Sources of Lightning

Since the time of Benjamin Franklin (1750), lightning has been recognized as being a gigantic spark occurring between an accumulation of electric charge in a cloud and the earth or another charged cloud. The most common source of such charged cloud centers is the thunderstorm, of which there are two main classes: (a) local convectional thunderstorms and (b) frontal storms. The former are the result of local heating of the air adjacent to the ground in summer, whereas the latter are the result of the overrunning of warm moist air by a mass of colder air, giving rise to turbulence as a result of relative motion of the air masses. In either case, there results an unstable condition that causes the warm moist air to rise at an accelerating rate and by the condensation of its moisture to form a tall cumulo-nimbus cloud. In such a thunderstorm cell, there is at first a violent updraft, followed later by strong down drafts. The little understood processes that lead to the separation of large amounts of positive and negative electricity are doubtless related to these vigorous air movements. The usual thunderstorm involves several such circulation "cells," and in the case of a frontal storm these may extend in a row for many miles. Usually negative electric charges accumulate in the lower portion of the cloud whereas positive charges are carried to the upper portions, with the result that enormous differences of electric potential are developed between the top and bottom of the cloud and between the latter and the earth.

Lightning has also been observed in the dust, steam and gas clouds arising from volcanoes in eruption in dense smoke clouds over large fires, in the dust clouds of deserts, and in clear skies probably from charged bodies of air that drifted near each other or near the earth. In addition, there are apparently silent luminous discharges within cloud layers and haze that have been observed at all times of the year, especially in regions where thunderstorms are scarce.

Lightning Characteristics

Lightning is an electrical discharge which occurs between clouds and also from a cloud to earth. Crest magnitude will vary greatly from stroke to stroke depending chiefly upon meteorological factures. Figure la shows the magnitude of stroke currents to aerial structures.

The waveshape of lightning stroke current near the stroke point is essentially a undirectional surge or impulse. It is characterized by a rapid rise to crest value and a tail which decays exponentially at a considerably slower rate. It is customary to define the waveshape of a lightning impulse by two numbers, such as 1.2 x 50 microseconds. In this example, the first number, 1.2, is the risetime in microseconds from zero to crest value, and the second number, 50, gives the time interval from zero to a point on the wave tail at which the magnitude has decayed to half of crest value (See Figure lb.)

For purposes of standardization in the power industry, a 1.2 x 50-impulse voltage wave is customarily used for the testing of insulation and the sparkover of gaps, insulators, and arresters. A current test wave of 8 x 20 is used extensively for the testing of lightning arresters used on power lines. These test waves do not characterize all lightning surges but a large amount of test data have been accumulated using these techniques and standardization appears to be reasonably successful on this basis. Furthermore, laboratory generation of steeper current waves having sufficient duration to constitute a meaningful test is difficult.

Probable Incidence of Strokes

Extensive data are compiled by weather observers regarding the annual incidence of thunderstorm days. Such data are plotted in the form of isokeraunic maps which are available through governmental weather bureaus for most parts of the world. Such a map for the United States is shown in Figure 2.

Structures do not influence the mechanism or path of a thunderstorm. Tall structures, such as antenna towers, only provide a favorable discharge point for strokes that would otherwise strike the earth in the vicinity of the structure if they were not present. The area from which strokes are likely to be diverted to a structure varies with its effective height. This critical area in the case of antenna towers, in the range frequently encountered (about 100 to 500 feet), is roughly a circle having a radius of 3 to 4 times the height of the tower. On flat terrain the effective height is that of the tower; however, for one located on a prominent hill, it would be supplemented by the elevation of the site.

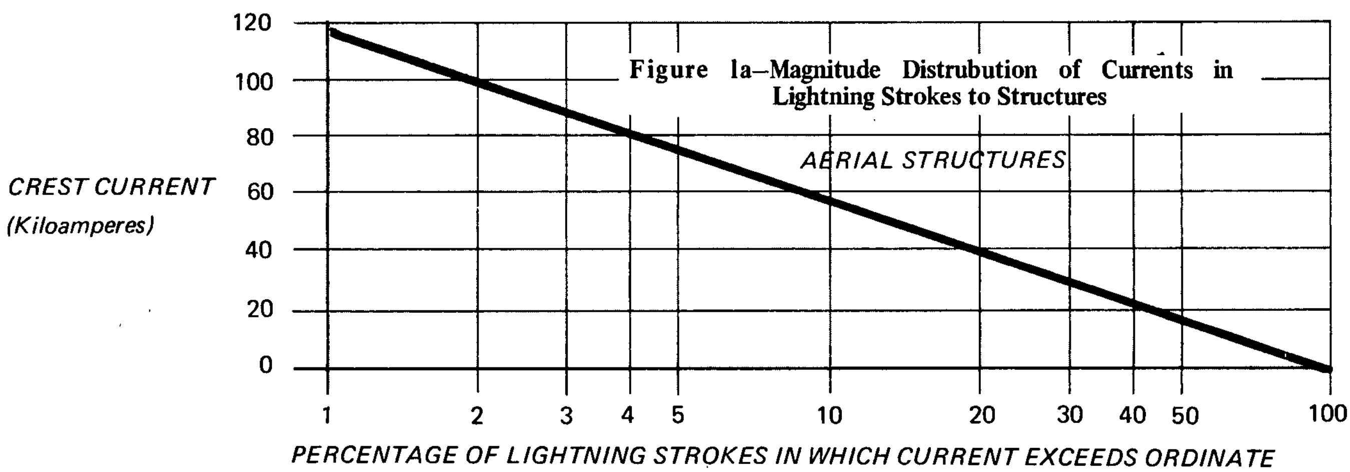

Figure la–Magnitude Distrubution of Currents in Lightning Strokes to Structures

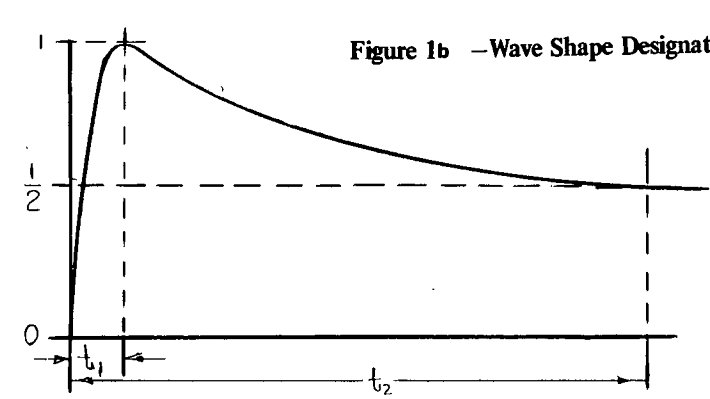

Figure 1b –Wave Shape Designation of an Impulse (t_1 x t_2)

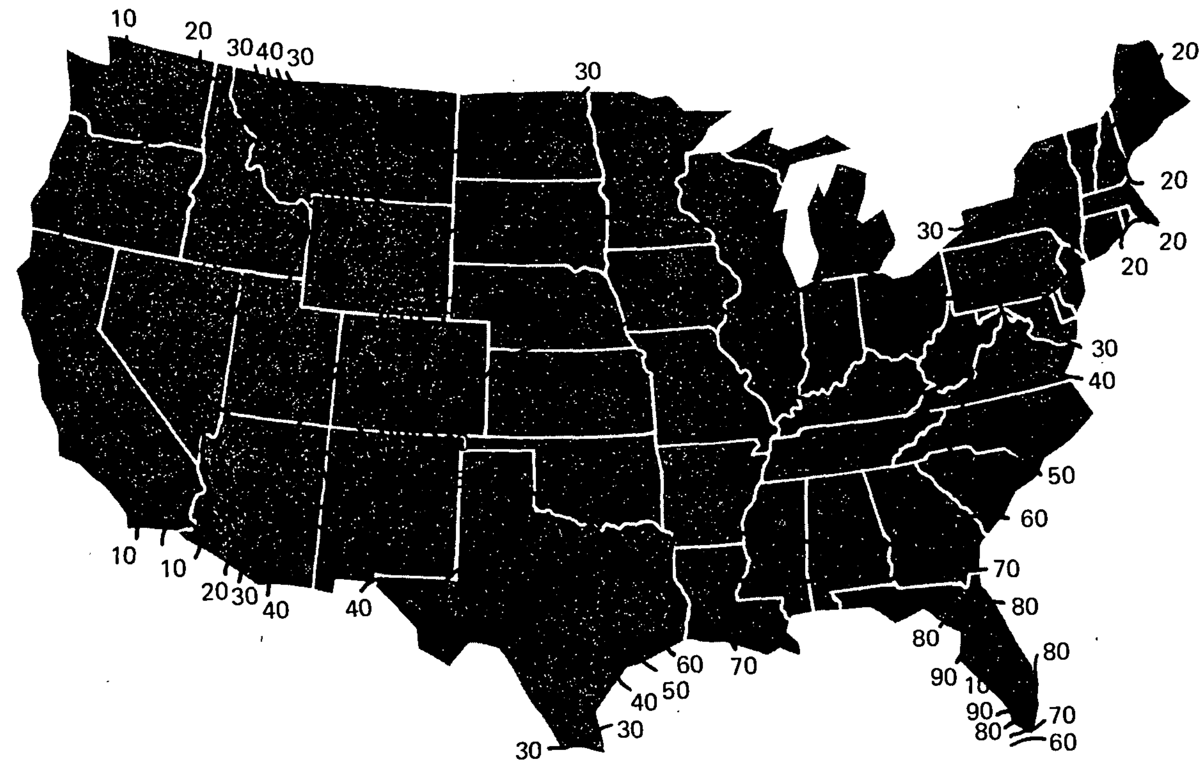

Figure 2—Mean Annual Number of Days with Thunderstorms in the United States

Grounding Effects

All electrical facilities are inherently related to earth either by capacitive coupling, accidental contact, or an intended connection. The earth forms a natural, readily available form of common potential reference for all electrical circuits. In the case of a cloud-to-earth lightning discharge, the earth is one of the ultimate terminal points. If a conducting path for lightning stroke currents is provided between the point of contact of a stroke to a structure and a suitable grounding electrode, physical damage and shock hazards may be substantially reduced. However, supplemental measures are required, in addition to simple grounding, to obtain highly effective protection.

When objects likely to be contacted by an energized power line are wellgrounded, fault current resulting from such a contact will be large. This assures rapid operation of breakers or sectionalizing fuses. In the case of enclosed low-voltage power circuits, the grounding conductor and the continuity of metallic conduit, or equivalent, back to a fuse or breaker point insure that the interrupting devices will operate rapidly on faults to ground. It is interesting to note that in this latter case, an absolute connection to ground is not essential to operate the interrupting devices. Still, a good ground connection is desirable to limit voltages to ground of equipment cabinets and enclosures.

Shielding of sensitive electrical circuits is an essential protective measure to obtain reliable operation in a disturbing environment. Metallic coverings, solid or braided, employing metals such as lead, aluminum, copper, and iron, are frequently used on communication and signal wiring to obtain shielding. However, without proper grounding, such coverings provide very little shielding. Such measures are employed more frequently to control extraneous potentials in the noise magnitude range, but potentials hazardous to both personnel and equipment may also appear under certain exposure conditions, unless adequate shielding is provided. Potentials of hazardous proportion can be produced by high currents associated with faulted power circuits through magnetic and resistive coupling.

Bonding effects

Grounding is an important element of most protection arrangements, but it is only one of several measures necessary to achieve an effective level of protection. Unfortunately, the incorrect notion still exists that all protection problems can be solved by simply providing a connection to earth. This, of course, is simply not true. **All grounding electrodes have a finite resistance to earth,** even such extensive structures as metallic water pipes, **and to this must be added the impedance of grounding conductors.** Obviously, more must be accomplished than can be secured by simple grounding. This suggests the need of potential equalization which is obtained by frequent bonding (inter-connection) of all conducting components of an installation (See Figure 3). In addition, supplemental conducting paths should be provided to a ground electrode system to reduce the impedance of grounding paths to a practical minimum.

With bonding it is possible to approach an equipotential zone throughout an installation, thus assuring personnel safety and also contributing to equipment protection. Figure 4 illustrates the weakness of simple grounding arrangements and the need for supplemental bonding. Only by placing a bonding conductor between the cabinets will dangerous voltages in the operating area be eliminated. It is also interesting to note that the resistance to earth of the grounding electrode does not affect potentials within the installation. It is evident from this simple example that merely reducing the resistance of a station ground is not a panacea for all protection problems.

Protectors and Arresters

Protectors and arresters are normally open-circuit devices that pass no significant current at the normal operating potentials of the circuits to which they are connected. However, they are capable of sparking over on extraneous voltages at predetermined values and discharge current, usually from an energized conductor, to ground. During the period of the discharge, such a device will limit voltage across its terminals to values sometimes less, but rarely greater, than the initial spark-over value. However, the ability of these devices to limit anticipated potentials can be seriously impaired by excessively long connection leads.

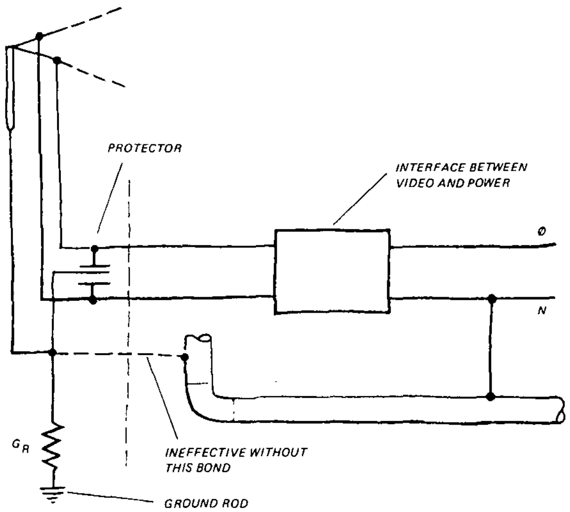

Figure 3—Protection of TV Receiver

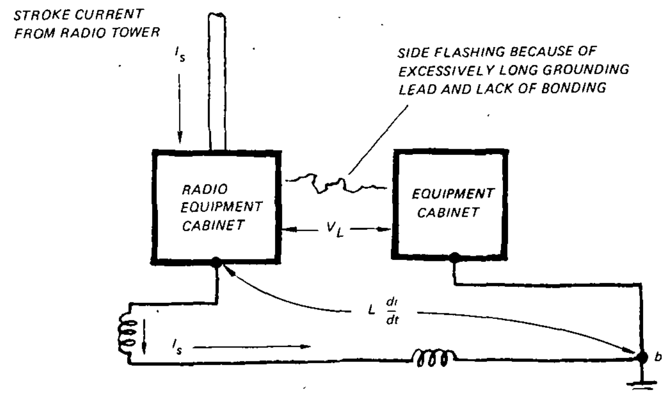

Figure 4—The Weakness of Simple Grounding Arrangements

Protectors are effective devices for limiting voltages on communication circuits that can tolerate the shunt capacitance they introduce (fraction of a picofarad). Protectors should be distinguished from arresters. Arresters are designed for use on power circuits. They are larger in size to permit the discharge of higher current, but more important, they interrupt the flow of steady-stage current, normally on the circuit, promptly after discharge of the surge or transient current is completed. The use of protectors is restricted to communication circuits which typically operate at relatively low voltages and currents.

Communication protectors typically consist of gas-tube devices or closely spaced, flat carbon electrodes (carbon blocks) discharging in air. The gas tubes use metal electrodes in an enclosure with inert gas at reduced pressure. The physics* of the gas-tube design allows much wider spacing of the electrodes (0.015" to 0.030") and retains the same, and in some cases lower, sparkover voltage as a 0.003" protector gap in air having a nominal sparkover of about 600 peak volts. Thus, the gas-tube protector provides essentially the same level of protection as the carbon block device but the wider gap spacing gives a much longer service life with a commensurate reduction in maintenance.

Solid-State Devices

There are a variety of solid-state devices that limit voltage. Generally, their major protection application is on low-voltage circuits in communication apparatus as "second order" protection. These are usually used in conjunction with heavier duty devices (protectors) that provide "first order" protection against the large extraneous voltages and currents on the outside transmission facilities. These can be very useful protection devices, particularly when they are incorporated during the design stage. They have some important limitations, however, among which are rather limited surge capability relative to size and high capacitance.

Fuses and circuit breakers are not satisfactory for interrupting lightning surge current because of inherent time delay. Such surges must be diverted to other paths having adequate current-carrying capability. For example, an excessive and destructive current can be bypassed around a vulnerable component by means of a discharge gap, selected so that it will sparkover before the destructive current goes through the component.

**Paschen's Law—sparkover potential is a function of the product of pressure and gap length.*

Coaxial Lines and Waveguides

Coaxial lines are subject to two possible hazards from surge currents flowing in the outer conductors. One hazard is the induced surge voltages that may damage line dielectric or associated equipment, and the other is the mechanical crushing forces. Small-diameter (3/8") air dielectric lines have been crushed by magnetic forces, but solid dielectric lines and the larger diameter air dielectric lines (7/8" and larger) now in common use are sufficiently strong to withstand such forces. The solution to both problems is relatively simple—merely provide a shunt path to ground for antenna stroke currents. This is easily accomplished in the case of metal poles and towers by bonding the line to the conducting structure at the top and bottom. Where lines are supported at intermediate points, supplemental bonding at such points will eliminate possible arcing. In the case of wood supporting structures, supplemental conduction can be satisfactorily provided by a parallel conductor as described for antenna support structures in the previous section.

Waveguides supported on metal structures should also be bonded to the structure at the top and bottom and also at intermediate points of support. This will provide sufficient additional conductivity in shunt with flexible sections to prevent possible damage at these critical points. Where the supporting structure cannot be used for this purpose, conducting bonds should be placed across all flexible waveguide sections.

Protection Measures

An **arrester** is a discharge device used on power circuits to limit abnormal surge and transient potentials. In this text we are only concerned with arresters for low voltage circuits (600 volts and less) which are frequently referred to as secondary type arresters. The common term used to identify the simple discharge gap used on communication circuits is **protector.** Although both these devices discharge current resulting from abnormal voltages, they are quite different in construction and application. From a safety standpoint, it is desirable to use the proper term, when referring to these devices since "protector" suggests association with a circuit in which the normal operating voltage presents no shock hazard.

Arresters are used on circuits having appreciable, steady-state voltage; therefore, a simple discharge gap would continue to conduct steady-state current after the abnormal surge which initially operated the gap has attenuated. The steady-state current flowing through an arrester after the surge has attenuated is referred to as "power-follow current" and cannot be tolerated for any appreciable time because: (1) current disconnect devices will operate and de-energize the circuit; and (2) the arrester will be damaged. It is necessary, therefore, that arresters incorporate some "clearing" mechanism in addition to the discharge gap to promptly interrupt the flow of power-follow current. Clearing on dc-circuits is much more difficult than on 60-Hz circuits. Consequently, typical clearing voltages for one given type of arrester are usually given as: 50V dc, 175V rms, 60 Hz.

The arresters that a power utility installs on its primary distribution circuits adjacent to a transformer are intended exclusively to protect the transformer. They do not provide protection for secondary circuits and the associated utilization equipment. However, a delta primary or an ungrounded or unigrounded primary cannot be interconnected by a solid connection, but essentially the same result may be obtained through the use of an isolating gap as shown in Figure 5. Interconnection of primary and secondary grounds, is a desirable measure because, in effect, it connects the arresters directly across the transformer windings; and a radio station ground has a much lower resistance to earth than the usual arrester ground, a single ground rod driven at the base of the pole.

It should be recognized that secondary type arresters used for commercial applications such as at radio stations and other communication centers are subject to much more severe duty and the dependability requirements are substantially greater than at a residence. In view of this, there is a trend to fuse secondary arresters that are connected to high KVA secondary buses as a precaution against the possibility, small as it is, that the arrester might develop a permanent short circuit in the gap structure and thus fail to adequately clear power-follow current.

An old arrangement which requires a multiplicity of arresters in shown in Figure 6. This arrangement served its purpose before lower sparkover, secondary type arresters became available. The minimum 20-foot length of steel conduit was essential to assist the sparkover of the higher voltage arrester at the service head. This length is minimal in providing the inductive drop necessary to assist the operation of the higher voltage arrester and field people report that it is an expensive inconvenience. Also, on many shower surges and switching transients, the higher voltage device fails to operate. This places the entire duty on the small branch circuit arrester and substantially reduces its useful life. This protection arrangement was useful when no alternative existed, but since devices are not available offering both improved performance and greater dependability, this arrangement is no longer attractive. It was produced principally for use at residences.

Most of the material used in this article was excerpted, with permission from a booklet entitled "Electrical Protection Guide for Land-Based Radio-Facilities". Copies of this 67 page booklet are available from Joslyn Electronic Systems, Santa Barbara Research Park, P.O. Box 817, Goleto, Calif. 93017.

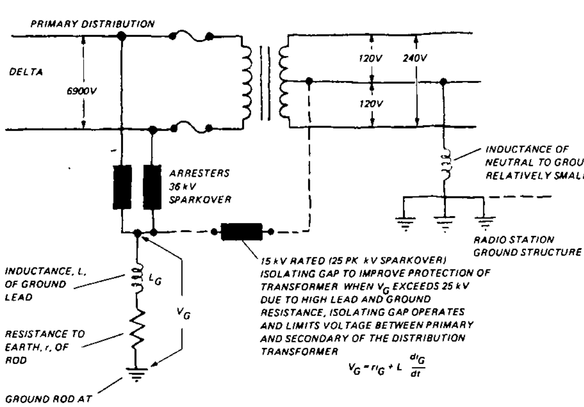

Figure 5—Effective Use of an Isolating Gap on a Delta Distribution System to Interconnect Primary And Secondary Protection Grounds (Arrangement Improves Transformer Protection)

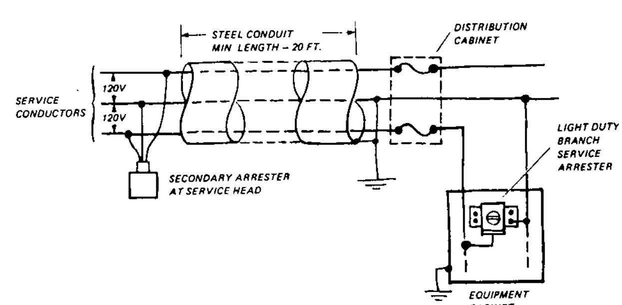

Figure 6—Old Arrangement Requiring a Multiplicity of Arresters