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LIGHTNING PROTECTION

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It may seem strange that the subject of lightning protection for transmission lines is receiving so much attention on the part of electrical engineers, since lightning protective devices have nothing whatever to do with the ordinary operating characteristics of a transmission system. However, the reliability of a line is often dependent upon its adequate protection from lightning-discharges and in some sections of the country satisfactory service would be out of the question without such protection.

The origin of lightning seems still to be a matter of much conjecture. A possible explantion is that the clouds become strongly charged positively during storms, as a result of the ionization of the atmosphere by the sun's rays. Particles of moisture collecting about the negative electrons carry them down in their fall, thus increasing the electrical tension in the space between the separated electrons. This effect is illustrated in the familiar experiment in which the plates of a condenser are charged by the application of a moderate potential, and then separated some distance apart. The potential between the two charged bodies greatly increases, due to the greater distance of dielectric through which the given constant electrostatic field is maintained. During storms moisture collects also about the positively charged electrons, and they tend to follow the others. The earth is hot compared with the upper strata, and heated air tends to rise, with the result that cloud masses of great difference in electrical potential are brought nearer each other and electrical discharges take place; and further great upheavals or overturnings of air, the hot lying below the cold, cause the well-known cold gusts and showers of a thunderstorm. These heavy charges in the atmosphere and the succeeding discharges affect all conducting bodies in the neighborhood. The effects are as follows:

(1) The slow approach of positively charged masses to a line tends to draw a bound charge into the line, which charge leaks slowly on to the wires over the insulators. This bound charge is maintained at practically the potential of the charged earth beneath. This effect is illustrated in Fig. 1.

If a discharge to earth occurs, the bound condition no longer exists, and the potential of the line is immediately raised as by a second charged body being suddenly removed to an infinite distance. The high potential of the line must be equalized in some way and a discharge occurs, either over the insulators or through apparatus, to the earth.

(2) Lightning discharge passing from one charge body to another induces high electromotive-forces in transmission lines

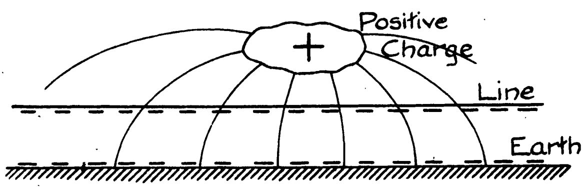

Fig. 1

just as e. m. f. is induced in the secondary windings of a transformer.

(3) Lines may become highly charged by direct stroke of the lightning. This actual discharge may take the form of heavy visible discharges or of silent discharges of more mild and of more frequent occurrence. These discharges cause local effects which usually result in a puncturing or an arcing-over at the insulators. The majority of these lightning disturbances are harmless when not reaching the line, and pass unnoticed.

They remind one of electrostatic experiments with spheres or long cylinders, representing the transmission line, and with electrostatic charges being constantly given to the charged body, adding to the charge already upon it. In fact, by lightning effects is understood any sort of disturbances of the nature of those occurring in electrostatic apparatus. For instance, if a 100,000-volt line accidently comes in contact with a low tension system a disturbance closely resembling a lightning stroke occurs. A sudden rise of potential will accompany the redistribution of charges on the system. Such disturbances are even caused by short-circuits, synchronous motors falling out of step and similar occurrences which cause a disturbance of the electrostatic and electromagnetic field about the conductors of the transmission line.

In a transmission line the inductance and capacity of the system is distributed along its length as indicated in Fig. 2. A

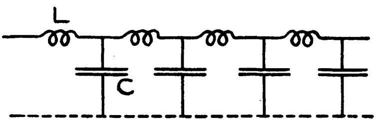

FIG. 2

transfer of energy from one end to the other, as when lightning discharges occur cannot take place instantaneously. A charge in passing along charges one condenser, is opposed by the next choke coil; later the second condenser reaches its maximum potential and so on, the current passing as a wave, which moves along until it reaches the far end. This resembles a wave of water in a long trough, which is reflected upon reaching the end and retraces its course, gradually losing force as its energy is dissipated in friction. A disturbance passing along a line per-

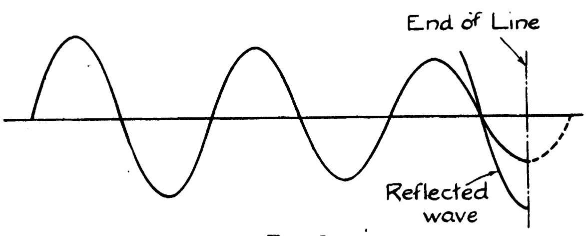

FIG. 3

haps maintains its shape from end to end. If upon reaching the end of the line, it encounters an open circuit, the wave is reflected and follows the line back, which process may continue until the energy is entirely dissipated. If the wave of potential is at its crest at the open end of the line, the reflected wave has twice the value of the oncoming wave, due to the superposition upon it of the reflected wave. This is illustrated in Fig. 3.

The magnitude of such disturbances is limited by the wave length of the disturbance. A mile-long wave cannot support a great amount of energy, due to the limited capacity and inductance of this length of line. As the disturbances are of high frequency the wave length cannot be very long. Sufficiently high potentials are frequently generated to puncture or arc over the insulators.

Effects of Lightning. A direct stroke of lightning passes to earth within a few poles of the point struck, usually shattering the poles through which it passes to earth. Insulators are punctured or broken by such discharges.

Lightning disturbances often cause break-down of insulation in transformers and short-circuiting of the coils. This is explained by the fact that the high frequency disturbance upon meeting the high inductance of the transformer winding, induces such excessive potentials that an arc occurs through the insulation of the coils, which arc is often followed by the power-current of the generator and a short-circuit results.

Preventive or Protective Devices. In devising protective apparatus, two portions of the system must be considered separately

1. The line—exposed through its entire length.
2. The station—exposed only to waves coming in on the line.

Lightning will not pass far to go to the ground; therefore, to protect a line, lightning-arresters would have to be placed at frequent intervals. It is impossible to supply them as frequently as is ideally desirable, and yet a suspension of the service at any time is greatly objectionable. In some classes of service, particularly, a short interruption of service may be attended by serious results, as in the cases of pumps, keeping mines clear of water, or of fans supplying air to blast furnaces, where a stoppage of draft may mean a solidfying of the charge and necessity for dismantling the entire furnace.

(*a*) *Grounded Wires.* One means of protecting the lines is to mount a grounded wire above the wires of the transmission line, as shown in Fig. 4. While this affords some protection, the charge often jumps to the transmission line in what is called a "side flash." That the grounded wire does not afford a sufficiently easy path for the disturbance to reach the earth is evidenced by the fact that in one case the discharge punctured a 30,000-volt insulator, rather than pass to a ground provided at only one pole distance. Two ground-wires placed over a system afford better protection than one, as the charges do not usually come vertically but are swept along from the side, resulting in the discharge passing into one of the working conductors, rather than into the solitary ground-wire above.

The main objections raised against the ground-wires are:

1. Often the wires are not put up strongly enough and become loosened, with the result that they come in contact with the line conductors, causing a shut-down which is the very thing they were supposed to prevent.

2. A cost of several hundred dollars per mile is necessary if

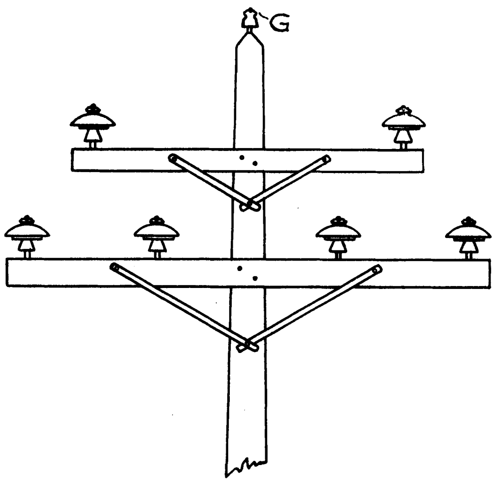

FIG. 4

suitable grounded wires be installed. In view of their lack of reliability, managers are unwilling to put the necessary money into them.

(*b*) *Spark-Gaps.* For the protection of apparatus against grounding, the simple device of an air-gap connected between the line and the ground at a choke-coil (Fig. 5) affords satis-

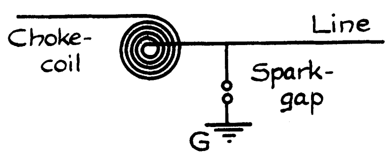

FIG. 5

factory protection in the case of such lines as telegraph lines. Where the power transmitted is considerable, this is not sufficient on account of the liability of the arc to continue and constitute a short-circuit on the system.

(*c*) *Lightning-Arresters.* Much money and thought have been expended in developing a suitable lightning arrester and new types have recently been developed which seem superior to earlier types. As the energy capacity of the prime mover is increased, it becomes increasingly difficult to devise protectors which will allow the lightning discharge to take place and which will prevent the power-arc following. This has been attempted in several ways. First, means were devised to draw out the arc, and thus rupture it after the high-tension discharge had passed. This brought relief to low-capacity systems only.

The magnetic blowout was devised and is still largely utilized on low-tension and direct-current systems. Here the short-circuit current in flowing through the coils of an electromagnet suitably placed with regard to the spark-gap, produces a magnetic field in which the arc is drawn out and ruptured.

A further improvement was introduced by Wurtz, who used a

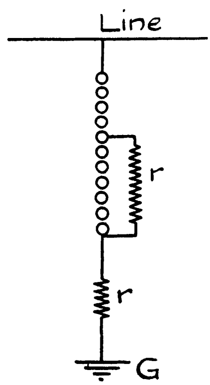

FIG. 6

multiple spark-gap consisting of several cylinders of non-arcing (zinc-brass) metal. This is satisfactory for systems using comparatively low powers only. Its utility has been enhanced by the insertion of resistances in parallel with the portion of the multiple gap, as shown in Fig. 6. This allows the passage of the high-potential discharge, while somewhat limiting it, but the resistance reduces the power-arc and it is ruptured by the non-arcing gaps.

The type of arrester which promises most for high-tension, high-power systems is, the electrolytic arrester. In principle it is ideal and in application it is simple. It provides a shunt path to the ground through which the normal current cannot pass, while static charges find a fairly easy issue, after which the normal high resistance is returned.

The principle of the electrolytic arrester is as follows: If two aluminum plates be immersed in a suitable alkaline solution and subjected to a difference of potential, a momentary deposition of an hydroxide of aluminum takes place on the cathode, establishing a very high resistance to the further flow of current. Such a film has a puncture voltage of about 400 volts. If the potential is reversed, current flows and dissolves the thin film previously formed and deposits a new film on that plate which is now the cathode. Such a cell if connected between the line-wire and the ground prohibits by its resistance the flow of current at the normal voltage of the line (if less than 400) but allows higher potential currents of lightning phenomena to pass unhindered, after which the insulating film is re-established. In order to make such an arrester applicable to high potential lines a number of such cells must be connected in series. This is ordinarily

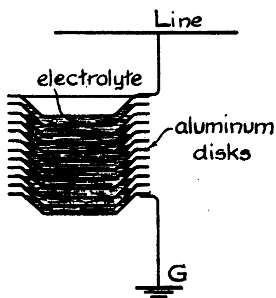

FIG. 7

done by placing one dish-shaped plate within another (Fig. 7.) each dish being filled with the electrolyte and the whole placed in a jar, which may be cooled and insulated by oil. While superior to earlier types such arresters have several weak points.

The electrolyte must be very pure, or the film will be easily punctured.

The arrester must be kept cool.

The arrester must be put up level to prevent the flow of electrolyte over the edges of the plates.

The electrolyte must not freeze, because while frozen it will not operate.

It is difficult to insulate the series of plates at the edges.

In spite of these objections this type of arrester promises to be the best arrester so far developed for high-potential systems.

Protection of Apparatus. Well-insulated choke coils are inserted in lines to receive the static wave and divert it to arresters. Transformers are now built with such adequate insulation that they are not liable to be punctured. The winding is so designed that adjacent conductors in the same layer are subject to but slight differences in potential, while consecutive layers of conductors are heavily insulated from each other.

Choke coils in the leads of generators tend to limit the current established on short circuit. This simple device has proven of great assistance in limiting the damage of short-circuits in the generating station of the New York, New Haven and Hartford Railroad.

While it is possible to design transformers so that they will stand a tremendous increase in potential, the same is not true to a great extent in electric generators, as there the nature of the windings, with sharp bends, proximity of conductors of very different potential, and the impossibility of using oil for insulation, conspire to make the problem a more difficult one, so that alternators are rarely built for potentials above 10,000 or 15,000 volts.

Caution should be used in installing instruments requiring series transformers, as these transformers act as choke coils to the wave of disturbance, and their insulation is often punctured, resulting in grounds, serious in that they endanger the lives of employes and lead to the burning out of meter coils and to other damage to apparatus. A spark-gap is sometimes put around such coils to allow the over-potential to discharge around the instruments. These coils being in series with the line are not subject to the generator potential between terminals, and the generator current does not, in general, follow the arc so established.

In the application of lightning-arresters to outdoor distributing circuits, as in lighting circuits in municipalities where transformers are widely scattered on the lines, account must be taken of the fact that serious disturbances do not follow the line for any great distance, but pass to the ground within a few poles of the occurrence of the disturbance. It is therefore necessary, theoretically, to install a great many arresters. As a compromise, only as many arresters are installed as are found by practice to be necessary to maintain a fair reliability of service. The place of arresters is often taken by trees which are close to the wires and transformers, so that in cities a great many arresters may be dispensed with.