Oct. 25, 1938. N. J. CONRAD 2,134,470

METHOD OF AND MEANS FOR INTERRUPTING CURRENT FLOW

Original Filed Oct. 13, 1932 3 Sheets-Sheet 1

Fig. 1.

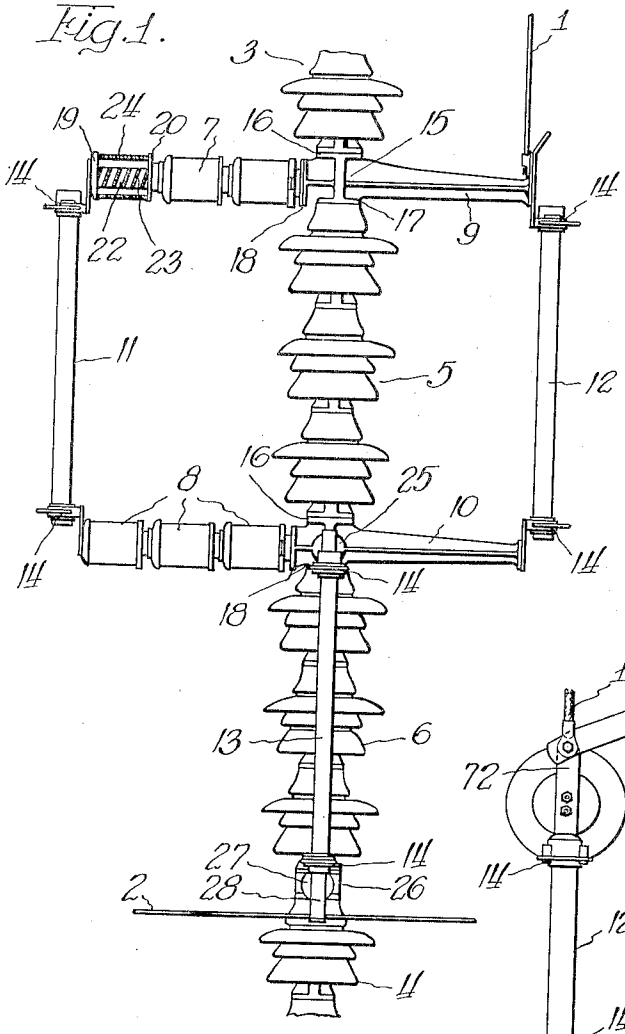


Fig. 3.

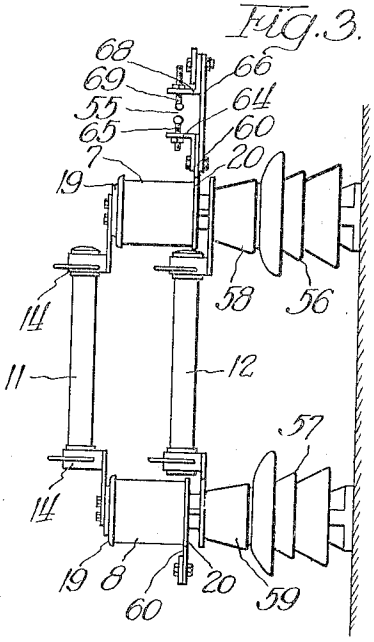


Fig. 4.

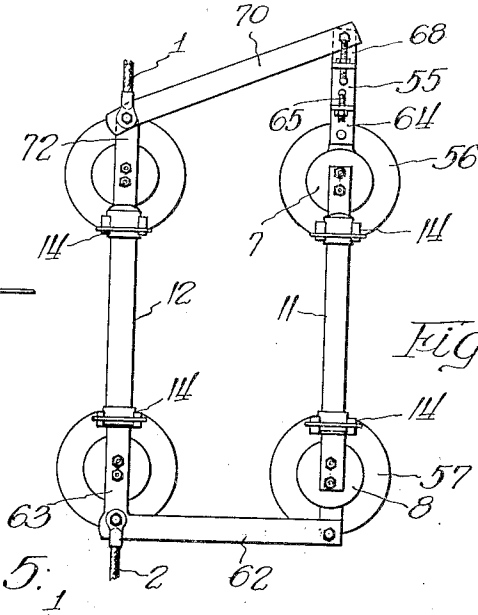


Fig. 2.

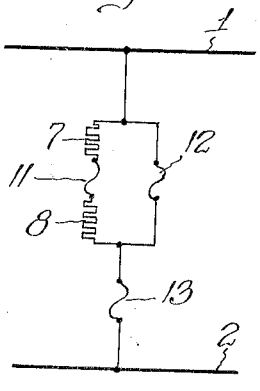
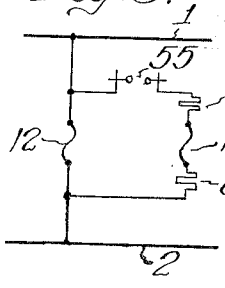


Fig. 5.

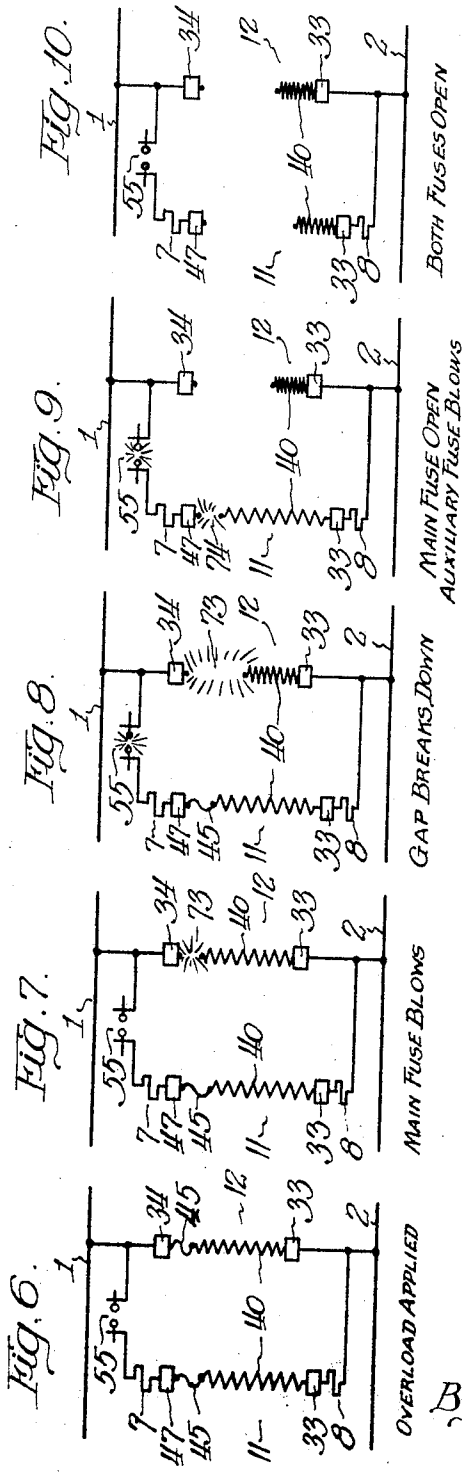


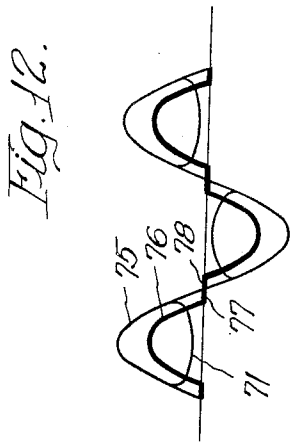
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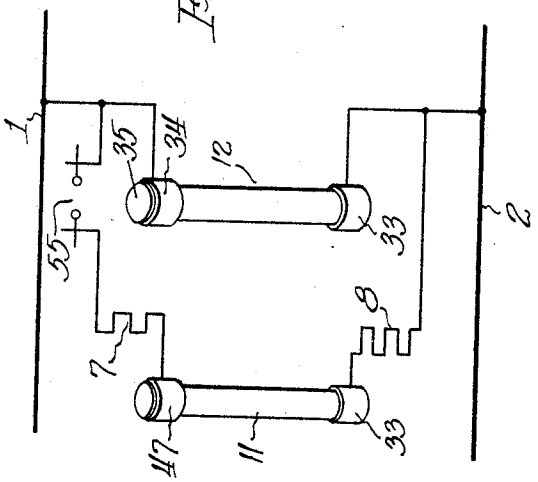
Oct. 25, 1938. N. J. CONRAD 2,134,470

METHOD OF AND MEANS FOR INTERRUPTING CURRENT FLOW

Original Filed Oct. 13, 1932 3 Sheets-Sheet 2







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METHOD OF AND MEANS FOR INTERRUPTING CURRENT FLOW

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Fig. 13.

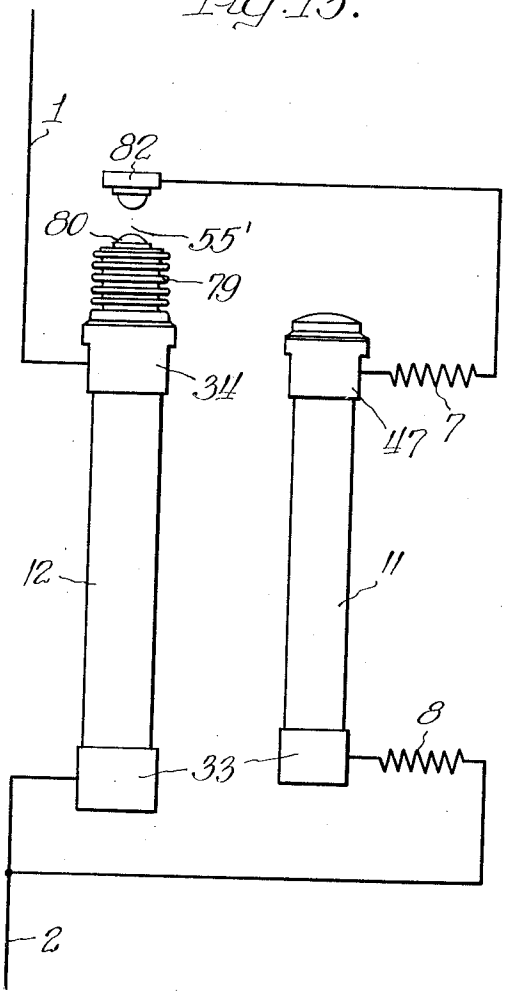
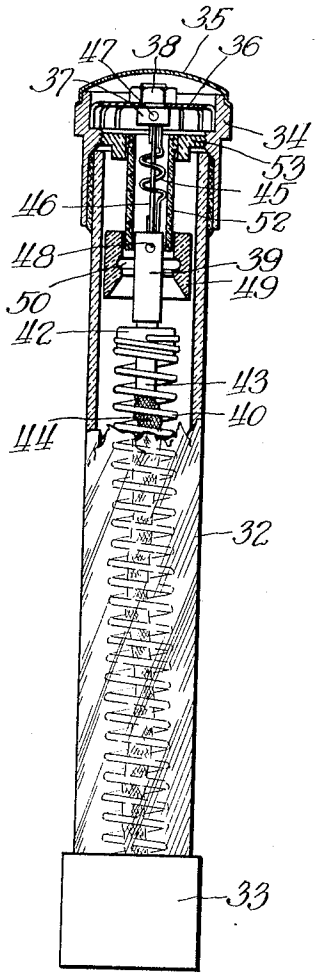


Fig. 14.



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Patented Oct. 25, 1938 2,134,470

UNITED STATES PATENT OFFICE

2,134,470

METHOD OF AND MEANS FOR INTERRUPTING CURRENT FLOW

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Application October 13, 1932, Serial No. 637,593
Renewed April 7, 1937

7 Claims. (Cl. 175—294)

My invention relates to a method of and means for interrupting current flow.

The invention involves the use of a fusible conductor or link which performs the two-fold function of first detecting the presence of excessive current, reacting accordingly, and second, establishing a gap in which conductivity to current flow is destroyed.

The primary object of the invention is to provide a method of and means for increasing the range of interrupting capacity of devices of the foregoing type.

Another object is to increase the reliability or certainty of operation of devices of the aforesaid type.

A further object is to secure increased capacity of interruption and/or certainty of operation, by the use of fusible elements which, of themselves, are of insufficient capability to accomplish the desired purposes. For example, the capacity or characteristics of a power circuit, or the nature of the overload occurring therein, may be such that a fuse of a design or rating suitable for the circuits of a comparable voltage or rating finds difficulty in interrupting the current flow. By the use of my invention certainty of interruption is secured, without change of design or rating of the fuse employed. Hence, with a limited number of standard forms of fuses, automatic circuit interrupters of widely varying ability may be constructed to suit various requirements.

The invention is particularly advantageous in the interruption of very heavy current flow.

According to my invention a main interrupter, which automatically begins the action of mechanically opening the circuit upon the occurrence of overload, is bridged or shunted by a conducting path which is not adapted to carry the rated or normal current flow continuously, as soon as the main interrupter has reached a certain stage where the shunting conductor becomes effective.

According to this invention the main circuit interrupter normally carries all or the major portion of the normal or rated current flow. The auxiliary circuit interrupter normally carries none or only a small part of the normal or rated current flow. These circuit interrupters are herein illustrated as liquid quenched fuses of a kind and type now on the market, but the teachings of the present invention are not to be limited to the use of fuses of that kind or type, for the actions and functions which are secured by my invention may be attained through the use of different forms of fuses, as will be apparent from the detailed specification appearing hereafter.

The current flow which is normally carried by the circuit in which the interrupter of my invention appears, passes mainly or wholly through the main fuse. Upon the occurrence of overload in the circuit the fusible link of the main fuse melts, and an arc tends to form. The spring then separates the terminals between which the arc exists, and there is injected into the arc an arc extinguishing material the effect of which is a tendency to deactivate or deionize the gases which constitute the conducting path, or substance of the arc. The combined effect of lengthening of the arc and deionization or deactivation of the substance of the arc tends to render the conductive path less conductive to the flow of current. In other words, the potential drop across the arc tends to become greater. The auxiliary fuse, which is bridged or shunted around the main fuse, is thereupon subjected to a greater impressed potential and, in the case where a gap is included in the bridge or shunt circuit, the gap is broken down and a conductive path about the main fuse is completed. This conductive path has sufficient capacity, for at least a brief period, to diminish the current flow through the main fuse, whereby the combined action of lengthening the main arc and the deionization of the same results in putting out the main arc and transfer of such current flow as persists to the shunt, or auxiliary circuit. Meanwhile, the separation of the terminals of the main fuse has proceeded to such a point, and the arc extinguishing material has so acted, as to prevent restriking of the arc in the main fuse.

The auxiliary or bridged circuit includes a certain amount of resistance, preferably in the form of a resistance wire such as a nickel, chromium-alloy, commonly sold on the market as "Nichrome" or "Chromel". Such resistance tends to absorb a part of the potential drop and reduces current flow in this circuit to a value which may be easily interrupted by the auxiliary fuse.

Instead of including a gap in the bridged or shunt circuit this circuit may be connected conductively in shunt or bridge with the main circuit at all times, and therefore a certain small part of the normal load current of the circuit may flow through the bridge or shunt circuit, with its included auxiliary fuse, during normal conditions. Upon the occurrence of overload the operation is substantially identical with the foregoing, except that the transfer of current flow does not wait for

the breaking down of the gap as previously described.

In either event, however, the transfer of the main flow of current to the shunt circuit depends upon producing sufficient potential drop across the first fuse to force the current through the shunt circuit. This cannot be produced by the arc alone, inasmuch as an arc, particularly that following the fusion of a metal conductor, generally has the capability of increasing its cross section to the amount required to produce the optimum conditions of current density. The arc, therefore, may be of lower resistance than the conductor which it replaces. It is therefore not possible to divert more current to the shunt circuit than the natural division due to initial resistance would compel unless some means of increasing the potential drop across the arc be provided.

When the two fuses are connected conductively without the intervening gap, the current initially tends to divide in proportion to the resistance of the circuits. When the resistance of the shunt circuit is low, this division of current may be sufficient to give great assistance to the first or main fuse, particularly on a heavy overload.

I conceive that in the operation of fuses of this character the projection or injection of the arc extinguishing material upon or into the arc acts to deactivate the ionized or activated gases which conduct the current. The rate of deactivation or deionization is high, and no doubt, in the drawing of an arc in a fuse of this type, there is always the tendency to extinguish the arc quickly, but there appears to be a reactive, or after-voltage created by sudden interruption which builds up to a relatively higher value than the potential drop across the arc, tending to reestablish the same. This may be accounted for by the fact that upon the cessation of current flow through the conductors of the circuit the potential drop which is due to the I. R. loss immediately ceases, with the result that live potential on the fuse terminals rises very sharply, tending again to reestablish the arc. The presence of the shunt or bridge circuit and the continuing current flow therethrough holds down this recrudescent voltage and prevents reestablishment of the arc at the terminals of the main fuse. The result is that the current flow, instead of being sharply interrupted and again spilling over, is reduced in value to a quantum which is easily interrupted by the auxiliary fuse or interrupter.

The action is automatic. The separation of the main fuse terminals tends to increase, perhaps not greatly, but very definitely, the potential drop across the main fuse terminals. The potential across the main fuse terminals is, of course, limited by the I. R. drop through the shunt circuit. This increase in potential drop forces the current through the auxiliary fuse in the shunt circuit. The shunt circuit has a certain thermal capacity which permits the establishment of a large enough current flow to permit the main fuse to open its circuit definitely and completely. The blowing of the auxiliary fuse takes sufficient time to allow the main arc to be extinguished. Then the progressive action of separating the auxiliary fuse terminals, injecting deactivating or deionizing arc extinguishing materials into the arc all cooperate to reduce and finally stop the flow of current in the auxiliary or shunt circuit. While the operations are described as occurring successively, the action as a whole is extremely rapid.

Now, in order to acquaint those skilled in the art with the manner of constructing and operating a device embodying my invention, I shall describe, in connection with the accompanying drawings, a specific embodiment of the same and the actions involved therein.

In the drawings:

Figure 1 is a side elevational view of a circuit interrupter of my invention;

Figure 2 is a diagram of the same;

Figure 3 is a side elevational view of another embodiment of my invention;

Figure 4 is a front elevational view of the same;

Figure 5 is a diagram of the circuit of the device shown in Figures 3 and 4;

Figures 6, 7, 8, 9 and 10 are diagrams illustrating successive actions in the operation of the device shown in Figures 3 and 4;

Figure 11 is a diagram illustrating another embodiment in which the gap is subject to the action of the gases evolved from the arc in the main fuse;

Figure 12 is a diagram explaining the effects of the gap in the circuit of the embodiments shown in Figures 3 to 11;

Figure 13 is a diagrammatic illustration of another embodiment in which the pressure in the main fuse switches in the auxiliary fuse; and

Figure 14 is a side elevational view, partly in section, of one form of fuse which may be employed in the practice of my invention.

Referring first to Figures 1 and 2, the circuit interrupter is indicated between conductors 1 and 2. This circuit interrupter includes a suitable insulated support comprising, as here shown, four stacks of insulators, namely, a top stack 3 which is connected to a suitable support above (not shown), the bottom stack 4 which is likewise connected to a suitable support below (not shown) and two intermediate stacks 5 and 6 which are mounted between stacks 3 and 4. The stacks 3 and 4 are of the same insulating value and are suitable for 220 k. v. The stacks 5 and 6 together are the equivalent, in insulating value, of one of the stacks 3—4, inasmuch as the voltage is divided between them.

Three liquid quenched fuses 11, 12 and 13 are employed, the fuse 11 being connected through the resistors 7 and 8 in parallel with the fuse 12, conducting arms 9 and 10 being provided for supporting the fuse 12 at the ends of the insulator stack 5.

Suitable fuse clips, indicated generally at 14 throughout, support the metallic terminals or ferrules of the fuses in well known manner, these fuse clips being shown in Conrad Patent No. 1,665,446, of April 10, 1928. The inner end of the arm 9 constitutes a metallic fitting 15 and provides clamping flanges at 16 and 17 for the adjacent insulator stacks 3 and 5, respectively, and provides also a clamping flange 18 for the resistance units, three of which are shown as constituting the resistance 7. These units are of the type shown in my copending application, Serial No. 244,015, filed December 31, 1927, and constitute metallic end members such as 19 and 20, between which a porcelain or like core 22 is supported with a coil of nickel-chromium-alloy wire 23, or its equivalent, wound upon the core 22 and connected to the end pieces 19 and 20. A glass enclosing sleeve 24 is secured between the metallic end members 19 and 20, whereby an enclosed resistor, protected from atmospheric and outside influences, is provided. Obviously, other forms of resistance units or of resistances may be em-

ployed. The resistance 8 is composed of similar units.

The inner end of the arm 10 is formed in a manner similar to the fitting 15. There is provided, however, in addition, an extension terminating in a clamping flange 25 to support the terminal of the spring clip 14 at the upper end of fuse 13. A metallic fitting 26 is supported between insulator stacks 4 and 6 and it provides a support for the lower fuse clip 14 of the fuse 13 through the flange 27. The line wire 2 is connected to the terminal 28 of the fuse clip 14 at the lower end of fuse 13. In a similar manner line wire 1 is connected to the terminal of the fuse clip 14 at the upper end of fuse 12. The flanges 25 and 27 which support the clips for the fuse 13 are mounted upon extended arms similar to the arms 9 and 10 so as to support the fuse 13 away from the insulator stack 6, substantially as the fuse 12 is supported away from the stack 5. The connections for the above are shown in Figure 2.

The proportions of the fuses may, for example, be as follows:

Fuse 11, ½ ampere rating; fuse 12, 25 ampere rating, and fuse 13, 75 ampere rating, with the resistance of the resistors 7 and 8 consisting of 55.5 ohms.

Another example of proportioning, for a different circuit, is as follows:

Fuse 11, 5 amperes rating; fuse 12, 100 amperes rating; fuse 13, 100 amperes rating, with a resistance, in series, of 55.5 ohms.

Another example which I have employed successfully is:

Fuse 11, 5 amperes rating; fuse 12, 100 amperes rating; fuse 13, 200 amperes rating, with a resistance, in series with the fuse 11, of 4 ohms.

The desideratum in this case is to keep the rating of the fuse 11 low and include sufficient resistance that for normal current flow or rated capacity of the circuit the fuse 11, which is constantly in circuit, will not be melted. The fuse 12 is intended to operate at a predetermined value of fault current and the fuse 13 is intended to operate at the same time as the fuse 12. During short circuit the flow of current is interrupted in fuse 12 before the arc in fuse 13 is extinguished. The arc in fuse 13 is extinguished at the same time as the arc is extinguished in the fuse 11.

In the present embodiment the fuses 11, 12 and 13 are of only 110 k. v. rating, hence the addition of the fuse 13 in series with the fuses 11 and 12, for 220 k. v. service.

The fuses 11, 12 and 13 are preferably well known fuses now on the market. A suitable construction of fuse is shown in Figure 14. With various modifications the fuse of Figure 14 is disclosed in my copending application, Serial No. 470,416, filed July 24, 1930 now Patent No. 2,091,430. A suitable fuse for this purpose is also disclosed in my prior patents, No. 1,743,322 of January 14, 1930, and No. 1,834,578 of December 1, 1931. A sufficient description of such fuses and their operation is contained in the said prior patents, and a brief description of the fuse shown in Figure 14 will suffice for present purposes.

The fuse comprises a glass sleeve 32 having metallic terminals at the ends thereof, the lower terminal 33 being in the form of a closed cap cemented on the glass sleeve, and the upper terminal 34 being in the form of a ferrule or sleeve likewise cemented on the upper end of the glass sleeve 32. The upper ferrule 34 is closed releasably by a cap 35 which, in case of excessive pressure and upon heavy blowing of the fuse, is adapted to be removed by the internal pressure. The sleeve or ferrule 34 is counterbored to provide a shoulder for mounting the upper terminal plate 36, which has slotted spring fingers pressing radially against the walls of the counterbore and axially against the shoulder formed by the counterbore. A terminal stud 37 has a threaded shank extending through the plate 36 and it is held in place by the nut 38 threaded on said shank. A cooperating movable terminal 39 is mounted upon the upper end of the tension spring 40 through the medium of a spring head 42, to which the spring 40 is anchored. This spring head 42 has a threaded coupling with the terminal 39 and also has a socket 43 to which the flexible cable 44 is firmly anchored, electrically and mechanically. The cable 44 shunts the spring 40. A silver fuse wire 45 formed in the shape of a helix with the ends straightened out axially is connected between the movable terminal 39 and the stationary terminal 37. A high tensile strength wire, preferably of nickel-chromium-alloy composition, indicated at 46, has loops formed at each end and these loops are engaged by pins 47 and 48 in the terminals 37 and 39, respectively. The ends of the fusible link 45 are mechanically anchored in slots in the terminals 37 and 39 to give a good mechanical and electrical anchorage, the edges of the slots being riveted or battered over to grip the fuse wire along a considerable length. A liquid director 49 is supported on radially extending arms 50 upon the terminal 39. An explosion chamber is provided about the fusible element by means of the sleeve 52, the upper end of which is pressed into or otherwise anchored in the barrier plate 53, which barrier plate is threaded into the bore of the ferrule 34 to form a transverse wall. The upper end of the liquid director 49 embraces loosely but fairly closely the upper end of the explosion chamber sleeve 52. The glass sleeve is filled with arc extinguishing liquid to a point preferably just above the liquid director 49.

In operation, upon the occurrence of overload the fuse element 45 first melts, throwing the load over upon the high tensile strength wire 46, termed the strain wire. Thereupon the strain wire melts and looses the coil spring 40 to retract the terminal 39. At the same time arc extinguishing liquid is thrown into the explosion chamber 52, this stream of liquid being rapidly vaporized and to some extent broken down, and discharged upwardly into the chamber formed above the barrier plate 53. Here the vapors and gases are condensed and chilled, and if the arc is interrupted before the pressure rises to too high a value the operation of interrupting current flow occurs without blowing of the cap 35. If the operation is severe, as in a short circuit on a system of large capacity, the pressure in the fuse may rise to a value high enough to blow off the cap 35. The terminal plate 36 and terminal 37 may then also be expelled, and as the terminal 39 and liquid director 49 descend, vapors and gases of high pressure and very high velocity are expelled through the explosion chamber, tending to deionize or deactivate the gases carrying the arc, to put out the same.

The operation of the interrupter shown in Figures 1 and 2 is as follows:

Normally the main current flow is through the fuses 12 and 13 in series, with a small fraction of the current flowing through the fuse 11 and resistances 7 and 8, which are connected in shunt

of the fuse 12. Upon the occurrence of overload there is a tendency for the current to increase in proportion through both branches, including the fuses 11 and 12. However, the fuse 12 is selected in rating so as to be melted before the fuse 11 is melted. Upon melting of the fuse 12 it proceeds to lengthen the gap and inject arc extinguished material, this material being the liquid in the fuse heretofore described. It may be carbon tetrachloride, or any of the liquids disclosed in Reissue Patent No. 14,897 of June 22, 1920, or any equivalent material, solid, liquid or gaseous, for performing the same function, namely, of deionizing and extinguishing the arc. It is desirable that there be interposed in the gap formed by melting of the fuse 12 a medium of high dielectric value. As the length of the arc is increased and the tendency to extinguish the same makes it more difficult for the flow of electric current to continue through the fuse 12, the proportions of the parallel circuits change, that is, the potential drop across the fuse 12 increases, tending to throw more current through the fuse 11. If, at the same time, the current flow is great enough to melt the fuse 13, it begins its operation almost immediately after the start of operations of the fuse 12.

As soon as the current flow through the fuse 11 increases to a point where the fusible link thereof melts, the fuse 11 begins to separate the terminals and project arc extinguishing material into the arc. However, the transfer of current flow from the circuit of the fuse 12 to the circuit of the fuse 11 allows the arc to be extinguished in the fuse 12, and not become reestablished. The separation of the fuse terminals in the fuse unit 12 is accompanied by the interposition of the insulating liquid, which prevents any restriking of the arc in fuse unit 12 when the current flow is finally and completely interrupted in fuse unit 11, or any time prior thereto. Thereupon, with the resistances 7—8 in circuit, the current flow is diminished to a value which may easily be interrupted by the combined action of the fuses 11 and 13. Clearing the arc at either fuse 11 or 13 is effective to interrupt current flow without reestablishment of the arc, since the two fuses are acting in series, and since they are both in series with resistances 7—8.

The flow of current initially divides between the two fuses 11 and 12, dividing in proportion to the resistance of the parallel circuits in which they are included. When a sudden increase of potential comes upon the terminals of the parallel circuit, as by a short circuit, the tendency of the current flow is to increase in the same proportion, since the resistance of the circuits remains substantially the same. The initial division of current is valuable for relieving the main fuse particularly on heavy overload.

The main fuse 12 invariably melts first. When the next cyclical current zero arrives, the arc in this fuse 12 goes out. Now the fuse 11 protects the fuse from restriking an arc upon the next potential wave, even though this is a recovery voltage wave of abnormal height, because the potential across the gap of main fuse 12 cannot rise above the IR drop in the auxiliary fuse 11, even with resistance in said auxiliary circuit. It will thereby have an interval of time to become completely deionized and to present a much higher dielectric strength by the injection of arc extinguishing material in the gap, and by separation of the terminals. Meanwhile, assume that as soon as the arc in fuse 12 has ceased at cyclical current zero the next wave of current flow through fuse 11 produces an arc by melting of the fuse wire. Then the fuse 11 proceeds to inject arc extinguishing material to deionize the arc and at some succeeding current zero the arc is finally extinguished in said fuse 11. Then the real stress of full line voltage comes upon both fuses. However, no arc can be reestablished at the main fuse 12, because it has had time to perform its static disconnecting function, i. e., interpose an adequate dielectric medium and separate its terminals while the second fuse is stil in its active or kinetic condition of discharging a gaseous arc extinguishing medium. Also due to the resistance in the circuit of fuse 11, with consequent reduction in current flow, the recovery voltage will not be as violent as it would be without much resistance. Also the lag or phase angle is improved, and the second fuse has much less severe duty than would be the case if a single fuse were called upon to extinguish the full overload.

Thus the second fuse provides a certain timing function for the first fuse within which the first fuse may put itself in condition to withstand the reapplication of full line voltage. In brief, the first fuse initially protects the second fuse, and then the second fuse protects the first fuse in a unique manner not accomplished in prior devices. This cooperation also prevails in the construction when a gap is interposed in the auxiliary or shunt circuit.

Where the voltage rating of the fuses 11 and 12 is sufficient to withstand the full voltage between conductors 1 and 2, the fuse 13 may be dispensed with, as its function in the present organization is largely to add sufficient dielectric gap to make up for 220 k. v.

In the embodiment shown in Figures 3 and 4, the main fuse 12 is connected between the conductors 1 and 2 and the auxiliary fuse 11 is connected in shunt of the fuse 12 with the air gap 55 in series. Resistance units 7 and 8, of a form similar to those previously described in connection with Figure 1, are mounted upon the insulators 56 and 57, the fuse clips 14—14 for the fuse 11 being connected to the metallic members 19—19 of the units 7 and 8. The corresponding fittings 20—20 at the inner ends of the resistance units 7 and 8 are clamped to the metallic insulator caps 58 and 59. These members 20—20 are provided with extending terminals 60—60. The terminal 60 of the resistance unit 8 is connected by a copper bar conductor 62 to the terminal 63, which terminal forms an extension of the fuse clip 14 at the lower end of fuse 12. The terminal 20 at the base of the resistance unit 7 has connected thereto a bracket 64 which supports a threaded rod 65, forming one terminal of the air gap 55. A bar of insulating material 66 is clamped on the opposite side of the terminal 20 and it forms a support for a corresponding bracket 68 carying a threaded rod 69 for the other electrode of the air gap 55. These terminals 65 and 69 are threaded in the corresponding brackets 68 and 64, respectively, and after being adjusted to the proper sparking distance between them are fixed in place by lock nuts or the like. The bracket 68 has a flat bar conductor 70 clamped thereto, the opposite end of the bar 70 being fastened mechanically and electrically to the terminal 72, which forms an extension of the fuse clip 14 at the upper end of the fuse 12. Thus, as will be seen from the above description, and as shown diagrammatically in Figure 5, the

fuse 11 is connected in series with the resistances 7 and 8 and air gap 55 in a circuit which forms a shunt around fuse 12. The air gap is adjusted to such a value that the voltage across the shunt circuit will not break down the gap until after the fuse 12 has begun to draw an arc.

In the diagrams of Figures 6 to 10, inclusive, I have indicated the operation of the device shown in Figures 3, 4 and 5. The fuses 11 and 12 may be of a type shown in the aforesaid patents and patent application. The fusible links 45 of the fuses 11 and 12 may be of the relative proportions heretofore indicated in connection with fuses 11 and 12 in the embodiment of Figure 1, and the resistance values of the resistors 7 and 8 may likewise be of the character previously referred to. The spark gap 55 is set to such a breakdown value as will prevent any flow of current through the shunt circuit during normal operation but will definitely be broken down upon the blowing of the main fuse 12.

There is another distinct virtue in the use of the spark gap, or air gap 55, for it introduces a feature of very considerable value, as illustrated in connection with Figure 12, namely, of preventing any current flow through the fuse 11 until the succeeding voltage wave has risen to a value great enough to break down the gap 55. This assists in securing the desired timing of operations.

The spark gap 55 may be totally enclosed and may, if desired, be provided with a dielectric of greater strength than air between the electrodes. For example, it may be placed in an insulating liquid such as oil, or any of the arc extinguishing liquids above referred to, or their equivalents.

The operation of the device shown in Figures 3, 4 and 5 is as follows:

Assuming that the proportioning of the fuses 11 and 12, resistances 7 and 8, and the spark gap 55 have been properly selected, and this, as above explained, may be varied to secure the desired cooperation of the elements and the timing of the same, the occurrence of overload upon the device causes the current flow in the fuse 12 to rise and melt the element 45 of main fuse 12. An arc thereupon forms and the spring 40 of the fuse 12 draws the terminal down into the liquid and projects liquid into the arc space, as heretofore described, in connection with Figure 14. The action of lengthening the arc (see Figure 7) increases the potential drop between the fuse terminals 33 and 34. This imposes a greater E. M. F. upon the terminals of the gap 55 and, as shown in Figure 8, while the arc 73 persists, the gap 55 is broken down and current begins to flow through the fuse 11. As soon as the conducting path in shunt of the arc 73 is established the current subdivides and, together with the lengthening of the arc 73 and the projection of arc extinguishing material into the same, the arc 73 is extinguished as indicated in Figure 9, current flow persisting through the shunt circuit. The fuse terminals of the main fuse having been so far separated that the arc will not reform between them, all of the current flow now passes through the fuse 11. This, however, is limited, first by the resistors 7 and 8, next, by the spark gap 55, and finally, by the arc 74 which has now formed by blowing of the fuse link 45 of the auxiliary fuse 11.

With the limiting resistances in series with the fuse 11, current flow has been gradually reduced and the fuse 11 therefore finds no great difficulty in extinguishing the arc and in stopping current flow, the terminals of the fuse 11, like the terminals of fuse 12, being separated by so great a distance as to prevent restriking of the arc.

During the operation of clearing a circuit through the fuse 11 the air gap 55 has a useful function in giving the fuse 11 a longer time period, when the current reverses, to clear the circuit and prevent resumption of current flow. This is illustrated in exaggerated form in Figure 12, where the curve 75 represents a sine wave of impressed voltage and the curve 76 represents the current flowing through the fuse 11 as modified by the air gap 55. The curve 71 illustrates in exaggerated form the voltage across the gap 55. As the current flow passes through zero, assuming in this case that the current flow is strictly in phase with the impressed voltage, that is, in phase with the curve 75, the current flow through the shunt circuit, including the fuse 11, tends to drop to zero because of the effect of the gap 55. The arc tends to go out at the gap 55, as the current flow in the shunt circuit approaches zero at each reversal. This is due to the deionizing effect of the surrounding medium (in this case air) upon the arc of the gap 55. As the arc goes out the voltage across the gap 55 rises, as indicated by curve 71. In other words, the arc tends to go out as the current flow goes through zero. This is represented by the flat part 77 of the heavy curve 76 in Figure 12. Then, after an appreciable period of time while the voltage is rising, tending to reverse current flow, the gap is not sufficiently conductive to permit current to flow, with the result that for a short period of time, represented by the flat part 78 of the curve 76, current does not flow through the shunt circuit. Meanwhile, the voltage on the gap has risen, as shown by curve 71. Due to this lengthened time of zero current flow it is much easier to deionize the arc in the fuse 11 and extinguish the arc than would be the case if the gap 55 were not present. This action may be promoted by any preferred deionizing material at the gap 55, as above explained.

A great advantage of the liquid arc extinguishing material is that it conforms itself to every position of the fuse terminals, tending to close into the space in which the arc is formed. Obviously, a gas under pressure has the same ability. The liquid arc extinguishing material evolves gas by both vaporization and by decomposition under the heat of the arc, and this gas, together with the liquid, tends to break up and deactivate the substance of the arc so that when the current flow passes through zero value and reverses the conductivity of the space previously occupied by the arc is so low that the voltage cannot restrike or again form the arc.

The present device, namely, the device of Figures 3 and 4, has the same advantage as previously explained of reducing the current flow before stopping the same, whereby the reestablished or recrudescent voltage rise does not reach so high a value as to break down the dielectric and again establish the arc.

The devices shown in Figures 3 and 4 automatically transfer the current flow from the main fuse to the shunt circuit, including the gap and auxiliary fuse 11, as the voltage drop across the main fuse increases during the operation of clearing the main fuse.

In both the embodiment of Figure 1 and of Figures 3 and 4 the rated capacity of the fuse 11 is small as compared with the rated capacity of

the fuse 12. In one example above given the rated capacity of the main fuse 12 is from 20 to 40 times the rated capacity of the auxiliary fuse 11. The fuse 12 being of larger rating has a heavier fusible link, a larger diameter glass sleeve, more arc extinguishing material, and is of heavier construction throughout. The fuse 11, on the contrary, has a very small mass of metal in the fusible link, the sleeve is of smaller diameter and the construction throughout is less expensive and less massive than the fuse 12. There is a distinct advantage in the use of a small amount of metal in the fusible link 11, inasmuch as metallic vapor greatly assists in maintenance of an arc.

If it were possible to make the fuse without any metallic vapor that would obviously be highly desirable, but since sufficient conductivity must be present to carry the normal or rated current flow, the practical limit of reducing the mass of metal in the fusible link is quickly reached. I provide a silver fuse wire. Silver has a very high conductivity and has the further advantage of being relatively free from corrosion. By the use of silver I have decreased the mass of metal in the gap to the minimum for the required conductivity. By transferring the current flow from the circuit of the fuse 12, which circuit has very low resistance, to the circuit of the fuse 11, which has appreciable resistance, with less metal in the arc which results, the duty imposed on the fuse 11 is much less severe than the duty which would be imposed upon the fuse 12 if it were called upon alone to interrupt the current flow.

I may carry the method of interruption through more than the two steps, as, for example, by connecting a fuse of even less capacity and greater circuit resistance in shunt with the fuse 11, with or without an additional air gap in series with such third fuse and its resistance. It can be seen, therefore, that I have provided a progressive system of increasing the resistance of the circuit and thereby decreasing the current which must be interrupted and simultaneously decreasing the metal of the arc which results upon blowing of the auxiliary fuse or fuses.

The air gap may be subjected to the ionized gases released upon blowing of the fuse 12. Thus, in the embodiment of Figure 11, I have placed the gap 55 in such position with respect to the main fuse 12 that when the cap 35 blows off the upper terminal 34 the arc gases will ionize the gap 55 and more quickly switch in the shunt circuit. The gap 55 may be made large enough that it will require blowing of the gases from the fuse 12 thereupon before the shunt circuit is switched in. In other words, if the overload can be handled by the fuse 12 without blowing of the cap 35, that is, if the violence is not so great as to require the use of the auxiliary fuse 11, it will not be called into play. Therefore it will be seen that I have provided a selective method of including the shunt circuit only when the character of the overload is such as to require an action greater than can safely be expected from the fuse 12.

In Figure 13 the fuse 12 is provided with an expansible member 79 which carries a contact 80 adapted to cooperate with the contact 82, forming the terminals of the gap 55'. In this case the pressure developed in the fuse 12 switches in the shunt circuit by either bringing the contacts 80 and 82 into engagement or bringing them near enough to each other that the voltage drop across the gap will break the gap down and switch in the shunt circuit.

Obviously I may build the two fuses into a common structure, and by employing an auxiliary contact I may cause the motion of the spring 40 of the main fuse 12 to switch in the shunt circuit when the terminals of the fusible link of the main fuse have been separated a predetermined distance. That is to say, by the mechanical separation of the main fuse terminals, the shunt circuit with the resistances and auxiliary fuse may be automatically connected.

Instead of having the resistances 7—8 in separate parts they may be combined into one unit, and also they may be embodied in the fuse construction itself, as is shown in Figure 15 of Patent No. 1,215,722, issued February 13, 1917.

I do not intend to be limited to the specific details which I have above described. I do not wish to limit the arc extinguishing material, nor the specific form of the fuses, to the forms above described for the reason that those skilled in the art will at once appreciate that the method which I have set forth and the mode of operation which I have explained may be embodied in forms structurally quite different but mechanically the equivalent of the aforesaid.

I claim:

1. The method of interrupting current flow through a circuit including a fusible link, which comprises fusing the link and establishing an arc, then progressively increasing the length of the arc and simultaneously injecting an arc extinguishing medium into the arc to deionize the arc and by said lengthening and deionizing of the arc increasing the potential drop across the arc, thereafter extinguishing said arc, substituting for the arc in the circuit a fluid dielectric of a strength greater than air to resist breakdown by the circuit voltage, by increase of potential drop across said arc breaking down a gap in shunt of said arc, creating an arc in series with said gap, then progressively increasing the length of said second arc and simultaneously injecting arc extinguishing medium into the second arc to deionize the second arc and thereby extinguish the same.

2. In a circuit interrupter, the combination of a pair of circuit terminals, fusible links having terminals connected in parallel between said terminals, one of said links being of a current carrying capacity lower than the other, means including an arc gap connected in series with said link of lower capacity to delay the fusing of the same upon overload being applied to said terminals, and spring means for separating the fuse terminals of said fusible link of higher capacity to prevent the restoration of potential in the circuit following interruption of current by the link of lower capacity from breaking down the gap at the terminals of the fusible link of higher capacity.

3. An automatic alternating current interrupter for connection in an electric circuit and through which current normally flows comprising, in combination, a pair of terminal conductors, a pair of fusible elements connected in parallel between said terminal conductors, and means independent of the fusible elements for determining the order in which they are fused by excess of current flow in said electric circuit, said means comprising a resistor connected in series circuit relation with only one of said fusible elements and an arc gap in series circuit relation with said resistor.

4. An automatic alternating current interrupter for connection in an electric circuit and

through which current normally flows comprising, in combination, a pair of terminal conductors, a pair of fusible elements connected in parallel between said terminal conductors, and means independent of the fusible elements for determining the order in which they are fused by excess of current flow in said electric circuit, said means including an arc gap connected in series circuit relation with only one of said fusible elements.

5. An automatic alternating current interrupter for connection in an electric circuit and through which current normally flows comprising, in combination, a pair of terminals, a first circuit connecting said terminals, a second circuit parallel to the first circuit and also connecting said terminals, fusible links of different current carrying capacity in said circuits, and a gap connected in series circuit relation with the fusible link of lower current carrying capacity whereby no current is carried thereby until the fusible link of higher current carrying capacity is blown by excess of current flow in said electric circuit.

6. An automatic alternating current interrupter for connection in an electric circuit and through which current normally flows comprising, in combination, a first fuse, a second fuse of small capacity relative to the first fuse, a resistance element, means including a spark gap connecting said resistance element and said second fuse in series circuit relation with each other and in parallel circuit relation with said first fuse whereby no current is carried by said second fuse until said first fuse is blown by excess of current flow in said electric circuit, and means for automatically increasing the voltage breakdown value of said first fuse after it operates so that subsequent interruption of current flow by said second fuse does not result in reestablishment of current flow through said first fuse.

7. A circuit control device comprising, in combination, a pair of circuit terminals, a first circuit interconnecting said terminals and including an automatic circuit interrupter adapted to carry the entire circuit current under normal operating conditions and to automatically open said first circuit under predetermined overload conditions, and a second circuit interconnecting said terminals including a permanent arc gap and a fusible element in series circuit relation, said arc gap being adapted to prevent the flow of current through said fusible element under normal operating conditions until the arc gap is broken down on operation of said automatic circuit interrupter in said first circuit.

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