ELECTRICAL PROTECTION FUNDAMENTALS

CONTENTS

1. GENERAL

1.1 This section provides REA borrowers, engineers and other interested parties with information on the electrical protection of telephone systems. The general concepts of system protection for modern telephone plant are illustrated. It replaces Issue No. 3, dated July 1974.

1.2 Protection engineering may be defined as the protection of subscribers, telephone company personnel, the public and telephone plant (inside and outside) against high voltage contacts and lightning; the reduction of interference caused by low frequency induction from power and other sources to the transmission of speech and other forms of transmitted intelligence; the mitigation of crosstalk between telephone circuits; the mitigation of noise induced in the telephone plant from external sources; and the investigation and mitigation of electrolysis in underground and buried cable. The most appropriate time for combating these influences is during the design and construction of telephone plant. Details on specific protection recommendations can be found in the 400 and 800 series of the TE&CM and those sections of the 600 series pertaining to the National Electrical Safety Code, clearances and corrosion.

1.3 Telephone systems are subject to disturbances from external sources of electrical energy. These sources include electrical power supply circuits and natural phenomena, such as lightning and low energy static charges. The electrical disturbances enter the telephone system via direct contacts, magnetic fields, or electrical fields. The effect in the telephone plant may be confined to interference with its normal use or operation, as in the case of noise or interference with signaling; or they may be capable of creating hazards to subscribers, the public, telephone personnel, and damage to plant (outside and inside).

1.3.1 The electrical protection discussed in this section deals with the control of abnormal potentials and currents that may appear in the telecommunications plant. It is impossible to provide simple specific rules to cover all protection requirements. Therefore, due to variations in plant and equipment making up the total system, only generalized recommendations are offered. Additional recommendations for the protection of specific types of plant, equipment and environmental conditions are provided in the TE&CM sections listed in Paragraph 1.2.

1.3.2 Equipment and material design engineers need to be aware of the abnormal voltages and currents which may occur within the telecommunications plant.

1.3.3 Evaluation of the effects of abnormal potentials and currents on various types of plant and equipment in the telephone system is a primary concern of the telephone system engineer. After determination of the effects, the most suitable form of mitigation must be recommended for each situation.

1.4 The field of electrical protection against foreign potential covers two areas.

1.4.1 First; is to minimize, as far as practical, electrical hazards to the general public and to individuals who use the telephone system. There is also the need to protect the employees who are involved in the construction, operation and maintenance of the telecommunications system.

1.4.2 Second; is to reduce, as far as practical, electrical damage to aerial, buried or underground plant and equipment and to buildings or structures that may be associated with such plant or equipment.

1.5 Protection of plant and equipment involves a balance between the initial cost of the appropriate protection measures and their maintenance expense versus the value of increased service reliability and cost of repairs to plant and equipment. Where the general public, customers or employees are concerned, safety from electrial shock and other hazard should be the prime consideration.

1.6 Those protection problems such as connections to multigrounded neutral, grounding locations, etc., relating to the economics of the design should be identified and studied early during the planning phase of a new facility. Most protection measures are more costly to implement after the plant has been installed. Where service continuity is essential, there is no reasonable alternative to providing an initial high level of protection.

1.7 Some protection measures are primarily designed to be effective against lightning. Other measures are utilized to minimize damage from electric power systems. There are also specific measures associated with the mitigation of noise and signaling problems. All of these are discussed in detail in the TE&CM sections listed in Paragraph 1.2.

1.7.1 Most protective measures designed for protection against lightning damage will also afford protection against electric power system damage and vice versa. Some will also provide improved noise performance. Likewise, some of the measures applied to the telecommunications system for noise reduction will also provide protection against the effects of lightning and power related problems.

1.8 Equipment located in the central office building is less exposed to direct lightning and high current from both power line contacts and induction than plant and equipment located outside the central office building. However, such equipment is exposed to lower magnitude induced currents from the outside plant facilities to which it is connected.

1.9 A factor in determining the protection to be used at an office, as compared with subscriber stations, is the effect of equipment failure on overall service continuity. Where the probability of trouble is small, some risk of equipment damage might be taken at a subscriber station providing there is no compromise of subscriber safety. However, with the same probability, the possibility of damage at an office may be too great due to the ultimate effect upon many circuits. In the majority of subscriber circuits the only permanent connection to ground is at the office. In such cases the current, resulting from either a power fault current or induction in the communications facilities, would flow toward the office rather than toward the stations. The current will flow toward the point of least resistance. If the office protection is not adequate, such current might result in overheating of circuit elements in the line circuits.

1.10 Prior to designing a protection system the engineer should be familiar with the various methods and types of protective devices described in the TE&CM Sections listed in Paragraph 1.2. Familiarity with potential protection problems common to the particular area in which the telecommunication system is located is essential. For example, has there been frequent lightning damage, excessive power related damage, or perhaps high circuit noise in the area? With this information, a protective system can be designed to provide the best performance in the desired protection area.

2. CODES

2.1 The National Electrical Code (NEC) and the National Electrical Safety Code (NESC) are nationally recognized standards of electrical wiring to protect workers and the public against shock hazard and property against fire hazard. Both of the codes are approved by the American National Standards Institute (ANSI). The NEC, which is sponsored by the National Fire Protection Association, generally covers wiring in or on a building. The NESC is sponsored by the Institute of Electrical and Electronics Engineers, Inc. and covers outside wiring. Portions of the codes cover wire spacings, insulation, and clearances above the ground for telephone lines. Climbing space on poles is also included. Also covered are protector requirements, grounding of protectors, cables and guy wires and bonding between the power and communications systems.

2.2 The NEC in Article 90-2 (b) (4) states that; "Installation of communications equipment under the exclusive control of communications utilities, located outdoors or in building spaces used exclusively for such installations" are not covered by NEC requirements. Regardless of this exemption, it is recommended that companies comply with the code requirements at all times.

2.3 At all other locations, telecommunications plant and apparatus must meet the applicable provisions of the codes or local ordinances. In some instances local ordinances may be stricter than the national codes. The engineer should become familiar with both national and local codes.

3. SOURCES OF ELECTRICAL DISTURBANCES IN TELECOMMUNICATIONS SYSTEMS

3.1 Lightning

3.1.1 Lightning is a transient high current electrical discharge. It occurs when some region of the atmosphere attains an electrical charge of sufficient potential to cause dielectric breakdown of the air. Lightning is usually an electrical discharge from cloud to cloud or from cloud to earth. Cloud to cloud discharges are the most numerous but are of little concern to the protection engineer responsible for the protection of customers, plant personnel and telecommunications equipment. The cloud to cloud discharges produce electrostatic induction in telecommunication plant susceptible to this type interference. The magnitude is relatively low and may be a source of noise but is rarely a hazard to personnel or equipment. Lightning strokes to ground are a source of hazardous potentials and currents. Direct strokes to wire and cable plant may produce serious arcing near the point of contact. This is due to the plant becoming a part of the series path between the cloud and earth along which large amplitude surge currents will flow. Voltage differences will occur in the plant that are great enough to produce dielectric breakdown and hazardous shock conditions. Strokes to earth near telecommunication plant may involve the telephone plant in two ways. Should the magnitude of the ground potential rise be great enough, dielectric breakdown of the sheath material may result and the cable will become part of the conductive discharge path. The effects on the plant are similar to those produced by a direct stroke but the voltage and current magnitudes will be lower. When a nearby stroke does not involve the plant directly through a conductive discharge path, the fields associated with such strokes may be sufficiently intense to produce inductive effects hazardous to personnel and plant. There is another lightning related phenomenon which may be the greatest source of hazardous potentials and current. A direct stroke to the power system may produce a dielectric breakdown (ionization) of the air resulting in an arc between two components of the system. This can occur between two phase wires, a phase and neutral wire or a phase wire and grounded hardware. The resulting unbalanced condition of the power system may induce high potentials in parallel telecommunications plant. These induced potentials last for longer time periods, than do the induced potentials associated with nearby lightning strokes, and can result in greater damage in the telecommunications plant.

3.1.2 Lightning occurs in practically all areas of the United States. The annual incidence and relative intensity of thunderstorms vary greatly from area to area. It can therefore be assumed that the telecommunications plant will be exposed to the effects of lightning in varying degrees. The exposure in sparsely settled rural areas will be the greatest because there is little benefit from the shielding provided by other grounded structures. Plant located in cities and other built up areas has less exposure due to the presence of high structures that tend to intercept lightning strokes. There are also the benefits from shielding provided by other grounded conducting media such as public water systems. Between these two extremes, there are varying degrees of exposure depending on the density of grounded structures in the area.

3.1.3 There are two general types of thunderstorms.

a. Convection storms are local in area and of relatively short duration. Convection type thunderstorms account for the majority of thunderstorm days in the United States.

b. Frontal storms extend over greater areas and may last for several hours. Studies show that frontal type storms cause appreciably more damage than convection type storms.

3.1.3.1 Convection type storms are caused by local heating of the air near the earth which rises and meets cold air at higher altitudes. These storms are predominant during the summer months and in warm climates. They are nonregenerative in nature and the rain usually accompanying such disturbances cools the earth dissipating their energy source. There are indications that the magnitude and incidence of lightning strokes to ground during these storms are lower than with frontal type storms.

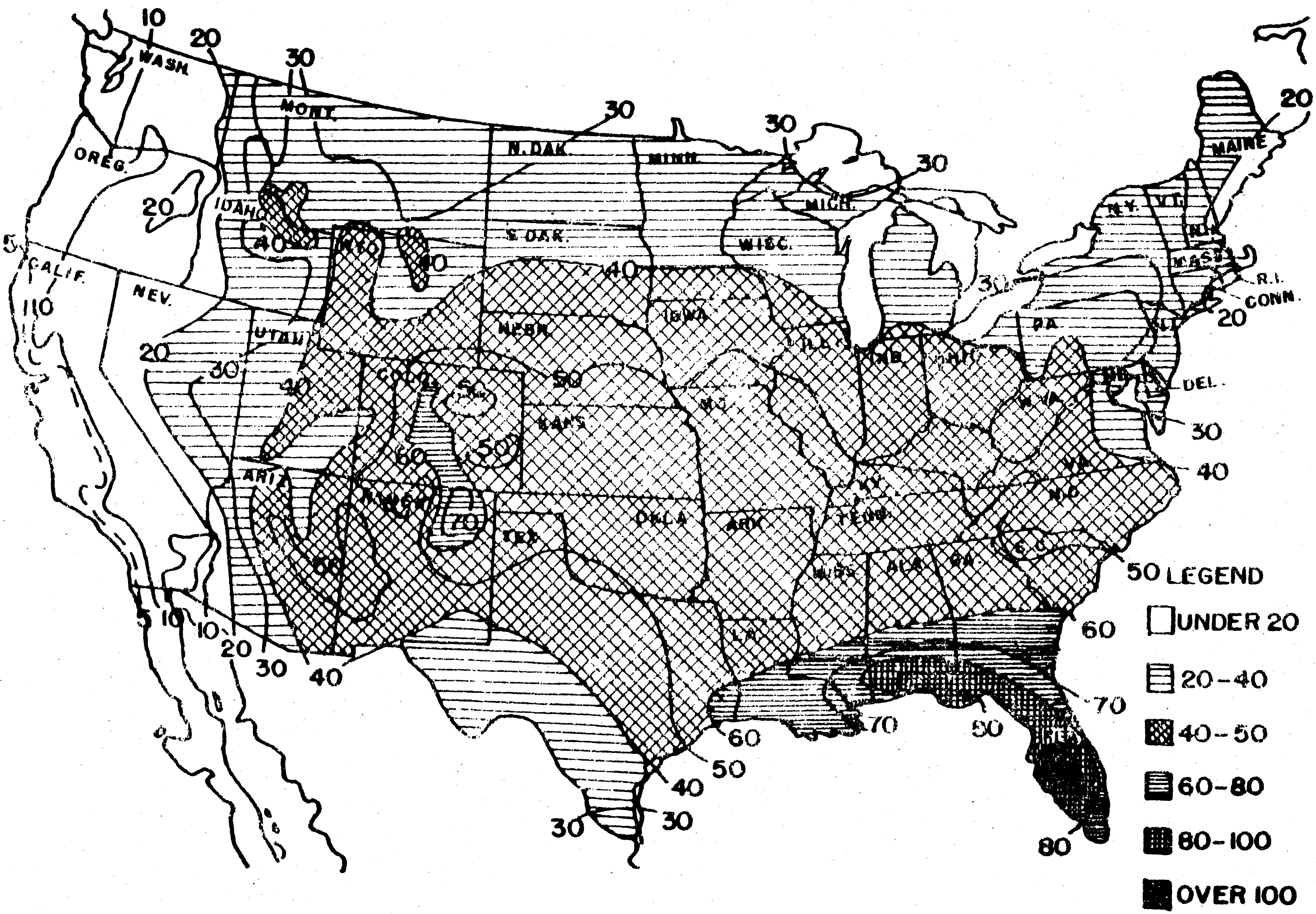
3.1.3.2 Frontal type thunderstorms are produced when a front of warm moist air meets with a cold front. These storms may extend for several hundred miles and expose large areas to severe lightning discharges. They are regenerative in nature because the frontal air masses may continue to move into the area and maintain the turbulent conditions for hours.

3.1.4 The measure of storm frequency is the number of "thunderstorm days" experienced at a specific location during the year. A "thunderstorm day" is defined by the National Weather Service as any day during which thunder is heard at a specific observation point. Such observations merely confirm the presence of lightning but do not provide information relative to the number of strokes to earth.

3.1.4.1 The National Weather Service has compiled extensive data on the annual incidence of thunderstorm days in the United States. Data has been obtained from several hundred observation points. The data has been plotted in the form of an isoceraunic map. This map is used extensively for estimating plant exposure to lightning. See Figure 1.

3.1.4.2 Information on stroke incidence for various areas is essential for estimating the probable telecommunications plant exposure. It has been customary to use a "Stroke Factor" based on areas typically experiencing each type of storm for this purpose. This provided a rough approximation since there were only two factors; one, for frontal type storms and the second for convection type storms. Later work in this area has developed a "Proportion Factor" based on latitude which provides a better representation of the exposure.

Fig. 1 - MEAN NUMBER OF DAYS WITH THUNDERSTORMS, ANNUAL



3.1.4.3 The electrical resistivity of the earth (resistance of the earth to the flow of current) is almost as important as the intensity and frequency of occurence of lightning strokes in determining the probability of lightning damage. The unit of earth resistivity, the ohm-meter, is defined as the resistance, in ohms, between opposite faces of earth one cubic meter in volume. An alternate measure, the ohm-centimeter, is defined as the resistance, in ohms, between opposite faces of a one cubic centimeter cube of earth. If earth resistivity is high, the voltage which a given stroke develops across a dielectric, and the distance that lightning currents travel along a conductor before attenuating to harmless values are greater than if the earth resistivity is low. The result is that the probability of lightning damage is greater in some parts of the country, with high earth resistivity and only moderate incidence of storms, than it is in other parts with low resistivity and greater incidence. Earth resistivity varies over a considerable range in the continental United States; from a few ohm-meters along part of the Gulf of Mexico coast to 10,000 ohm-meters or more in upland or mountainous country. Table I gives range of earth resistivity values to be expected for various soils.

TABLE I: RESISTIVITY OF VARIOUS SOILS

Soil	Resistivity Range - (Ohm-Meters)
Loam	5 - 50
Clay	4 - 100
Sand/Gravel	50 - 1,000
Limestone	5 - 10,000
Shale	5 - 10,000
Sandstone	20 - 2,000
Granite	1000
Slates	600 5,000

3.1.4.4 By combining data on thunderstorm days, earth resistivity and latitude a lightning damage probability map (Figure 2) has been developed. It should be noted that this map is intended as a broad guideline indicating areas in which very high, high, average, low and very low lightning damage can be expected. The map represents a useful tool when employed as intended. It is a broad area system map to be employed in assessing generalized protection practices over a wide geographical area. For example, by examining the map one could quickly justify the use of maximum duty gas tubes on a system-wide basis in Florida while determining this would not be cost-effective in California.

3.1.4.5 While Figure 2 is valuable for determining if broad areas may experience greater than average lightning problems, local experience can reveal exceptions to these guidelines. A microwave tower on a hilltop in a low lightning damage area may require special protection while equipment in a city of tall buildings served by cable in ducts may require minimal protection even when located in a very high damage area. Establishing concise standards for evaluation of local experience is impossible. Good engineering judgement, based on the best available experience and information must be exercised to obtain optimum protection for the system under consideration.

3.1.5 The characteristic cloud formation normally associated with convection and frontal type storms is the cumulo-nimbus cloud, commonly referred to as the "thunderhead." Strong winds, heavy rain, hail and lightning are associated with such clouds. These clouds, when fully developed and observed from a long distance, have a characteristic anvil shape with a broad top, a sharply defined outline with a brilliant white near the top and sometimes a cap of ice crystals. There are several theories relating to thunderstorm electrification. They all have the common problem of accounting for the quantity of charge that is required to produce lightning. The goal of continuing research in this area is to better understand the electrification process and develop a model for thunderstorm electrification. This will provide a key tool toward the development of more effective lightning protection systems.

3.1.6 Knowledge as to the polarity of a lightning stroke is of little practical value to a protection engineer. A surge propagated through an object in either direction will have the same effect. As a matter of interest, studies indicate that strokes to ground can occur from either positively or negatively charged clouds. The majority of strokes to ground, however, are between negatively charged clouds and corresponding positively charged earth. The resulting electron flow is from the cloud to earth.

3.1.6.1 A lightning discharge is usually initiated from the charge center in a cloud in ionization steps that are called a stepped leader. The stepped leader may be initiated at a structure where the discharge involves a tall structure. If it is assumed that a negative cloud is being discharged to positive earth, the stepped leader path is preionized by a steady moving pilot leader. The pilot leader leaves no visible track. The stepped leader follows the pilot leader path in approximately 50-yard increments at 50-μsec intervals, with accompanying luminosity at each step. This discharge pattern has been recorded on fast-moving film.

3.1.6.2 As soon as the stepped leader reaches the earth, neutralization of the negatively charged channel begins at the earth and travels in a brightly luminous path toward the cloud at 10 percent of the velocity of light. This is the main lightning stroke. The upward progress of the main stroke toward the cloud is accompanied by a rising surge of current from cloud to earth. This main surge of current, which lasts less than a millisecond, may be followed by a low current lasting approximately 0.1 second. A second leader, called a dart leader, may then occur which originates in a different part of the cloud charge center. It will follow the same path to earth but does not exhibit the stepped characteristic of the first leader. The

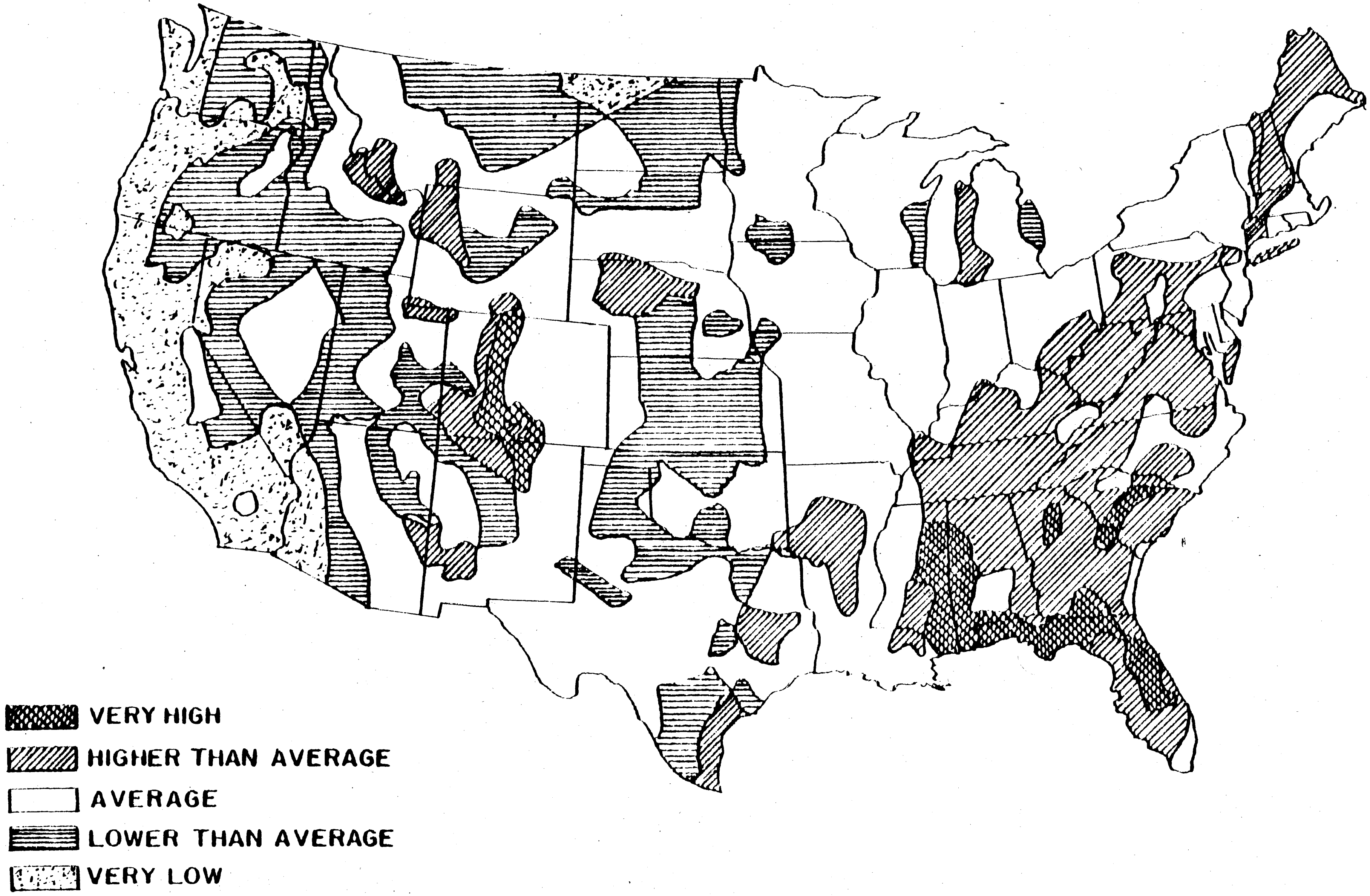


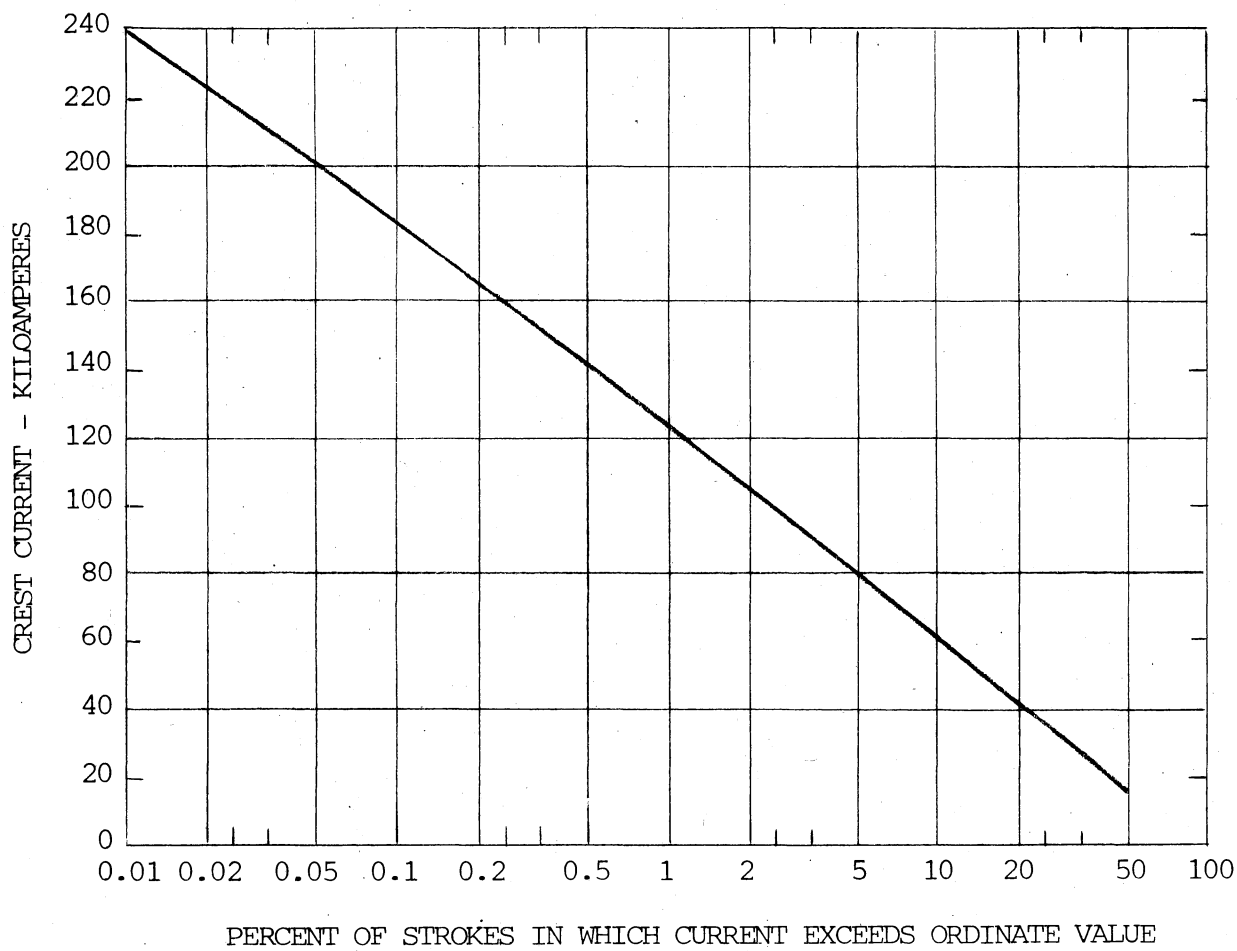
FIG. 2 - LIGHTNING DAMAGE PROBABILITY MAP

dart leader may result in a second main stroke which in turn may be followed by a third dart leader and so on. The average number of strokes in multiple discharges is about four. Single stroke discharges are quite common while discharges having more than six strokes are rare. The median number of strokes per multiple discharge is two. The time interval between strokes in a multiple discharge is so short (0.02 second) that several strokes may appear to the eye as one bright stroke. The first stroke in a multiple discharge is assumed to contain the highest energy discharge to earth similar to the discharge of a capacitor.

3.1.7 Potentials associated with a lightning discharge are very high. Estimates of the potentials required to initiate a discharge are in the order of 5 to 20 million volts. It would require potentials in excess of these values were it not for the nonuniformity of the electrostatic field between cloud and earth. Ionization of the charge center in a cloud initiates the pilot leader which carries charge with it toward earth. The field at the tip of the leader becomes progressively intense and ultimately proceeds until it contacts the earth or some object on it. Occasionally, the charge fed from the cloud to the leader is not sufficient to maintain its progress, and the charge will dissipate without producing a stroke. The primary concern of a protection engineer is not related to the potentials associated with lightning strokes but rather the damage to plant from high magnitude currents. Crest-current values vary over a wide range from stroke to stroke. The magnitude depends on meteorological factors and the overall impedance of the stroke. Figures A and B are representative curves showing the distribution of the crest magnitudes for direct lightning strokes to aerial and buried structures. The average initial stroke is about 16KA in the case of aerial structures and 30 KA for buried. While these currents are large it should be remembered that they are values associated with <u>direct</u> strokes. <u>Typical</u> surges conducted or induced into telecommunications facilities are considerably smaller. Ordinarily, the energy in a direct stroke is so great as to make protective measures unfeasible and uneconomical for normal telecommunications plant. However, radio towers and similar structures should be designed to withstand most direct strokes.

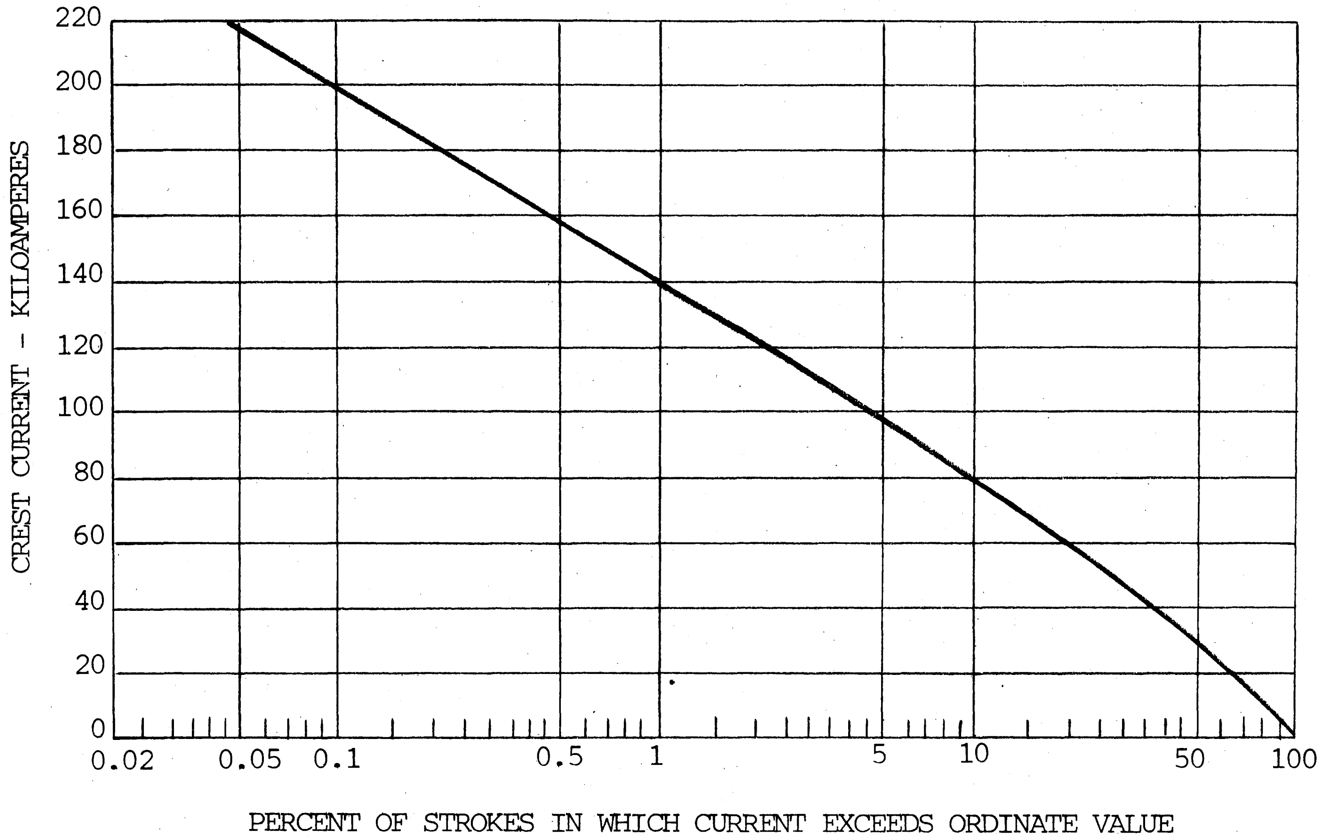
3.1.7.1 The impedance of objects such as telecommunications plant, which may become part of the path along which the elctrical charges flow, is considerably lower than the total stroke path impedance. It is therefore, appropriate to consider a lightning stroke as essentially a constant current source.

3.1.7.2 Recorded measurements reveal that there are wide variations in rise and decay times between lightning strokes. Lightning strokes are sometimes referred to as "hot" or "cold" lightning. "Cold" lightning is characterized by rapid rates of rise, high crest currents and relatively short decay times. These strokes leave no trace of burning or fusing but do develop explosive pressures in materials where the vapor produced cannot readily be vented. "Hot" lightning will generally have much lower crest current values with slower rise and delay times. Such long duration surges do not produce significant explosive effects but may ignite combustible materials and fuse conductors.



Distribution of Lightning Stroke Crest Currents to Aerial Structures

FIGURE 3A



Distribution of Lightning Stroke Crest Currents to Buried Structures

FIGURE 3B

3.1.8 The very high current values associated with lightning strokes to earth combined with the possible hazard to the public, personnel, and telecommunications plant must be given proper respect. Such appreciation should be tempered with the knowledge that statistically there is a probability that strokes to earth may not always produce plant damage. The possible hazard is real, but there is considerable information indicating that there are limiting factors on the probability that any stroke to earth will occur at or near enough to telephone plant to cause damage. Factors that reduce the nature and frequency of the hazard are as follows:

a. The actual number of lightning strokes to earth that may occur in any given square mile per thunderstorm day is small; probably less than one. Based on this, it is evident that even in areas with maximum frontal storm activity such as the southern tip of Florida (See Figure 1) there will not be a high number of strokes to earth per square mile per year.

b. Telecommunications plant actually occupies only a very small part of the area affected by the storm. The probability, therefore, that strokes to earth within that area might affect the plant by direct stroke, induction or even distance conduction and produce damage or hazard is limited.

c. Reference to Figures 3A and B shows that of those few strokes to earth which do affect aerial and buried structures, only a small percentage are of the high current, destructive type.

d. Severe local terrain variations and shielding of telecommunications plant by tall trees and/or other tall structures will further limit the probability of damage from a stroke to ground. Aerial cable in joint construction is well shielded by the power system.

e. Towers, structures, etc. are designed and further protected to provide low-resistance high-current paths to ground for direct strokes with minimum or no resulting damage. Telecommunications cable shields are designed and further protected against the effects of all except a direct stroke. The induced voltage in the plant is the major concern of the protection engineer.

3.1.9 D. W. Bodle and P. A. Gresh, of Bell Laboratories, conducted a study of the effects of lightning surges in paired telephone cable facilities. The report "Lightning Surges in Paired Telephone Cable Facilities" was published in the Bell System Technical Journal, March 1961. Five trunk routes were studied in an urban environment. Two routes were entirely underground while three had aerial complements.

The plant was well shielded by closely spaced buildings, extensive power distribution and buried metallic pipe systems, and other telecommunications cables in the same conduit run. During the period of study surges on cable pairs did not exceed 90 volts. Pairs with aerial extensions should still be considered as exposed to lightning since surges will propagate for considerable distances into the underground cable.

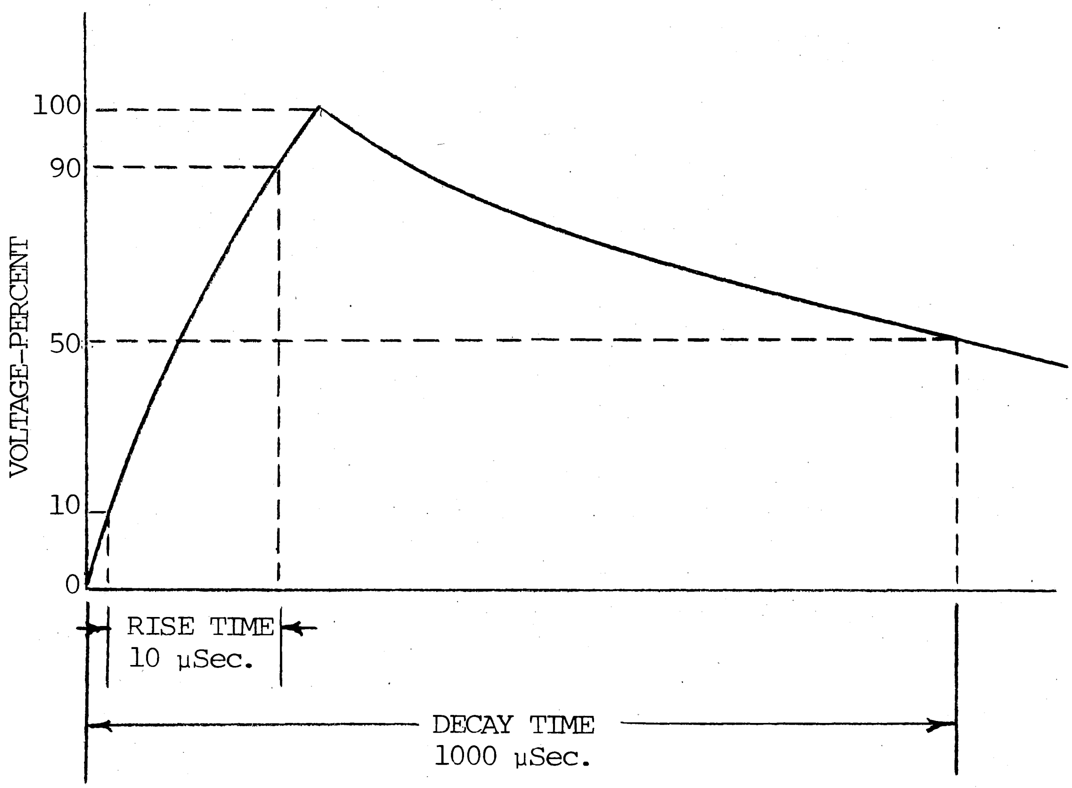
3.1.9.1 Two aerial and one buried trunk cable routes were also studied. Some rather conclusive results were obtained relating to the characteristics of lightning surges to which terminal equipment can be exposed. The test location for all of these studies was at a central office and the test pairs were equipped with 3 mil carbon block protectors. Subsequent studies by REA and Bell Laboratories did record higher voltage levels but both studies were conducted on cable pairs at a field location rather than at the central office. The Bell Laboratories test locations were equipped with 6 mil carbon block protectors rather than 3 mil.

3.1.9.2 Even though there were considerable differences in the types of paired cable studied, the statistical results were quite similar. For each thunderstorm, it was found that 20 surges are likely to exceed 100 volts, five are likely to exceed 250 volts and one is likely to exceed 400 volts. The maximum surge recorded was 450 volts.

3.1.9.3 The study indicated that the surges were fundamentally impulses with a measurable rise time to peak value and an exponential decay time without severe oscillations or polarity reversals. All three cables studied had a median rise time of 100 µsecs. This is quite long in comparison to the common thinking of lightning related surges. A small number of surges had a rise time as slow as a millisecond while some were as fast as a few microseconds.

3.1.9.4 There was a definite similarity in the decay times recorded for the three test cables. The average decay time was in the order of 400 µsec with the 1-to-99-percent range falling between 100 and 200 µsec.

3.1.9.5 Based on these studies, a composite wave shape was selected for use as a standard test wave for cable circuits. This wave is commonly described as the 10x1000 µsec wave (Figure 4). It is customary to define the wave shape of a surge by two numbers such as 10x1000 (ten by one-thousand) where both values express time in microseconds. The number 10 expresses the rise time from 10% to 90% peak value and the number 1000 represents the subsequent decay time interval from zero (beginning of surge) to 50 percent of the peak surge value. This wave is now used as a reproducible wave shape for testing low dielectric and low power apparatus used on paired telephone facilities, especially solid-state type apparatus. The magnitude of the peak voltage for this test is determined by the character-itics of the protection devices behind which the equipment will operate. REA uses 1000 volts peak for the standard voltage surge testing of electronic equipment.



SURGE TEST WAVE FORM

FIGURE 4

3.1.10 The effects of lightning on the telephone plant and a general discussion of lightning protection techniques are covered in paragraphs 4 and 5.

3.2 Electric Power Systems

3.2.1 Since the power and telecommunications companies normally serve the same customers their outside plant facilities are usually closely associated. It is advantageous to the companies, as well as in the best interest of the general public; that both plants be coordinated as to location, design, construction, operation and maintenance. Unnecessary conflicts can thus be avoided, and the possibility of direct contacts, the effects of normal and abnormal low frequency induction, and noise can be reduced.

3.2.1.1 Damage to the telephone system originating from electric power supply lines may occur in two ways. These are by direct contact between overhead power supply lines and aerial telephone facilities (wire or cable) and by magnetic induction. Magnetic induction which is related to power system unbalances is discussed in REA TE&CM Section 451, paragraph 7.

3.2.1.2 There is also another power line source, the power follow arc, which is lightning associated. Damage to the telephone system can be similar to that from a direct contact when the arc occurs between the power and telephone lines. Where the arc occurs between power system conductors or a power system conductor and ground the telephone system damage will result from magnetic induction due to the large power system unbalance.

3.2.2 The possibility of damage to telephone systems due to accidental contacts between electric power supply and aerial telephone lines is an important hazard requiring protection measures. The most common causes of these accidental contacts are: lack of adequate care installing telephone facilities in joint use lines, falling tree limbs, improper conductor sag, damage to power and/or telephone plant by the public, structural failures, poor maintenance, sleet and wind storms, and conductor failure due to lightning burns. These contacts may occur at crossings, underbuilds, in joint construction, and where power supply and telephone lines are paralleled with inadequate separation. The National Electrical Safety Code (ANSI C2) provides information on minimal separation and construction, and should be consulted when joint use, close parallels with power lines, or crossings are being installed. Due to the decrease in aerial telephone plant construction, which is most vulnerable to this type of problem, damage due to direct power contacts is decreasing.

3.2.2.1 An area of increasing concern is the joint burial of power and telecommunications cables in a common trench. In this situation, should a dig-in occur, (for example, an excavation company's trenching machine digs through and severs the power and telephone cables) there is a likelihood that the telephone facilities may become energized. As a result, care must be taken to assure fusing coordination of telephone plant in joint burial situations.

3.2.2.2 Two steps should be taken to avoid power contact or follow arc hazards. The first is to design, construct, operate, and maintain the power and telephone lines in such a manner that adequate separations and mechanical strengths are achieved where possible. The second step is to coordinate the protective equipment of the two systems to insure prompt deenergization of the power line in the event of a contact.

3.2.2.3 When a line fault to ground occurs in wye-grounded power system (unigrounded or multigrounded) thousands of amperes may flow. If the fault conductor makes a direct contact with aerial telephone plant the magnitude of impressed voltage and current on the aerial plant and the duration of the fault will depend on how well the telephone system is grounded. This is due to the current flowing back to the substation transformer through the ground path. The objective is to provide a low resistance path to ground to insure the prompt and positive de-energization of the power system through the operation of its overload protection equipment. In addition, it is desirable to reduce the potential on the telephone cable shield below the shield-to-core dielectric level to minimize damage in the telephone system from power system faults. In the case of a common multi grounded neutral (MGN) type power sytem 1/ prompt and positive de-energization of a power circuit can usually be assured in the event of contact with aerial telephone plant by grounding to the MGN.

3.2.2.4 With a non-grounded (delta) systems, the current through a single contact with telephone plant is substantially the charging current of the metallically-connected power network through a single-phase fault to ground. This current is proportional to the normal power voltage to ground and to the total line mileage (three-phase basis) of the metallically-connected power network. Involvement of REA-financed telephone plant with delta systems is mostly with the lower voltage system (4.2 kv or below) which because of the low voltage are of relatively short lengths. Hence, in these cases, the current in the telephone plant will be small and of no significance from an outside plant hazard standpoint. The maximum voltage from the telephone plant to ground at the point of contact, -- significant as regards hazards to linemen -- is proportional to this current and to the impedance of the telephone plant to ground as seen from the point of contact. Again, voltages of 4.2 kv or lower, are hardly high enough to constitute a hazard. However, occasional cases may

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1/ A common multigrounded neutral (MGN) electric power supply system is a "Wye" connected system which has solidly interconnected primary and secondary neutrals, and at least four grounds per mile (2.5 grounds/ Km) of line in every mile (kilometer) of line, exclusive of grounds at customer's premises.

occur in some parts of the country where contacts are possible with delta systems at higher voltages and of greater mileage. Such cases may require special attention from the standpoint of telephone plant voltage to ground from a single contact, especially where the telephone plant impedance to ground is high (as with high protector ground resistance). But even here the currents in the telephone plant are so small that hazards to plant or other property -- as distinguished from possible hazards to persons -- are negligible. Power system protective devices such as pole-top reclosers, fuses, etc., would, of course, not be operated. Even where no material hazard is created by the single contact, noisy conditions in the telephone system will ordinarily call attention to its existence although the power system will not be made inoperative and power operating personnel may be unaware of the condition, at least for some time after it occurs.

3.2.2.5 When a double fault to ground occurs on a delta system with one of the two faults to telephone plant, practically the full phase to phase voltage may be impressed on the telephone plant but the ability to deenergize the power system will be limited by the resistances of the two ground connections. Protection against single faults to ground (involving contact with telephone plant) on unigrounded wye systems with ground relaying, and on delta systems equipped with wye-connected grounding banks and ground relaying, can be achieved in some instances by equipping open wire telephone line with power contact protectors connected to ground rods. Aerial cable plant can usually be protected in similar circumstances by connecting the support strand to driven ground rods at frequent intervals. The chances, however, of achieving satisfactory coordination are still much poorer than in the case of MGN systems. For the above reasons, coordinated protection at crossings and in joint use with other than MGN systems is difficult to achieve and safety is largely dependent on mechanical strength. <u>In view of these considerations, joint use with other than MGN power systems should be avoided wherever practicable</u>.

3.2.2.6 Buried, rather than aerial, plant should be considered when joint use construction with non-multigrounded neutral types of power systems is necessary. If aerial plant must be used under these conditions, a study of local grounding conditions and the power system characteristics should be made by the borrower's engineer to determine if there are any practical means of obtaining coordinated protection. REA should be contacted for advice.

3.2.3 When telephone circuits are in close proximity to alternating current power lines, a voltage (which is sometimes called an electrostatic voltage)[2/] appears on the telephone wires as a result of the electric field surrounding the power conductors; this field is

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2/ Though the relations depend upon electrostatic principles, the term "electrostatic" is not appropriate for this situation due to the continuously varying field which is involved.

due, in turn, to electric charges on the power wires. Refer to TE&CM Section 451 for a discussion of electric induction. Under normal conditions, the electrically induced voltage on telephone cable conductors is limited to a very low value by drainage provided by cable shielding and the central office line termination. Cable capacitance and central office line terminations are also effective in holding electrically induced voltage to a reasonable level on open wire conductors which are extended from a cable. However, if open wire circuits are disconnected from the cable or central office for any reason, and also where the open wire lines are long, the induced voltage on these open wire circuits may be hazardous and therefore, require reduction. In some instances its open circuit value may be in excess of 800 volts to ground. The possibility of injury to persons -- linemen in particular -- in contact with a wire subject to this induced voltage does not depend upon the open circuit voltage but upon the current drawn through the circuit. This current is so small (due primarily to the poor regulation characteristics of the capacitive coupling between the power and telephone wires) that no serious hazard from electric shock as such is to be expected. Nevertheless, the shock, though it be mild in intensity, may have a surprise effect causing hazard to a man working on a pole. That is, the worker may be startled, release his hold on a tool or the pole as a reflex action, and either drop something on personnel below or fall from the pole. While the shock hazard is of primary concern, the induced voltage may also cause equipment damage or phenomena such as bell tapping or noise which are bothersome to subscribers, thus leading to trouble reports.

3.2.3.1 The proper methods of rectifying this problem are discussed in detail in TE&CM 820.

3.2.4 When an energized phase conductor of a grounded neutral power system is grounded, current flows between the substation power source and the point where the ground fault occurs. This is similar to the condition that would exist if the majority of a three-phase power system load was connected to a single phase. See REA TE&CM Section 451, for a discussion of magnetic induction. A similar situation occurs when two phase conductors of a delta or an isolated neutral system become grounded. In this case the fault current will flow between the two fault points rather than back to the substation. This earth return fault current, in either case, results in an increased magnetic field intensity surrounding the power line involved. The increased magnetic field intensity in turn will induce higher voltages in parallel telephone circuits. The magnitude of the induced voltage is proportional to the magnitude of the fault current and the degree of coupling involved.

3.2.4.1 Following the operation of power system overload protection equipment due to a phase conductor ground fault the power system will be operating in an unbalanced state. The phase on which the ground fault occur will be de-energized resulting in an operating unbalanced two phase system. This results in an increased magnetic field intensity with an associated higher induced voltage in parallel telephone circuits. While the magnetic field intensity will be less than that found during the fault it will be much higher than that found during normal three phase operation. This unbalanced operation will extend over a much longer period of time than that of the original ground fault. Depending on the separation and the length of exposure the induced voltage magnitude could be high enough to be a personnel hazard and result in plant damage.

3.2.4.2 A power follow arc which occurs between two power system conductors or a conductor and ground will also produce a high power system unbalance of short duration. As with ground faults the magnetic field intensity surrounding the power lines is a function of the earth return current flow. The magnitude of voltage induced in the telephone system depends on the earth return current magnitude and the degree of coupling.

3.2.4.3 Where there are parallel power and telephone lines at close separation the coupling between them is fairly high. The earth resistivity in the area has a bearing on the coupling between the power and telephone system. This is discussed in detail in TE&CM Section 452 under the subject of mutual impedance. If there is also a high unbalanced earth return current the induced voltage may be of sufficient magnitude to be dangerous to personnel working on the telephone system. The high current may be due to power system load unbalance or a fault condition. The induced voltage may result in hazards to the public, acoustic shock, and damage to telephone plant. If the induced voltage exceeds the breakdown of station protectors, it is probable that many station protectors may become permanently grounded.

3.2.4.4 High voltage transmission lines used to transfer bulk electric power from one location to another are usually delta or unigrounded wye connected. They also normally have a good load balance between the three phases. As a result the magnetic field intensity is not as high as that associated with power distribution systems. The harmonic content of a high voltage transmission line is usually quite low so they are not a source of noise in a telephone system. There is a possibility of a high induced 60 Hertz voltage on telephone circuits where a long parallel exists. With unigrounded wye systems the potential for extremely high earth return fault currents with high associated power system unbalance will produce an excessive magnetic field intensity. This also will induce damaging voltage in parallel telephone systems. Because of these possibilities, long parallel exposures to high voltage transmission lines should be avoided. Where unavoidable, special protective measures as described in TE&CM Section 825 are available and should be employed.

3.2.5 In some areas open wire lines are subject to excessive static potentials through wind blown sand and snow. Such potentials are low in energy, which is proportional to the capacitance between line and earth and therefore, proportional to the length of the lines involved. The resulting interference effects are entirely in the category of circuit noise, mainly due to intermittent breakdown of protective devices. Remedial measures for open wire lines are discussed in TE&CM Section 820.

3.2.6 Telephone equipment interfacing with electric power is exposed to overvoltage transients. Some transients are related to the normal switching operation of the power system. These are normally at a relatively low magnitude which may not be damaging but can result in electronic equipment operational problems. Transients of higher magnitude may be produced by lightning surges. Damage to telephone plant apparatus associated with low voltage ac powered circuits is a problem of increasing concern to the telecommunications industry. This is due to the trends toward miniaturization and the greater use of semiconductor components. Equipment using silicone controlled rectifiers (SCR) and semiconductor diodes such as in battery chargers and power supplies can be particularly vulnerable to power line overvoltages. The occurrence and magnitude of these potentially damaging voltages range from minimum in highly urban areas to maximum in remote rural locations. They may arise from:

a. Surges on primary distribution circuits due to lightning and switching operations,

b. Surges originating in secondary circuits from such sources as lightning strokes coupling with grounding electrodes,

c. Transients generated within load circuits. Such transients may also be electrically adjacent loads.

3.3 Electromagnetic Pulse (EMP) Phenomena

3.3.1 Hardening of telecommunications plant is usually understood to refer to a modification of its structural design to resist the blast and shock effects of a nuclear type explosion. It has become evident, however, that these effects are not the only components of concern. The effects of radiation have been recognized for some time. The effect of the electromagnetic pulse (EMP) is of increasing concern to those engineers who must ensure that an electronic system will function during and after a nearby nuclear explosion. This is primarily due to the increasing use of semiconductor equipment and magnetic memory devices which are especially sensitive to EMP.

3.3.2 A nuclear explosion at or near the earth's surface produces two transient effects which may damage aerial, buried, or underground plant, and electronic equipment. First, there is a pulse of current in the ground which flows radially from the point of explosion. Second, there is a pulsed electromagnetic field that propagates away from the point of explosion as from a vertical dipole. The damage to the plant from these components of the EMP phenomena may be compared in a very general way to that of the currents and fields associated with a lightning stroke. High altitude bursts generate electromagnetic fields of large magnitude but relatively small earth currents.

3.3.3 At the present time there are no plans for hardening most telecommunications plant. Such action is limited to plant carrying essential defense communications.

4. EFFECTS OF LIGHTNING SURGES IN TELECOMMUNICATIONS SYSTEMS

4.1 Lightning surges can appear in various parts of a communications system. They may produce explosive effects from arcing, dielectric failures, and fusing of conductors. Discussion of the effects in various types of plant follow:

4.2 Aerial Facilities

4.2.1 Supporting metallic structures are generally relatively immune to significant lightning damage. Concrete footings and guy anchors, associated with such structures, must be protected from the explosive effects of lightning related to arcing when surging through concrete. This protection is provided by bypassing the footings or anchors from the metallic tower legs or guy wires to ground via heavy gauge ground wire. The wire connects the leg or guy wire to buried ground electrodes.

Wood poles are frequently splintered and sometimes shattered by a direct stroke. The shattering is produced by sudden vaporization of moisture present in the pole. Sustained combustion of a wood pole due to lightning is improbable. Major damage usually occurs in the pole top as the stroke current ultimately arcs to the line facilities.

The stroke current may fuse open wire plant and in cable may fuse through the sheath to the core conductors. Once a surge has contacted the line facilities, it will seek paths to ground, and the extent of plant damage will depend upon how rapidly and in what manner the surge reaches effective ground. Surges on open wire or other well insulated wire propagate for considerable distances. They finally reach electronic equipment or lower dielectric plant where frequently damage occurs unless adequate protection is present to limit potential rise and provide effective paths to ground.

4.2.2 With metallic shield cable, stroke currents of low magnitude may not seriously damage the shield through arcing or produce core conductor problems. As surge current propagates along the shield, it produces a potential between the core conductors and the shield (core-shield voltage). The shield potential with respect to ground is a function of the impedance drop along the shield while the core-shield voltage is a function of the resistive component only. This is a result of practically all the magnetic flux established by the shield current cutting the core conductors and thus canceling out the reactive component. The core-shield voltage, therefore, is essentially equal to the product of surge current and the shield resistance. For illustration, consider a section of cable that is completely insulated from ground except for a single good ground connection at one end. A surge current entering the shield at the ungrounded end flows through the entire length. The crest magnitude of the core-shield voltage is the product of the surge current and the shield resistance of the cable section. (This is essentially true because the small capacitive current may be neglected.) In actual cable plant, the problem is complicated through ground paths established by arc-over to grounded hardware and by randomly distributed grounds such as guys connected to the supporting strand. Because of such complexities, solutions involving actual plant are usually only approximations. Since the surge currents will not have a constant value except in short sections of shield, it is necessary to add the incremental IR drops along the shield.

4.2.3 The core-shield voltage will normally be maximum at the point a surge current enters the shield. When a breakdown occurs at or near the stroke point, or if a protector operation occurs at or near the point, the facility voltage to ground drops to essentially zero and increases gradually with increasing distances from the stroke point. The voltage is a function of the facility IR drop compared to ground. The core-shield voltage builds up again, but to a substantially lower value than at the stroke point prior to the initial breakdown. If the original core-shield voltage at the stroke point is quite high, it is probable that several punctures will occur along the cable.

4.2.4 Lightning problems are principally of the core-shield type in trunk cables where all pairs proceed from one terminal point to another with a minimum of side taps. Conductor to conductor faults are more common in distribution plant where there are frequent connections to individual stations. In this latter type plant, the possible combinations of grounds, which not only act as sinks for lightning surges but on rare occasions as sources, are so much greater than trunk plant that theoretical analysis is impractical.

4.3 Buried Cable Plant

4.3.1 Lightning surge currents along the shield of a buried cable produce core-shield voltages in the same manner as in the aerial plant previously discussed. Those lightning effects described for trunk versus distribution cable also apply to the buried forms of these cables. The manner in which surge currents flow into the ground from a buried cable is more predictable than for an aerial cable. This is especially true when fairly accurate data is available on soil resistivities.

4.3.2 Since the core-shield voltage is, for practical purposes, equal to the product of the surge current in the shield and the dc shield resistance, determination of the core shield voltage for any given set of conditions is basically a matter of adding the incremental IR drops along the shield.

4.3.3 The resistivity of the soil in which a cable is buried has a significant effect upon its lightning performance with regard to direct strokes, earth potential gradients, and the rate at which current leaves the shield. In areas of high earth resistivity, lightning strokes will arc through greater distances to a cable than in areas of low earth resistivity. The higher the soil resistivity the more susceptible the cable is to damage from strokes that produce extremely high voltage gradients in the soil near or across the cable path but do not necessarily arc to the cable.

4.3.4 Soil resistivity will vary even along relatively short sections of a cable route. The usual practice from a practical standpoint, is to use a value of soil resistivity which is assumed to be representative of a reasonably large area. This representative value may be determined by averaging the recorded soil resistivity values from several measurements along the route (REA TE&CM Section 817). As a simplification, it is frequently assumed that the soil resistivity is uniform and the current leaves the shield at an exponential rate.

4.3.5 When a more rigorous consideration of core-shield voltages is desired in a buried cable, it is necessary to consider the condition of a two-layer earth structure which provides a closer approximation of actual field conditions. The average resistivity of the surface layer of earth in which the cable is buried will usually be significantly different from that at greater depth. The effects of lightning voltages in two-layer earth will be entirely different from those in uniformly conducting soil. For example, where the resistivity of the soil below the surface layer is low, strokes that do not arc directly to the cable will not usually cause trouble, even though the surface layer in which the cable is buried has a high resistivity. Such strokes will channel through the surface layer to the more conductive layer below and the resulting earth potential will be lower than in a uniform soil of even a moderately high resistivity. This condition can be assumed to occur where the low resistivity layer is at a depth of about 10 meters (30.5 feet) or less. Conversely, when the lower layer has high earth resistivity, cable faults may be experienced from strokes contacting earth at a considerable distance from the cable. This can occur even though the surface resistivity is only moderately high.

4.3.6 The computation of core-shield voltage is a tedious, time consuming operation. The many factors and considerations involved have been incorporated in a series of empirical formulas, graphs, and tables of cable electrical specifications which can be used to determine core-shield or conductor-to-conductor voltage for a given situation. Combining these with environmental factors such as earth resistivity it is possible to estimate whether a cable provides the necessary safety margin between dielectric breakdown voltage and expected lightning induced voltages. Discussion of the computation techniques is beyond the scope of this practice.

4.3.7 Insulated jackets are commonly used over the shields of buried cable and wire for mechanical and corrosion protection. Even though these jackets may have substantial dielectric strength they do not provide effective protection against direct lightning strokes. The voltages associated with direct strokes will in most cases exceed jacket dielectric strength. After the initial puncturing of the jacket, which occurs at or near the stroke point, subsequent puncturing is highly probable. Higher stroke currents with buried cable will produce punctures to the extent that, from a surge standpoint and along the punctured length, it may be considered essentially the same as a shield in direct contact with the soil.

4.4 Station and Other System Equipment

4.4.1 Any equipment connected to outside plant will be exposed to lightning surges to some degree. Cable in urban areas will have the lowest exposure while that located in sparsely settled rural areas will have the highest. A cable in an urban area which extends into a rural area will have a higher exposure to lightning surges than one entirely located in an urban area.

4.4.2 Equipment installed along a line, such as voice frequency or carrier repeaters, will be exposed to higher surge potentials than terminal equipment. This is due to the equipment being located closer to the major sources of lightning.

4.4.3 Lightning primarily produces longitudinal surges on a cable pair which subject equipment connected to the pair to high potentials between the cable conductors and ground. Due to cable circuit unbalances and asymmetrical operation of protection devices, metallic surge potentials may occur. When determining appropriate protection requirements both types of extraneous potentials must be considered. For components that are connected in series with the line, such as loading coils, the ability of the components to carry surge current must be considered.

5. FUNDAMENTAL PROTECTION MEASURES

5.1 It is not economically feasible to provide total protection for all situations through basic insulation and conductivity incorporated in the design of equipment, material and plant. Some additional protection measures are usually required in situations involving relatively high lightning or power contact exposure. These supplementary measures are the following basic principles of protection:

a. Shielding: By diversion of lightning surges before contact with telecommunications plant.

b. Parallel Conductivity: By providing parallel conducting paths to reduce the surge current that would otherwise flow through the telecommunications plant.

c. Grounding: By diverting surge or fault current from the telecommunications plant to ground as close to the point of contact as practical. This can be accomplished by direct connections or through insulating discharge gaps.

d. Voltage Limitation and Equalization: By means of bonding and use of discharge gaps, semiconductor diodes, and nonlinear resistances.

e. Current Interruption: By use of fuses, fuse links and circuit breakers.

f. Current Limitation: By use of circuit impedance.

g. Acoustical Click Limitation: By use of semiconductor click suppressors (varistors).

h. Construction and Spacing: By provision of sturdy construction and adequate spacing between power and communications facilities.

5.2 Shielding:

5.2.1 Shielding is provided by placing a grounded conductor or conductors so that they will intercept lightning strokes that might otherwise arc directly to telecommunication plant. To shield aerial plant a conductor may be placed above it with sufficient separation to reduce the possibility of arcing between the shield wire and the telecommunications plant but close enough to create a shielding zone. Existing plant on a pole line will provide sufficient shielding for facilities installed below it to eliminate the need for placing a shield wire. In joint construction with a power system there is adequate shielding provided for the telecommunications plant located beneath the power wires. High induction into the communications system may occur should a lightning stroke produce a power follow arc.

5.2.2 Telecommunication cable buried in the earth may be damaged by lightning strokes that arc to it through the earth. Those having heavy metallic coverings of such materials as wire and tape armor are less susceptible to damage from heat developing at the arc contact point. A core-to-shield insulation failure may still occur as a result of surge current flowing in the shield. Where there is a record of such trouble, buried shield wires may be installed along the cable. The shield wires distribute sufficient current to earth so that the remnant current reaching the cable will not be great enough to cause a cable fault.

5.3 Parallel Conductivity:

5.3.1 A lightning current flowing in the shield of a cable develops a voltage between the core conductors and the shield. This core-shield voltage is a function of the surge current and the resistance of the shield. Shield resistance is therefore a critical factor in cable protection problems. It is also essential that good longitudinal shield continuity is maintained for the total cable length.

5.3.2 In the manufacture of lead shield cables, the shield for any given core diameter was made only as thick as necessary for mechanical reasons. The thickness of a lead shield varies with the core diameter. In most cases, the lead shield thicknesses provided to meet mechanical requirements was adequate the meet electrical conductivity requirements. The thickness of an aluminum shield has been selected to have approximately the same conductivity as the shield of equivalent size lead sheath cables up to about 25mm (1-inch) in diameter. Satisfactory mechanical properties are obtained, in aluminum shield cables manufactured today, even in larger sizes without increasing the thickness of the shield material above that used on 25mm (1-inch) diameter cables. The lower conductivity, of an aluminum shield versus lead in the large size cables, is not of practical significance since it is adequate for most applications.

5.3.3 It may be necessary to consider alternative measures in areas of high lightning exposure where the resistance of the cable shield is such that there is a probability of excessive core-shield potentials. Alternative measures include the use of cable with a double jacket to increase the core shield dielectric strength, installation of cable with a 0.25mm (10 mil) copper shield to increase the shield conductivity, or provision of shield wires to reduce the magnitude of lightning current reaching the cable. In some severe situations it may be necessary to use a combination of alternatives to effectively protect the cable.

5.4 Grounding:

5.4.1 Grounding is the first line of defense against excessive lightning damage in telecommunications plant and equipment. When lightning current has entered telecommunication plant, the extent of possible damage may be reduced if some means are available for its rapid removal. C. F. Boyce of the South Africa Post Office wrote 3/ that a cable with the shield in continuous contact with the earth is less likely to be damaged by a nearby lightning stroke than one with a plastic sheath.

5.4.1.1 It is impractical, due to corrosion problems, to bury commonly used shield materials in direct contact with earth. While research has been in progress to develop semi-conductive plastic sheaths which would approximate the protective characteristic of a shield in direct contact with earth, it is at the present time not completed. Reported results from this research effort are promising since significant reductions in the magnitude of measured lightning surges on the cable pairs have been achieved, when compared to those recorded on pairs in a standard plastic sheath cable. This technique provides no solution for draining surge currents from aerial cable plant.

5.4.1.2 The method available to provide paths to earth for surge currents to leave the cable is the provision of frequent grounding connections along the route. Multigrounded power neutrals that have frequent connections to ground generally provide a convenient means of grounding telecommunications plant. Underground metallic pipe systems and other extensive buried structures provide very effective grounding mediums. Ground connections must be constructed at locations where the previously mentioned means of grounding are not available. Effective grounding is discussed in TE&CM Section 817.

3/ Lightning, Volume 2, "Lightning Protection", Chapter 25, "Protection of Telecommunications Systems", edited by R. H. Golde, 1977.

5.4.1.3 Grounding is also an effective means for controlling noise in telecommunications cables. When designing a grounding system specific connections should be included that are proven to be effective in noise reduction. These connections are discussed in TE&CM Section 451.7.

5.4.2 Even under an ideal grounding condition, such as an extensive metallic water pipe system where the contact resistance to earth is very low, the earth itself introduces additional resistance. It is, therefore, practically impossible to secure a resistance-free path to remote earth. A grounding connection may have a significant reactive component when conducting steep wavefront surge currents. As a consequence, there will always be differences of potential between grounded plant and remote earth. The plant is considered to be adequately grounded where such potentials do not present a <u>shock hazard</u> or exceed the dielectric strength of the plant involved.

5.4.3 Direct grounding is preferable and may be used for those parts of a telecommunications system such as cable or guy wires that do not carry intelligence. Working conductors are usually grounded through discharge gaps which effectively isolate the conductors for all normal working voltages. The introduction of a discharge gap provides a path to ground which will clamp working circuits during breakdown discharge periods.

5.4.4 Grounding is also used to reduce the possibility of electric shock. The use of grounding alone may not assure protection unless supplemented by reliable solid bonding connections between conducting objects which personnel may contact either accidentally or in the normal performance of their duties. Among the more obvious applications of bonding are the interconnection of power and telecommunications system grounds, equipment cases, and other metallic components of an installation, such as cable shields at a pedestal. A less obvious situation is the case of personnel standing on the ground while operating, maintaining or repairing equipment. A conductive grid under the areas where personnel stand that is bonded to the equipment will reduce the voltage difference between the person and ground.

5.4.5 The grounding and bonding at a central office installation is complex. Special designs are essential with digital switching machines. It is suggested that TE&CM Section 810 be consulted for a discussion of this subject.

5.5 Voltage Limitation and Equalization

5.5.1 Voltage equalization is the prevention of hazardous voltage differences developing between various plant components. Direct bonding by solid mechanical, soldered, or welded connections is the most effective way to equalize potentials. The technique of direct bonding cannot be used on lines and equipment during normal operation. The most common method of limiting and equalizing voltages in working lines and equipment is by means of discharge gaps called protectors. These discharge devices are connected from line to line and/or between line and ground to limit longitudinal voltages.

5.5.2 Grounding provides limitation of voltages with respect to local ground. Calculations to determine the effectiveness of a grounding system in limiting voltages to earth and providing good voltage equalization are complex. Such calculations are seldom made since experience has shown that the provision of frequent grounds along a cable route to provide a low effective resistance to ground will provide the desired voltage equalization.

5.5.3 Telephone lines should be brought into a building as near as possible to the power service entrance (REA TE&CM Section 805). This reduces the possible hazard of high potential differences and danger of side flashing by establishing short, low impedance connections to a common ground.

5.6 Metallic Voltages

5.6.1 Metallic voltages are produced from longitudinal surge voltages in two ways. The first is due to unbalances in the plant and occurs in the same manner as circuit noise from induced power influence. This conversion is discussed in detail in TE&CM Section 451. Metallic voltage levels produced from plant unbalances should not be high enough to damage properly designed equipment. For example, a 2000 volt longitudinal surge when the plant has 60dB balance will produce a metallic voltage of only 2 volts. The second and more damaging way is due to non-uniformity in protector block operation. Metallic surge voltages, under some conditions, can be as high as 700 to 800 volts peak. To illustrate, such voltages may occur when the protector gap connected to the tip conductor has a 450 voltage peak breakdown and the gap connected to the ring conductor has a 800 voltage peak operating value. A longitudinal surge up to 800 volts peak on the ring conductor could then cause current to flow through the connected equipment to ground via the lower voltage gap connected to the tip and side.

5.6.2 Where there is sufficient magnitude of longitudinal surge potentials to operate both protectors, the metallic surge potential will be much lower after both protectors have operated. There may still be residual peaks that might damage some types of miniaturized equipment. The presence of metallic transients is well known and of concern with circuits such as pilot wire and audio tone relaying circuits. The problem in such cases is not one of insulation damage but rather that of false signaling which has been minimized through the use of protector drainage.

5.7 Open Wire Plant

5.7.1 Lightning surges entering open wire plant conductively may occasionally exceed 5000 crest amperes. The protector is the first line of protection against damage in such cases. Remote lightning discharges produce a relatively large amount of lower voltage induced static in addition to the higher magnitude surges, which cause operation of the protectors. This voltage induced static is capable of damaging some types of solid state equipment.

5.7.2 Static discharges, in open wire pairs, produce line transients in the form of damped oscillations having a relatively low fundamental frequency with superimposed higher frequency components. The amplitude of each half cycle drops off rapidly so that subsequent peaks are only about 50 to 60 percent of the amplitude of the preceding one. While the entire transient has a total duration in the order of 2000 microseconds, only the first 400 to 600 microseconds are of concern from the standpoint of dielectric breakdown and life of protection devices.

5.8 Aerial, Buried, and Underground Cable

5.8.1 Studies of lightning surge effects on aerial and buried cable show that during a single thunderstorm day it is likely there will be at least one surge of 1000 to 1300 volts peak induced on the cable pairs as observed at the station end of the loop. These cable pairs were all equipped with 6-mil carbon blocks during the studies. Protectors normally used at the station end of the loop provides dependable surge voltage limitation of about 600 volts peak.

5.8.2 Field tests indicate that, in underground cable pairs located in metropolitan areas, electrical surges do not exceed 90 volts peak. When connected apparatus used exclusively in this environment is capable of withstanding such surge magnitude, no further protection is needed.

5.9 Solid State Electronic Equipment: The trend to integrated circuits and large scale integration has presented a problem, i.e. developing methods of limiting abnormal voltages in some cases to only a few volts. In such cases, low voltage protection such as semiconductor diode circuits are used as a second stage of protection behind the normal protectors. This type protection is provided by the manufacturing during the manufacturing process.

5.10 Current Interruption:

5.10.1 Under steady state conditions, the current in a circuit can be interrupted by use of a fuse or circuit breaker. When the current through a fuse reaches a magnitude greater than some value above its nominal rating the fuse will open and interrupt the current. The excess current value determines the time lapse before interruption occurs. If current is just above the nominal value it may take several minutes to interrupt. With much larger currents the fuse will operate in a very short time. A fuse is considered effective:

a. When its time current operating characteristic is lower than that of the circuit it is intended to protect.

b. When the voltage holdover and short circuit current rating characteristic is properly coordinated with the circuit being protected.

5.10.2 Fuses are <u>not</u> satisfactory for interrupting lightning surge currents because of inherent time delay. The primary use of fuses is for interruption of power fault current before wiring and components can be damaged by overheating.

5.10.3 Since fuses are not effective for limiting short duration surges, it is sometimes desirable to provide some means of diverting surge currents through other paths having adequate current carrying capacity. One way to achieve this is by providing an alternate path of lower impedance around the vulnerable components (See REA TE&CM 822).

5.11 Acoustical Click Limitation:

5.11.1 Acoustical click is a short duration abnormal sound level output from a telephone receiver. Abnormally high receiver currents may be caused by system switching transients, however, the principal source is usually metallic surges initiated by foreign potentials such as lightning. These metallic surges are sometimes aggravated by such things as circuit unbalance, sparkover, and protector operation.

5.11.2 The intensity of these clicks is effectively reduced by non-linear click suppression devices (usually a varistor) connected in parallel with the receiver in the receiver cavity. They consist of a small pile of copper oxide discs or a silicon diode semiconductor.

5.12 Construction and Spacing

5.12.1 The first line of defense against power contacts and induction is good construction which assures adequate mechanical strength and proper spacing between power and communications facilities. A second defense measure is provided by establishing paths to ground along the communications facilities sufficient to prevent excessive voltage rise in those facilities. These ground paths will pass enough power line fault current to provide either rapid operation of deenergizing devices (fuses, breakers, etc.) on the faulted power line or to cause line conductors to "fuse" open at the fault point. The joint cooperative effort of telecommunication and power company personnel is essential to achieve coordinated protection.

5.12.2 The insulation on telecommunications conductors may often be adequate to withstand power voltages, but reliance upon insulation alone introduces considerable hazard. The insulation of many items in the outside plant is not sufficient to prevent energizing the plant as a result of power contacts.

5.12.3 Cooperative effort should be sought where there is a high probability of a power contact requiring protective measures. For example, telecommunications lines in joint construction with power lines should be equipped with protectors capable of discharging sufficient current to insure prompt deenergization of the faulted power circuit. Protector grounds should be connected to the power system multigrounded neutral. In some cases, exposed circuits may be equipped with fusible links. These circuits should be adequately grounded to prevent excessive rise in potential at the equipment locations.

5.12.4 Line conductors, cable and cable strand in the vicinity of power circuits should be adequately bonded and grounded as a safety measure. Personnel working on these conductors should treat them as energized power conductors.

5.13 Special Protection

5.13.1 There are situations, such as telecommunications facilities serving power stations, where special protection measures are required. These are discussed in REA TE&CM Section 825.

6. COMMONLY USED PROTECTION DEVICES

6.1 Voltage Limiting Devices

6.1.1 The general category of voltage limiting devices includes not only gap devices, such as air gap carbons and gas tubes, but also solid state units such as zener diodes and varistors. The voltage limiter appears as an open circuit until a threshold or breakdown voltage is reached. At this point the device changes to a conducting mode and provides a low impedance shunt across the terminals it is protecting. In this manner voltage across a load in parallel with the voltage limiting device will be restricted to approximately the voltage limiter's threshold voltage.

6.1.2 Perhaps the most common category of voltage limiting devices in the typical telephone system is the gap type arrester, such as the carbon arrestor, which employs the dielectric breakdown of an air discharge gap as a means of providing the low impedance shunt. The discharge gap type arrester will generally handle more energy than solid state devices of equivalent cost. Unfortunately, it is difficult to produce discharge gaps with extremely low breakdown voltages. Also, by its nature, the discharge gap provides a broad range of probable breakdown voltages, frequently ± 25% from the nominal. In some instances these limitations may take the discharge gap useless without additional supplemental protection, while in others they may not matter and the discharge gap will be the most economical means of protection.

6.1.2.1 Carbon block air discharge gap arresters are available in a number of breakdown ranges, and are color coded as shown in Table 2.

TABLE 2: CARBON BLOCK ARRESTER COLOR CODES

COLOR CODE	NOMINAL DC BREAKDOWN VOLTAGE RANGE
White	350 - 600
Blue	500 - 1,100
Yellow	700 - 1,400

The primary objection to the carbon block form of arrester is the high maintenance associated with low breakdown voltage units. When a small gap is employed, there is a tendency for carbon particles to become lodged in the gap, thus permanently grounding the unit and disabling the circuit. Where larger gaps can be employed, permanent grounding occurs less infrequently.

6.1.2.2 An arrester assembly from a carbon block station protector, as shown in Figure 5, is an excellent example of discharge gap type protector which will fail in a short circuited mode when subjected to long duration energization. The cylindrical electrode is recessed about 0.01mm (0.004 inches) from the top of the ceramic insulator so that when the unit is assembled an isolation gap exists between the carbon disk and cylindrical carbon. This is the air gap that must be ionized for the unit to provide a low impedance path to ground. In the event of a long duration energization, such as from a power contact, cement between the ceramic insulator and cylindrical carbon softens, permitting the carbon to slip, under spring pressure, and close the gap. If energization continues beyond this point, the generation of heat within the unit melts the fusible pellet, permitting the cage to slide completely over the ceramic insulator and contact the mounting base electrode, thus providing a metallic by-pass around the carbon electrodes.

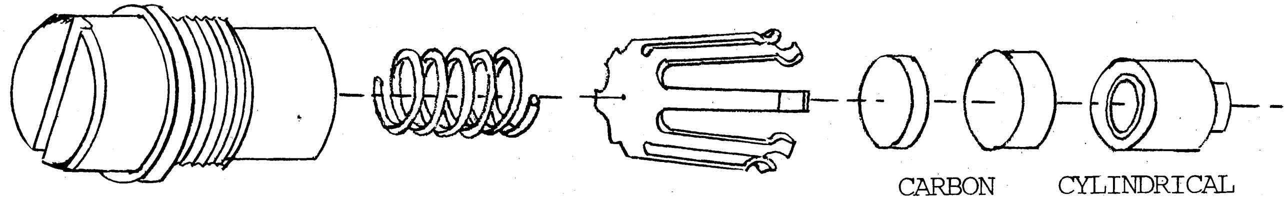
6.1.3 Gas tube arresters, covered in detail in TE&CM Section 823, are discharge gap electrodes in a sealed atmosphere of inert gas. In general, maintenance of gas tubes is lower than for carbon block protection, however, the initial cost of the gap tube arrester is higher than for the carbon block arrester.

6.1.3.1 Gas tube arresters are available that will fail in a short circuited mode when subjected to long duration energization. All station protector assemblies with gap tube protectors included in the REA List of Materials employ gas tubes of this type.

6.1.4 At present, due to their relatively high cost and comparatively low energy handling ability, solid state voltage limiting devices are in very limited use within the telephone industry as main energy handling, or "primary" protection. The foremost use of these devices is as low voltage "secondary" protection for electronic equipment, as covered in TE&CM Section 822. Due to the solid state devices' relative insensitivity to surge rate of rise, and its ability to furnish a precise, low breakdown voltage, these units are invaluable for protecting delicate electronic components from electrical over-loads.

6.2 Current Limiting Devices

6.2.1 The fuse, such as used in a fused type station protector is probably the prime example of a current limiting device. It should be noted, however, that other devices, such as the fuse link, circuit breaker, and heat coil are also current limiting devices. The current limiting device appears as a short or low impedance until excessive current is forced through it. When this happens it opens the circuit and isolates the equipment being protected from the line. Since most current limiting devices are thermally activated, there is a significant delay before the



Exploded View of Arrester Assembly

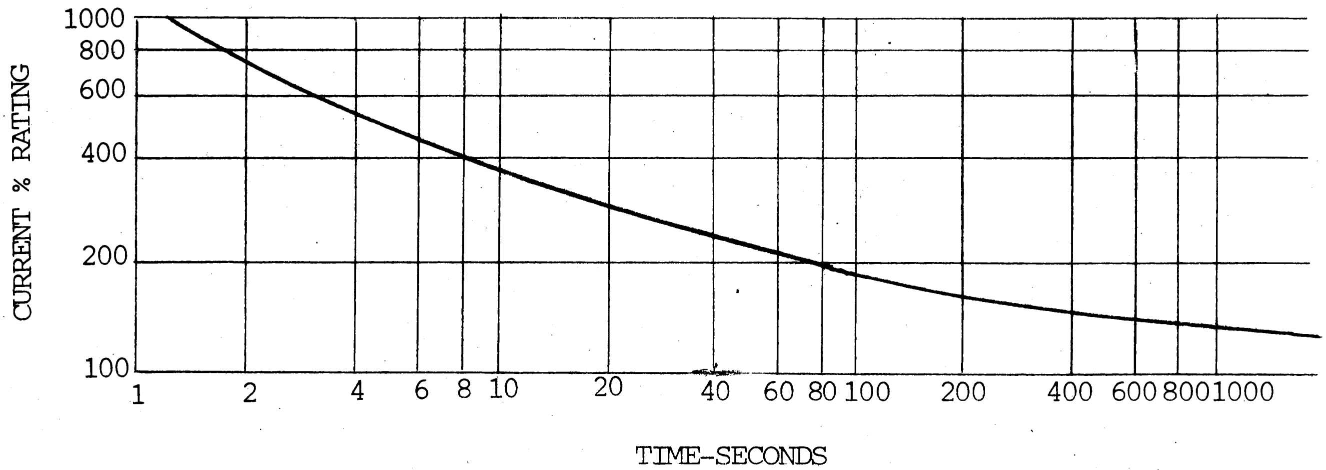
FIGURE 5

device operates. Figure 6, illustrates the time versus current curve for a typical self-resetting circuit breaker. While this device is slow compared with most fuses, it provides an excellent illustration of what the protected device must withstand before this form of protection will operate.

6.2.2 The fused type station protector, as shown in Figure 7, illustrates one method of reducing current passing through the protected load while still causing fuse operation. It is essential that fuse type station protectors be connected in this manner, with the fuses between the line and the arresters so that operation of the arresters provide current paths to ground for operation of the fuses.

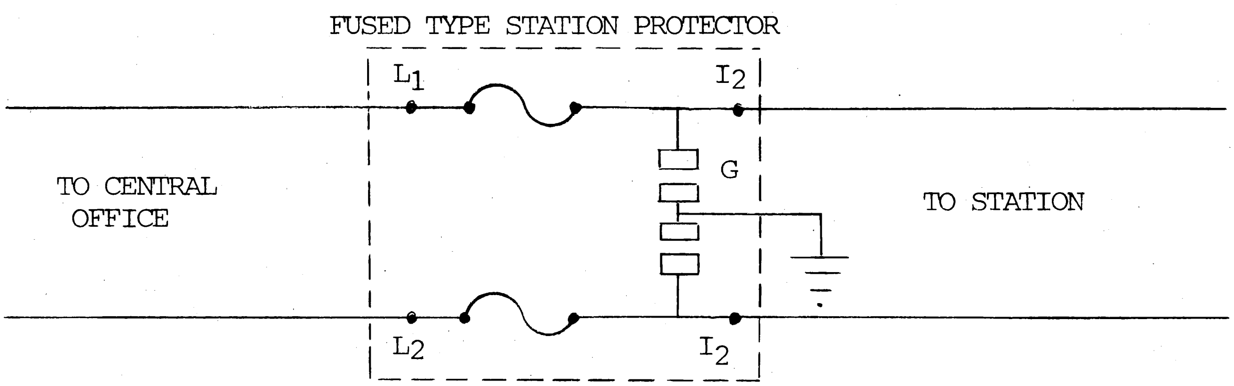
6.2.3 Fuseless station protectors in preference to fused protectors are strongly recommended by REA where ever the National Electrical Code (NEC) requirements can be met. These requirements are set forth in Article 800 of the NEC. Fuseless protectors, when properly installed provide equivalent voltage limiting to fused protectors, but must be connected in series with a fuse link consisting of a short length of wire, usually 24 AWG copper, instead of a cartridge fuse. The 24 AWG fuse link has a time-current fusing characteristic that is equivalent to about a 30 ampere fuse instead of the 7 ampere unit used in fused type station protectors. As a result, the fuseless protector should require much less maintenance. Because much greater energy is required to open the 24 AWG fuse link than is required to open the 7 ampere fuse, the current carrying parts of fuseless station protectors must be capable of handling relatively large amounts of energy without becoming a fire hazard. This capability is provided by a metallic by-pass consisting of the cap, spring, cage, and melting of the fusible pellet shown in Figure 5. The advantage of fuseless station protectors, and the disadvantages of fused station protectors are discussed in TE&CM Section 805.

6.2.4 Heat coils are not fuses, but may be connected in series between the line and the line circuit equipment of the central office. Abnormal current through the winding of the heat coil generates heat which softens a soldered connection and permits a spring to open a set of contacts and isolate the equipment from the line circuit while optionally grounding the energized outside plant conductor. Tests conducted by REA have shown that heat coils are generally not effective in protecting modern switching equipment because they are not sufficiently sensitive. In most cases, the energy required to operate the heat coil results in current through the line circuit equipment which will damage the equipment prior to heat coil operation. It is not practical to make the heat coil more sensitive, so the use of heat coils is not recommended as they represent a possible source of noise as well as an unnecessary cost with no engineering benefit. Heat coils were dropped from the COE contract in 1963 (See REA TE&CM Section 810).



Circuit Breaker Trip Delay

FIGURE 6



Installation of Fused Type Station Protector

FIGURE 7

6.3 Other Protection Devices

6.3.1 While the items covered in paragraphs 6.1 and 6.2 are the most frequently used protection devices, other items exist whose application is important to comprehensive protection of a telephone system. Several of the more important examples are as follows:

6.3.2 Neutralizing Transformer. The principle of the neutralizing transformer is to produce induced potentials in the telephone conductors equal in magnitude and opposite in polarity to the potentials developed by power line induction or a ground potential rise at a power station. The two ends of the primary winding are connected to the ground at different locations so that the voltage to be neutralized appears across this winding. Secondary windings having a 1:1 ratio to the primary are connected in series with the telephone circuit conductors in such a way that the potentials induced from the primary are opposed to and approximately equal to the induced foreign potential on the conductors. Use of the neutralizing transformer for electrical protection is covered in detail in TE&CM Section 825. Neutralizing transformers might also be used for noise control in some situations. Data on this application is covered in REA TE&CM Section 451.5.

6.3.3 Drainage Units. Drainage units usually consist of inductor-capacitor networks connected from each side of the line to ground. Drainage units are designed to reduce electrically induced voltages in open wire telephone circuits with a minimum of disturbance to the communications signals. Electrically induced voltages are caused by capacitive coupling between a power supply line and a telephone line. The application of these units is covered in TE&CM Sections 820 and 825.

6.3.3.1 Isolating Transformer. The isolating transformer is simply a 1:1 transformer with high dielectric capability which "isolates" the station terminal equipment from the remainder of the communications facility. Thus, the station terminal is free to "float" with the local ground without feeding excess voltage back into the communications facility.

6.3.3.2 Isolating transformers are generally less expensive and more compact than neutralizing transformers. They are available with dielectric withstand capability from 1000V to approximately 25 KV and insertion losses of approximately 1 dB at either voice or carrier frequencies, depending on the transformer selected. One shortcoming of the isolating transformer is that it does not provide dc continuity. The use of isolating transformers is discussed further in REA TE&CM Section 825.

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