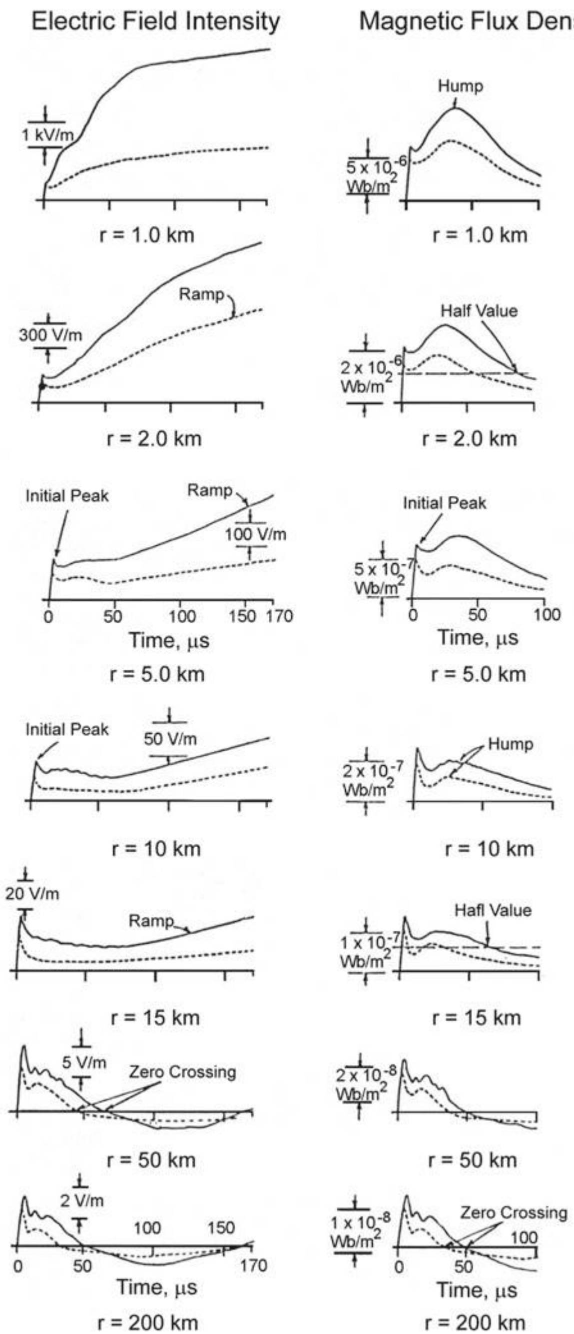

Fig. 13 Typical vertical electric field intensity (left column) and azimuthal magnetic flux density (right column) waveforms for first (solid line) and subsequent (broken line) return strokes at distances of 1, 2, 5, 10, 15, 50, and 200 km. Adapted from Lin et al. [15]

formula) is required. The vertical component of electric field and the azimuthal component of magnetic field are usually employed.

Rakov et al. [21] proposed the following empirical formula (linear regression equation) to estimate the negative return-stroke peak current, *I*, from the initial electric field peak, *E*, and distance, *r*, to the lightning channel:

$$I = 1.5 - 0.037Er \quad (1)$$

where *I* is in kA and taken as negative, *E* is positive and in V/m, and *r* is in km. Equation 1 was derived using data for 28 triggered-lightning strokes acquired by Willett et al. [33] at the Kennedy Space Center (KSC), Florida. The fields were measured at about 5 km and their initial peaks were assumed to be pure radiation. The currents were directly measured at the lightning channel base.

Lightning peak currents can also be estimated using the radiation-field-to-current conversion equation based on the transmission line (TL) model [31], which for the electric field is given by:

$$I = \frac{2\pi \varepsilon_0 c^2 r}{v} E \quad (2)$$

where ε_0 is the permittivity of free space, *c* is the speed of light, and *v* is the return-stroke speed (assumed to be constant). The return-stroke speed is generally unknown and its range of variation is from one-third to two-thirds of the speed of light. Both *I* and *E* in Eq. 2 are absolute values. The equation is thought to be valid for instantaneous values of *E* and *I* at early times (for the initial rising portion of the waveforms, including the peak).

4 Lightning Measurements

In this section, measurements of lightning electric and magnetic fields will be considered. Both the principles and practical aspects will be covered.

A sensor that is commonly used to measure the lightning vertical electric field is a metallic disk placed flush with the ground surface, the so-called flat-plate antenna. Figure 14a schematically shows such an antenna, where it is assumed that the area A of the antenna sensing plate is small enough to consider the electric field E constant over that area and C_a is the capacitance of the antenna. The downward directed electric field induces negative charge Q on the surface of the antenna, which can be found as the product of the surface charge density ρ_s and the area A of the antenna sensing plate. From the boundary condition on the vertical component of electric field on the surface of good conductor, $\rho_s = \varepsilon_0 E$, where ε_0 is the electric permittivity of free space, and hence $Q = \varepsilon_0 EA$. If E is varying with time, there will be current $I = dQ/dt = \varepsilon_0 A dE/dt$ flowing via C_a to ground. This current is proportional to

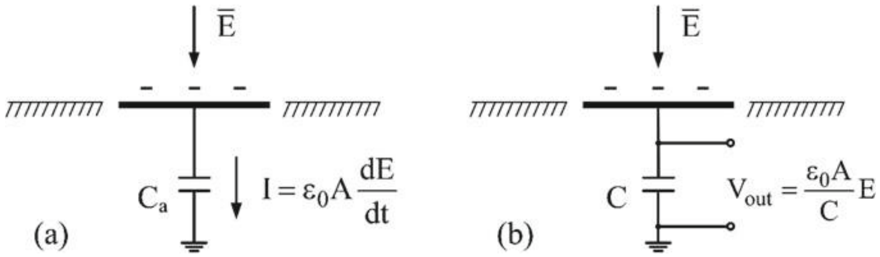

Fig. 14 Illustration of the principle of operation of the flat-plate antenna. **a** Antenna without external circuit. **b** Antenna with external integrating capacitor $C \gg C_a$. Drawing by Potao Sun

dE/dt. In order to measure E, it is necessary to use an integrating capacitor $C \gg C_a$, (see Fig. 14b), since C_a is usually too small for measuring lightning fields, as will be discussed later in this section. Thus, the voltage across the integrating capacitor (capacitive voltage drop) will be

$$V_{out} = \frac{1}{C_a + C_0} \int_0^t I(t')dt' \approx \frac{1}{C} \int_0^t I(t')dt' = \frac{Q}{C} = \frac{\varepsilon_0 AE}{C} \tag{3}$$

Strictly speaking, Eq. 3 applies only to the case of infinitely large input impedance of the recorder. In practice, the input resistance of the recorder (or fiber-optic-link transmitter) plays an important role, limiting the time interval or the lower end of the frequency range over which Eq. 3 is valid. To examine this further, it is convenient to use the Norton equivalent circuit of the antenna, which is the antenna short-circuit current, $I = \varepsilon_0 Aj\omega E$ (ideal current source), in parallel with antenna impedance, $1/j\omega C_a$, where $\omega = 2\pi f$ with f being frequency in hertz. The equivalent circuit including the Norton equivalent of the antenna (in the time domain), integrating capacitance, and input resistance R_{in} and capacitance C_{in} of the recorder is shown in Fig. 15.

Since $C \gg C_a$ and usually $C \gg C_{in}$, the current basically splits between C and R_{in}, and Eq. (3) holds when $1/\omega C \ll R_{in}$; that is, $\omega \gg 1/(R_{in}C)$ or $f \gg 1/(2\pi R_{in}C)$. In the time domain, Eq. 3 is valid when the variation time (duration) of the signal of

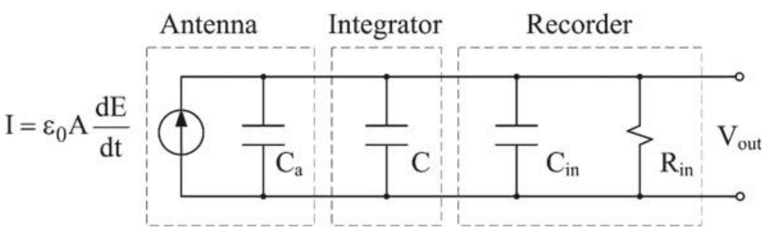

Fig. 15 Norton equivalent circuit of electric field antenna shown along with the integrating capacitance and the input impedance of recorder (usually $C \gg C_a$ and $C \gg C_{in}$). Drawing by Potao Sun

interest $\Delta t \ll \tau$, where $\tau = R_{in}C$ is the decay time constant of the measuring system (when E is a step-function, V_{out} will exponentially decay to 1/e, where e is the base of the natural logarithm, or about 37% of its initial value over the time equal to τ). For example, if $C = 1\ \mu F$ and $R_{in} = 1\ M\Omega$, $\tau = 1$ s, long enough for recording electric fields produced by lightning processes occurring on time scales of the order of tens of milliseconds (for example, stepped leaders or return strokes followed by continuing currents). Typical values of C_a and C_{in} are of the order of tens to hundreds of picofarad ($1\ pF = 10^{-12}$ F) or less, clearly much smaller than $C = 1\ \mu F$ (10^{-6} F) in this example. For recording return-stroke pulses, τ of the order of milliseconds is usually sufficient, while for the faithful reproduction of overall flash waveforms it should be of the order of 10 s or so. For recording microsecond- and sub-microsecond-scale pulses, τ shorter than a millisecond or so can be used. Measuring systems with decay time constants of the order of seconds are sometimes referred to as "slow antenna" systems, and those with sub-millisecond time constants as "fast antenna" systems. "Fast-antenna" systems usually have higher gains than "slow-antenna" ones. The terms "slow" and "fast" have nothing to do with the upper frequency response of the system, which is usually determined by the amplifier or fiber-optic link. The measuring system shown in Fig. 15 employs a passive integrator. In the case of active integrator, $\tau = RC$ is determined by R and C connected in parallel in the feedback circuit of the operational amplifier.

We now discuss the situation when the condition of $\Delta t \ll \tau$ is not satisfied. Such situations are not rare. Indeed, since the range of lightning electric field changes is very large (it spans orders of magnitude), it is practically impossible to build a single measuring system that would have a dynamic range suitable for recording all those changes. Smaller field changes require a higher gain that usually leads to system saturation by larger field changes. On the other hand, a lower gain needed to keep the larger field changes on scale would render the smaller field changes unresolved. The larger field changes are usually relatively slow, varying on time scales of the order of milliseconds and longer (e.g., electric field changes produced by long continuing currents), while the smaller field changes are usually microsecond-scale pulses. One way to enable a field measuring system to record relatively small and relatively short pulses is to allow the larger and slower field changes to decay with a relatively short time constant. In order to avoid distortion of the pulses, this time constant should be much longer than the expected duration of the pulses. As discussed above, time constants satisfying the latter requirement are shorter than a millisecond or so. In this case, some associated field changes varying on a millisecond time scale (e.g., overall field changes produced by K- and M-processes) will be distorted. Specifically, ramp-like electric field changes due to lightning K-processes can be converted to pulses, with the falling edge of the pulse being due to instrumental decay, as opposed to occurring in response to source variation. In principle, the instrumental decay can be compensated in post-processing of measured field waveforms, to remove the distortion and reconstruct the undistorted waveform [25].

Placement of flat-plate antenna flush with the ground ensures that the electric field to be measured is not influenced by the antenna. This gives an advantage of theoretical calibration of the measuring system (see Eq. 3). Any antenna elevated above the ground surface will enhance the field that would exist at the same location in the absence of antenna. As a result, experimental calibration is required to determine the field enhancement factor (except for the spherical antenna with isolated cutouts, for which the enhancement factor is known; it is equal to 3) the inverse of which is to be used as a multiplier in Eq. 3. Calibration can be done by placing the antenna in a uniform field of a large parallel-plate capacitor or by comparing the antenna output with that of a flush-mounted reference antenna. When calibration is done experimentally, an antenna of any geometry (e.g., a vertical rod (monopole) with or without capacitive loading at its top or an inverted antenna with a grounded "bowl" above the elevated sensing plate) can be used. However, slender antennas are generally not used for measuring fields at close distances from the lightning channel. Such antennas can enhance the electric field to a degree that corona discharge occurs from the antenna. It is impossible to accurately measure electric fields in the presence of corona from the antenna, since, besides the current charging the antenna, there will be corona current transporting charges into the air surrounding the antenna, both currents flowing through the same integrating capacitor across which the output voltage is measured.

If an essentially flush with the surface flat-plate antenna is installed of the roof of a building or other structure, another field enhancement factor, due to the presence of the building, is to be taken into account. This latter enhancement factor can be calculated numerically. For example, Baba and Rakov [2], who used the 3-D finite-difference time-domain (FDTD) method, estimated that for a building having a plan area of 40×40 m^2 and a height of 20 m the electric field enhancement factor (at the center point of its flat roof) is 1.5 and it is 3.0 if the height of the building is 100 m. For comparison, the enhancement factor on the top of hemispherical structure is independent of its size and equal to 3. The magnitude of vertical electric field at ground level in the immediate vicinity of the building is reduced relative to the case of no building, with this shielding effect becoming negligible at horizontal distances from the building exceeding twice the height of the building. In contrast to the electric field, the magnitude of magnetic field was found to be not much influenced by the presence of building. Note that Baba and Rakov [2] (see their Table VI) showed that the electric field enhancement due to the presence of building is only slightly influenced by building conductivity ranging from 1 mS/m (dry concrete) to infinity and essentially independent of relative electric permittivity ranging from 1 to 10.

The use of long horizontal coaxial cables between the antenna and the associated electronics should be avoided, since the horizontal component of electric field (present due to the finite ground conductivity) can induce unwanted voltages in these cables. The horizontal electric field waveshape is similar to that of the derivative of the vertical field. As a result, the measured field waveform may be a superposition of the vertical field, which is being measured, and the unwanted horizontal field, which causes a distortion of the vertical field waveform by making peaks and valleys sharper than they actually are in the vertical field [29]. The problem can be solved by using a fiber-optic link instead of the coaxial cable. Further, significant reduction of noise can be achieved by digitizing signals at the antenna location and digitally transmitting them to recorder.

One can check if the electric field measuring system is working properly by comparing electric field waveforms produced by individual lightning events (e.g., return strokes) with the corresponding magnetic field waveforms. At large distances (>50 km or so), those waveforms are dominated by their radiation components and, hence, their shapes should be identical. Further, the ratios of electric and magnetic field peaks at large distances for sources near ground (return strokes) should be equal to the speed of light ($E/B = c$).

If in Figs. 14b and 15 the integrating capacitor C is replaced with the resistor R (such that $R \ll 1/(\omega C_a)$ and $R \ll 1/(\omega C_{in})$), the output voltage is proportional to dE/dt. Measured dE/dt waveforms can be numerically integrated over time to obtain E waveforms, although the integration interval should not be too long in order to avoid accumulation of significant error.

To measure the magnetic field produced by lightning processes a loop of wire can be used as an antenna. According to Faraday's Law, a time varying magnetic field passing through an open-circuited loop of wire will induce a voltage (electromotive force) at the terminals of the loop (see Fig. 16). The induced voltage is proportional to the rate of change of magnetic flux passing through the loop area. Assuming that the loop area, A, is small enough to consider the normal component of magnetic flux density, $B_n = B \cos\alpha$, where α is the angle between the magnetic flux density vector and the normal to the plane of the loop, to be constant over that area, we can express the magnitude of induced voltage as follows:

$$V = A\frac{dB_n}{dt} \tag{4}$$

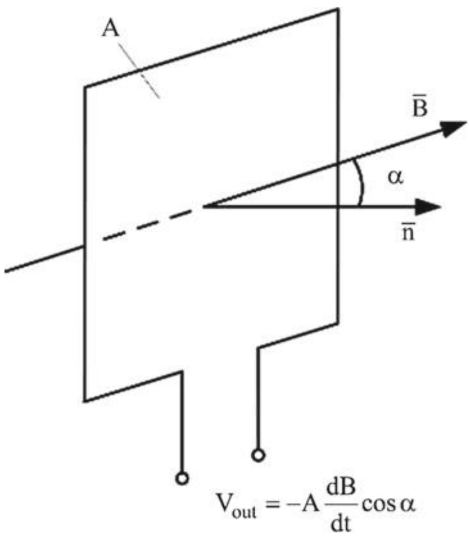

Fig. 16 Illustration of the principle of operation of the loop antenna. Drawing by Potao Sun

When $\cos\alpha = 1$ ($\alpha = 0$), the induced voltage is maximum, and when $\cos\alpha = 0$ ($\alpha = 90°$), the induced voltage is zero. It follows, that a vertical loop antenna in a fixed position is directional in that the magnitude of voltage induced across its terminals is a function of the direction to the source, and two such antennas with orthogonal planes can be used for magnetic direction finding. In order to obtain the horizontal (azimuthal) component of magnetic field, which is the dominant component for essentially vertical lightning channels, two vertical loop antennas are required, unless the direction to the lightning channel is known (for example, in the case of rocket-triggered lightning; see Sect. 5 of this chapter).

Since the signal at the output of a loop antenna is proportional to the magnetic field derivative, the signal must be integrated to obtain the field. This can be accomplished using either an RC or RL circuit, or the measured field derivative signal can be integrated numerically. We will consider below the case of RC integrator. In the following, we will assume that B is normal to the plane of the loop antenna ($\alpha = 0$), so that $B = B_n$. The voltage induced at the terminals of a loop antenna is the open-circuit voltage, AdB/dt or AjωB, and, hence, it can be used for building the Thevenin equivalent circuit of the antenna. The source impedance is predominantly inductive, jωL. The overall equivalent circuit including, besides the antenna, the RC integrator and input impedance (input resistance in parallel with input capacitance) of the recorder is shown in Fig. 17.

In contrast with the electric field antenna (see Fig. 15), the integrating capacitor in Fig. 17 has two discharge paths, one through the input resistance of the recorder (similar to Fig. 15) and the other through resistor R of the integrating circuit and the source (the ideal voltage source has zero impedance). As a result, there are three conditions for undistorted recording of magnetic field with the measuring system shown in Fig. 17. The first one, $R \gg 1/\omega C$ ($\omega \gg 1/(RC)$; C_{in} is neglected), determines the lower frequency limit and is equivalent to the $\Delta t \ll \tau$ ($\tau = RC$) condition. The second one, $R \gg \omega L$ ($\omega \ll R/L$), determines the upper frequency limit. The third one, $R_{in} \gg R$, requires that C discharges through R, not R_{in}. Under those three conditions, the output voltage is independent of frequency and given by

$$V_{out} = \frac{AB}{RC} \tag{5}$$

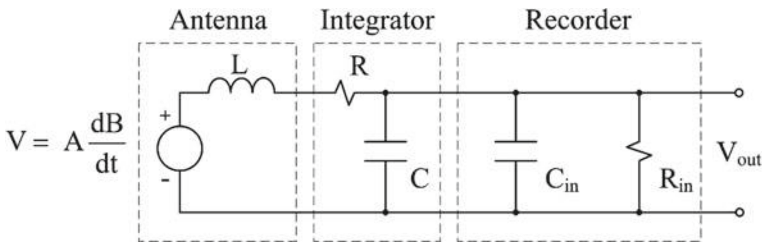

Fig. 17 Thevenin equivalent circuit of magnetic field antenna shown along with the integrating circuit and the input impedance of recorder. Drawing by Potao Sun

Magnetic field measuring circuits are rarely passive; active integrators and amplifiers are usually required. A loop antenna developed by George Schnetzer and used by the University of Florida Lightning Research Group is described in Sect. 7.2 of Rakov [20].

In designing field measuring systems, one needs to know expected magnitudes and durations of signals to be recorded. Different lightning processes produce different electromagnetic signatures, these signatures change with distance, and at the same distance there is large variation in source strength. Both variations in the source and with distance should be considered. Given below is a brief review of characteristics of lightning electric and magnetic fields expected at different distances from the source.

At ground level and at distances greater than a few kilometers, the initial electric field peak is dominated by its radiation component. Typical electric field peak values normalized to 100 km are about 6 and 3 V/m for negative first and subsequent return strokes, respectively. The largest radiation field peaks due to stepped and dart-stepped leaders are typically a factor of 10 smaller than the corresponding return-stroke field peak at the same distance. Radiation fields vary inversely with distance (1/r dependence), if propagation effects due to finite ground conductivity can be neglected. Generally, the typical radiation field peak values normalized to 100 km can be scaled to either smaller or larger distances in the range from about 5 to about 200 km. For example, if the field peak at 100 km is 6 V/m, it is expected to be 60 V/m at 10 km and 3 V/m at 200 km. The corresponding magnetic radiation field peaks can be readily found by dividing the electric field peak by the speed of light (3×10^8 m/s) to find the magnetic flux density (B) and by the intrinsic impedance of free space (377 Ω) to find the magnetic field intensity (H). At a given distance, the field can be at least a factor of 5 greater and a factor of 5 smaller, due to variation in the source.

5 Rocket-Triggered Lightning

An understanding of the physical properties and deleterious effects of lightning is critical to the adequate protection of power and communication lines, aircraft, spacecraft, and other objects and systems. Many aspects of lightning are not yet well understood and are in need of research that often requires the termination of lightning channel on an instrumented object or in the immediate vicinity of various sensors. The probability for a natural lightning to strike a given point on the earth's surface or an object of interest is very low, even in areas of relatively high lightning activity. Simulation of the lightning channel in a high-voltage laboratory has limited application, since it does not allow the reproduction of many lightning features important for lightning protection and it does not allow the testing of large distributed systems such as overhead power lines. One promising tool for studying both the direct and the induced effects of lightning is an artificially initiated (or triggered) lightning discharge from a natural thundercloud to a designated point on ground. The most effective technique for artificial lightning initiation is the so-called rocket-and-wire technique. It allows generation of full-scale lightning discharges with currents up to tens of kiloamperes and potentials of the order of 10 MV. Energy tapped by these discharges is naturally accumulated in the cloud that would otherwise produce natural lightning. In most respects, the rocket-and-wire triggered lightning (often referred to as rocket-triggered or just triggered lightning) is a controllable analog of natural lightning.

The rocket-and-wire technique involves the launching of a small rocket extending a thin wire (either grounded or ungrounded) into the gap between the ground and a charged cloud overhead. In the former case, the triggered lightning is referred to as classical and in the latter case as altitude triggered one. The sequence of processes (except for the transition from leader to return stroke stage that is referred to as the attachment process) in classical triggered lightning is schematically shown in Fig. 18. When the rocket, ascending at about 150–200 m/s, is about 200–300 m high, the field enhancement near the rocket tip launches a positively charged leader that propagates upward toward the cloud. This upward positive leader vaporizes the trailing wire, bridges the gap between the cloud and the ground, and establishes an initial continuous current with a duration of some hundreds of milliseconds that transports negative charge from the cloud charge source region to the triggering facility. After the cessation of the initial continuous current, one or more downward dart-leader/upward return-stroke sequences may traverse the same path to the triggering facility. The dart leaders and the following return strokes in triggered lightning are similar to dart-leader/return-stroke sequences in natural lightning, although the

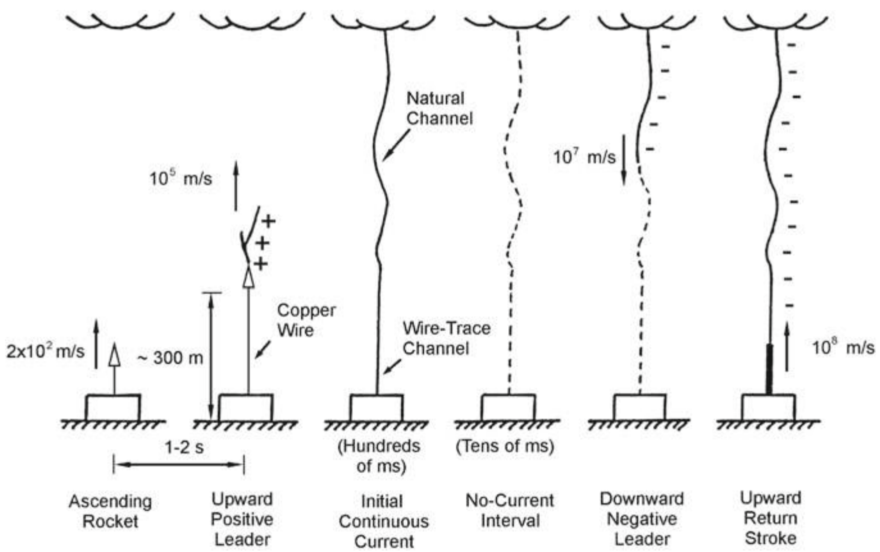

Fig. 18 Sequence of events (except for the attachment process) in classical rocket-triggered lightning. The upward positive leader and initial continuous current constitute the initial stage of a classical rocket-triggered flash. Adapted from Rakov et al. [24]

initial processes in natural downward and rocket-triggered lightning are distinctly different.

First lightning triggering was done in the 1960s over water (inspired by lightning unintentionally initiated by a plume of water resulting from an underwater explosion; see Fig. 1 of Brook et al. [5]) and since the early 1970s has been performed over land. To date, over 1,500 lightning discharges have been triggered by researchers in different countries (United States, France, Japan, China, and Brazil) using the rocket-and-wire technique, with over 450 of them at Camp Blanding, Florida. Presently, there are four facilities, two in China (Binzhou and Conghua) and two in the United States (Florida and New Mexico), where triggered-lightning experiments can be performed. Photographs of two classical rocket-and-wire triggered lightning flashes are shown in Fig. 19. Examples of some results of triggered-lightning experiments are shown in Figs. 20 and 21.

Figure 20 shows a photograph of surface arcing during a triggered-lightning flash from experiments at Fort McClellan, Alabama. The soil was red clay and a 0.3 or 1.3-m steel vertical rod was used for grounding of the rocket launcher. The surface arcing appears to be random in direction and often leaves little if any evidence on the ground. Even within the same flash, individual strokes can produce arcs developing in different directions. In one case, it was possible to estimate the current carried by one arc branch which contacted the instrumentation. That current was approximately 1 kA, or 5% of the total current peak in that stroke. The observed horizontal extent of surface arcs was up to 20 m, which was the limit of the photographic coverage during the Fort McClellan experiments. These results suggest that the uniform ionization of soil, usually postulated in studies of the behavior of grounding electrodes subjected to lightning surges, may be not an adequate assumption.

In 1993, an experiment, sponsored by Electric Power Research Institute (EPRI), was conducted at Camp Blanding by Power Technologies, Inc. to study the effects of lightning on underground power cables. In this experiment three 15 kV coaxial cables with polyethylene insulation between the center conductor and the outer concentric stranded shield (neutral) were buried 5 m apart at a depth of 1 m, and lightning current was injected into the ground at different positions with respect to these cables. The cables differed only in the level of insulation from the surrounding soil. One of the cables (Cable A) had an insulting jacket and was placed in (a) PVC conduit (pipe), another one (Cable B) had an insulating jacket and was directly buried, and the third one (Cable C) had no jacket and was directly buried. About 20 lightning flashes were triggered directly above the cables which were unenergized.

The underground power cables were excavated by the University of Florida researchers in 1994. The damage found ranged from minor punctures of the cable jacket to extensive puncturing of the jacket and melting of nearly all the concentric neutral strands near the lightning attachment point. Some damage to the cable insulation between the center (phase) conductor and the neutral was also observed. In the case of the PVC conduit cable installation, the side wall of the conduit was melted, deformed, and blown open, and the lightning channel had attached to the cable inside and damaged its insulation. Photographs of the damaged parts of the cables are shown in Fig. 21. Note fulgurites (glassy tubes formed when lightning

Fig. 19 Photographs of lightning flashes triggered using the rocket-and-wire technique at Camp Blanding, Florida. Top—a distant view of a strike to the test airport runway; bottom—a close-up view of a strike to the test power system

Fig. 20 Photograph of surface arcing associated with the second stroke (current peak of 30 kA) of flash 9312 triggered at Fort McClellan, Alabama. Lightning channel is outside the field of view. One of the surface arcs approached the right edge of the photograph, a distance of 10 m from the rocket launcher. Adapted from Fisher et al. [8]

current flows through sandy soil) in Fig. 21a, b. The presence of fulgurites indicates that the lightning channel continues to extend below the ground surface, in addition to developing along the ground surface in the form of surface arcs (see Fig. 20). Overall, these experiments showed that buried cables attract lightning striking ground within a distance of 10 m or so from the cable and that three layers of insulation (insulating jacket, PVC pipe, and air inside the PVC pipe; see Fig. 21a) plus 1-m layer of soil do not make cables “invisible” to lightning.

Further information on rocket-triggered lightning can be found in works of Horii and Nakano [10], Rakov and Uman [23], Chap. 7), Dwyer and Uman [7], and Qie and Zhang [19].

The results of rocket-triggered-lightning experiments have provided considerable insight into natural lightning processes that would not have been possible from studies of natural lightning due to its random occurrence in space and time. Among such findings are detailed observations of lightning propagation and attachment to ground, discovery that all types of negative lightning leaders produce hard X-rays, identification of the M-component mode of charge transfer to ground, direct measurements of NO_x production by an isolated lightning channel section, estimation of lightning input energy, and many others. The first terrestrial gamma-ray flash (TGF) observed at ground level was associated with triggered lightning. Triggered-lightning experiments have contributed significantly to testing the validity of various lightning models and to providing ground-truth data for testing the performance characteristics of lightning locating systems. Triggered lightning is a very useful tool for studying

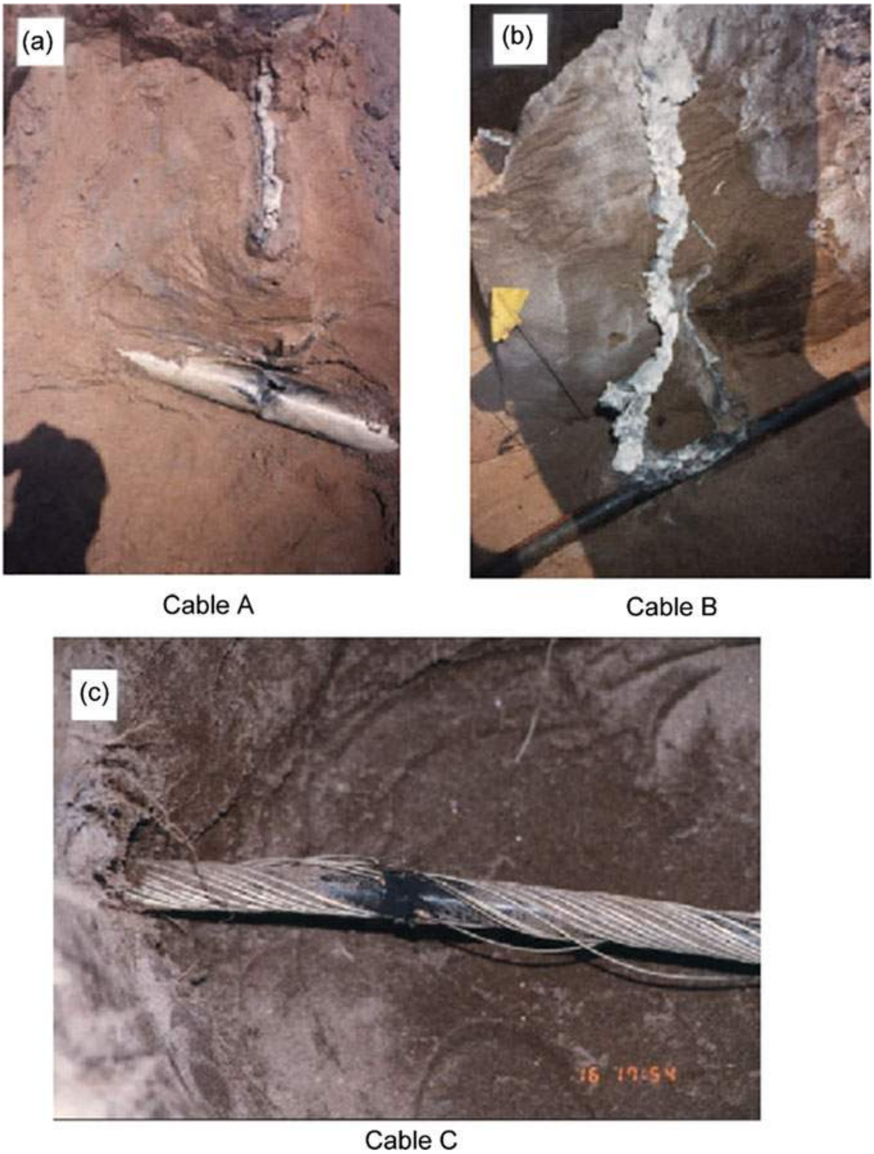

Fig. 21 Lightning damage to underground power cables. **a** coaxial cable in an insulating jacket inside a PVC conduit (pipe); note the section of vertical fulgurite in the upper part of the picture (the lower portion of this fulgurite was destroyed during excavation) and the hole melted through the PVC conduit, **b** coaxial cable in an insulating jacket, directly buried; note the fulgurite attached to the cable, **c** coaxial cable whose stranded neutral was in contact with earth; note that many strands of the neutral are melted through. Photos in **a**, **b** were taken by V. A. Rakov and in **c** by P. P. Barker

the interaction of lightning with various objects and systems and testing lightning protection schemes.

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Life on Siwalik and Lesser Himalayas under the Extreme Threat of Lightning

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Abstract—**Of natural disasters in Nepal, lightning is the second highest killer after earthquakes. According to the data available from the Disaster Risk Reduction (DRR) portal of the Ministry of Home Affairs (MoFA), an average of 108 people are killed by lightning each year. As would be expected, fatalities over the high mountains are rare due to both low population and low lightning flash density. Surprisingly, most fatalities and injuries are reported over the hilly areas of the Siwalik and lesser Himalayas in the middle of Nepal, despite the southern region having both a significantly higher population and higher lightning flash density.**

Keywords-Fatalities, Siwalik lightning, Nepal, lightning injury, lightning casualty, lightning fatality, lightning safety.

I. Introduction

Exact numbers on fatalities and injuries from lightning are not available for most countries. One estimate of global fatalities is several thousand [1], another 6000 fatalities per year [2], and the third 24,000 fatalities per year [3]. Holle and Lopez [3] also estimated 240,000 people injured each year based on lightning stroke density and populations in the tropical and subtropical areas of the world. Holle found fatality rates in developed countries are much lower than in lesser-developed countries [4].

Fatality rates were highest in Malawi (84 deaths per million people per year) and lowest in developed countries such as the UK, Austria and Japan. These differences in fatality rates have been attributed to several factors common in developing countries:

1) Fewer lightning-safe homes, workplaces, schools, and other facilities than in more developed countries.
2) High rate of labor-intensive manual agriculture.
3) Lack of awareness or data about the lightning threat, how to avoid injury, and medical treatment.
4) Fewer easily available fully enclosed metal-topped vehicles or similar safe enclosures.

Reference [1] developed an empirical formula to estimate the annual fatality rate in any given region. The equation takes factors into account such as lightning ground flash density, population density, literacy, fraction of urban population, etc. However, when this formula was applied to Mongolia, it was unsuccessful in estimating the fatality rate. It was suggested in [5] that other parameters including landscape topography may have a significant influence on annual deaths due to lightning.

Although lightning is a threat to people and livestock, particularly in the developing world, this natural hazard has largely been ignored in many countries. Lightning injury data are unavailable in the literature for most developing countries. In Nepal, too, lightning hazards in the past have been largely underrated, even though it is a one of most frequent and dangerous natural hazards that people encounter.

II. Geography and Weather Patterns of Nepal

Nepal is a country of diversified geographical configuration with altitudes as low as 59 m to as high as 8848 m above mean sea level (Fig. 1). Over 83% of Nepal is hilly or mountainous, including the world's highest peak, Mt. Everest, and eight other peaks over 8000 m. The Himalayan peaks cover the northern part of Nepal. The southern strip is a plain, whereas much of the middle area is covered by hills. This geographic structure plays a vital role in the observed meteorological effects.

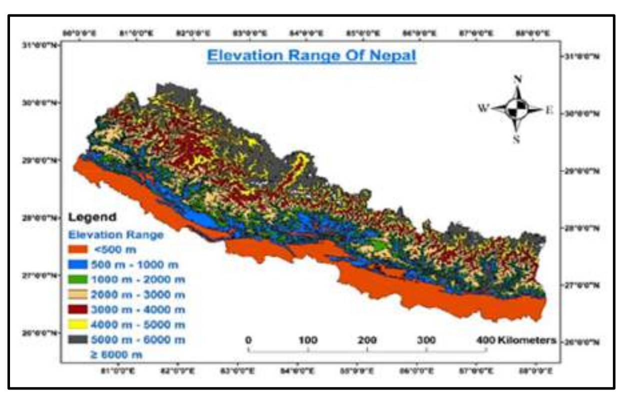

Figure 1. Topographic map of Nepal with elevation.

Nepal is topographically divided into three regions. The Himalayas and its foothills make up the northern border of the country and cover 16% of the total land area. This is the least inhabited region of Nepal with less than 8% of the population. Most permanent settlements in Nepal are at less than 400 m altitude. The Mahabharat range and the Churia hills in the middle of the country cover about 65% of the total land area and are home to about 44% of population. The Terai southern part of Nepal is an extension of the Gangetic plains and covers 17% of the total land area with 48% of the population for the highest population density.

Monsoons occur during July and August with heavy rainfall resulting in landslides, floods, and inundations. Thunderstorms and lightning occur mostly during the pre- and post-monsoon periods. The meteorological changes occurring in the Himalayan range have a role in the occurrence of lightning flashes. Thunderstorms generally begin in March (the pre-monsoon season) and cease by August (post-monsoon). The pre-monsoon is the most active lightning period followed by the post-monsoon period, although monsoonal thunderstorms are also prevalent. Winter lightning is very rare, although lightning casualties and incidents have been reported.

Lightning occurs almost everywhere over Nepal, although it is relatively infrequent over the high mountains. In contrast, the southeast part of the country receives the highest number of lightning strokes followed by the Chure range (Fig. 2). This is the range of hills that extends from Indus river of Pakistan in the west to the Brahmaputra river of India in the east. These Chure hills, also known as Siwalik hills, are the southernmost foothills of Himalayas, shaped like a hedge with an average elevation of 600 m to 1220 m above sea level.

The atmospheric structure and hydro-meteorological processes along the southern slopes of the Himalayas are not well known or well documented, mainly because of the rugged and remote terrain. Also, the mountain range lies within several developing countries, such as Nepal, that do not have the resources to carry out sophisticated meteorological studies [6]. Lightning stroke density, as measured by the Global Lightning dataset (GLD360), is over 18 strokes km^{-2} y^{-1} along the southern Nepal border, typically 4 to 8 strokes km^{-2} y^{-1} in the central region, with very small densities over the northern mountainous border. These densities from GLD360 are estimated to be 70% of the actual cloud-to-ground flash values.

In this study, we analyze the distribution of lightning activities over Nepal and compare the association of lightning fatalities with the altitude and population density.

III. LIGHTNING DATA AND FATALITY INFORMATION

A. Occurrence of Lightning

Lightning activity over Nepal has been continuously monitored in recent years by the Global Lightning Dataset GLD360 network that is owned and operated by Vaisala, Inc. [7]. Figure 2 shows the spatial distribution of nearly 3 million strokes per year for Nepal and adjacent regions. The location accuracy of GLD360 during the three years of the map in Fig. 2 is about 3 km. The detection efficiency of cloud-to-ground flashes is about 70% for this region and time period.

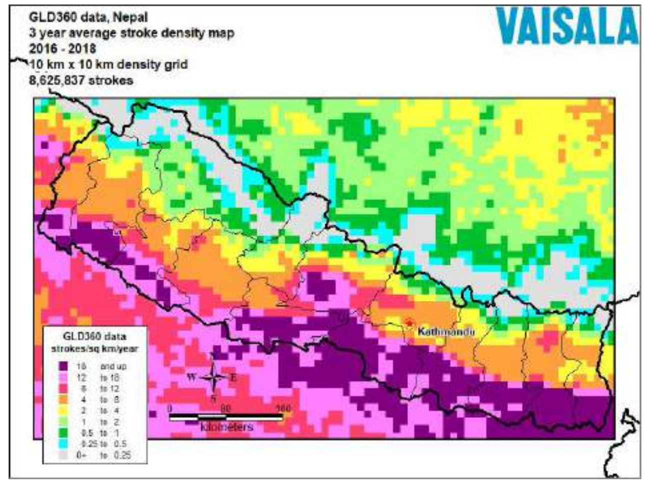

Figure 2. Average annual lightning stroke density over Nepal and adjacent regions at 10×10 km resolution from Vaisala's Global Lightning Dataset GLD360 network from 2016-2018. A total of 8,625,837 strokes were detected in the three years.

Fig. 2 shows that the southern border of all of Nepal receives more lightning than elsewhere in the region. In particular, the southeastern plains region of Nepal receives the most lightning strokes followed by the southern part of the central region over the Siwalik or Chure range. The high mountains, stretching along the northern border with China from east to west, have considerably fewer lightning strokes.

The maximum at the base of the high mountains is attributable to the major elevation change that faces the influx of low-level moisture from the south during the pre-monsoon and monsoon seasons. This maximum has been observed to occur over all the Indian Subcontinent [8]. To the north of the band of maximum lightning, the frequency reduces quickly as the low-level moisture impinging on the mountain slopes is depleted. At the highest elevations, almost no thunderstorms exist because no low-level atmospheric water vapor content is present. All three of these features are evident in Colombia [9], Venezuela, East Africa, the Andes, and Southeast Asia [10].

B. Fatalities from Lightning

Fortunately, lightning is becoming recognized as one of the major natural hazards in Nepal, claiming over 100 lives each year. Data obtained from the Disaster Risk Reduction (DRR) portal of Ministry of Home Affairs (MoHA), Nepal, show an average 108 people killed by lightning each year and 262 people injured (Fig. 3). It can be safely assumed that the data obtained from the DRR portal underestimate the true number as has been observed in many countries, including the United States. [11].

The largest number of casualties (131) was recorded in the year 2012/13 and the least number (68) in 2018/19. During the last eight years, 841 people were killed, and 2095 people injured by lightning for a fatality rate of 3.7 deaths per million people per year. This rate is higher than in many other countries [4].

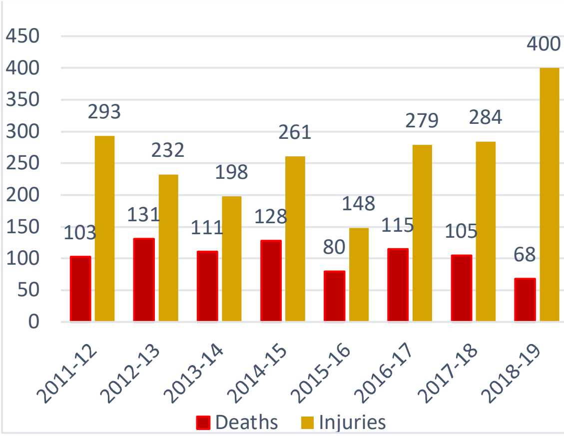

Figure 3. Annual lightning fatalities and injuries in Nepal from 2011 through 2019.

C. Population Density

Fig. 4 shows the population density over the 77 districts of Nepal according to the 2011 census. As can be seen, the southern plains districts are the most densely populated, followed by the hilly districts, with the mountainous region sparsely populated.

Fig. 5 shows the spatial distribution of lightning fatalities in Nepal. Out of 841 fatalities, 515 were reported from the hilly region, 286 fatalities from the Terai plains region, and 40 fatalities from the mountainous districts. Of these 40 fatalities, none were reported from the high mountains above 6000m. Clearly, most of the fatalities are reported from the lesser Himalayas and Siwalik hills region.

Using only the numbers for the plains (Terai) region, the fatality rate is 2.68 deaths per million people per year. However, the fatality rate for the hilly (lesser Himalayas and Siwalik) region, is 5.28 deaths per million people per year – twice that of the plains region.

IV. Discussion and Conclusions

Most of Nepal is clad with high hills and mountains. The mountainous region has both a sparse population and minimal lightning occurrence, resulting in fewer fatalities, as would be expected. The fatality rate of the middle hilly region is twice that of the southern plains region, despite the plains region having both a considerably higher population density combined with a significantly higher lightning stroke density.

There are likely two reasons for this disparity. Most people in the hilly regions live in houses with roofs thatched with hay and similar material. Such houses provide no protection against lightning [12, 13]. Further, the people living on the hills tend to make their livelihood from labor-intensive agriculture and other outdoor activities, fully exposed to thunderstorms. Combining the factors of housing and activity, these people have no or few safe areas to seek refuge and are exposed to all lightning without safe alternatives to choose.

Although there are some urban and suburban areas in the hilly region, lightning fatalities in these urbanized areas, where the houses are constructed with steel reinforcement or iron components, are negligible.

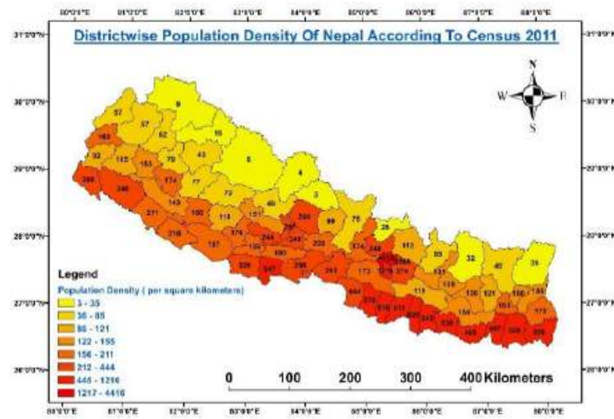

Figure 4. Population density of Nepal over all the districts using 2011 census data.

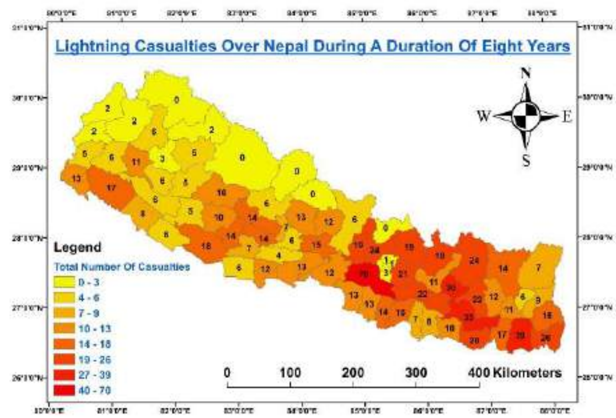

Figure 5. Spatial distribution of lightning fatalities over the 77 districts of Nepal.

Clearly, there is an acute need for the development of effective, inexpensive lightning protection systems to be installed for each house, particularly in the hilly region [12, 13]. Additionally, extensive lightning awareness-raising and safety programs should be conducted throughout the hilly regions.

Acknowledgments

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Chapter 17
Basic Principles of Lightning Protection

17.1 Function of a Lightning Conductor

A lightning conductor is a device invented by Benjamin Franklin to protect buildings from lightning strikes. It provides a low-resistance path for the lightning current to flow to the ground, preventing any damage that would have resulted if the lightning current had passed through the building to the ground. Let us now consider how a lightning conductor acts during a lightning strike.

As described in previous chapters, when the lower end of a stepped leader is roughly 100–200 m from the Earth, connecting leaders are likely to initiate at protruding earthed objects and to propagate toward the tip of the stepped leader channel. Several connecting leaders may start from different objects or from different protrusions on the same object. Usually only one of these connecting leaders reaches the stepped leader and the protrusion or the object that sent up the successful connecting leader receives the current in the lightning flash. However, the lightning conductor, being located at the highest point of the structure, will be the first object on the structure to be affected by the electric field of the stepped leader and, hence, the first object on the structure to launch a connecting leader. Because of this lead, it is usually the lightning conductor that succeeds in making a connection with the downward moving stepped leader and receives the current in the lightning flash. Thus, the function of a lightning conductor is to divert to itself a lightning discharge that might otherwise strike a vulnerable part of the structure requiring protection and to safely conduct the current in the lightning flash to the ground.

Benjamin Franklin assumed that a lightning conductor functioned by generating a positive corona charge from its tip that will flow into the cloud and neutralizes the negative charge. For this reason, the tips of lightning conductors were made sharp to promote the generation of corona currents. However, today we know that this concept does not work because the charge generated by such corona currents is very small in comparison to the charge in the cloud. But as we will discuss later, this

V. Cooray, *An Introduction to Lightning*,
DOI 10.1007/978-94-017-8938-7_17

same discarded concept is being used by some lightning protection system manufacturers to create and commercialize lightning protection systems.

Recent research has shown that when allowed to compete with each other, lightning rods with moderately blunt tips perform better than rods with sharp tips.

17.2 Attractive Range of a Lightning Conductor – Electro-Geometrical Method

The electro-geometrical method (EGM) is a simple procedure used by lightning protection engineers to evaluate the attractive range of a lightning conductor [1]. Let us first examine the basic assumptions of this method.

Two basic assumptions are made in EGM. The first assumption is that in evaluating a lightning attachment to structures one can neglect the effect of connecting leaders. Since connecting leaders are an integral part of lightning attachment, this assumption is not justified. However, the length of the connecting leader depends on the height of the structure. It increases with increasing structure height. This assumption is therefore justified only in the case of short structures where the influence of the connecting leader on the lightning attachment is slight. With increasing structure height the effect of connecting leaders on lightning attachment increases, and one would expect the results obtained from EGM to deviate from reality. The second assumption is that a stepped leader is attracted to a grounded structure when it reaches a critical distance from the grounded structure. This critical distance is called the *striking distance*. It can be described as the distance of the field of vision of the stepped leader. If the distance from a grounded structure to the stepped leader is larger than the striking distance, then the stepped leader is not aware of the grounded structure. The reason for this assumption in EGM is as follows. As the distance between a grounded structure and the tip of the stepped leader decreases, the average electric field in the space between the grounded structure and the tip of the stepped leader increases. When this average electric field reaches a critical value, the positive streamers (in the case of a negative stepped leader, of course) generated from the extremity of the structure will be able to propagate in the space between the structure and the stepped leader connecting the stepped leader to the grounded structure. When the electric field that exists between the stepped leader and the grounded structure reaches this critical value, the attachment process is said to have reached the final jump condition. Once the final jump condition is established beween a point on the structure and the stepped leader the attachment of the lightning flash to that point is imminent. As we saw in Chap. 2, the background electric field necessary for the propagation of positive streamers is approximately 5×10^5 V/m. Therefore, when the final jump condition is reached, the average electric field between the grounded structure and the stepped leader is equal to the aforementioned value. From another point of view,

the average electric field between the stepped leader and the ground is given by V/d, where V is the potential of the tip of the stepped leader (in volts) and d (in meters) is the separation between the structure and the tip of the stepped leader. Thus, the striking distance S is given by

$$S = V/5 \times 10^5. \tag{17.1}$$

Observe that the electric field in the space between the stepped leader and the grounded structure is determined by the charge on the stepped leader. Of course with increasing V the charge on the stepped leader increases. Thus, the greater the charge, the larger the striking distance (i.e., the distance over which the final jump condition is reached). The charge on the leader channel is related to the peak current of the prospective return stroke: as the charge on the leader channel increases, the peak return stroke current increases. Thus, a larger charge corresponds to a larger return stroke current. Consequently, the striking distance of the stepped leader increases with increasing prospective return stroke peak current. The same conclusion was arrived at by analyzing the potential of the stepped leader in Chap. 14. In lightning protection standards it is assumed that the striking distance, S (given in meters), is related to the prospective peak return stroke current (i.e., the return stroke generated by the given stepped leader), I_p (given in kA), by the equation [1]

$$S = 10I_p^{0.65}. \tag{17.2}$$

This equation is based on the voltages necessary for the breakdown of long gaps in the laboratory. Recall that in Chap. 14, the striking distance was estimated as a function of the first return stroke peak current by plugging in an expression for the potential of the stepped leader as a function of return stroke peak current. The expression arrived at in Chap. 14 is

$$S = 11.7 + 3.14I_p - 0.656 \times 10^{-2}I_p^2. \tag{17.3}$$

Figure 17.1 depicts these two functions. Note that from 3 to 30 kA the difference between the two curves is less than 10 %. The difference increases to approximately 25 % at 100 kA.

Once the striking distance is known as a function of return stroke peak current, it is possible to evaluate how a lightning conductor will function. Let us consider a lightning conductor of height h. We will also consider the approach of a stepped leader, with a prospective return stroke current of I_p having a striking distance of S, toward the ground in the vicinity of this lightning conductor. For simplicity, we assume that the path of the stepped leader is straight and vertical. In reality, the direction of approach of the stepped leader can have any angle. Now, the downward moving leader has two options. It can strike either the lightning conductor or the ground. At any given moment in time the tip of the stepped leader is at a certain distance from the rod, say S_r, and a

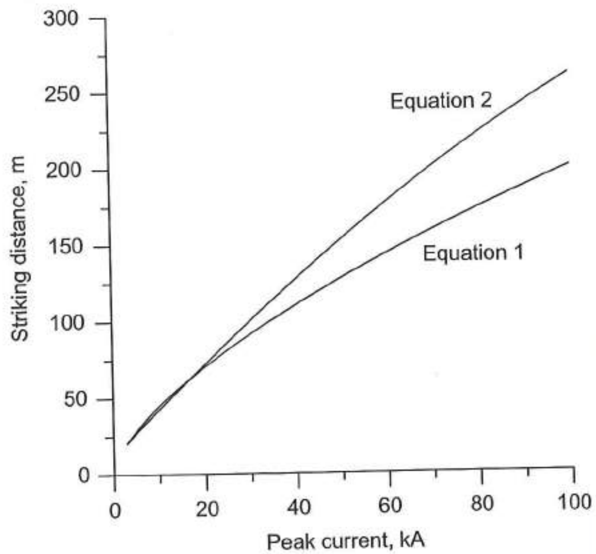


Fig. 17.1 Striking distance as given by Eqs. 17.2 and 17.3 (Figure created by author)

certain distance from the ground, say S_g. If S_r becomes equal to S before S_g, then the stepped leader will strike the rod. If S_g becomes equal to S before S_r, then the stepped leader will go to ground. With this information in mind, let us consider what happens as the lateral distance from the lightning conductor to the stepped leader, say d, changes. The possible outcomes of this exercise are shown in Fig. 17.2. Two situations are depicted in this figure, namely, for $S < h$ and $S > h$. Recall that what is given in Fig. 17.2 is just a cross section of three-dimensional space. The flat line shows the final location of the tip of the stepped leader where it will be attracted to the ground, and the curved region shows the location of the stepped leader tip where it will be attracted to the conductor. In the case where $S < h$, the stepped leader can end on the side of the conductor, whereas when $S > h$ it is always attracted to the tip of the conductor. The maximum lateral distance from which a stepped leader is attracted to a lightning conductor is called the *attractive radius*. From the preceding analysis the attractive radius R of a lightning conductor can be derived as

$$R = \sqrt{S^2 - (S - h)^2} \quad \text{for} \quad S > h, \tag{17.4}$$

$$R = S \quad \text{for} \quad S \leq h. \tag{17.5}$$

By combining these equations with Eq. 17.2 or 17.3, one can estimate the attractive range of lightning conductors of different heights as a function of peak return stroke current.

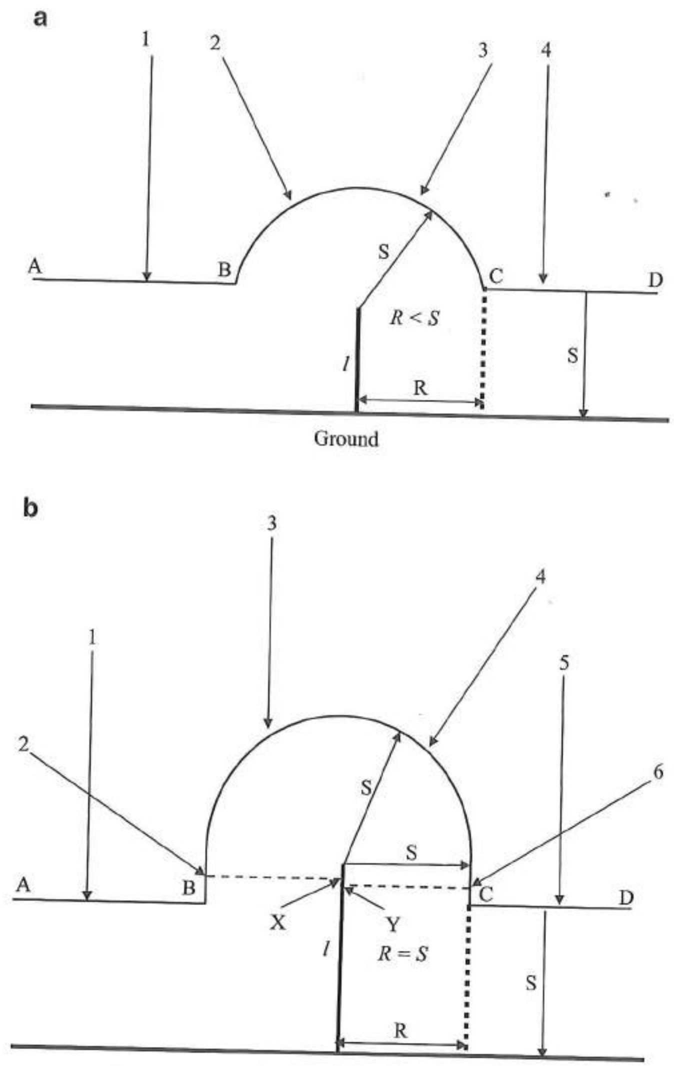


Fig. 17.2 (**a**) Cross section of three-dimensional surface describing possible outcomes in case of a stepped leader approaching ground in vicinity of a lightning conductor for the case $S > l$ where S is the striking distance and l the height of the structure or the conductor. The *straight line* sections (i.e., AB and CD) show cases where the stepped leader goes to ground, and the *curved region* shows cases where the stepped leader is attracted to the lightning conductor. If the downward moving stepped leader ends on the *straight line section*, it goes to ground. Otherwise, it ends on the conductor. The downward moving stepped leaders 1 and 4 go to ground, while stepped leaders 2 and 3 end on the conductor. In the figure, R is the attractive radius of the lightning conductor, and in this case, $R < S$ (Figure created by author). (**b**) Cross section of three-dimensional surface describing possible outcomes in case of a stepped leader approaching ground in vicinity of lightning conductor for the case $S < l$ where S is the striking distance and l the height of the structure or the conductor. The *straight line sections* (i.e., AB and CD) show cases where the stepped leader goes to ground and the *curved region* shows cases where the stepped leader is attracted to the lightning conductor. If the downward moving stepped leader ends on the *straight line section*, it goes to ground. Otherwise, it ends on the conductor. In this case, the conductor can

17.3 Estimating the Location of Lightning Conductors Using EGM – Rolling Sphere Method

The assumption that the striking distance of a downward moving stepped leader depends only on the prospective return stroke current made it possible to utilize the concept very conveniently in lightning protection. Since the EGM striking distance depends only on the return stroke current, it can be assumed that whatever the structure under consideration, the part of the structure that comes within the striking distance is the part that receives the lightning strike. Since S is constant (or assumed to be constant) for a given stepped leader (or a given prospective return stroke current), it can be assumed that there is a spherical region of radius S with the tip of the stepped leader at the center having the following property: the first structure or part of the structure that enters this spherical volume is the one to receive the lightning strike. This concept can be utilized in locating lightning conductors on a grounded structure. Since the goal of lightning protection is for a stepped leader approaching a structure from any direction to be attracted to the lightning conductors, the lightning conductors should be placed on the structure in such a way that when a sphere of radius S is rolled over the protected structure, the sphere touches only the conductors of the lightning protection system (Fig. 17.3). Once this is done, the first object that enters the sphere of vision of the stepped leader is a lightning conductor, and as a consequence, the leaders coming down in the vicinity of and over the structure will be attracted to the lightning conductor and spare the structure. This method of locating lightning conductors on a structure is called the *rolling sphere method* [1].

As is apparent from Eq. 17.1, the striking distance is a function of the prospective return stroke peak current, as is the radius of the sphere that should be rolled around the structure to determine the location of lightning conductors. So what is the radius of the sphere to be selected in lightning protection? To solve this problem, lightning protection engineers have categorized lightning protection of structures into four levels. These levels are presented in Table 17.1. If a structure is protected at Level I, then any return stroke peak current larger than 3 kA will be stopped by the lightning protection system. That is, the radius of the sphere used in designing the lightning protection system will be 20 m. If a structure is protected at level II, then any peak current larger than 5 kA will be intercepted by the lightning protection system. At level II the safety level is 10 kA and at level IV 16 kA.

Consider a structure that is protected at level IV. This does not mean that all leaders that come down over the structure having prospective return stroke currents smaller than 16 kA will strike it. Many of these stepped leaders will also be captured

Fig. 17.2 (continued) be struck below its top by a stepped leader that approaches the conductor at an angle. The stepped leaders marked 1 and 5 strike the ground, while stepped leaders 3 and 4 strike the tip of the conductor. Stepped leaders 2 and 6 strike the side of the conductor at points X and Y, respectively. In the figure, R is the attractive radius of the lightning conductor, and in this case, $R = S$ (Figure created by author)

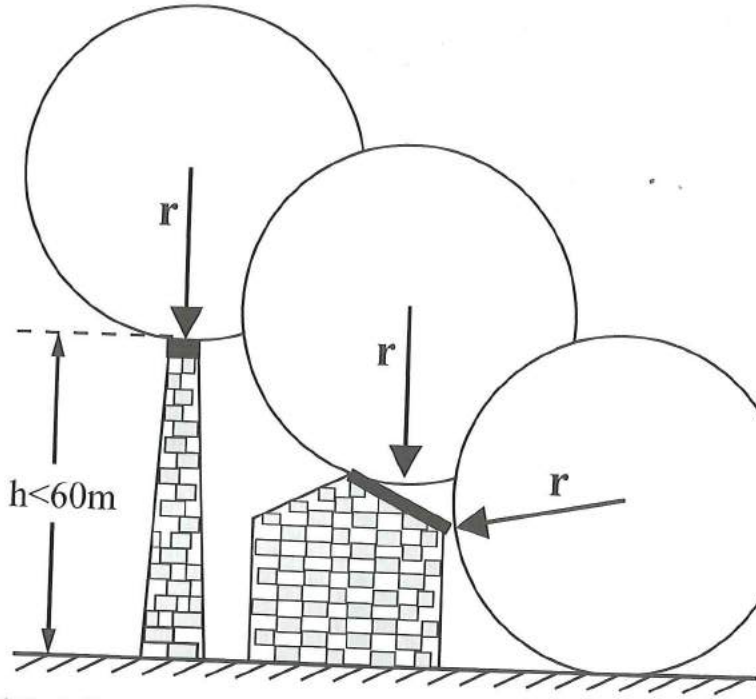


Fig. 17.3 Rolling sphere method of lightning protection. The radius of the rolling sphere that should be selected in the analysis depends on the level of protection or risk level selected. In the case of risk levels I–IV, the corresponding radii are 20, 30, 45, and 60 m, respectively. The corresponding critical currents are 3, 5, 10, and 16 kA. The lightning protection system is designed in such a way that when the sphere is rolled over the structure, it makes contact only with the lightning protection system (Adapted from [1])

Table 17.1 Minimum current allowed to penetrate the structure corresponding to different classes of the lightning protection system

Class of lightning protection system	Minimum associated current (kA)
I	3
II	5
III	10
IV	16

by the lightning protection system. For example, any stepped leader having a prospective return stroke current less than 16 kA approaching the structure within its striking distance from a lightning conductor will be intercepted by the lightning conductor (Fig. 17.4).

Observe that having a lightning protection system does not mean that the structure will not be struck by lightning. It will be struck by lightning having current peaks smaller than one associated with the level of protection. Thus, before

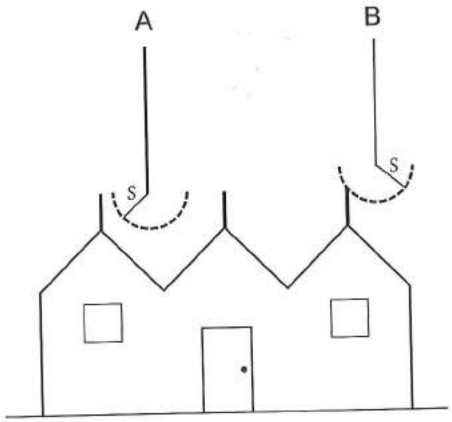


Fig. 17.4 If a structure is protected based on a certain risk level (i.e., level I, II, III, or IV) with an optimum current (e.g., level I corresponds to 3 kA), this does not mean that all stepped leaders with prospective currents less than that optimum value will strike the ground. Some of them are still captured by the lightning protection system. For example, stepped leader B is captured by the conductor, whereas stepped leader A, though it has the same prospective return stroke current (or the same rolling sphere radius), does strike the structure (Figure created by author)

installing a lightning protection system, one must have some idea of the magnitude of the peak return stroke current that the structure can safely withstand. Once this decision is made, the level of protection necessary can be selected. Observe that the higher the sensitivity of the structure (or its contents) to lightning flashes, the higher the level of protection that should be selected. Accordingly, for sensitive structures level I of lightning protection must be selected.

The lowest level of protection at which a structure is protected according to lightning protection standards is level IV. This corresponds to a striking distance of 60 m and, hence, a rolling sphere radius of 60 m. What happens when the structure is taller than 60 m? In this case the rolling sphere method indicates that the sides of the structure can be struck by lightning (Fig. 17.5). This fact was also illustrated in Fig. 17.2b. This makes it necessary to provide lightning protection at the side of the structure if the structure is taller than 60 m.

17.4 Angle of Protection

Consider a tall lightning conductor. Applying the rolling sphere method to this conductor we observe that there is a region around the conductor where stepped leaders do not penetrate. This region is identified in Fig. 17.6. The smaller the sphere radius, the smaller the protected volume. In other words, the volume of protection offered by a lightning conductor increases with increasing return stroke current. The protected region can be approximately described by a conical region,

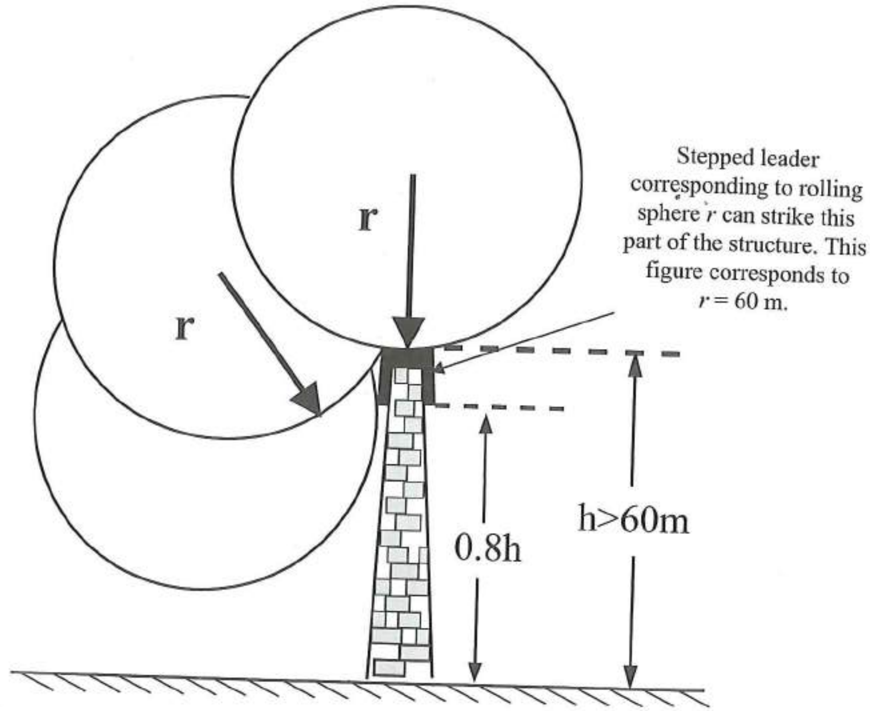


Fig. 17.5 If the structure is higher than the radius of the rolling sphere used in the design, then lightning flashes can strike the sides of the structure. The side of the structure where a lightning flash could terminate is marked by a *thick line* (Adapted from [1])

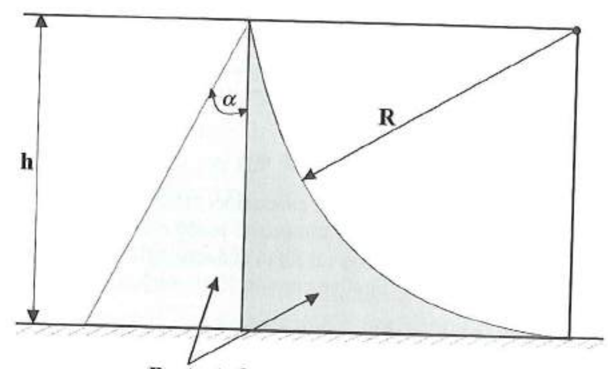


Fig. 17.6 Volume of space protected by lightning conductor. *Right side*: volume protected by conductor according to rolling sphere method; *left side*: this volume is approximated by a conical region (note that the figure is a cross section of a three-dimensional volume). The definition of the angle of protection, marked α, is based on this approximation (Figure created by author)

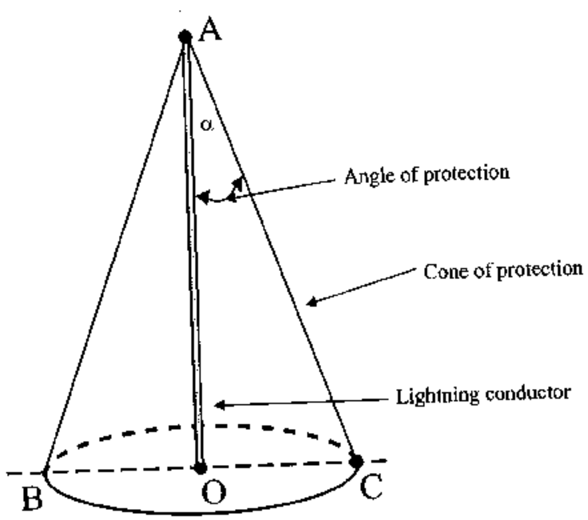


Fig. 17.7 Definition of angle of protection. The volume protected by a lightning conductor according to the angle of protection method (Adapted from [1])

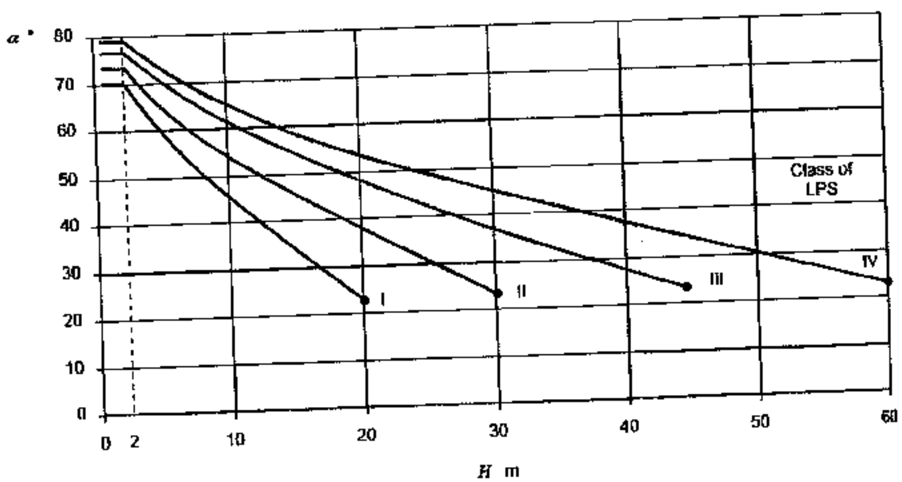


Fig. 17.8 Angle of protection corresponding to conductors of different heights and for different protection levels according to IEC lightning protection standards [1]. Note that for protection level I, the corresponding rolling sphere radius is 20 m and the angle of protection is defined only for conductors of length up to 20 m. Similar consideration applies to protection levels II–IV (Adapted from [1])

and this has come into practice as the cone of protection of the protection angle method. That is, each conductor protects a conical region around it, and the angle at the apex of the cone is called the *angle of protection* (Fig. 17.7). Naturally, the angle of protection decreases with decreasing current amplitude. Figure 17.8 shows a cone of protection corresponding to conductors of different heights.

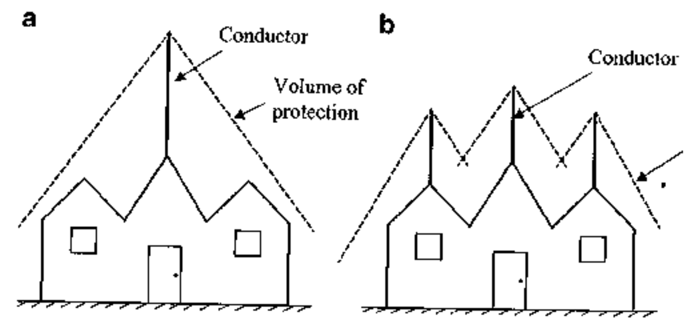


Fig. 17.9 A structure can be protected either by a tall single conductor as in (**a**) or by a large number of short conductors as in (**b**). The main idea is that the structure lies in the protection zone of the conductor(s) (Figure created by author)

The cone of protection can be used in estimating the location of lightning conductors on a structure. Thus, an extensive structure can be protected by a small number of tall conductors or a larger number of small conductors (Fig. 17.9). The idea is to set up lightning conductors in such a way that the cumulative effect of the cone of protection of all the conductors covers the structure completely, providing it with protection from lightning flashes.

17.5 Volume of Protection Provided by Horizontal and Vertical Conductors

The protection volume offered by a horizontal conductor located at a height h from the ground can be calculated using either the rolling sphere method or the protection angle method. The shape of this volume is shown in Fig. 17.10a. The volume of protection offered by a horizontal conductor terminated at both sides by vertical conductors is shown in Fig. 17.10b. Note again that the volume of protection depends on the peak amplitude of the return stroke current. The volume of protection offered by vertical and horizontal conductors can be used to protect grounded structures employing simple procedures. For example, as shown in Fig. 17.11a, two conductors can be erected in such a way that the structure is within the cone of protection of the conductors. As shown in Fig. 17.11b, a combination of two vertical conductors and a horizontal conductor can be applied to create a protective volume within the location of conductors. Figure 17.11c shows how three vertical conductors or towers are used to protect rockets on a launching pad.

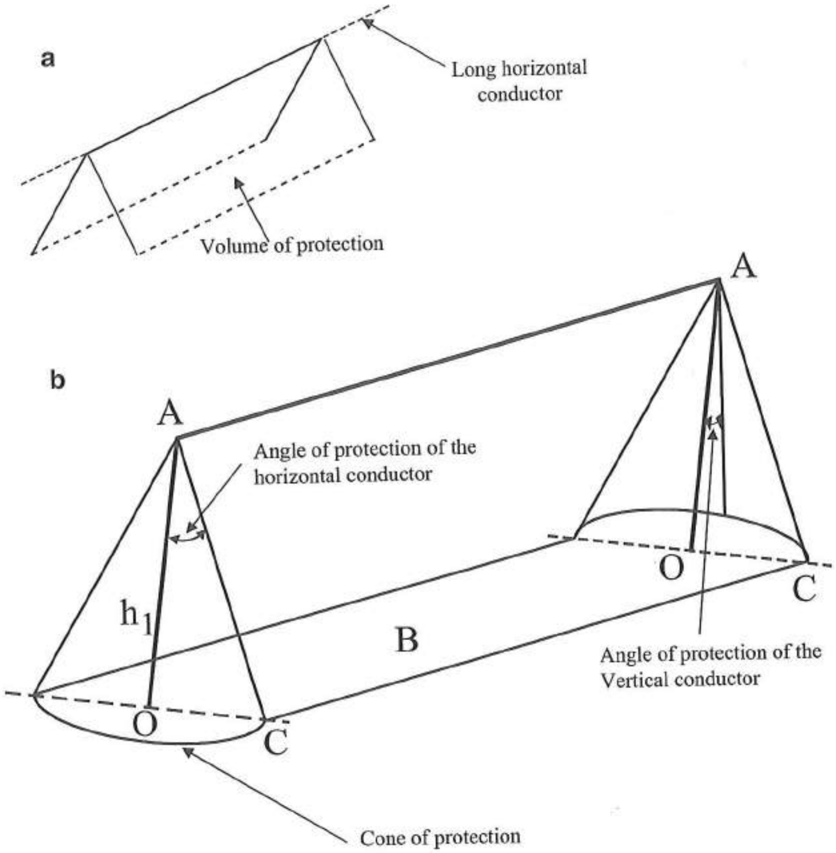


Fig. 17.10 (**a**) Volume of protection provided by a long horizontal conductor. (**b**) Volume of protection provided by a horizontal conductor terminated at both sides by a vertical conductor. This is actually the sum of the volumes protected by vertical and horizontal conductors (Adapted from [1])

17.6 Estimating the Number of Lightning Flashes Striking a Structure Over a Given Period of Time

The principles outlined previously can be used to estimate the number of lightning flashes striking a given structure over a given time interval. To estimate that, first we must know the ground flash density, the number of lightning flashes striking a unit area (usually 1 km^2) over a given period of time (usually 1 year), in the region under consideration. Let us denote this by N_g. Since the first return stroke current amplitude changes from one lightning flash to another, we should know the probability distribution $f(i_p)$ of the first return stroke currents in lightning flashes in the region under consideration. The probability distribution $f(i_p)$ is defined in such a way that $f(i_p)di_p$

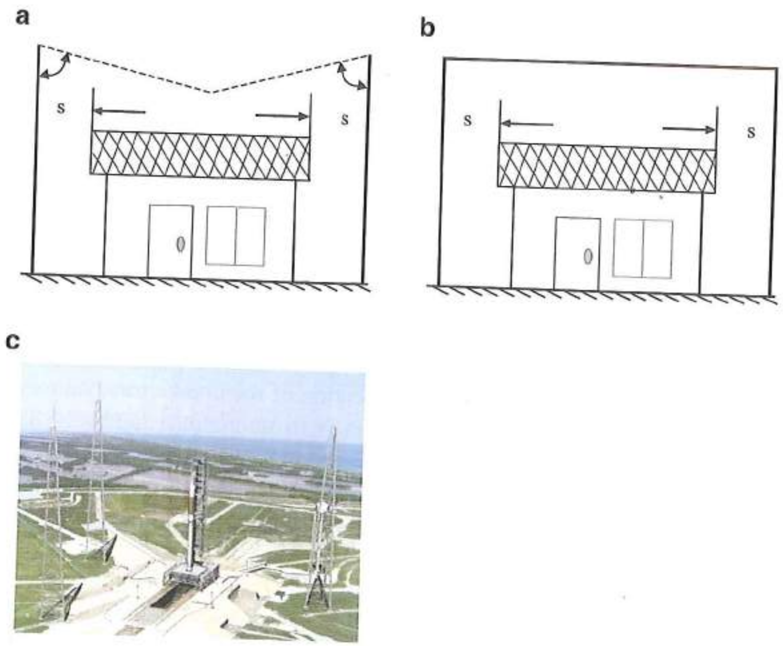


Fig. 17.11 Different methods of protecting a structure using vertical and horizontal conductors. (**a**) Placing two vertical conductors by the side of the structure so that the structure is within the cone of protection of the two conductors. Note that to avoid side flashes from the conductor, there should be a minimum critical distance (marked *s*) between the conductor and the structure. (**b**) By introducing a horizontal conductor that connects the two vertical conductors, it is possible to increase the level of protection. (**c**) A rocket in a launching pad protected by three tall masts arranged in a triangle around the launching pad (panels a and b are adapted from [1] and panel c is from http://www.nasa.gov/mission_pages/constellation/multimedia/LPS_concept.html, 2014)

gives the fraction of lightning flashes having peak current amplitudes in a range of i_p to $i_p + di_p$. Now, let the attractive area of the structure for a peak current i_p be $R(i_p)$. Thus, all lightning flashes with stepped leaders having prospective return stroke currents i_p and $i_p + di_p$ approaching the structure within a radius of $R(i_p)$ will strike the structure. Because N_g is the number of lightning flashes per unit area, $N_g f(i_p) di_p$ gives the total number of lightning flashes having current amplitudes in the range i_p and $i_p + di_p$ that occur in a unit area. Thus, in an area of $\pi R^2(i_p)$ we have $\pi R^2(i_p) N_g f(i_p) di_p$ number of lightning flashes with currents in the previously given range. They all will strike the structure because their attractive radius is equal to $R(i_p)$. Now, to estimate the total number of lightning flashes striking the structure, we must sum up the contributions from all the ranges of currents, and this can be done by integration. Thus, the total number of lightning flashes that strike the structure over a given period of time (specified in the definition of ground flash density) is

$$N = \int_0^\infty \pi R^2(i_p) N_g f(i_p) di_p. \quad (17.6)$$

Thus, knowing the ground flash density, the attractive radius of the structure as a function of return stroke peak current and the lightning current distribution makes it possible to estimate the total number of lightning flashes striking a structure over a given time.

17.7 Basic Features of External Lightning Protection System

So far we have discussed the attractive range of lightning conductors and the method used by scientists to estimate the location of the conductors. As mentioned earlier, the function of lightning conductors is to intercept a lightning flash and safely transport the lightning current to the ground so that the structure will not experience a lightning strike. The part of the lightning protection system that intercepts the lightning flashes is called the *air terminals*, and they form one unit of the external lightning protection system (Fig. 17.12). The dimensions of the air terminals should be such that they will not explode or vaporize even in the case of very large lightning currents. The correct dimensions are specified in the international lightning protection standard [1].

A lightning current intercepted by air terminals must be safely transported to the ground by the lightning protection system. The conductors that do this job are called *down conductors*. In placing down conductors, one must consider several facts. As the currents flow along these conductors, they will be raised to a high potential (depending on the self-inductance and the impedance at the point of grounding), and there should be no metal structures in the vicinity of these down conductors on which a side flash could be generated. If this is not possible in practice, then these

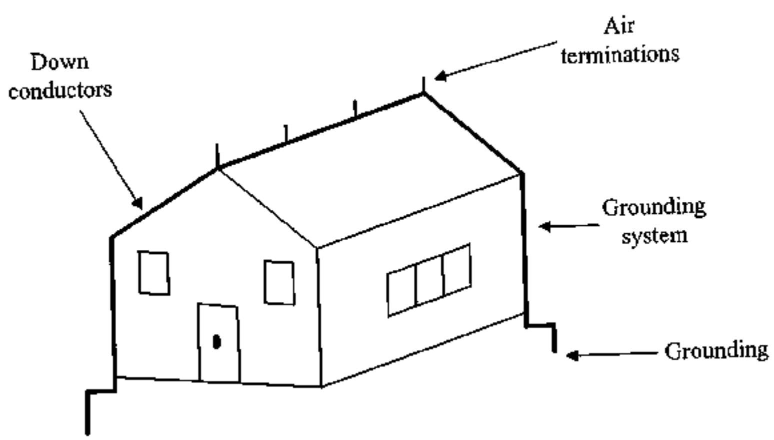
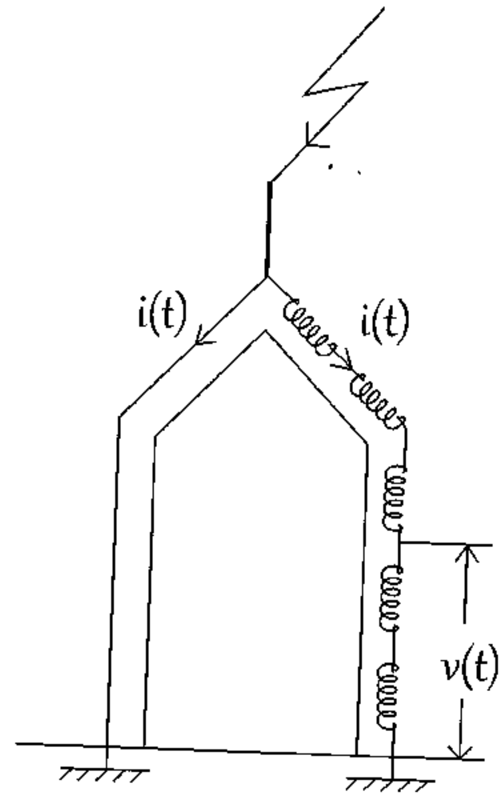


Fig. 17.12 Different parts of external lightning protection system. It consists of air termination, down conductors, and a grounding system (Figure created by author)

Fig. 17.13 During a lightning strike to a lightning conductor, even if the grounding resistance is zero, different parts of the conductor could be at different potentials because of the inductance of the conductor. For this reason, any conductors in the vicinity of down conductors should be bonded to the down conductor or the separation between them should be such that no side flashes can occur from the down conductor to the conductor connected to ground (Figure created by author)



additional conductors or metal elements must be bonded to the down conductors to make their potentials equal. This is called *potential equalization*. If the down conductors are located along reinforced concrete walls, they should be connected to the reinforcing steel at the top and the bottom of the structure so as to avoid any voltage difference between the down conductors and the reinforced steel structure. The probability of occurrence of side flashes can also be reduced by reducing the resistance or impedance at the ground end of the down conductors. But even when the ground resistance is zero, there is still a voltage difference between the top of the down conductor and its lower end because of the self-inductance of the down conductor (Fig. 17.13). Second, the current flowing along the down conductor generates a magnetic field that varies with time. The interaction of this magnetic field with any other conducting loops in the vicinity of the down conductors can generate induced voltages in these loops, disturbing or damaging any electronic equipment connected to them. Moreover, these induced voltages can generate sparks between small gaps in conductors. The down conductors should be arranged in such a way so as to minimize these unwanted voltages. This can be done by symmetrically placing the down conductors (at least two of them) around the structure to share the current and to minimize the magnetic field inside the structure. Of course, all such down conductors and the air terminals should be connected to each other. Placing several down conductors around the building also makes it possible to approximate the topology of the lightning protection system to a Faraday cage, which is an effective method of protecting the structure.

The goal of lightning protection systems is to transport lightning current safely to ground. This means the current transported down by the down conductors should dissipate safely into the ground without increasing the potential of the down conductor to high values capable of causing sparks. When grounding down conductors, attention must be paid to several important facts. First, at the point of grounding the resistance must be very small. For example, if the grounding resistance is R, then the peak voltage that develops at the grounding point is I_pR, where I_p is the peak current. For a 10-Ω grounding impedance the voltage generated by a 30-kA peak current is 300 kV. This will be the voltage to which the down conductor is raised. Different arrangements of ground conductors to reduce the grounding resistance are shown in Fig. 17.14. Another fact to take into account in grounding is the corrosion of metal parts. Ground conductors should not be made of aluminum, and if the soil is corrosive, then a corrosive protection cover in the ground rods, including part of the down conductor, must be provided.

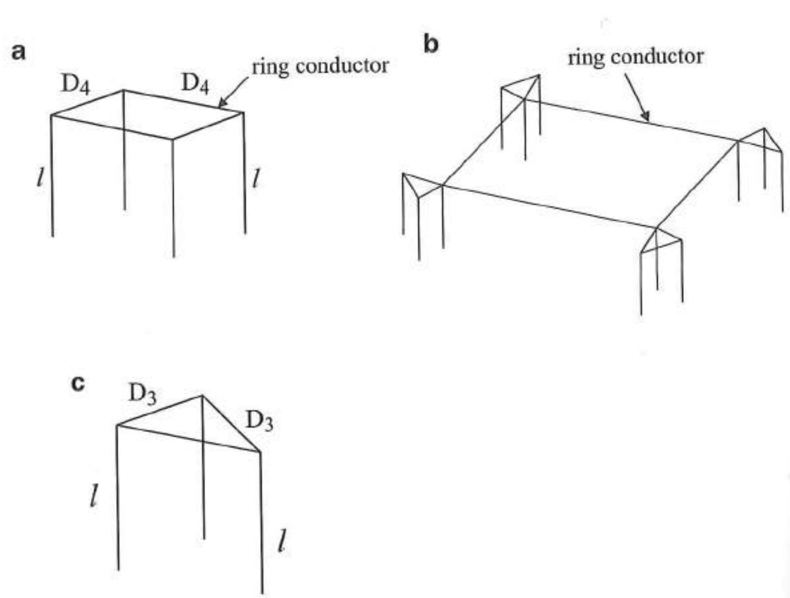


Fig. 17.14 To reduce the ground resistance, grounding rods of the grounding system should extend vertically to a depth of 3 m. Different arrangements of grounding rods as recommended by IEC are shown in the diagram [1]. (**a**) This arrangement could be used as a grounding system of a small metallic shelter (D4: sides of shelter). (**b**) Grounding system including ring conductor and triangular prismatic arrangement of vertical ground conductors. (**c**) Prismatic arrangement of vertical ground conductors

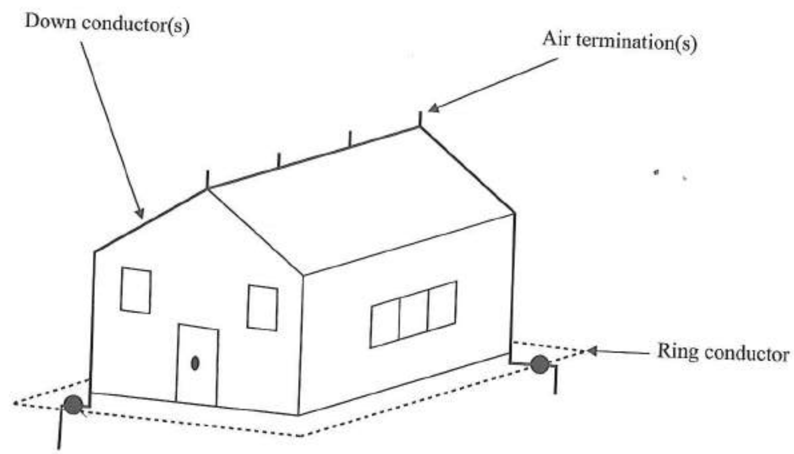


Fig. 17.15 The ring conductor can reduce the large potential differences that may occur at different points on the ground located inside it during lightning strikes. The ring conductor should be bonded to the down conductors (Figure created by author)

As a current enters the ground along the ground conductors, the current flow into the ground creates a potential difference at different points on the ground, and this can cause injuries because of step potentials during lightning strikes (Chap. 16). To reduce such voltages, a ring conductor that connects to all the down conductors is placed around the structure (Fig. 17.15). Such a conductor reduces the differences in potential at different points on the ground and reduce the strength of the step potentials.

17.8 Mesh Protection Method

As the preceding discussion makes clear, a lightning protection system cannot completely remove the lightning strikes to a structure. Lightning flashes with small currents could penetrate the structure by bypassing the lightning system. However, there might be structures where even a small lightning current could cause severe consequences, for example, structures storing ammunition and flammable liquids. On the other hand, according to the Faraday cage principle, if a current is injected into a closed metal container, the current will flow only along the outer surface of the container and no current will penetrate into the inner space. Thus, in principle, by enclosing a structure with a metal screen one can completely remove the lightning strikes to the structure. Obviously, this cannot be done in practice, but a derivative of this concept exists as a lightning protection method. It is called the *mesh method of lightning protection*. The idea is to cover part of the structure by a metal mesh. Usually, this method is used to protect large flat areas of a roof. The idea is to place a metal mesh at the top of the structure, instead of lightning conductors, and connect the mesh to ground using down conductors. In this method, the selection of the mesh size is done using a principle identical to the one used in evaluating the separation between lightning terminations. The current that is allowed to creep into the structure across the mesh is given by the same level of protection as was given earlier. The lower the amplitude of the currents allowed to strike the structure, the smaller the dimension of the cells of the mesh (Fig. 17.16). Reducing the size of the cells of the mesh makes it possible in principle to reduce the number of lightning flashes striking the structure to insignificant levels. The mesh can also be used to protect the sides of a tall structure where lightning flashes are expected to terminate (Fig. 17.17).

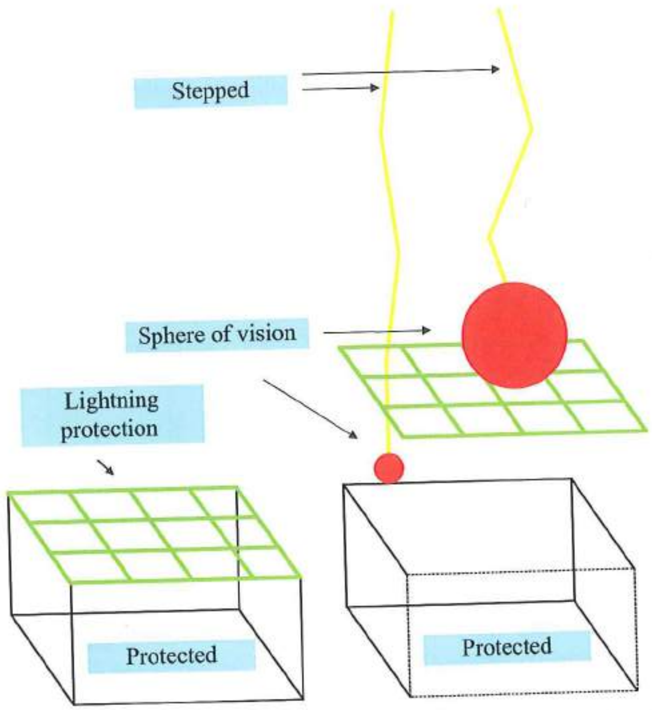


Fig. 17.16 Mesh method of lightning protection. One can visualize that at the tip of each stepped leader is a sphere of vision. The radius of the sphere of vision is equal to the radius of the corresponding rolling sphere. The stepped leader becomes attached to the first object that comes into the sphere of vision. The idea of the mesh method is to remove or filter out stepped leaders having a sphere of vision (or rolling sphere) larger than a certain radius. Since this radius is related to the peak current of the prospective return stroke, the idea is to filter out return strokes having peak currents larger than a certain critical value. For example, a mesh designed for lightning protection level (risk level) I filters out peak return stroke currents larger than 3 kA. Stepped leaders with prospective peak currents smaller than this critical value can penetrate through the mesh and strike the structure (Figure created by author)

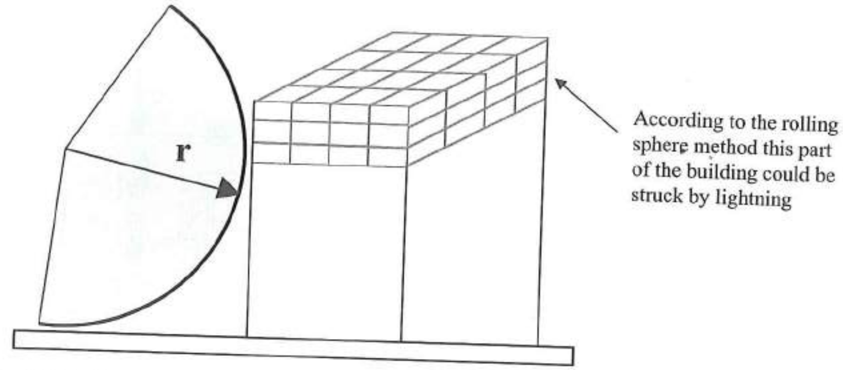


Fig. 17.17 The mesh method can be used to protect the sides of a structure. The mesh can be used not only to protect the roof but also sides of the tall building that might be struck by lightning. The height of the building is greater than the radius of the rolling sphere (Adapted from [1])

Table 17.2 Mesh sizes corresponding to different classes of the lightning protection system

Class of lightning protection system	Mesh size (m × m)
I	5 × 5
II	10 × 10
III	15 × 15
IV	20 × 20

Like the lightning protection using the rolling sphere method, the protection offered by the mesh method is divided into several levels. The mesh sizes corresponding to different levels of protection are given in Table 17.2. In practice, small air terminations are provided on the mesh to intercept lightning flashes.

Consider a stepped leader associated with a given rolling sphere radius. Figure 17.18 illustrates the location of the sphere at the interception of the stepped leader by the conductors of the mesh. Note that the sphere can penetrate through the mesh to a certain distance. To avoid any lightning strikes to the structure resulting from this penetration of part of the sphere through the mesh, in practice, the mesh is located slightly above the ground plane.

17.9 Summary of External Lightning Protection System

The aforementioned methods of protection – rolling sphere method, protection angle method, and mesh method – are applied in the protection of houses, tents, boats, power lines, and other structures. Basically, each system consists of lightning receptors, down conductors, and a grounding system. As mentioned previously, the goal is to safely conduct the lightning current to ground.

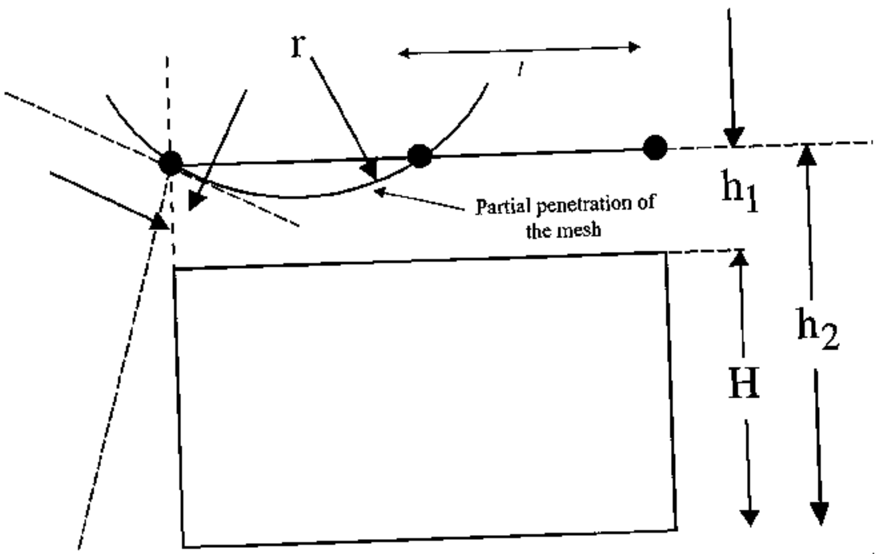


Fig. 17.18 To take into account the partial penetration of the sphere through the mesh, in practice the mesh is located slightly above the roof that is to be protected. In the diagram, the mesh is located at a height of h_1 from the roof. Note also that in the diagram, the parameter l is the size of the sides of the squares in the mesh (Adapted from [1])

17.10 Internal Lightning Protection System

It is important to understand that in any structure those belonging to the lightning protection system are not the only metal conductors crisscrossing different parts of the structure. A typical structure contains conductors belonging to a power system, telecommunications system, gas supply system, and water and drainage system. In the case of a lightning strike, all conductors belonging to these systems will be raised to a high potential, and if they are not properly bonded together, then large voltage differences can arise between conductors of different systems, causing flashover from one system to another. Thus, protecting a building from the effects of lightning requires not only an external lightning protection system but also procedures to reduce the occurrence of overvoltages in different conductors inside the building and mitigate their effects. The set of procedures developed to reduce the effects of lightning inside a building is collectively called the *internal lightning protection system*.

The first step to developing such a system is to bond all the conductors entering the building to a common ground bar, which is also bonded to the external lightning protection system. This is called *potential equalization* (Fig. 17.19). In some cases, the conductors entering a building cannot be bonded to ground at the entrance to the building. Conductors bringing in power to the building are an example. Thus, during a lightning strike, large voltages may appear in these conductors with respect to the other conductors that are bonded together to ground (including the ground wire of the incoming power). Since these conductors cannot be directly

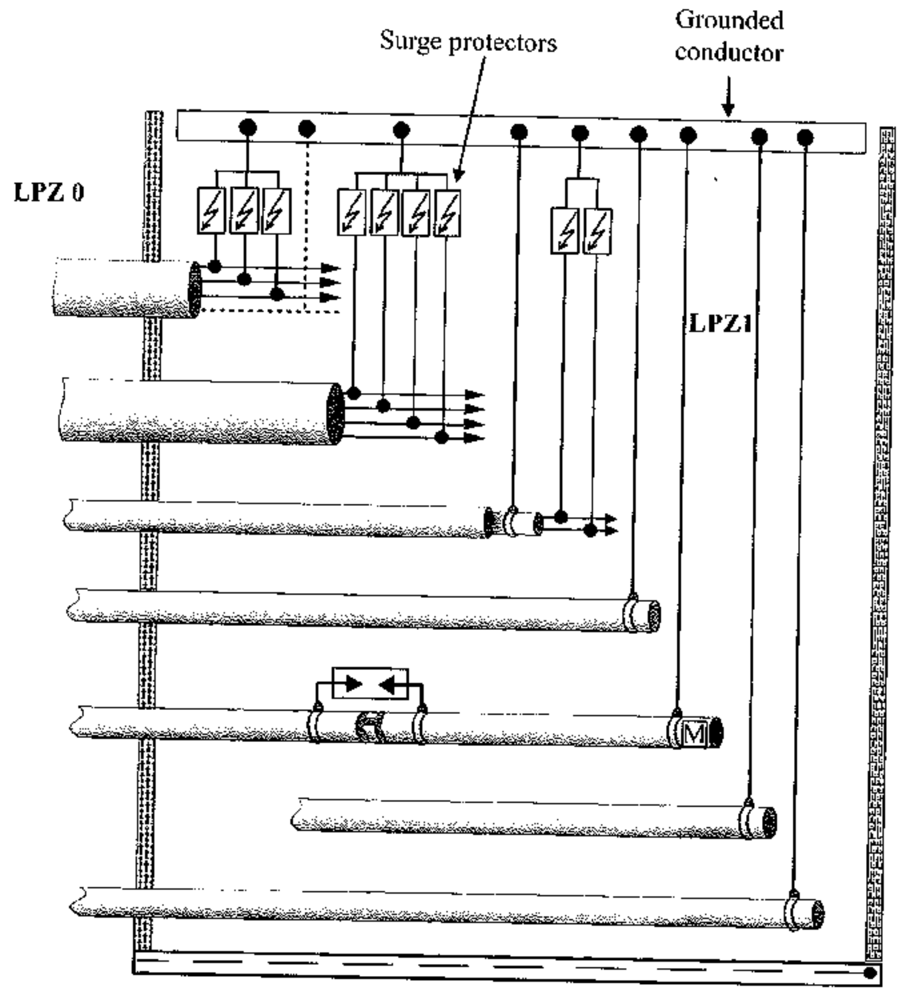


Fig. 17.19 In lightning protection practice, all conductors entering a building are connected to each other and to ground at the entrance to the building. Conductors that cannot be connected to ground directly are connected to it across surge protective devices (Figure created by author)

connected to ground, they are connected to ground across surge diverters or surge protective devices (Fig. 17.20).

17.10.1 Surge Protective Devices

A surge protective device (SPD) provides a high impedance between its terminals as long as the voltage between the terminals of the device is below a specific value. Thus, when a surge protector is connected between the phase conductor and the ground wire of an electricity supply to a building, under normal operation the

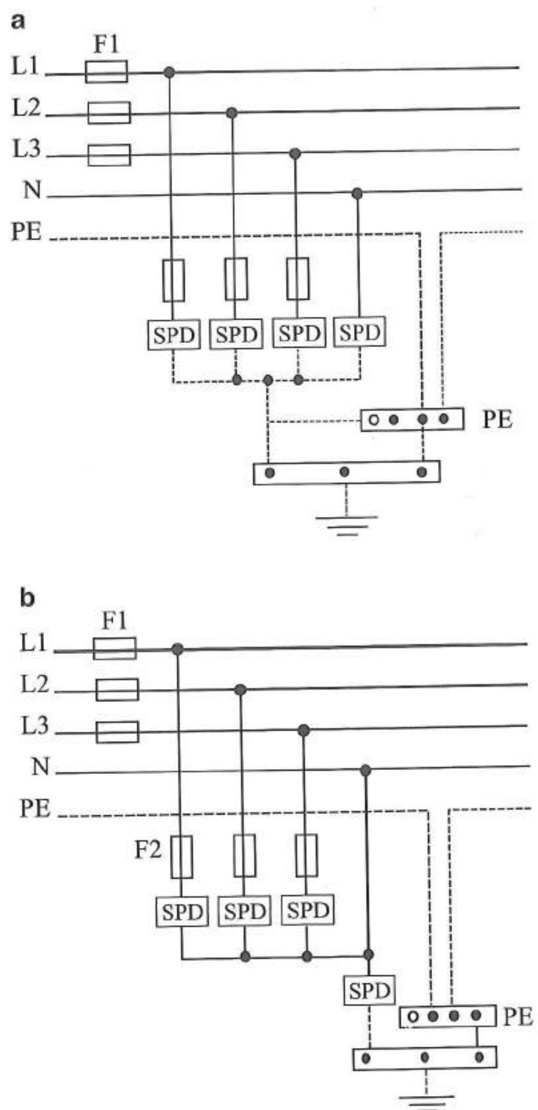


Fig. 17.20 (**a**) Conductors that cannot be connected to ground directly (such as those carrying electricity and data signals) are connected to ground across surge arresters. The figure shows an arrangement corresponding to a system with an isolated neutral conductor (Adapted from [1]). (**b**) Conductors that cannot be connected to ground directly (such as those carrying electricity and data signals) are connected to ground across surge arresters. The figure shows an arrangement corresponding to a system with neutral connected to the PE at the structure (Adapted from [1])

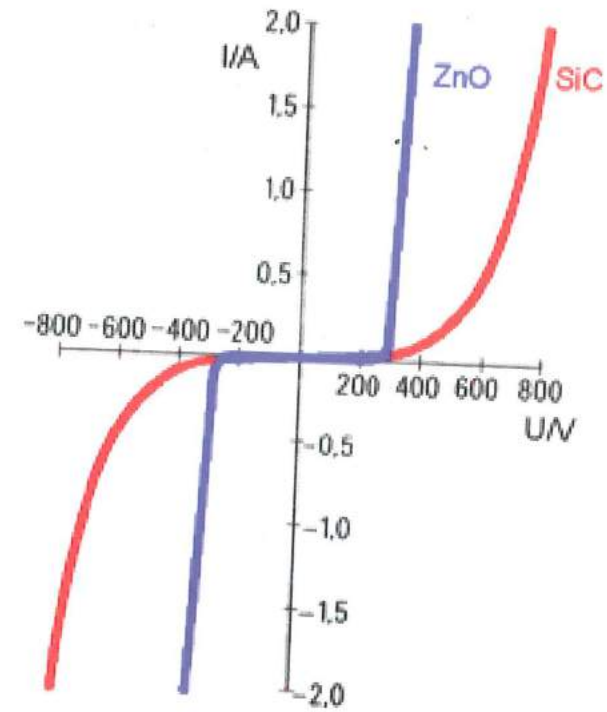


Fig. 17.21 Voltage current characteristics of a surge protective device (SPD). In the example, the V-I characteristics are shown for ZnO and SiC varistors where the nominal voltage (i.e., the voltage at which the device starts conducting) is approximately 300 V. Note that the device starts conducting when the voltage across it reaches the nominal voltage (figure from http://en.wikipedia.org/wiki/Varistor, 2014)

conductors operate as if they are not connected to each other. When the voltage between the terminals of the surge protector increases beyond the specified value or the firing voltage, the impedance reduces to a small value, creating almost a short circuit between the two terminals. Once the voltage is reduced, the impedance reverts back to the original value. Examples of SPDs are gas discharge tubes, varistors, and zener diodes. Figure 17.21 shows the voltage current characteristics of a SPD.

In an electrical power line supplying power to a building, SPDs are usually connected between the phase wires and between the phase wires and the ground (Fig. 17.20). Whenever a high voltage arises in one conductor with respect to the others, and if the amplitude of the voltage is higher than the nominal or firing voltage of the SPD, then the incoming voltage is diverted to ground when the SPD is short-circuited. In designing the internal lightning protection using a SPD it is important to have some idea of the magnitude and temporal variation of the voltages and currents entering the system so that the correct SPD can be selected for the application. The information concerning the amplitude of surges is necessary in selecting the proper nominal operating voltage of the SPD so that unwanted signals can be diverted to ground. The information concerning the temporal variation of the unwanted voltages is necessary for two reasons. First, the rapidity with which the SPD changes from a high-impedance stage to a low-impedance stage varies from one type of SPD to another. For example, if the incoming voltage has a very fast rise time, then a

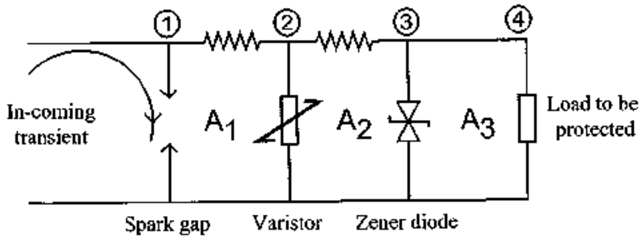


Fig. 17.22 In practice, sensitive electronics are protected by a series of surge protectors. See text for the reasons behind this arrangement (Figure created by author)

SPD that reacts very fast is necessary to divert the signal. Second, the amount of energy dissipation that can be withstood by a surge protector also varies from one type to another. The duration of the incoming voltages, together with their amplitude provides information concerning the possible energy dissipation in the SPD.

In practice, several stages of SPD are connected to reduce the unwanted voltages in a series of steps (Fig. 17.22). The first element in the series is usually a gas discharge tube. It removes a large portion of the incoming voltage. Gas discharge tubes can withstand rather high currents and therefore are suitable for this purpose. Unfortunately, the firing time of a gas discharge tube is not that short, and therefore a residual voltage is kept on moving downstream. The residual voltage that remains after the transient has passed through the gas discharge tube (voltage below the firing threshold of the gas discharge tube) is removed by a varistor. What remains after the varistor is removed by zener diodes, which are the least tolerant and most sensitive to the energy dissipation of the three types of surge protectors. In arranging the various protective elements, it is important to reduce the loop areas (marked A_1, A_2 and A_3 in Fig. 17.22) associated with various elements. During the firing of a gas discharge tube, for example, very rapid changes in currents that can cause unwanted voltages in any nearby loops are produced.

In internal lightning protection systems, SPDs are not only connected at the entrance of the structure; they are usually placed at the entrance of the power system to sensitive electronic devices. Thus, if an unwanted voltage signal were to bypass the SPD at the entrance of a building, such voltages would be removed by these SPDs protecting the sensitive electronic device.

17.10.2 Electromagnetic Zoning

General internal lightning protection can be described using the concept of zones. Assume that sensitive equipment has to be protected from unwanted voltages, currents, and electromagnetic fields. The equipment can be surrounded with several metallic shields to prevent unwanted electromagnetic fields from entering the system. However, power and other communication cables must be supplied to the equipment from outside. The procedure to do that is shown in Fig. 17.23a.

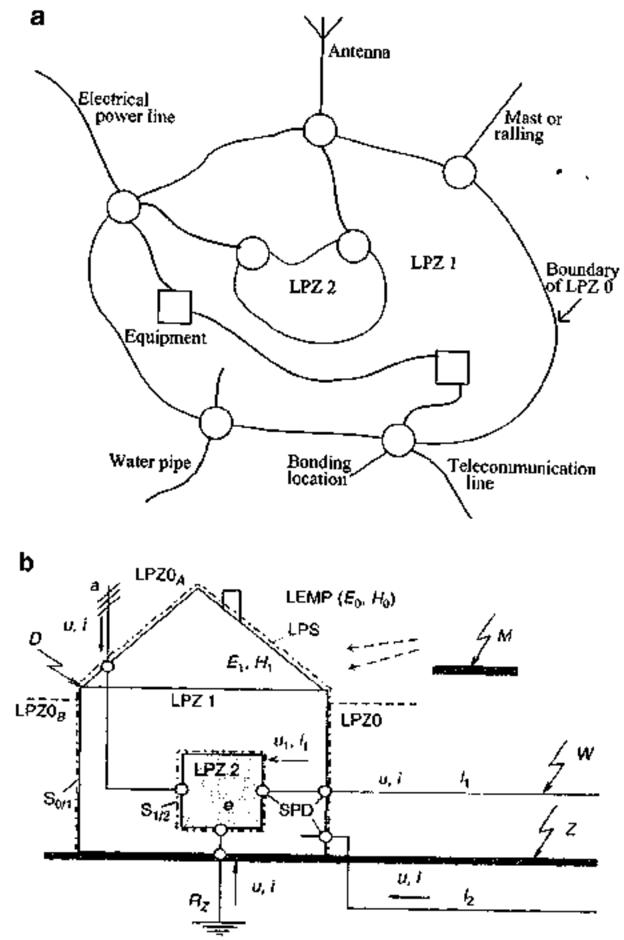


Fig. 17.23 (a) The concept of electromagnetic zoning. The idea is to screen sensitive objects with several screens that block unwanted voltages, currents, and electromagnetic fields penetrating the structure. In the method, the ground screen of any conductor penetrating through the screen is connected to the screen, and any live conductors that cannot be connected to the screen are connected to it through surge protectors (Adapted from [1]). (b) Lightning protection system of a building arranged according to the zone concept. LPZ0 is the outer zone where sources of current and voltages may directly interact with the system (i.e., a direct lightning strike). LPZ1 is the inner zone where most of the unwanted currents and voltages are removed using surge protective device (SPDs). But electromagnetic fields may exist in this region. LPZ2 is a secured zone where almost all the currents, voltages, and electromagnetic fields are removed using screens and SPDs (Adapted from [2])

Here three zones, namely, zone 0, zone 1 and zone 2 are shown. In zone 0 the direct threat of lightning current and the full exposure to the lightning generated electromagnetic fields exists. In zone 1 the impulse currents are limited by the SPD's and the electromagnetic fields are attenuated by the shield at the boundary of zone 1 and zone 0. In zone 2 the impulse currents and the electromagnetic fields are lower than in zone 1. The impulse current level and the electromagnetic fields in zone 2 can be withstood by the electrical systems in zone 2. At each entrance all the cables carrying signals are connected to the screen (at the boundary) using SPDs (shown by circles). All the screens are connected together so that they maintain the same potential. The outer screen is connected to ground. By increasing the number of screens one can drastically reduce the unwanted signals entering the equipment. Of course, in reality it may not be possible to find physical shields or screens as shown in the diagram in lightning protected buildings, but such metal shields are there in very sensitive equipment. For example, the metallic chassis of a sensitive electronic system acts as a shield. In protecting buildings from lightning, the idea is to place the conductors that divert the currents at each stage in such a way that they form an approximate shield (Fig. 17.23b). Moreover, the down conductors of the lightning protection system that represent the outer screen of the zoning procedure are placed in such a way that electromagnetic fields are reduced inside the structure.

Let us now see how a metallic screen can remove unwanted currents and electromagnetic fields.

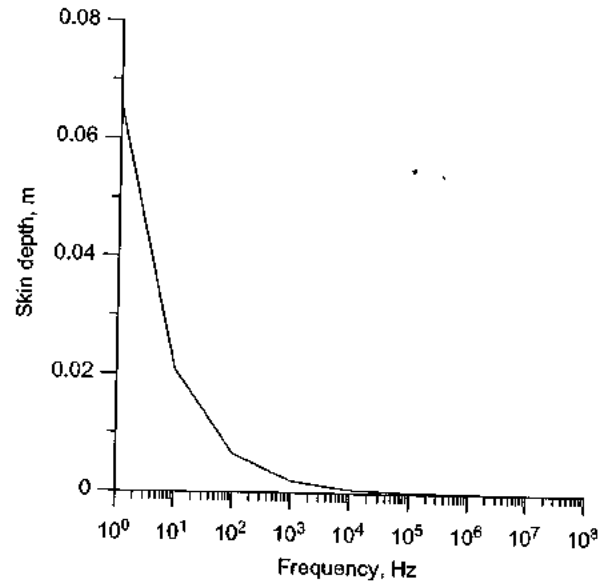
17.10.2.1 Skin Depth

Assume that an electromagnetic field with a certain frequency (i.e., a sinusoidal signal) is incident on a metallic surface. The electromagnetic field penetrates the material and generates currents in it. However, the depth to which the electromagnetic fields penetrate can be characterized by the skin depth. As the electromagnetic field penetrates the conducting medium, its amplitude decreases exponentially with depth. The skin depth is the depth where the amplitude of the electromagnetic field is reduced to one-third the value it had at the surface. The value of skin depth is given by

$$\delta = \sqrt{\frac{1}{\pi f \mu \sigma}}, \tag{17.7}$$

where f is the frequency of the electromagnetic field, μ is the magnetic permeability of the material, and σ is the conductivity. This equation is plotted for copper in Fig. 17.24. Since the frequencies of interest in lightning currents are a few kilohertz to several tens of megahertz, a few millimeters of copper screen can prevent unwanted lightning signals from appearing inside the enclosure. As is clear from the preceding equation, skin depth increases with decreasing frequency. Does that mean that extremely low-frequency signals can pass through a copper screen? The answer is no. When a time-varying electromagnetic field falls on a conducting medium, two processes take place. Part of the signal is reflected and the other part penetrates the medium. As the frequency decreases, the reflected part becomes increasingly higher, and only an increasingly smaller fraction enters the medium. When the frequency becomes zero, the entire signal is completely reflected. This is why a copper screen is effective in screening equipment from static fields.

Fig. 17.24 Skin depth of copper as function of frequency of incident electromagnetic wave (Figure created by author)



17.11 Inadequacies of EGM

In EGM it is assumed that the connection between the stepped leader and the grounded structure takes place when the stepped leader comes to within striking distance of the grounded structure (i.e., when the final jump condition is reached). But in reality, the situation is more complicated. Depending on the height of the structure, before the final jump condition is reached between the tip of the leader and the grounded structure a connecting leader is issued from it. If the structure is very short, then the connecting leader is issued when the separation between the stepped leader and the grounded structure is almost equal to the striking distance. Thus, for short structures the presence of the connecting leader can be neglected. But in the case of tall structures, a connecting leader is issued long before the separation between the stepped leader and the grounded structure approaches the striking distance. The reason for this is the larger electric field that results at the top of the structure due to field enhancement. In this case, the final connection is made not between the structure and the stepped leader but between the connecting leader and the stepped leader. Again as before it can be assumed that the connecting leader will be connected to the stepped leader when the final jump condition is reached between the tip of the connecting leader and the stepped leader. When the connection between the connecting leader and the stepped leader takes place in the presence of a long connecting leader, the tip of the stepped leader will be located at a distance much greater than that stipulated by EGM. This is illustrated in Fig. 17.25. Thus, to correctly describe the attachment process, the generation of the connecting leader and its propagation and the final connection between it and the stepped leader must be taken into account.

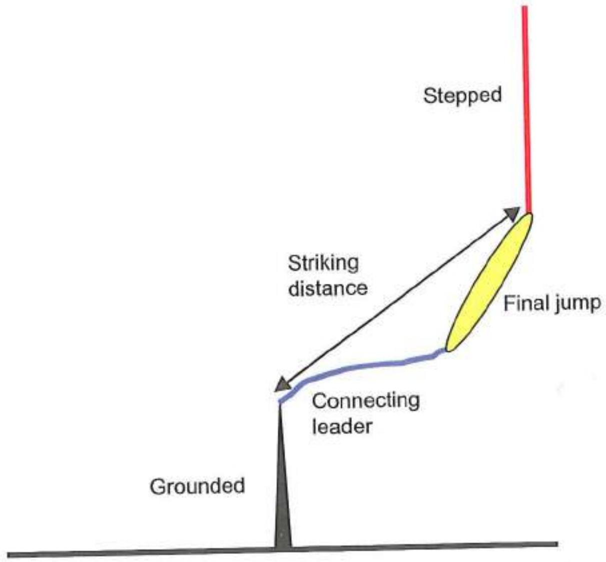


Fig. 17.25 In general, the stepped leader is met by a connecting leader issued from the lightning conductor. The striking distance in this case can be defined as the distance between the tip of the stepped leader and the point on the structure where the connecting leader is issued when the final jump condition is satisfied between the connecting leader and the stepped leader. At the final jump condition, the average electric field in the gap between the connecting leader and the stepped leader is equal to 500 kV/m (Figure created by author)

17.12 Attachment Models More Advanced Than EGM

To overcome the inadequacies of the EGM, scientists have developed several models that are capable of taking into account the presence of connecting leaders during lightning attachment. These models are described in Chap. 18.

17.13 Unconventional Lightning Protection Systems

17.13.1 *Early Streamer Emission Principle*

The analysis given in the previous section shows that tall structures have a longer attractive range because streamers and, hence, connecting leaders are generated when the leader is at a larger distance from its tip than in the case of short structures. Now, this will raise a question. Assume that by some other means, say by applying an external voltage, streamers are generated at the tip of a lightning conductor. Will these artificially created streamers give rise to a connecting leader, making the attractive range larger? All studies conducted to date, both theoretical and experimental, show that just by creating streamers at the tip of a lightning conductor it is not possible to enlarge the attractive range of a lightning conductor because the

generation of streamers is not a sufficient criterion for making a stable upward moving connecting leader (Chaps. 2 and 18). To create a successful connecting leader, the streamers must be transformed into a leader, and once initiated, the leader should be able to propagate continuously toward the stepped leader. The energy necessary for all these physical processes is supplied by the background electric field. Each of these processes requires the background electric field to be above a certain critical value for its completion. On the other hand, artificial generation of a streamer at the tip of a conductor is just a local effect. If these streamers are created when the leader is far away, they will just die out without leading to a connecting leader. If this is the case, how about artificially generating streamers from the conductor when all the conditions necessary for the streamer-to-leader transition and the leader propagation are satisfied? In principle, it should work, but the problem is that streamer inception from lightning rods takes place naturally long before the field conditions necessary for the successful launch of a connecting leader are satisfied. This means that when these conditions are satisfied, nature itself will provide the streamers necessary for the process. Nothing can be changed by artificially generating streamers at the tip of a rod.

Unfortunately, notwithstanding the theoretical and experimental data available, some vendors have introduced lightning rods where gadgetry is provided for the artificial generation of streamers at the tip of lightning rods. These are called early streamer emission (ESE) devices. It is claimed that these rods can generate connecting leaders long before a normal rod of similar height, and hence they have attractive radii longer than those of normal lightning rods. At present, there are no theoretical or experimental data to validate that claim. Of course, some laboratory experiments are cited in support of the claims of the ESE principle [3]. Indeed, it was a laboratory experiment that led to the creation of ESE devices. Analysis has shown that laboratory experiments cannot be used to simulate the lightning attachment process that takes place under natural conditions [4] because the electric fields used to expose the lightning rods in the laboratory are very different from the electric fields present under natural field conditions. In summary, neither theory nor experiment justifies the claims of ESE manufacturers. These conductors have no advantage over normal lightning conductors of similar heights.

17.13.2 *Lightning Dissipaters*

It took some time for scientists to understand how a lightning conductor works. Recall that Benjamin Franklin was of the erroneous opinion that a lightning conductor works by generating positive charges that travel upward into the charge center of a cloud and dissipating the electric charge in the cloud. In other words, he believed that a lightning conductor could dissipate the charge in a cloud, thereby preventing lightning strikes. This wrong concept is used today by manufactures of lightning dissipaters. The idea is as follows. On a tall conductor a net of sharp points is connected in the form of an umbrella. The umbrella is grounded with a ground conductor. It is claimed that the charges generated by these sharp points can

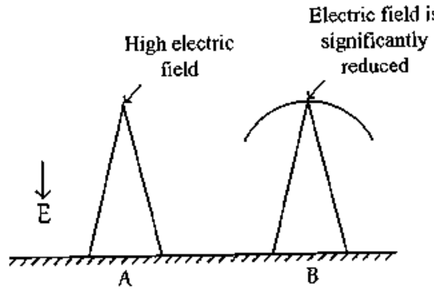


Fig. 17.26 The inception of upward initiated lightning flashes can be reduced by reducing the field enhancement at the top of the tower by placing an umbrellalike structure at the top of the tower (Figure created by author)

dissipate either the charge in a cloud or the charge in a downward moving stepped leader. These are called *dissipation arrays*. Calculations show that the charge generated by a dissipation array is not large enough to dissipate either the charge in a cloud (which is continuously formed) or the charge in a downward moving stepped leader. Indeed, there are many instances in which such dissipation arrays are struck by lightning directly. Thus, there is no truth to the manufacturers' claim that they can dissipate the charge in clouds and prevent lightning strikes. There are some instances where it was claimed that after connecting a dissipation array on a very tall tower, the number of lightning incidents were reduced. A possible reason for this observation is that, in the case of very tall structures, most lightning flashes are upward initiated. The ability of a tall tower to launch a connecting leader that culminates in an upward initiated lightning flash depends on the field enhancement at the extremity of the tower. By placing an umbrellalike structure at the top of a thin cylindrical tower, it is possible to reduce the field enhancement at the top, and this may lead to a reduction in upward initiated lightning flashes (Fig. 17.26). However, this effect has nothing to do with the creation of corona charges at the sharp points of the structure.

In summary, scientific claims of dissipation arrays have not been substantiated, either by theory or experiment, and they should not be used as part of structural lightning protection systems.

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Chapter 18 Advanced Procedures to Estimate the Point of Location of Lightning Flashes on a Grounded Structure

18.1 Introduction

The attachment of a stepped leader to a grounded structure is mediated by a connecting leader issued by the grounded structure. In the case of short structures, the length of the connecting leader is usually small, but it could be several tens of meters long in the case of tall structures. However, in the electro-geometrical method (EGM), the presence of a connecting leader is neglected (Chap. 17). Thus, the conclusions based on EGM on the attachment of stepped leaders to tall grounded structures could be in error. This simplifying assumption in EGM motivated several scientists to create lightning attachment models that included the effect of connecting leaders. Four models are used by lightning researchers at present, and this chapter presents the basic ideas associated with these models. The four models were introduced by Eriksson [1], Dellera and Garbagnati [2], Rizk [3], and Becerra and Cooray [4, 5]. These models are referred to here as the Eriksson model, the Dellera and Garbagnati model, the Rizk model, and the Becerra and Cooray model.

A physically reasonable lightning attachment model should be able to describe the generation of a connecting leader, its subsequent propagation, and the final attachment to the stepped leader. First of all, let us consider how the initiation of a connecting leader from a grounded structure is treated in the four models. Eriksson and Dellera and Garbagnati use the *critical radius concept* (described subsequently) to determine when a connecting leader is issued by a grounded structure under the influence of a downward moving stepped leader. Rizk used his own criterion, which we refer to as the *Rizk criterion*, and Becerra and Cooray used a criterion based on the known physics of electrical discharges as outlined in Chap. 2. We refer to the latter criterion as the *Becerra and Cooray* criterion for leader inception. Let us consider these criteria individually.

V. Cooray, *An Introduction to Lightning*,
DOI 10.1007/978-94-017-8938-7_18

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Chapter 17
Basic Principles of Lightning Protection

17.1 Function of a Lightning Conductor

A lightning conductor is a device invented by Benjamin Franklin to protect buildings from lightning strikes. It provides a low-resistance path for the lightning current to flow to the ground, preventing any damage that would have resulted if the lightning current had passed through the building to the ground. Let us now consider how a lightning conductor acts during a lightning strike.

As described in previous chapters, when the lower end of a stepped leader is roughly 100–200 m from the Earth, connecting leaders are likely to initiate at protruding earthed objects and to propagate toward the tip of the stepped leader channel. Several connecting leaders may start from different objects or from different protrusions on the same object. Usually only one of these connecting leaders reaches the stepped leader and the protrusion or the object that sent up the successful connecting leader receives the current in the lightning flash. However, the lightning conductor, being located at the highest point of the structure, will be the first object on the structure to be affected by the electric field of the stepped leader and, hence, the first object on the structure to launch a connecting leader. Because of this lead, it is usually the lightning conductor that succeeds in making a connection with the downward moving stepped leader and receives the current in the lightning flash. Thus, the function of a lightning conductor is to divert to itself a lightning discharge that might otherwise strike a vulnerable part of the structure requiring protection and to safely conduct the current in the lightning flash to the ground.

Benjamin Franklin assumed that a lightning conductor functioned by generating a positive corona charge from its tip that will flow into the cloud and neutralizes the negative charge. For this reason, the tips of lightning conductors were made sharp to promote the generation of corona currents. However, today we know that this concept does not work because the charge generated by such corona currents is very small in comparison to the charge in the cloud. But as we will discuss later, this

V. Cooray, *An Introduction to Lightning*,
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same discarded concept is being used by some lightning protection system manufacturers to create and commercialize lightning protection systems.

Recent research has shown that when allowed to compete with each other, lightning rods with moderately blunt tips perform better than rods with sharp tips.

17.2 Attractive Range of a Lightning Conductor – Electro-Geometrical Method

The electro-geometrical method (EGM) is a simple procedure used by lightning protection engineers to evaluate the attractive range of a lightning conductor [1]. Let us first examine the basic assumptions of this method.

Two basic assumptions are made in EGM. The first assumption is that in evaluating a lightning attachment to structures one can neglect the effect of connecting leaders. Since connecting leaders are an integral part of lightning attachment, this assumption is not justified. However, the length of the connecting leader depends on the height of the structure. It increases with increasing structure height. This assumption is therefore justified only in the case of short structures where the influence of the connecting leader on the lightning attachment is slight. With increasing structure height the effect of connecting leaders on lightning attachment increases, and one would expect the results obtained from EGM to deviate from reality. The second assumption is that a stepped leader is attracted to a grounded structure when it reaches a critical distance from the grounded structure. This critical distance is called the *striking distance*. It can be described as the distance of the field of vision of the stepped leader. If the distance from a grounded structure to the stepped leader is larger than the striking distance, then the stepped leader is not aware of the grounded structure. The reason for this assumption in EGM is as follows. As the distance between a grounded structure and the tip of the stepped leader decreases, the average electric field in the space between the grounded structure and the tip of the stepped leader increases. When this average electric field reaches a critical value, the positive streamers (in the case of a negative stepped leader, of course) generated from the extremity of the structure will be able to propagate in the space between the structure and the stepped leader connecting the stepped leader to the grounded structure. When the electric field that exists between the stepped leader and the grounded structure reaches this critical value, the attachment process is said to have reached the final jump condition. Once the final jump condition is established beween a point on the structure and the stepped leader the attachment of the lightning flash to that point is imminent. As we saw in Chap. 2, the background electric field necessary for the propagation of positive streamers is approximately 5×10^5 V/m. Therefore, when the final jump condition is reached, the average electric field between the grounded structure and the stepped leader is equal to the aforementioned value. From another point of view, the average electric field between the stepped leader and the ground is given by V/d, where V is the potential of the tip of the stepped leader (in volts) and d (in meters) is the separation between the structure and the tip of the stepped leader. Thus, the striking distance S is given by

$$S = V/5 \times 10^5. \tag{17.1}$$

Observe that the electric field in the space between the stepped leader and the grounded structure is determined by the charge on the stepped leader. Of course with increasing V the charge on the stepped leader increases. Thus, the greater the charge, the larger the striking distance (i.e., the distance over which the final jump condition is reached). The charge on the leader channel is related to the peak current of the prospective return stroke: as the charge on the leader channel increases, the peak return stroke current increases. Thus, a larger charge corresponds to a larger return stroke current. Consequently, the striking distance of the stepped leader increases with increasing prospective return stroke peak current. The same conclusion was arrived at by analyzing the potential of the stepped leader in Chap. 14. In lightning protection standards it is assumed that the striking distance, S (given in meters), is related to the prospective peak return stroke current (i.e., the return stroke generated by the given stepped leader), I_p (given in kA), by the equation [1]

$$S = 10 I_p^{0.65}. \tag{17.2}$$

This equation is based on the voltages necessary for the breakdown of long gaps in the laboratory. Recall that in Chap. 14, the striking distance was estimated as a function of the first return stroke peak current by plugging in an expression for the potential of the stepped leader as a function of return stroke peak current. The expression arrived at in Chap. 14 is

$$S = 11.7 + 3.14 I_p - 0.656 \times 10^{-2} I_p^2. \tag{17.3}$$

Figure 17.1 depicts these two functions. Note that from 3 to 30 kA the difference between the two curves is less than 10 %. The difference increases to approximately 25 % at 100 kA.

Once the striking distance is known as a function of return stroke peak current, it is possible to evaluate how a lightning conductor will function. Let us consider a lightning conductor of height h. We will also consider the approach of a stepped leader, with a prospective return stroke current of I_p having a striking distance of S, toward the ground in the vicinity of this lightning conductor. For simplicity, we assume that the path of the stepped leader is straight and vertical. In reality, the direction of approach of the stepped leader can have any angle. Now, the downward moving leader has two options. It can strike either the lightning conductor or the ground. At any given moment in time the tip of the stepped leader is at a certain distance from the rod, say S_r, and a

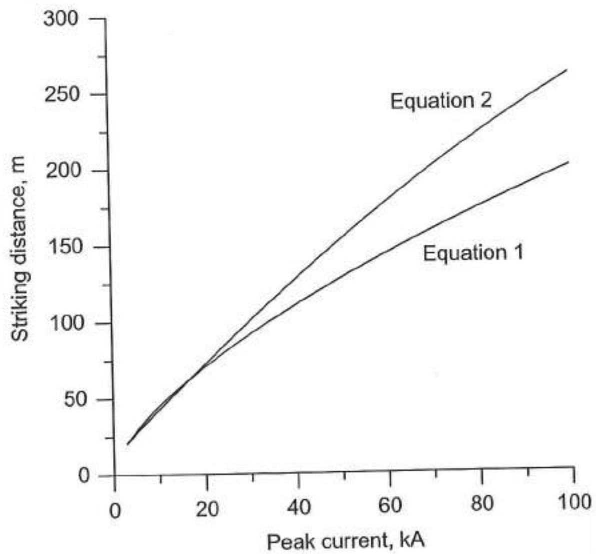


Fig. 17.1 Striking distance as given by Eqs. 17.2 and 17.3 (Figure created by author)

certain distance from the ground, say S_g. If S_r becomes equal to S before S_g, then the stepped leader will strike the rod. If S_g becomes equal to S before S_r, then the stepped leader will go to ground. With this information in mind, let us consider what happens as the lateral distance from the lightning conductor to the stepped leader, say d, changes. The possible outcomes of this exercise are shown in Fig. 17.2. Two situations are depicted in this figure, namely, for $S < h$ and $S > h$. Recall that what is given in Fig. 17.2 is just a cross section of three-dimensional space. The flat line shows the final location of the tip of the stepped leader where it will be attracted to the ground, and the curved region shows the location of the stepped leader tip where it will be attracted to the conductor. In the case where $S < h$, the stepped leader can end on the side of the conductor, whereas when $S > h$ it is always attracted to the tip of the conductor. The maximum lateral distance from which a stepped leader is attracted to a lightning conductor is called the *attractive radius*. From the preceding analysis the attractive radius R of a lightning conductor can be derived as

$$R = \sqrt{S^2 - (S - h)^2} \quad \text{for} \quad S > h, \tag{17.4}$$

$$R = S \quad \text{for} \quad S \leq h. \tag{17.5}$$

By combining these equations with Eq. 17.2 or 17.3, one can estimate the attractive range of lightning conductors of different heights as a function of peak return stroke current.

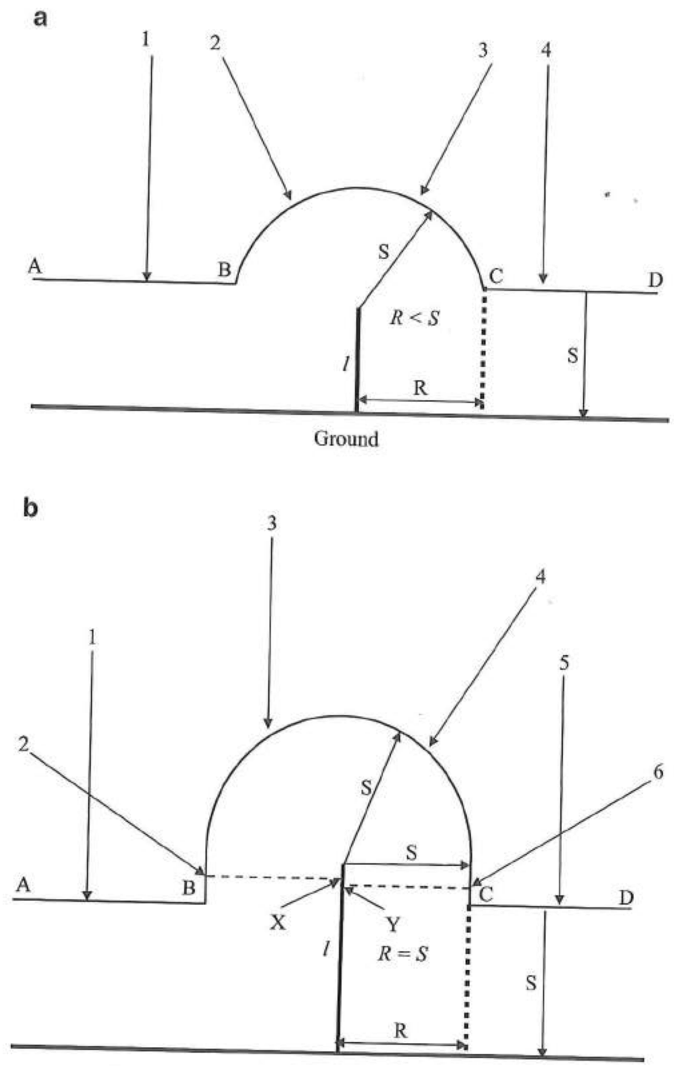


Fig. 17.2 (**a**) Cross section of three-dimensional surface describing possible outcomes in case of a stepped leader approaching ground in vicinity of a lightning conductor for the case $S > l$ where S is the striking distance and l the height of the structure or the conductor. The *straight line* sections (i.e., AB and CD) show cases where the stepped leader goes to ground, and the *curved region* shows cases where the stepped leader is attracted to the lightning conductor. If the downward moving stepped leader ends on the *straight line section*, it goes to ground. Otherwise, it ends on the conductor. The downward moving stepped leaders 1 and 4 go to ground, while stepped leaders 2 and 3 end on the conductor. In the figure, R is the attractive radius of the lightning conductor, and in this case, $R < S$ (Figure created by author). (**b**) Cross section of three-dimensional surface describing possible outcomes in case of a stepped leader approaching ground in vicinity of lightning conductor for the case $S < l$ where S is the striking distance and l the height of the structure or the conductor. The *straight line sections* (i.e., AB and CD) show cases where the stepped leader goes to ground and the *curved region* shows cases where the stepped leader is attracted to the lightning conductor. If the downward moving stepped leader ends on the *straight line section*, it goes to ground. Otherwise, it ends on the conductor. In this case, the conductor can

17.3 Estimating the Location of Lightning Conductors Using EGM – Rolling Sphere Method

The assumption that the striking distance of a downward moving stepped leader depends only on the prospective return stroke current made it possible to utilize the concept very conveniently in lightning protection. Since the EGM striking distance depends only on the return stroke current, it can be assumed that whatever the structure under consideration, the part of the structure that comes within the striking distance is the part that receives the lightning strike. Since S is constant (or assumed to be constant) for a given stepped leader (or a given prospective return stroke current), it can be assumed that there is a spherical region of radius S with the tip of the stepped leader at the center having the following property: the first structure or part of the structure that enters this spherical volume is the one to receive the lightning strike. This concept can be utilized in locating lightning conductors on a grounded structure. Since the goal of lightning protection is for a stepped leader approaching a structure from any direction to be attracted to the lightning conductors, the lightning conductors should be placed on the structure in such a way that when a sphere of radius S is rolled over the protected structure, the sphere touches only the conductors of the lightning protection system (Fig. 17.3). Once this is done, the first object that enters the sphere of vision of the stepped leader is a lightning conductor, and as a consequence, the leaders coming down in the vicinity of and over the structure will be attracted to the lightning conductor and spare the structure. This method of locating lightning conductors on a structure is called the *rolling sphere method* [1].

As is apparent from Eq. 17.1, the striking distance is a function of the prospective return stroke peak current, as is the radius of the sphere that should be rolled around the structure to determine the location of lightning conductors. So what is the radius of the sphere to be selected in lightning protection? To solve this problem, lightning protection engineers have categorized lightning protection of structures into four levels. These levels are presented in Table 17.1. If a structure is protected at Level I, then any return stroke peak current larger than 3 kA will be stopped by the lightning protection system. That is, the radius of the sphere used in designing the lightning protection system will be 20 m. If a structure is protected at level II, then any peak current larger than 5 kA will be intercepted by the lightning protection system. At level II the safety level is 10 kA and at level IV 16 kA.

Consider a structure that is protected at level IV. This does not mean that all leaders that come down over the structure having prospective return stroke currents smaller than 16 kA will strike it. Many of these stepped leaders will also be captured

Fig. 17.2 (continued) be struck below its top by a stepped leader that approaches the conductor at an angle. The stepped leaders marked 1 and 5 strike the ground, while stepped leaders 3 and 4 strike the tip of the conductor. Stepped leaders 2 and 6 strike the side of the conductor at points X and Y, respectively. In the figure, R is the attractive radius of the lightning conductor, and in this case, $R = S$ (Figure created by author)

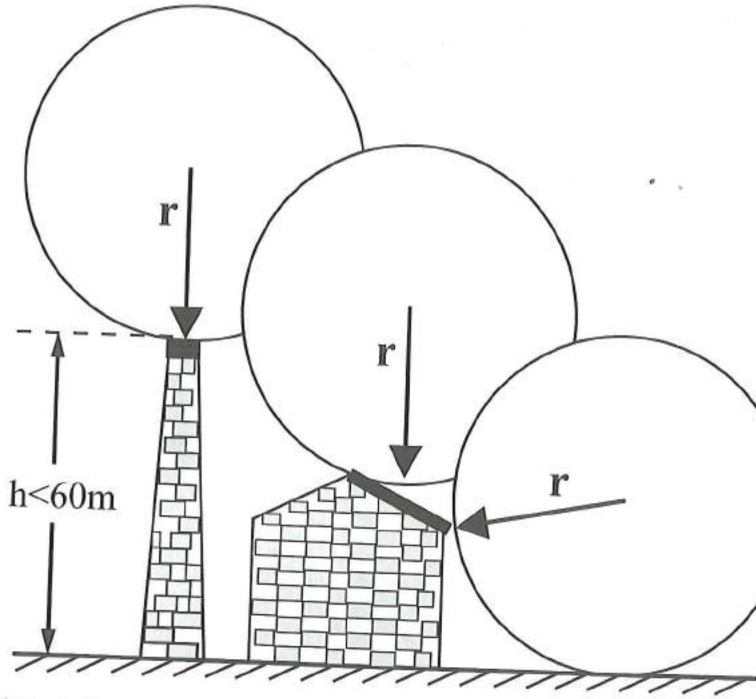


Fig. 17.3 Rolling sphere method of lightning protection. The radius of the rolling sphere that should be selected in the analysis depends on the level of protection or risk level selected. In the case of risk levels I–IV, the corresponding radii are 20, 30, 45, and 60 m, respectively. The corresponding critical currents are 3, 5, 10, and 16 kA. The lightning protection system is designed in such a way that when the sphere is rolled over the structure, it makes contact only with the lightning protection system (Adapted from [1])

Table 17.1 Minimum current allowed to penetrate the structure corresponding to different classes of the lightning protection system

Class of lightning protection system	Minimum associated current (kA)
I	3
II	5
III	10
IV	16

by the lightning protection system. For example, any stepped leader having a prospective return stroke current less than 16 kA approaching the structure within its striking distance from a lightning conductor will be intercepted by the lightning conductor (Fig. 17.4).

Observe that having a lightning protection system does not mean that the structure will not be struck by lightning. It will be struck by lightning having current peaks smaller than one associated with the level of protection. Thus, before

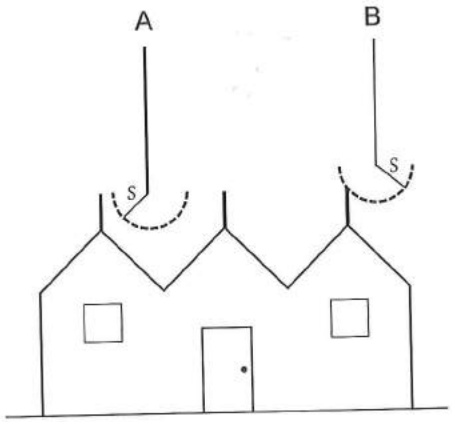


Fig. 17.4 If a structure is protected based on a certain risk level (i.e., level I, II, III, or IV) with an optimum current (e.g., level I corresponds to 3 kA), this does not mean that all stepped leaders with prospective currents less than that optimum value will strike the ground. Some of them are still captured by the lightning protection system. For example, stepped leader B is captured by the conductor, whereas stepped leader A, though it has the same prospective return stroke current (or the same rolling sphere radius), does strike the structure (Figure created by author)

installing a lightning protection system, one must have some idea of the magnitude of the peak return stroke current that the structure can safely withstand. Once this decision is made, the level of protection necessary can be selected. Observe that the higher the sensitivity of the structure (or its contents) to lightning flashes, the higher the level of protection that should be selected. Accordingly, for sensitive structures level I of lightning protection must be selected.

The lowest level of protection at which a structure is protected according to lightning protection standards is level IV. This corresponds to a striking distance of 60 m and, hence, a rolling sphere radius of 60 m. What happens when the structure is taller than 60 m? In this case the rolling sphere method indicates that the sides of the structure can be struck by lightning (Fig. 17.5). This fact was also illustrated in Fig. 17.2b. This makes it necessary to provide lightning protection at the side of the structure if the structure is taller than 60 m.

17.4 Angle of Protection

Consider a tall lightning conductor. Applying the rolling sphere method to this conductor we observe that there is a region around the conductor where stepped leaders do not penetrate. This region is identified in Fig. 17.6. The smaller the sphere radius, the smaller the protected volume. In other words, the volume of protection offered by a lightning conductor increases with increasing return stroke current. The protected region can be approximately described by a conical region,

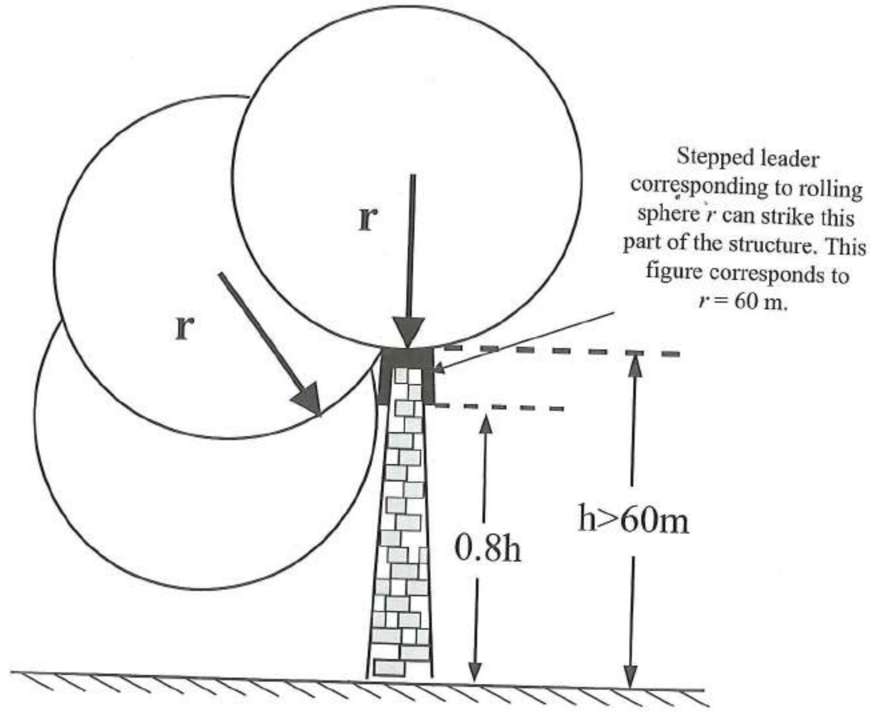


Fig. 17.5 If the structure is higher than the radius of the rolling sphere used in the design, then lightning flashes can strike the sides of the structure. The side of the structure where a lightning flash could terminate is marked by a *thick line* (Adapted from [1])

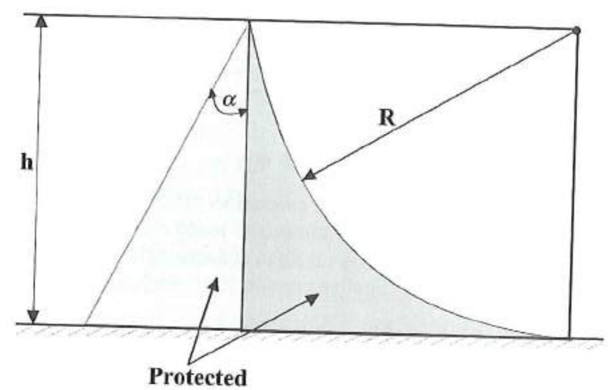


Fig. 17.6 Volume of space protected by lightning conductor. *Right side*: volume protected by conductor according to rolling sphere method; *left side*: this volume is approximated by a conical region (note that the figure is a cross section of a three-dimensional volume). The definition of the angle of protection, marked α, is based on this approximation (Figure created by author)

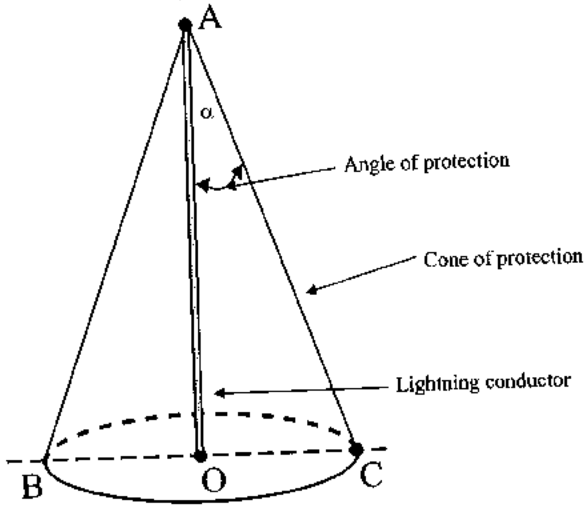


Fig. 17.7 Definition of angle of protection. The volume protected by a lightning conductor according to the angle of protection method (Adapted from [1])

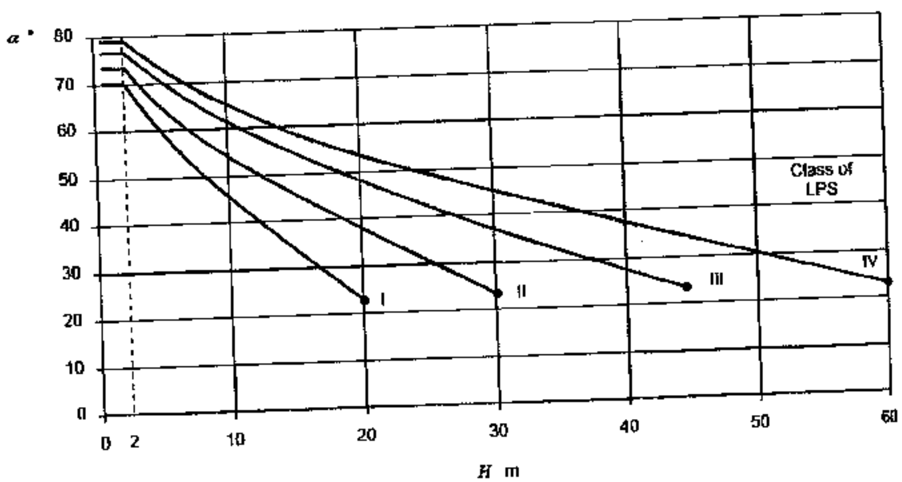


Fig. 17.8 Angle of protection corresponding to conductors of different heights and for different protection levels according to IEC lightning protection standards [1]. Note that for protection level I, the corresponding rolling sphere radius is 20 m and the angle of protection is defined only for conductors of length up to 20 m. Similar consideration applies to protection levels II–IV (Adapted from [1])

and this has come into practice as the cone of protection of the protection angle method. That is, each conductor protects a conical region around it, and the angle at the apex of the cone is called the *angle of protection* (Fig. 17.7). Naturally, the angle of protection decreases with decreasing current amplitude. Figure 17.8 shows a cone of protection corresponding to conductors of different heights.

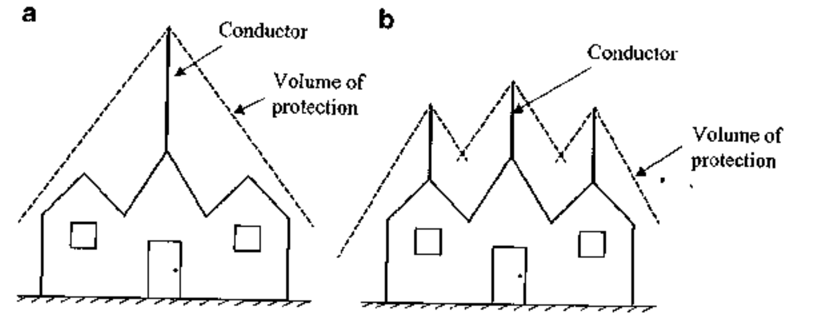


Fig. 17.9 A structure can be protected either by a tall single conductor as in (**a**) or by a large number of short conductors as in (**b**). The main idea is that the structure lies in the protection zone of the conductor(s) (Figure created by author)

The cone of protection can be used in estimating the location of lightning conductors on a structure. Thus, an extensive structure can be protected by a small number of tall conductors or a larger number of small conductors (Fig. 17.9). The idea is to set up lightning conductors in such a way that the cumulative effect of the cone of protection of all the conductors covers the structure completely, providing it with protection from lightning flashes.

17.5 Volume of Protection Provided by Horizontal and Vertical Conductors

The protection volume offered by a horizontal conductor located at a height h from the ground can be calculated using either the rolling sphere method or the protection angle method. The shape of this volume is shown in Fig. 17.10a. The volume of protection offered by a horizontal conductor terminated at both sides by vertical conductors is shown in Fig. 17.10b. Note again that the volume of protection depends on the peak amplitude of the return stroke current. The volume of protection offered by vertical and horizontal conductors can be used to protect grounded structures employing simple procedures. For example, as shown in Fig. 17.11a, two conductors can be erected in such a way that the structure is within the cone of protection of the conductors. As shown in Fig. 17.11b, a combination of two vertical conductors and a horizontal conductor can be applied to create a protective volume within the location of conductors. Figure 17.11c shows how three vertical conductors or towers are used to protect rockets on a launching pad.

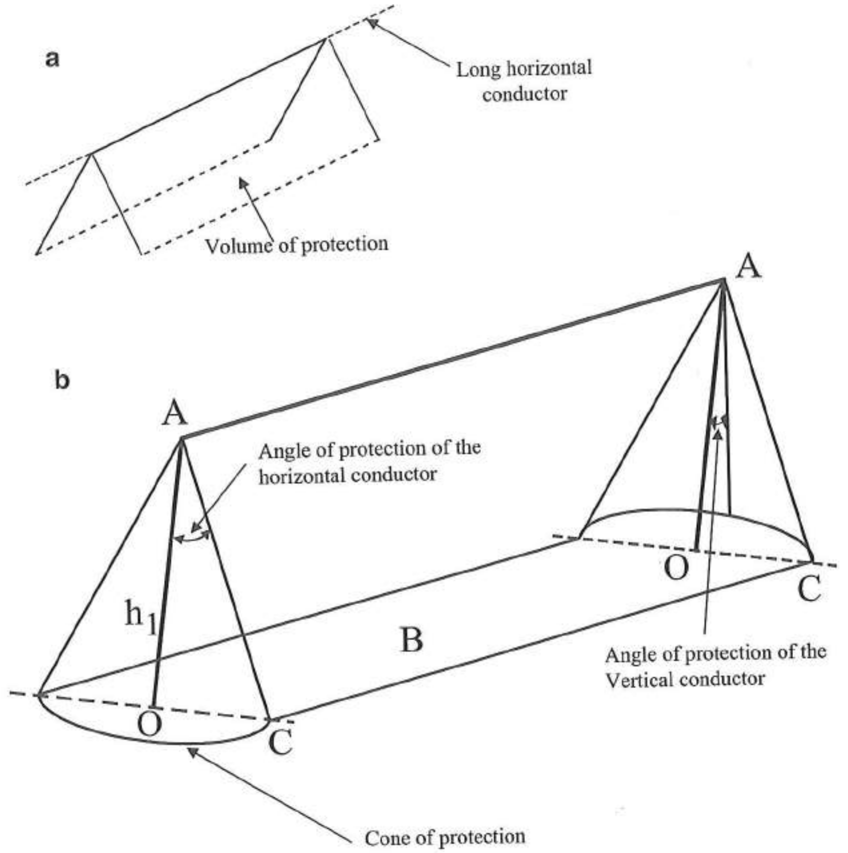


Fig. 17.10 (a) Volume of protection provided by a long horizontal conductor. (b) Volume of protection provided by a horizontal conductor terminated at both sides by a vertical conductor. This is actually the sum of the volumes protected by vertical and horizontal conductors (Adapted from [1])

17.6 Estimating the Number of Lightning Flashes Striking a Structure Over a Given Period of Time

The principles outlined previously can be used to estimate the number of lightning flashes striking a given structure over a given time interval. To estimate that, first we must know the ground flash density, the number of lightning flashes striking a unit area (usually 1 km^2) over a given period of time (usually 1 year), in the region under consideration. Let us denote this by N_g. Since the first return stroke current amplitude changes from one lightning flash to another, we should know the probability distribution $f(i_p)$ of the first return stroke currents in lightning flashes in the region under consideration. The probability distribution $f(i_p)$ is defined in such a way that $f(i_p)di_p$

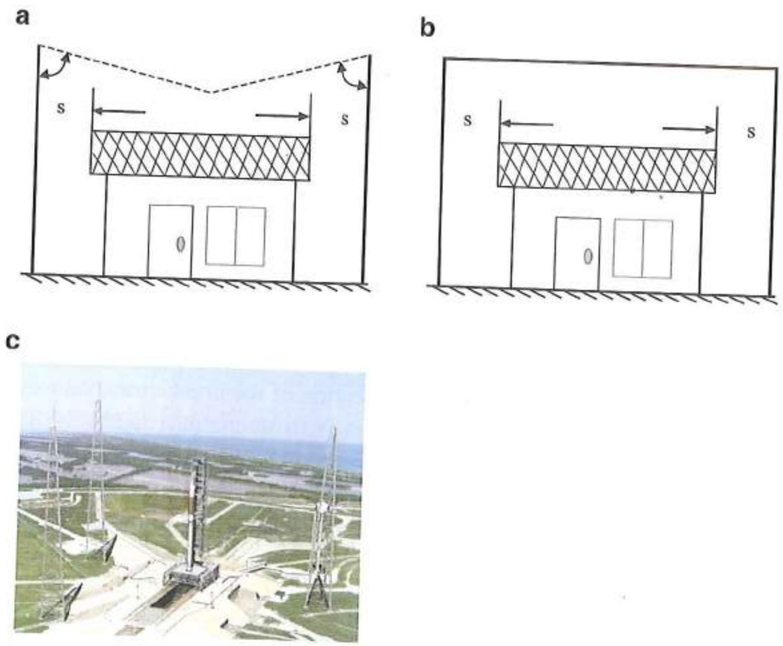


Fig. 17.11 Different methods of protecting a structure using vertical and horizontal conductors. (a) Placing two vertical conductors by the side of the structure so that the structure is within the cone of protection of the two conductors. Note that to avoid side flashes from the conductor, there should be a minimum critical distance (marked s) between the conductor and the structure. (b) By introducing a horizontal conductor that connects the two vertical conductors, it is possible to increase the level of protection. (c) A rocket in a launching pad protected by three tall masts arranged in a triangle around the launching pad (panels a and b are adapted from [1] and panel c is from http://www.nasa.gov/mission_pages/constellation/multimedia/LPS_concept.html, 2014)

gives the fraction of lightning flashes having peak current amplitudes in a range of i_p to $i_p + di_p$. Now, let the attractive area of the structure for a peak current i_p be $R(i_p)$. Thus, all lightning flashes with stepped leaders having prospective return stroke currents i_p and $i_p + di_p$ approaching the structure within a radius of $R(i_p)$ will strike the structure. Because N_g is the number of lightning flashes per unit area, $N_g f(i_p) di_p$ gives the total number of lightning flashes having current amplitudes in the range i_p and $i_p + di_p$ that occur in a unit area. Thus, in an area of $\pi R^2(i_p)$ we have $\pi R^2(i_p) N_g f(i_p) di_p$ number of lightning flashes with currents in the previously given range. They all will strike the structure because their attractive radius is equal to $R(i_p)$. Now, to estimate the total number of lightning flashes striking the structure, we must sum up the contributions from all the ranges of currents, and this can be done by integration. Thus, the total number of lightning flashes that strike the structure over a given period of time (specified in the definition of ground flash density) is

$$N = \int_0^\infty \pi R^2(i_p) N_g f(i_p) di_p. \quad (17.6)$$

Thus, knowing the ground flash density, the attractive radius of the structure as a function of return stroke peak current and the lightning current distribution makes it possible to estimate the total number of lightning flashes striking a structure over a given time.

17.7 Basic Features of External Lightning Protection System

So far we have discussed the attractive range of lightning conductors and the method used by scientists to estimate the location of the conductors. As mentioned earlier, the function of lightning conductors is to intercept a lightning flash and safely transport the lightning current to the ground so that the structure will not experience a lightning strike. The part of the lightning protection system that intercepts the lightning flashes is called the *air terminals*, and they form one unit of the external lightning protection system (Fig. 17.12). The dimensions of the air terminals should be such that they will not explode or vaporize even in the case of very large lightning currents. The correct dimensions are specified in the international lightning protection standard [1].

A lightning current intercepted by air terminals must be safely transported to the ground by the lightning protection system. The conductors that do this job are called *down conductors*. In placing down conductors, one must consider several facts. As the currents flow along these conductors, they will be raised to a high potential (depending on the self-inductance and the impedance at the point of grounding), and there should be no metal structures in the vicinity of these down conductors on which a side flash could be generated. If this is not possible in practice, then these

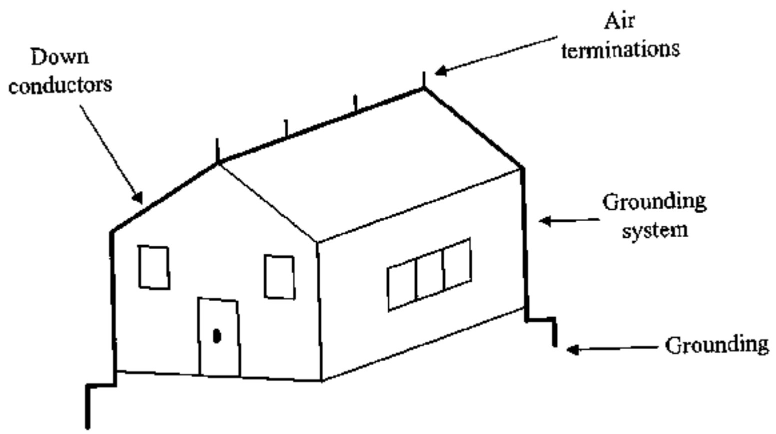
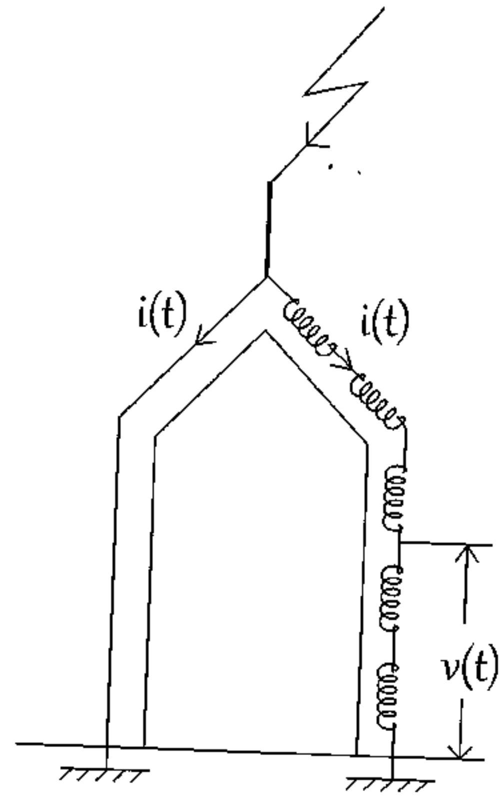


Fig. 17.12 Different parts of external lightning protection system. It consists of air terminations, down conductors, and a grounding system (Figure created by author)

Fig. 17.13 During a lightning strike to a lightning conductor, even if the grounding resistance is zero, different parts of the conductor could be at different potentials because of the inductance of the conductor. For this reason, any conductors in the vicinity of down conductors should be bonded to the down conductor or the separation between them should be such that no side flashes can occur from the down conductor to the conductor connected to ground (Figure created by author)



additional conductors or metal elements must be bonded to the down conductors to make their potentials equal. This is called *potential equalization*. If the down conductors are located along reinforced concrete walls, they should be connected to the reinforcing steel at the top and the bottom of the structure so as to avoid any voltage difference between the down conductors and the reinforced steel structure. The probability of occurrence of side flashes can also be reduced by reducing the resistance or impedance at the ground end of the down conductors. But even when the ground resistance is zero, there is still a voltage difference between the top of the down conductor and its lower end because of the self-inductance of the down conductor (Fig. 17.13). Second, the current flowing along the down conductor generates a magnetic field that varies with time. The interaction of this magnetic field with any other conducting loops in the vicinity of the down conductors can generate induced voltages in these loops, disturbing or damaging any electronic equipment connected to them. Moreover, these induced voltages can generate sparks between small gaps in conductors. The down conductors should be arranged in such a way so as to minimize these unwanted voltages. This can be done by symmetrically placing the down conductors (at least two of them) around the structure to share the current and to minimize the magnetic field inside the structure. Of course, all such down conductors and the air terminals should be connected to each other. Placing several down conductors around the building also makes it possible to approximate the topology of the lightning protection system to a Faraday cage, which is an effective method of protecting the structure.

The goal of lightning protection systems is to transport lightning current safely to ground. This means the current transported down by the down conductors should dissipate safely into the ground without increasing the potential of the down conductor to high values capable of causing sparks. When grounding down conductors, attention must be paid to several important facts. First, at the point of grounding the resistance must be very small. For example, if the grounding resistance is R, then the peak voltage that develops at the grounding point is I_pR, where I_p is the peak current. For a 10-Ω grounding impedance the voltage generated by a 30-kA peak current is 300 kV. This will be the voltage to which the down conductor is raised. Different arrangements of ground conductors to reduce the grounding resistance are shown in Fig. 17.14. Another fact to take into account in grounding is the corrosion of metal parts. Ground conductors should not be made of aluminum, and if the soil is corrosive, then a corrosive protection cover in the ground rods, including part of the down conductor, must be provided.

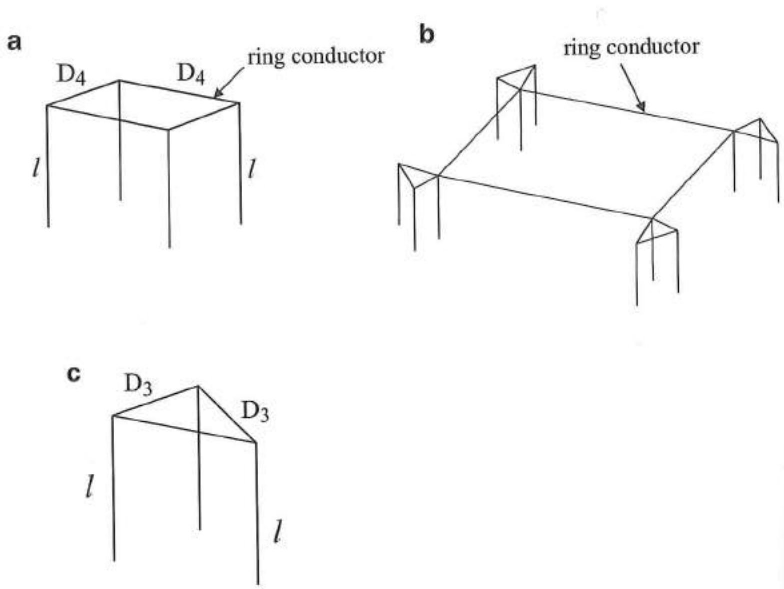


Fig. 17.14 To reduce the ground resistance, grounding rods of the grounding system should extend vertically to a depth of 3 m. Different arrangements of grounding rods as recommended by IEC are shown in the diagram [1]. (**a**) This arrangement could be used as a grounding system of a small metallic shelter (D4: sides of shelter). (**b**) Grounding system including ring conductor and triangular prismatic arrangement of vertical ground conductors. (**c**) Prismatic arrangement of vertical ground conductors

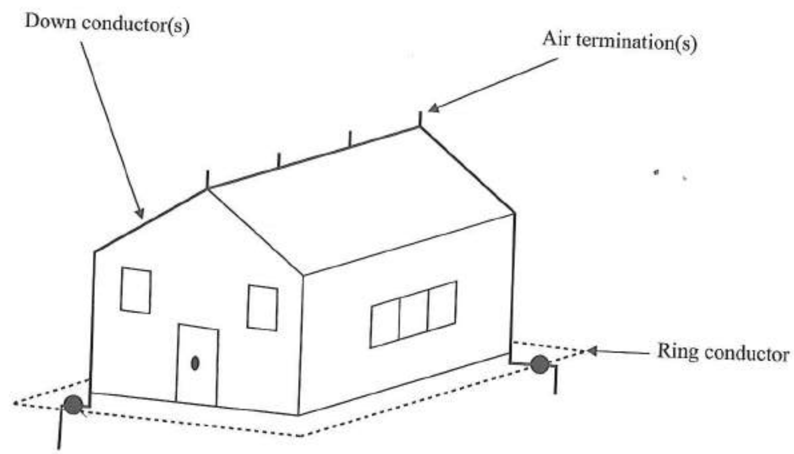


Fig. 17.15 The ring conductor can reduce the large potential differences that may occur at different points on the ground located inside it during lightning strikes. The ring conductor should be bonded to the down conductors (Figure created by author)

As a current enters the ground along the ground conductors, the current flow into the ground creates a potential difference at different points on the ground, and this can cause injuries because of step potentials during lightning strikes (Chap. 16). To reduce such voltages, a ring conductor that connects to all the down conductors is placed around the structure (Fig. 17.15). Such a conductor reduces the differences in potential at different points on the ground and reduce the strength of the step potentials.

17.8 Mesh Protection Method

As the preceding discussion makes clear, a lightning protection system cannot completely remove the lightning strikes to a structure. Lightning flashes with small currents could penetrate the structure by bypassing the lightning protection system. However, there might be structures where even a small lightning current could cause severe consequences, for example, structures storing ammunition and flammable liquids. On the other hand, according to the Faraday cage principle, if a current is injected into a closed metal container, the current will flow only along the outer surface of the container and no current will penetrate into the inner space. Thus, in principle, by enclosing a structure with a metal screen one can completely remove the lightning strikes to the structure. Obviously, this cannot be done in practice, but a derivative of this concept exists as a lightning protection method. It is called the *mesh method of lightning protection*. The idea is to cover part of the structure by a metal mesh. Usually, this method is used to protect large flat areas of a roof. The idea is to place a metal mesh at the top of the structure, instead of lightning conductors, and connect the mesh to ground using down conductors. In this method, the selection of the mesh size is done using a principle identical to the one used in evaluating the separation between lightning terminations. The current that is allowed to creep into the structure across the mesh is given by the same level of protection as was given earlier. The lower the amplitude of the currents allowed to strike the structure, the smaller the dimension of the cells of the mesh (Fig. 17.16). Reducing the size of the cells of the mesh makes it possible in principle to reduce the number of lightning flashes striking the structure to insignificant levels. The mesh can also be used to protect the sides of a tall structure where lightning flashes are expected to terminate (Fig. 17.17).

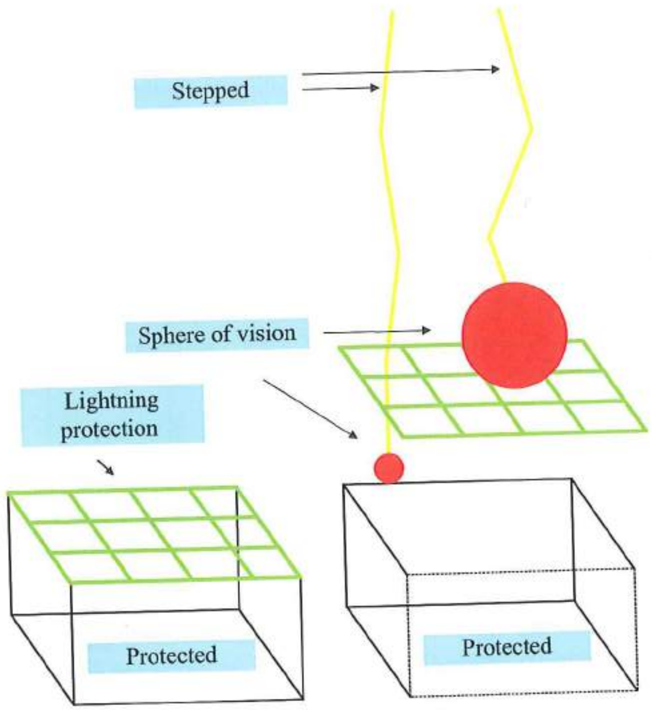


Fig. 17.16 Mesh method of lightning protection. One can visualize that at the tip of each stepped leader is a sphere of vision. The radius of the sphere of vision is equal to the radius of the corresponding rolling sphere. The stepped leader becomes attached to the first object that comes into the sphere of vision. The idea of the mesh method is to remove or filter out stepped leaders having a sphere of vision (or rolling sphere) larger than a certain radius. Since this radius is related to the peak current of the prospective return stroke, the idea is to filter out return strokes having peak currents larger than a certain critical value. For example, a mesh designed for lightning protection level (risk level) I filters out peak return stroke currents larger than 3 kA. Stepped leaders with prospective peak currents smaller than this critical value can penetrate through the mesh and strike the structure (Figure created by author)

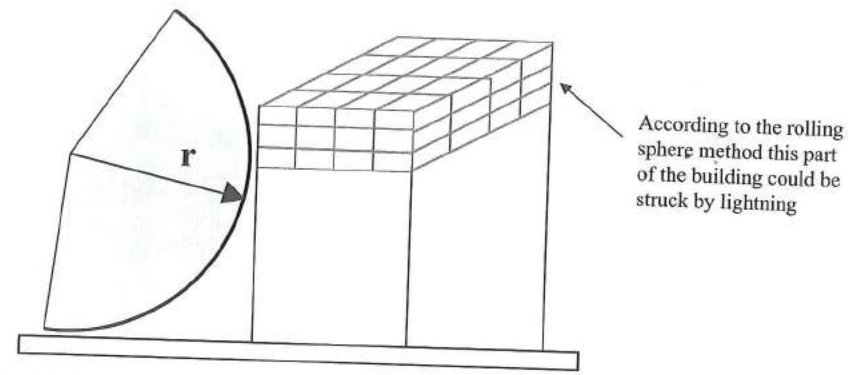


Fig. 17.17 The mesh method can be used to protect the sides of a structure. The mesh can be used not only to protect the roof but also sides of the tall building that might be struck by lightning. The height of the building is greater than the radius of the rolling sphere (Adapted from [1])

Table 17.2 Mesh sizes corresponding to different classes of the lightning protection system

Class of lightning protection system	Mesh size (m × m)
I	5 × 5
II	10 × 10
III	15 × 15
IV	20 × 20

Like the lightning protection using the rolling sphere method, the protection offered by the mesh method is divided into several levels. The mesh sizes corresponding to different levels of protection are given in Table 17.2. In practice, small air terminations are provided on the mesh to intercept lightning flashes.

Consider a stepped leader associated with a given rolling sphere radius. Figure 17.18 illustrates the location of the sphere at the interception of the stepped leader by the conductors of the mesh. Note that the sphere can penetrate through the mesh to a certain distance. To avoid any lightning strikes to the structure resulting from this penetration of part of the sphere through the mesh, in practice, the mesh is located slightly above the ground plane.

17.9 Summary of External Lightning Protection System

The aforementioned methods of protection – rolling sphere method, protection angle method, and mesh method – are applied in the protection of houses, tents, boats, power lines, and other structures. Basically, each system consists of lightning receptors, down conductors, and a grounding system. As mentioned previously, the goal is to safely conduct the lightning current to ground.

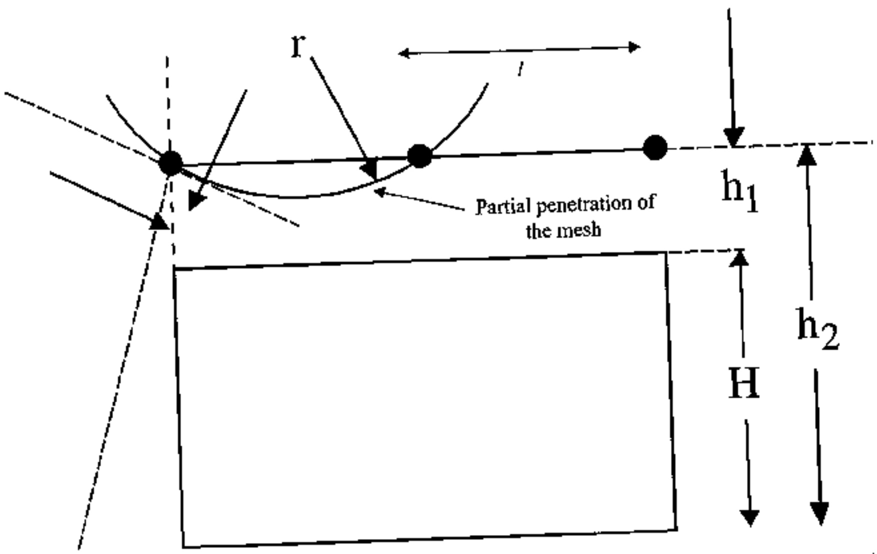


Fig. 17.18 To take into account the partial penetration of the sphere through the mesh, in practice the mesh is located slightly above the roof that is to be protected. In the diagram, the mesh is located at a height of h_1 from the roof. Note also that in the diagram, the parameter l is the size of the sides of the squares in the mesh (Adapted from [1])

17.10 Internal Lightning Protection System

It is important to understand that in any structure those belonging to the lightning protection system are not the only metal conductors crisscrossing different parts of the structure. A typical structure contains conductors belonging to a power system, telecommunications system, gas supply system, and water and drainage system. In the case of a lightning strike, all conductors belonging to these systems will be raised to a high potential, and if they are not properly bonded together, then large voltage differences can arise between conductors of different systems, causing flashover from one system to another. Thus, protecting a building from the effects of lightning requires not only an external lightning protection system but also procedures to reduce the occurrence of overvoltages in different conductors inside the building and mitigate their effects. The set of procedures developed to reduce the effects of lightning inside a building is collectively called the *internal lightning protection system*.

The first step to developing such a system is to bond all the conductors entering the building to a common ground bar, which is also bonded to the external lightning protection system. This is called *potential equalization* (Fig. 17.19). In some cases, the conductors entering a building cannot be bonded to ground at the entrance to the building. Conductors bringing in power to the building are an example. Thus, during a lightning strike, large voltages may appear in these conductors with respect to the other conductors that are bonded together to ground (including the ground wire of the incoming power). Since these conductors cannot be directly

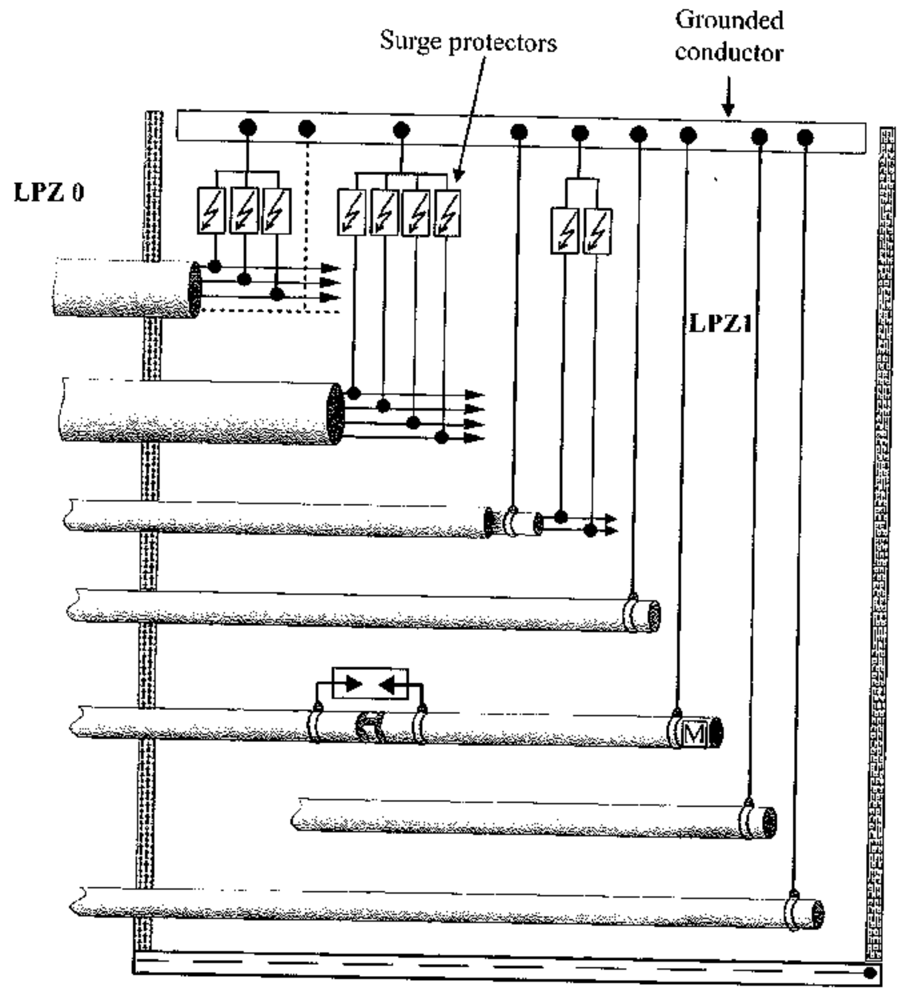


Fig. 17.19 In lightning protection practice, all conductors entering a building are connected to each other and to ground at the entrance to the building. Conductors that cannot be connected to ground directly are connected to it across surge protective devices (Figure created by author)

connected to ground, they are connected to ground across surge diverters or surge protective devices (Fig. 17.20).

17.10.1 Surge Protective Devices

A surge protective device (SPD) provides a high impedance between its terminals as long as the voltage between the terminals of the device is below a specific value. Thus, when a surge protector is connected between the phase conductor and the ground wire of an electricity supply to a building, under normal operation the

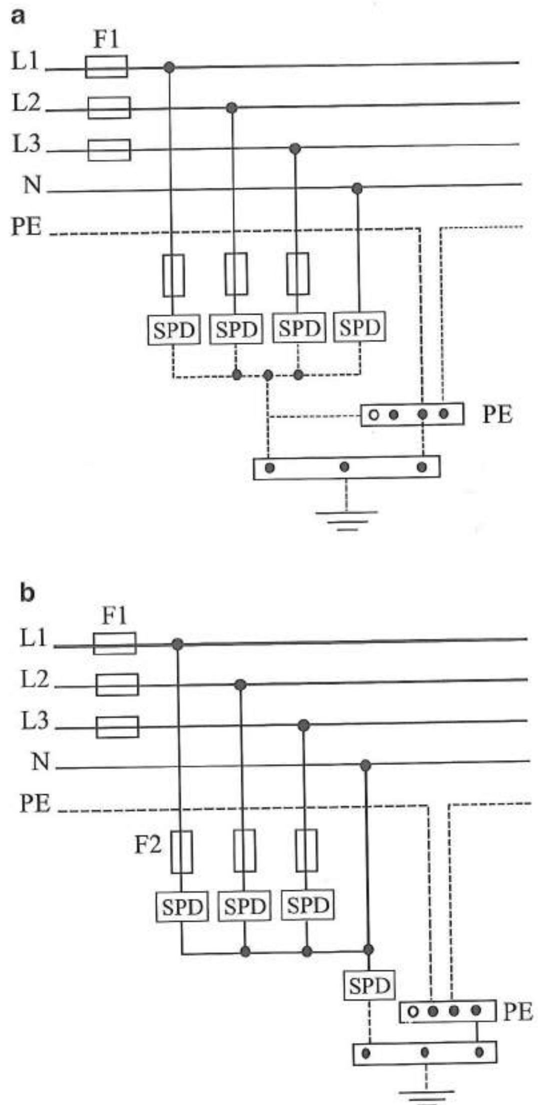


Fig. 17.20 (**a**) Conductors that cannot be connected to ground directly (such as those carrying electricity and data signals) are connected to ground across surge arresters. The figure shows an arrangement corresponding to a system with an isolated neutral conductor (Adapted from [1]). (**b**) Conductors that cannot be connected to ground directly (such as those carrying electricity and data signals) are connected to ground across surge arresters. The figure shows an arrangement corresponding to a system with neutral connected to the PE at the structure (Adapted from [1])

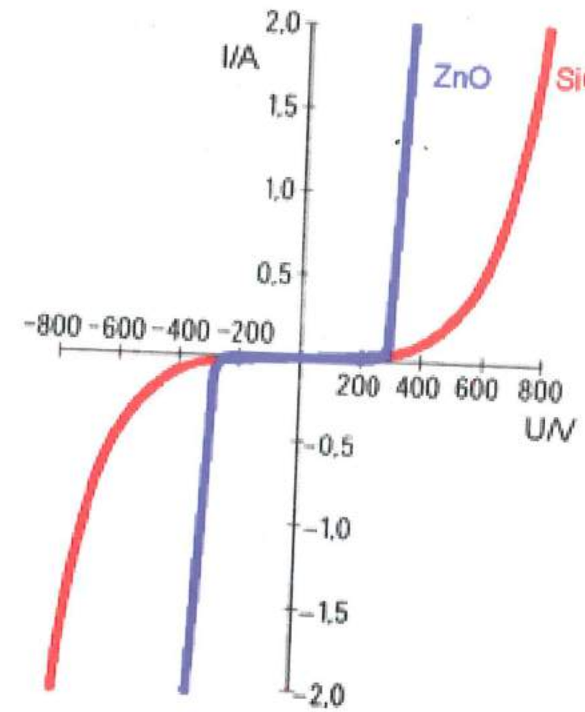


Fig. 17.21 Voltage current characteristics of a surge protective device (SPD). In the example, the V-I characteristics are shown for ZnO and SiC varistors where the nominal voltage (i.e., the voltage at which the device starts conducting) is approximately 300 V. Note that the device starts conducting when the voltage across it reaches the nominal voltage (figure from http://en.wikipedia.org/wiki/Varistor, 2014)

conductors operate as if they are not connected to each other. When the voltage between the terminals of the surge protector increases beyond the specified value or the firing voltage, the impedance reduces to a small value, creating almost a short circuit between the two terminals. Once the voltage is reduced, the impedance reverts back to the original value. Examples of SPDs are gas discharge tubes, varistors, and zener diodes. Figure 17.21 shows the voltage current characteristics of a SPD.

In an electrical power line supplying power to a building, SPDs are usually connected between the phase wires and between the phase wires and the ground (Fig. 17.20). Whenever a high voltage arises in one conductor with respect to the others, and if the amplitude of the voltage is higher than the nominal or firing voltage of the SPD, then the incoming voltage is diverted to ground when the SPD is short-circuited. In designing the internal lightning protection using a SPD it is important to have some idea of the magnitude and temporal variation of the voltages and currents entering the system so that the correct SPD can be selected for the application. The information concerning the amplitude of surges is necessary in selecting the proper nominal operating voltage of the SPD so that unwanted signals can be diverted to ground. The information concerning the temporal variation of the unwanted voltages is necessary for two reasons. First, the rapidity with which the SPD changes from a high-impedance stage to a low-impedance stage varies from one type of SPD to another. For example, if the incoming voltage has a very fast rise time, then a

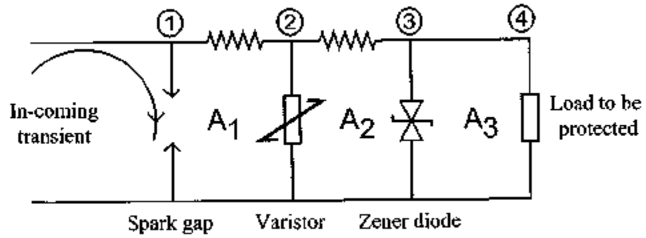


Fig. 17.22 In practice, sensitive electronics are protected by a series of surge protectors. See text for the reasons behind this arrangement (Figure created by author)

SPD that reacts very fast is necessary to divert the signal. Second, the amount of energy dissipation that can be withstood by a surge protector also varies from one type to another. The duration of the incoming voltages, together with their amplitude provides information concerning the possible energy dissipation in the SPD.

In practice, several stages of SPD are connected to reduce the unwanted voltages in a series of steps (Fig. 17.22). The first element in the series is usually a gas discharge tube. It removes a large portion of the incoming voltage. Gas discharge tubes can withstand rather high currents and therefore are suitable for this purpose. Unfortunately, the firing time of a gas discharge tube is not that short, and therefore a residual voltage is kept on moving downstream. The residual voltage that remains after the transient has passed through the gas discharge tube (voltage below the firing threshold of the gas discharge tube) is removed by a varistor. What remains after the varistor is removed by zener diodes, which are the least tolerant and most sensitive to the energy dissipation of the three types of surge protectors. In arranging the various protective elements, it is important to reduce the loop areas (marked A_1, A_2 and A_3 in Fig. 17.22) associated with various elements. During the firing of a gas discharge tube, for example, very rapid changes in currents that can cause unwanted voltages in any nearby loops are produced.

In internal lightning protection systems, SPDs are not only connected at the entrance of the structure; they are usually placed at the entrance of the power system to sensitive electronic devices. Thus, if an unwanted voltage signal were to bypass the SPD at the entrance of a building, such voltages would be removed by these SPDs protecting the sensitive electronic device.

17.10.2 *Electromagnetic Zoning*

General internal lightning protection can be described using the concept of zones. Assume that sensitive equipment has to be protected from unwanted voltages, currents, and electromagnetic fields. The equipment can be surrounded with several metallic shields to prevent unwanted electromagnetic fields from entering the system. However, power and other communication cables must be supplied to the equipment from outside. The procedure to do that is shown in Fig. 17.23a.

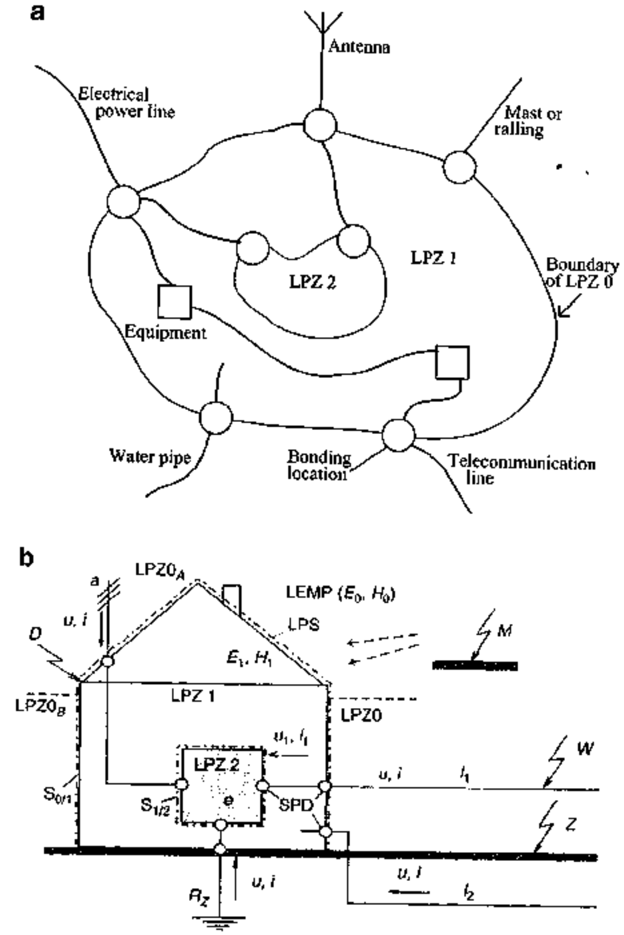


Fig. 17.23 (a) The concept of electromagnetic zoning. The idea is to screen sensitive objects with several screens that block unwanted voltages, currents, and electromagnetic fields penetrating the structure. In the method, the ground screen of any conductor penetrating through the screen is connected to the screen, and any live conductors that cannot be connected to the screen are connected to it through surge protectors (Adapted from [1]). (b) Lightning protection system of a building arranged according to the zone concept. LPZ0 is the outer zone where sources of current and voltages may directly interact with the system (i.e., a direct lightning strike). LPZ1 is the inner zone where most of the unwanted currents and voltages are removed using surge protective device (SPDs). But electromagnetic fields may exist in this region. LPZ2 is a secured zone where almost all the currents, voltages, and electromagnetic fields are removed using screens and SPDs (Adapted from [2])

Here three zones, namely, zone 0, zone 1 and zone 2 are shown. In zone 0 the direct threat of lightning current and the full exposure to the lightning generated electromagnetic fields exists. In zone 1 the impulse currents are limited by the SPD's and the electromagnetic fields are attenuated by the shield at the boundary of zone 1 and zone 0. In zone 2 the impulse currents and the electromagnetic fields are lower than in zone 1. The impulse current level and the electromagnetic fields in zone 2 can be withstood by the electrical systems in zone 2. At each entrance all the cables carrying signals are connected to the screen (at the boundary) using SPDs (shown by circles). All the screens are connected together so that they maintain the same potential. The outer screen is connected to ground. By increasing the number of screens one can drastically reduce the unwanted signals entering the equipment. Of course, in reality it may not be possible to find physical shields or screens as shown in the diagram in lightning protected buildings, but such metal shields are there in very sensitive equipment. For example, the metallic chassis of a sensitive electronic system acts as a shield. In protecting buildings from lightning, the idea is to place the conductors that divert the currents at each stage in such a way that they form an approximate shield (Fig. 17.23b). Moreover, the down conductors of the lightning protection system that represent the outer screen of the zoning procedure are placed in such a way that electromagnetic fields are reduced inside the structure.

Let us now see how a metallic screen can remove unwanted currents and electromagnetic fields.

17.10.2.1 Skin Depth

Assume that an electromagnetic field with a certain frequency (i.e., a sinusoidal signal) is incident on a metallic surface. The electromagnetic field penetrates the material and generates currents in it. However, the depth to which the electromagnetic fields penetrate can be characterized by the skin depth. As the electromagnetic field penetrates the conducting medium, its amplitude decreases exponentially with depth. The skin depth is the depth where the amplitude of the electromagnetic field is reduced to one-third the value it had at the surface. The value of skin depth is given by

$$\delta = \sqrt{\frac{1}{\pi f \mu \sigma}}, \qquad (17.7)$$

where f is the frequency of the electromagnetic field, μ is the magnetic permeability of the material, and σ is the conductivity. This equation is plotted for copper in Fig. 17.24. Since the frequencies of interest in lightning currents are a few kilohertz to several tens of megahertz, a few millimeters of copper screen can prevent unwanted lightning signals from appearing inside the enclosure. As is clear from the preceding equation, skin depth increases with decreasing frequency. Does that mean that extremely low-frequency signals can pass through a copper screen? The answer is no. When a time-varying electromagnetic field falls on a conducting medium, two processes take place. Part of the signal is reflected and the other part penetrates the medium. As the frequency decreases, the reflected part becomes increasingly higher, and only an increasingly smaller fraction enters the medium. When the frequency becomes zero, the entire signal is completely reflected. This is why a copper screen is effective in screening equipment from static fields.

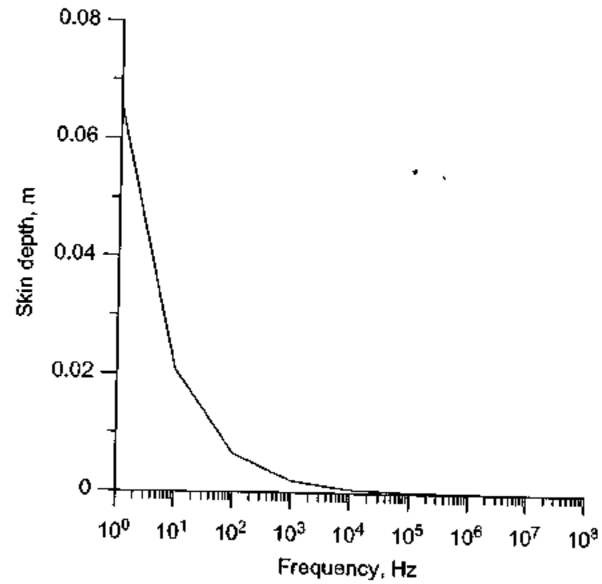


Fig. 17.24 Skin depth of copper as function of frequency of incident electromagnetic wave (Figure created by author)

17.11 Inadequacies of EGM

In EGM it is assumed that the connection between the stepped leader and the grounded structure takes place when the stepped leader comes to within striking distance of the grounded structure (i.e., when the final jump condition is reached). But in reality, the situation is more complicated. Depending on the height of the structure, before the final jump condition is reached between the tip of the leader and the grounded structure a connecting leader is issued from it. If the structure is very short, then the connecting leader is issued when the separation between the stepped leader and the grounded structure is almost equal to the striking distance. Thus, for short structures the presence of the connecting leader can be neglected. But in the case of tall structures, a connecting leader is issued long before the separation between the stepped leader and the grounded structure approaches the striking distance. The reason for this is the larger electric field that results at the top of the structure due to field enhancement. In this case, the final connection is made not between the structure and the stepped leader but between the connecting leader and the stepped leader. Again as before it can be assumed that the connecting leader will be connected to the stepped leader when the final jump condition is reached between the tip of the connecting leader and the stepped leader. When the connection between the connecting leader and the stepped leader takes place in the presence of a long connecting leader, the tip of the stepped leader will be located at a distance much greater than that stipulated by EGM. This is illustrated in Fig. 17.25. Thus, to correctly describe the attachment process, the generation of the connecting leader and its propagation and the final connection between it and the stepped leader must be taken into account.

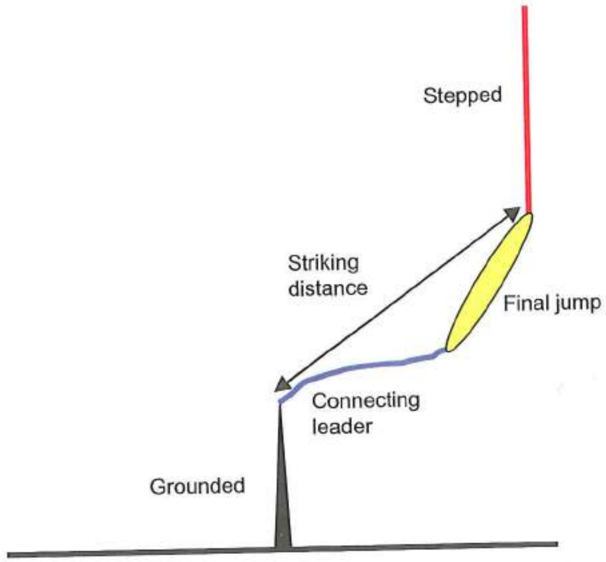


Fig. 17.25 In general, the stepped leader is met by a connecting leader issued from the lightning conductor. The striking distance in this case can be defined as the distance between the tip of the stepped leader and the point on the structure where the connecting leader is issued when the final jump condition is satisfied between the connecting leader and the stepped leader. At the final jump condition, the average electric field in the gap between the connecting leader and the stepped leader is equal to 500 kV/m (Figure created by author)

17.12 Attachment Models More Advanced Than EGM

To overcome the inadequacies of the EGM, scientists have developed several models that are capable of taking into account the presence of connecting leaders during lightning attachment. These models are described in Chap. 18.

17.13 Unconventional Lightning Protection Systems

17.13.1 Early Streamer Emission Principle

The analysis given in the previous section shows that tall structures have a longer attractive range because streamers and, hence, connecting leaders are generated when the leader is at a larger distance from its tip than in the case of short structures. Now, this will raise a question. Assume that by some other means, say by applying an external voltage, streamers are generated at the tip of a lightning conductor. Will these artificially created streamers give rise to a connecting leader, making the attractive range larger? All studies conducted to date, both theoretical and experimental, show that just by creating streamers at the tip of a lightning conductor it is not possible to enlarge the attractive range of a lightning conductor because the

generation of streamers is not a sufficient criterion for making a stable upward moving connecting leader (Chaps. 2 and 18). To create a successful connecting leader, the streamers must be transformed into a leader, and once initiated, the leader should be able to propagate continuously toward the stepped leader. The energy necessary for all these physical processes is supplied by the background electric field. Each of these processes requires the background electric field to be above a certain critical value for its completion. On the other hand, artificial generation of a streamer at the tip of a conductor is just a local effect. If these streamers are created when the leader is far away, they will just die out without leading to a connecting leader. If this is the case, how about artificially generating streamers from the conductor when all the conditions necessary for the streamer-to-leader transition and the leader propagation are satisfied? In principle, it should work, but the problem is that streamer inception from lightning rods takes place naturally long before the field conditions necessary for the successful launch of a connecting leader are satisfied. This means that when these conditions are satisfied, nature itself will provide the streamers necessary for the process. Nothing can be changed by artificially generating streamers at the tip of a rod.

Unfortunately, notwithstanding the theoretical and experimental data available, some vendors have introduced lightning rods where gadgetry is provided for the artificial generation of streamers at the tip of lightning rods. These are called early streamer emission (ESE) devices. It is claimed that these rods can generate connecting leaders long before a normal rod of similar height, and hence they have attractive radii longer than those of normal lightning rods. At present, there are no theoretical or experimental data to validate that claim. Of course, some laboratory experiments are cited in support of the claims of the ESE principle [3]. Indeed, it was a laboratory experiment that led to the creation of ESE devices. Analysis has shown that laboratory experiments cannot be used to simulate the lightning attachment process that takes place under natural conditions [4] because the electric fields used to expose the lightning rods in the laboratory are very different from the electric fields present under natural field conditions. In summary, neither theory nor experiment justifies the claims of ESE manufacturers. These conductors have no advantage over normal lightning conductors of similar heights.

17.13.2 Lightning Dissipaters

It took some time for scientists to understand how a lightning conductor works. Recall that Benjamin Franklin was of the erroneous opinion that a lightning conductor works by generating positive charges that travel upward into the charge center of a cloud and dissipating the electric charge in the cloud. In other words, he believed that a lightning conductor could dissipate the charge in a cloud, thereby preventing lightning strikes. This wrong concept is used today by manufactures of lightning dissipaters. The idea is as follows. On a tall conductor a net of sharp points is connected in the form of an umbrella. The umbrella is grounded with a ground conductor. It is claimed that the charges generated by these sharp points can

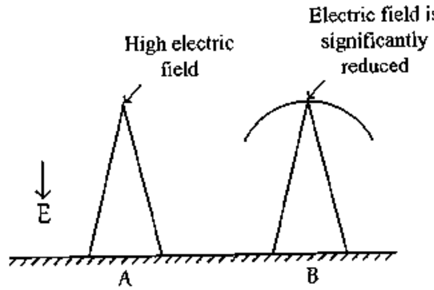


Fig. 17.26 The inception of upward initiated lightning flashes can be reduced by reducing the field enhancement at the top of the tower by placing an umbrellalike structure at the top of the tower (Figure created by author)

dissipate either the charge in a cloud or the charge in a downward moving stepped leader. These are called *dissipation arrays*. Calculations show that the charge generated by a dissipation array is not large enough to dissipate either the charge in a cloud (which is continuously formed) or the charge in a downward moving stepped leader. Indeed, there are many instances in which such dissipation arrays are struck by lightning directly. Thus, there is no truth to the manufacturers' claim that they can dissipate the charge in clouds and prevent lightning strikes. There are some instances where it was claimed that after connecting a dissipation array on a very tall tower, the number of lightning incidents were reduced. A possible reason for this observation is that, in the case of very tall structures, most lightning flashes are upward initiated. The ability of a tall tower to launch a connecting leader that culminates in an upward initiated lightning flash depends on the field enhancement at the extremity of the tower. By placing an umbrellalike structure at the top of a thin cylindrical tower, it is possible to reduce the field enhancement at the top, and this may lead to a reduction in upward initiated lightning flashes (Fig. 17.26). However, this effect has nothing to do with the creation of corona charges at the sharp points of the structure.

In summary, scientific claims of dissipation arrays have not been substantiated, either by theory or experiment, and they should not be used as part of structural lightning protection systems.

References

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2. Flisowski Z, Mazzetti C (2010) Risk analysis. In: Cooray V (ed) Lightning protection. IET Publishers, London
3. Berger G (1992) The early streamer emission lightning rod conductor. In: Proceedings of 15th international conference on aerospace and ground: ICOLSE, Atlantic City, NJ, USA
4. Becerra M, Cooray V (2008) Laboratory experiments cannot be utilized to justify the action of early streamer emission terminals. J Phys D Appl Phys 41:085204

Chapter 18
Advanced Procedures to Estimate the Point of Location of Lightning Flashes on a Grounded Structure

18.1 Introduction

The attachment of a stepped leader to a grounded structure is mediated by a connecting leader issued by the grounded structure. In the case of short structures, the length of the connecting leader is usually small, but it could be several tens of meters long in the case of tall structures. However, in the electro-geometrical method (EGM), the presence of a connecting leader is neglected (Chap. 17). Thus, the conclusions based on EGM on the attachment of stepped leaders to tall grounded structures could be in error. This simplifying assumption in EGM motivated several scientists to create lightning attachment models that included the effect of connecting leaders. Four models are used by lightning researchers at present, and this chapter presents the basic ideas associated with these models. The four models were introduced by Eriksson [1], Dellera and Garbagnati [2], Rizk [3], and Becerra and Cooray [4, 5]. These models are referred to here as the Eriksson model, the Dellera and Garbagnati model, the Rizk model, and the Becerra and Cooray model.

A physically reasonable lightning attachment model should be able to describe the generation of a connecting leader, its subsequent propagation, and the final attachment to the stepped leader. First of all, let us consider how the initiation of a connecting leader from a grounded structure is treated in the four models. Eriksson and Dellera and Garbagnati use the *critical radius concept* (described subsequently) to determine when a connecting leader is issued by a grounded structure under the influence of a downward moving stepped leader. Rizk used his own criterion, which we refer to as the *Rizk criterion*, and Becerra and Cooray used a criterion based on the known physics of electrical discharges as outlined in Chap. 2. We refer to the latter criterion as the *Becerra and Cooray* criterion for leader inception. Let us consider these criteria individually.

V. Cooray, *An Introduction to Lightning*,
DOI 10.1007/978-94-017-8938-7_18

clamps, conductors and rods) are compliant with the series of component standards in IEC 62561.

6 Internal Lightning Protection System

The internal lightning protection will be covered in detail in a separate chapter. However, for the sake of completion of the external protection, which has no strict boundary of separation from internal protection, a brief overview of the latter is given below.

Wikipedia's definition for electrical bonding highlights the importance of electrically bonding any and all conductive parts of a system to the same potential (i.e. equipotential bonding).

> the practice of intentionally electrically connecting all exposed metal items not designed to carry electricity in a room or building as protection from electric shock. If a failure of electrical insulation occurs, all bonded metal objects in the room will have substantially the same electrical potential, so that an occupant of the room cannot touch two objects with significantly different potentials. Even if the connection to a distant earth ground is lost, the occupant will be protected from dangerous potential differences.

i. Lightning equipotential bonding (LEB)

This concept is definitely one of our industry's tongue twisters, but to try and simplify the concept we use the example of a cold beer (i.e. own potential) being placed outside on a hot day (i.e. high potential) then condensation happens as a result of the energy (i.e. heat) being transferred due to the fact that there exists a large temperature difference. The exact opposite is proven when a glass of red wine is placed in a room then we notice no condensation for there is no temperature difference. During a lightning strike potential differences (i.e. a hot day, cold beer) are created either through ground potential rise (GPR) from a direct strike or through magnetic excitation from a distant strike. This gives rise to uncontrolled flashovers and or dangerous sparking (i.e. condensation in the previous example) inside the building between the external lightning protection system and other conductive elements such as gantries, facades, walkways and handrails, but the same goes for internal systems such as electrical and electronic systems thus the need to establish lightning equipotential bonding (i.e. create a condition where the temperatures are the same, like the glass of red wine in the room).

All conductive parts, which have no other potential, can directly be bonded to the main earth bar (i.e. common potential in the building) using for e.g. bonding conductors. However, internal systems that have their own potential (e.g. 230 V), such as an electrical distribution board, can only be bonded indirectly to the main earth bar. Indirect bonding is made possible by installing surge protection devices (SPD) (Fig. 28).

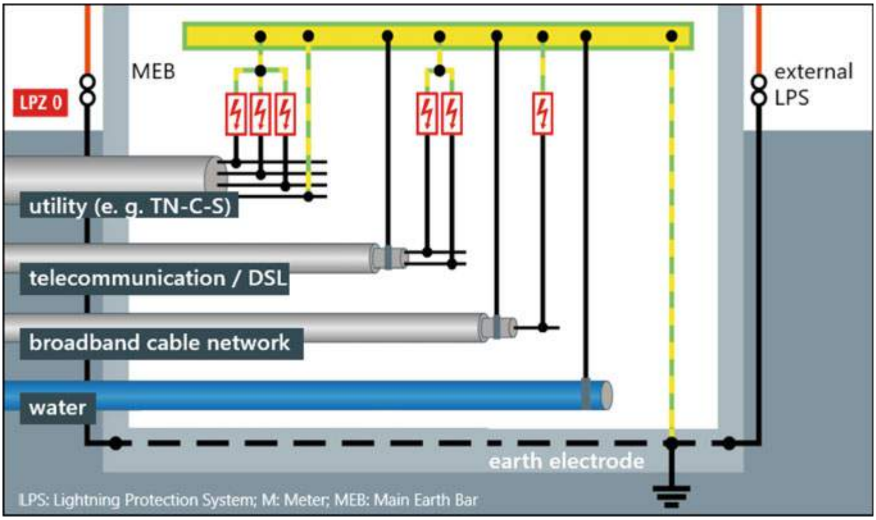


Fig. 28 Typical lightning equipotential bonding [1]

By establishing lightning equipotential bonding, it is important to note that parts of the lightning current can pass through both the direct and indirect bonding methods and this effect shall be considered in terms of the sizing of materials/components.

a. Direct bonding

The minimum values of the cross-section of the bonding conductors connecting different bonding bars and of the conductors connecting the bars to the earth-termination system and the minimum values of the cross-section of the bonding conductors connecting internal metal installations to the bonding bars are listed in Table 10.

b. Indirect bonding

It is a common misunderstanding that SPDs are used to only limit overvoltages conditions and although these devices can do this as well, the main purpose of

Table 10 Material requirements for bonding conductors

Material	Bonding to ETS (mm^2)	Bonding of Internal metals (mm^2)
Copper	16	6
Aluminium (alloy)	25	10
Steel (stainless, galvanised)	50	16

fitting these devices is to ensure lightning equipotential bonding between the earth-termination system and the conductors (i.e. live conductors) of the internal electrical and electronic equipment (Fig. 29).

Therefore, it is important to distinguish between the three types of SPDs.

- Type 1—Lightning current arrester (Direct lightning current)
- Type 2—Surge current arrester (Induced lightning current)
- Type 3—Voltage limiting arrester (Voltage limiting).

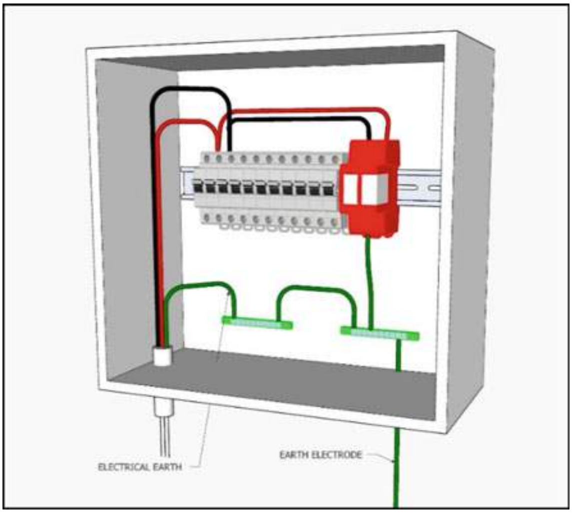
The use of Type 1 devices is required for lightning equipotential bonding whereas the Type 2 devices are used to mitigate the effect of magnetic coupling caused by distant strikes and Type 3 devices are used to limit overvoltages caused by e.g. switching operations.

For a building or structure with an external LPS, it is imperative to fit a combination type 1 + 2 surge protection device in the main electrical distribution board. Thereafter type 2 SPDs can be fitted in sub-distribution boards, when they are located more than 10 m away from the main distribution board, and finally for finer protection a Type 3 can be fitted on the terminal device itself (Fig. 30). Note, only fitting a Type 3 SPD is considered inadequate, an upstream and coordinated Type 1 or Type 2 SPD must be fitted as well.

The figure above illustrates wiring details that needs to be taken into consideration by the lightning protection designer and or electrical contractor. It is important to ensure that a connection from the SPD is made to both the electrical earth (main earth bar) as well as the local earth electrode.

Furthermore, please note that the protection level of SPDs decrease when the wiring length (the length of a wire from a live conductor to the closest earth) increase, therefore it is recommended to keep the total wire length below 1 m. In order to avoid nuisance tripping, ensure that SPDs are wired upstream from any earth-leakage or RCCD devices (Fig. 31).

Fig. 29 A typical indirect lightning equipotential bonding method



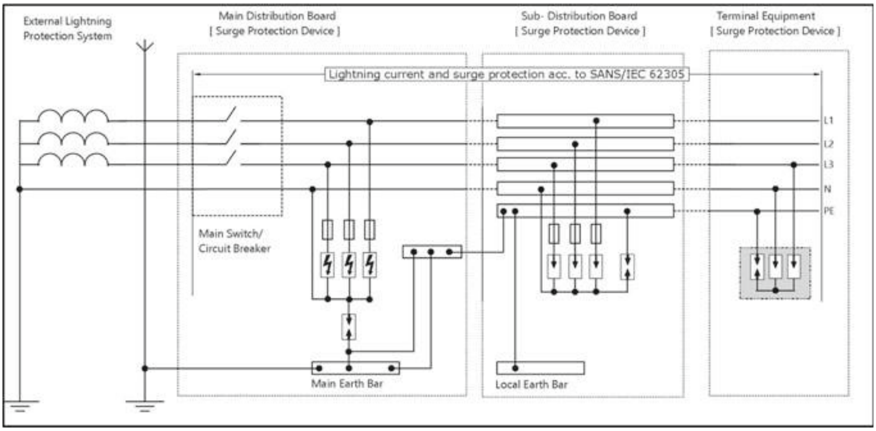


Fig. 30 Coordination of surge protection devices

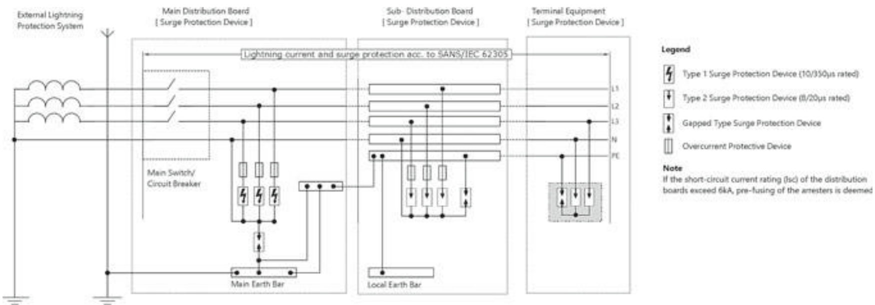


Fig. 31 Wire lengths of SPDs [1]

Please note that, untested and non-compliant SPDs have been known to cause electrical short-circuits and fires this is why the lightning protection designer should ensure to always use compliant (tested as per IEC 61643 series) surge protection devices.

ii. Separation distance (S)

In order to avoid uncontrolled flashovers between the external LPS and other conductive parts or electronic systems, a separation distance (air gap) between these parts needs to be kept. An isolated external LPS should be used to achieve this separation distance in order to ensure that the flow of the lightning current into bonded internal conductive parts do not cause damage to the structure or its contents. This is achieved by placing air-terminals or masts adjacent to the conductive parts or electronic systems needing protection.

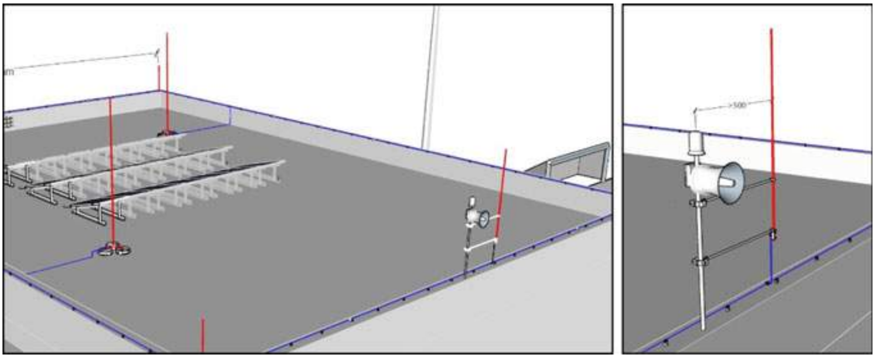


Fig. 32 Separation distance between external LPS and lightning detection system

An isolated LPS is frequently used when a roof is covered with flammable material (e.g. thatched roof) or also for systems located in hazardous areas (e.g. tanks) but for most buildings, these are used to protect electrical and electronic systems which are situated in or on the roof (e.g. solar systems, cameras, cooling systems, and in this case the lightning detection system) see the figure below (Fig. 32).

Annex E of IEC 62305-3 describes the detailed approach on how to calculate the separation distances, but for the safest and most practical method the simplified approach should be taken.

$$S = k_i \frac{k_c}{k_m} l$$

k_i: depends on the selected class of LPS (assume worse case LPL1).

k_m: depends on the electrical insulation material (predominately air).

k_c : depends on the lightning current flowing on the (single conductor)

l : length, in meters, where the separation distance is to be considered, to the nearest equipotential bonding point or the earth termination.

Then a safe and practical equation can be redefined as

$$S = 0.08 \times l$$

References

1. DEHN + SÖHNE (2014) Lightning Protection Guide (3rd updated edn.)
2. Standards International Electrotechnical Commission (2018) Physical damage to structures and life hazard, IEC 62305 Part 3

Inspection, Testing and Certification (Part 6)

F 1 Introduction

Part 6 of BS 7671: 2008 is entitled 'Inspection and Testing' but covers the subjects of certification and reporting as well as inspection and testing.

The Part comprises three chapters as follows;

- 61 Initial Verification;
- 62 Periodic Inspection and Testing;
- 63 Certification and Reporting.

The subject of Periodic Inspection and Testing is discussed in Appendix 15 of this book as many organizations do not undertake such work, which is generally regarded as a little more 'specialist'.

Chapter F therefore discusses and provides explanation and guidance on the inspection, testing and certification of new installations, including alterations and additions.

The main part of the chapter addresses the 'initial verification' of the Regulations and confirmation that the installation meets the requirements of the Regulations.

F 1.1 Inspection and testing – an integrated procedure

The activities of carrying out visual inspection and of then carrying out testing should be considered as complementary procedures. These procedures should not be considered to be separate functions carried out by separate individuals or organizations; this is particularly true of the inspection confirmation part of the inspection and testing.

To illustrate this point: in general there would be little point in carrying out a continuity test on a cable if it had been found that some of its connection terminals were loose. The defect would need to be remedied before the test was conducted.

Another aspect to consider are the stages of inspection and stages of testing for larger installations. For many such installations the inspection is formally carried out at the end of the constructional element of the electrical installation process; often a separate 'test' electrician or engineer undertakes this task.

However, the amount of visual inspection undertaken during the electrical construction stage is often very significant. Most electricians check visual elements like polarity, tightness of connections, and indeed many of the items required under the visual inspection element of inspection and testing (see Section F 2 below). These visual checks are done as a matter of course, but often the 'test engineer' completes the visual inspection separately and often without consultation with the installation electricians. It is suggested that this 'inspection' facet of the inspection and testing process is more efficient, and generally better, if carried out 'inherently' by the installers. Of course, there are exceptions; a particular example is where semi-skilled labour is being utilized for installation.

It is suggested, for larger organizations, that a system be created that allows the installer to confirm facts about the visual inspection. Table F 2.1 suggests items that can and should be carried out during the electrical construction procedure.

F 2 Visual inspection

The visual inspection part of the initial verification is the process of assessing the installation prior to testing. Regulation 611.2 specifies the purpose of the visual inspection, summarized as follows:

- equipment complies with a product standard (see Section D 2);
- equipment is correctly selected and erected (see Chapter D);
- equipment is not damaged.

Table F 2.1 summarizes the requirements for the inspection part of the initial verification. To be consistent with the restructured Chapter 41 (see Chapter C) the protective measures like 'placing out of reach', and similar, have been removed from this table, as they are not considered at the installation stage. The table has been constructed with a 'should have an automatic tick' column. This column indicates facets that should be automatically inspected by the installer. For example, how can an installer install a cable if he does not know the designer's specified cable size? As a further example, the installer should not be terminating cables if he does not know BS 7671 aspects relating to the tightness of connections; thus, he should be inspecting this part of the work. This column should be inherently carried out by the installing operative, completed on the inspection checklist paperwork and passed to the 'test engineer' if this is a separate individual.

Table F 2.1 Visual inspection requirements of BS 7671: 2008.

Inspection	Should have automatic tick	At 'installed' stage	Confirmed separately at final 'testing' stage	Notes
Erection methods	✓	✓	Not required	
Conductor terminations	✓	✓	Not required	
Identification (colour/labelling of cables)	✓	✓	Not required	
Installation of cables (mechanical protection, 522 etc.)	✓	✓	Not required	
Cable size as design specification	✓	✓	Not required	
Building sealing around cables and trunking etc.		✓	Not required	Spot checks may be useful
Presence of means of earthing	✓	✓	Not required	
Presence of protective conductors, cpcs and bonding	✓	✓	Not required	
Isolation	✓	✓	Not required	
Warning notices	✓	✓	Not required	
Diagrams	✓	✓		
Equipment to standards, and IP	✓	✓	Not required	Spot checks may be useful
Detrimental influences		✓	Spot checks may be useful	
Adequate access to switchgear	✓	✓	Not required	Spot checks may be useful
Overcurrent devices correctly sized as specified	✓	✓	Not required	Spot checks may be useful
Presence of RCD protection where required	✓	✓	Not required	Spot checks may be useful
Undervoltage devices where required		✓	Check	

The detail of inspection to this table is covered in the other chapters of this book, and is not expanded upon here with the exception of some labelling and warning notices; for these, refer to BS 7671: 2008 directly.

It should be apparent that if an organization employs separate 'inspection and test engineers', much of the inspection work should be a conversation and completing paperwork exercise with the test engineer. This exercise is better if the inspection paperwork originates with the designer and is passed on to the test engineer. In these situations it should not be the function of the 'test engineer' to repeat inspections of items confirmed by the installers; this is not a requirement of the Regulations.

F 3 Testing

F 3.1 Introduction – pass and fail nature

This section discusses methods for achieving the physical testing requirements of BS 7671. It should be noted that, in some books and advice, too much emphasis is placed on particulars of test methods, often in areas that are not important and do not make any difference to the safety of an installation.

It should be remembered that, of the seven 'everyday' tests required by BS 7671, five are really pass/fail tests. Also, the test methods suggested by industry guidance and manufacturers' literature are just that – guidance. Other methods can and will produce satisfactory results and may be used; and this is, of course, true of this part of this book.

F 3.2 Required tests

The tests required by Part 7 of BS 7671: 2008 fall into two categories:

- The seven 'everyday' tests. These are regularly and continually used by installers and are described in this section of the book.
- Additional tests that may be used occasionally. They would include, for example, testing the insulation of an IT 'floor structure'. These are discussed in Appendix 14.

The 'everyday tests' required by Part 6 of BS 7671: 2008 have been required in the Regulations for a considerable number of years. The Regulations and guidance

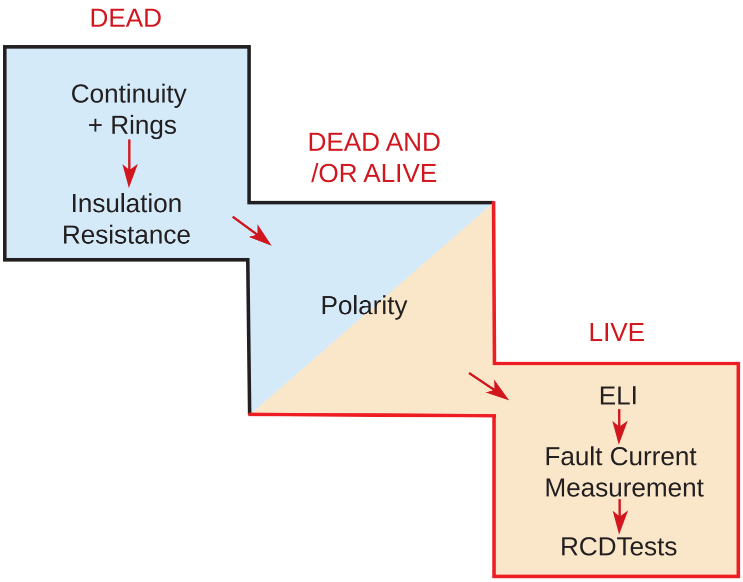


Figure F 3.1 'Everyday tests' order and state of energization.

have suggested an order of tests based on safety and logic. The suggested order is to carry out at least two tests prior to energization (cpc continuity and insulation resistance, with the possible addition of polarity checks) and the remainder to be carried out after energization. A diagram of the seven 'everyday tests' and the suggested order of tests is given in Figure F 3.1.

Working to the suggested order of tests is recommended, but you should bear in mind that some tests will require disconnection of the circuit's neutral; the exact order should not be cast in stone, although the dead tests should certainly be completed prior to energization for safety reasons.

F 3.3 Continuity testing

This is the first suggested test as it is important for the safety of the circuit, and it helps confirm a reference for the remainder of the tests. Continuity testing is carried out on all protective conductors including cpcs, main and supplementary protective bonding conductors.

The test is carried out with a low d.c. voltage continuity tester, and this may detect loose and unsound connections; other instruments may be used.

It is important to establish the path of the conductor that is being measured, as often there will be parallel paths in circuit. This is virtually always the case in commercial and industrial installations where parallel metalwork has a significant bearing on readings.

Consider the luminaire circuit in Figure F 3.2 installed in a typical commercial installation. The figure shows a luminaire mounted with a substantial metal fixing to the structure. There are numerous earth return paths back to the source earth point including the cable cpc, trunking, metal supports, the cable ladder rack and the superstructure of the building. It is unrealistic to disconnect the luminaire from these to test for continuity. Even if the luminaire had an 'insulated' cable supply, unlikely in this environment, the cpc would need to be disconnected at every luminaire on the circuit in order that the cable cpc be tested correctly. This would defeat the object, as the connections are the most vulnerable parts of the circuit. Thus, the only test possible is to test for continuity of the luminaire, including the multiple parallel return paths.

In effect, the reading is confirming that the equipment under test is earthed and, with this test, it is possible that a cable cpc is open circuit. Some do not like this situation and it is one of the reasons that the ECA would recommend using metallic trunking or metallic conduit as a cpc and not a cable cpc within these systems.

This brings us to the two popular methods for continuity testing, namely:

1. 'wandering lead' method;
2. utilization of circuit cable by 'shorting'.

Wandering lead method

The author, mainly for the reasons given above concerning parallel returns, prefers this method. Figure F 3.2 shows a 'wandering lead' continuity test.

You will notice by studying the figure that the cpc has not been removed from the earth terminal at the distribution board. This is due to the fact that there are parallel metallic earth return paths and removal of this conductor will not change this.

Once set up, testing using the 'wandering lead' method is quick and simple. Metalwork in the vicinity of the equipment under test can be quickly checked (often all that is needed is a piece of timber with cable and spike!). Extraneous-conductive-parts can be checked using the same method.

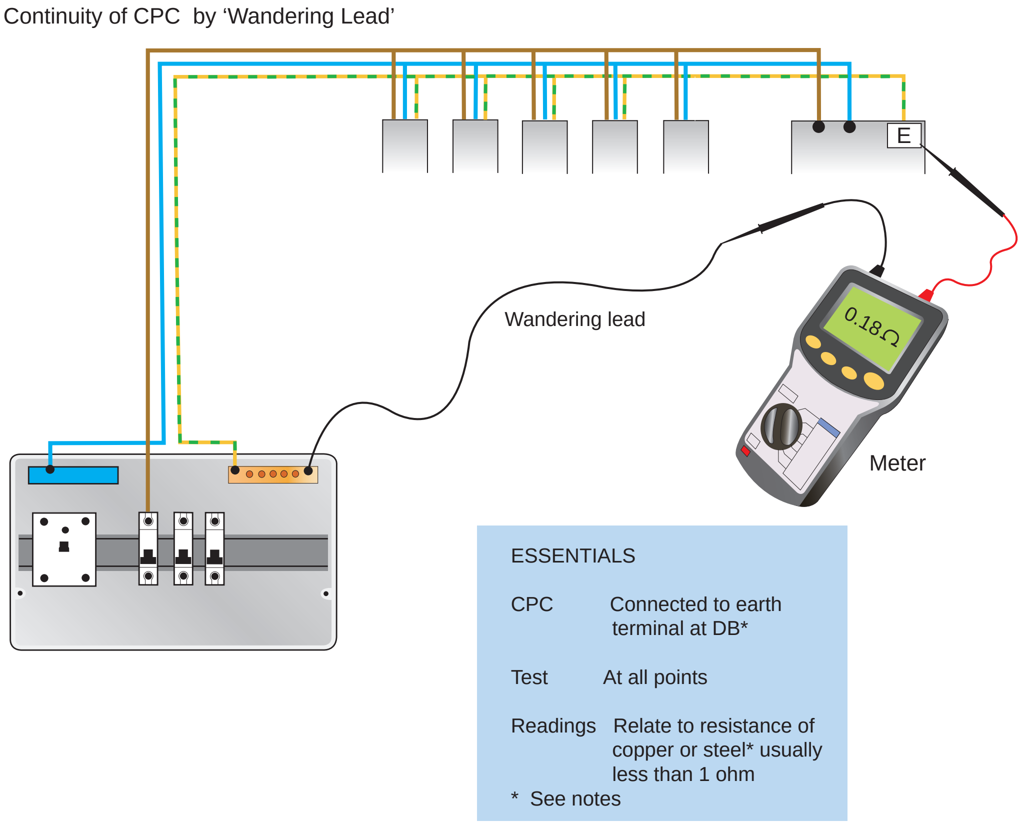


Figure F 3.2 Continuity of cpc by 'wandering lead' method.

It is recommended that this method be used for commercial installations with parallel earth return paths. Also, the recording of a resistance value for each circuit is rather pointless, as parallel paths do not fall neatly into 'circuits'. Instead, all equipment relevant to a distribution board is tested and the following recorded on the test sheet relating to the distribution board:

> 'All circuits tested for continuity maximum reading 1.2 ohms (luminaire director's office)'

As for readings, many tests using this method will show readings approaching zero or typically less than one or two ohms.

Utilizing the circuit cable and $R_1 + R_2$ method

The second method involves using the circuit cable and shorting or linking it out at one end as shown in Figure F 3.3.

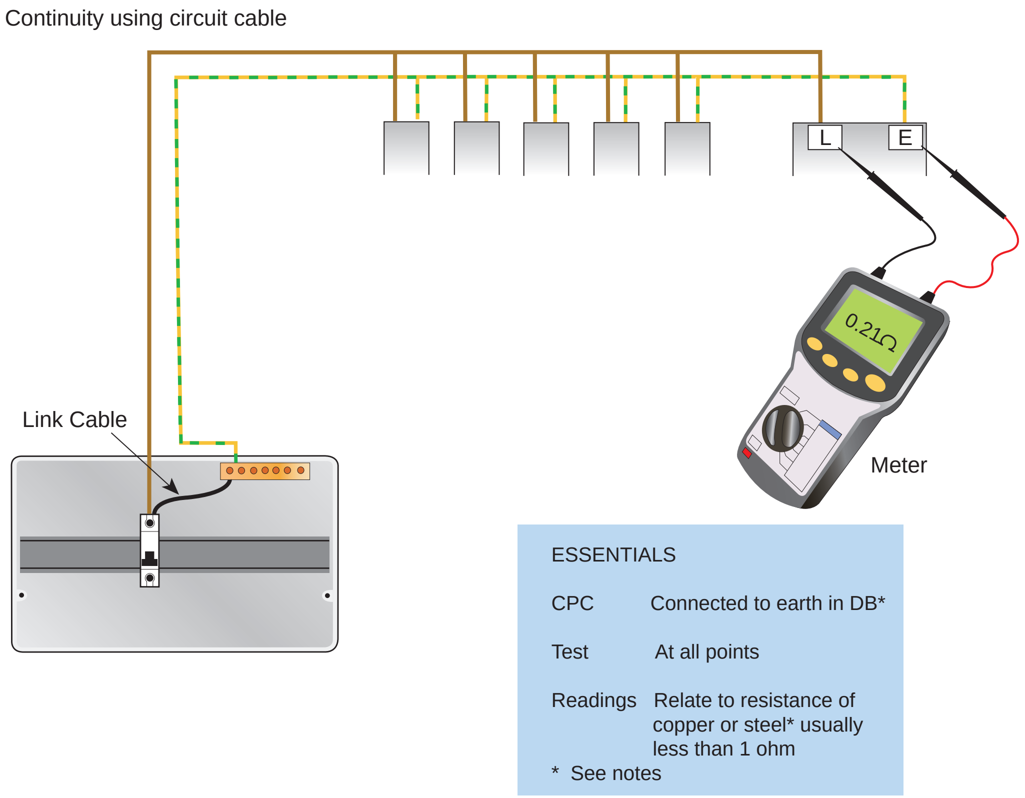


Figure F 3.3 Continuity of cpc by circuit cable method.

The method is simple enough, and if the line conductor is used, this method can be used to record the circuit's $R_1 + R_2$ value. However, the comments made in the 'wandering lead' method about parallel metallic return paths also apply to this method, and therefore in virtually all commercial and industrial applications this test only measures R_1 plus a value of a parallel multi-connected return path. It is therefore a little misleading to record results for this method as a circuit's $R_1 + R_2$ value without a cautionary note on the test sheet.

When compared with the 'wandering lead' method, this test method is slow to repeat at all outlets on a particular circuit (except for socket outlets) as it involves access to equipment terminals.

The method does find favour with some, and can be used to establish a circuit's earth fault loop impedance value as discussed later.

F 3.4 Ring continuity

The continuity of ring final circuits is something that is a little more involved. Methods have evolved over the years to establish whether the rings are indeed wired as ring circuits, and not 'shorted' forming a 'figure of eight' layout and similar.

Whether the 17th Edition requires this test is questionable. The best advice here is not to use ring circuits for commercial and industrial installations.

For completeness and where ring final circuits are used, the following continuity tests are recommended. It should be noted that the stage 3 tests involving using the circuits cpc will suffer from the problem of parallel multi-metallic return paths as mentioned in Section F 3.3, and unless circuit wiring, socket outlets and accessory boxes are insulated from earth this test stage should not be used.

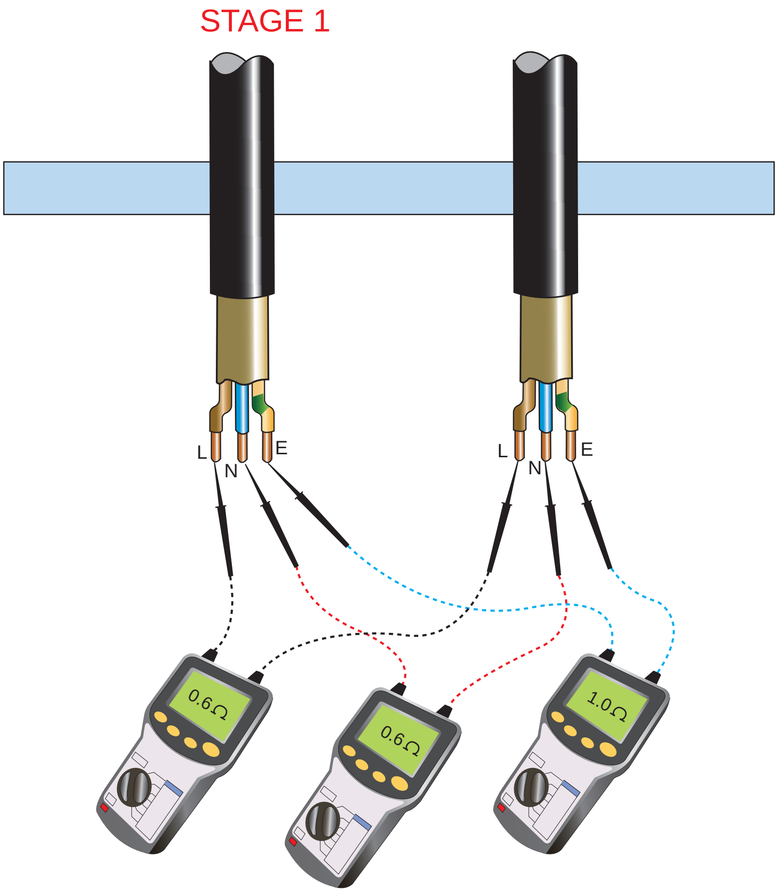


Figure F 3.4a Continuity of ring final circuits, stage 1.

Stage 1 – open loop resistances

Measure the end-to-end resistance of each conductor, R_1 (line), R_n (neutral) and R_2 (cpc) respectively as indicated in Figure F 3.4a. An open circuit result would suggest either the incorrect conductors have been selected or the circuit is incorrectly terminated. As phase and neutral conductors will be of the same cross-sectional area, the resistance values obtained for both conductors should be similar.

Where twin and earth cables to BS 6004 are used, and the cross-sectional area of the cpc is reduced in comparison with the live conductors, the resistance of R_2 will be comparatively higher than that of the phase and neutral loops.

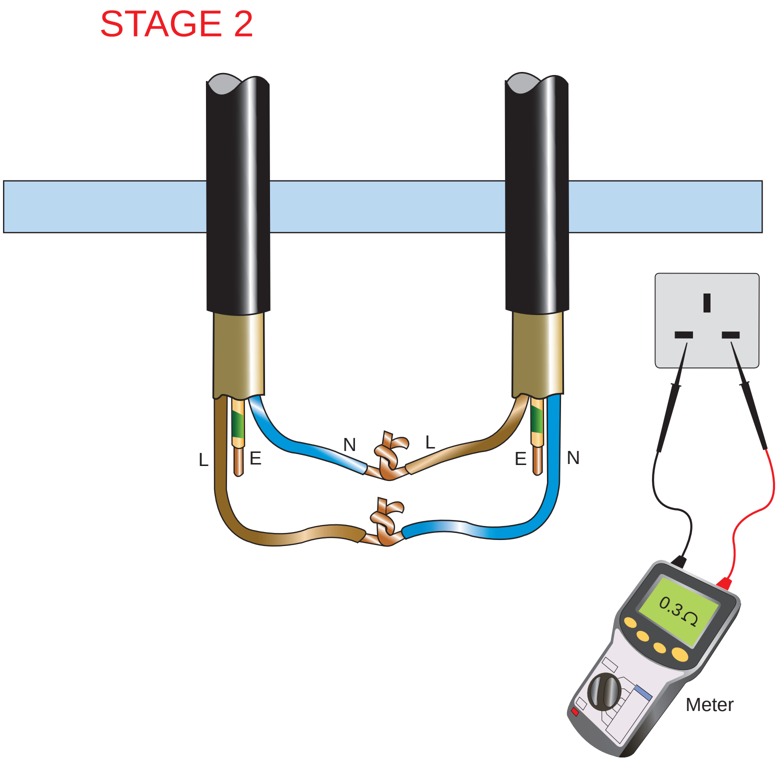


Figure F 3.4b Continuity of ring final circuits, stage 2.

Stage 2 – interconnected L-N

With phase and neutral interconnected as Figure F 3.4b, measure resistance between phase and neutral conductors at each socket outlet using a continuity tester or similar instrument. If the ring is not interconnected the measurements taken on the ring circuit will be similar. The measurements obtained will be approximately one quarter of the resistance of the sum of the open loop resistances from stage 1, that is $(R_1 + R_n)/4$.

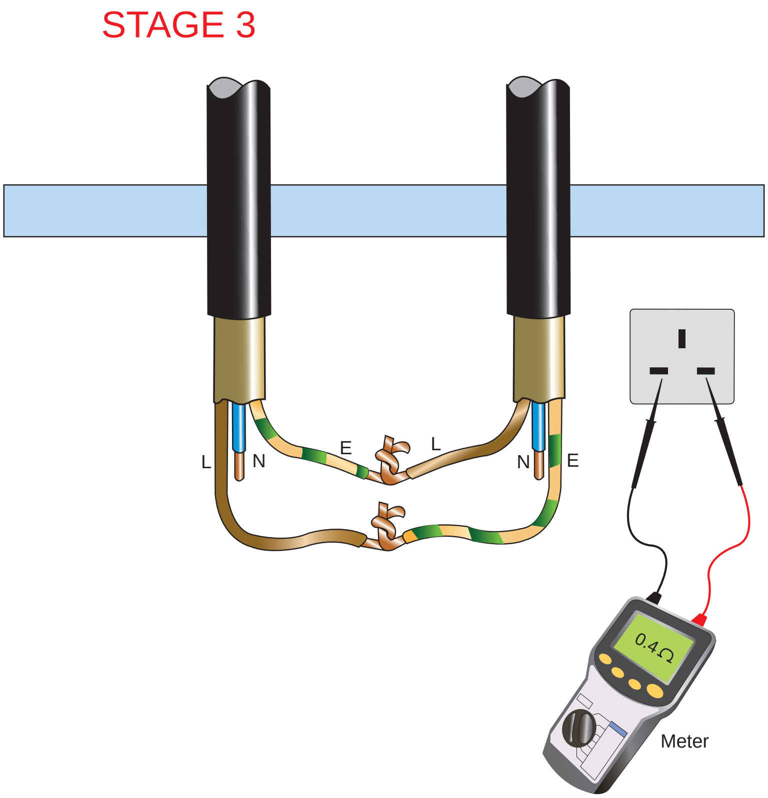


Figure F 3.4c Continuity of ring final circuits, stage 3.

Stage 3 – interconnected L-cpc (for all insulated systems)

With phase and cpc interconnected as Figure F 3.4c, measure resistance between phase and cpc conductors at each socket outlet using a continuity tester or similar instrument. If the ring is not interconnected the measurements taken on the ring circuit will be similar. The measurements obtained will be approximately one quarter of the resistance of the sum of the open loop resistances from stage 1, that is $(R_1 + R_2)/4$.

F 3.5 Insulation testing

Insulation testing is fundamental and will be used as cables are being installed. On completion of the circuit and before energization, the circuit insulation is again checked. The tests show faults or shorts as well as low insulation caused by moisture and similar. Electrical equipment and appliances such as controlgear and lamps should be disconnected prior to testing. Many such devices if left in-circuit would show as an insulation failure; also, sensitive electronic equipment such as dimmer switches and electronic ballasts could be damaged in the test.

Insulation resistance is measured between:

- live conductors, including the neutral;
- live conductors and the protective conductor connected to the earthing arrangement.

It should be noted that Regulation 612.3.1 states that insulation testing is to be made between the live and protective conductors with the protective conductors connected to the earthing arrangement. This is an additional requirement compared with previous editions of the Standard where, for example, cable could be tested to its cpc and then terminated. This procedure may catch you out as you may not be accustomed to carrying it out – so please note.

The basic method of insulation testing is shown in Figures F 3.5 and F 3.6.

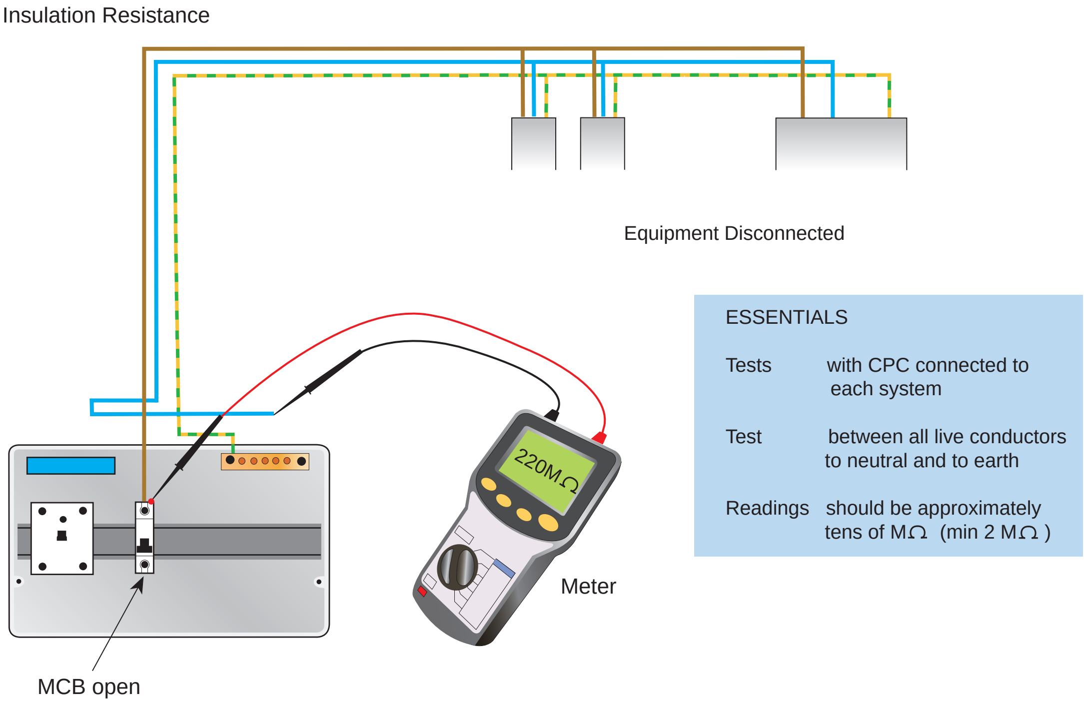


Figure F 3.5 Insulation testing.

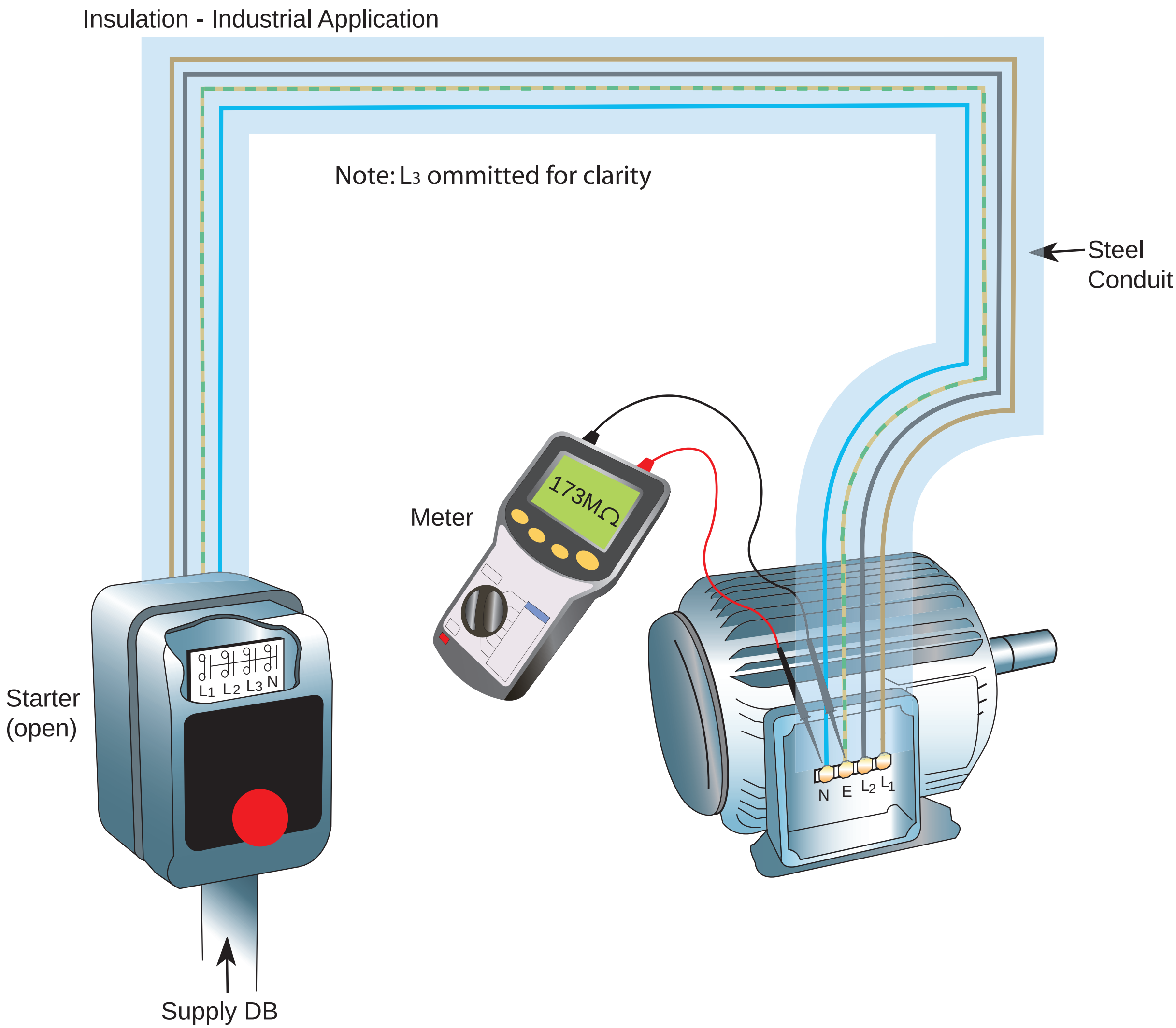


Figure F 3.6 Insulation testing of motor circuit.

Table F 3.1 Minimum value of insulation resistance – normal circuits.

Circuit nominal voltage (V)	Test voltage d.c. (V)	Minimum insulation resistance (MΩ)
Normal LV circuits up to 500 V	500	≥ 1.0
Normal LV circuits up to 500 V where it is difficult to disconnect sensitive equipment	250	≥ 1.0

Table F 3.2 Minimum value of insulation resistance SELV, PELV and circuits above 500 V.

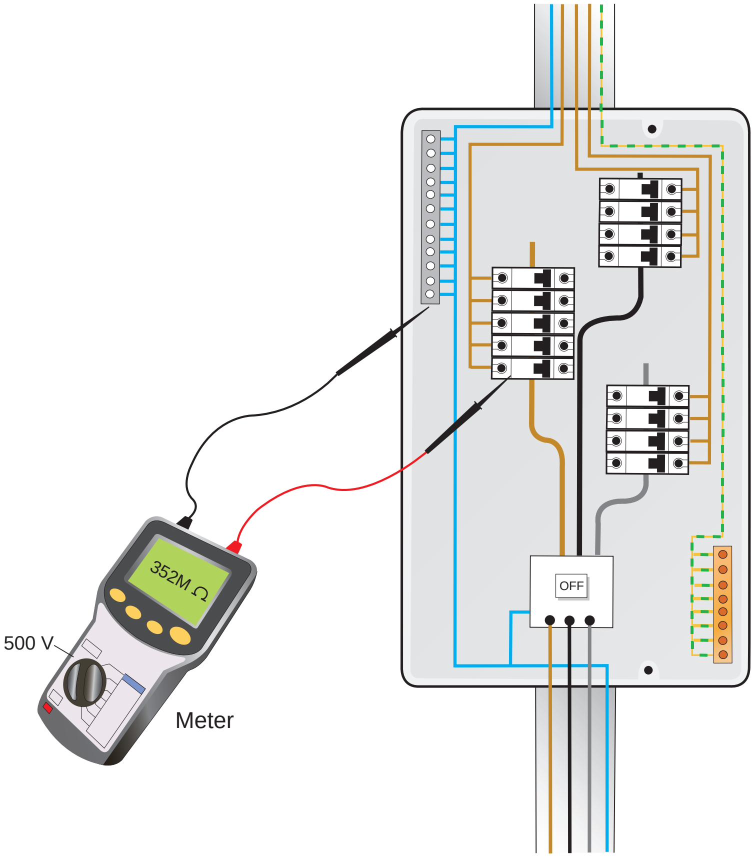
Circuit nominal voltage (V)	Test voltage d.c. (V)	Minimum insulation resistance (MΩ)
SELV and PELV	250	≥ 0.5
Above 500 V	1000	≥ 1.0

The minimum values of insulation resistance are given in Table 61 of BS 7671: 2008 reproduced here in Table F 3.1 for normal circuits.

This minimum value of 1 MΩ is an increase from the 0.5 MΩ of the 16th Edition. For most new circuits values would be way in excess of this, usually approaching the maximum scale on the meter.

Lesser used, Table F 3.2 gives minimum insulation resistance values for other circuits.

Perhaps an underused technique is that of carrying out insulation testing on groups of circuits together as shown in Figure F 3.7, and it is recommended that this is limited to 50 outlets per test.



ESSENTIALS

Up to 50 outlets in final circuits can be tested together as demonstrated here

Figure F 3.7 Insulation test of a group of circuits.

F 3.6 Polarity testing

Polarity testing is very easy to carry out. There are a few methods and all of the following are acceptable:

- visual checks where coloured cables are used;
- checks as part of the continuity testing using shorted out cable;
- neon and similar voltage probes;
- multimeters;
- indicators on ELI testers and similar.

Of all of these the visual check is usually the easiest, and this test is one that is best carried out by the person installing and terminating cables, rather than by the 'test engineer'.

Regulation 612.6 requires that every fuse and single-pole control and protective device is connected in the line conductor only. It also requires a check that E14 and E27 lampholders, not to BS EN 60238, have the outer or screwed contacts connected to the neutral conductor; but this does not apply to new installations, as new lampholders should be BS EN 60238 type.

Phase rotation

The correct phasing of three-phase circuits must of course be checked. For all sub-circuits this is usually completed by cable identification and shorting out cables as appropriate. For transformers, generators and the incoming mains LV supply, a phase rotation meter should be used to check for correct phase rotation (Regulation 612.12); follow equipment manufacturers' instructions.

F 3.7 Earth fault loop impedance (ELI) testing

Earth fault loop impedance is required to be checked at various places throughout the installation, and generally at every point where a protective device is installed.

For final circuits, there are two alternative methods of determining the earth fault loop impedance:

1. Direct measurement of total ELI.
2. Measurement of the circuit $R_1 + R_2$ value and addition to the Z_{DB} (earth fault loop impedance at the local distribution board).

Method 2 is not favoured, as explained in Section F 3.3, but if used the general procedure in this section for ELI measurement is followed, and this is added to the circuit $R_1 + R_2$ value, measured as described in Section F 3.3.

F 3.7.1 External earth fault loop impedance (Z_e)

Measurement of external ELI is necessary in LV supplies to confirm the supply earth condition. External ELI is measured live at the intake position, or close to it, with the means of earthing disconnected from the installation and the loop tester connected to it as illustrated in Figure F 3.8. The supply to the installation will need to be isolated. Care should be taken that the installation main equipotential bonding is in place, or that the test is carried out under controlled conditions. The test current on some ELI meters may make exposed-conductive-parts and extraneous-conductive-parts rise in potential in relation to true earth, presenting a

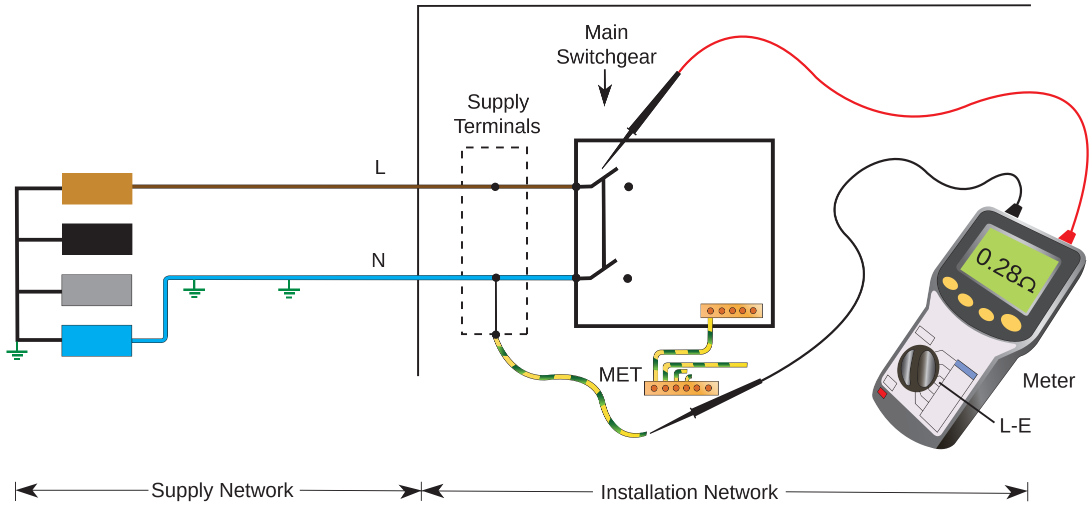


Figure F 3.8 Measurement of external earth fault loop impedance.

potential hazard to persons or livestock. If main equipotential bonding is in place the potential should be no more than a few volts.

Figure F 3.8 is a typical arrangement; in this case for a TN-C-S PME supply. Note that all loop testers illustrated in this book are two lead meters. Three lead loop meters usually perform the same task as two lead units if the neutral and earth leads are connected together, but you should confirm this by consulting the manufacturer's data. Also note that the connection point of the live supply to the meter is not critical to the result.

For UK low-voltage supplies the values should be no more than in Table F 3.3.

Table F 3.3 Maximum external ELI values.

Type of system	External earth fault loop impedance Z_e (Ω)
TN-C-S	0.35
TN-S	0.8
TT	21

Substations

It should be noted that where a transformer is installed on-site, the use of a 'contractors' ELI meter is inappropriate. Small values of resistance cannot be measured on conventional ELI instruments. Confirmation of impedances and d.c. resistance can only accurately be made by calculation and inspection or by the use of 'milli-ohmmeters' utilizing four lead connections. Both methods are outside the scope of this book.

Conventional ELI meters can be very inaccurate at resolutions below 0.1 ohm. Even at readings of 0.2 and similar a digit ± fluctuation has to be applied, and this should be borne in mind when reading the meter at low values (you may have a negative ELI value!).

F 3.7.2 Testing for total earth fault loop impedance (Z_s)

As mentioned in Section C, earth fault loop impedance may be required at various points throughout the installation and will generally need to be measured at every level of protective device.

For confirmation of final circuit disconnection times where RCDs are not installed, measured total earth fault loop impedance is usually required for all circuits.

Z_s may be carried out by direct measurement at the extremity of a circuit. Alternatively, Z_s may be collectively measured using the components in the following formula:

$$Z_s = Z_{DB} + (R_1 + R_2)$$

where:

Z_{DB} is the earth fault loop impedance at the distribution board supplying the final circuit;

$(R_1 + R_2)$ is the circuit measured line-cpc loop resistance (see Section F 3.3).

Whilst carrying out Z_s testing, both the main equipotential bonding and the means of earthing are left connected. This advice was given by the ECA for a number of years in order to maintain consistency between Z_s results when carrying out periodic testing and testing new installations. When carrying out periodic testing, disconnection of earthing and bonding is simply not practicable. The ECA advice was adopted by the IET.

This does mean that in some installations Z_s values measured directly will be less than those measured using the collectively measured $Z_s = Z_{DB} + (R_1 + R_2)$ formula. When comparing the results of measured earth fault loop impedance values with design values, this possible discrepancy should be remembered, as should the matter of possible parallel metallic earth return paths.

The physical measurement of ELI is generally as shown in Figure F 3.9, and it should be remembered that RCDs in circuit will trip unless the test instrument has a facility to block unwanted tripping. Some ELI testers can test at such small current levels that they are below the threshold of tripping. Alternatively, the RCD must be linked-out of the circuit.

The measured values of Z_s should be less than the values given in Chapter 41 of BS 7671: 2008 Tables 41.2, 41.3, 41.4 and 41.5, which are reproduced in Appendix 3. It should be noted that the limiting ELI values given in these tables are design values and should be de-rated by a factor of 0.8.

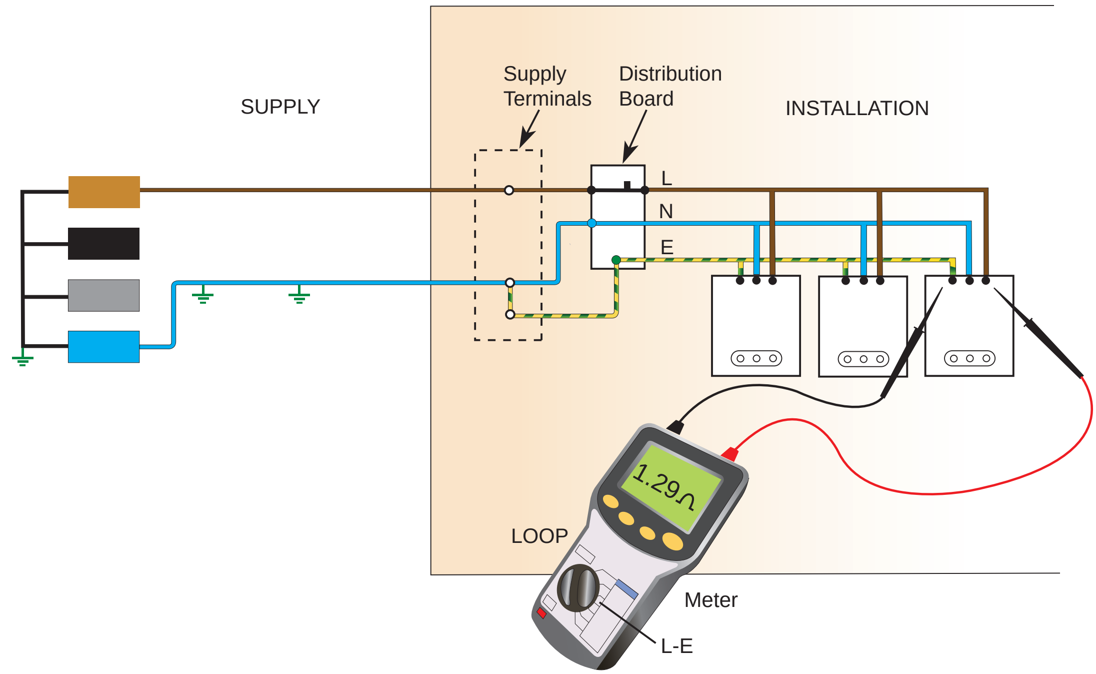


Figure F 3.9 Measurement of total ELI (Z_s).

F 3.8 Prospective fault current testing

Regulation 612.11 requires that the prospective fault current, I_{PF}, under both short-circuit and earth fault conditions, be measured, calculated or determined by another method, at the origin and at other relevant points in the installation. For domestic and LV supplies the utility values can be used and measurement is not required (the utility value is a maximum of 16 kA).

Fault current measurement, however, is quite easy to measure for modest fault levels. Most earth fault loop impedance meters double as fault current measuring devices, capable of measuring phase-neutral prospective fault current as well as earth fault current. Figure F 3.10 shows measurement at two positions within an installation.

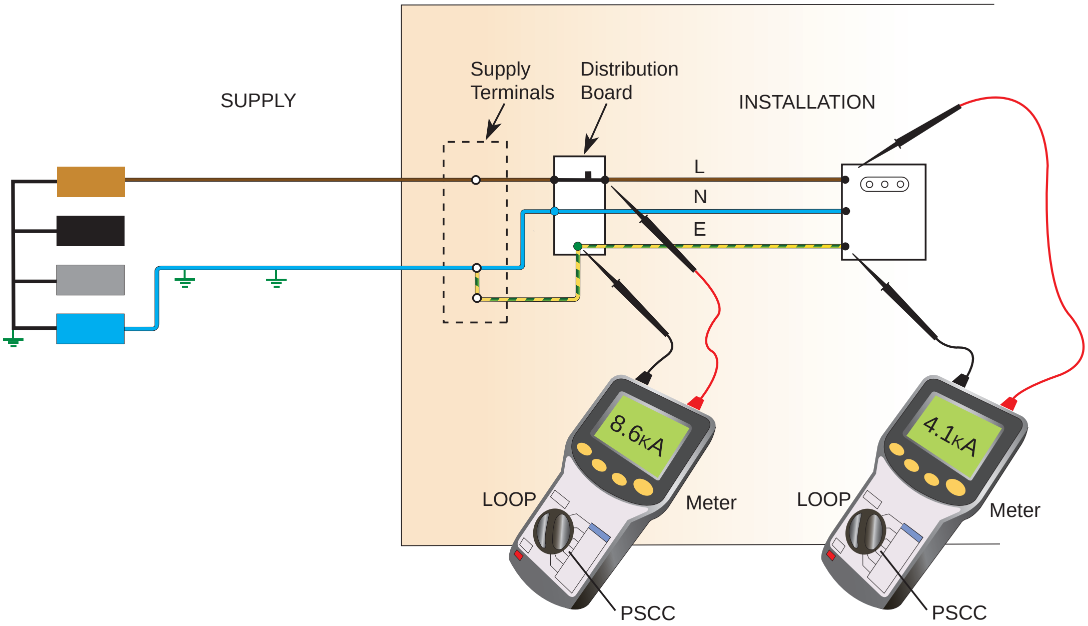


Figure F 3.10 Measurement of prospective fault current.

Bear in mind that these instruments simply measure the loop impedance and, by Ohm's law, calculate the fault current. This will give an overestimate of fault current as the fault will have a low power factor, not taken into consideration by the ELI meter.

Some test instruments are capable of measuring line-to-line fault current. These work by measuring the line-to-line loop impedance. If these instruments are not used the three-phase fault current is approximated as twice the single-phase level.

F 3.9 Testing RCDs and other functional tests

Regulation 612.13.2 requires that switchgear and control gear assemblies, controls and interlocks be functionally tested to check that they work as required. This is part of the commissioning of the electrical installation and not part of the subject of this book.

RCD testing

RCDs should have their functionality tested by operating the integrated 'trip' button. BS 7671: 2008 only requires operating time testing of RCDs where fault protection is provided by an RCD. Where final circuits have overcurrent protection by a fuse or MCB, here are a couple of options:

- either test the RCD and rely on this to achieve the disconnection time (usually within 0.4 s); or
- test the circuit for Z_s and if compliant with the tables in Chapter 41, RCD testing is not essential.

In similar fashion to other daring statements in this book, some may be uncomfortable with this suggestion, but you should consider that RCDs are a manufactured 'type-tested' device; we do not routinely test the operating characteristics of MCBs.

RCD testing itself is relatively simple in terms of using your test instrument connected on the load side of the RCD; Figure F 3.11 shows a typical RCD test.

Interpreting results, especially with time-delayed RCDs, can be a little confusing. Table F 3.4 summarizes the maximum RCD trip times for comparison with measured results and includes minimum trip times for time-delayed RCDs.

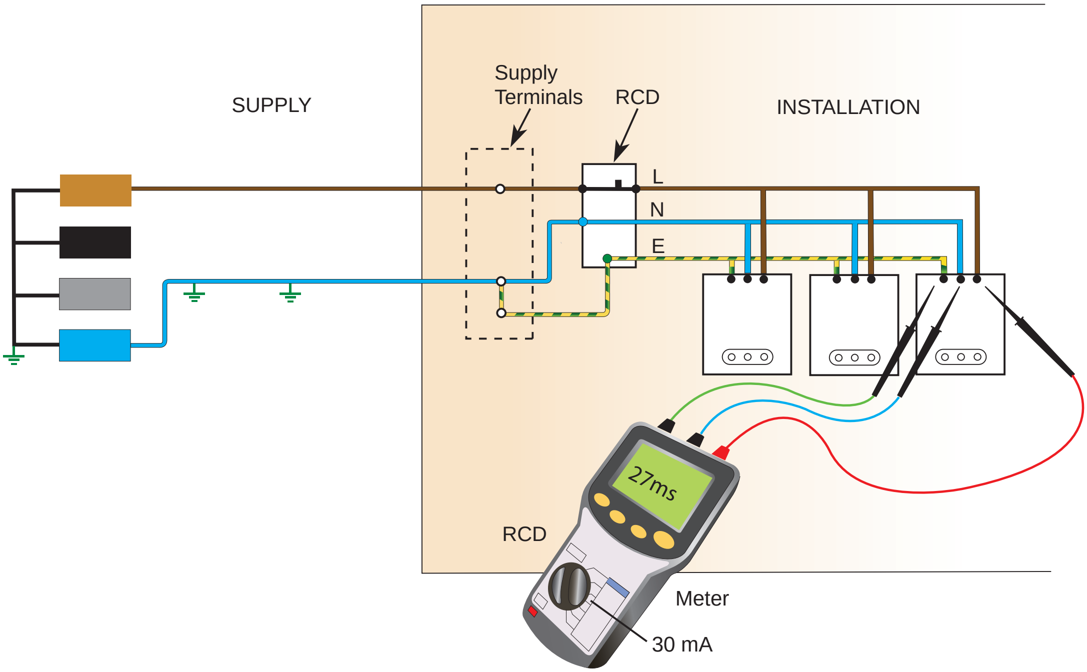


Figure F 3.11 Testing RCD trip operating times.

Table F 3.4 Trip times for RCDs.

RCD type	Sensitivity (mA)	Test current 1 × Δn (mA)	Trip time (ms)	Test current 5 × Δn (mA)	Trip time (ms)
General	10	10	200 max	50	40 max
	30	30		150	
	100	100		500	
	300	300		1500	
	500	500		2500	
Delay type S	100	100	130 min 500 max	500	40 min 150 max
	300	300	130 min 500 max	1500	40 min 150 max
	500	500	130 min 500 max	2500	40 min 150 max

Note: Testing should include a 50% no trip test

F 3.10 Verification of voltage drop

Notes have been included on this subject because it appears in Part 6 of BS 7671: 2008 and gives rise to some confusion.

Regulation 612.14 gives two methods for checking voltage drop, either by measuring a circuit's impedance or by checking design criteria.

The regulation only suggests doing this where it is necessary to verify compliance with the voltage drop requirements. In practice, this will mean where there is a voltage drop problem.

The single most important factor that will affect voltage drop under running conditions is the running current, of both the circuit and the whole installation.

F 4 Certification paperwork

F 4.1 Introduction, various certificates and schedules

Part 6 of BS 7671: 2008 requires various certificates and schedules to be issued on completion of the installation as follows:

- a completion certificate; or
- periodic report form where undertaken; and
- accompanying either of these, results of inspection and test.

This chapter provides in Section F 4.2 a brief overview of the various certificates and accompanying schedules, and a line-by-line brief of how to complete the various forms, in Section F 4.3.

Section F 4.3 describes typical certificates and forms and A4 versions of these are available in Appendix 17. The models suggested are as in BS 7671: 2008 with ECA graphics applied.

F 4.2 Overview of certificates and schedules

Electrical installation certificate (BS 7671: 2008)

This certificate should be used for new installations including alterations and additions. The certificate requires signatures for the three different aspects of design, construction, inspection and test. The certificate should be accompanied by the appropriate schedules of inspections and test results.

Single signatory electrical installation certificate (BS 7671: 2008)

This is a certificate complying fully with BS 7671: 2008 and is used where one individual or organization has been responsible for the all the aspects of design, construction, inspection and testing. The form is combined with a test schedule comprising a maximum of 18 circuits and a schedule of inspections.

Minor electrical installation works certificate (BS 7671: 2008)

For certification of installation work that does not include the introduction of new circuits, e.g. the addition of a socket outlet or lighting point to an existing circuit.

Schedule of test results

This schedule includes all the relevant information from the 'everyday tests' described in Section F 3.

Schedule of inspections

This form is used by the person carrying out the visual inspection and confirms the visual inspections undertaken.

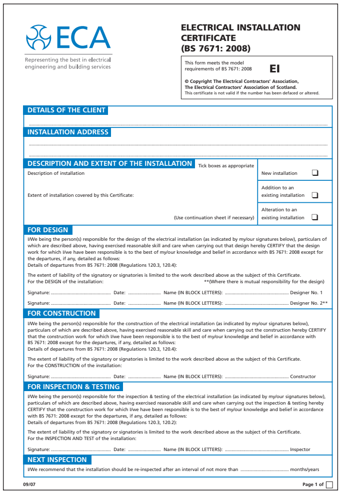
Periodic inspection report for an electrical installation (BS 7671: 2008)

This is discussed in Appendix 15.

F 4.3 Completing the paperwork

This section has been added for completeness and may be skipped by some readers.

F 4.3.1 Electrical installation certificate (BS 7671: 2008)



ECA
Representing the best in electrical engineering and building services

ELECTRICAL INSTALLATION CERTIFICATE (BS 7671: 2008)

This form meets the model requirements of BS 7671: 2008 **EI**

© Copyright The Electrical Contractors' Association, The Electrical Contractors' Association of Scotland.
This certificate is not valid if the number has been defaced or altered.

DETAILS OF THE CLIENT

INSTALLATION ADDRESS

DESCRIPTION AND EXTENT OF THE INSTALLATION Tick boxes as appropriate

Description of installation — New installation ☐

Extent of installation covered by this Certificate: — Addition to an existing installation ☐

(Use continuation sheet if necessary) — Alteration to an existing installation ☐

FOR DESIGN

I/We being the person(s) responsible for the design of the electrical installation (as indicated by my/our signatures below), particulars of which are described above, having exercised reasonable skill and care when carrying out that design hereby CERTIFY that the design work for which I/we have been responsible is to the best of my/our knowledge and belief in accordance with BS 7671: 2008 except for the departures, if any, detailed as follows:
Details of departures from BS 7671: 2008 (Regulations 120.3, 120.4):

The extent of liability of the signatory or signatories is limited to the work described above as the subject of this Certificate.
For the DESIGN of the installation: **(Where there is mutual responsibility for the design)

Signature: .... Date: .... Name (IN BLOCK LETTERS): .... Designer No. 1

Signature: .... Date: .... Name (IN BLOCK LETTERS): .... Designer No. 2**

FOR CONSTRUCTION

I/We being the person(s) responsible for the construction of the electrical installation (as indicated by my/our signatures below), particulars of which are described above, having exercised reasonable skill and care when carrying out the construction hereby CERTIFY that the construction work for which I/we have been responsible is to the best of my/our knowledge and belief in accordance with BS 7671: 2008 except for the departures, if any, detailed as follows:
Details of departures from BS 7671: 2008 (Regulations 120.3, 120.4):

The extent of liability of the signatory or signatories is limited to the work described above as the subject of this Certificate.
For the CONSTRUCTION of the installation:

Signature: .... Date: .... Name (IN BLOCK LETTERS): .... Constructor

FOR INSPECTION & TESTING

I/We being the person(s) responsible for the inspection & testing of the electrical installation (as indicated by my/our signatures below), particulars of which are described above, having exercised reasonable skill and care when carrying out the inspection & testing hereby CERTIFY that the construction work for which I/we have been responsible is to the best of my/our knowledge and belief in accordance with BS 7671: 2008 except for the departures, if any, detailed as follows:
Details of departures from BS 7671: 2008 (Regulations 120.3, 120.2):

The extent of liability of the signatory or signatories is limited to the work described above as the subject of this Certificate.
For the INSPECTION AND TEST of the installation:

Signature: .... Date: .... Name (IN BLOCK LETTERS): .... Inspector

NEXT INSPECTION

I/We recommend that the installation should be re-inspected after an interval of not more than .... months/years

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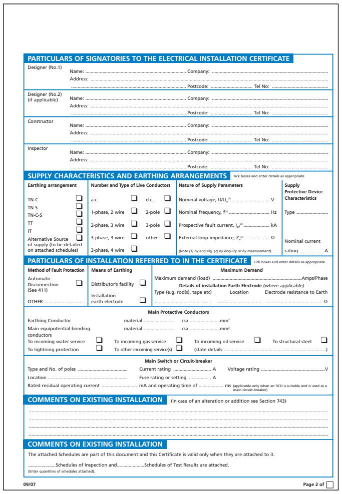

PARTICULARS OF SIGNATORIES TO THE ELECTRICAL INSTALLATION CERTIFICATE

Designer (No.1) Name: .... Company: .... Address: .... Postcode: .... Tel No: ....

Designer (No.2) (if applicable) Name: .... Company: .... Address: .... Postcode: .... Tel No: ....

Constructor Name: .... Company: .... Address: .... Postcode: .... Tel No: ....

Inspector Name: .... Company: .... Address: .... Postcode: .... Tel No: ....

SUPPLY CHARACTERISTICS AND EARTHING ARRANGEMENTS Tick boxes and enter details as appropriate

Earthing arrangement	Number and Type of Live Conductors		Nature of Supply Parameters	Supply Protective Device Characteristics
TN-C ☐	a.c. ☐	d.c. ☐	Nominal voltage, U/U_0 (1) V	
TN-S ☐	1-phase, 2 wire ☐	2-pole ☐	Nominal frequency, f (1) .... Hz	Type ....
TN-C-S ☐	2-phase, 3 wire ☐	3-pole ☐	Prospective fault current, I_{pf} (2) .... kA	
TT ☐	3-phase, 3 wire ☐	other ☐	External loop impedance, Z_e (2) .... Ω	
IT ☐	3-phase, 4 wire ☐		(Note (1) by enquiry, (2) by enquiry or by measurement)	Nominal current rating .... A
Alternative Source of supply (to be detailed on attached schedules) ☐				

PARTICULARS OF INSTALLATION REFERRED TO IN THE CERTIFICATE Tick boxes and enter details as appropriate

Method of Fault Protection: Automatic Disconnection (See 411) ☐; OTHER ....

Means of Earthing: Distributor's facility ☐; Installation earth electrode ☐

Maximum Demand: Maximum demand (load) .... Amps/Phase
Details of installation Earth Electrode *(where applicable)*: Type (e.g. rod(s), tape etc) .... Location .... Electrode resistance to Earth .... Ω

Main Protective Conductors

Earthing Conductor material .... csa .... mm²
Main equipotential bonding conductors material .... csa .... mm²
To incoming water service ☐ To incoming gas service ☐ To incoming oil service ☐ To structural steel ☐
To lightning protection ☐ To other incoming service(s) ☐ (state details ....)

Main Switch or Circuit-breaker

Type and No. of poles .... Current rating .... A Voltage rating V
Location .... Fuse rating or setting .... A
Rated residual operating current .... mA and operating time of .... ms (applicable only when an RCD is suitable and is used as a main circuit-breaker)

COMMENTS ON EXISTING INSTALLATION (in case of an alteration or addition see Section 743)

COMMENTS ON EXISTING INSTALLATION

The attached Schedules are part of this document and this Certificate is valid only when they are attached to it.
........Schedules of Inspection and........Schedules of Test Results are attached.
(Enter quantities of schedules attached).

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(For A4 versions, see Appendix 17.)

Details of the client

Insert client's name and title.

Installation address

Insert address of installation.

Description and extent of installation

Describe the extent and limitation of the certificated work.

Tick, as appropriate, the box for either new installation, addition to an existing installation or alteration to an existing installation.

Design, Construction, Inspection & Testing

The appropriate sections should be completed and signed by competent personnel authorized by those responsible for the work of design, construction, inspection and testing respectively. The relevant amendment date of BS 7671 must be added. Any departures from BS 7671 must be indicated.

Next inspection

Add the appropriate recommended date of next inspection – see Section F 4.3.6.

Particulars of signatories

To be completed by the organizations responsible for each aspect of design, construction, inspection and test.

Supply characteristics and earthing arrangements

Earthing arrangement

Add tick to the appropriate box noting the (external) supply characteristic.

Number and type of live conductors

Tick appropriate box(es).

Nature of supply parameters

The nominal supply voltage between phases (U), the voltage to earth (U_o) and the frequency must be added after confirmation by the supply company. The prospective fault current, being the larger of the short-circuit current and the earth fault current, shall be recorded – this is determined either by enquiry, measurement or calculation. The external earth fault loop impedance, Z_e, shall be recorded and is determined either by enquiry, measurement or by calculation.

Supply protective device characteristic

Type – add type of supply protective device. Also add the protective device current rating.

Particulars referred to in the certificate

Method of fault protection

Either tick EEBADOS (Earthed Equipotential Bonding and Automatic Disconnection of Supply) or, if this method is not used, enter 'see attached' in space provided and include the necessary details with the certificate.

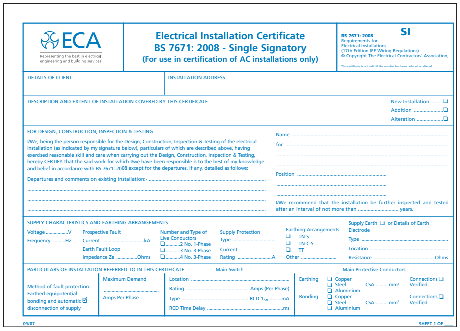
Means of earthing

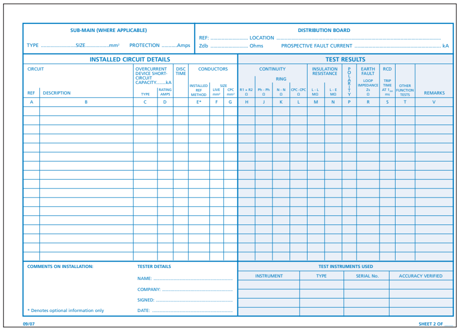
Tick appropriate box – see Chapter E.

Maximum demand

The maximum demand is the designer's estimation of the maximum load demand of the installation expressed in kVA or amps per phase and takes into account diversity. Further guidance on this subject can be found in Chapter C of this book.

F 4.3.2 Single signatory electrical installation certificate (BS 7671: 2008)


Electrical Installation Certificate
BS 7671: 2008 - Single Signatory
(For use in certification of AC installations only)
SI
DETAILS OF CLIENT
INSTALLATION ADDRESS:
DESCRIPTION AND EXTENT OF INSTALLATION COVERED BY THIS CERTIFICATE
New Installation
Addition
Alteration
FOR DESIGN, CONSTRUCTION, INSPECTION & TESTING
SUPPLY CHARACTERISTICS AND EARTHING ARRANGEMENTS
PARTICULARS OF INSTALLATION REFERRED TO IN THIS CERTIFICATE


SUB-MAIN (WHERE APPLICABLE)
DISTRIBUTION BOARD
INSTALLED CIRCUIT DETAILS
TEST RESULTS
COMMENTS ON INSTALLATION:
TESTER DETAILS
TEST INSTRUMENTS USED

(For A4 versions, see Appendix 17.)

Certificate overview

Where design, construction and inspection and testing are the responsibility of one person or organization, this single signatory certificate can be used and fully complies with BS 7671: 2008. It also combines a test sheet and can be used for an installation of up to 18 circuits of any current rating.

Details of client

Insert client's name and title.

Installation address

Insert address of installation.

Description and extent of installation

Briefly describe the installation and describe the extent and limitation of the certificated work.

Tick, as appropriate, the box for either new installation, addition to an existing installation or alteration to an existing installation.

Design, construction, inspection and testing

This section should be completed and signed by the individual responsible for the work of design, construction, inspection and testing of the installation. The relevant BS 7671 amendment date should be added.

Next inspection

Add the appropriate recommended date of next inspection – see Section F 4.3.6.

Supply characteristics and earthing arrangements

Voltage

Add supply voltage to earth (U_o) and supply frequency in Hz. The prospective fault current must be recorded, and is the larger of the short-circuit current and earth fault current established by enquiry or measurement. The external earth fault loop impedance Z_e shall be recorded and may be measured or determined by enquiry.

Number and type of live conductors

Tick appropriate box(es).

Supply protection

Type – add type of supply protective device. Also add the protective device current rating.

Earthing arrangement

Tick appropriate box noting the (external) supply characteristic.

Supply earth and earth electrode

Where there is an electricity company earth, tick the box. If there is a private earth electrode system, provide details here.

Particulars of installation referred to in this certificate

Method of fault protection

The certificate can only be used for normal ADOS (Automatic Disconnection of Supply) and this method has been pre-ticked to indicate this.

Maximum demand

The maximum demand is the designer's estimation of the maximum load demand of the installation expressed in kVA or amps per phase and takes into account diversity. Further guidance on this subject can be found in Chapter C.

Main switch or circuit breaker

Complete all entries.

Main protective conductors

Complete as necessary.

Submain

Add details of submain where applicable.

Distribution board

Add details – Z_s and prospective fault current are measured (or calculated) at the distribution board. Note: do not add external readings.

Installed circuit details

A Add circuit reference.
B Describe circuit briefly, i.e. ring, socket outlets.

Top of columns C & D

Add short circuit breaking capacity of overcurrent device as follows:

BS	Type	Typical breaking capacity (kA)
BS 88	HRC cartridge fuse	80
BS 3036	Rewireable	2
BS 1361	Household cartridge fuse	16.5
BS EN 60898	Circuit breaker	3, 6, 9, or 16

C Add type of protection device. For fuse add BS number, for circuit breaker add sensitivity type B, C or D.
D Add current rating of protective device.
E *Optional column.*
Add installed reference method from Appendix 4 of BS 7671.

F Add line and neutral conductor size where they are the same. If reduced neutral add to remarks column.

G Add cpc size. Optionally, for armoured cables, add cross-sectional area of armour in mm^2. If not SWA add material type.

H Continuity. Add maximum value obtained from method used to check continuity of cpc at all points on circuit and delete $R_1 + R_2$ or R_2 as appropriate, depending upon method used.

Optionally, this column may be ticked.

Where the circuit is a ring the ($R_1 + R_2$) value must be inserted into column H and will be the ($R_1 + R_2$) on the ring with the phase and cpc cross-connected at the board. See Section F 3.4.

J, K & L ring continuity only

J Add open phase/phase resistance.

K Add open neutral/neutral resistance.

L Add open cpc/cpc resistance.

Insulation resistance

M Test between phase conductors and phase to neutral and record the minimum.

N Test phase to earth and neutral to earth either together or separately and record the minimum.

P *Polarity*. Tick when polarity at all points has been checked.

R *Earth fault loop impedance*. Either add Z_e at incomer (distribution board) to the ($R_1 + R_2$) value or measure at remote part of circuit. Record the maximum value measured.

Functional tests

S Check RCD trip time at normal rate current setting only.

T Tick this column after functional checks are made including: assemblies, switchgear/control gear, drives, controls and interlocks to show they are properly mounted, adjusted and installed in accordance with BS 7671: 2008.

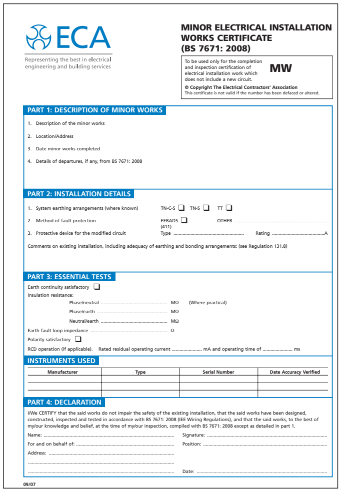
Other comments

Add relevant comments.

Test instruments used

Add details of all instruments used whilst testing.

F 4.3.3 Minor electrical installation works certificate (BS 7671: 2008)



ECA
Representing the best in electrical engineering and building services

MINOR ELECTRICAL INSTALLATION WORKS CERTIFICATE (BS 7671: 2008)

To be used only for the completion and inspection certification of electrical installation work which does not include a new circuit. **MW**

© Copyright The Electrical Contractors' Association
This certificate is not valid if the number has been defaced or altered.

PART 1: DESCRIPTION OF MINOR WORKS

1. Description of the minor works
2. Location/Address
3. Date minor works completed
4. Details of departures, if any, from BS 7671: 2008

PART 2: INSTALLATION DETAILS

1. System earthing arrangements (where known) TN-C-S ❑ TN-S ❑ TT ❑
2. Method of fault protection EEBADS (411) ❑ OTHER ....
3. Protective device for the modified circuit Type .... Rating ....A

Comments on existing installation, including adequacy of earthing and bonding arrangements: (see Regulation 131.8)

PART 3: ESSENTIAL TESTS

Earth continuity satisfactory ❑
Insulation resistance:
Phase/neutral .... MΩ (Where practical)
Phase/earth .... MΩ
Neutral/earth .... MΩ
Earth fault loop impedance .... Ω
Polarity satisfactory ❑
RCD operation (if applicable). Rated residual operating current .... mA and operating time of .... ms

INSTRUMENTS USED

Manufacturer	Type	Serial Number	Date Accuracy Verified

PART 4: DECLARATION

I/We CERTIFY that the said works do not impair the safety of the existing installation, that the said works have been designed, constructed, inspected and tested in accordance with BS 7671: 2008 (IEE Wiring Regulations), and that the said works, to the best of my/our knowledge and belief, at the time of my/our inspection, compiled with BS 7671: 2008 except as detailed in part 1.

Name: .... Signature: ....
For and on behalf of: .... Position: ....
Address: ....
....
.... Date: ....

09/07

(For A4 version, see Appendix 17.)

This certificate is fully compliant with BS 7671: 2008 when used for the certification of electrical work which does not include a new circuit (e.g. circuit extensions). It should not be used for a consumer unit change.

Description of minor works

Complete as necessary.

Installation details

1 System earthing arrangements – tick appropriate box.
2 Tick boxes or describe other methods as appropriate.
3 Add BS and type of protective device and list its rating.

Add any relevant comments.

Essential tests

Complete these minimum essential tests including the installation phase to neutral test only where practical.

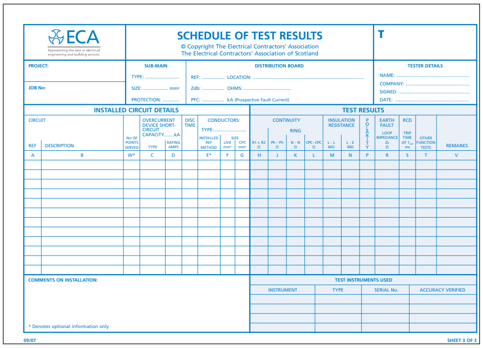
Instruments used

List all instruments used while testing.

Declaration

Sign as necessary.

F 4.3.4 Schedule of test results



(For A4 version, see Appendix 17.)

Project
Add details.

Job no.
Optional, for your company use.

Submain
Add details where applicable.

Distribution board
Add details – Z_s and prospective fault current are measured (or calculated) at the distribution board.

Installed circuit details
A Add circuit reference.
B Describe circuit briefly, i.e. ring, socket outlets.

Top of columns C & D
Add short circuit breaking capacity of overcurrent device as follows:

BS	Type	Typical breaking capacity (kA)
BS 88	HRC cartridge fuse	80
BS 3036	Rewireable	2
BS 1361	Houshold cartridge fuse	16.5
BS EN 60898	Circuit breaker	3, 6, 9, or 16

C Add type of protection device. For fuse add BS Number, for circuit breaker add sensitivity type B, C or D.
D Add current rating of protective device.

E *Optional column*
Add installed reference method from Appendix 4 of BS 7671.

F Add line and neutral conductor size where they are the same. If reduced neutral add to remarks column.

G Add cpc size. Optionally, for armoured cables, add cross-sectional area of armour in mm^2. If not SWA add material type.

H Continuity. Add maximum value obtained from method used to check continuity of cpc at all points on circuit and delete $(R_1 + R_2)$ or R_2, as appropriate, depending upon method used.

Optionally, this column may be ticked.

Where the circuit is a ring the $(R_1 + R_2)$ value must be inserted into column H and will be the $(R_1 + R_2)$ on the ring with the phase and cpc cross-connected at the board. See Section F 3.4.

Ring continuity only

J Add open phase/phase resistance.

K Add open neutral/neutral resistance.

L Add open cpc/cpc resistance.

Insulation resistance

M Test between phase conductors and phase to neutral and record the minimum.

N Test phase to earth and neutral to earth either together or separately and record the minimum.

P *Polarity*. Tick when polarity at all points has been checked.

R *Earth fault loop impedance*. Either add Z_e at incomer (distribution board) to the $(R_1 + R_2)$ value or measure at remote part of circuit. Record the maximum value measured.

Functional tests

S Check RCD trip time at normal rate current setting only.

T Tick this column after functional checks are made including: assemblies, switchgear/control gear, drives, controls and interlocks to show they are properly mounted, adjusted and installed in accordance with BS 7671: 2008.

V Add any relevant remarks to each circuit.

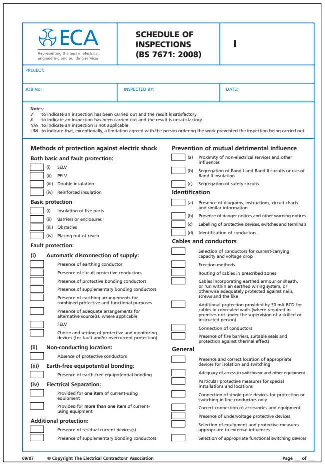
Other comments

Add relevant comments to section.

Test instruments used

Add details of all instruments used whilst testing.

F 4.3.5 Schedule of inspections



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SCHEDULE OF INSPECTIONS (BS 7671: 2008)

I

PROJECT:

JOB No: | INSPECTED BY: | DATE:

Notes:
✓ to indicate an inspection has been carried out and the result is satisfactory
✗ to indicate an inspection has been carried out and the result is unsatisfactory
N/A to indicate an inspection is not applicable
LIM to indicate that, exceptionally, a limitation agreed with the person ordering the work prevented the inspection being carried out

Methods of protection against electric shock

Both basic and fault protection:
- (i) SELV
- (ii) PELV
- (iii) Double insulation
- (iv) Reinforced insulation

Basic protection
- (i) Insulation of live parts
- (ii) Barriers or enclosures
- (iii) Obstacles
- (iv) Placing out of reach

Fault protection:

(i) Automatic disconnection of supply:
- Presence of earthing conductor
- Presence of circuit protective conductors
- Presence of protective bonding conductors
- Presence of supplementary bonding conductors
- Presence of earthing arrangements for combined protective and functional purposes
- Presence of adequate arrangements for alternative source(s), where applicable
- FELV
- Choice and setting of protective and monitoring devices (for fault and/or overcurrent protection)

(ii) Non-conducting location:
- Absence of protective conductors

(iii) Earth-free equipotential bonding:
- Presence of earth-free equipotential bonding

(iv) Electrical Separation:
- Provided for **one item** of current-using equipment
- Provided for **more than one item** of current-using equipment

Additional protection:
- Presence of residual current devices(s)
- Presence of supplementary bonding conductors

Prevention of mutual detrimental influence
- (a) Proximity of non-electrical services and other influences
- (b) Segregation of Band I and Band II circuits or use of Band II insulation
- (c) Segregation of safety circuits

Identification
- (a) Presence of diagrams, instructions, circuit charts and similar information
- (b) Presence of danger notices and other warning notices
- (c) Labelling of protective devices, switches and terminals
- (d) Identification of conductors

Cables and conductors
- Selection of conductors for current-carrying capacity and voltage drop
- Erection methods
- Routing of cables in prescribed zones
- Cables incorporating earthed armour or sheath, or run within an earthed wiring system, or otherwise adequately protected against nails, screws and the like
- Additional protection provided by 30 mA RCD for cables in concealed walls (where required in premises not under the supervision of a skilled or instructed person)
- Connection of conductors
- Presence of fire barriers, suitable seals and protection against thermal effects

General
- Presence and correct location of appropriate devices for isolation and switching
- Adequacy of access to switchgear and other equipment
- Particular protective measures for special installations and locations
- Connection of single-pole devices for protection or switching in line conductors only
- Correct connection of accessories and equipment
- Presence of undervoltage protective devices
- Selection of equipment and protective measures appropriate to external influences
- Selection of appropriate functional switching devices

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(For A4 version, see Appendix 17.)

Simply insert a tick into the appropriate box indicating the inspections made. Add a 'N/A' to the box where the inspection is not applicable.

You may feel it is appropriate to insert 'LIM' (for limitation) into a box where the inspection type is limited to certain areas. If this is the case, you should create your own 'LIM' legend on the schedule.

The schedule should be used with an associated Electrical Installation Certificate or Periodic Inspection Report.

F 4.3.6 Recommended frequencies of next inspection

The frequencies of 'next' inspection are shown in Table F 4.1 and reproduced from IEE Guidance Note 3.

Table F 4.1 Recommended initial frequencies of electrical installation inspections.

Type of installation	Maximum period between inspections and testing as necessary	Reference (see notes below)
Domestic	Change of occupancy/10 years	
All commercial i.e. shops, offices, hospitals and labs etc.	Change of occupancy/5 years	1
Industrial	3 years	
Places subject to entertainment licence	1 (note 2)	1,2
Public swimming pools, caravan parks	1 year	1,2

[1] See also Electricity at Work Regulations 1989.
[2] This is normally a requirement of local licensing organizations.

RESEARCH

HOME ELECTRICAL FIRES

Richard Campbell
March 2019

Key Findings

Fires involving electrical failure or malfunction

- Local fire departments responded to an estimated average of 44,880 home fires involving electrical failure or malfunction each year in 2012-2016.
- Home fires involving electrical failure or malfunction caused an estimated average of 440 civilian deaths and 1,250 civilian injuries each year in 2012-2016, as well as an estimated $1.3 billion in direct property damage a year.
- Electrical distribution, lighting, and power transfer equipment accounted for half (50%) of home fires involving electrical failure or malfunction, followed by cooking equipment (15%), heating equipment (9%), fans (6%), air conditioners (3%), and clothes dryers (3%).
- Nearly two of five fires (39%) involving electrical failure or malfunction occurred in the cold weather months from November through February. These fires were less likely to occur in the overnight hours between midnight and 8 a.m. (22% of total), but fires during this time period accounted for 60% of the civilian deaths.

Fires involving electrical distribution and lighting equipment[1]

- Local fire departments responded to an estimated average of 35,150 home fires involving electrical distribution and lighting equipment each year in 2012-2016.
- Home fires involving electrical distribution and lighting equipment caused an estimated average of 490 civilian deaths and 1,200 civilian injuries each year in 2012-2016, as well as an estimated $1.3 billion in direct property damage a year.
- Home fires involving electrical distribution and lighting equipment most often originated in a bedroom (17% of total), attic or ceiling (12%), or a wall assembly or concealed space (9%).
- Approximately one-quarter (24%) of these fires occurred between midnight and 8 a.m., but these fires accounted for 60% of deaths.

[1] Estimates exclude the six structure fire incident types for confined cooking fires, chimney or flue fires, fuel burner or boiler fires, incinerator, compactor, or trash fires.

Home Electrical Fires

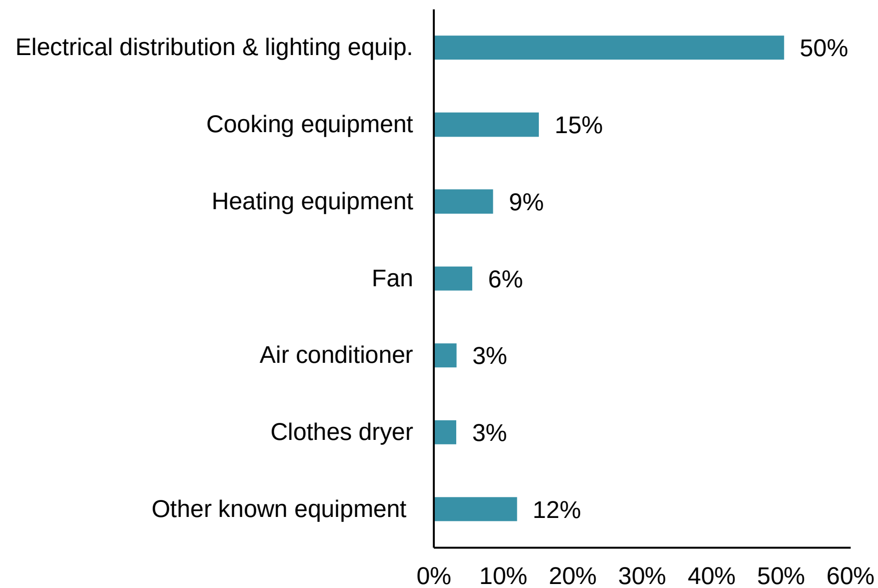
Home electrical fires can start in wiring, electrical distribution systems, and lighting equipment, as well as in any equipment powered by electricity such as cooking, heating, office and entertainment equipment, washers and dryers, as well as electrical distribution or lighting equipment. To better understand if these types of fires can be prevented through code changes, equipment changes, and/or public education, this report splits home electrical fires into two groups, based on data from two separate data elements in the National Fire Incident Reporting System (NFIRS):

1. Fires in which electrical failure or malfunction is a factor contributing to ignition.

2. Fires involving electrical distribution and lighting equipment. These are fires in which electrical distribution or lighting equipment are somehow involved in a fire's ignition. The form of involvement could include electrical failure or malfunction but may also involve other types of involvement, such as serving as a heat source by being in close proximity to combustible material or by overloaded equipment.

Figure 1 shows the types of equipment involved in home fires in which electrical failure or malfunction contributed to ignition. As indicated, electrical distribution and lighting equipment accounts for half of these fires.

Figure 1. Home Fires Involving Electrical Failure or Malfunction by Equipment Involved in Ignition 2012-2016



Home Fires Involving Electrical Failure or Malfunction

Electrical failures or malfunctions are a leading factor in the ignition of fires in U.S. homes. Electrical failures or malfunctions were responsible for 13% of home structure fires in 2012-2016, ranking as the second leading contributing factor behind fires caused by unattended equipment. Electrical failure or malfunction fires also accounted for nearly one-fifth (18%) of civilian deaths (the second leading contributing factor behind fires caused by heat sources too close to combustibles), 11% of civilian injuries, and accounted for the greatest share of direct property damage (20%).

Types of Electrical Failure or Malfunction Contributing to the Ignition of Home Fires

As shown in Figure 2, home fires due to electrical failure or malfunction primarily involve some form of arcing, which results from an unintentional discharge of electrical current between conductors. Given sufficient time and level of current, arc faults can produce enough heat to ignite a fire. Arc faults are produced by damaged conductors and connectors and may involve damaged wiring, frayed appliance cords, loose connections in wall outlets, or faulty switches and junction boxes. Arc faults may originate in different areas of the home or virtually any electrical fixture or equipment.

Electrical fault sparks fire that displaces residents

An electrical fault in a ceiling fan was blamed for an early morning fire in a multifamily residence.

Firefighters were dispatched to the fire following a 911 call from one of the occupants after a smoke alarm in his unit activated just after midnight. On arrival, crews reported fire on the second floor of a two-and-a-half-story wood-frame structure.

The fire escalated to four alarms before firefighters were able to knock it down. News reports indicated that 11 occupants were displaced by the fire, but none were injured. One firefighter was reported to have suffered a back injury at the scene.

Investigators determined that the fire was caused by an electrical short circuit in a ceiling fan in a second-floor bathroom.

The building was composed of five residential units. According to news reports, a city inspector indicated that he did not find the number of smoke alarms in the building that were required by municipal codes. The building did not have sprinkler protection.

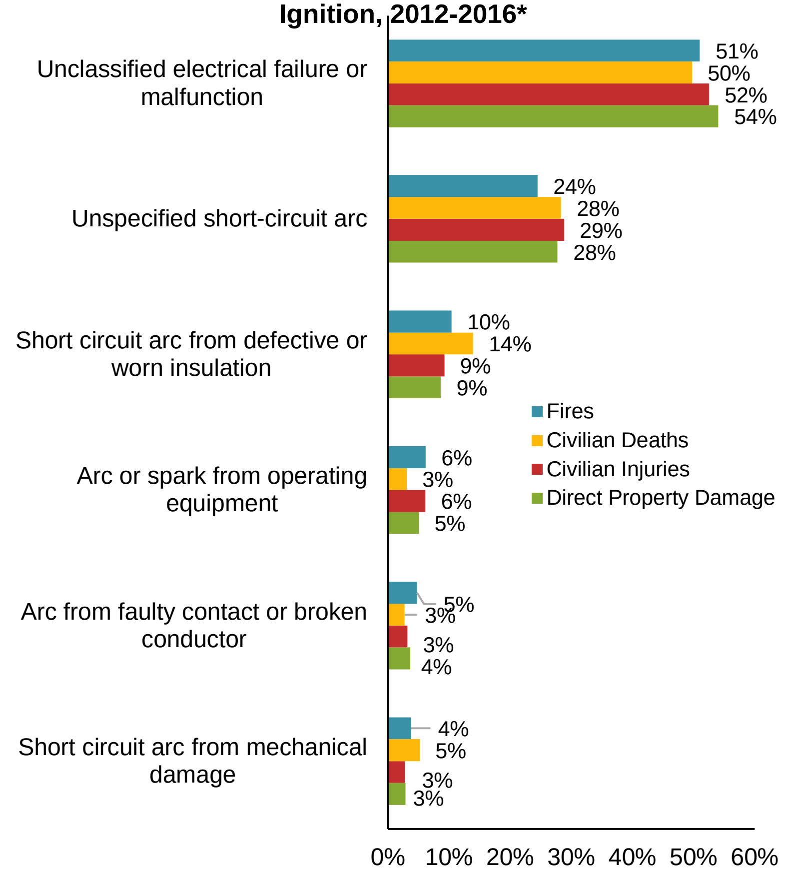
The fire caused an estimated $500,000 in damage to the structure and an additional $500,000 in damage to its contents.

Source: Richard Campbell, "Firewatch," *NFPA Journal*, July/August, 2018.

- Short circuits from defective and worn insulation caused 14% of civilian home fire deaths as shown in Figure 2. This can be caused when cords are pinched by doors or furniture or through repetitive flexing of appliance cords. It can also be due to damaged wiring inside walls from nails, screws, or drill bits that puncture insulation during ordinary activities like hanging a picture. Even electrical cords running under carpets can generate enough heat to produce an arc fault.

- Aging electrical systems in older homes can be a source of arc faults, either through normal wear and tear or because the systems cannot accommodate the greater demands of modern appliances. Circuits can also be overloaded by providing electricity to too many appliances, often through power cords.

Figure 2. Home Fires Involving Electrical Failure or Malfunction by Factor Contributing to Ignition, 2012-2016*



Trends in Home Fires Involving Electrical Failure or Malfunction

The number of home fires involving electrical failure or malfunction has followed a distinct downward trend since 1980, despite year-to-year fluctuations. From a peak of 75,000 fires in 1980, the estimated number of fires involving electrical failure or malfunction has fallen to fewer than 60,000 annual fires since 1998 and fewer than 50,000 each year since 2008, with the 40,900 fires in 2012 representing a new low point (Figure 3).

A recent NFPA report on home structure fires by Marty Ahrens found that overall home structure fires have plateaued over the past two decades. The continued, if uneven, decline in home fires involving electrical failure or malfunction over this same period suggests that this is an area of relative progress. The data indicate that civilian deaths in these fires have not followed a similar downward trend to that seen in fires, showing distinct fluctuations from year to year (Figure 4).

Figure 3. Home Fires Involving Electrical Failure or Malfunction, 1980-2016

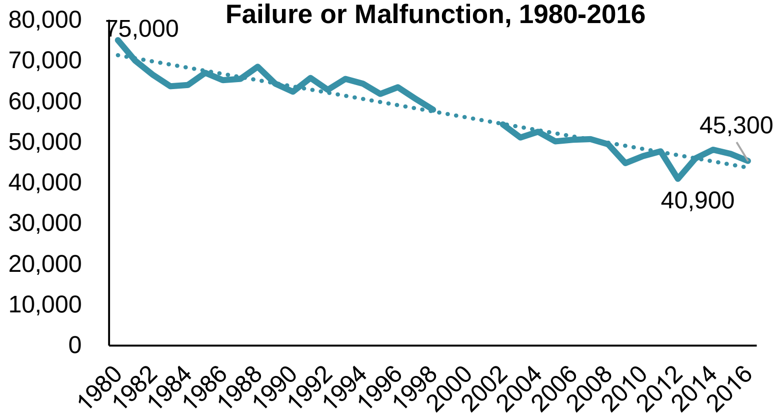
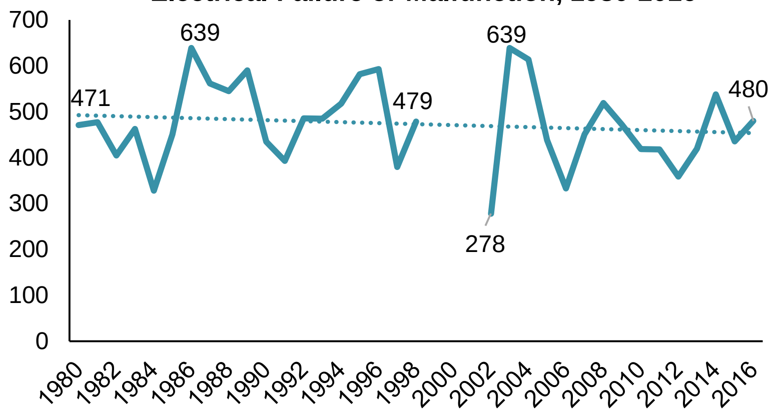


Figure 4. Civilian Deaths in Home Fires Involving Electrical Failure or Malfunction, 1980-2016

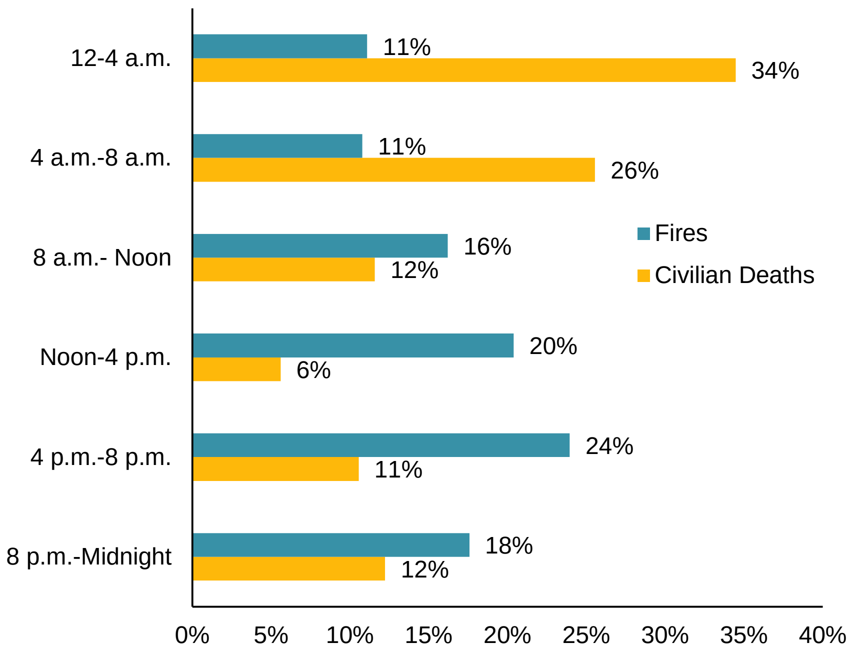


Note: Because of low participation in NFIRS Version 5.0 during 1999-2001, data from these years is not reported in these graphs.

When do home fires involving electrical failure or malfunction occur?

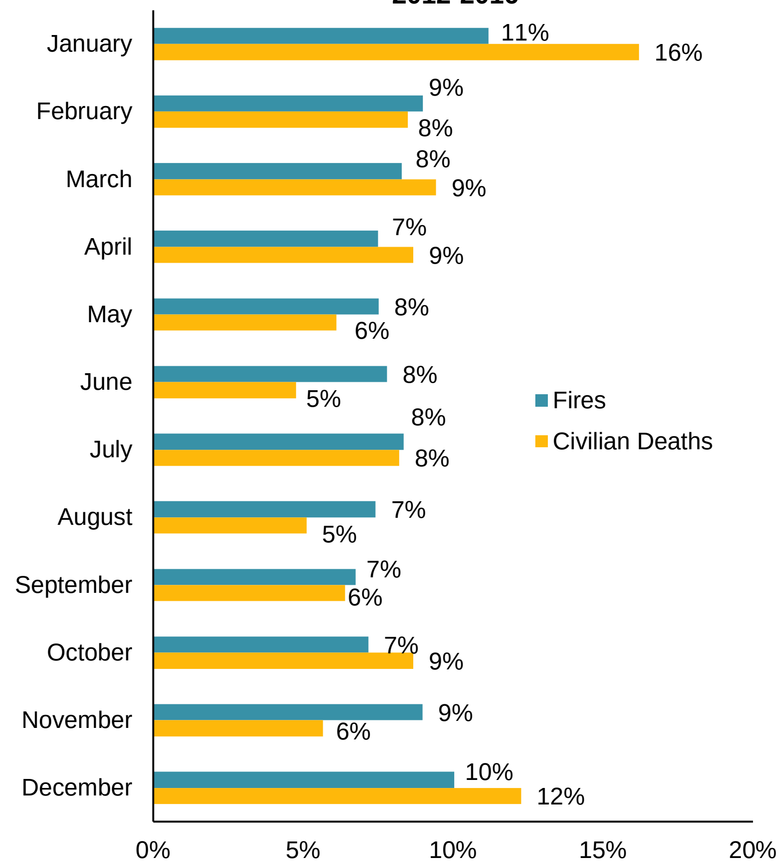
Home fires involving electrical failure or malfunction are less likely to occur in the overnight hours between midnight and 8 a.m. (22% of total), but these fires account for 60% of the civilian deaths. Fires that occur during the night when most people are asleep are more likely to be fatal. Working smoke alarms can provide an early warning of fire and allow additional time for evacuation.

Figure 5. Home Fires Involving Electrical Failure or Malfunction, by Time of Day 2012-2016



The peak months for home fires involving electrical failure or malfunction are November through March (47% of total), and these fires account for 52% of the civilian deaths. This is the time of year when more time is spent indoors, leading to an increased use of electrical equipment.

Figure 6. Home Fires Involving Electrical Failure or Malfunction by Month 2012-2016

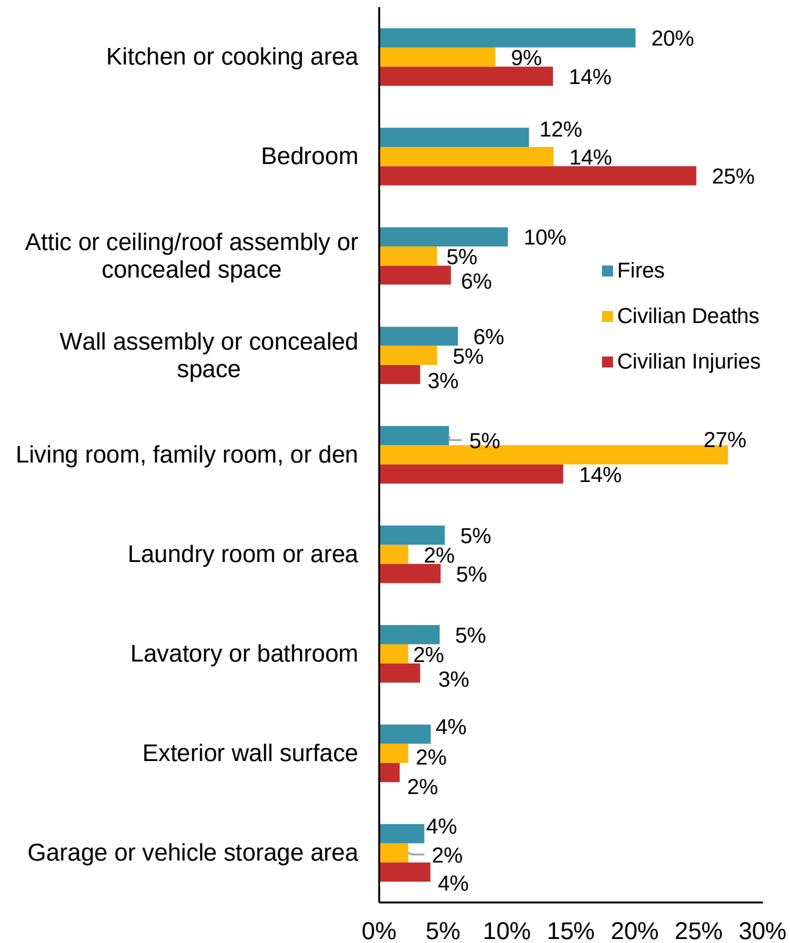


Area of Origin in Home Fires Involving Electrical Failure or Malfunction

One in five home fires (20%) involving electrical failure or malfunction originated in a kitchen or cooking area, with another 12% originating in a bedroom and 10% originating in an attic or ceiling/roof assembly or concealed space. Electrical failures or malfunctions within the wall assembly or concealed space is the fourth leading area of origin for these fires.

Fires originating in a living room, family room, or den accounted for a disproportionately large share of civilian deaths, while those originating in a bedroom accounted for a disproportionately large share of civilian injuries.

Figure 7. Area of Origin in Home Fires Involving Electrical Failure or Malfunction 2012-2016*



*Only leading areas of origin shown

Home Fires Involving Electrical Distribution and Lighting Equipment

Electrical distribution and lighting equipment was the third leading type of equipment involved in fires in U.S. homes in 2012-2016, accounting for 10% of fires (behind cooking equipment and heating equipment). These fires accounted for a disproportionate share of home fire deaths (19%) and direct property damage (20%), as well as 10% of civilian injuries.

The previously mentioned change in data entry rules for incidents with an equipment-related heat source or factor contributing to ignition in 2012 is likely to have influenced estimates of electrical distribution and lighting equipment fires.

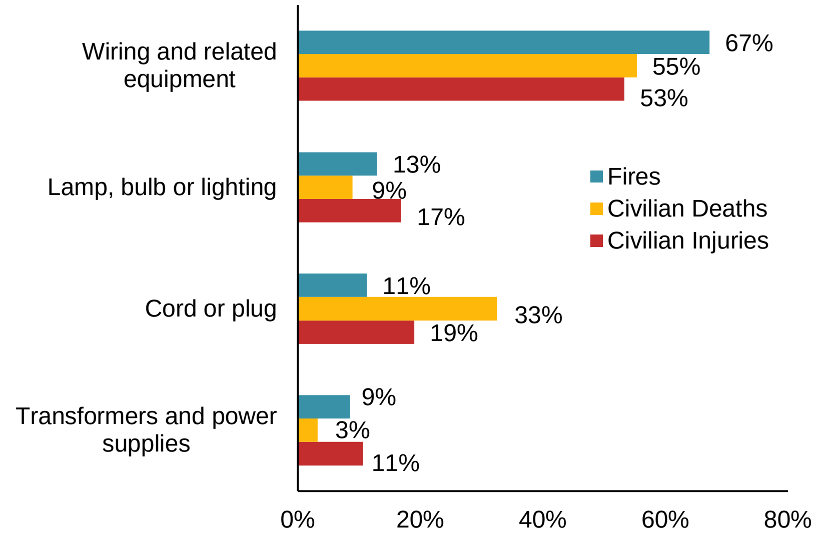
Types of Electrical Distribution and Lighting Equipment Involved in Home Fires

As shown in Figure 8, wiring and related equipment accounted for two-thirds of home fires caused by electrical distribution and lighting equipment and the same share of direct property damage, as well as over half of the civilian deaths and injuries.

Faulty wiring in concealed spaces, such as attics or behind walls, is particularly dangerous because it can start fires that burn for a prolonged period of time before detection.

Aluminum wire connections have been found to be prone to deterioration that results in increased resistance to electric current, with the cumulative damage capable of producing hazardous overheating, leading the Consumer Product Safety Commission (CPSC) to recommend that home aluminum wiring be replaced or repaired by a qualified electrician to reduce the potential for fire.

Figure 8. Types of Electrical Distribution or Lighting Equipment Involved in Home Fires, 2012-2016*

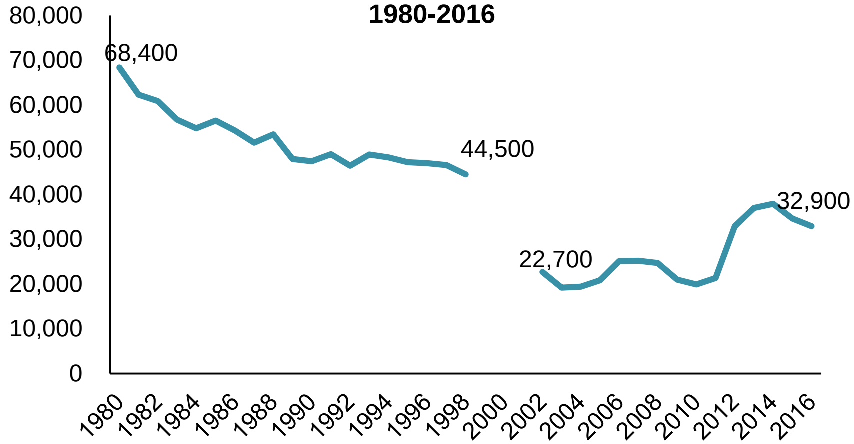


*All data in this section are non-confined fires only.

Trends in Home Fires Involving Electrical Distribution and Lighting Equipment

Home fires involving electrical distribution or lighting equipment showed a steady downward trend between 1980 and 1998, declining by about one-third during this period. See Figure 9. Following the introduction of a new version of NFIRS (NFIRS 5.0) and a transition period of 1999-2001, the downward trend was arrested and even reversed between 2011 and 2014 before falling again in 2015 and 2016, although fires are still well below those reported prior to 1999. A 2012 change in NFIRS data entry rules which required a valid entry in the "equipment involved in ignition" field for incidents having an equipment-related heat source or contributing factor had the largest impact on estimates of electrical distribution or lighting equipment fires.

Figure 9. Home Fires Involving Electrical Distribution and Lighting Equipment, 1980-2016



Note: Because of low participation in NFIRS Version 5.0 during 1999-2001, data from these years is not reported in this graph.

Electrical wiring causes house fire that kills elderly resident

An elderly resident died when degraded electrical wiring ignited combustible material in a wall cavity in the kitchen of his residence.

The fire department was summoned to the scene following a neighbor's call to 911 at 1:15 a.m., but investigators estimated that the fire had burned for an hour before it was detected.

According to news reports, firefighters found flames shooting from the rear of the house upon arrival, but they located the victim on a couch in a front room and quickly rushed him to the hospital. The victim, who had a mobility disability, succumbed to smoke inhalation injuries shortly afterwards.

Reports indicated that the resident had an unspecified physical disability.

The house was equipped with smoke alarms in the living room, bedroom, and on the second floor, and the engine company indicated that they were activated by the fire. It did not have sprinkler protection.

The house was a two story building with brick walls, a wooden roof frame, and an asphalt roof deck. It occupied a ground floor area of 700 square feet (65 square meters).

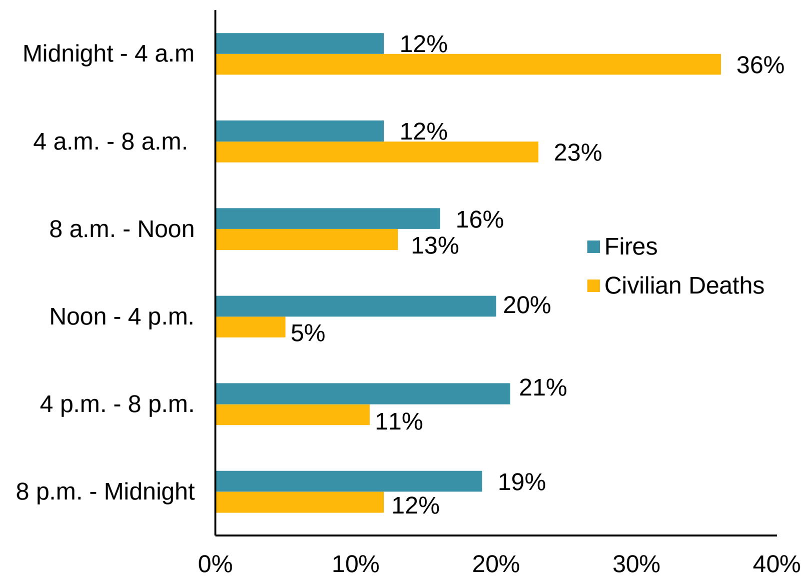
The house, valued at $80,000, and its contents, with an estimated value of $50,000, were a total loss.

Source: Richard Campbell, "Firewatch," *NFPA Journal*, January/February, 2017.

When do Home fires involving electrical distribution and lighting equipment occur?

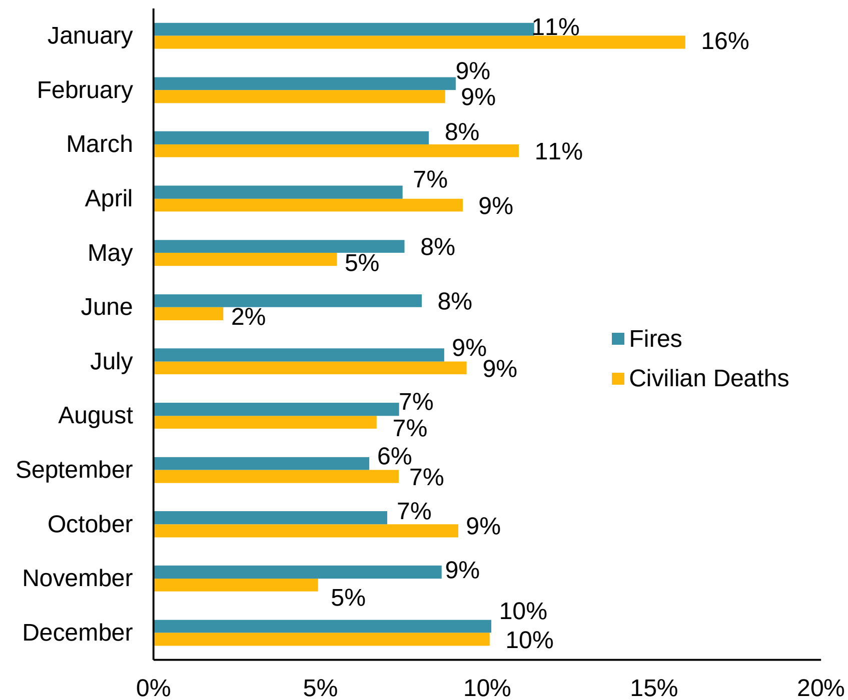
Home fires involving electrical distribution and lighting equipment are less likely to occur in the overnight hours between midnight and 8 a.m. (24% of total), but these fires account for three of five (59%) of the civilian deaths, reflecting the likelihood that people are more apt to be in the home and asleep than in the daytime hours. See Figure 10.

Figure 10. Home Fires Involving Electrical Distribution and Lighting Equipment by Time of Day, 2012-2016



As with fires caused by electrical failure or malfunction, the peak months for home fires involving electrical distribution or lighting equipment are November through March (47% of total). These fires also account for 51% of civilian deaths. This again is likely to reflect the greater tendency for people to be in the home and using electrical equipment during the cold weather months. Another one-quarter (24%) of fires occur from May through July. See Figure 11.

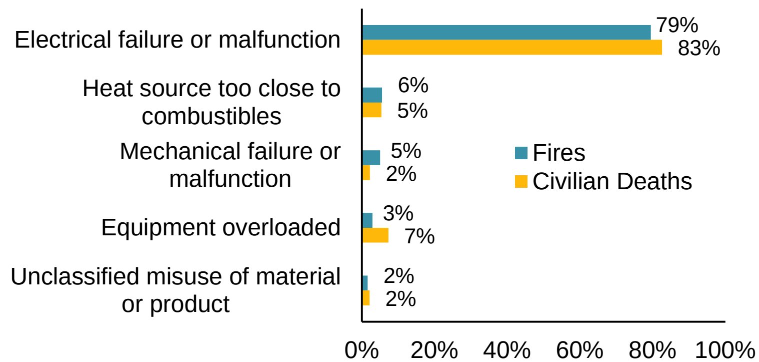
Figure 11. Home Fires Involving Electrical Distribution and Lighting Equipment by Month 2012-2016



Factors Contributing to the Ignition of Home Fires Involving Electrical Distribution or Lighting Equipment

Electrical failures or malfunctions were a factor contributing to the ignition of nearly four of five home fires (79%) involving electrical distribution or lighting equipment, and these fires accounted for 83% of civilian deaths. Other factors contributing to home fires involving electrical distribution and lighting equipment included heat sources being too close to combustibles, mechanical failures or malfunctions, overloaded equipment, and unclassified misuse of productions or materials.

Figure 12. Factors Contributing to the Ignition of Home Fires Involving Electrical Distribution and Lighting Equipment, 2012-2016*



*All data in this section is for non-confined fires only.

Some differences can be observed between specific types of electrical distribution and lighting equipment in relation to factors contributing to the ignition of fires. For instance, electrical failure or malfunction is a factor in nearly nine of ten home fires involving wiring and related equipment (Figure 13), but just less than half of those involving lamps, bulbs, or lighting (Figure 14). Approximately three in ten of the latter fires are caused by lamps, bulbs, or lighting being too close to combustible material.

In home fires involving cords and plugs, in addition to the fires involving electrical failure or malfunction (three-quarters of the total), overloaded equipment contributed to just over one in ten fires, as shown in Figure 15.

Electrical failure or malfunction also accounted for a smaller share of home fires involving transformers and power supplies (65%) than those involving wiring and related equipment or cords and plugs, but higher shares of these fires involved mechanical failures or malfunctions (9%), heat sources too close to combustibles (8%), and equipment overloaded (6%), as shown in Figure 16.

Figure 13. Factors Contributing to the Ignition of Home Fires Involving Wiring and Related Equipment, 2012-2016

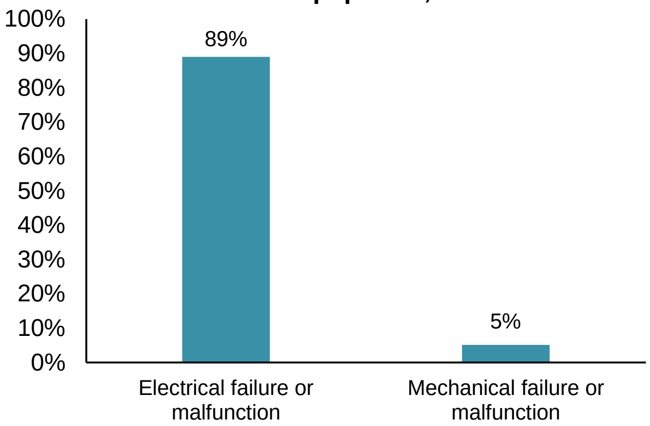


Figure 14. Factors Contributing to the Ignition of Home Fires Involving Lamps, Bulbs, or Lighting, 2012-2016

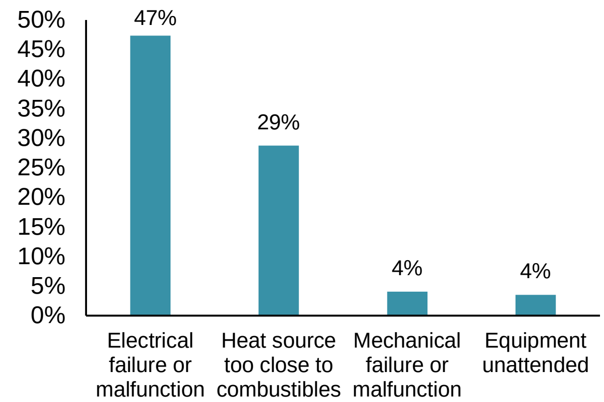


Figure 15. Factors Contributing to the Ignition of Home Fires Involving Cords or Plugs, 2012-2016

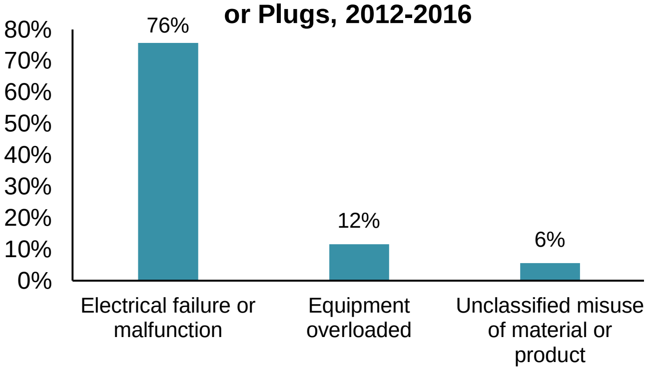
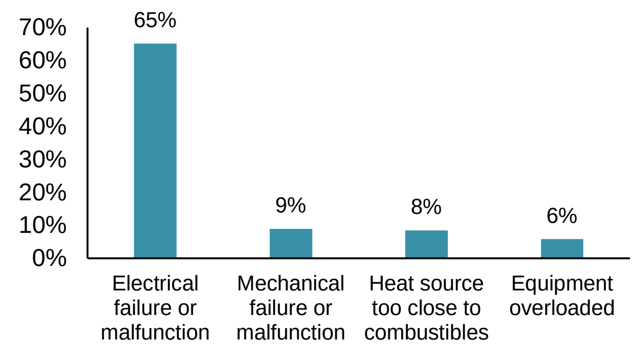


Figure 16. Factors Contributing to the Ignition of Home Fires Involving Transformers and Power Supplies 2012-2016

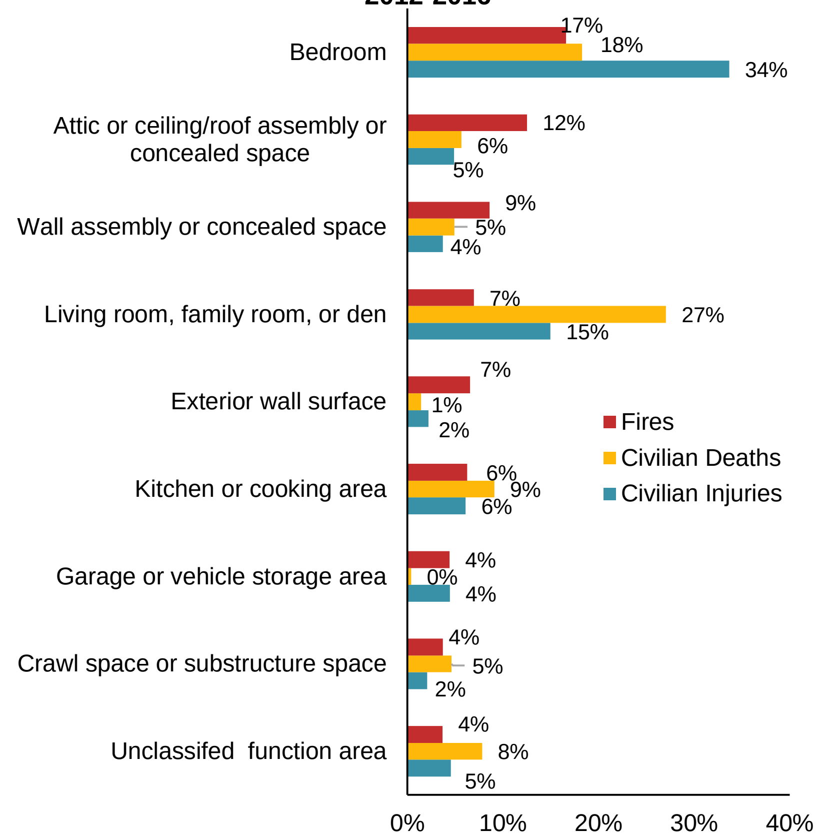


Area of Origin in Home Fires Involving Electrical Distribution or Lighting Equipment

Almost one in five home fires (17%) involving electrical distribution or lighting equipment originated in a bedroom, with another 12% originating in an attic or ceiling/roof assembly or concealed space. Fires originating in a living room, family room, or den accounted for a disproportionately large share of civilian deaths, while those originating in a bedroom accounted for a disproportionately large share of civilian injuries. Fires originating in concealed spaces, such as attics or ceiling roof assemblies, wall assemblies, and crawl spaces, were also common.

Although the bedroom is the leading area of origin for overall electrical distribution and lighting equipment home fires, there are some differences by type of equipment. Figure 18 shows that fires involving wiring and related equipment, which accounts for the great majority of these fires (67%), are most likely to originate in the attic or ceiling/roof assembly or concealed space (16% of total), followed by bedrooms (13%), and wall assemblies or concealed spaces (12%). Hence, over two of five (42%) of the wiring and related equipment fires originate in areas where they are unlikely to be immediately detected.

Figure 17. Area of Origin in Home Fires Involving Electrical Distribution or Lighting Equipment 2012-2016



The bedroom is the leading area of origin in home fires involving lamps, bulbs, or lighting, cords or plugs, and transformers and power supplies. As Figure 19 shows, lamp, bulb, and lighting fires can also originate in areas that may not be readily detected, including attics or ceiling/roof assemblies or concealed spaces, exterior wall surfaces, ceilings/floor assemblies or concealed spaces, and exterior balconies.

Figure 18. Area of Origin in Home Fires Involving Wiring and Related Equipment, 2012-2016

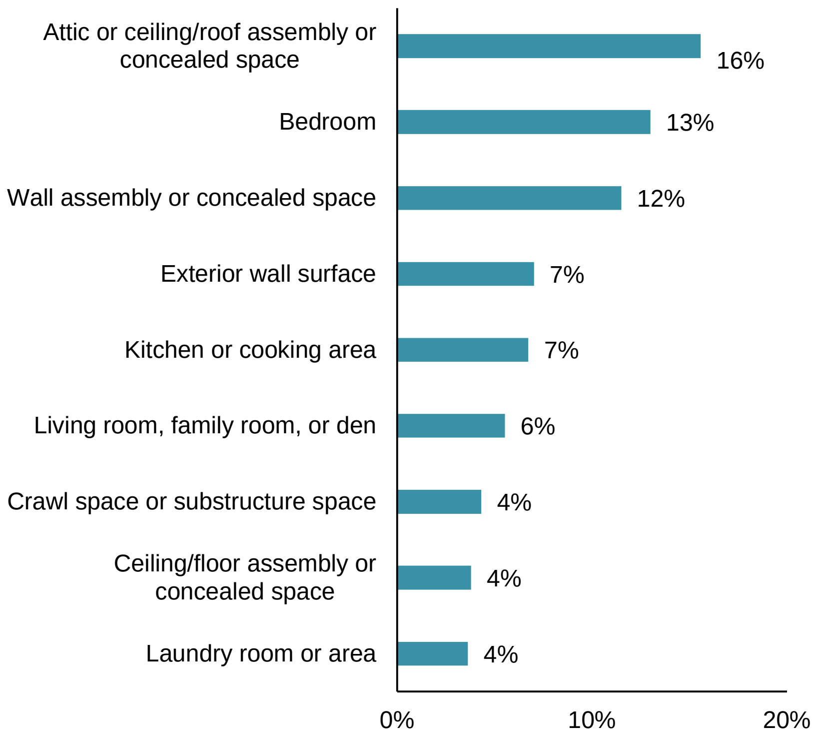


Figure 20 indicates that fires involving cords and plugs are less likely to originate in concealed areas, with nearly half of the fires originating in either the bedroom, living room, family room, or den.

Of home fires involving electrical distribution or lighting equipment that originated in a garage or vehicle storage area, the largest share were those involving transformers and power cords, as shown in Figure 21.

Figure 19. Area of Origin in Home Fires Involving Lamps, Bulbs, or Lighting 2012-2016

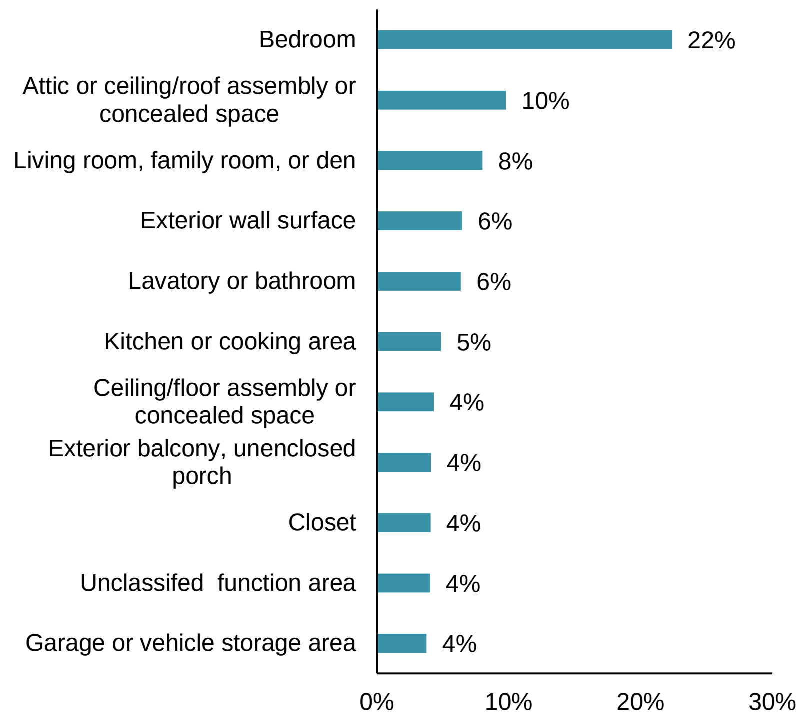


Figure 20. Area of Origin in Home Fires Involving Cords or Plugs, 2012-2016

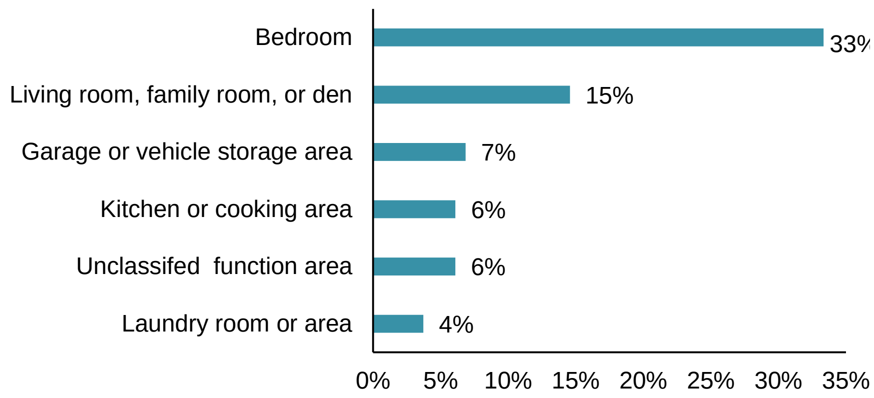
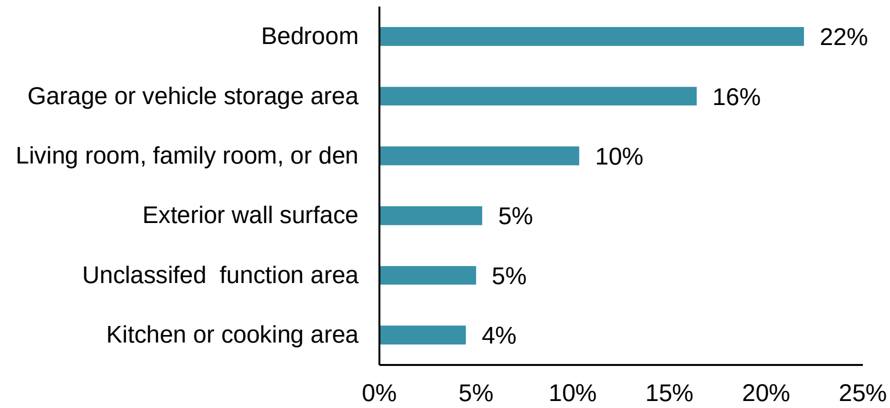


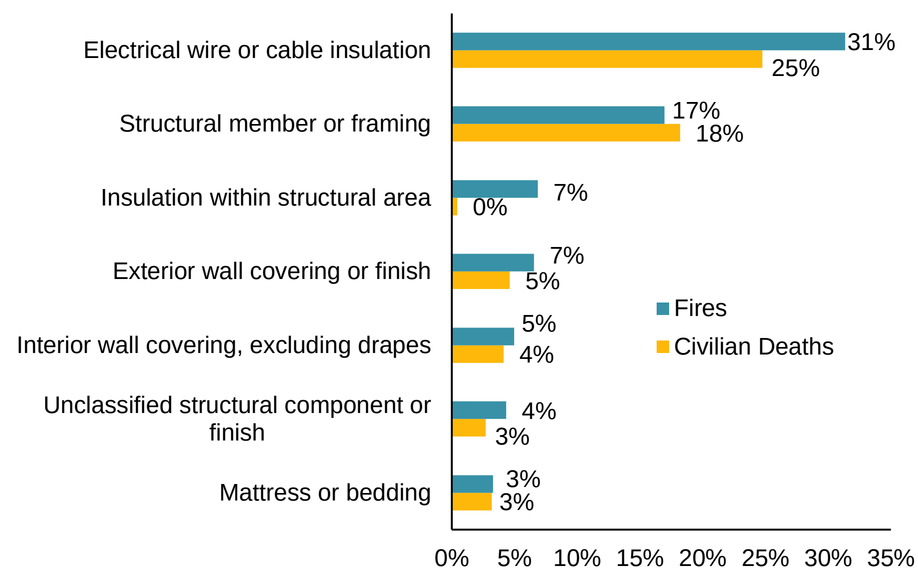
Figure 21. Area of Origin in Home Fires Involving Transformers and Power Supplies, 2012-2016



Home Fires Involving Electrical Distribution and Lighting Equipment by Item First Ignited

The item that first ignited in home fires involving electrical distribution and lighting equipment was electrical wire or cable insulation (31% of fires). Two of five fires (40%) involving electrical distribution and lighting equipment first ignited an item that was part of the building (i.e., structural member or framing, insulation within building area, exterior or interior wall cover or finish, unclassified structural component or finish). See Figure 22. This indicates the need to be attentive to hidden electrical hazards, including electrical distribution and lighting equipment that is installed close to combustible structural elements.

Figure 22. Item First Ignited in Home Fires Involving Electrical Distribution or Lighting Equipment 2012-2016



Methodology

The statistics in this analysis are estimates derived from the U.S. Fire Administration's (USFA's) National Fire Incident Reporting System (NFIRS) and the National Fire Protection Association's (NFPA's) annual survey of U.S. fire departments. Fires reported to federal or state fire departments or industrial fire brigades are not included in these estimates. Only civilian (non-firefighter) casualties are discussed in this analysis.

NFPA's fire department experience survey provides estimates of the big picture. NFIRS is a voluntary system through which participating fire departments report detailed factors about the fires to which they respond. To compensate for fires reported to local fire departments but not captured in NFIRS, scaling ratios are calculated and then applied to the NFIRS database using the formula below.

NFPA's fire experience survey projections
NFIRS totals

The NFIRS data element of Factors Contributing to Ignition was used to identify and estimate electrical failures or malfunctions. In this field, the code "none" is treated as an unknown and allocated proportionally. Multiple entries are allowed in this field. Percentages are calculated on the total number of fires, not entries, resulting in sums greater than 100%. Any fire in which no factor contributing to ignition was entered was treated as unknown.

Entries in the "electrical failure, malfunction" category (factor contributing to ignition 30-39) were grouped together in this analysis.

This category includes:

31. Water-caused short circuit arc
32. Short-circuit arc from mechanical damage
33. Short-circuit arc from defective or worn insulation
34. Unspecified short circuit arc
35. Arc from faulty contact or broken connector, including broken power lines and loose connections
36. Arc or spark from operating equipment, switch, or electric fence
37. Fluorescent light ballast
30. Electrical failure or malfunction, other

NFIRS data element Equipment Involved in Ignition (EII) codes 200-263 were used to identify and estimate electrical distribution and lighting equipment as identified by NFIRS.

NFPA noticed that many fires in which EII was coded as None (NNN) have had other causal factors that indicated equipment was a factor or were completely unknown. To compensate, NFPA treats fires in which EII = NNN and heat source is not in the range of 40-99 as an additional unknown.

To allocate unknown data for EII, known data is multiplied by

All fires
(All fires – blank – undetermined – [fires in which EII =NNN and heat source <>40-99])

In addition, fires and losses associated with code EII 200, "electrical distribution, lighting, and power transfer, other," were allocated proportionally across specific kitchen and equipment codes EII codes, 211-263. Equipment that is totally unclassified (EII code 000) was not allocated further. Unfortunately, equipment that is truly different is erroneously assigned to other categories.

Because of the large number of specific EII codes, most have been grouped into more general categories.

Code Grouping	EII Code	NFIRS definition
Fixed wiring and related equipment	210	Unclassified electrical wiring
	211	Electrical power or utility line
	212	Electrical service supply wires from utility
	213	Electric meter or meter box
	214	Wiring from meter box to circuit breaker
	215	Panel board, switch board or circuit breaker board
	216	Electrical branch circuit
	217	Outlet or receptacle
	218	Wall switch
	219	Ground fault interrupter
Transformers and power supplies	221	Distribution-type transformer
	222	Overcurrent, disconnect equipment
	223	Low-voltage transformer
	224	Generator
	225	Inverter
	226	Uninterrupted power supply (UPS)
	227	Surge protector
	228	Battery charger or rectifier
	229	Battery (all types)
Lamp, bulb or lighting	230	Unclassified lamp or lighting
	231	Lamp-tabletop, floor or desk
	232	Lantern or flashlight
	233	Incandescent lighting fixture
	234	Fluorescent light fixture or ballast
	235	Halogen light fixture or lamp
	236	Sodium or mercury vapor light fixture or lamp
	237	Work or trouble light
	238	Light bulb
	241	Nightlight
	242	Decorative lights – line voltage
	243	Decorative or landscape lighting – low voltage
	244	Sign
Cord or plug	260	Unclassified cord or plug
	261	Power cord or plug, detachable from appliance
	262	Power cord or plug-permanently attached
	263	Extension cord

For more information on the methodology used for this report see, *How NFPA's National Estimates Are Calculated for Home Structure Fires.*

Acknowledgements

The National Fire Protection Association thanks all the fire departments and state fire authorities that participate in the National Fire Incident Reporting System (NFIRS) and the annual NFPA fire experience survey. These firefighters are the original sources of the detailed data that make this analysis possible. Their contributions allow us to estimate the size of the fire problem.

We are also grateful to the U.S. Fire Administration for its work in developing, coordinating, and maintaining NFIRS.

To learn more about research at NFPA visit www.nfpa.org/research.
E-mail: research@nfpa.org.
NFPA No. USS37

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PERSATUAN JURUTERA PERUNDING MALAYSIA

Load Test on Instrumented 600mm Diameter Bored Pile in the City Centre of Kuala Lumpur

Conventional and Unconventional Lightning Air Terminals: An Update

HARTONO Zainal Abidin, BSc, MIEEE and ROBIAH Ibrahim, BSc, MIEEE

1. Introduction

The lightning protection systems (LPS) used in this country and around the world is basically divided into two types:

a) Conventional or standard LPS i.e. that which comply with the technical standards/codes of practice
b) Unconventional or non-standard LPS i.e. those that do not comply with the standards/codes

The air terminals associated with the conventional LPS is the Franklin rod while those associated with the unconventional LPS are the so-called "active" air terminals e.g. the early streamer emission (ESE) and the charge transfer system (CTS).

In the last decade, the conventional LPS have been validated in a number of studies conducted by lightning protection experts around the world. On the other hand, similar studies have discredited the un-conventional LPS and this has led to their rejection by various scientific and standards organizations. In 2005, the International Conference on Lightning Protection (ICLP) issued a warning that the use of the unconventional LPS presents a danger to the end users. Nevertheless, the local vendors and proponents of the unconventional LPS were not deterred by these events and continued to market their dangerous products to the public and even invented a new one.

This article is a follow-up on the paper presented by the authors during the lightning protection forum organized by ACEM in January 2004. Readers can download the paper from the Lightning Safety Alliance website (www.lightningsafetyalliance.org).

2. Lightning protection standards

The recognized lightning protection standards frequently applied in Malaysia are the MS-IEC 61024 (Malaysian/IEC), BS6651 (United Kingdom), NFPA780 (USA), AS/NZS 1768 (Australia/New Zealand), and CP33 (Singapore). These standards are regularly updated to incorporate the new findings on lightning protection researches.

In addition to the above, the vendors of the unconventional LPS have introduced/proposed their own "product standards" such as the French NFC 17-102. These so-called "standards" have already been rejected by the scientific organizations in their country of origin.

2.1 AS/NZS 1768

Work to revise this standard commenced in the late 1990s and the new interim standard, AS/NZS 1768(Int) 2003, was published in December 2003. The existing methods for positioning the air terminals, namely the Protection Angle Method (PAM), the Rolling Sphere Method (RSM) and the Faraday Cage Method (FCM), are still retained.

The standard also incorporates a new air terminal positioning method that is based on observations of lightning induced damages in Malaysia. The description of this new method is as follows:

"Field data of damage caused by lightning flashes terminating on structures (See Appendix G, Refs 2 & 3) identify the parts that are vulnerable to strikes. The most vulnerable, associated with over 90% of observed lightning damage, are nearly always located on upper parts of structure, such as:

(a) pointed apex roofs, spires and protrusions;

(b) gable roof ridge ends; and

(c) outer roof corners.

Other areas of vulnerability, in decreasing order, are:

(d) the exposed edges of horizontal roofs, and the slanting and horizontal edge of gable roofs (<10%);
(e) lower horizontal edges and vertical edges on outer-sides just below corners (<5%);
(f) flat surfaces near points and corners (<3%); and
(g) intruding surfaces and other surfaces, particularly flat surfaces (<1%)."

To maximize the probability of intercepting the lightning strikes, the air terminals must be positioned according to the above high-risk locations.

2.2 New IEC standard, IEC 62305

Work on the revised standard commenced in the late 1990s and it was finally published in February 2006 to replace the IEC 61024. The new standard is divided into four parts:

a) IEC 62305-1: General Principles

b) IEC 62305-2: Risk Management

c) IEC 62305-3: Physical damage to structures and life hazard

d) IEC 62305-4: Electrical and electronic systems within structures

In the IEC 62305-3, the PAM, RSM and FCM methods for positioning the air terminals are also retained. In addition, a new paragraph on air terminal positioning, which is similar to that found in the AS/NZS 1768(Int):2003 above has been added.

The IEC 62305 is currently in the process of being evaluated by the SIRIM Working Group on Lightning Protection to replace the MS-IEC 61024.

2.3 French ESE "standard", NFC 17-102

This "standard" was published in 1995 by GIMELEC, the association of French ESE manufacturers, in order to standardize the manufacture, test and installation of the ESE air terminals. The "standard" has been copied by other non-French ESE manufacturers e.g. Spain.

The NFC 17-102 was criticized in 2002 in a report [1] by the French scientific agency, INERIS, for non-implementation by the ESE manufacturers. Although the manufacturers have agreed to revise the document, no action has been taken so far. Hence the ESE air terminals now in use worldwide have not only failed to comply with the recognized national/international standards but they also failed to comply with the manufacturers' own standard.

2.4 Proposed standard for the CTS system

Between 1989 and 2005, the inventor of the CTS made five applications to the NFPA to include the CTS in the NFPA780 standard. All the applications were rejected because the inventor could not provide the required scientific theory to support the CTS. The latest rejection [2] was made by the NFPA in 2005.

2.5 Proposed standard for the Collection Volume Method (CVM)

The CVM is a proprietary method for positioning the Dynasphere® air terminal, an active air terminal developed in Australia. This method was included in the appendix of the AS/NZS 1768:1991 for information only. However, it was applied in many countries for the installation of the Dynasphere ® air terminals. The CVM was also re-named as the Field Intensification Method (FIM) in 2002.

Field data collected in Malaysia over ten years on the application of the CVM/FIM failed to prove that the method is valid for air terminal positioning since most of the buildings that used the method had been struck and damaged by lightning. Consequently, the CVM/FIM was deleted from the AS/NZS 1768(Int):2003.

The CVM/FIM was also rejected by the NFPA [3] in 2004 for the same reasons.

3. Legality of advertising the ESE air terminal

Following the rejection of the ESE technology by the NFPA in 2000, several American ESE vendors brought the matter to court alleging "unfair trading practices" on the part of their opponents. However, after lightning experts were called in to testify on the workings of the ESE technology, the court issued a judgement [4] prohibiting the ESE vendors from claiming that their product can provide a protection zone that is much bigger than that of the Franklin rod. The court had decided that the claims made by the ESE vendors constituted false advertising and violated the US Lanham Act.

4. Unconventional LPS and Public Safety

In September 2005, the ICLP issued a warning [5] that the use of the unconventional LPS posed a danger to the end user and general public. The warning highlighted the studies of ESE air terminal failures under real lightning conditions conducted in the USA and Malaysia. Following this warning, ACEM had issued an advisory (Ref: ACEM/sec/2005/13 dated October 27, 2005) to all its members to stop using the unconventional LPS.

The following cases highlight the recent failures of the ESE air terminals in Malaysia:

4.1 Residential buildings

The ESE air terminals are being used by some home developers to protect detached houses and low rise apartment blocks. However, the cases below show that the claimed enhanced zone of protection of the ESE air terminals had failed to prevent lightning from striking these buildings, either singular or in a cluster.

Case 1: Cluster application failure

Fig. 1: The damaged roof of a house that was struck by lightning.

Fig. 2: Close-up view of the ESE air terminal (arrowed) on the adjacent house.

Lightning struck the roof of a house which is adjacent to another house that had been installed with an ESE air terminal. The roof was partially burnt as a result of the strike. This case shows that the ESE air terminal is not capable of protecting clustered small buildings.

Case 2: Single application failure

Fig. 3: The fire damaged top floor of a house that was struck by lightning.

Fig. 4: Close-up view of the ESE air terminal on the roof (arrowed).

Lightning struck the roof of a house which had been installed with an ESE air terminal. The roof and upper floor were badly burnt as a result of the lightning strike. This case shows that the ESE air terminal is not capable of protecting small buildings like a detached house.

4.2 Putrajaya Mosque

The minaret of the mosque, completed in 1998, is a slim 116 m high structure that was installed with a single ESE air terminal on the apex. According to the RSM, the sides of the minaret from about 50 m and above are exposed to lightning strikes and require protection.

The protection provided by the ESE air terminal, according to the NFC 17-102 “standard”, should be at its best since the diameter of the minaret is less than 10 m. However, in 2005, lightning struck the side of the minaret about 30 m below the apex. This clearly shows that the claimed enhanced zone of protection for the ESE air terminal is non-existent.

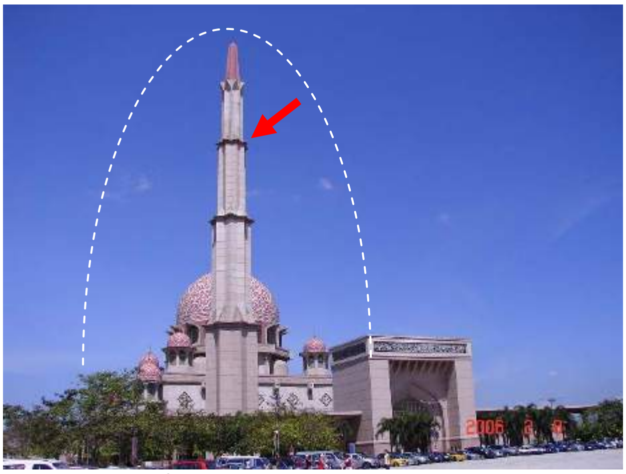

Fig. 5: Minaret of Putrajaya Mosque. The claimed protection zone is shown by the dotted line while the lightning strike location is shown by the arrow.

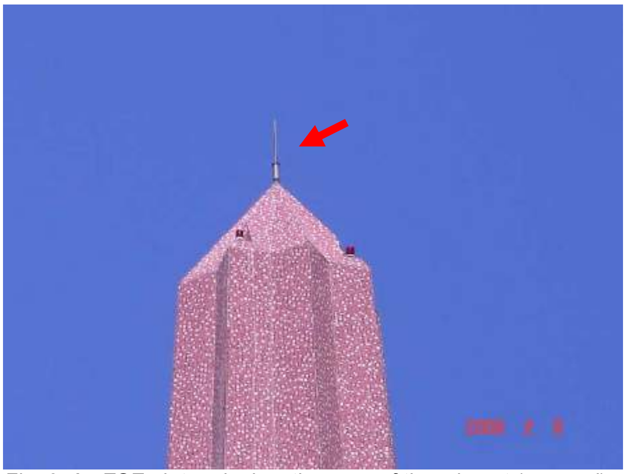

Fig. 6: An ESE air terminal on the apex of the minaret (arrowed).

Fig. 7: Close-up view of the lightning damaged section of the minaret (arrowed).

The failure of the ESE air terminal to protect the minaret explains why normal buildings are always struck by lightning on the upper corners and edges. This is due to the fact that these locations fall outside the hypothetical ESE protection zone. Installing the ESE air terminals on tall poles also has no effect on enhancing the protection zone.

4.3 Prime Minister Department building, Putrajaya

This large building has been installed with at least five ESE air terminals, one on the apex of the dome and four on ridge ends of the metal roofs below the dome. A photograph of a lightning strike to the dome air terminal was recently captured by a news photographer.

An analysis of the lightning path that terminated on the air terminal shows that the ESE principle is incorrect. If it was correct, then the lightning path would be approximately straight for several tens of meters above air terminal since the streamer would be moving towards the down leader.

The curved path of the lightning stroke just above the air terminal indicates that no streamer was emitted. In addition, no visible streamers were observed from the nearby ESE air terminals on the metal roofs. As already shown in the previous report, a corner of the building next to one of the lower ESE air terminals had been struck by lightning.

Fig. 8: A photograph of lightning striking the ESE air terminal on the Prime Minister Department building.
(Photo credit: The Star Publications plc)

Fig. 9: The dotted line represents the hypothetical path of the early streamer according to the ESE hypothesis.
(Photo credit: The Star Publications plc)

5. Local studies on the CTS and ESE

Studies in support of the CTS and ESE technologies were made by University of Technology Malaysia (UTM) researchers since 2003. Although they claimed to have found the proof for these technologies, the findings were still inconclusive.

5.1 CTS studies

These studies were made jointly with researchers from Telekom Malaysia Research and Development. The studies by Ramli and Ahmad [6],[7] claimed to have validated the CTS technology based on data obtained from the Malaysian lightning detection network (LDN), lightning video recordings and lightning current measurements made on the CTS air terminals. However, it was found that the erroneous conclusions were made based on misinterpretation of all the three data [8].

5.2 ESE studies

These studies were conducted at the university's high voltage institute, IVAT.

In a study by Ngu and Darus [9], the ESE technology was validated based on observed field data which consist of the number of observed lightning strike damages and selected lightning counter readings. However, the data in this study were found to be similar to the CVM/FIM data submitted by an ESE vendor to Standards Australia. Since the CVM/FIM has been rejected by Standards Australia and the NFPA, the validity of this study is questionable.

In a study by Sidik and Ahmad [10], a new ESE air terminal equipped with a wind-driven electrostatic generator and a palm-sized laser device was invented. They claimed [11] that the laser device is capable of attracting lightning strikes and that the air terminal operates on the CVM principle. They also claimed [12] that their invention need not be installed on the building for protection against direct lightning strikes.

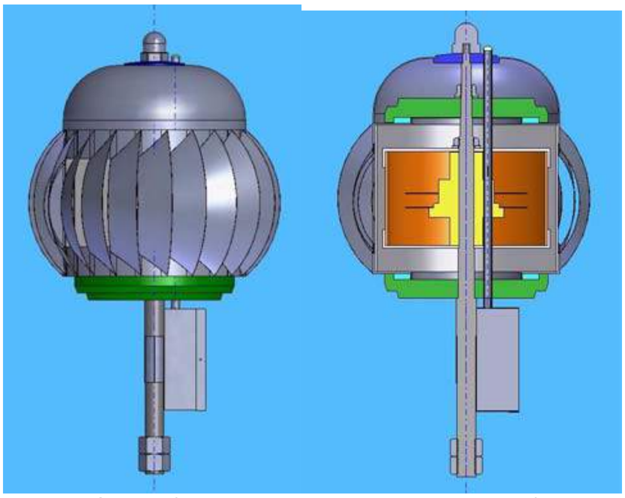

Fig. 10: Side (left) and cross-section (right) views of the UTM invented ESE air terminal. The box-shaped laser device is located below the wind-operated static generator. (Photo credit: UTM)

Several western studies have shown that the laser devices required to ionize very long air paths to create conducting channels for lightning are large and powerful; hence the claim that the palm-sized laser device can produce the same results in the field is doubtful.

The use of a wind-driven static generator means that the streamer generation is only practical on windy days. The CVM claim is unproven since the method had already been discredited and rejected by Standards Australia and the NFPA.

The last claim is also very doubtful since centrally positioned ESE air terminals have repeatedly been shown to be ineffective in protecting buildings from lightning strikes, what more an ESE air terminal that is positioned on one side of a large building.

To avoid a controversy on the status of their ESE invention, the inventors have also claimed [13] that their invention is a conventional air terminal due to the presence of the Franklin rod at the core.

6. Conclusion

Since 2004, no new evidence has been submitted to support the hypotheses behind the unconventional LPS. On the other hand, more evidence has been presented to demonstrate the inefficacy of the unconventional LPS in field applications. The ICLP has issued a warning that the use of the unconventional LPS is dangerous.

The revised national and international lightning protection standards have also included a new air terminal positioning method that will significantly improve the protection of buildings from direct lightning strikes.

Studies conducted by local research institutions in support of the unconventional LPS have also been shown to be inconclusive while a new ESE air terminal developed by a local university is based on discredited and unproven technologies.

7. Acknowledgement

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Lightning Interception
Non Conventional Lightning Protection Systems

VERNON COORAY ON BEHALF OF CIGRE WORKING GROUP C4.405
(This is the second of two reports, the first of which appeared in the August edition of Electra)

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Non conventional lightning protection systems

The external lightning protection systems used by engineers in different countries can be divided into two categories, namely, conventional and non-conventional lightning protection systems. The conventional systems use Franklin rods. Many decades of experience shows that by combining Franklin rods located at critical points on a structure with a proper down conductor and grounding system the damage due to lightning could be reduced significantly [1]. The Early Streamer Emission rods and Dissipation Arrays (sometimes called Charge Transfer Systems) belong to the category of non conventional lightning protection systems. The latter systems have been introduced into several lightning protection standards without testing them over the same long period of time in the field as done for conventional ones to assess and validate their performances. In this note we will summarize the results of studies pertinent to these systems as reported in the scientific literature.

The Early Streamer Emission (ESE) concept

The ESE terminals used in practice are equipped with a discharge triggering device to initiate streamers from the terminal in an attempt to increase the probability of inception of a connecting leader from the terminal during the approach of a downward lightning leader [2 ,3]. According to the proponents of ESE the time advantage realized by the early inception of the connecting leader from a ESE terminal in comparison to a normal Franklin rod would provide a possibility for the connecting leader generated by an ESE terminal to travel a longer distance in comparison to that from a Franklin rod. Consequently, it is claimed that under similar circumstances an ESE terminal will have a larger protection area than a Franklin rod of similar dimensions. However, recent experimental and theoretical investigations find results that are in conflict with the claimed performance of ESE devices [4].

Experimental data that are in conflict with the concept of ESE

Case studies conducted by Hartono et al. [5] in Malaysia, provide clear evidence that lightning do bypass the ESE terminals and strike the protected structures well within the claimed protective region of the ESE devices. The same study showed that no damages were observed at the corners of structures equipped with Franklin rods installed according to the international lightning protection standard to cover the vulnerable points such as edges or corners of the structure. However, in structures where Franklin rods were installed without consideration of these high risk interception points, lightning strikes have been observed at these points.

In another study conducted in New Mexico [6], ESE lightning rods were allowed to compete with symmetrically spaced Franklin rods to validate the enhanced attractive zone of ESE devices claimed by its proponents. If, as claimed, ESE rods can initiate an upward leader before the Franklin rods and if they have a larger attractive zone, one would expect ESE rods to be the preferential point of attachment of the lightning strikes. However, according to the observations all the lightning strikes got attached to Franklin conductors and not a single one terminated on the ESE devices. It is worth mentioning that among Franklin conductors only those with blunt rods were struck by lightning, while those with sharp rods were not struck. This experiment represent an additional indication that the ESE terminals do not have an advantage over the Franklin rods and the claimed enhanced protective range does not exist.

Proponents of ESE sometimes refer to an experiment conducted in France using triggered lightning [7] to support the action of ESE terminals. In this experiment an ESE terminal was put in competition with a Franklin rod to get attached to a down coming leader created in an altitude triggered lightning experiment. The downward moving leader got attached to the ESE terminal and the proponents of ESE claim that this proves the superior action of ESE terminals in comparison to Franklin rods. However, it is important to note that in the experiment the ESE terminal was located closer to the rocket launcher than the conventional one. The reason for the attachment of the lightning flash to the ESE rod could simply be due to the spatial advantage it had with respect to the conventional rod. Unfortunately, the positions of the rods were not interchanged to validate the claimed enhanced attractive range of the ESE terminal. Thus, one has to conclude that this experiment does not provide evidence for the claimed superiority of the ESE terminals against the conventional ones.

Theoretical evidence that are in conflict with the concept of ESE

The whole concept of ESE is based on the observed fact that by artificial triggering of streamers from the tip of a lightning terminal (i.e. ESE rod) stressed by a switching impulse, one can cause the terminal to initiate a leader earlier than from a lightning terminal placed under identical circumstances but without the action of artificial streamers (i.e. Franklin rod) [2]. In the laboratory, it was found that the time advantage (i.e. the time interval between the initiation of leaders from ESE and Franklin rods), Δt of an ESE terminal is about 75 μs. Proponents of ESE terminals have taken this laboratory observation and extended it to natural conditions claiming that a 75 μs advantage will give rise to a length advantage equal to the product $v\,\Delta t$ where v is the speed of the upward moving leader. Assuming a leader speed of 10^6 m/s ESE proponents claim that an ESE terminal would have a length advantage of about 75 m over a conventional rod. Thus, the following two conditions have to be satisfied for the ESE devices to function according to their specifications:

1) The early initiation of leaders from ESE terminals observed in the laboratory takes place also under natural conditions. In other words, an ESE terminal can launch a connecting leader long before a conventional rod under natural conditions.
2) The time advantage observed will translate to a length advantage of $v\,\Delta t$ over a conventional terminal.

Let us first assume that a time advantage exists in ESE devices when exposed to lightning-generated electric fields. This time advantage was converted to a length advantage of about 75 m over a conventional rod by assuming a leader speed of about 10^6 m/s. The majority of speeds of upward connecting leaders reported in the literature is from those in either rocket triggered lightning or from those in upward initiated lightning flashes. In these cases the upward connecting leader moves in a more or less static background electric field created by thunderclouds. These leader speeds are not relevant to the study under consideration. Yokoyama et al. [8] managed to measure the speeds of upward connecting leaders initiated from an 80 m tall tower as a result of the electric field generated by downward moving leaders. In four examples analyzed in the study they found that the connecting leader speeds just before the connection is made between them and the downward moving leaders were 1.3×10^6 m/s, 1.4×10^6 m/s, 2.9×10^6 m/s and 0.5×10^6 m/s. These speeds are similar to the one used by ESE manufactures in calculating the striking distance. However, it is not correct to use these speeds in the analysis of ESE terminals because what is required to calculate the length of the connecting leader given the time advantage is the average speed of the •••

connecting leader. The average speed of connecting leaders measured by Yokoyama et al. [8] varied from 0.8 x 10^5 m/s to 2.7x10^5 m/s. This average speed is an order of magnitude less than the one used by ESE manufactures. Moreover, the connecting leaders photographed in the study originated from an 80 m tall structure. In general, the connecting leaders issued from tall structures are relatively longer than the ones issued by short structures during lightning interception. Long leaders have ample time to thermalize their channel and this makes them move faster than short connecting leaders. If this experimentally observed value of average leader speed is used in the conversion of time advantage to distance, the resulting length advantage would be of no use in many practical situations. Second, this conversion of time advantage to a length advantage is not correct because the eventual length advantage depends on the ratio of the speeds of both downward and upward leaders. If this is taken into account the assumed length advantage will be less than the value calculated by just multiplying Δt by the speed of the leader. Third, according to the proponents of ESE the earlier initiation of a connecting leader from an ESE device occurs in a smaller electric field than is required for the initiation of a leader by a conventional rod. However, for a successful propagation of a connecting leader a certain background electric field is needed. If the background electric field is not large enough the initiated leader could be aborted [9]. The proponents of the ESE do not consider the requirements for the propagation of a leader and they do not consider the possibility that the initiated leaders could be aborted if the background electric field requirements are not met.

Now, we come back to the first assumption. Recently, Becerra and Cooray [10] constructed a model incorporating the physics of the attachment process to simulate lightning attachment to structures. This model has been validated using data from altitude triggered lightning [11]. Since the current measured at the base of the trigger wire showed the occurrence of several aborted streamer leader inceptions, in the validation of the model the space charge left behind by these unsuccessful leader inceptions (precursors) were taken into account. It is worth mentioning that the effect of corona generated by the trigger wire on the inception of leaders from its tip – disregarded in a first approximation in [10] – was the subject of a recent investigation [12]. Using their model Becerra and Cooray [9] have simulated the initiation and development of positive leaders under the influence of time varying electric fields used in laboratory as well as the time varying electric fields generated at ground level by the descent of the downward leaders. Their results show that indeed one can obtain a time advantage in the laboratory but also they show that such a time advantage will be practically negligible when the rods are exposed to the background electric fields of leaders. As shown in Figure 1, in order to change the striking distance significantly, ESE rods have to be supplied with Mega-volt strong generators.

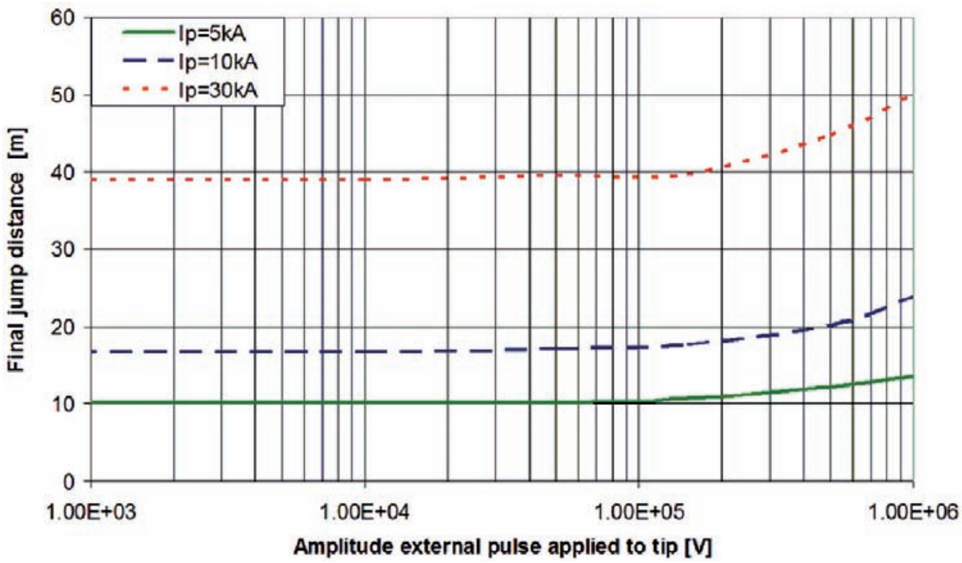

Figure 1: Distance between the downward leader tip and the ESE rod at the moment of connection between the connecting leader and the down-coming stepped leader as a function of the voltage impulse applied to the ESE rod. Calculations are given for three prospective return stroke currents

The concept of dissipation array systems and mounting scientific evidence against their principle of operation

The original idea of lightning eliminators or dissipation arrays is to utilize the space charge generated by one or several grounded arrays of sharp points to "dissipate" (i.e. neutralize) the charge in thunderclouds and thus prevent lightning strikes to a structure to be protected. The proponents of this system claimed that the space charge generated by the array will silently discharge the thundercloud. The following argument shows that this indeed is not the case. The mobility of small ions at ground level is about (1 – 2) x 10^{-4} m^2 V^{-1} s^{-1} [13] and in the background electric fields of 10 – 50 kV/m the drift velocity of these ions may reach 1 to 10 m/s. Even if the array can generate charge of sufficient quantities to neutralise the cloud charge, in the time of regeneration of charge between lightning flashes in the thundercloud of about 10 s the space charge can move only a distance of about 10 to 100 m. Thus, the space charge would not be able to reach the cloud in time to prevent the occurrence of lightning. Facing this challenging and convincing opposition from lightning researchers the proponents of lightning eliminators accepted that the arrays are not capable of neutralizing the cloud charge [14]. In turn they suggested that the function of the dissipation array is to neutralize the charge on the down coming stepped leaders.

Now, a typical stepped leader may bring down about 5 C of charge to ground and the dissipation array has to generate this charge in about 10 s, the time interval between lightning flashes. The proponents of dissipation arrays made the following argument to show the effectiveness of the array in generating sufficient quantity of charge to neutralize the stepped leader [14]. According to Zipse [14] a 12 point array (four sets of three points) located on a 20 m pole can produce about 1 - 2 mA as the storm sets in (no details as to how these measurements were carried out are given in the paper). Thus, a typical array with 4000 points can inject a charge comparable to that of a stepped leader in about 10 s, the time interval between lightning strikes. Firstly, the proponents of dissipation arrays do not explain the physics behind this claimed neutralization process. For example, since the charge generated by the array is distributed in space the stepped leader has to move into this space charge region before it could be neutralized. Recall that the bulk of this space charge is located in the near vicinity of the dissipation array. If the stepped leader channel, which is at a potential of 50 to 100 MV, moves into this space charge region, a critical potential gradient of about 500 kV/m could easily be established between the stepped leader and the dissipation array (which is at ground potential) leading to an imminent lightning strike. Secondly, in making the above claim proponents of dissipation arrays have assumed that the current generated by a multi point array is equal to the current generated by a single point multiplied by the number of points. Cooray and Zitnik [15] conducted experiments to investigate how the corona currents produced by an array of sharp points or needles vary as a function of number of needles in the array. The experimental setup consists of a parallel plate gap of length 0,3 m with 1.0 m diameter, Rogowski profiled electrodes. The bottom electrode of the gap was prepared in such a way that a cluster of needles can be fixed onto it. The needles used in the experiment were pointed, 2 cm long and 1 mm in diameter. The needles were arranged at the corners of 2 x 2 cm adjacent squares. A constant voltage was applied to the electrode gap and the corona current generated by the needles is measured as a function of the background electric field and the number of needles in the cluster using a micro ammeter. The lower limit of the corona current that could be measured in the experiment was about 1 μA. The results obtained are shown in Figure 2. Observe first that the corona current increases with increasing electric field and for a given electric field the corona current increases with increasing number of needles. Note, however, that for a given electric field the corona current does not increase linearly with the number of needles. Even though the conditions under which dissipation arrays are supposed to be working are different to the conditions under which this laboratory experiment was conducted, this experiment clearly demonstrates that the corona current does not increase linearly with increasing number of needles. The reason for this could be the screening of one needle from the other in a multiple needle array.

More recently, proponents of the dissipation arrays claimed that the dissipation arrays work by suppressing the initiation of upward leaders by screening the top of the structure by space charge. This claim was based on the study conducted by Aleksandrov et al. [16]. In that study Aleksandrov et al. showed that the electric field redistribution due to space charge released by corona discharges near the top of a high object hinders the initiation and development of an upward leader ● ● ●

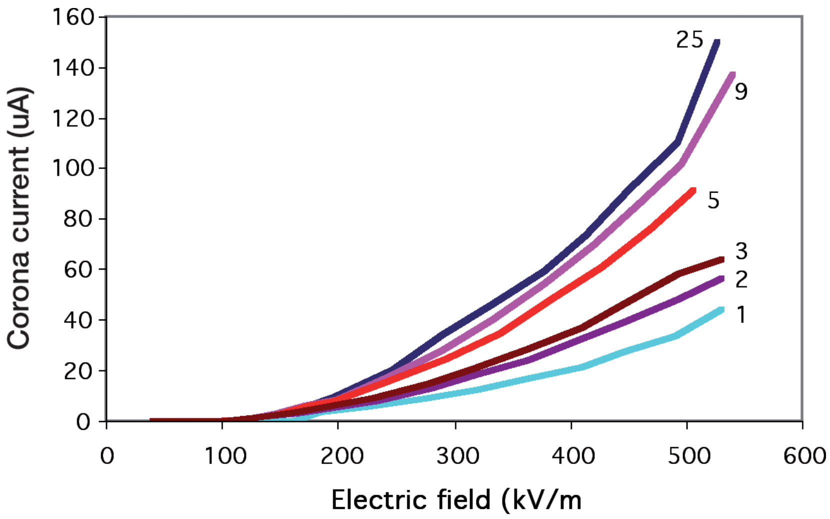

Figure 2: The corona current as a function of the background electric field from clusters of needles. The number of needles in the cluster is shown in the diagram.

from an object in a thunderstorm electric field. It is important to recognize, however, that the corona charge issued from the terminal would not screen the sides of the terminal or the tower. Thus, as the stepped leader approaches the dissipation array a connecting leader could be issued from the sides of the terminal which is not screened by the space charge. The main question is whether the space charge from the needles can counter balance the increase in the electric field caused by the down coming stepped leader at the tip of the structure to such an extent that the formation of a connecting leader is inhibited. Calculations done in [15] show that a tower without the space charge produced by the needles will launch a connecting leader before a tower with similar geometry but with space charge, generated during the descent of the leader, at the tower top. However, the space charge controlled field does not lag far behind the field that would be present in the absence of the space charge. For example, the difference in the stepped leader tip height from the tower top when the electric field at the tower top is large enough to launch a connecting leader in the presence and in the absence of space charge is no more than two meters [16]. This study indicates that the reduction in the striking distance caused by the space charge may not be more than a few meters.

In addition to the above points, there are several well documented cases in which lightning has been observed to strike dissipation arrays. The best procedure to conduct such a study is to compare two similar structures, one with a CTS and the other without. Several such studies have been conducted [17, 18, 19, 20]. All the studies show that CTS systems were struck by lightning as well as the control structure. No reduction in the frequency of lightning strikes to structures has been observed.

The proponents of dissipation arrays claim that according to the anecdotal evidence of the users there is a reduction in the cases of lightning damage after the installation of arrays. However, this does not necessarily mean that the array has prevented any lightning strikes. First, since the array is well grounded, it provides a preferential path for the lightning current to go to ground. This it self will reduce the damage due to lightning strikes even if it does not prevent a lightning strike. Second, as suggested by Golde [21], the connection of an umbrella shaped array at the top of a tower will increase the radius of curvature of its tip and inhibit the upward initiated lightning flashes by reducing the field enhancing effect of the tip. This may lead to a reduction in the number of upward initiated flashes from the tower. But, as noted by Mousa [22], upward initiated flashes are of interest in the case of towers of effective heights larger than about 300 m or more. The dissipation arrays will not have any effect on the number of lightning strikes to smaller structures.

Conclusions

Both theory and experiments show that (i) ESE principle, namely that the ESE rods have longer striking distances than conventional Franklin rods, does not work under natural field conditions and there is no justification at present to assume that the ESE rods perform better than Franklin rods and (ii) the dissipation arrays cannot dissipate an imminent lightning flash either to the protected structure or to the terminal itself.

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मूल्याङ्कनका औजारहरू

चट्टयाङ्ग र विद्युतीय लेखा परीक्षण प्रशिक्षण
प्रशिक्षण पुर्व र पश्चात जानकारी

सहभागी विवरण

नामः **संस्थाः**
पदः **जिल्लाः**

अन्य विवरण

क. लिङ्गः **ख. उमेरः**
ग. जाती (Ethnicity) **घ. शिक्षाः**

तलका प्रश्नहरु राम्रोसंग अध्ययन गरी सही उत्तरमा चिन्ह लगाउनुहोस् ।

१. चट्याङ पर्दा बादलबाट तल आउने उच्च मात्राको विद्युतीय चार्जलाई के गर्दा हामी सुरक्षित हुन्छौँ ?
क) कुचालकले त्यसलाई माथि नै रोक्दा
ख) त्यसलाई सजिलो बाटोबाट जमिनमा पठाउँदा
ग) घरमा भएको विद्युतीय सर्किटबाट बग्न दिँदा
घ) माथिका सबै
ङ) थाहा छैन

२. कुनै बिक्रेताले पाँच किलोमिटर वरिपरिको चट्याङबाट जोगाउँछ भनेर दावी गरेर राम्रो आकर्षक डिजाइनको एन्टेना बोकेर आयो भने के गर्नुहुन्छ ?
क) खुशी भएर त्यो जडान गर्न तयारी गर्छु
ख) IEC मापदण्डको हो कि होइन भनेर सुनिश्चत गर्छु
ग) मैले भरोसा गरेको इलेक्ट्रीसियनले शिफारिस गरेको हुनाले ढुक्क भएर जडान गर्छु
घ) माथिका कुनै पनि होइन
ङ) थाहा छैन

३. तपाईँ ढलान गरेको घरभित्र हुँदा पानी परेर चट्याङ पर्न थाल्यो भने सुरक्षित हुन के गर्नुहुन्छ ?
क) घरभित्र नै बसिरहन्छु
ख) बाहिर गएर खुल्ला चौरमा छाता ओढेर बस्छु
ग) बाहिर गएर रूखमुनि बस्छु
घ) माथिका कुनै पनि होइन
ङ) थाहा छैन

४. चट्याङ प्रतिरक्षी प्रणालीको छतमा राखिने धातुको छड जडान गर्ने विधि तलकामध्ये कुन होइन ?

क) बचावट कोण (Protection Angle)

ख) धातुको जाली (Mesh)

ग) डल्लो गुडाउने विधि (Rolling Sphere Method)

घ) अग्लो पाइपको टुप्पामा साइकलको चक्का राख्ने

ङ) थाहा छैन

५. अर्थिङको मेन इलेक्ट्रोड र पानी तन्ने पम्पको बाहिरी सतहबचीमा कति भोल्टेज हुनुपर्छ ?

क) झण्डै शून्य

ख) १ भोल्ट

ग) २ भोल्ट

घ) ५ भोल्ट

ङ) थाहा छैन

६. मानिसको शरिरबाट कतिभन्दा बढी करेण्ट बग्यो भने उसको मृत्यु हुनुसक्छ ?

क) १० मिलिएम्पेर

ख) ३० मिलिएम्पेर

ग) १०० मिलिएम्पेर

घ) १ एम्पेर

ङ) थाहा छैन

७. हाम्रो घरमा ६० एम्पेरको मिटर जडान गरेको छ भने चट्याङ षर्दा त्यसबाट कितसम्म करेण्ट बग्न सक्छ ?

क) ६० एम्पेर

ख) ३० एम्पेर

ग) ३००० एम्पेर

घ) ३ लाख एम्पेर

ङ) थाहा छैन

८. यदि कुनै घरमा भएको विद्युतीय सर्किटको मुख्य स्वीचबक्समा रातो र कालो तारलाई उल्टो पारेर जोडेमा घरमा आगो लाग्ने सम्भावना कस्तो हुन्छ ?

क) घट्छ

ख) केही फरक पर्दैन

ग) बढ्छ घ) निकै बढ्छ

घ) थाहा छैन

९. चट्याङ र सर्जबाट बचाउने प्रणाली तलकामध्ये कुन अन्तर्राष्ट्रिय मापदण्ड अन्तर्गत पर्दछ ?

क) IEC 62304

ख) IEC 62305

ग) IEC 62306

घ) माथिका कुनै पनि होइनन्

ङ) थाहा छैन

१०. विद्युतीय जडान र सामग्री सम्बन्धी नेपालमा लागू हुन लागेको इलेक्ट्रीकल कोड कुन अन्तर्राष्ट्रिय मापदण्ड अनुरूप छ ?

क) IEC

ख) ISO

ग) ISI

घ) माथिका कुनै पनि होइनन्

ङ) थाहा छैन

MCQ2: Lightning Introduction
For Session-01

सही उत्तरमा चिन्ह लगाउनुहोस्

११. चट्याङ सर्वप्रथम पृथ्वीमा प्रारम्भिक जीवको उत्पतिको कारण हो ।

च) ठीक हो ख) **गलत हो** ग) यी दुई कुराहरूबीच कुनै सम्बन्ध छैन

घ) भन्न सकिन्न ङ) थाहा छैन

१२. बादलमा भएको विशाल मात्राको विद्युतीय चार्ज चट्याङको माध्यमबाट अन्त जाने प्रकारमध्ये तलका कुन हुन सक्छन् ?

क) बादलबाट जमिनमा ख) बादल बादल बीचमा ग) बादलबाट हावामा

घ) माथिका सबै ङ) माथिका कुनै पनि होइन

१३. चट्याङ परेको समयमा हावाको तापक्रम कति पुग्छ ?

च) १०० डिग्री सेण्टिग्रेड ख) १००० डिग्री सेण्टिग्रेड ग) ३०००० डिग्री सेण्टिग्रेड

घ) १००००० डिग्री सेण्टिग्रेड ङ) थाहा छैन

१४. चट्याङ पर्दा बादलबाट जमिनमा कुन प्रकारको चार्ज बग्छ ?

क) ऋणात्मक ख) **धनात्मक** ग) माथिका दुवै हुन सक्छन् घ) माथिका कुनै पनि होइन ङ) थाहा छैन

MCQ3: Harmful effects of Lightning
For Session-02

सही उत्तरमा चिन्ह लगाउनुहोस्

१५. चट्याङका कारणले नेपालमा वर्षमा कति मानिसको मृत्यु हुन्छ ?

छ) १० ख) **५०** ग) १०० भन्दा बढी घ) माथिका कुनै पनि होइन ङ) थाहा छैन

१६. वि.सं. २०६८ –७५ सम्मको तथ्याँक अनसार भूकम्पपछिको सबैभन्दा धैरै मानिसको मृत्यु हुने प्राकृतिक प्रकोप कुन हो ?

ख) बाढी ख) पहिरो ग) चट्याङ घ) शित लहर ङ) माथिका कुनै पनि होइन

१७. नेपालमा चट्याङका कारणले सबैभन्दा धैरै मृत्यु र घाइते हुने जिल्ला कुन हो ?

छ) मकवानपुर ख) उदयपुर ग) काश्की घ) मोरङ ङ) थाहा छैन

१८. चट्याङबाट जोगिन हामीले गर्न सक्ने उपाय कुन हो ?

क) चट्याङ नै पर्न नदिने ख) चट्याङ सम्बन्धी सचेतना फैलाउने र प्रतिरक्षी उपकरण जडान गर्ने ग) नजिकैको रूखमुनि गएर लुक्ने घ) खुल्ला चौरमा गएर पाल टाँगेर बस्ने ङ) थाहा छैन

MCQ4: Lightning Protection System
For Session-03

सही उत्तरमा चिन्ह लगाउनुहोस्

१९. चट्याङ परेको बेलामा तलकामध्ये केभित्र बस्नु सबैभन्दा कम सुरक्षित हुन्छ ?

ज) हवाइजहाज ख) कार ग) छाप्रो घ) घोप्टाएको तामाको घ्याम्पो ङ) थाहा छैन

२०.तलकामध्ये कुन चीज नभए पनि चट्याङ प्रतिरक्षी प्रणालीले काम गर्छ ?

ग) छानामा राखेको त्रिशुल वा छड ख) छानामा राखेको छडबाट जमिनसम्म जोड्ने सुचालक ग) अर्थिङ घ) छानामा राखेको छडबाट जमिनसम्म जोड्ने सुचालकहरूबीचको उपयुक्त दुरी र समान भोल्टेज बन्धनिकरण ङ) माथिका सबै चाहिन्छन्

२१. भवन/संरचनाहरूलाई चट्याङबाट बचाउने हिसाबले बचावटका कति तह वा श्रेणी छन् ?

ज) २ ख) ३ ग) ४ घ) ५ ङ) थाहा छैन

२२.चट्याङबाट जोगाउन छतमा प्रयोग गरिने छडको मोटाइतिरको (क्रससेक्सनल) क्षेत्रफल कम्तीमा कति हुनुपर्छ ?

क) ५० वर्ग मिलिमिटर ख) १० वर्ग मिलिमिटर ग) जति भए पनि फरक पर्दैन घ) माथिका कुनै पनि होइनन् ङ) थाहा छैन

MCQ5: Lightning Protection System-Internal and SPD
For Session-04

सही उत्तरमा चिन्ह लगाउनुहोस्

२३.चट्याङबाट प्रथम श्रेणीको बचावट गर्दा अधिकतम कतिसम्मको करेण्टबाट सुरक्षित हुन्छ ?

झ) १०० किलोएम्पेर ख) १५० किलोएम्पेर ग) २०० किलोएम्पेर घ) ३०० किलोएम्पेर ङ) थाहा छैन

२४. चट्याङ प्रतिरक्षी प्रणालीमा अर्थिङ गर्दा समान भोल्टेज बन्धनिकरण (**Equipotential Bonding**) गर्नु कति जरूरी हुन्छ ?

घ) नभए पनि केही फरक पर्दैन ख) अनिवार्य रूपमा गर्नुपर्छ ग) अर्थिङ राम्रोसँग गरेको छ भने पर्दैन घ) माथिका कुनै पनि होइनन् ङ) थाहा छैन

२५. सर्जबाट बचाउने उपकरण (**SPD**) ले के गर्छ ?

झ) त्यो करेण्ट आफूबाट पठाएर बाँकी चीजलाई जोगाउँछ ख) आफूबाट करेण्ट नबगाएर अन्यत्र करेण्ट बाँडिदिन्छ ग) पड्किन्छ र सर्किटमा करेण्ट बग्न छोड्छ

घ) माथिका कुनै पनि होइनन् ङ) थाहा छैन

२६.सर्जबाट बचाउने उपकरण (**SPD**) कहिलेसम्म प्रयोग गर्न सकिन्छ ?

क) यसको सङ्केतमा हरियो वा पहेँलो देखिएसम्म ख) यसको सङ्केतमा रातो देखिएसम्म ग) यो डढेर खरानी नभएसम्म घ) माथिका कुनै पनि होइनन्

ङ) थाहा छैन

MCQ6: Conventional vs non-conventional LPS
For Session-05

सही उत्तरमा चिन्ह लगाउनुहोस्

२७. चट्याङबाट जोगाउन छानामा राखिने छड कुन मापदण्डको हुनुपर्छ ?

ञ) **IEC** ख) **ESE** ग) **DAS** घ) **SLE** ङ) माथिका कुनै पनि होइन

२८.चट्याङ प्रतिरक्षी प्रणाली कुन उपयुक्त छ भनेर कसरी छान्ने ?

ङ) बिक्रेताले कमसेकम २ किमिको क्षेत्रसम्म जोगाउँछ भनेर गरेको दावीको आधारमा

ख) हाल नेपाल र संसारको यो यो ठाउँमा जडान भइसकेको छ भनेर दिइएको लामो सूचीका आधारमा

ग) कम लागतमा धेरै संरचनाको सुरक्षा हुन्छ भन्दै आकर्षक डिजाइन देखाएको आधारमा घ) **IEC** मापदण्डमा आधारित छ भन्ने प्रमाणका आधारमा

ङ) माथिका कुनै पनि होइनन्

२९.छानामा उमारिएको सिउँडीको बोटले चट्याङबाट जोगाउँछ कि जोगाउँदैन ?

ञ) पूर्णरूपले जोगाउँछ ख) सानोतिनोबाट जोगाउँछ ग) जोगाउँदैन

घ) माथिका कुनै पनि होइनन् ङ) थाहा छैन

३०.**IEC** मापदण्डक अनुसार चट्याङ प्रतिरक्षी प्रणाली अन्तर्गत छानामा राख्ने छडमा रेडियोधर्मी पदार्थ हुनु आवश्यक छ कि छैन ?

क) चाहिँदैन ख) भएमा राम्रो ग) यो त प्रतिबन्धित छ

घ) अनिवार्य चाहिन्छ ङ) थाहा छैन

MCQ7: Electrical Hazards
For Session-06

सही उत्तरमा चिन्ह लगाउनुहोस्

३१. मानिसको शरीर विद्युतीय झड्काले पार्ने असर मुख्यगरी चारवटा कुराहरूमा भर पर्छन् । तिनमा यीमध्ये कुन चाहिँ पर्दैन ?

ट) करेण्ट र भोल्टेज ख) **अवरोध** ग) शरीरबाट करेण्ट बग्ने बाटो

घ) करेण्टको झड्काको अवधि ङ) चट्याङ पर्दा आएको आवाजको तीक्ष्णता

३२. स्क्र्यू टाइप बल्बमा स्वीच अफ गरेको समयमा पनि बाहिर छुँदा करेण्टको झट्का लाग्यो । के कारणले हुन सक्छ ?

च) सर्किटमा विपरित ध्रुबिकरण (**Reverse Polarity**) ख) अधिक करेण्ट ग) बल्बको पावर बढी भएर घ) माथिका कुनै पनि होइनङ) थाहा छैन

३३. आधा सेकेण्डसम्म ०.५ एम्पेर करेण्ट हाम्रो शरीरबाट बग्यो भने मुटुमा असर गरी हृदयघात हुने सम्भावना कति हुन्छ ?

क) ०% ख) २५% ग) ५०% वा बढी घ) १००% ङ) थाहा छैन

३४. तलकामध्ये कुन अवस्थामा विद्युतीय सर्किटमा आगलागी हुने सम्भावना बढी हुन्छ ?

ग) भोल्टेज र करेण्ट समान राखी अवरोध अत्यधिक बढाउँदा

घ) भोल्टेज र अवरोध समान राखी करेण्ट अत्यधिक बढाउँदा

ग) अवरोध र करेण्ट समान राखी भोल्टेज अत्यधिक बढाउँदा

घ) माथिका कुनै पनि होइन ङ) थाहा छैन

MCQ8: Electrical Codes and Auditing
For Session-07

सही उत्तरमा चिन्ह लगाउनुहोस्

३५. अन्तर्राष्ट्रिय इलेक्ट्रोटेक्निकल आयोग (**IEC**) को अन्तर्गत विद्युतीय जडान गर्दा पालना गर्नुपर्ने मापदण्ड तलकामध्ये कुन हो ?

ठ) **IEC-60364** ख) **IEC-60362** ग) **IEC-60366** घ) माथिका कुनै पनि होइन ङ) थाहा छैन

३६. विद्युतीय लेखापरिक्षण (**Electrical Auditing**) गर्दा गरिने परिक्षणहरूमा तलकामध्ये कुन पर्दैन ?

छ) सुचालकको निरन्तरता ख) इन्सुलेसनको अवरोध ग) ध्रुविकरण परिक्षण घ) सुचालकको तापक्रम ङ) थाहा छैन

३७. अर्थिङमा गडबढी भएको थाहा पाउन अवरोध नाप्ने उपकरण कुन हो ?

क) मल्टिमिटर ख) भोल्टमिटर ग) इन्सुलेसन परिक्षण मिटर

घ) अर्थ रेजिस्टेन्स मिटर ङ) फल्ट लुप अवरोध मिटर

ख) फेज सिक्वेन्स परिक्षण कस्तो विद्युतीय सर्किटमा गरिन्छ ?

ङ) एक फेज ख) तीन फेज ग) माथिका दुवै घ) माथिका कुनै पनि होइन

ङ) थाहा छैन

MCQ9: Electrical Meters - Practical
For Session-08

सही उत्तरमा चिन्ह लगाउनुहोस्

३८.अर्थिङको लागि जमिनको परिक्षण गर्न कुन उपकरण प्रयोग गरिन्छ ?

ङ) एमिटर ख) भोल्टमिटर ग) इन्सुलेसन परिक्षण मिटर

घ) अर्थ रेजिस्टेन्स मिटर ङ) फल्ट लुप अवरोध मिटर

३९.सुचालकको निरन्तरता परिक्षण गर्न कुन उपकरण प्रयोग गरिन्छ ?

क) मल्टिमिटर ख) भोल्टमिटर ग) इन्सुलेसन परिक्षण मिटर

घ) अर्थ रेजिस्टेन्स मिटर ङ) फल्ट लुप अवरोध मिटर

४०. विद्युतीय तारको इन्सुलेसनको गुणस्तर परिक्षण गर्न कुन उपकरण प्रयोग गरिन्छ ?

क) एमिटर ख) भोल्टमिटर ग) इन्सुलेसन परिक्षण मिटर

घ) अर्थ रेजिस्टेन्स मिटर ङ) फल्ट लुप अवरोध मिटर

४१.समान भोल्टेज बन्धनिकरण छ कि छैन परिक्षण गर्न कुन उपकरण प्रयोग गरिन्छ ?

ढ) एमिटर ख) मल्टिमिटर ग) इन्सुलेसन परिक्षण मिटर

घ) अर्थ रेजिस्टेन्स मिटर ङ) फल्ट लुप अवरोध मिटर

चट्टयाङ्ग र विद्युतीय लेखा परीक्षण प्रशिक्षण

दैनिक पृष्ठपोषण फाराम (..........................दिन)

नामः मितिः

१. आजका प्रशिक्षण सत्रहरूबाट के के सिकाइहरू भए ?

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२. तपाईँ ती सिकाइहरूलाई व्यवहारमा कसरी प्रयोग गर्नुहुन्छ ?

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३. प्रशिक्षणलाई अझ प्रभावकारी बनाउन के गर्नुपर्ला ?

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चट्टयाङ्ग र विद्युतीय लेखा परीक्षण प्रशिक्षण

प्रशिक्षण अन्तिम मूल्याङ्कन फाराम

प्रशिक्षणको नामः .... **प्रशिक्षण मितिः ....**

कृपया तलका प्रश्नहरूमा आफूलाई उपयुक्त लागेको विकल्पमा चिह्न लगाउनुहोस्।

१. यस प्रशिक्षणलाई तपाईं कसरी मूल्याङ्कन गर्नुहुन्छ ?
(क) उत्कृष्ट **(ख) ज्यादै राम्रो** **(ग) राम्रो** **(घ) ठिकै** **(ङ) सुधार गर्नुपर्ने**

टिप्पणी सुझाव ....

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२. सहजकर्ताहरूलाई तपाईं कसरी मूल्याङ्कन गर्नुहुन्छ ? (विषयवस्तुको ज्ञान, सञ्चार क्षमता, प्रस्तुतीकरण शैली आदि)
(क) उत्कृष्ट **(ख) ज्यादै राम्रो** **(ग) राम्रो** **(घ) ठिकै** **(ङ) सुधार गर्नुपर्ने**

टिप्पणी सुझाव...

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३. प्रशिक्षणको विषयवस्तु तपाईंलाई कस्तो लाग्यो ? (कामसँग सम्बन्धी र उपयोगी, ज्ञानमा वृद्धि, सिप र दक्षताको विकासमा सहयोगी आदि)
(क) उत्कृष्ट **(ख) ज्यादै राम्रो** **(ग) राम्रो** **(घ) ठिकै** **(ङ) सुधार गर्नुपर्ने**

टिप्पणी सुझाव...

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४. प्रशिक्षणमा प्रयोग भएको प्रशिक्षण विधि तपाईंलाई कस्तो लाग्यो ? (विषयवस्तु बुझ्नका लागि सहयोगी आदि)
(क) उत्कृष्ट **(ख) ज्यादै राम्रो** **(ग) राम्रो** **(घ) ठिकै** **(ङ) सुधार गर्नुपर्ने**

टिप्पणी सुझाव...

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५. प्रशिक्षणमा उपलब्ध गराइएका पाठ्यसामग्री तथा सन्दर्भसामग्रीहरू तपाईंलाई कस्ता लागे ? (विषयवस्तु बुझ्नका लागि सहयोगी, भावी प्रयोजनका लागि उपयुक्त आदि)
(क) उत्कृष्ट **(ख) ज्यादै राम्रो** **(ग) राम्रो** **(घ) ठिकै** **(ङ) सुधार गर्नुपर्ने**

टिप्पणी सुझाव...

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स्थानीय तहको क्षमता अभिवृद्धिका लागि तयार पारिएका प्रशिक्षण सामग्री

मोड्युल ११	भवन निर्माण मापदण्ड तथा भवन संहिता
मोड्युल १२	आगलागी र अग्नी नियन्त्रण उपकरण सञ्चालन
मोड्युल १३	फोहोरमैला व्यवस्थापन तथा वातावरण व्यवस्थापन
मोड्युल १४	जग्गा नापजाँच
मोड्युल १५	हरित आवास
मोड्युल १६	सडक ठेगाना र भौगोलिक सूचना प्रणाली
मोड्युल १७	एकीकृत स्थानीय विकास योजना प्रणाली
मोड्युल १८	Urban Design (अर्वन डिजाइन)
मोड्युल १९	सूचना र संचार प्रविधि
मोड्युल २०	पूर्वाधार निर्माण
मोड्युल २१	चट्टयाङ्ग र विद्युतीय लेखा परीक्षण

नेपाल सरकार
सङ्घीय मामिला तथा सामान्य प्रशासन मन्त्रालय

स्थानीय विकास प्रशिक्षण प्रतिष्ठान
(स्थानीय विकास प्रशिक्षण प्रतिष्ठान ऐन, २०४९ द्वारा स्थापित)
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