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PROTECTIVE RELAYING WITH DISCRIMINATIVE RECLOSURE

Filed Dec. 30, 1941 2 Sheets-Sheet 1

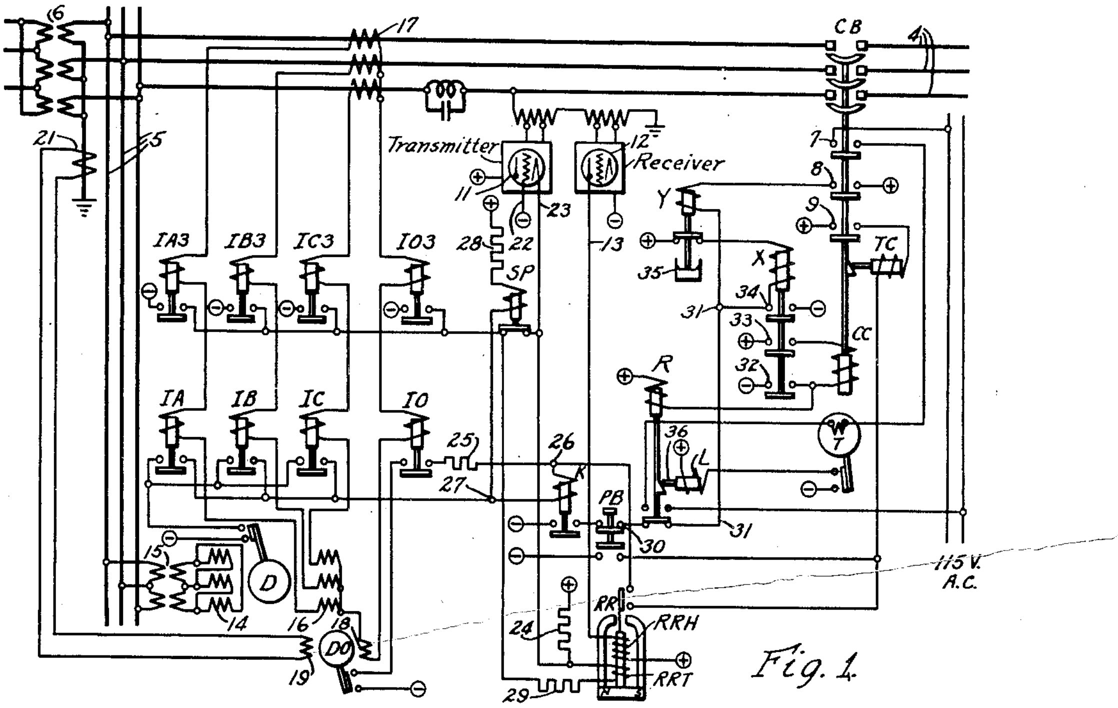
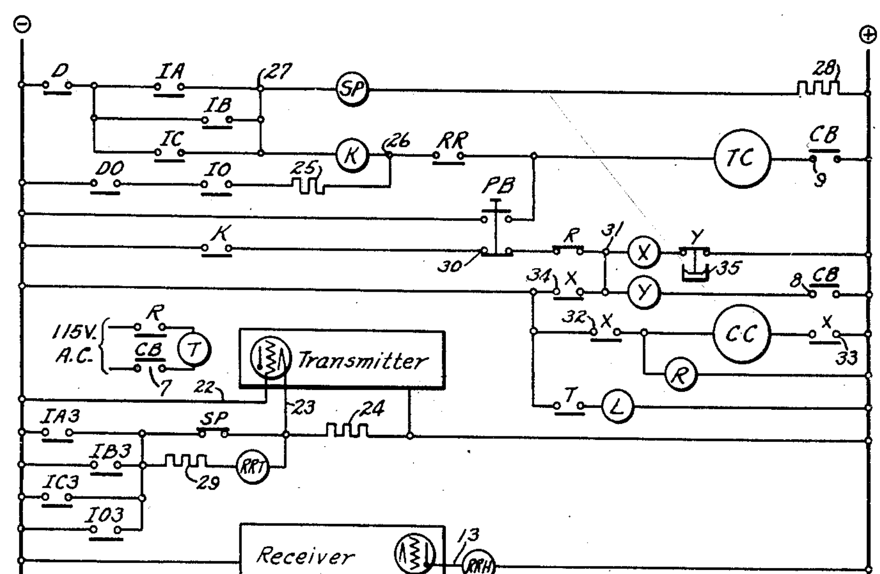


Fig. 1.



WITNESSES:

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Fig. 2.

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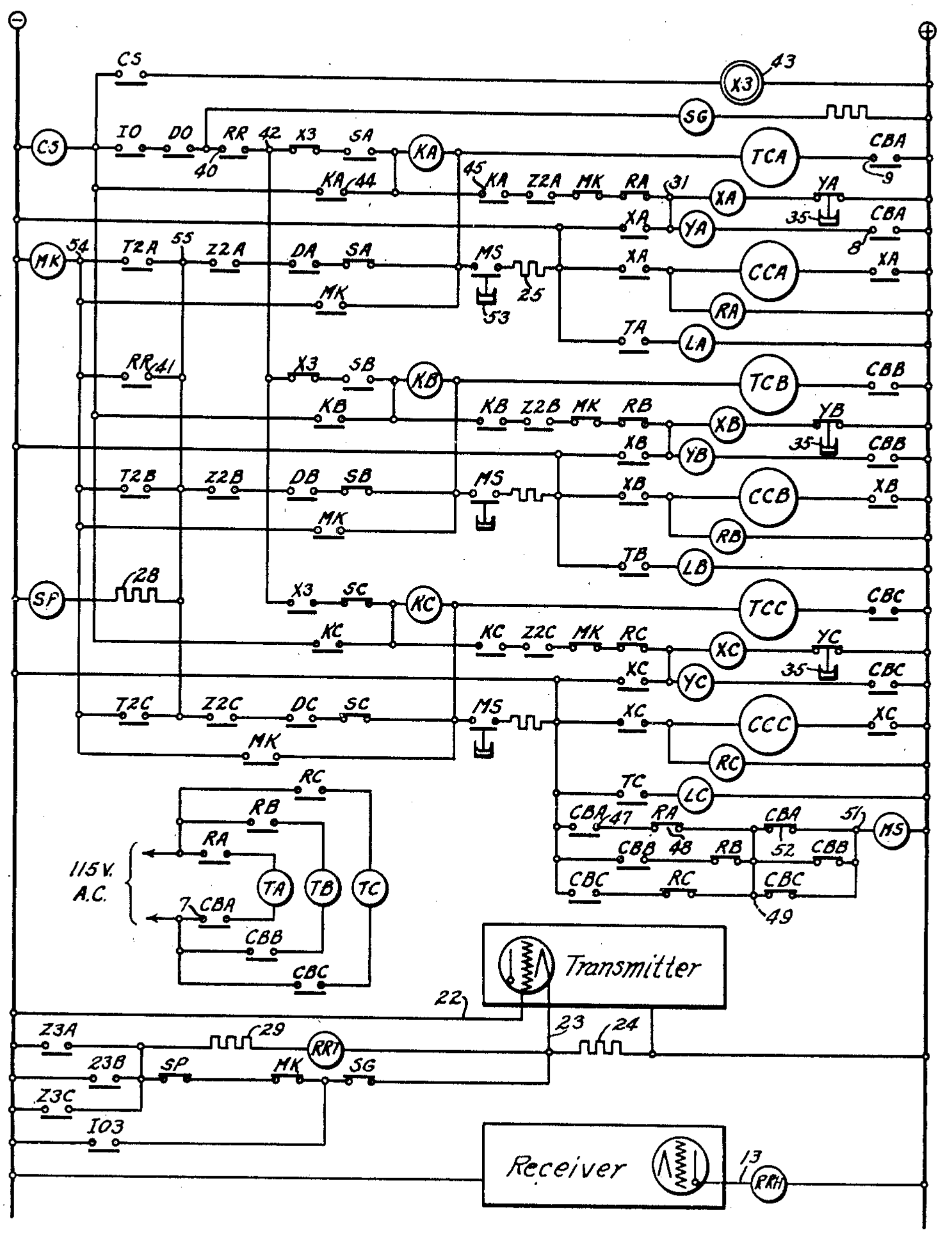

Fig. 3.

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PROTECTIVE RELAYING WITH DISCRIMINATIVE RECLOSURE

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Application December 30, 1941, Serial No. 424,958

11 Claims. (Cl. 175—294)

Our invention relates to protective relaying systems for protecting electrical transmission lines against faults.

One object of our invention is to provide a protective relaying system in which means are provided for automatically reclosing the tripped circuit-breaker, but only in case the tripping resulted from a fault-current of sufficient intensity to indicate the presence of a grounding arc. The reason for this is that, on many lines, notably low-voltage systems (as transmission-voltages go), a live phase-wire lying on the ground, or against a tree or other object, presents a distinct hazard to life, but if the ground is hard and dry, it may not draw sufficient current to actuate even the most sensitive residual-current or ground-fault relays for a matter of several minutes, or even hours, particularly after the phase-wire is lying quietly on the ground or other object, without moving. Such a condition obviously represents a life-hazard which cannot be ignored. If, however, the transmission line is faulted by reason of a power-arc to the grounded hardware, there is no life-hazard, and in over a majority of cases the arc will not restrike itself when voltage is restored to the line after a momentary period of deenergization. Hence, it is advantageous to automatically and immediately reclose a tripped circuit-breaker, when its fault-current resulted in a fault-current or a fault-conductance of sufficient magnitude to sustain an arc, or to indicate that the fault could have been an arcing fault, but definitely to lock out or prevent such reclosure in the event that the fault-current should have been of a more delicate nature.

A more specific object of our invention is to apply the discriminatory-reclosure idea just described to a single-pole tripping-scheme in which service-continuity is enhanced, in the event of a fault involving only a single line-conductor, by tripping out only that one line-conductor, by means of a single-pole circuit-breaker at each end of the protected-line section, and immediately reclosing the tripped single-pole breakers; but, in accordance with our invention, means are provided for preventing such reclosure in case the fault involved insufficient line-current to indicate the presence of a grounding arc.

With the foregoing and other objects in view, our invention consists in the circuits, combinations, apparatus, parts, methods and systems hereinafter described and claimed, and illustrated in the accompanying drawings, wherein

Figure 1 is a schematic view of circuits and apparatus embodying our invention in a simplified carrier-current relaying system,

Fig. 2 is an across-the-line diagram of the protective relaying system shown in Fig. 1, and

Fig. 3 is an across-the-line diagram of a protective relaying system for utilizing single-pole tripping and reclosure.

In Fig. 1, we have shown our invention as being embodied as a part of a simplified or inexpensive carrier-current relaying-system for the protection of a three-phase line 4 which is fed from a bus 5 which may be fed from a delta-star step-up power-transformer 6. It will be understood that similar protective equipment is provided at both ends of the protected line-section 4, but as the equipments at the two ends are similar, an illustration and description of one will suffice for both.

In the system shown in Fig. 1, the line 4 is protected by a three-phase circuit-breaker CB, which is provided with a trip-coil TC, a closing-coil CC, and three auxiliary switches or back-contacts 7, 8, 9, which are closed when the circuit-breaker is closed, and which open when the circuit-breaker opens.

The relaying system shown in Fig. 1 is a carrier-current system, involving a carrier-current transmitter, which is symbolized by a triode oscillator-valve 11, a carrier-current receiver, which is symbolized by a triode receiver-valve 12, and a polarized receiver-relay RR, having a restraining or holding-coil RRH which is energized from the anode-circuit 13 of the receiver, and an operating or tripping-coil RRT which is controlled by the protective relays.

The protective relays, in the simplified carrier-current system shown in Figs. 1 and 2, comprise a polyphase directional relay D, having voltage-coils 14 which are energized from potential-transformers 15 connected to the bus 5, and current-coils 16 which are energized from the respective phase-currents of the line, as delivered by a bank of star-connected line-current transformers 17 (Fig. 1). We also use a residual-current or ground-directional relay DO, which has a residual-current coil 18 which is connected in the neutral circuit of the current-transformers 17, and a polarizing-coil 19 which is shown as deriving its energization from an auxiliary current-transformer 21 in the grounded neutral circuit of the power-transformer 6.

In the simplified system shown in Figs. 1 and 2, we also utilize phase and ground-fault detectors, in the form of simple overcurrent phase-current and residual-current relays IA, IB, IC and IO, respectively, which are energized from the line-current transformers 17. These overcurrent relays may either have two sets of contacts, or the second set of contacts may preferably be provided by means of a second set of somewhat more sensitive overcurrent relays IA3, IB3, IC3 and IO3. We also utilize various auxiliary relays, which will be referred to in the description of the operation, which is as follows:

The transmitter-oscillator 11 is normally in a non-transmitting condition by reason of the fact that its grid-circuit 22 is connected to the negative bus, while its cathode-circuit 23 is at or near the potential of the positive bus, being connected thereto through a resistor 24.

When a fault involving ground-current, or residual current, occurs on the protected line-section, the ground-fault relays IO and IO3 respond to the residual current, and the ground-directional relay DO responds to an into-the-line-looking direction of the residual current. The sensitive ground-relay IO3 instantly initiates carrier-transmission by connecting the oscillator-cathode 23 to the negative bus, through a circuit which includes the back contacts of an auxiliary relay SP which will be subsequently referred to more in detail. The ground-directional relay DO, and the ground-overcurrent relay IO energize a partial tripping-circuit from the negative bus, through a small resistance 25, to a conductor 26 which will be referred to after some consideration has been given to phase-fault tripping.

In the event of a line-fault involving a material line-current in one or more of the phase-conductors of the three-phase line 4, carrier-current transmission is started by the contacts of one or more of the sensitive phase-overcurrent relays IA3, IB3 or IC3, which connect the oscillator-cathode 23 to the negative bus. At the same time, the phase-directional relay D responds to an into-the-line-looking direction of the polyphase line-current; and one or more of the phase-overcurrent relays IA, IB or IC respond to the line-current; thus again establishing a circuit from the negative bus to the previously mentioned conductor 26, through the contacts of the directional and overcurrent relays D and IA, IB or IC, a conductor 27, and also through the coil of an auxiliary relay K.

Whenever the conductor 27 is connected to the negative bus, either as a result of an into-the-line-looking response of the three-phase directional relay D (accompanied by a phase-overcurrent response IA, IB or IC) or an into-the-line-looking response of the ground-directional relay DO (accompanied by a ground-current response IO) energy is supplied to the coil of an auxiliary relay SP, the circuit of which is completed through a resistor 28, and thence to the positive bus. This SP relay thus responds to an internal, or into-the-line-looking, direction; and when the fault-current has this into-the-line-looking direction at both ends of the protected line-section, carrier-current is removed from both ends of said line-section, by the opening of the SP back-contacts in the cathode energizing-circuits of the carrier-current transmitters. When carrier is removed from both ends of the line-section, the receiver-relay holding-coil RRH, which is connected in the anode-circuit 13 of the receiver-tube 12, is deenergized.

The response of the SP relay has also another effect, because its back-contact SP is in shunt to a circuit comprising the receiver-relay tripping-coil RRT and a resistor 29, so that this receiver-relay tripping-coil RRT is energized in a circuit which can be traced from the negative bus through the contact of one of the four sensitive overcurrent relays IA3, IB3, IC3 or IO3, thence through the resistor 29, the coil RRT, and the resistor 24, to the positive bus. The receiver-relay RR thus responds, and closes its contact RR, thus completing a trip-coil circuit which may be traced from the previously mentioned conductor 26, through the RR make-contact, the trip-coil TC, and the auxiliary breaker-switch 9.

In accordance with our invention, we utilize means for effecting a discriminatory reclosing of the circuit-breaker CB when it is tripped, reclosing only for those ground-faults which draw enough current to indicate the possibility of an arcing fault, and not reclosing for those ground-faults which might involve a broken live line-conductor lying on dry ground. In the system as shown in Figs. 1 and 2, we utilize, for this purpose, the auxiliary relay K, which is energized whenever a tripping circuit is completed, to the conductor 26, through the phase-directional contacts D, the phase-overcurrent contacts IA, IB or IC, and the conductor 27. However, it will be noted that the auxiliary-relay coil K is not energized when a tripping circuit is completed, to the conductor 26, through the ground-fault-responsive circuits, including the contacts of the sensitive ground-directional relay DO and the residual-current relay IO, which is much more sensitive than the phase-fault relays IA, IB and IC. Thus one of the phase-fault relays IA, IB or IC, responds whenever a ground-fault on its particular phase draws a material amount of line-current, sufficient to indicate the possibility or probability of an arc, while the residual-current ground-directional and ground-fault relays DO and IO are necessarily made as sensitive as possible, so as to respond even when a line-conductor is lying on a hard, dry ground of very high resistance, which does not form an arc. The small resistance 25 is included in the ground-fault tripping-circuit to the conductor 26, for the purpose of preventing the short-circuiting of the coil K when this ground-fault tripping-circuit is energized. The resistance 25 should be very small, something like the order of magnitude of the resistance of the coil K, more or less (the coil K being an overcurrent coil of very low resistance), so that no material amount of impedance is imposed in the path of the relatively heavy tripping-current which is momentarily passed through the trip-coil TC.

When the auxiliary relay K selectively responds to a tripping-operation which is accompanied by an internal direction of a line-current of fault-magnitude, it is utilized to effect the reclosure of the circuit breaker, by any suitable means. In the particular embodiment of our invention which is shown in Figs. 1 and 2, the closure of the make-contact K energizes the coil of a closing-relay X, through a circuit which can be traced from the negative bus, through the contact K, the back-contact 30 of a tripping push-button PB, the back-contact of a toggle or latched relay R, a conductor 31, the X-coil, and the back-contact of a cutoff-relay Y, and thence to the positive bus. The closing-relay X instantly energizes the closing-coil CC of the circuit-breaker, through two of the make-contacts 32 and 33 of the closing-relay X. At the same time, the closing-relay X seals itself in, through its third make-contact 34, which shunts the circuit consisting of the K-contact, the push-button back-contact 30, and the R-relay back-contact.

The coil of the cutoff-relay Y is energized through a circuit which can be traced from the conductor 31, the Y-coil, and the auxiliary breaker-switch 8, to the positive bus. The cutoff-relay Y preferably, although not necessarily, has a slow pickup of two or three cycles, more or less, which is symbolically indicated by means of a dashpot 35 which permits the relay to drop out substantially instantaneously. The pick-up delay, when utilized, is for the purpose of permitting the breaker-switch 8 to get open, during the opening stroke of the circuit-breaker, before the cutoff-relay back-contact Y is opened. In this way, we avoid a momentary opening and closing of the reclosing-relay X at the very beginning of the opening stroke of the circuit-breaker.

At the same time that the closing-coil CC is energized, the coil of the toggle or latched relay R is also energized, from the make-contact 32 of the closing relay X. The toggle or latched relay R is a relay of the type which will stay in whatever position it is moved to, even after the deenergization of the coil which caused it to move to that position, and this relay will keep its position until something positive is done to the relay to change its position. A toggle relay is commonly used, but for illustrative purposes, we show the relay R as being of a latched type, as shown in Fig. 1, having a latch 36 which holds the relay in its actuated position, when it is picked up as a result of an energization of its operating-coil R. The latch 36 is released by means of a latch-coil L. The toggle or latched relay R is provided with a back-contact which has already been referred to in the description of the energizing-circuit for the closing relay X, and a make-contact which is utilized to energize a timer-coil T from a 115-volt alternating-current circuit, through the breaker-switch 7, so that the timer T will begin to move when the breaker finishes its reclosing-stroke. The timer-contact T is utilized to energize the unlatching-coil L.

It will be noted, from the foregoing, that the closing-coil CC of the circuit-breaker is energized practically as soon as the tripping-coil TC is energized, the only delay being the negligible delays due to the necessary operating-times of the instantaneously operating relays K and X. The time-constant of the closing-coil CC is so large, however, that the circuit-breaker has time to open its main contacts far enough to interrupt the arc, before the circuit-breaker mechanism starts to reclose. In an illustrative example, the circuit-breaker requires some twenty-five cycles to reclose itself after the initial tripping-impulse, assuming a 60-cycle line, although our invention is not limited, of course, to any particular closing-time.

The closing-coil CC is deenergized by the reclosure of the circuit-breaker, which closes the auxiliary breaker-switch 8, energizing the cutoff-relay Y through a circuit which can be traced from the positive bus, through the breaker-switch 8, the cutoff Y-coil, and the X-contact 34, to the negative bus. When the cutoff-relay Y is energized, it picks up, either instantly, or in a very few cycles as determined by the dashpot 35 (if used), opening its back-contact Y and deenergizing the closing-relay X and hence the closing-coil CC.

When the circuit-breaker recloses, if the fault still exists on the line, the trip-coil circuit will again instantly be energized, again tripping the breaker, but it will be noted that the closing-coil circuit will not again be energized because of the now-open back-contact of the toggle or latched relay R in the circuit of the X-coil. While we have thus provided for only one reclosure of the circuit-breaker, it is well understood, in the reclosing circuit-breaker art, that a cycle-counter may be utilized to provide for as many reclosures as may be desired, before the circuit-breaker is finally tripped out, and we desire our illustration to be construed as being typical of any desired type of reclosure-means.

The timer T is set for any convenient time, which may be of the order of from five to twenty seconds, depending upon the particular operating-conditions, and designed to provide a time-delay long enough to make sure that the arc which constituted the fault, in the first place, is not going to restrike itself again. If the circuit breaker remains reclosed, without reopening for the time for which this timer T is set, the timer-contacts T are closed, thus energizing the latch-coil L and restoring tht toggle or latched relay R to its initial or unresponsive position, ready for a new cycle of operations as hereinabove described.

In Fig. 3, we have shown our invention applied to a single-pole relaying-system such as that which is covered by an S. L. Goldsborough application, Serial No. 424,957, filed December 30, 1941. In this single-pole switching-system, three single-pole circuit-breakers, designated CBA, CBB and CBC, are connected in the respective phase-conductors of the protected three-phase line-section at each end thereof, these circuit-breakers having trip-coils TCA, TCB and TCC, and closing coils CCA, CCB and CCC. This single-pole system is designed to distinguish between a single line-to-ground fault, which affects only one of the line-conductors, and phase-faults affecting two or more of the conductors; and if only one line-conductor is faulted, only the single-pole breakers at the two ends of that particular line-conductor are opened, and immediately reclosed again, meanwhile transmitting single-phase power over the two unfaulted line-conductors during the 25-cycles, (more or less) necessary to trip out, and reclose, the single-pole breaker at each end of the line-section. If the single-ground fault still persists on the line after such reclosure, all of the single-pole breakers are tripped out; or if a fault should occur, involving two or more phases, all of the single-pole breakers are tripped out in the first place, without any reclosing.

In accordance with our invention, means are provided for discriminating between those single-ground faults which draw enough current to indicate the presence of an arc, and those which do not; reclosing the single-pole breaker, at the respective ends of the line-section, only in the event that the single-ground fault had a sufficiently low resistance, or a sufficiently high conductance, to indicate the possibility of an arc.

Referring, in detail, to the single-pole switching-system shown in Fig. 3, it will be noted that we have provided separate tripping-circuits for ground-faults and for phase-faults; and that we have also provided separate tripping-circuits for each of the three single-pole circuit-breakers in the respective phases of the three-phase line.

The carrier-current control is indicated at the bottom of Fig. 3, and is similar to that which has already been described in connection with Figs. 1 and 2, with certain slight exceptions. Thus, instead of the sensitive carrier-starting overcurrent phase-relays IA3, IB3 and IC3, we show, in Fig. 3, sensitive, or third-zone, impedance-relays Z3A, Z3B, Z3C, having contacts in the cathode-circuit 23 of the transmitter. In addition to the SP back-contact in the RRT shunting-circuit, we utilize, in Fig. 3, a serially connected back-contact of a phase-fault contactor MK, and also a serially connected back-contact of a ground-fault directionally responsive auxiliary relay SG, with the ground-fault carrier-starting contact IO3 connected between the MK and SG contacts, so as to be in series with only the SG contact in the cathode-energizing circuit **23** of the carrier-current transmitter.

The auxiliary ground-directional relay SG is energized whenever there is a response of the ground-overcurrent and the ground-directional relays IO and DO, as will be seen from the circuit near the top of Fig. 3.

The receiver-relay RR, in Fig. 3, is provided with two make-contacts **40** and **41**, one in the ground-fault tripping-circuits, and the other in the phase-fault tripping-circuits.

Whenever there is a ground-fault accompanied by an into-the-line-looking direction at both ends of the protected section, a common conductor **42**, for all phases of the ground-fault tripping-circuits, is partially energized, or connected to the negative bus, in a circuit which can be traced, at the top of Fig. 3, from the negative bus, through the coil of a contactor-switch CS, the make-contacts IO and DO, and the make-contact **40** of the receiver-relay RR, and thence to the aforesaid conductor **42**. From the common conductor **42**, the ground-fault tripping-circuit branches into three circuits, under the selective control of three ground-fault selector-relays or contacts, SA, SB and SC, which are designed to selectively designate the faulted phase-conductor of the line, but without reliable discrimination between faults involving only one phase, and faults involving a plurality of phases, or even between fault-conditions and some normal power-conditions.

Assuming, for example, that there is a ground-fault involving only the phase-conductor A of the protected line-section, and occurring within the limits of the protected line-section, the tripping-circuit is continued, from the common conductor **42**, through the back-contact of an auxiliary relay X3, the SA make-contact, the coil of a contactor KA, the trip-coil TCA, and the make-contact or auxiliary breaker-switch CBA of the single-pole breaker in said phase-conductor A. As soon as this trip-circuit is completed, the general ground-fault contactor CS, and the phase-A ground-fault contactor KA, are energized. The CS-contactor closes its contact and energizes the X3-coil, thereby blocking ground-fault tripping in the other two phases while the faulted phase, A, is being cleared, and for very few cycles thereafter, this time-delay of a few cycles being secured by means of a slow dropout of the X3-relay, as obtained by means of a short-circuited coil **43** which is associated therewith.

The phase-A ground-fault contactor KA has two make-contacts, a KA make-contact **44** which seals-in the KA contactor around the five contacts IO, DO, RR, X3 and SA, and a second KA make-contact **45** which responds substantially simultaneously with the phase-A ground-fault trip-circuit response, and which partially sets up a reclosing circuit for the tripped circuit-breaker.

In accordance with our invention, the reclosing circuit of the KA-contact **45** is supervised by a means responsive to the existence of a predetermined severity of the single-phase ground-fault which caused the tripping. By way of illustration, the particular means which is shown, in Fig. 3, for providing this current-magnitude supervision of the reclosing-means is the make-contact of a second-zone impedance-relay Z2A, it being understood that similar relay-contacts are provided for the other two phases, as indicated at Z2B and Z2C in Fig. 3.

Assuming a response of both the phase-A ground-fault tripping-contactor KA, and the phase-fault relay Z2A for the phase-A line-conductor, a reclosing circuit is completed through a back-contact of the previously mentioned MK-relay, the back-contact of a phase-A toggle or latched relay RA (corresponding to the relay R in Figs. 1 and 2), the conductor **31**, the coil of the phase-A closing-relay XA, and the YA back-contact, thence to the positive bus. From this point on, the closing-operation is similar to that which has already been described for Figs. 1 and 2, it being understood that a separate reclosing-apparatus is provided for each of the three phases A, B and C, as distinguished by the letters A, B and C added to the respective relay-designations.

If the single line-to-ground fault should persist, or restrike, on the faulted line-conductor (the phase-A conductor has been assumed), immediate retripping is obtained, but a second reclosure is blocked, for the time for which the timers TA, TB and TC are set, by the RA back-contact, corresponding to the R-relay in Figs. 1 and 2.

Since it is undesirable to leave two of the line-conductors carrying power for an extended period of time, after one of the three line-conductors has been finally switched out and locked out of service, we have indicated means for effecting an opening of the two closed circuit-breakers CBB and CBC when the tripped circuit-breaker CBA remains out for a predetermined time during which the other two breakers are not tripped.

In Fig. 3, we have illustrated this function as being accomplished by a master-switch MS, the coil of which is energized through a circuit which is shown immediately underneath the reclosing circuits of the phase-C breaker. If any one of the three single-pole breakers remains open at the time when the toggle or latched relay, RA for example, is reset after a single-pole reclosure-operation, that fact is determined by a circuit-breaker back-contact **47** of the circuit-breaker, for example, CBA, in series with an auxiliary back-contact **48** for the RA relay, thus completing a partial-circuit from the negative bus to the conductor **49**. The conductor **49** is joined to one of the terminals **51** of the MS-coil through three parallel-connected circuit-breaker make-contacts **52** of the three circuit-breakers CBA, CBB and CBC, respectively. The circuit-breaker make-contacts **52** are closed whenever the associated breaker is closed.

The circuit-breaker back-contacts **47** are closed only when the associated breaker is open, but, in general, the RA back-contact **48** will become latched open before the CBA circuit-breaker back-contact **47** opens during the tripping operation of the breaker. If desired, the MS relay may be given a slightly sluggish pickup, by means which are conventionally illustrated by a dash-pot **53** which is shown associated with each of the three MS make-contacts, in Fig. 3, so as to guard against the possible contingency of a closing of the CBA back-contact **47** an instant before the opening of the RA back-contact **48**.

If the single-phase line-fault is one which clears itself, the tripped single-pole breaker, CBA, will reclose and remain reclosed, so that its back-contact 47 will be open by the time that the toggle or latched relay RA is reset, and the master-switch MS will not be energized. If, however, the tripped circuit-breaker contact CBA has reopened by the time that the RA relay resets, and if, at the same time, either one or the other two circuit-breakers is closed, an energizing circuit will be made to the MS coil, picking up all three of the MS back-contacts, and energizing a direct tripping-circuit from the negative bus, through the respective MS contacts, to the respective tripping-circuits for all three trip-coils TCA, TCB and TCC, thus energizing those tripping coils whose breaker-switches 9 are closed, that is, only those tripping-coils whose breakers are closed.

The reclosing-circuit interlock which is provided by the MK back-contact, in the energizing-circuit of the XA relay just traced, is utilized for the purpose of preventing reclosure of the single-pole breaker in the event that a phase-fault tripping-circuit is completed for one of the phases in which the phase-selector SA, SB or SC, as the case may be, does not respond, thus indicating, by the non-response of the selector-relay, that there is no single-phase ground-fault on that phase. The phase-fault tripping-circuits will now be described.

The phase-fault tripping-circuit has a common branch which extends from the negative bus, through the coil of the common phase-fault contactor MK, and thence to a common conductor 54, which is common to all three branches of the phase-fault tripping-circuits. From the common conductor 54, the phase-fault tripping-circuits branch, extending through any one of four parallel paths to a second common phase-fault trip-circuit conductor 55, the four paths including the parallel-connected make-contacts of three second-zone timers T2A, T2B and T2C for the respective phases, and the receiver-relay make-contact 41. From the common conductor 55, the phase-fault tripping-circuits become individualized. As they are all alike, a description of one will suffice for all.

For the phase-A breaker, the tripping-circuit is continued, from the conductor 55, through the make-contact of the second-zone impedance-element Z2A, the make-contact of a phase-A directional relay DA, and the SA back-contact, and thence to the trip-coil TCA. As soon as a phase-fault tripping circuit is energized, for any one of the three phases, in the manner just indicated, the phase-fault contactor MK will respond, closing its three make-contacts MK which by-pass the four contacts T2, Z2, D and S for each of the phases, thus completing, and holding, a tripping-circuit to each of the three trip-coils TCA, TCB and TCC, resulting in a three-pole tripping-operation. At the same time, the phase-fault contactor MK opens its four back contacts MK. One of these four MK back-contacts is in series with the SP back-contact in the carrier-control circuit as previously mentioned, while the other three MK back-contacts are in the three reclosure-circuits for the three circuit-breakers, as also previously described.

The auxiliary phase-directional relay SP, in the form of our invention shown in Fig. 3, is connected between the negative bus and the common phase-fault conductor 55, so that it is energized whenever there is a second-zone phase-fault involving any one of the line-conductors, accompanied by an into-the-line-looking direction of the line-current in that conductor, and also accompanied by a non-response of the phase-selector (SA, SB or SC) for the same conductor, this SP-response being obtained before the response of the receiver-relay RR, and, in fact, being the means which is utilized for removing carrier, at each end where the SP-response is obtained, and thus bringing about the response of the receiver-relay RR whenever the SP directional response is obtained at both ends of the protected line-section, as will be understood from the explanation of the carrier-current control which has been given in connection with Figs. 1 and 2.

While we have illustrated our invention in two different forms of embodiment, one being a simplified carrier-current system, and the other being a somewhat more comprehensive single-pole carrier-current system, it will be understood that our invention is not limited to use with carrier, and that it is also not limited to any particular precise form of embodiment; as many changes, in the way of refinements, additions, omissions, and substitutions, may be made by those skilled in the art without departing from the essential principles of our invention. We desire, therefore, that the appended claims shall be accorded the broadest construction consistent with their wording.

We claim as our invention:

1. Fault-responsive protective relaying means for controlling the opening-means and the closing-means of a circuit-interrupter in a line to be protected, comprising the combination, with said circuit-interrupter, of relaying-means directionally responsive to either a heavy-current or a light-current fault on the protected line for effecting the energization of the circuit-interrupter opening-means, and simultaneously responsive relaying-means, selectively responsive only to a fault-current of sufficient intensity to indicate the possibility of an arcing fault, for effecting the energization of the circuit-interrupter closing-means.

2. Fault-responsive protective relaying means for controlling the opening-means and the closing-means of a circuit-interrupter in a line to be protected, comprising the combination, with said circuit-interrupter, of relaying-means responsive to either a line-to-line fault or a ground-fault on the protected line for effecting the energization of the circuit-interrupter opening-means, and simultaneously responsive relaying-mean, selectively responsive only to an operation resulting in such opening-means energization, and only when accompanied by a fault-current of sufficient intensity to indicate the possibility of an arcing fault, for effecting the energization of the circuit-interrupter closing-means.

3. Fault-responsive protective relaying means for controlling the opening-means and the closing-means of a circuit-interrupter means at both ends of a protected line-section, comprising the combination, with said circuit-interrupter means, of relaying-means directionally responsive to either a heavy-current or a light-current fault on the protected line, and responsive to an into-the-line-looking direction at both ends of the protected line-section, for effecting the energization of the circuit-interrupter opening-means, and simultaneously responsive relaying-means, selectively responsive only to a fault-current of sufficient intensity to indicate the possibility of

an arcing fault, for effecting the energization of the circuit-interrupter closing means.

4. Fault-responsive protective relaying means for controlling the opening-means and the closing means of a circuit-interrupter means at both ends of a protected line-section, comprising the combination, with said circuit-interrupter means, of line-current relaying-means, responsive to an into-the-line-looking direction at both ends of the protected line-section, for effecting the energization of both the opening-means and the closing-means of the circuit-interrupter means, and sensitive ground-current relaying-means, responsive to an into-the-line-looking direction at both ends of the protected line-section, for effecting the energization of only the opening-means of the circuit-interrupter means.

5. Fault-responsive protective relaying means for controlling the opening-means and the closing-means of a circuit-interrupter in a line to be protected, comprising the combination, with said circuit-interrupter, of relaying-means responsive to either a line-to-line fault or a ground-fault on the protected line for effecting the energization of the circuit-interrupter opening-means, and simultaneously responsive relaying-means, selectively responsive only to a ground-fault, and only when accompanied by a fault-current of sufficient intensity to indicate the possibility of an arcing fault, for effecting the energization of the circuit-interrupter closing-means.

6. Fault-responsive protective relaying means for controlling the opening-means and the closing-means of a circuit-interrupter means at both ends of a protected line-section, comprising the combination, with said circuit-interrupter means, of sensitive residual-current relaying-means, responsive to an into-the-line-looking direction at both ends of the protected line-section, for effecting the energization of the circuit-interrupter opening-means, and simultaneously responsive relaying-means, selectively responsive only to a ground-fault, and only when accompanied by a fault-current of sufficient intensity to indicate the possibility of an arcing fault, for effecting the energization of the circuit-interrupter closing-means.

7. Fault-responsive protective relaying means for controlling the opening-means and the closing-means of a circuit-interrupter means at both ends of a protected line-section, comprising the combination, with said circuit-interrupter means, of sensitive residual-current relaying-means, responsive to an into-the-line looking direction at both ends of the protected line-section, for effecting the energization of the circuit-interrupter opening-means, line-current relaying-means, responsive to an into-the-line-looking direction at both ends of the protected line-section, for effecting the energization of the circuit-interrupter opening-means, and simultaneously responsive relaying-means, selectively responsive only to a ground-fault, and only when accompanied by a fault-current of sufficient intensity to indicate the possibility of an arcing fault, for effecting the energization of the circuit-interrupter closing-means.

8. Fault-responsive protective relaying means for controlling the respective opening-means and closing-means of a plurality of single-pole circuit-interrupters in the phase-conductors of a polyphase line-section at both ends thereof, comprising the combination, with said circuit-interrupters, of selective relaying-means for determining which of the line-conductors is faulted, in the event of a single line-to-ground fault within the protected line-section, circuit-means responsive to said selective relaying-means for substantially simultaneously energizing the opening-means of only the single-pole circuit-interrupters at the two ends of the particular line-conductor which is faulted, and circuit-means, responsive to such a selective single-pole operation, but selectively responsive only to a fault-current of sufficient intensity to indicate the possibility of an arcing fault, for effecting the energization of the closing-means of the affected circuit-interrupters.

9. The combination, with the apparatus recited in claim 8, of means responsive to an open condition of any one or more of the plurality of single-pole circuit-interrupters at an end of the protected line-section, accompanied by a closed condition of any one or more of the other single-pole circuit-interrupters at that end, enduring after a tripping-and-reclosure operation, for effecting an opening of the closed circuit-interrupters.

10. Fault-responsive protective relaying means for controlling each of a plurality of single-pole circuit-interrupters in the several phase-conductors of a polyphase line, comprising the combination, with said circuit-interrupters, of selective ground-fault relaying-means for determining which of the line-conductors is faulted, in the event of a single line-to-ground fault on the line, and for causing an opening-operation of only the single-pole circuit-interrupter in that line-conductor, and for automatically thereafter causing a single-pole closing-operation of the same circuit-interrupter, and means for causing said single-pole closing-operation to be selectively responsive only to those single-phase ground-faults that involve at least a predeterminedly high fault-severity in the faulted line-conductor.

11. Fault-responsive protective relaying means for controlling each of a plurality of single-pole circuit-interrupters in the several phase-conductors of a polyphase line, comprising the combination, with said circuit-interrupters, of selective ground-fault relaying-means for determining which of the line-conductors is faulted, in the event of a single line-to-ground fault on the line, and for causing an opening-operation of only the single-pole circuit-interrupter in that line-conductor, and for automatically thereafter causing a single-pole closing-operation of the same circuit-interrupter, means for causing said single-pole closing-operation to be selectively responsive only to those single-phase ground-faults that involve at least a predeterminedly high fault-severity in the faulted line-conductor, and phase-fault relaying-means responsive only to predetermined fault-conditions involving two or more of the line-conductors for causing opening-operations of one or more of the single-pole circuit-interrupters.

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