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PROTECTIVE DEVICE FOR ELECTRIC CIRCUITS

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Fig. 1.

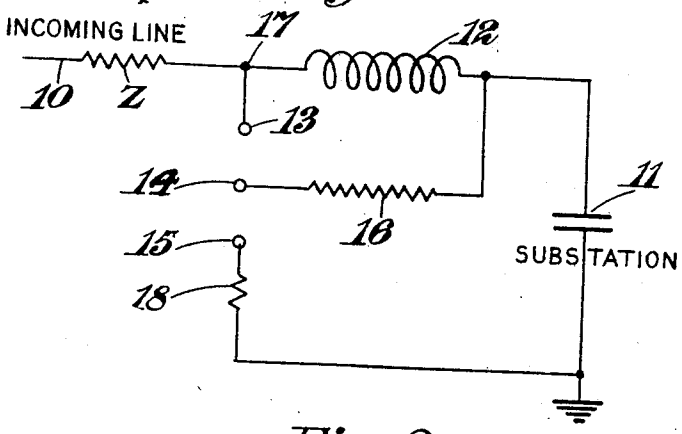
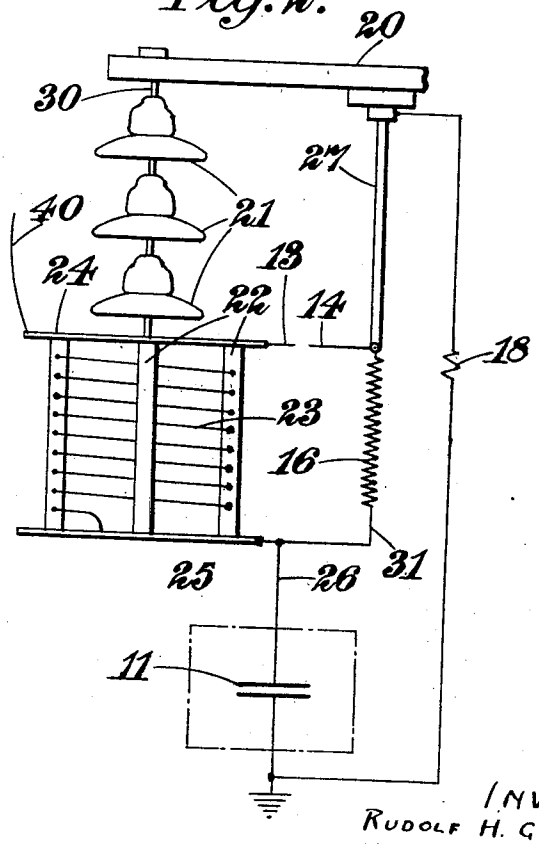


Fig. 2.



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PROTECTIVE DEVICE FOR ELECTRIC CIRCUITS

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5 Claims. (Cl. 175—30)

The invention is for improvements in protective devices for electrical circuits, such as power transmission systems, and is particularly designed to protect apparatus at sub-stations on an overhead power transmission line against the effect of high voltage surges on the line, due, for example, to strokes of lightning. This application is a continuation-in-part of our application Serial No. 314,342, filed January 17, 1940.

Our invention comprises a multiple discharge gap, an inductance which is in series with the circuit, and a resistance which is normally disconnected. Upon the arrival of a surge a high voltage is first set up across the inductance which breaks down the first part of the gap and puts the resistance in parallel with the inductance; the following part of the gap then breaks down, establishing a path to earth. The ohmic value of the resistance is calculated, in respect to the other electrical values of the system, to produce certain desirable results. These are (1) causing the abstraction of energy from the incoming surge, and (2) the suppression of oscillations between the inductance and the capacitance of the sub-station, both to a considerable degree requisite to the prevention of damage to the apparatus at the sub-station. The value of this resistance must be of an order considerably higher than any resistance which is inserted, or is suitable for insertion, in the path to earth. The principal object of the invention is the provision of improved devices and combinations of the character and for the purposes referred to.

In the accompanying drawing,

Figure 1 is a diagram showing the manner in which the protective device according to the invention is connected to an overhead transmission line, and

Figure 2 is a diagram of a constructional form of the apparatus.

As shown in Figure 1 of the drawing, an overhead transmission line 10, where it enters a sub-station indicated as a capacitor 11, has an inductance 12 connected in series. The two ends of the inductance are connected to the electrodes 13 and 14 of a three-electrode air-gap the third electrode 15 of which is connected to earth as shown. The electrode 14 is connected to the sub-station side of the inductance through a resistance 16.

When a surge which is travelling towards the sub-station reaches the device, its first effect will be to cause a high voltage to be set up across the inductance 12. This voltage is applied across the gap between electrodes 13 and 14, thereby causing it to break down, and thereupon putting resistance 16 in parallel with the inductance. The breakdown of this gap causes the potential of the middle electrode 14 to rise to a value approximately equal to that on the line end of the inductance, with the result that the gap between electrodes 14 and 15 also breaks down, thereby diverting to earth any portion of the surge which has not passed the point, 17, of connection of the electrode, 13, with the incoming line.

Now to discuss the theory of the device as above described, we note that the incoming line has an impedance, conventionally indicated as Z, which is known as the surge impedance of the line. This is an inherent characteristic, and represents the ratio between the voltage and current in any incoming surge.

It is important for our purpose that energy should be abstracted from the incoming surge, that the front of the wave should be flattened, and that the oscillations presently to be described should be suppressed to a considerable degree. It will first be noted in this connection that, if no device such as is here described were interposed, the capacitance of the sub-station would have the effect of reducing slightly the steepness of the front of the incoming wave, owing to the time taken to charge this capacitance through the surge impedance of the line. The interposition of the inductance 12 between the line and the sub-station increases the time taken to charge the capacitance, thereby increasing the extent to which the front of the wave is flattened.

In the absence of resistance, however, there would subsequently occur an interchange of energy between the inductance and the capacitance of the sub-station, thereby increasing the voltage impressed on the sub-station in the form of a somewhat violent oscillation. This harmful oscillation can be suppressed by inserting a resistance of suitable magnitude in parallel with the inductance, as is done herein. If, however, the suppression of oscillations is the only consideration, a wave of too step a front may reach the sub-station after the gap between electrodes 13 and 14 has broken down, with harmful effect, and provisions should accordingly be made to overcome this difficulty.

If, now, the ohmic value of resistance 16 is made too low it, while possibly being effective to suppress oscillations, will provide a path of relatively low impedance for incoming surges, after the gap 13—14 has broken down, and con-

sequently very little reduction in the steepness of the wave reaching the sub-station at this time is effected. If, on the other hand, it is made too high, it will not be effective in preventing or minimizing the oscillation produced by the interchange of energy between inductance 12 and the capacitance of the sub-station.

There is a precise mathematical relationship between the maximum value of the resistance 16 and the other three quantities, namely the surge impedance of the line, the inductance 12, and the capacitance of the sub-station, which will prevent oscillation and which we have calculated. This resistance value, ideal for oscillation suppression, is too low for the best results in reduction of the steepness of the wave. We have found, however, that this ideal value can be exceeded sufficiently to make possible the desired flattening of the wave, because the amount of oscillation produced through exceeding the ideal value is not serious unless the value used is many times the ideal value. We have found in practice that the best results are obtained by using a value for the resistance of the order of from two to three times the theoretical ideal value.

The mathematical relationship referred to above may be expressed as follows:

$$R=\frac{Z_s^2}{2Z_s+Z}$$

where R=the maximum resistance in ohms which will prevent oscillation, $Z_s=\sqrt{L/C}$, L=inductance inserted in the line in henries, C=sub-station capacitance in farads, and Z=line surge impedance in ohms. In a typical example, referred to hereafter, in which L is 0.7 mh., C is 1000 $\mu\mu$f. and Z is 500 ohms, the value of R as calculated is 322 ohms.

It will be noted that with the described construction the inductance, by itself, is most effective in the very early stages of the operation, when it operates with maximum efficiency in flattening the front of the wave. Consequently there is appreciable advantage to be gained by causing the resistance to be inserted only after the first part of the wave has passed. This advantage is secured in our invention by causing the resistance to be inserted only after the gap between electrodes 13 and 14 has broken down. It will further be noted that the gap 13—14 breaks down very quickly, followed almost immediately by the breakdown of the second gap 14—15 in the path to earth, these electrodes being spaced so that the double gap is only of about the length of a single gap in the earth path of formed devices for protection against such surges, employing single gaps, so that the time lag of the entire gap is correspondingly reduced. The surge which reaches the sub-station is accordingly of extremely brief duration, i. e. of the order of a few micro-seconds, and it is upon these short waves that a combination of inductance and resistance, as described is most effective.

The value of the inductance used will depend upon the conditions in which the protective device is required to operate. As applied to a device for protecting a sub-station from surges in an overhead transmission line values of from 0.4 to 10 milli-henries have been found to give satisfactory results. In most cases in actual practice in inductance at the lower end of this range, say up to 1 milli-henry is found to serve the purpose desired, as is explained later. A resistance for connection in parallel with the inductance of from 500 to 1000 ohms is suitable for use with an inductance of from ½ to 1 milli-henry, assuming the line surge impedance to be about 500 ohms, as it normally is, in practice. These values are in accordance with the theoretical considerations given above, enabling both the reduction of steepness of the wave and suppression of oscillations, as described, to be accomplished to a considerable degree. As a specific example, with a line surge impedance of 500 ohms, an inductance of 0.7 mh., and a sub-station capacitance of 1000 $\mu\mu$f. the mathematical ideal value of the resistance for suppressing oscillations would lie between 300 and 350 ohms, and best results, considering both reduction of steepness and suppression of oscillations, were obtained with a resistance of approximately 1000 ohms.

In some cases it is advantageous to interpose a resistance of relatively small magnitude 18 in the line leading to earth from the electrode 15. The breakdown of the two gaps 13—14 and 14—15 may cause current of normal frequency to follow the impulse discharge to earth, and if the short-circuit current of the system is very high, it may impose serious mechanical strain on the apparatus connected to the system. The insertion of suitable resistance in the earth lead reduces the risk of mechanical damage to such apparatus by reducing the magnitude of the current which follows this path.

Another reason for inserting resistance in the earth lead is that it may simplify the design of any device which may be used to interrupt the flow of current at normal frequency, following the surge discharge. For example, in the practical application of the invention, gap 14—15 may consist of a device known as a protector tube or expulsion gap. In this the gap, provided for protection against surges, is formed inside an insulating tube, and interruption of the normal frequency current is effected by the rise in pressure which occurs when current flows, producing a blast effect. When such a device is used there is the same risk of mechanical damage to apparatus due to the sudden rush of current during the very brief interval before the extinguishing function of the device becomes effective, but there is also another reason why control of the current is desirable. These devices operate satisfactorily only over a definite current range. If the current is too low the pressure set up is insufficient to cause interruption and if it is too high the insulating tube may burst. The insertion of resistance in series with the expulsion gap not only reduces the maximum current but also reduces the ratio between the maximum and minimum currents which can flow.

The permissible magnitude of this resistance (if it be decided to insert resistance in the earth lead) depends on the extent to which it reduces the degree of protection against surges. The presence of resistance in the earth lead prevents the surge voltage at the point 17 falling to zero when the gaps 13—14 and 14—15 break down. The proportion of the original surge voltage which is left on the line at the point 17 is equal to the ratio of the resistance 18 to resistance 18 plus surge impedance Z. The resistance 18 would normally be small compared with Z, and consequently this ratio is approximately that of the value of resistance 18 to that of Z. If therefore it is decided that it is permissible to allow ten per cent of the surge voltage to remain on the line, the permissible value of resistance 18 is approximately 50 ohms. A somewhat lower value

of this resistance would be sufficient, however, to serve the other purposes mentioned, and it is probable that in practice a value of from 10 to 20 ohms would be used. It is noted that in any case this resistance must be of an entirely lower order of magnitude than that required for resistance 16.

Some reference to the value of the inductance 12 may be made. In general, the higher the value the greater the protection afforded, provided that the value of resistance 16 is chosen to suit, up to a limit governed by the reactance which it inserts in the system. The magnitude of inductance which would be undesirably high from this point of view is, however, greatly in excess of what is required to give adequate surge protection. The designer, therefore, should use the minimum amount of inductance which will give adequate surge protection, in order to avoid unnecessary cost. We have found that in general an inductance of from 0.7 to 1.0 mh. gives adequate protection.

A constructional form of the apparatus is shown in Figure 2 as applied to the protection of apparatus in a sub-station against surges of steep wave-front in an overhead transmission line. A gantry 20 supports, by means of post-type or suspension-type insulators 21, a wooden frame 22 on which is wound an inductance coil 23. Top and bottom conducting plates 24 and 25 carried by the frame 22 are connected respectively to the two ends of the coil 23. The lead-in 40 is also connected to the top-plate 24 and the bottom plate 25 is connected by a conductor 26 to the sub-station, which is again represented by a capacitor 11. The gantry 20 also supports an expulsion-gap 27 of the known type comprising a tube coated on the inside with material which volatilises when the gap discharges. From the lower end of the expulsion-gap 27 a resistance 16 is carried which is connected by a conductor 31 to the plate 25 and by a conductor 26 to the sub-station 11.

The lower end of the expulsion-gap 27 carries a conductor 14 which projects towards a rod-electrode 13 carried by the plate 24. It will be seen that the parts 13 and 14 in Figure 2 are arranged in identically the same manner as, so as to constitute, the gap-electrodes 13 and 14 of Figure 1. The gap between the electrodes 14 and 15 of Figure 1 is constituted in Figure 2 by the expulsion-gap 27.

The resistance 18 inserted in the lead to earth from the expulsion-gap is the same as has been discussed above in connection with Figure 1.

We claim:

1. A protective device for an electric circuit comprising an inductance in series with the circuit, a multi-electrode discharge gap comprising at least three electrodes of which a first electrode is connected directly to the inductance at the line end of it, a second electrode is connected permanently to earth, and a third electrode is arranged between said first and second electrodes so as to form two air-gaps, and a resistance connected directly between the said third electrode and the other end of said inductance whereby, when the said gaps break down, the resistance lies in parallel with the inductance which remains in series with the line and the line is connected directly by said gaps to the earthed electrode, said resistance being of relatively high value suitable for abstracting maximum energy from the surge and yet suitable for suppressing oscillations between the inductance and the station capacitance but unsuitable for inclusion in the path from line to earth.

2. A protective device for an overhead power transmission circuit comprising an inductance in series with the incoming line and a sub-station capacitance, a multi-electrode discharge gap comprising at least three electrodes of which a first electrode is connected directly to the inductance at the line end thereof, a second electrode is connected permanently to earth, and a third electrode is arranged between said first and second electrodes so as to form two air gaps, and a resistance connected directly between said third electrode and the other or sub-station end of said inductance whereby, when the said gaps break down, said resistance lies in parallel with the inductance which remains in series with the line and the line is connected directly by said gaps to the earthed electrode, said resistance being of the order of 500 to 1000 ohms when the inductance is from ½ to 1 milli-henries, the surge impedance of the line about 500 ohms and the sub-station capacitance is of the order of 1000 $\mu\mu$F.

3. A protective device for an overhead power transmission circuit comprising an inductance in series with the incoming line and a sub-station capacitance, a multi-electrode discharge gap comprising at least three electrodes of which a first electrode is connected directly to the inductance at the line end thereof, a second electrode is connected permanently to earth, and a third electrode is arranged between said first and second electrodes so as to form two air gaps, and a resistance connected directly between said third electrode and the other or sub-station end of said inductance whereby, when the said gaps break down, said resistance lies in parallel with the inductance which remains in series with the line and the line is connected directly by said gaps to the earthed electrode, and a resistance in the path to earth from said second electrode, said first resistance being of a relatively high value suitable for abstracting maximum energy from the surge and yet suitable for suppressing oscillations between the inductance and the station capacitance, and said second resistance being of a much lower order of magnitude, suitable for inclusion in the path to earth.

4. A protective device for an overhead power transmission circuit comprising an inductance in series with the incoming line and a sub-station capacitance, a multi-electrode discharge gap comprising at least three electrodes of which a first electrode is connected directly to the inductance at the line end thereof, a second electrode is connected permanently to earth, and a third electrode is arranged between said first and second electrodes with an expulsion gap device connected between said second and third electrodes, there being an air gap between said first and third electrodes, and resistance connected directly between said third electrode and the other or sub-station end of said inductance whereby, when said gaps break down, said resistance lies in parallel with the inductance which remains in series with the line and the line is connected directly by said gaps to said earthed electrode, and a resistance in the path to earth from said second electrode, said first resistance being of a relatively high value suitable for abstracting maximum energy from the surge and yet suitable for suppressing oscillations between the inductance and the station capacitance, and said second resistance being of the order of not over

ten per cent of the value of said first resistance.

5. A protective device for an overhead power transmission circuit comprising an inductance in series with the incoming line and a sub-station capacitance, a multi-electrode discharge gap comprising at least three electrodes of which a first electrode is connected directly to the inductance at the line end thereof, a second electrode is connected permanently to earth, and a third electrode is arranged between said first and second electrodes so as to form two air gaps, and a resistance connected directly between said third electrode and the other or sub-station end of said inductance whereby when the said gaps break down, said resistance lies in parallel with the inductance which remains in series with the line and the line is connected directly by said gaps to the earthed electrode, said resistance being of the order of from two to three times the maximum resistance, R, which will prevent oscillations between said inductance and sub-station capacitance upon the arrival of a high voltage surge, where said maximum resistance is calculated from the formula

$$R=\frac{Z_s^2}{2Z_s+Z}$$

in which R is in ohms, $Z_s=\sqrt{L/C}$, L=inductance inserted in the line in henries, C=sub-station capacitance in farads, and Z=line surge impedance in ohms.

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