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THE GROUNDED WIRE AS A PROTECTION AGAINST LIGHTNING.

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Some of the transmission lines of this country have installed upon them as a protection against lightning one or more wires strung parallel to the power wires and grounded at intervals. There is a difference of opinion amongst those operating such lines in different parts of the country as to the efficacy of this device. The importance of the subject makes it desirable to have an expression of opinion upon it from those members of the INSTITUTE who have had experience in operating such lines or who have given the matter close consideration. This can perhaps be best arrived at by a discussion on the subject.

THEORY.

There are three ways in which lightning can affect a transmission line; by a direct stroke, by electromagnetic induction and by electrostatic induction. Protection against the first of these would be almost impossible, certainly impracticable. Fortunately, lines are not often struck by lightning. The second, electromagnetic induction, is, in the opinion of the writer, a theoretical possibility—nothing more. It is against the effects of the third, electrostatic induction, that lines are to be protected, whether by lightning arresters or by grounded wires.

The theory of the electrostatic induction action may be explained with practical accuracy as follows: The whole transmission system, line, transformers, etc., may be regarded as an electrostatic conductor, insulated from the earth. Suppose a cloud heavily charged with, say, a positive charge, to move up to the region over the transmission line. There will be a positive charge "set free" on the transmission system and it will have a tendency to pass to earth. It will pass to earth by gradual leakage over and through the insulation of the system if the approach of the cloud is slow enough to give time for such leakage; if not it may puncture the insulation and thus pass to earth. The intensity of the charge will depend upon the potential at the line wires due to the charge of the cloud. Suppose there be near the transmission wires other wires parallel to them and grounded at frequent intervals. They will also be subject to the inductive action and the charge set free upon them will pass to earth as fast as liberated, the "bound" charge of the opposite sign of that of the cloud remaining and depending for its magnitude on the potential due to the cloud and the electrostatic capacity of the grounded wires. Under these conditions the intensity of the charge on the transmission wires will no longer depend only upon the potential at them due to the cloud, but upon the combined action of the charge of the cloud and the bound charge of the grounded wires. In other words, the potential of the line wires will be equal to the difference of the potentials due respectively to the cloud and the grounded wires and will in general be less than that due to the cloud. This action constitutes what may be designated as the "shielding action" of the grounded wires.

Return now to the condition where with no grounded wires the system has been gradually charged and the charge has gradually leaked away, leaving a bound charge of negative sign on the system. Suppose now the cloud be discharged by a lightning flash to earth. The potential due to it at the transmission wires is now zero and there is consequently left upon the transmission system the negative charge which was previously "bound" but is now "free" and which has a tendency to pass to earth and will probably do so suddenly, since the charge has been rendered free suddenly. Its passage to the earth may mean a puncture of the insulation of the system. If, however, we assume that the grounded wires are again present and the charge bound on them by the cloud and set free upon them by the lightning flash can readily pass to earth, there will be less tendency towards the puncture of the insulation of the system because of the fact that, as previously explained, the impressed potential of the line wires before the flash is less with the grounded wires than without them. If the charge on the grounded wires cannot pass readily to earth the charge on them will tend to set free a negative charge on the line wires, which will be added to that set free on the line wires by the lightning flash. The worst condition would be that under which the charge on the grounded wires could not pass to the ground at all, in which case the sum of the two charges on the line wires will be just equal to that which would have existed if there were no ground wires. The passage of the charge from the grounded wire to ground will always be more or less obstructed by the inductance of the discharge path, the effectiveness of this inductive obstruction depending upon the suddenness with which the cloud discharges. This inductive action of the ground wires due to the charge left upon them we will designate as the "direct action" of the wires.

The "shielding action" of the ground wires may be calculated by making assumptions which will approximate to a degree those which obtain in practice, but the calculation of the "direct action" is less satisfactory since it involves a number of assumptions, all more or less speculative in their nature. This is due amongst other things to the fact that we cannot know how long the lightning flash will last or whether it will be oscillatory or not. Furthermore, we do not know what the dielectric strength of the insulation of the system will be for periods of time so short as those involved under the conditions mentioned. We do know, however, that under the worst conditions that can obtain the insulation stress due to the "direct action" of the grounded wires can be no greater than though they were not present and will in general be less. We also know that whatever be the maximum value of this insulation stress it will diminish rapidly either in an oscillatory or non-oscillatory manner, the rapidity of the diminution depending upon the freedom of the discharge path from obstruction. It is to be noted that the time-element of dielectric strength is not involved in the calculation of the "shielding action" to the degree that it is in the "direct action"; since in the former case the charge comes on to the system more or less gradually and we may assume without great error that ordinary values of dielectric strength hold.

In order to get an idea as to the magnitude of the "shielding action" let us calculate its effect under the most simple conditions. Suppose we have two No. 00 wires stretched side by side on a pole line 20,000 feet in length, the wires being one foot apart. Call these wires A and B. Suppose first that both wires are insulated from ground and that the space occupied by them is raised by the inductive action of a cloud to a potential V above the earth. The expression for the potential of a long cylinder or wire of length l and diameter d, having upon it a charge whose density is δ is

$$v_1 = 2\,\pi\,d\,\delta\,\log_e \frac{2l}{d}$$

The potential outside such a wire at a distance s from its axis is

$$v_2 = 2\,\pi\,d\,\delta\,\log_e \frac{l}{s}$$

Each of the wires A and B has upon it, therefore, a free charge of such a density that

$$V = 2\,\pi\,d\,\delta\,\log_e \frac{2\,l}{d} \;\therefore\; \delta = \frac{V}{2\,\pi\,d\,\log_e 2\,l/d}$$

Now let one of the wires A be connected to earth. The free charge on A goes to earth leaving a "bound" charge whose density is equal and opposite to that of the free charge or

$$-\delta = \frac{-V}{2\,\pi\,d\,\log_e 2\,l/d}$$

The potential of any point distance s from the wire A and due to the bound charge of density $-\delta$ is, therefore,

$$V_1 = -2\,\pi\,d\,\delta\,\log_e \frac{l}{s} = -\frac{V \log_e l/s}{\log_e 2\,l/d}\,s$$

The resultant potential therefore at any point distant s from the axis of the wire A due to the combined actions of the charge on the cloud and the bound charge on A is

$$V + V_1 = V\left[1 - \frac{\log l/s}{\log 2\,l/d}\right] = V\left[1 - \frac{\log l - \log s}{\log 2\,l - \log d}\right]$$

This expression will give the resultant potential at the wire B when A is grounded, if we substitute in it the value $l = 20{,}000$, $d = .3648$ inches $= .0304$ feet $=$ diameter of No. 00 wire and $s = 1$ foot. Substituting these values we have

$$V + V_1 = .297.V$$

It appears therefore from this rough calculation that if each wire of a transmission line 20,000 feet in length, the conductors of which consist of No. 00 wire, have stretched parallel to it and at a distance of 12 inches, a grounded wire equal in size to the line wire, the potential of the line wire due to a charged cloud could not rise to exceed 30 per cent. of the value to which it would rise if the grounded wire were not present. As a matter of fact, if each of the line wires had its corresponding ground wire the potential to which they could rise would be even less than this because each line wire would be influenced not only by its own grounded wire but by all of the other grounded wires also. However, it is not usually the practice to employ a grounded wire so large as that assumed, and 12 inches is a smaller distance from grounded wire to line wire than would usually have place. The usual variation from these quantities will about compensate for the effect due to a greater number of grounded wires as usually arranged, so that the example taken serves its purpose as furnishing a criterion as to the magnitude of the effect of the grounded wires. It does not and is not intended to furnish a criterion as to construction or practical details.

Material and Dimensions of Ground Wires.

Ground wires are usually of galvanized iron. This material is probably as good from an electrical standpoint as any other, since with the rapid flow which must take place at discharge the material of the wire itself will probably make little difference in the obstruction offered to the flow. The size of the wire will have an important bearing since in general the larger the wire the less obstruction it will offer and also the greater its "shielding action." Greater effectiveness will be obtained of course for a given amount of material from a number of grounded wires of smaller size than from a smaller number of larger size. Barbed wire is often used for grounded wires but in the opinion of the writer it has no advantage over smooth wire. It seems to have been adopted with the idea that the points would in some way discharge the atmosphere, but if the accumulation of a charge on the line wires is in accordance with the explanation already given the points cannot be effective in any way.

Method of Installation.

Usually three grounded wires are installed, one on top of the pole and one on each end of a cross-arm. They are generally tied to glass insulators presumably for mechanical reasons, as all three wires are of course grounded. The wires should be grounded as often as possible, so that the obstruction to the flow between grounded wire and earth shall be kept as low as possible, thus keeping down the direct action of the grounded wire to as low a figure as possible.

Results in Practice.

The writer has known of a number of plants where grounded wires were installed. In one of these, as the result of a number of years of operation, those in charge of the plant feel sure that the grounded wires furnish a reliable and effective protection against lightning. In some of the other plants those operating think that the grounded wires furnish more or less protection but are doubtful as to the amount. In still other plants those in charge feel sure that the grounded wires are of no value whatsoever and constitute a nuisance and menace because of their liability to break and fall across the power wires. In some of the cases of doubtful success or failure the trouble may have been due to poor grounds or to the wires not having been grounded frequently enough, as in some of these cases the wires were not grounded at every pole. In all of the doubtful cases lightning arresters which were installed in addition to the grounded wires received more or less discharges during thunder storms.