

Feb. 11, 1958

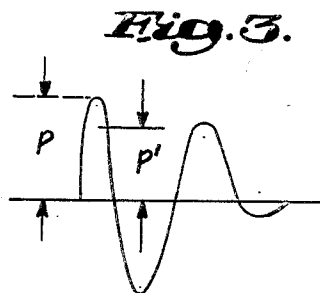
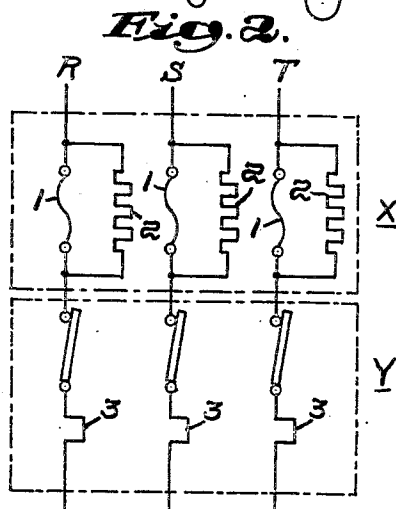
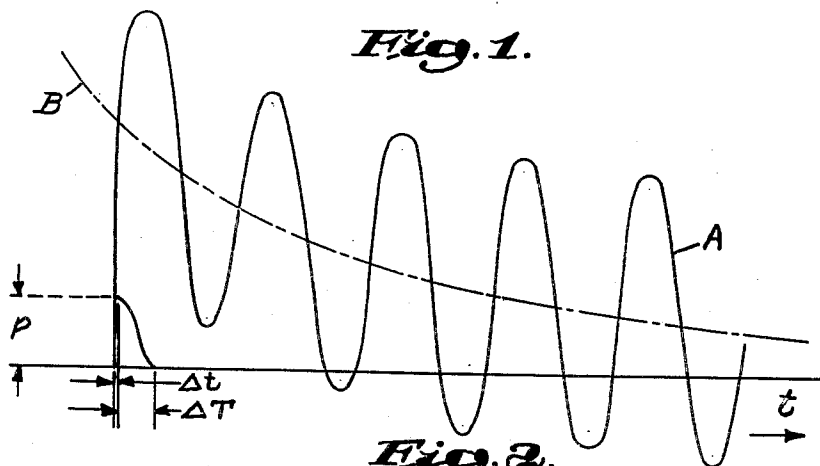
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2,823,338

COORDINATED COMBINATIONS OF CURRENT-LIMITING
FUSES AND CIRCUIT INTERRUPTERS

Filed July 29, 1953

2 Sheets-Sheet 1



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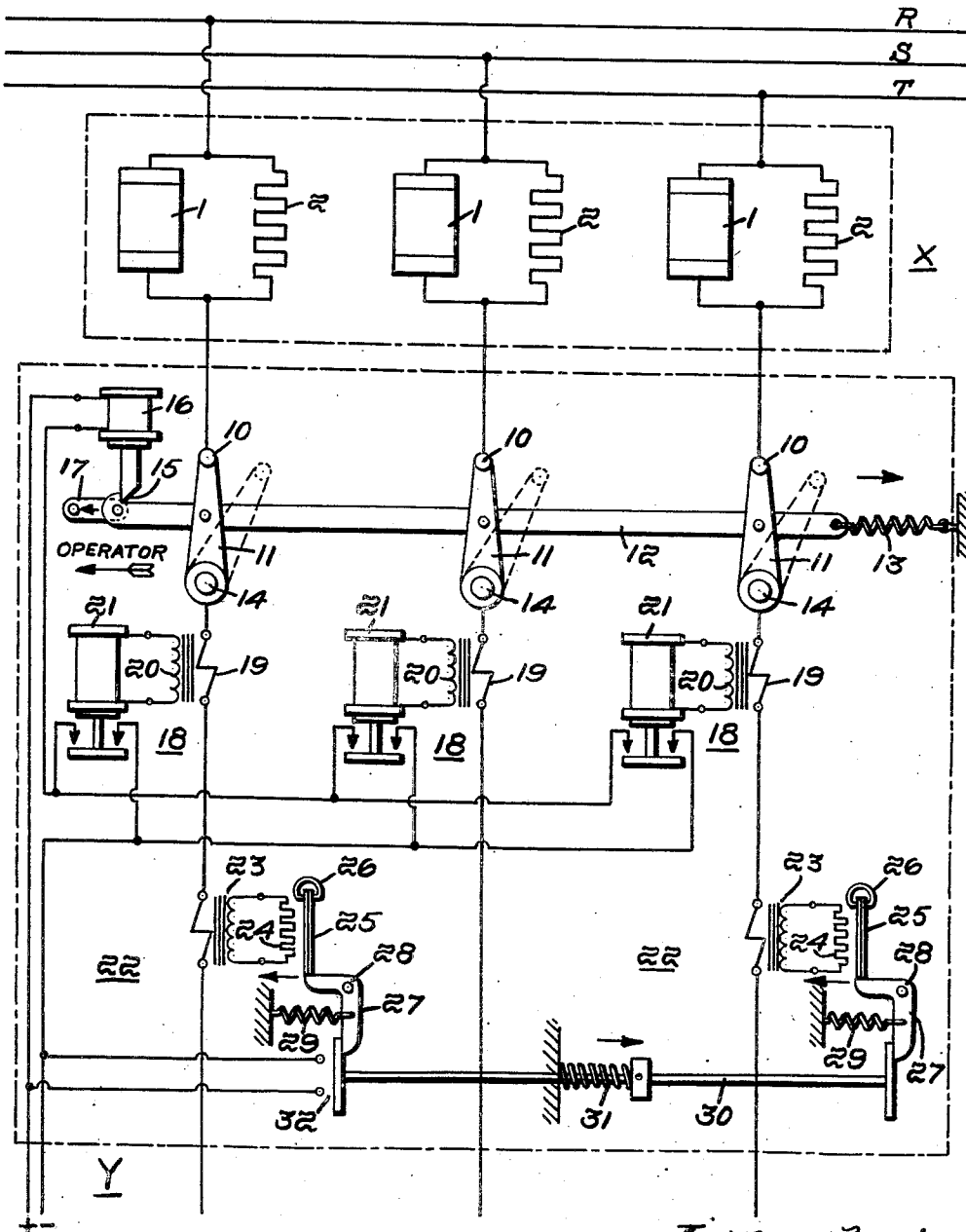
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2 Sheets-Sheet 2

Fig. 4.



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COORDINATED COMBINATIONS OF CURRENT-LIMITING FUSES AND CIRCUIT INTERRUPTERS

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7 Claims. (Cl. 317—37)

This invention relates to coordinated combinations of current-limiting fuses and automatic circuit interrupters of the type comprising pairs of cooperating separable contacts.

It is one object of this invention to provide a combination of a current-limiting fuse and of an automatic circuit interrupter of the aforementioned type wherein the task of interrupting fault currents tending to be of relatively large magnitude is effected in two consecutive steps of which the first is performed by the current-limiting fuse and the second by the interrupter.

Another object of the invention is to provide a series arrangement including a current-limiting fuse and an automatic circuit interrupter of the aforementioned type wherein load currents and relatively small overload currents are being interrupted solely by the action of the interrupter and wherein relatively high overload currents and short-circuit currents are being interrupted by the joint action of the current-limiting fuse and of the interrupter, a current-limiting impedance being arranged in series with the interrupter when interrupting currents tending to rise to high peak values.

Another object of the invention is to provide a combination of a current-limiting fuse and of an automatic circuit interrupter of the aforementioned type wherein the interrupting task imposed upon the current-limiting fuse is easier than in prior art combinations comprising a current-limiting fuse and an interrupter serially arranged in an electric circuit.

Still another object of the invention is to provide protection against single-phasing upon blowing of a current-limiting fuse in multiphase circuits comprising a combination of current-limiting fuses and of a multipolar automatic circuit interrupter serially arranged in the electric multiphase circuit.

Still another object of the invention is to provide an arrangement including a multipolar automatic circuit interrupter of the aforementioned type wherein the tripping devices of the interrupter cause separation of the contacts of all the poles thereof upon blowing of but one of a plurality of current-limiting fuses arranged in series with the interrupter in a multiphase circuit.

A further object of the invention is to provide a series arrangement including a current-limiting fuse and a circuit interrupter of the aforementioned type wherein the current-limiting fuse blows at fault currents which could be cleared by the interrupter alone to keep onerous interrupting task away from the interrupter to increase the length of the life of the contacts thereof.

Another object of the invention is to provide coordinated combinations of current-limiting fuses and automatic circuit interrupters of the type comprising pairs of cooperating separable contacts which make it possible to reclose a circuit instantly upon interruption thereof to test whether the fault which caused blowing of the current-limiting fuses and tripping of the circuit interrupters has been cleared, or still persists.

A further object of the invention is to provide a co-

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ordinated pair of serially connected protective devices comprising an automatic switching device and a striker-pinless back-up current-limiting fuse therefor which combination has an inherently high degree of flexibility in regard to the selection of the let-through current of the current-limiting fuse.

It is moreover my object and purpose to generally improve coordinated combinations of current-limiting fuses, and of automatic circuit interrupters of the type comprising pairs of cooperating separable contacts.

For a better understanding of my invention reference may be had to the accompanying drawing in which:

Fig. 1 is the time-current characteristic of a typical short-circuit current including a substantial D.-C. component;

Fig. 2 is a diagrammatic illustration of a first embodiment of the invention;

Fig. 3 is the time-current characteristic of the current which flows in the same system as the current shown in Fig. 1 upon occurrence of a fault of the same nature if the system is protected according to the present invention; and

Fig. 4 is a diagrammatic illustration of another embodiment of the invention.

Referring now to Fig. 1, line A indicates a typical short-circuit current i plotted against time t . Line A is the resultant of an A.-C. component (not shown separately) and of a D.-C. component B which decreases with time. The right portion of Fig. 1 shows a current having a small D.-C. component, which current comes fairly close to the steady state short-circuit current of the system under consideration. A circuit-interrupter inserted into the system to clear the fault by separation of a pair of contacts would initiate the interrupting process a number of half cycles after fault inception and achieve final interruption of the circuit after an arcing time of, say, a few cycles of the current wave.

If a current-limiting fuse were inserted into the circuit the short-circuit current would be allowed to rise only up to a limited peak value p which is substantially less than the peak value of the first half cycle of the fault current A. The period of time Δt between fault inception and the time when the fault current A reaches the peak value p is the fusing time of the fuse link, frequently also referred to as the pre-arcing time of the current-limiting fuse. After the time Δt has elapsed the fault current begins to decay and reaches zero after ΔT which is the interrupting time of the fuse. ΔT may be in the order of a quarter cycle and is generally less than half a cycle of the current wave.

The arrangement shown in Fig. 2 comprises a fuse-resistor unit generally designated by the reference letter X and an automatic interrupter unit generally designated by the reference letter Y. Both units X, Y are serially arranged in a multiphase circuit R, S, T. The fuse-resistor unit X comprises three current-limiting fuses 1 and three substantially ohmic resistances, or resistors 2. Each current-limiting fuse 1 is arranged in one of the three phases R, S, T and shunted by one of the three resistors 2. The interrupter unit Y is in essence an automatic multipolar load break switch having three tripping devices 3, of which each is capable of tripping the circuit interrupter to cause separation of the cooperating pairs of contacts thereof. The current-limiting fuses 1 and the circuit-interrupter unit Y have a current-carrying capacity of the same order. The current-limiting fuses 1 do not blow on the occurrence of small overloads of excessive duration. Under such conditions the tripping elements 3 trip the circuit interrupter, resulting in the separation of the contacts in all the poles thereof. Thus the circuit interrupter unit is caused to interrupt the circuit without assistance of the fuse-resistor unit X,

provided that the interrupting task is relatively light, i. e. that the current under interruption is only of relatively small overload proportions.

If a very high overload or a phase-to-phase or a phase-to-ground fault occurs, the interrupting process is initiated by blowing of one or more current-limiting fuses 1. The current which continues to flow in the faulted portion of the circuit after blowing of one or more current-limiting fuses 1 is limited to load current proportions by one or more of the resistors 2. Therefore the circuit interrupter unit X does not need to have a substantial interrupting capacity. Nor is there any danger of thermal destruction of the tripping elements 3 by the effects of short-circuit currents. The tripping elements 3 are subjected to the let-through current of the fuses 1 which may be kept sufficiently low not to endanger these elements. After blowing of one or more current-limiting fuses 1 the tripping elements 3 are subjected to a transient current which is far below the available short-circuit current of the system R, S, T because the transient is limited by the resistors 2. The duration of this transient is equal to the interrupting time of the circuit interrupter unit Y and may be controlled within wide limits by the selection of resistors 2.

Normally the transient phase angle between the system voltage and a short-circuit current is in the order of 90 electrical degrees. At the point of time the short-circuit current goes through zero the system voltage goes through its peak and this makes it normally particularly difficult to interrupt a short-circuit current by means of an automatic circuit interrupter or circuit breaker. However, in the arrangement of Fig. 3 the transient phase angle between system voltage and short-circuit current shifts during the interrupting process due to the insertion of ohmic resistance into the circuit during the process of interruption thereof, and at the time the contacts of the interrupter unit Y part the amount of resistance inserted into the circuit is sufficiently high to reduce the transient phase angle between the current under interruption and the system voltage substantially to zero. Under such conditions the interrupting task of the interrupter unit Y is greatly reduced and interrupter unit Y requires but compact arc chutes, or arc chutes can even be entirely dispensed with. Because the interrupting duty of the interrupting unit Y is greatly eased by the operation of current-limiting fuses 1 and resistors 2, the life of the interrupting unit, and particularly that of the contacts thereof, is high and the cost of maintaining that unit are comparatively very low.

In case of severe fault currents it may be desirable to accelerate the operation of unit Y, i. e. to shorten the operating time of the same. This can be achieved by providing the interrupting unit Y with rapidly acting electromagnetic tripping devices which become operative at say 10 times the rated current of the interrupting unit Y. Such tripping devices would not become operative on motor starting inrush currents which never reach the minimum values at which the electromagnetic tripping devices become operative. The circuit interrupter may include thermally responsive tripping devices for protection against relatively small overloads which do not cause blowing of any of the current limiting fuses 1.

Fig. 3 shows the trace of a fault current produced by an oscillograph when the fault current is interrupted by the joint action of a current-limiting fuse shunted by a resistor and of an automatic load-break-switch type circuit interrupter having quickly acting electromagnetic tripping devices of the kind illustrated in Fig. 4 and more fully described in connection with this figure.

Referring now to Fig. 3, the fault current rises up to a peak p which is of the same order as the peak of the let-through current shown in Fig. 1 but may be slightly higher on account of the fact that the current-limiting fuse is shunted by a resistor 2. Initially the fault current lags the circuit voltage by 90 electrical degrees, and the

fact that the resistance of the link increases during the pre-arcing period on account of the intense heating thereof by the fault current has but limited effect upon the transient phase angle between current and voltage. The metallic continuity of the fuse link is broken at the time the current reaches the peak value p thereof and from that time on the gaseous current path formed by the arc which is kindled within the fuse takes the place of metallic current path through the fuse link. As the resistance of the fuse link increases during the pre-arcing period some of the fault current is shunted through the resistor 2. The resistance of the current path through the current-limiting fuse 1 begins to increase significantly during the arcing period. At less than a half cycle of the current wave the resistance of the arc path through the fuse 1 may, and ordinarily will, have increased to such an extent that the portion of the fault current which flows through the fuse is very small compared to the portion of the fault current which flows through the resistor 2. The latter's resistance is sufficiently high to bring the fault current substantially in phase with the circuit voltage. This eases greatly the task of the circuit interrupter unit Y when final interruption of the circuit is being achieved by it.

The limitation of a short-circuit current to a current of high overload proportions can be achieved by shunting the current-limiting fuse 1 with an appropriate impedance, which may, or may not, have an appreciable self-induction. It is preferable to shunt the fuse by an impedance which has preponderantly ohmic resistance and as little self-inductance as possible. It is possible to manufacture compact ohmic resistors capable of readily withstanding the relative high transients which occur because their duration is very short, not exceeding a few cycles of the current wave.

The interrupting capacity of the circuit interrupter unit Y should be in excess of the peak p of the let-through current of the current-limiting fuse 1 but be less than the peak of the available short-circuit current of the circuit under interruption at the point thereof where unit Y is located.

Referring now to Fig. 4, the electric system shown therein comprises three phases R, S, T. Each phase R, S, T includes a pair of parallel branches into one of which a current-limiting fuse 1 and into the other of which a current-limiting impedance, e. g. a current-limiting resistor 2 is inserted. A circuit interrupter unit Y is arranged in the circuit R, S, T in series relation to the above referred to parallel branches thereof. The circuit interrupter unit Y comprises pairs of cooperating separable contacts 10, 11 which are normally in engagement and normally biased to the separated position thereof. Contacts 10, 11 are mechanically tied together by a cross-bar 12 the right end of which is acted upon by a biasing spring 13. Biasing spring 13 tends to rock contacts 11 about their pivots 14 in clockwise direction to the open position thereof which is shown in dotted lines. Normally cross-bar or tie-bar 12 is restrained by a latch 15 under the control of a tripping solenoid 16 from moving to the right under the action of spring 13. The left end of tie bar 12 supports a toggle link 17 adapted to be acted upon by an operator (not shown). The operator for moving tie bar 12 to the left against the action of biasing spring 13 may either be of the manual type, or of the motor type, e. g. it may be a solenoid or a pneumatic motor. Each phase R, S, T of the circuit includes a current transformer generally designated by the reference numeral 18. The primary windings 19 of current transformers 18 are arranged in the phases R, S, T whereas the secondary windings 20 of the current transformers 18 each supply one tripping relay 21 with current. Each of the three tripping relays 21 is adapted to close an auxiliary circuit designated + -. Closing of tripping circuit + - by any of the three tripping relays 21 causes energization of solenoid 16, unlatching of the latching mechanism 15, freeing of cross-bar 12 to follow the bias of spring 13 and separation of the three pairs of contacts 10, 11.

The current-limiting impedances or resistors 2 and the primary windings 19 of transformers 18 are designed to withstand for a relatively short time, i. e. a few cycles of the current wave the heat would result from the flow in system R, S, T of currents in the order of the R. M. S. value of the highest of the short-circuit currents flowing through the impedances or resistors 2 upon blowing of the current-limiting fuses 1 as a result of a bolted short-circuit at the point of the system R, S, T where interrupter unit Y is located. The R. M. S. value of this highest short-circuit current indicated by reference letter p' in Fig. 3 must be determined for the most unfavorable fault angle which can occur. Since this current i includes the portion of the total current which is shunted by current-limiting fuses 1 away from the impedances or resistors 2, the R. M. S. value of the current actually flowing through parts 2 is considerably smaller and also shorter. Parts 2 and 19 are designed not to withstand even for a quarter of a cycle the heat that would result from the flow of currents in the multiphase circuit R, S, T in the order of I , I being the R. M. S. value during the first half cycle of the highest fault current available in the circuit R, S, T upon replacement of current-limiting fuses 1 and impedances 2 by a conductor of infinitely small impedance and upon occurrence of a bolted short-circuit at the point of the circuit R, S, T where the circuit interrupter unit Y is located. In determining the magnitude of i and I due account must be taken of the D.-C. component of the short-circuit current which may vary roughly between zero and 1.8 the R. M. S. value of the A.-C. component of the short-circuit current.

It will be apparent that impedances 2 and primary windings 19 designed to have the above limits of short time ratings can be very compact and therefore accommodated with a minimum of space available. Carbon or similarly fabricated resistors may be used the general dimensions of which are considerably less than that of the current-limiting fuses 1, provided that there is no objection to transient heating of the resistors to a fairly bright red. Instead of carbon and similarly fabricated resistors bifilarly wound wire resistors may also be used, if desired.

Current transformers generally designated by the reference numerals 22 are arranged in the phases R, T in series with the current transformers 18. The secondary winding 23 of each transformer 22 supplies current to a resistor 24. Resistors 24 heat bimetallic elements 25 of which the upper ends are clamped at 26 and of which the lower ends normally restrain bell-cranked-shaped levers 27 from pivoting under the action of springs 29 in clockwise direction about pins 28. Transverse control rod 30 is biased to the right by a helical spring 31 but can be shifted from right to left by either of the two bell-crank-shaped levers 27 upon release thereof by bimetallic elements 25. Control rod 30 controls a switch 32 arranged in the auxiliary circuit + —. Upon closing of switch 32 the solenoid 16 is energized, thus unlatching the latching mechanism 15 and permitting spring 13 to separate the movable contacts 11 from the stationary contacts 10.

It will be seen from the foregoing that solenoid 16 will be energized to cause opening of the interrupter unit Y either by the operation of solenoids 21 or by the operation of the bimetallic elements 25. Solenoids 21 cause opening of the interrupting unit Y in response to relatively heavy fault currents. Bimetallic elements 25 cause opening of interrupter unit Y in response to small overloads of inadmissible duration and are time delay type tripping means. All heavy fault currents interrupter unit Y has to cope with are limited by the action of the current-limiting fuse 1 and the action of the current-limiting resistor 2, and therefore the interrupting capacity of interrupter unit Y may be relatively small. In other words, interrupter unit Y does not need to be a

circuit breaker; it may be an automatic switch of the so-called load-break-switch type.

The electromagnetic tripping means 18, 21 are adapted to cause separation of contacts 10, 11 on the occurrence of major faults, e. g. fault currents ten times or more the rated current of current-limiting fuses 1 and of interrupter unit Y. The resistors 2 shunting the current-limiting fuses 1 reduce any fault current causing blowing of said fuses upon blowing thereof to a current of overload current proportions. If a fault current causes blowing of but one of the three fuses 1, the resulting operation of interrupter unit Y will interrupt simultaneously all three phases R, S, T, thus precluding single-phasing and overheating of polyphase motors which may be connected into the system R, S, T.

It is preferable to accommodate the protective system in two separate housings, i. e. one common housing for the current-limiting fuses 1 and the impedances or resistors 2, and an additional housing for the interrupter unit Y. The above separate housing feature has been diagrammatically indicated in Figs. 2 and 4.

It will be apparent from the foregoing that the resistors 2 limit the rate of rise of the recovery voltage in addition to limiting the magnitude of fault currents. Whereas in prior art devices auxiliary resistors for that purpose are generally shunted into the circuit after parting of a pair of separable contacts, resistors 2 are permanently inserted into the circuit, i. e. before the contacts of the interrupter unit Y part. The transient power factor improvement is already effected by the resistors 2 at the time when the contacts of the interrupter unit Y part and the arcing time of the interrupter unit Y is shortened because the normal 90-degree lagging position of the fault current is already changed at the time when the final interruption of the circuit is initiated by the interrupter unit Y.

Upon occurrence of a major fault units X and Y operate sequentially. Unit Y can be reclosed immediately upon tripping and opening thereof since it is protected against the inrush of a heavy fault current by the series impedances 2. If an overload condition still persists at the time unit Y is reclosed, unit Y is tripped by the overload current. In case that the fault has been cleared by the joint operation of units X and Y, the current flowing through impedances 2 may be too small to trip unit Y, thus indicating to the operator of unit Y that the blown fuses 1 in unit X can safely be replaced without any danger of immediate repeated blowing. Thus unit Y serves the important function of a fault detector.

Whenever the term circuit interrupter is used in this context, it is intended to refer to an interrupting device capable of interrupting an electric circuit by means of separable contacts which draw an arc therebetween upon separation thereof and wherein the gaseous conductive arc path is subsequently converted into a gaseous insulating gap. Hence the term circuit interrupter is intended to include circuit breakers and various other automatic switching devices having tripping means such as automatic load-break-switches and motor starters. While some motor starters are provided with thermal tripping devices in only two phases of three phase circuits, other motor starters for three phase circuits are provided with a thermal tripping device in each phase thereof. Unit Y shown in Fig. 4 could be provided, if desired, with a thermal tripping device in each of the three phases thereof, in the same way as shown in the embodiment of the invention illustrated in Fig. 2.

Where the term interrupting capacity has been used in this context as, for instance, with reference to Fig. 3, this term refers to the ability of interrupting the circuit under actually prevailing conditions of let-through current through current-limiting fuses 1, and follow-current through impedances 2, etc., rather than to interrupting capacity determined by some standard test conditions

often implied when speaking of the interrupting capacity of a given protective device.

It will be understood that if the impedances shunting the current-limiting fuses were omitted, the let-through currents through the latter might, under certain circumstances, be sufficient to trip the automatic switch or circuit interrupter. This prior art arrangement does not permit to reduce the peaks of the let-through currents to the extent to which they ought to be reduced in some instances since it compels to maintain the peaks of the let-through current at a sufficiently high level to be able to cause tripping of the automatic switch or circuit interrupter. As clearly shown in Fig. 3, the duration of the total current flowing through the current-limiting fuses and through their shunt impedances may be made to be considerably longer than the let-through current through a non-impedance-shunted current-limiting fuse, and this fact enables to trip an automatic circuit interrupter by currents having a relatively small peak value. If the shunt resistors were lacking, the entire task of interrupting major fault currents would be cast upon the current-limiting fuses since in such an arrangement the automatic switch or circuit interrupter operates merely as a disconnect upon successful operation of the current-limiting fuses. Considering the structures of Figs. 2 and 4, the current-limiting fuses may be on the verge of failure on account of overheating during the process of interruption, yet as long as the total current through the current-limiting fuses and the shunt impedances is capable of tripping the automatic switch or circuit interrupter, the resulting series breaks will effectively preclude the impending destruction of the current-limiting fuses.

Having disclosed two preferred embodiments of my invention, it is desired that the same be not limited to any particular structure disclosed. It will be obvious to any person skilled in the art that many modifications and changes may be made without departing from the broad spirit and scope of my invention. Therefore it is desired that the invention be interpreted as broadly as possible and that it be limited only as required by the prior state of the art.

I claim as my invention:

1. In combination an electric multiphase circuit, a plurality of current-limiting fuses one in each phase of said circuit, an automatic multipolar circuit interrupter comprising a plurality of pairs of separable contacts each in one pole thereof and each arranged in series with one of said plurality of current-limiting fuses, said circuit interrupter including a latching mechanism common to all poles thereof, said circuit interrupter further including a plurality of instantaneous electromagnetic tripping relays operatively related to said latching mechanism for causing separation of said plurality of pairs of separable contacts upon occurrence of a fault current of overload current proportions in one of the phases of said circuit, and a plurality of resistors each shunting one of said plurality of current-limiting fuses to reduce any fault current causing blowing of any of said plurality of current-limiting fuses to a current of overload current proportions.

2. In combination an electric circuit, a pair of parallel branches formed by said circuit, one of said pair of branches comprising a current-limiting fuse having a predetermined maximum let-through current substantially less than the available short-circuit current of said circuit at the point thereof where said current-limiting fuse is located and the other of said pair of branches comprising a current-limiting impedance, an automatic circuit interrupter arranged in said circuit in series relation with respect to said pair of branches of said circuit, said circuit interrupter being provided with tripping means of the instantaneous type responsive to the current flowing through said impedance upon blowing of said fuse and having an interrupting capacity less than the available short-circuit current of said circuit at the point of said circuit where said circuit interrupter is located but in

excess of the peak of said let-through current of said current-limiting fuse.

3. In combination an electric circuit, a pair of parallel branches formed by said circuit, one of said pair of branches comprising a current-limiting fuse having a predetermined maximum let-through current substantially less than the available short-circuit current of said circuit at the point thereof where said current-limiting fuse is located and the other of said pair of branches comprising a substantially ohmic resistance, an automatic circuit interrupter arranged in said circuit in series relation with respect to said pair of branches of said circuit, said circuit interrupter including a pair of cooperating separable contacts and tripping means of the instantaneous type responsive to the flow of current through said ohmic resistance, and said circuit interrupter having an interrupting capacity in excess of the peak of said let-through current of said current-limiting fuse but less than the peak of the available short-circuit current of said circuit at the point of said circuit where said circuit interrupter is located.

4. In combination an electric circuit, a pair of parallel branches formed in said circuit, one of said pair of branches including a current-limiting fuse having a predetermined maximum let-through current substantially less than the available short-circuit current of said circuit at the point thereof where said current-limiting fuse is located and the other of said pair of branches including a current-limiting impedance, a circuit interrupter arranged in said circuit in series relation with said pair of branches thereof, said circuit interrupter comprising a pair of separable, normally engaging contacts biased to the separated position thereof, said circuit interrupter further comprising a latching mechanism normally restraining said pair of contacts in the engaged position thereof, said circuit interrupter further comprising electromagnetic tripping means of the instantaneous type including a current transformer arranged with the primary winding thereof in said circuit and a tripping device supplied with current from the secondary winding of said current transformer and controlling said latching mechanism to cause separation of said contacts, said current-limiting impedance and said primary winding of said transformer being designed to withstand for a relatively short time only the heat that would result from the flow in said circuit of currents in the order of i and said current-limiting impedance and said primary winding being designed not to withstand even for a quarter of a cycle the heat that would result from the flow in said circuit of currents in the order of I , i being the R. M. S. value of the highest of the short-circuit currents flowing through said current-limiting impedance immediately upon blowing of said fuse as a result of a bolted short-circuit at the point of said circuit where said circuit-interrupter is located, and I being the R. M. S. value during the first half cycle of the highest fault current available in said circuit upon replacement of said pair of parallel branches by a conductor of infinitely small impedance and upon occurrence of a bolted short-circuit at the point of said circuit where said circuit interrupter is located.

5. In combination an electric multiphase circuit, a pair of parallel branches formed in each phase of said circuit, one of each said pair of branches comprising a current-limiting fuse having a predetermined maximum let-through current substantially less than the available short-circuit current of said circuit at the point thereof where said current-limiting fuse is located and the other of each of said pair of branches comprising a current-limiting impedance, a multipolar circuit interrupter arranged in said circuit with each pole thereof in series relation with one of said pair of branches of said circuit, said circuit interrupter having in each pole thereof a pair of separable normally engaging contacts biased to the separated position thereof, said circuit interrupter further comprising

means common to all poles thereof normally restraining said pair of contacts in each pole in engaged position, said circuit interrupter further comprising a plurality of tripping elements of the instantaneous type responsive to the flow of current in said circuit operatively associated with said common restraining means to cause separation of said pair of contacts in each pole upon occurrence of predetermined fault currents in said circuit, each of said plurality of tripping elements being designed to withstand for a relatively short time the heat that would result from the flow in said circuit of currents in the order of i and each of said plurality of tripping elements being designed not even for a quarter of a cycle to withstand the heat that would result from the flow in said circuit of currents in the order of I , i being the R. M. S. value of the highest of the short-circuit currents flowing through said current-limiting impedance in each of said pair of branches of said circuit immediately upon blowing of said fuse in each of said pair of branches of said circuit as a result of a phase-to-phase bolted short-circuit involving all the phases of said circuit at the point of said circuit where said circuit interrupter is located, and I being the R. M. S. value during the first half cycle of the highest fault current available in said circuit upon replacement of each said pair of branches in each phase of said circuit by a conductor of infinitely small impedance and upon occurrence of a phase-to-phase bolted short-circuit involving all the phases of said circuit at the point thereof where said circuit interrupter is located.

6. In combination an electric circuit, a current-limiting fuse having a predetermined maximum let-through current substantially less than the available short-circuit current of said circuit at the point thereof where said current-limiting fuse is located arranged in said circuit, a resistor shunting said current-limiting fuse, and an automatic circuit interrupter comprising a pair of separable contacts

serially arranged in said circuit with said current-limiting fuse and said resistor, said circuit interrupter comprising a thermally responsive tripping device of the time delay type and an electromagnetically responsive tripping device of the instantaneously acting type, said electromagnetically responsive tripping device being designed to trip said circuit interrupter in response to fault currents reduced in magnitude by the presence of said current-limiting fuse and of said resistor.

7. In combination an electric circuit, an automatic circuit interrupter having a predetermined current-carrying capacity and a predetermined interrupting capacity arranged in said circuit, said interrupter comprising a pair of cooperating separable contacts, normally ineffective contact separating means and instantaneous tripping means responsive to the flow of current in said circuit operatively related to said contact separating means to cause separation of said pair of contacts upon occurrence of excessive currents in said circuit, a resistor in series with said interrupter in said circuit, and a current-limiting fuse having a current-carrying capacity in the order of said current-carrying capacity of said interrupter shunting said resistor, said current-limiting fuse being adapted to have a maximum let-through current in said circuit less than said predetermined interrupting capacity of said interrupter to relieve said interrupter of the interruption of currents within a predetermined margin below said predetermined interrupting capacity thereof.

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