

June 10, 1952

E. H. YONKERS
PROTECTIVE SYSTEM

2,600,149

Filed Aug. 30, 1949

2 SHEETS--SHEET 1

Fig. 1

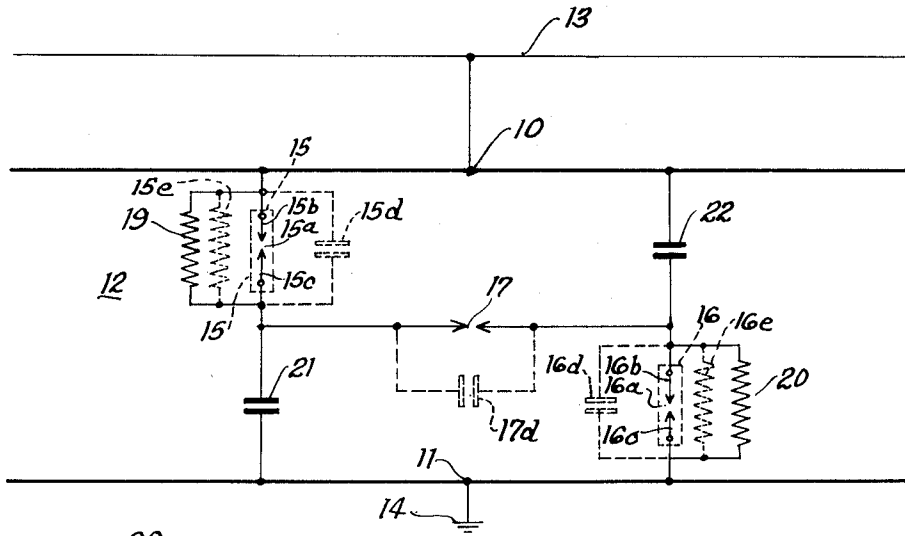


Fig. 4

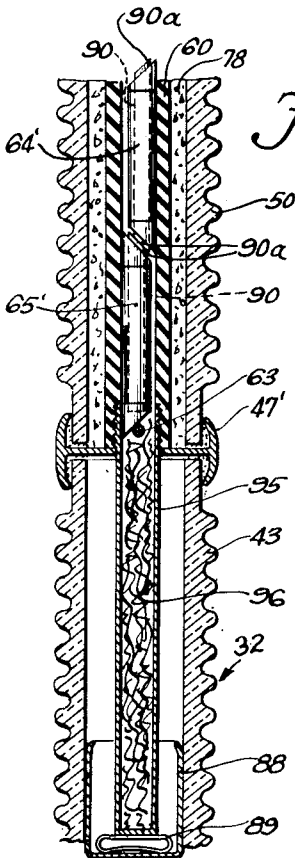
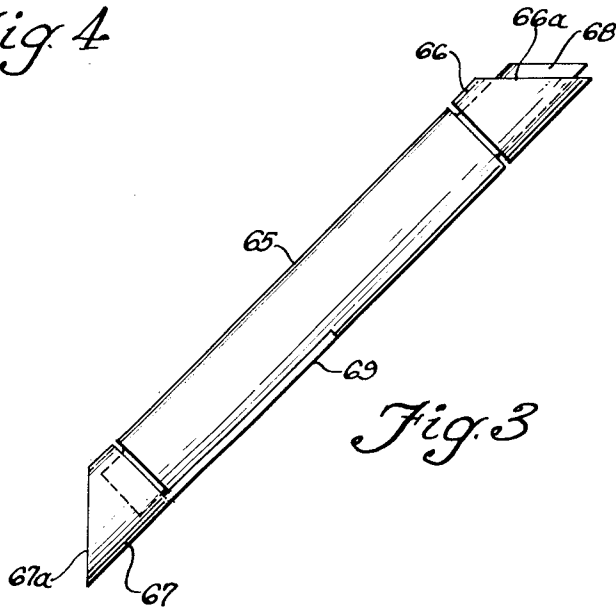


Fig. 3



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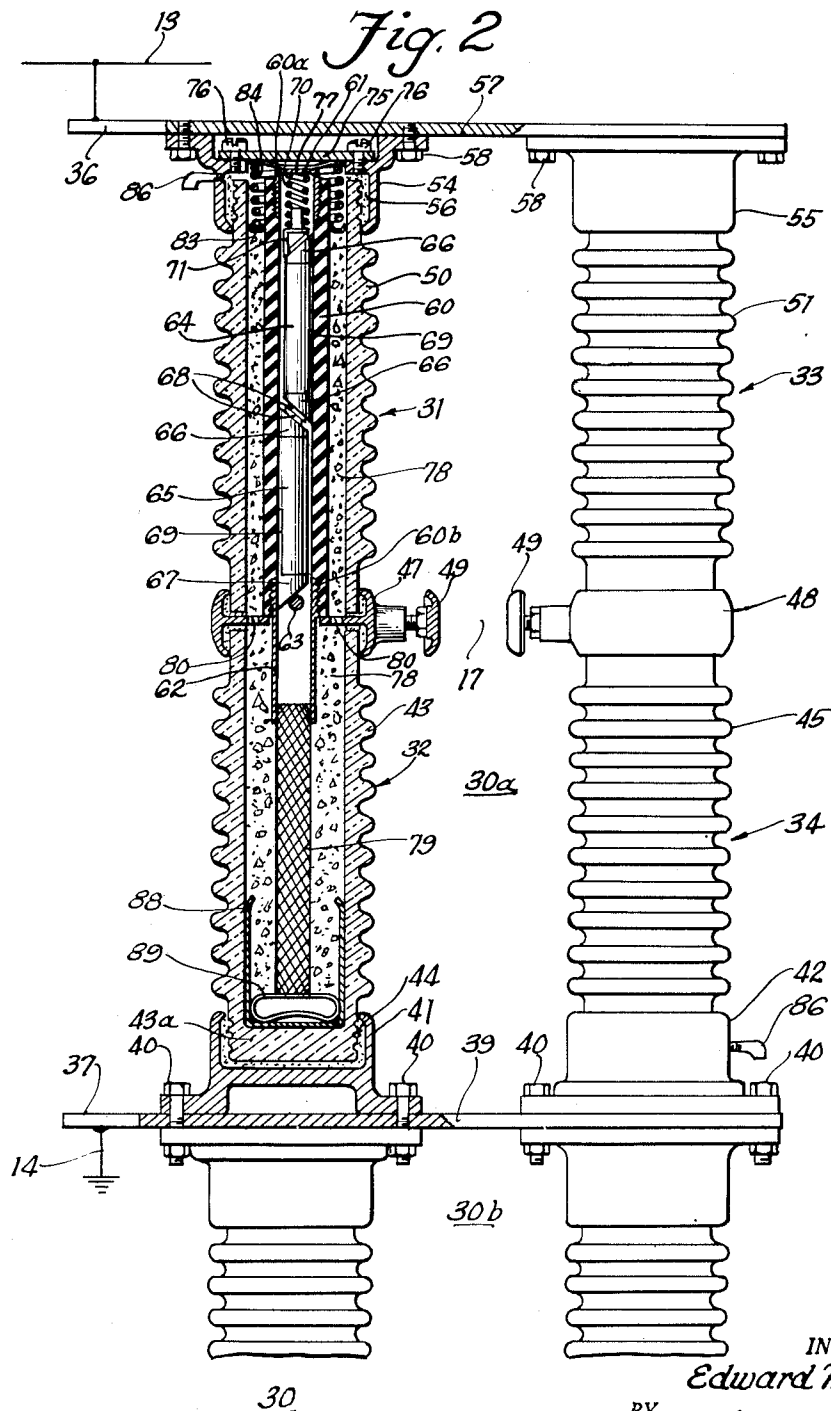
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2 SHEETS—SHEET 2



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UNITED STATES PATENT OFFICE

2,600,149

PROTECTIVE SYSTEM

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14 Claims. (Cl. 175-30)

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The present invention relates to a protective system or protective devices for electrical systems and apparatus, and more particularly to protective devices for protecting power transmission and distribution lines as well as station or other equipment from damage occasioned by lightning and other dangerous over-voltage surges upon the line.

This application is a continuation in part of copending application Serial No. 583,499 filed March 19, 1945, now abandoned.

In general, protective devices of the character mentioned may properly be termed "voltage limiting devices" in that their purpose is to prevent the voltage between an energized current carrying conductor and ground from exceeding a predetermined dangerous level. The assigned functions of such devices are threefold: First, they must act to provide a low impedance path between the energized conductor and ground as quickly as possible after the voltage applied to the terminals of the device exceeds a predetermined dangerous level. Second, the device must permit surge currents to flow between the energized conductor and ground with a potential drop across the device which does not exceed the protective level. Third, the device must eliminate the low impedance path between the energized conductor and ground as soon as possible after the voltage surge disappears or dies out so that a minimum of system or "follow current" is permitted to flow between the conductor and ground. Practically all commercially available protective devices capable of handling lightning and other dangerous over-voltages appearing upon a power line conductor employ one or more spark gaps or an isolating spark gap in series with valve material or a second spark gap housed within an arc extinguishing chamber of some sort. There are on the market today two well known types of such protective devices generally referred to as "valve type" arresters and "expulsion type" arresters. The valve type arresters employ what is generally termed as "valve" material to limit the follow current. This valve material has peculiar characteristics in that its impedance changes in accordance with the voltage applied. For high voltages the impedance is relatively low, whereas for low voltages the impedance is fairly high, thereby acting as a valve to shut off the 60-cycle follow current following a break-down of the gaps associated with the arrester. The expulsion arrester, on the other hand, comprises generally an arc extinguishing chamber enclosing a pair of electrodes defining an arc gap. Generally the

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expulsion type arrester is provided with an arc confining insulating material from which gas is evolved when subjected to the heat of the arc, which gas aids in rapidly extinguishing the arc following the disappearance of the surge voltage.

Both valve type arresters and expulsion type arresters are characterized by a time lag before they spark over when a transient potential is applied thereto. More specifically, the impulse-volt-time characteristic of all known protective devices rises rapidly in the short time region of the characteristic and approaches infinity as the time of voltage application approaches zero. That is to say, in the limiting condition lightning arresters require a voltage approaching infinity to cause flash over as the time of application of this voltage approaches zero.

Since the starting or arc initiating voltage of a protective device is permitted to appear across the terminals of the device, it obviously is also permitted to reach the apparatus or circuit which the device is intended to protect. One of the basic problems in the development of lightning protective devices, therefore, is that of keeping the time-lag of the device as low as possible, or stated otherwise, to speed up the starting of all of the elements of the device which exhibit the above-described time-lag effect. The impulse-failure characteristic of insulation also exhibits an inherent time-lag. However, it is not necessarily of the same shape as that of the protective device, and it may vary widely under different service conditions. It is imperative, therefore, to maintain a liberal margin between the starting characteristic of a protective device and the impulse-failure characteristic of the insulation associated with apparatus or electrical circuits which the protective device is designed to protect. In general the voltage at which a protective device may be set to spark over or start operating is determined by the generated voltage of the system to which the protected apparatus and circuits as well as the protective device are applied. In other words, the protective device must work rapidly when a transient or surge voltage exceeding a certain threshold value is applied to its terminals, but it must not operate on harmless system over-voltages which approach but do not exceed this threshold level.

Both valve type and expulsion type arresters or protective devices are commonly equipped with so-called "series isolating gaps." The purpose of such gaps is to minimize the flow of system current through the device during inactive periods

and many times to eliminate the system voltage under normal conditions from the arresters to prevent "tracking" in the case of expulsion arresters and to eliminate leakage current through the valve element in the case of valve arresters. Such gaps conventionally comprise two or more spaced apart electrodes which exhibit the above described time-lag effect wherein the voltage increases steeply in the short time region of the impulse volt-time characteristic. All gaseous discharge devices including isolating gaps, valve elements and expulsion type arc extinguishing units exhibit time-lag characteristics, and where two or more discharge paths provided by such elements are connected in series the time-lag effects are more or less additive, with the result that the overall time required to start such a device or to initiate the surge by-passing function of such device may be too great to provide the protection when most needed, i. e., when a steep wave front transient of large magnitude appears across the terminals of the protective device.

Accordingly it is an object of the present invention to provide an improved arrangement for reducing the starting time of protective apparatus of the character described.

It is another object of the present invention to provide improved facilities for decreasing the overall sparkover time of a protective device employing a plurality of discharge paths in series.

It is a further object of the present invention to provide a protective device in the form of a reversing network which distinguishes between ordinary system voltages and surge voltages to the extent of causing a major change in voltage distribution across the discharge path of the protective device when the system voltage changes to a surge voltage and vice versa.

Still another object of the present invention resides in the provision of protective apparatus of the character described wherein different surge drain circuits having different over-all impulse volt-time characteristics are provided for limiting the rise of abnormal transient voltages of different magnitudes and having different transient characteristics.

A still further object of the present invention is to provide, in conjunction with a series connected multi-discharge path protective device an auxiliary impedance network having the function of simultaneously developing across each discharge path a voltage which exceeds a major fraction of the voltage applied to the terminals of the apparatus at the instant that breakdown of the arc path should occur.

It is another object of the present invention to provide a multi-gap discharge path protective apparatus wherein a minor fraction of the system voltage normally appearing across the terminals of the apparatus is applied to each of the end discharge paths of the apparatus and wherein these voltages are each increased to a major fraction of the terminal voltage upon the application of a transient voltage to the terminals of the apparatus.

It is another object of the present invention to provide protective apparatus of the character described which affords completely reliable protection with respect to any and all forms of dangerous voltage waves which may appear upon a power line conductor with a minimum of disturbance to the power service.

Further objects and advantages of the present invention will become apparent as the following description proceeds, and the features of novelty

which characterize the invention will be pointed out with particularity in the claims annexed to and forming a part of this specification.

For a better understanding of the present invention reference may be had to the accompanying drawings, in which:

Fig. 1 is a schematic diagram illustrating generally the protective device of the present invention;

Fig. 2 is an elevational view, partly in section, of a commercial embodiment of a protective device as schematically illustrated in Fig. 1;

Fig. 3 is an enlarged perspective view of one element of the protective device of Fig. 2; and

Fig. 4 illustrates an enlarged section of a portion of Fig. 2 showing a modification of the present invention.

Referring now to the drawings and specifically to Fig. 1 of the drawings, the improved protective device of the present invention generally designated at 12 is illustrated as comprising a pair of terminals 10 and 11. Such protective devices are generally connected between a device or circuit to be protected, such as a high voltage transmission line and ground. As indicated in Fig. 1, the terminal 10 of the protective device 12 is connected to a transmission line 13 while the terminal 11 is connected to ground, generally indicated at 14. Thus the potential difference between the transmission line or conductor 13 and ground 14 appears across the terminals 10 and 11 at all times. It is the function of the protective device 12 to prevent the voltage across the terminals 10 and 11 from rising to an abnormally high and dangerous value.

In accordance with the present invention, the protective device 12 between the terminals 10 and 11 comprises what is termed hereinafter as a reversing network, including a plurality of discharge paths 15a, 16a and 17, which bridge the terminals 10 and 11 in series. The two end discharge paths 15a and 16a are each provided between the electrodes 15b—15c and 16b—16c of arrester units 15 and 16, respectively, designated schematically by dotted lines in Fig. 1 of the drawings. These arrester units 15 and 16 may comprise any conventional type of arrester units. Thus the arrester units 15 and 16 might comprise either expulsion type arresters or valve type arresters as mentioned above. Preferably the arresters 15 and 16 are of the improved expulsion type disclosed in Pittman Patents 2,336,420 and 2,418,791 granted December 7, 1943, and April 8, 1947, respectively.

It will be understood that the impedance of each of the three identified discharge paths 15a, 16a and 17 before sparkover is comprised of a shunt capacitance component schematically indicated as 15d, 16d and 17d respectively. In the event that there is no leakage current across the gaps, the only impedance presented before sparkover is that schematically designated by the capacitors 15d, 16d and 17d. In the event of leakage current prior to sparkover, these discharge paths will also present a resistive shunt impedance, which is designated in dotted lines as 15e and 16e in Fig. 1 of the drawings. This resistive impedance might be sufficiently low in the case of a valve arrester to be important in determining the total shunt impedance of the discharge path, whereas in the case of a discharge path such as an air gap 17 under dry conditions, this resistive impedance is substantially infinite and is negligible from the standpoint of the shunt impedance. Consequently in the case of

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the discharge path 17 no shunt resistance is indicated since this path is assumed to be an air gap. In the absence of the facilities described below forming an important part of the present invention, the terminal voltage as measured at the terminals 10 and 11 of the device 12 would necessarily divide between the three discharge paths in accordance with the relative impedances thereof. As a result, the discharge paths tend to spark over in succession during non-overlapping intervals such that the time-lag effects of the paths are cumulative and retard the complete sparkover between the terminals 10 and 11 when a transient voltage appears across these terminals.

For the purpose of more nearly equalizing the voltages individually developed across the three discharge paths 15a, 16a and 17 upon the occurrence of a transient voltage between the terminals 10 and 11, an auxiliary impedance network is connected in circuit with the three discharge paths, the component impedances of which are so proportioned as normally to maintain a minor fraction of the terminal voltage across each of the end discharge paths 15a and 16a and to increase these voltages in response to the appearance of an abnormal transient voltage between the terminals 10 and 11 to at least a major fraction of the terminal voltage. Specifically, this auxiliary impedance network comprises resistors 19 and 20 respectively shunting the arrester units 15 and 16 including the discharge paths 15a and 16a, and two relatively large capacitors 21 and 22 connecting the discharge paths 15a and 16a respectively directly across the terminals 10 and 11. The total shunt resistance across the discharge path 15a is, therefore, the combined resistance afforded by the parallel resistors 19 and 15e. As was mentioned above, in some cases the ohmic impedance of the resistor 15e is so high that it can be neglected in determining the shunt resistive impedance of the discharge path 15a, and only the auxiliary resistor 19 need be considered. This is similarly true with respect to the resistor 20 and the associated resistor 16e. In the event that the arresters 15 and 16 are valve type arresters the resistance value of the resistor 16e becomes important. As has been mentioned above, since the gap 17 is an air gap, the shunt resistance is of such high value as to have no appreciable effect upon the operation of the network as a whole, and consequently it has not been indicated even in dotted lines. The shunt capacities, however, 15d, 16d and 17d, although very small in the case of ordinary gaps, are shown in dotted lines in the drawings, since under certain frequency conditions from the standpoint of reactive impedance they become important. Although the auxiliary impedances 19 and 20 have been specifically indicated as resistors, it will become apparent as the following description proceeds that these auxiliary impedances might also comprise, under certain conditions, inductances, and it is intended in the appended claims to cover impedances including resistance as well as inductance which will perform the function set forth above and elaborated upon in greater detail hereinafter.

Further in accordance with the present invention and before considering the operation of the protective apparatus 12 of the present invention, the capacitor 21 is designed to have a reactive impedance which is only a fraction of the reactive impedance provided by the capacitor 15d. This same fractional relationship also holds with re-

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spect to the reactive impedances of capacitors 22 and 16d. On the other hand, the effective resistance in shunt with each of the discharge paths 15a and 16a, which is the parallel impedance afforded by the resistors 15e and 19 in the case of discharge path 15a, and 16e and 20 in the case of discharge path 16a, has a resistive impedance which is small compared with the reactive impedance of the capacitors 21 and 22 at the system or 60-cycle frequency. More specifically, the capacitance of the capacitor 15d is preferably of the order of one-twentieth that of the capacitance of capacitors 21, and the effective shunt resistance of the parallel arranged resistors 15e and 19 provides a resistive impedance of approximately one-tenth the reactive impedance of the capacitor 21 at the system or 60-cycle frequency. The same impedance relationships should also prevail with respect to the circuit components comprising elements 22, 16d, 16e and 20.

As has been pointed out above, in many cases the resistors 15e and 16e may be completely eliminated from the calculations, since they are negligible in so far as the effective parallel resistive impedance across the discharge paths is concerned. However, Fig. 1 illustrates the general case where any type of discharge path may be employed which might have substantial leakage current and consequently relatively low inherent resistive impedance. With these impedance relationships established, the resistive impedance of the equivalent resistance comprising the parallel elements 19 and 15e is of the order of one per cent of the reactive impedance of the capacitor 15d. Accordingly the distribution of the normal system or 60-cycle voltage between the terminals 10 and 11 across the discharge path 15a and the capacitor 21 is determined primarily by the resistive impedance of the parallel resistor elements 19 and 15e and the reactive impedance of the condenser 21. With the described relationships prevailing approximately one-tenth of the system voltage, or ten per cent in other words, will appear across the discharge path 15a and ninety per cent of the system voltage will appear across the capacitor 21. Similarly the voltage appearing across the discharge path 16a at the system voltage frequency, normally 60 cycles, it will be approximately ten per cent of that which would appear across the capacitor 22. In this regard it is noted that the capacitance of capacitor 17d which is the inherent capacitance of the air gap, is of such low value that it does not materially affect the operation of the network either at the system voltage frequency or under surge voltage conditions. This is similarly true in so far as the system voltage conditions are concerned of the capacitors 15d and 16d, which for the values mentioned above present an ohmic impedance two hundred times that of the parallel resistors associated therewith and are effectively an open circuit condition, so that substantially all of the impedance under 60 cycle conditions is determined by the auxiliary impedances 19 and 20, or in certain cases as mentioned above by the equivalent resistance presented by the parallel resistors 19 and 15e in the case of discharge path 15a, and 20 and 16e in the case of discharge path 16a.

From the above description it will be apparent that by appropriately proportioning the value of the shunt resistance comprising the auxiliary resistor 19 and the resistor 15e relative to the

capacitance of the capacitor 21, approximately ninety per cent of the normal system voltage applied between the terminals 10 and 11 may be made to appear across the capacitor 21, with the residue ten per cent of the terminal voltage appearing across the discharge path 15a. If the terminal voltage is similarly divided between the discharge path 16a and the capacitor 22, ten per cent of the normal terminal voltage will normally appear across the discharge path 16a. This, of course, means that eighty per cent of the voltage normally applied across the terminals 10 and 11 will appear across the isolating gap 17. Analyzed in a different way, the voltage across the discharge path 17 is equal to the difference between the voltage across the capacitor 21 and that across the discharge path 16a. It will thus be apparent that normally a minor fraction, that is less than fifty per cent, of the normal 60-cycle system voltage applied across the terminals 10 and 11 of the apparatus 12 appears across each of the two end discharge paths 15a and 16a and that a major fraction of the terminal voltage, that is more than fifty per cent, of the 60-cycle voltage applied across the terminals 10 and 11 is developed across the center discharge path or isolating gap 17.

It will be understood by those skilled in the art that the reactive impedance of a capacitor varies inversely with the frequency of the applied voltage, whereas the resistive impedance of a resistor is substantially unaffected by changes in the frequency of the applied voltage. In other words, the reactive impedance of the capacitor may be expressed as follows:

$$Z_c = \frac{1}{2\pi fC}$$

where Z_c is the impedance in ohms due to capacitive reactance, f is the frequency in cycles per second and C is the capacitance in farads. The resistive impedance of a resistor, on the other hand, may be expressed as follows:

$$Z_r = R$$

where Z_r is the impedance in ohms and R is the resistance in ohms. These expressions indicate clearly that the reactive impedance is dependent on frequency, whereas the resistive impedance is independent of frequency. In the system under consideration, if the frequency of the voltage across the terminals 10 and 11 is increased 100 times, or in other words, if the 60-cycle frequency value is increased to 6,000 cycles per second, the reactive impedance of the capacitors 21 and 22 will fall to a value approximately one-tenth that of the resistive impedance of the equivalent resistors defined by the parallel resistors 19 and 15e in one case, and 20 and 16e in the other case, thereby producing a reversal in the distribution of the applied voltage with change in frequency such that approximately ninety per cent of the terminal voltage at a frequency 100 times the system frequency appears across each of the end discharge paths 15a and 16a and the remaining ten per cent appears across the capacitors 21 and 22. In such case the percentage of terminal voltage appearing across the isolating gap 17 remains at eighty per cent just as was described above. At this higher frequency of 6,000 cycles the reactance of the capacitors 15d and 16d decreases substantially so that it is no longer negligible and begins to approach the effective shunt impedance provided by the elements 19 and 15e in one case, and 20 and 16e in the other case.

Consequently the reactances of these capacitors must be considered as a part of the network and the effective resistance defined by the elements 19 and 15e, and 20 and 16e become less and less important as the frequency increases. In other words, the capacitors 16d and 15d act to set a limit upon the redistribution of the applied voltage between the discharge path 15a and the condenser 21, and between the discharge path 16a and the condenser 22. For example, if the capacitance of the capacitor 15d is one-twentieth as large as the capacitance of the capacitor 21, the applied voltage redistribution with increasing frequency will approach a condition wherein ninety-five per cent of the voltage appears across the capacitor 15d and the residue of five per cent appears across the condenser 21, and at these extremely high values of frequency of the applied voltage the impedance of the resistors 19 and 15e may be completely neglected.

Lightning surges upon distribution lines result in rapidly rising line to ground potentials which may be regarded for purposes of analysis as having a certain frequency characteristic. For example, it is common practice to subject protective equipment to test voltage surges having a wave shape which rises to crest value in from one to one and one-half microseconds and then falls at varying rates. In terms of frequency, the rising portion of such a transient wave would represent one-quarter cycle at a frequency of 250,000 cycles per second, which is approximately 4,000 times greater than the normal system current frequency of 60 cycles. It can thus be seen that the above described voltage distribution under surge voltage conditions is realized, since, as pointed out above, it is obtained when a voltage having a frequency only 100 times greater than normal system frequency is applied.

Thus it will be apparent that the voltage across each of the two end discharge paths 15a and 16a is increased to a major fraction of the available terminal voltage in response to the application of an abnormal transient voltage across the terminals 10 and 11, without decreasing the percentage of the available terminal voltage which is developed across the discharge path 17 of the isolating gap. In short, the voltages respectively appearing across the three paths 15a, 16a and 17 tend to become equalized and approach substantially simultaneously the applied terminal voltage, with the end result that all three of these discharge paths tend to spark over simultaneously. This is because, as is obvious from Fig. 1, when a high frequency transient occurs the capacitors 21 and 22 substantially become short circuits for such transients, with the result that the discharge paths 15a, 16a and 17 are each connected in parallel across the terminals 10 and 11. It will be understood, therefore, that by providing the auxiliary impedance network in circuit with the three series connected discharge paths comprising primarily the shunt resistors including the auxiliary resistors 19 and 20, and the inherent resistances of the discharge paths 15a and 16a represented as 15e and 16e respectively, together with the capacitors 21 and 22, that the overall time-lag in starting operation of the apparatus may be materially reduced.

As pointed out above, the instantaneous voltage across the isolating gap 17 is equal to the difference between the instantaneous voltages across the capacitor 21 and the discharge path 16a. This, of course, means that under certain transient voltage conditions the instantaneous

voltages across the discharge path 17 may be quite low. Thus in the case where the rate of voltage change between the terminals 10 and 11 is such that the instantaneous voltage across the discharge paths 15a and 16a and the capacitors 21 and 22 are all equal, no voltage is developed across the discharge path 17. This will be obvious from the above discussion. However, when any one of the three discharge paths 15a, 16a and 17 sparks over, its impedance instantaneously decreases to a relatively low value, namely the arc drop across the path, thus causing a redistribution of the terminal voltage between the other two discharge paths. It will be seen, therefore, that the order in which sparkover of the three discharge paths may occur depends, in part at least, upon the steepness of the transient wave form of voltage applied to the terminals 10 and 11, and may be different for impressed transients of different characteristics. The manner in which system current flow through the three series connected discharge paths is interrupted after the surge current is drained from the conductor 13 to ground will readily be apparent to those skilled in the art.

The advantages of the present improved system in surge protective apparatus may be more apparent when its operation is considered in terms of "impulse ratio." This term refers to the ratio of the high frequency or impulse voltage to the low frequency voltage required to initiate a protective device. It is, of course, desirable that a lightning arrester afford substantially a short circuit to ground for high voltage transients and furthermore afford substantially an open circuit to ground for ordinary system voltages. Thus, impulse ratio is a true measure of the effectiveness of a lightning arrester. A high impulse ratio obviously indicates a slow and therefore a poor impulse protective device, whereas a low impulse ratio indicates an efficient one. For example, if it were desired to determine the impulse ratio of a standard rod gap and a standard sphere gap a surge voltage rising to its crest value in one and one-half microseconds and decaying to half value in forty microseconds might be applied as the impulse voltage and a quarter cycle of sixty cycle voltage of sufficient magnitude to cause spark over should also be applied. It would be discovered that the impulse ratio for a standard rod gap would be of the order of 1.5, while for a sphere gap of proper design the impulse ratio would approach unity, but always more than one. The present improved system, on the other hand, permits impulse ratios to be realized of less than unity which is very desirable since it indicates that the protective device recognizes the difference between surges and ordinary system voltages. In the particular case considered above the impulse ratio would be approximately 0.75, or about half that of the standard rod gap. Consequently a device based upon the present invention would have an improved impulse protective level of one-half that of the rod gap for the same total gap spacing. Referring to Fig. 1 of the drawings, the impulse sparkover voltage for the system without the capacitors 21 and 22 would be about twice what it is with the complete reversing network as shown and described above. In other words, a very great improvement is produced by employing the reversing network of the present invention.

In the description of Fig. 1 of the drawings it was mentioned that lightning arresters such as

15 and 16 might be employed having inherently included therein sufficient shunt resistance 15e and 16e as to supply completely the shunt resistance required for the reversing network of the present invention without requiring any auxiliary resistors such as 19 and 20. Such an arrangement is disclosed in Fig. 2 of the drawings, where there is illustrated a commercial embodiment of the schematic arrangement shown in Fig. 1. As illustrated in Fig. 2, there is disclosed a protective device or lightning arrester 30 which may be in the form of a station arrester comprising a plurality of complete units 30a, 30b, etc., the unit 30a being completely shown while only a portion of the unit 30b is illustrated. For certain voltage ratings the unit 30a may be all that is necessary, whereas for higher potentials additional units are added thereto in a manner well understood by those skilled in the art. Each unit such as 30a and 30b comprises a plurality of separate sections 31, 32, 33 and 34 which embody the reversing network discussed above. The additional units such as the unit 30b, only a portion of which is shown, are mentioned merely to indicate the possibility of additional units for higher voltages, but it should be understood that the portion 30a of the protective device 30 shown in Fig. 2 between the terminals 36 and 37 thereof is completely operative by itself and for a predetermined voltage range would comprise a complete protective device. The terminal 37 is illustrated as the low voltage terminal and is schematically illustrated as being connected to ground 14 in the same manner as the terminal 11 of Fig. 1. Correspondingly the terminal 36 is indicated schematically as being connected to the high tension transmission line 13, which in the illustrated embodiment is the protected system portion. It should be understood that the protected system portion might be a central station, a substation or the like.

The terminal 37, which is the ground terminal, is connected to a suitable conducting support 39 which if only the unit 30a is employed defines the base of the arrester and upon which are supported, as by suitable bolts or fastening means 40, metal castings 41 and 42, which form parts of the sections 32 and 34 respectively. The section 32 further includes an insulated cylindrical housing 43, closed at the bottom as indicated at 43a and preferably formed of porcelain or the like, which is suitably united to the casting 41 by an insulating cement 44. Preferably the casting 41 includes a flanged portion into which the closed end of the housing 43 may be received and fastened therein by the cement 44. The section 34 also includes a porcelain housing 45 identical with the housing of the unit 31 described hereinafter and fastened to the casting 42 in a manner similar to that used in fastening the casting 41 to the housing 43. The open upper ends of the housings 43 and 45 are provided with suitable ring castings 47 and 48 respectively, suitably attached to the housings 43 and 45, and each includes an electrode member 49 between which is defined an isolating gap designated as 17, so that its relationship to the gap 17 in Fig. 1 of the drawings may be apparent. The electrodes 49 are adjustably mounted on the ring castings 47 and 48 to permit any desired gap setting for the isolating gap 17.

Suitably supported on the ring castings 47 and 48 are insulating housings 50 and 51, preferably formed of porcelain cylinders. The housing 50 is identical with the housing 45 except that the

former is inverted and similarly the housing 51 is identical with the housing 43 if the latter were inverted. As will become apparent the arrester sections 33 and 34 are substantially identical with the sections 32 and 31 respectively assuming the latter sections are inverted. Attached to the upper end of the cylindrical housings 50 and 51 are end castings 54 and 55 respectively, which are shaped to receive the upper ends of the housings 50 and 51 therein so as to be fastened thereto by a suitable cement indicated at 56 with reference to the housing 50 and the flange 54. A suitable top conducting member 57 extends across the castings 54 and 55 which castings are preferably fastened thereto by suitable fastening means 58. The top conducting member 57 comprises the high potential end of the protective device 30 and is connected with the terminal 36.

For the purpose of relating the commercial embodiment illustrated in Fig. 2 of the drawings with the schematic disclosure of Fig. 1, it is pointed out at this time that the section 31 defines a discharge path and substantially corresponds to the discharge path 15a of Fig. 1. The section 32 includes a condenser corresponding with the condenser 21 of Fig. 1. Similarly the section 34 includes a discharge path corresponding to the discharge path 16a of Fig. 1 and the section 33 includes a condenser corresponding to the condenser 22 of Fig. 1. These elements of Fig. 2 including the isolating gap 17 as will be apparent from the ensuing description, are connected into an electrical circuit identical with that schematically shown in Fig. 1 of the drawings.

Essentially the discharge path associated with the section 31 of the protective device 30 comprises an expulsion unit including an expulsion tube 60 preferably formed of insulating material capable of evolving an arc extinguishing gas when subjected to the heat of an electric arc. This expulsion tube 60 is illustrated as being internally threaded adjacent its upper and lower ends as designated at 60a and 60b in the drawings. The upper end of the expulsion tube is completely closed by means of a cup-shaped cap 61 threadedly engaging with the thread 60a defined at the upper end of the expulsion tube 60. Preferably the lower end of the expulsion tube 60 which is concentrically disposed within the housing 50 rests upon the central casting 47 which is provided with a central opening through which extends a suitable conducting tube 62 having its upper end threadedly engaged with the thread 60b and having an inner bore coextensive with the bore within the expulsion tube 60. A suitable transverse conducting rod 63 defining the lower terminal of the expulsion arrester extends transversely across the lower end of the expulsion tube and electrically connects the ring casting 47 thereto so that the external isolating gap 17 is electrically connected to one terminal of the discharge path corresponding to the path 15a in Fig. 1 of the drawings.

For the purpose of defining the spark over gap and also providing means for aiding in rapidly extinguishing the arc drawn there are disposed within the bore of the expulsion tube 60 a pair of filler rods 64 and 65 arranged in end to end relationship. Only two of these rods are shown in Fig. 2 of the drawings, but it will be understood that additional rods may be employed or disposed in end to end relationship to give the desired expulsion characteristic. The lower filler rod 65 is best shown in Fig. 3 of the drawings and

comprises a rod of gas evolving insulating material such as hard fibre or the like having a tubular metal ferrule 66 at the upper end thereof and a ferrule 67 at the lower end thereof. The ends of the filler rod are of reduced cross section so as to be received within the ferrules 66 and 67. The ends of the ferrules 66 and 67 are furthermore cut at an angle designated as 66a and 67a respectively. The upper ferrule 66 is of tubular configuration so that a portion 68 of the insulating filler rod 65 extends beyond the end of the ferrule 66 as is clearly shown in the drawings. This end is also cut at the same angle as the corresponding end of the ferrule.

To provide a short spark over gap the lower ferrule 67 is provided with an integral extension 69 embedded in the surface of the filler rod 65 as shown so as to provide a fairly short arc gap between the upper end thereof and the ferrule 66. The conductor 69 and the initial arc path defined between its upper end and the ferrule 66 are so arranged with respect to the angular surfaces 66a and 67a that the maximum lengths along the longitudinal axis of the ferrules 66 and 67 are colinear with the conductor 69. The filler rod 64 is substantially identical with the filler rod 65 except that the ferrule at the lower end thereof is identical with the ferrule 66 of the filler rod 65 and is designated by the same reference numeral. These filler rods 64 and 65 are of somewhat smaller diameter than the bore of the tube 60 so that when disposed in this bore a crescent shaped chamber is defined between the filler rod and the tube bore.

In order to increase the arc interrupting ability the filler rods are biased to cause the portions thereof colinear with the conductors 69 to engage the walls of the bore of the tube 60. To this end the angular end surface 67a of the lower ferrule 67 engages with the transverse conductor 63 at the lower end of the expulsion tube 60 to force the filler rod 65 away from the center of the tube 60 so that the conductor 69 bears against the wall of the expulsion tube 60. The upper filler rod 64 is inserted so that the interengaging angular end surfaces of the upper and lower filler rods are in the position shown in Fig. 2 with the insulating extensions 68 in engagement. The purpose of the insulating extensions 68 at the interengaging faces of the filler rods 64 and 65 is to prevent metal to metal contact between the adjacent ferrules such as 66 so as to prevent welding together of these ferrules under the heat of the arc.

For the purpose of aiding in positively forcing the conductor portions 69 on each filler rod into intimate engagement with the walls of the bore of the expulsion tube 60 there is provided a suitable compression spring 70 disposed within the cup-shaped cap 61 compressed between the upper end of the filler rod 64 and the top of the cap 61. Preferably there is interposed an adapter member 71 between the lower end of the compression spring 70 and the upper end of the filler rod 64 to permit proper cooperation between this end of the compression spring and the upper angular end of the filler rod 64.

In order to connect the upper terminal of the expulsion device described above with the line terminal 36 there is provided a suitable conducting plate 75 supported within the upper casting 54 by fastening means illustrated at 76. A suitable spring member 77 interposed between the plate 75 and the closure cap 61 of the expulsion tube 60 completes the electrical circuit from the

terminal 36 to the upper terminal of the expulsion discharge path, and also maintains the expulsion tube 60 in proper position with respect to the ring casting 47. The expulsion arrester described in detail above forms no part of the present invention but is disclosed and claimed in a Pittman Patent 2,434,010.

The operation of the expulsion device described above will be understood by those skilled in the art. In the event of a surge voltage appearing on the conductor 13 of sufficient magnitude to initiate a discharge between the transverse conducting rod 63 and the upper ferrule 66 of the filler rod 64, there first are formed a series of arcs, one between the upper ferrule 66 of the filler rod 64 and the upper end of the conductor 69 of that filler rod, another between the upper ferrule 66 of the lower rod 65 and the conductor 69 of that filler rod, and still another short arc between an upper ferrule 66 of the lower filler rod 65 and lower ferrule 66 of the upper rod 64. These initial arcs and particularly the two long arc sections thereof will be initiated in the most confined space between the filler rods and the expulsion tube walls by virtue of the action of the compression spring 70 tending to bias these filler rods against different wall portions of the expulsion tube 60. The immediate production of arc extinguishing gases which are evolved from the walls of the expulsion tube 60 and the filler rods 64 and 65 causes the arcs to be transferred to the larger space between the filler rods and the expulsion tube walls opposite the conductors 69. The combined action of the arc extinguishing gas and the arc elongation tends rapidly to extinguish the arc in the conventional manner of an expulsion tube. The arc discharge products are exhausted through the lower end of the expulsion tube 60.

With the arrangement described thus far, it will be understood that arc gases escaping from the lower end of expulsion tube 60 might tend to cause a flash over around the outside of the expulsion device. To prevent this the annular space between the expulsion tube 60 and the housing 50 is filled with an arc cooling material of some sort. Preferably a refractory material having the desired resistivity such as granular silicon carbide generally designated at 78 is employed to serve a dual function of cooling the escaping arc gases and furthermore providing a discharge path for surges of a magnitude insufficient to cause spark over of the discharge device described above. To insure proper cooling of the escaping arc gases and proper diffusion through the mass of granular silicon carbide 78, the conducting tube 62 may extend substantially to the bottom of the housing 43 and be provided with suitable openings such as saw cuts or other openings or perforations. As illustrated in the drawings, however, a suitable tubular extension 79 for the conducting tube 62 is defined by a perforated screen like material having a mesh such as to require the arc gases to escape throughout substantially the entire surface thereof. With this arrangement the entire annular space in the lower housing 43 as well as the upper housing 50 may be filled with granular silicon carbide thereby increasing the path length through which the arc gases may be diffused. The ring casting 47 is preferably provided with a plurality of perforations 80 to provide a path for arc gases from the lower to the upper annular chamber. In order to maintain the granular silicon carbide mass in the desired compressed condition there is disposed

adjacent the upper end of the housing 50 an annular piston like member 83 which is forced downwardly by a compression spring 84 whose upper end bears against the plate 75. A suitable downwardly directed vent to atmosphere 86 is associated with the upper casting 54 to provide a suitable escape passageway for arc gases released through the gas cooling mass 78.

In accordance with the present invention there is disposed within the lower end of the housing 43 a cup-shaped conducting member 88 which together with the adjacent surface of the casting 41 defines a capacitor having a porcelain dielectric comprising the portion 43a of the housing 43 disposed between the capacitor plates. The capacitance defined between the member 88 and 41 corresponds to the capacitor 21 in Fig. 1 of the drawings. To insure positive electrical connection between the condenser plate 88 and the lower electrode of the expulsion type discharge path described above there is provided a resilient member 89 formed of conducting material which is compressed between the end of the extension 79 of the tubular member 62 and the condenser plate 88.

Although the discharge path within the housing 50 essentially comprises an expulsion arrester, by employing in shunt therewith the silicon carbide granules for gas cooling purposes there is effectively provided a shunt resistor which corresponds to the resistor 15e in Fig. 1 of the drawings since it is an inherent part of the arrester unit. This shunt resistance formed of granular silicon carbide furthermore functions as a valve member in shunt with the expulsion discharge path to by pass surge currents when the surges are insufficient to cause breakdown of the expulsion arrester. The valve action is such as to limit the flow of power follow current.

In view of the detailed description included above, the operation of the protective device 30 in Fig. 2 of the drawings, which has been shown to be basically identical with Fig. 1 of the drawings, will be understood by those skilled in the art. Since the silicon carbide granules which are an inherent part of the arresters employed in the protective device 30 and correspond to the resistors 15e and 16e of Fig. 1 of the drawings, provide a low shunt resistance path no auxiliary resistors such as 19 and 20 may be required, assuming that this shunt resistance path provides the desired resistance for the proper functioning of the reversing network. When properly designed, under normal system voltage conditions the major portion of the system voltage appears across the plates of the capacitor defined by the capacitor electrodes 88 and 41. A minor portion, and preferably less than 10 per cent voltage appears across the discharge paths defined within the housings 50 and 45 whereas about 80 per cent of the system appears across the discharge path 17. In the event of a surge voltage condition however, the potential reversing function of the network comes into effect with the result that a major portion of the surge voltage appears across the discharge paths to initiate a discharge through the expulsion device if the surge is of sufficient magnitude or through the granular silicon carbide in the event of a surge of lower magnitude. In either case the arrester is provided with greatly improved impulse characteristics.

In the event that the inherent shunt resistance of the arrester units is insufficient to give the desired voltage distribution under normal and

surge conditions auxiliary resistors 19 and 20 may readily be provided with the arrangement disclosed in Fig. 4 of the drawings, by providing the filler rods 64 and 65 with cores of resistance material to provide the shunt resistance path of the desired resistance value. In Fig. 4 of the drawings there is illustrated a portion of the sections 31 and 32 of Fig. 2 to illustrate this modification of the invention. The corresponding parts of Fig. 4 are designated by the same reference numerals as in Fig. 2 of the drawings. In this case each of the filler rods designated as 64' and 65' are identical with those in Fig. 2 of the drawings except for the fact that each is provided with a center core 90 formed of a suitable resistance material to provide a predetermined resistance across the ends of the respective filler rods. These cores furthermore extend beyond the ends of the filler rods 64' and 65' as indicated in Fig. 4 of the drawings to provide extensions 90a functioning just like the extensions 68 in the arrangement disclosed in Fig. 3 of the drawings, except that these extensions 90a are formed of resistance material to provide a continuous resistance path through both filler rods 64' and 65'.

In Fig. 4 the expelled arc gases from the expulsion tube 60 are not permitted to be dispersed through the granular silicon carbide, and accordingly, attached to the lower end of the expulsion tube 60 is a tubular member 95 filled with suitable baffling material 96 to aid in cooling the arc gases. A suitable vent to atmosphere may be provided to permit the arc gases to escape after being suitably cooled. Under these conditions obviously no filler material need be provided within the lower housing 43 and the ring casting designated as 47' is constructed so as to seal off the annular space between the expulsion tube 60 and the housing unit 50 from the lower section 32. This space above the ring casting 47 may again be filled with a mass of valve material such as granular silicon carbide to provide a discharge path for surges insufficient to cause a spark over within the expulsion device. The resistance cores 90 of the filler rods 64' and 65' provide an auxiliary resistance corresponding to the element 19 in Fig. 1 which combined with the inherent resistance provided by the granular silicon carbide in shunt therewith determines the effective shunt resistance. In the event that the granular silicon carbide is omitted from Fig. 4 the resistance cores 90 provide substantially the entire shunt resistance.

While certain particular embodiments of the invention have been shown, it will be understood, of course, that the invention is not limited thereto since many modifications may be made, and it is contemplated by the appended claims to cover any such modifications as fall within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. Protective apparatus comprising a pair of terminals across which a relatively low frequency alternating current voltage is normally impressed and across which an abnormal surge voltage may occasionally be impressed, means providing a plurality of discharge paths connected in series between said terminals, auxiliary impedance means connected in circuit with said discharge paths including a resistance shunting each end discharge path and a capacitor connecting each end discharge path across said terminals, said resistance having such a value of impedance relative to the remainder of said auxiliary impedance means

for causing only a minor fraction of said low frequency voltage across said terminals to appear across said end discharge paths.

2. Protective apparatus comprising a pair of terminals adapted to have a normal low frequency alternating current voltage impressed thereacross but occasionally subject to abnormal transient voltages, means providing a plurality of discharge paths connected in series between said terminals, a static impedance means associated with one of said discharge paths comprising one impedance independent of frequency connected across said one discharge path and another impedance dependent on frequency connected in series with said one impedance across said terminals, said one impedance having such a value relative to said other impedance at normal low frequency alternating currents to cause the voltage across said one of said discharge means to comprise a minor fraction of said low frequency alternating current voltage and a major fraction of said abnormal transient voltage.

3. Protective apparatus comprising a pair of terminals adapted to have an alternating system voltage and abnormal transient voltages impressed thereacross, a pair of expulsion type lightning arresters and an isolating gap connected in series between said terminals with said isolating gap connected between said arresters, capacitance means connecting each of said arresters directly across said terminals, and a resistive impedance shunting each of said arresters to coact with said capacitance means in normally maintaining only a minor fraction of the system terminal voltage across each of said arresters, said capacitance means co-acting with said resistive impedances to increase the voltage across each of said arresters to a major fraction of the terminal voltage when a transient voltage appears between said terminals.

4. Protective apparatus comprising a pair of terminals adapted to have an alternating system voltage and fast rising transient voltages impressed thereacross, a pair of expulsion type lightning arresters and an isolating gap connected in series between said terminals with said isolating gap connected between said arresters, capacitance means connecting each of said arresters directly across said terminals, and a resistive impedance shunting each of said arresters, the resistive impedance shunting each arrester being, at the system voltage frequency, a minor fraction of the capacitive impedance of the capacitance means connecting the associated arrester across said terminals and the latter impedance being, at the system voltage frequency, a minor fraction of the capacitive impedance of the associated arrester, whereby a minor fraction of the system terminal voltage normally appears across each of said arresters and a major fraction of said system terminal voltage normally appears across said gap and whereby the decrease in said capacitive impedances relative to said resistive impedances resulting from the appearance of a fast rising transient voltage between said terminals causes a major fraction of the terminal transient voltage to appear across each of said arresters without substantially decreasing the fraction of the terminal voltage appearing across said gap.

5. Protective apparatus comprising a pair of terminals adapted to have an alternating system voltage and steep wave front transient voltages impressed thereacross, means providing

three discharge paths connected in series between said terminals, each of the two end discharge paths having inherent shunt capacitance and shunt resistance, the ohmic reactance of the capacitance of each end discharge path being high relative to the shunt resistance at the system voltage frequency and the reactance of the capacitance of each end discharge path being low relative to the shunt resistance at the rate of voltage change of a fast wave front transient voltage, and a capacitor connecting each of said end discharge paths directly between said terminals, the capacitor associated with each end discharge path having a capacitance exceeding by several times the capacitance of the associated end discharge path, whereby a major fraction of the terminal voltage normally appears across each of said capacitors and the center discharge path, a minor fraction of the terminal voltage normally appears across each of the end discharge paths, and a voltage exceeding a major fraction of a steep wave front transient voltage appearing between said terminals is developed across each of said discharge paths each time a steep wave front transient voltage appears across said terminals.

6. Protective apparatus comprising a pair of terminals adapted to have a normal voltage and abnormal transient voltages impressed thereacross, means providing a plurality of discharge paths connected in series between said terminals, capacitor means for connecting each path directly across said terminals, and a reversing network comprising said discharge paths, capacitor means and static impedance means, said static impedance means being connected in parallel with at least one of said discharge paths whereby said reversing network is responsive to a transient voltage between said terminals to increase from a minor ratio to a major ratio the magnitude of the voltage across each end discharge path as related to the normal voltage across said terminals.

7. The protective system comprising a pair of terminals adapted to have a normal voltage and abnormal transient voltages impressed thereacross, means providing a plurality of discharge paths connected in series between said terminals, means including a resistance shunted across each end discharge path having such a value of impedance relative to the total impedance across said terminals for normal voltage that the normal voltage applied to said terminals is unequally distributed across said paths, and means including said last mentioned means responsive to a transient voltage between said terminals for reducing the inequality between the voltages across said paths.

8. Protective apparatus comprising a pair of terminals adapted to have an alternating system voltage and abnormal transient voltages impressed thereacross, means providing three discharge paths connected in series between said terminals, the two end discharge paths comprising resistive and capacitive impedances in parallel, and capacitance means connecting each of the end discharge paths directly across said terminals, the capacitances of said capacitance means being so proportioned relative to the resistive and capacitive impedances of said end discharge paths that a minor fraction of the terminal voltage normally appears across each of the end discharge paths and a major fraction of a transient voltage appearing between

said terminals is developed across each of the three discharge paths.

9. Protective apparatus comprising a pair of terminals, a pair of current paths bridging said terminals in parallel and each serially including a capacitor and a discharge gap having shunt resistance and capacitance, said paths being oppositely connected between said terminals so that one path includes its capacitor adjacent one terminal and the other path includes its capacitor adjacent the other terminal, and means defining at least one additional gap bridging the junction points between said first-named gaps and their respective associated capacitors.

10. A protective device comprising an insulating supporting structure including a cylindrical housing, a pair of terminals mounted on said structure, an expulsion type discharge path disposed in said housing electrically connected between said terminals, and gas cooling means disposed in said housing for cooling arc gases developed upon operation of said expulsion type discharge path, said gas cooling means also inherently providing a surge discharge path in shunt with said expulsion type discharge path.

11. A protective device comprising an insulating supporting structure including a cylindrical housing, a pair of terminals mounted on said structure, an expulsion type discharge path disposed in said housing electrically connected between said terminals, and gas cooling means comprising a mass of granular silicon carbide disposed in said housing for cooling arc gases developed upon operation of said expulsion type discharge path, said granular silicon carbide being disposed in said housing to provide a surge discharge path in shunt with said expulsion type discharge path.

12. A protective device comprising an insulating supporting structure including a plurality of cylindrical housing sections, a pair of terminals mounted on said structure, an expulsion type discharge path electrically connected to one of said terminals and disposed in one of said housing sections so as to define an annular chamber in said one housing section, means electrically connecting said discharge path to said other terminal, and gas cooling means within said chamber for cooling arc gases developed upon operation of said expulsion type discharge path, said gas cooling means comprising a resistance material providing a path for surge currents in shunt with said expulsion type discharge path.

13. A protective device comprising an insulating supporting structure including a plurality of cylindrical housing sections, a pair of terminals one mounted adjacent each end of said structure, means defining an air gap disposed outside said housing sections between said terminals, an expulsion type discharge path disposed within one of said housing sections and electrically interconnected between one of said terminals and one electrode of said air gap, a conducting member disposed in another of said housing sections, and defining with means connected with the other of said pair of terminals a capacitor, said conducting member comprising one plate of said capacitor, means connecting said one plate of said capacitor to said one electrode of said air gap, and gas cooling means within said housing sections for cooling arc gases developed upon operation of said expulsion type discharge path, said gas cooling means com-

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prising granular silicon carbide and providing a path for voltage surges in shunt with said expulsion type disclosure path.

14. A protective device comprising an insulating supporting structure including a cylindrical housing, a pair of terminals mounted on said structure, an expulsion type discharge path disposed in said housing comprising an expulsion tube and a pair of electrodes disposed therein and electrically connected between said terminals, an arc confining filler rod formed of gas evolving insulating material disposed in said expulsion tube between said terminals, and a resistance core in said filler tube for providing a resistance in shunt with said discharge path.

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