July 20, 1948. S. L. GOLDSBOROUGH 2,445,429

GROUND-FAULT PROTECTIVE RELAYING SYSTEM

Filed April 6, 1945 2 Sheets-Sheet 1

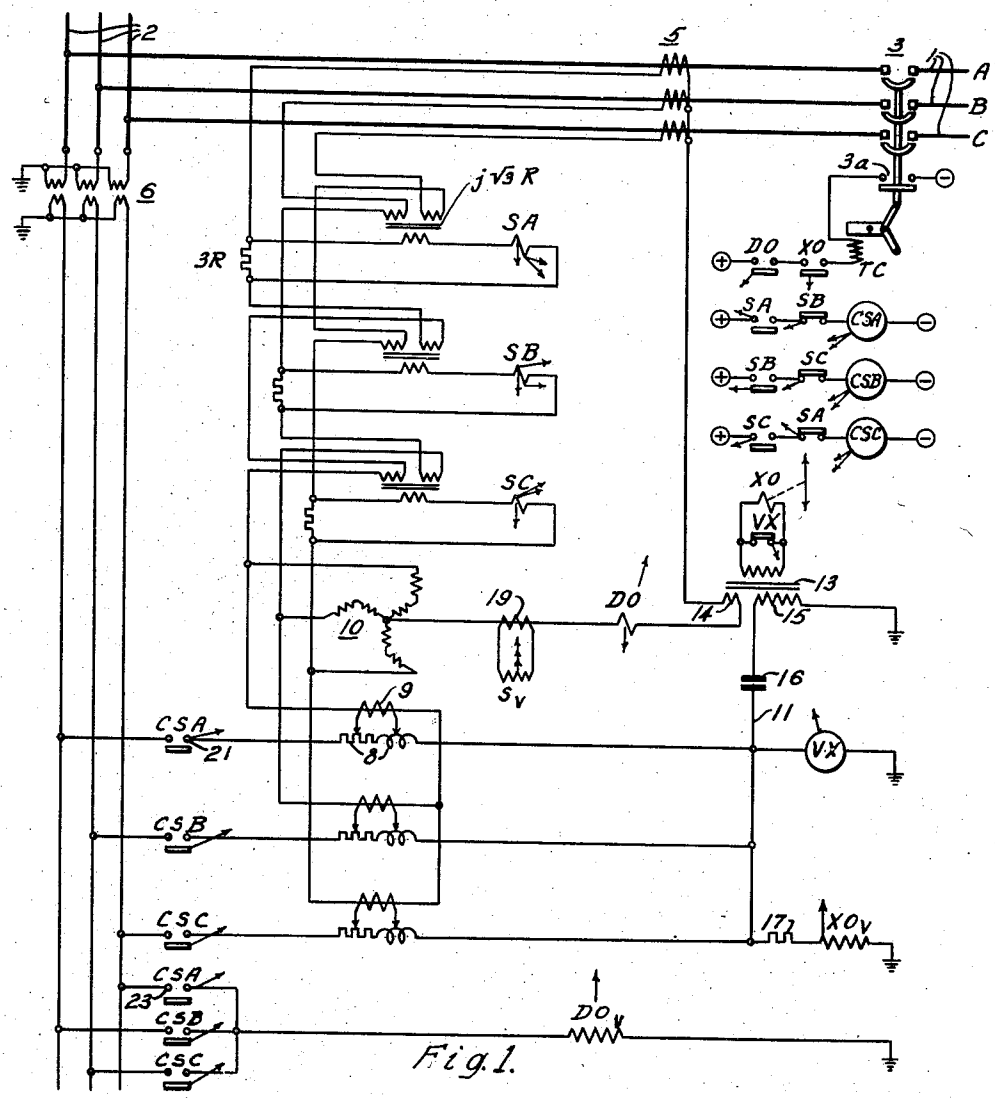


Fig. 1.

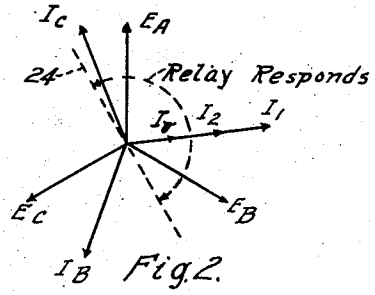


Fig. 2.

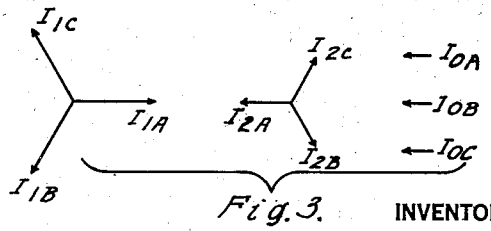


Fig. 3.

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July 20, 1948. S. L. GOLDSBOROUGH 2,445,429

GROUND-FAULT PROTECTIVE RELAYING SYSTEM

Filed April 6, 1945 2 Sheets-Sheet 2

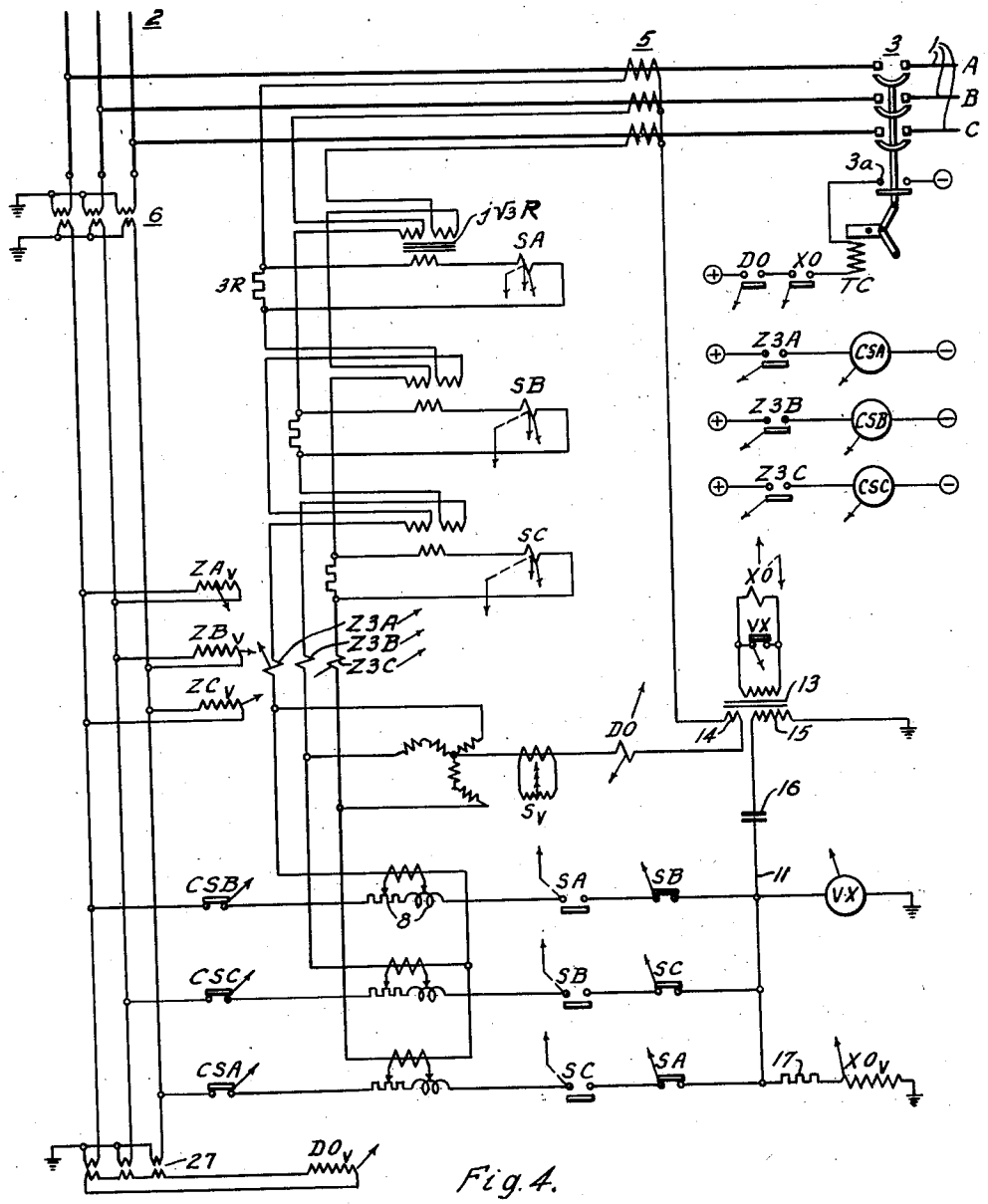


Fig. 4.

WITNESSES:

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Patented July 20, 1948 2,445,429

UNITED STATES PATENT OFFICE

2,445,429

GROUND-FAULT PROTECTIVE RELAYING SYSTEM

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Application April 6, 1945, Serial No. 586,991

25 Claims. (Cl. 175—294)

1

My invention relates to a protective relaying system and apparatus, for providing a distance-response to ground-faults on a polyphase transmission line.

One of the objects of my invention is to provide a simplified reactance ground relay which utilizes only one reactance element, or two elements if a second-zone response is required as well as a first-zone response.

The application of distance-type relaying to ground-relaying requires a comparison of the line-to-ground voltage of the faulted phase with either the line-current of that phase, or the residual current, or both, as set forth in the Lewis Patent 1,897,022, granted February 7, 1933. It also requires some sort of automatic supervision, because it gives improper tripping-responses if the ground-fault involves two phases. Furthermore, both the distance-responsive ground-relay and its double-ground supervisory-relay must be quite sensitive to light ground-faults, without responding to load-currents. The cost of such relays, and the imperfection with which they have met their conflicting requirements, have militated strongly against them in the past.

In my copending application Serial No. 521,801, filed February 10, 1944, Patent No. 2,408,208, granted September 24, 1946, I have shown a simplified and improved distance-measuring ground-fault-relaying-system, requiring only one distance-measuring element for a three-phase line, and having improved double-ground supervisory-means; but its limitations were such that I preferred not to use it on solidly grounded systems which are apt to have ground-faults having little fault-resistance.

An object of my present invention is to provide a distance-measuring ground-fault relay or relays, which are so supervised as to be generally applicable, whether the transmission system has resistance in its grounded neutral or in its ground-faults, or not.

A more specific object of my invention is to provide means for so energizing the ground-directional element that it will have no response on internal two-phase-to-ground faults involving no substantial neutral-resistance or fault-resistance, thus making the directional element perform this part of the supervisory function.

Another specific object of my invention is to provide means for providing this supervision against resistanceless double-ground faults, by a special connection of the distance-type phase-relays, which are, in general, required on any

2

system having distance-type ground-fault relaying.

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

Figure 1 is a diagrammatic view of circuits and apparatus illustrating my invention in a form of embodiment utilizing the ground directional element to block the action of the ground distance relay on two-phase-to-ground faults involving no substantial neutral-resistance or fault-resistance.

Figs. 2 and 3 are vector diagrams, and

Fig. 4 is a view similar to Fig. 1 showing a form of embodiment in which a distance-responsive phase-fault relay is utilized to prevent the response of the distance ground relay on two-phase-to-ground faults.

I have illustrated my invention, in Fig. 1, as being applied to the protection of a three-phase line-section 1, having phases A, B and C. This may be a part of a three-phase, 60-cycle transmission or distribution system. The three-phase line 1 is connected to a three-phase bus 2 through a three-phase circuit-breaker 3, which is illustrated as having an auxiliary make-contact 3a, and a trip-coil TC. The three-phase relaying currents and voltages are derived from the line by means of current-transformers 5 and potential transformers 6, respectively.

When the relaying equipment is utilized for the protection of a power-system which is grounded at more than one point, or which otherwise involves errors in ground-fault distance-measurement due to the manner in which the positive, negative, and zero-sequence currents distribute themselves, it is necessary to utilize some sort of compensating means as set forth in the aforesaid Lewis Patent 1,897,022. By way of illustration, I have chosen the voltage-compensator method which is shown in Fig. 9 of the Lewis patent.

The illustrated compensating method utilizes three compensators 8, which are energized, through auxiliary current-transformers 9, from the respective phase-currents from which the zero-sequence component has been removed. The zero-sequence current-component is removed by means of a suitable grounding-transformer, such as an interconnected star bank 10.

The various relays which make up my protective-relaying system include various line-responsive relays, the various coils and contacts of which are separated into alternating-current circuits

and direct-current circuits, respectively, the various circuits being arranged, so far as practicable, after the matter of a schematic diagram or "across-the-line" diagram. In each case, the main or operating coil of the relay is given a letter-designation or legend, and the same letter-designation or legend is applied to all of the contacts of that relay. The relays and switches are invariably shown in their open or deenergized positions. When a given relay has, in addition to its main or operating winding, an auxiliary winding, such as a restraining or polarizing coil or winding, the auxiliary winding is given the same letter-designation, with a subscript. Arrows or dotted lines are used, to symbolically indicate how the various parts of each relay are connected together. When corresponding elements are utilized in different phases, they are distinguished by suffixes, such as A, B and C, for the different phases.

My improved relaying system, which is shown in Fig. 1, utilizes a single distance-responsive ground-fault relay XO, which suffices for all three phases of the protected line-section. This distance-responsive ground-fault element XO is a differential relay of the reactance type, having a current and voltage-responsive operating coil XO, and having a voltage-responsive restraining-coil XO_V, as shown in the Lewis Patent 1,967,093, granted July 17, 1934. This distance-type ground-fault relay XO is provided with a make-contact which is also designated XO.

The ground-reactance or distance-responsive relay XO is responsive to a selected voltage which is applied to a relaying-bus 11, as will be subsequently described. As explained in the Lewis Patent 1,967,093, the operating winding XO of the ground-reactance relay XO is energized to be responsive to the vectorial sum of the residual current or zero-sequence current-component of the line-current, and the proper line-to-ground voltage-phase. In order to obtain such a response, I have shown a mixing transformer 13 for energizing the operating coil XO. This mixing transformer 13 has two primary windings 14 and 15. The first primary winding 14 is a current-responsive winding which is connected in the residual-current circuit of the line-current transformers 5. The other primary winding 15 is a voltage-responsive winding which is energized from the relaying-bus 11 through a phase-advancing means such as a capacitor 16. The restraining winding XO_V of the ground reactance relay XO is energized from the same relaying-bus 11, through a resistor 17 which keeps the current approximately in phase with the applied voltage.

I also preferably utilize an auxiliary voltage-relay VX, which is energized from the same voltage-responsive relaying-bus 11 which energizes the ground directional relay XO, as explained in my copending application. The auxiliary relay VX has a back-contact VX which is connected in shunt across the operating coil XO of the ground reactance element XO, so as to normally keep the operating coil XO in an unenergized condition, and so that said coil XO will not be energized until a moment after the application of a voltage to the relaying-bus 11.

The distance-measuring ground-reactance relay XO properly responds to the distance (or reactance) of a single line-to-ground fault, provided that the relay is properly energized from the suitably compensated line-to-ground voltage of the faulted phase, and from the residual or zero-sequence line-current. In the case of a two-line-to-ground fault, however, the ground-reactance relay XO will underrespond if its voltage-response is obtained from the leading phase of the two faulted phases, which is quite satisfactory because this type of fault is taken care of by the usual phase-fault relays with which my present invention is not concerned. However, on such a two-phase-to-ground fault, if the voltage-response of the ground-reactance relay XO is obtained from the lagging phase of the two faulted phases, it will overrespond; that is, it will respond for faults beyond the distance to which the distance-responsive relay should reach, which would result in a faulty tripping-operation; and if the ground-reactance relay XO is energized from the sound phase, on a two-phase-to-ground fault, the relay will very much overreach.

In order to select the proper ground reactance response, in the event of a two-phase-to-ground fault, it is necessary to provide some suitable form of ground-fault selector-means, which will either render the ground-reactance relay inoperative, or select the voltage-response to the leading faulted phase, so that the ground-reactance relay will underrespond and do no harm. Thus, phase-selector supervision is needed, whether three ground-reactance relays are utilized, one for each phase of the line, or whether only a single ground-reactance element is utilized, which is properly energized to respond to a selected one of the line-to-ground voltage-phases. Since, in either event, a phase-selector supervision is needed, I have preferred to illustrate, in Fig. 1, a relaying system utilizing only a single ground-reactance element XO, utilizing the phase-selector as a means for selecting the proper voltage-energization for the relay.

Several forms of ground-fault phase-selector means are known, all of which are subject to one disadvantage or another. I have chosen, as the preferred form of phase-selector, a group of sequence-responsive directional elements SA, SB and SC, one for each phase, each being directionally responsive to its own phase of two different phase-sequence components of a three-phase quantity derived from the line; that is, phase-sequence components of either the line-current or the line-voltage. I have chosen to illustrate directional phase-selector relays SA, SB and SC, having current coils SA, SB and SC which are energized in response to the corresponding phase of the negative-sequence component of the line-current, and having voltage coils which are diagrammatically indicated, as a group, under the designation S_V in the drawing, said voltage coils S_V being energized in response to the residual line-current, or the zero-sequence component of the line-current. Such a phase-selector is described and claimed in my Patent 2,320,861, granted June 1, 1943. It directionally compares the corresponding phase of the negative-sequence current with the zero-sequence current-component.

In the case of a single line-to-ground fault, the phase-selectors SA, SB and SC properly select the faulted phase, through the response of the selector which is energized from that phase, while the other two selectors do not respond.

In the case of a double line-to-ground fault, several different kinds of selector-responses can be obtained, depending upon the transmission-line condition. Thus, if the double ground-fault has no neutral-resistance or fault-resistance, the negative- and zero-sequence directional selectors

SA, SB and SC will erroneously select the sound phase for the ground-reactance or distance-response, which would cause the reactance or distance relay to very much overreach, and this action must be blocked. If the double ground-fault has either neutral or fault resistance, the leading faulted phase may be additionally selected by the phase-selectors, in addition to the sound phase, so that it is necessary to provide circuit-connections for selecting only the lagging one of the two phases selected by the phase-selectors, if two phase-selectors respond, so that the ground-reactance or distance-responsive element will be energized from the leading faulted phase, and will underrespond rather than overrespond.

In the drawing, the negative-sequence current-component, for energizing the current-coils SA, SB and SC, is obtained, for each phase, by adding the voltage-drop produced by passing the line-current of that phase through a resistor **3R**, to the voltage-drop which is obtained by passing the difference between the other two line-currents through an impedance $j\sqrt{3}R$, as described and claimed in the Lenehan Patent 2,309,649, granted February 2, 1943. Thus, the operating coil SA of the phase-A selector, is energized so as to be responsive to $3RI_a+j\sqrt{3}R(I_c-I_b)$.

The zero-sequence current-response, for energizing the voltage coils S_V of the three phase-selectors SA, SB and SC, is obtained by means of an auxiliary current-transformer **19** in the residual-current connections of the line-current transformers **5**.

I also utilize a ground-directional element DO, which is a wattmetric or product-responsive relay, having a current-coil DO, a voltage-coil DO_V, and a make-contact DO.

The tripping-circuit, for energizing the trip-coil TC of the circuit-breaker **3**, is extremely simple, consisting simply of the contacts DO and XO, of the ground-directional and ground-reactance elements, respectively, these contacts being connected in series with each other, and in series with the auxiliary breaker-switch **3***a*, to energize the trip-coil TC.

In the form of embodiment of my invention shown in Fig. 1, I utilize a special voltage-coil energization of the ground-directional element DO. The current-coil DO is energized from the zero-phase-sequence or residual current, as usual. Ordinarily, the voltage-coil DO_V would be energized in response to the zero-sequence voltage, so that the ground-directional element properly responds to the direction of the residual current, or zero-sequence component of the line-current. However, in the form of my invention shown in Fig. 1, I make a special use of the ground-directional relay DO, by making it respond just oppositely to the proper directional response, in the event of a two-phase-to-ground fault, having no neutral or fault resistance, so that the ground-directional relay DO may be used to block the erroneous response of the ground-reactance or distance-responsive element under such circumstances.

I accomplish this special response of the ground-directional element DO by energizing its voltage coil DO_V in response to the phase-to-ground voltage which leads the phase selected by the ground-fault phase-selector. To accomplish this, I utilize three auxiliary contactor-switches CSA, CSB and CSC, the operating coils of which are energized in series with the make-contacts of the corresponding phases of the phase-selectors SA, SB and SC, supervised by the back-contacts of the next lagging phase-selectors SB, SC and SA, respectively, so that, if two of the phase-selectors respond, the one having the lagging phase is selected. Thus, the CSA coil is energized in response to the closure of the SA make-contact, and the non-opening of the SB back-contact, thus energizing this CSA coil if the SA relay responds and the SB relay does not respond. If both the SA and SB relays respond, but not the SC relay, the CSB coil is energized in response to the closure of the SB make-contact. It is to be noted that the selected phase, B, is the lagging one of the two phases A and B which are selected, or responded to, by the phase-selectors SA and SB in the event of a two-phase-to-ground fault.

As shown in the bottom half of Fig. 1, I make two uses of the relay-contacts CSA, CSB and CSC. One set of make-contacts of the auxiliary relays CSA, CSB and CSC, as indicated at **21**, is utilized to energize the previously mentioned relaying-bus **11** from the correspondingly lettered phase of the line-to-ground voltage, with the compensator-impedance **8** included in series with the line-to-ground voltage. A second set of make-contacts of the auxiliary relays CSA, CSB and CSC, as shown at **23**, is utilized to connect the next leading phase-to-ground voltage-phase to the voltage-coil DO_V of the ground-directional relay DO, so that, for example, if the phase-A auxiliary relay CSA picks up, it energizes the ground-directional voltage-coil DO_V in response to the phase-C line-to-ground voltage.

The operation of my specially energized ground-directional element DO will more readily be understood by reference to Figs. 2 and 3. Fig. 2 shows the three line-to-ground phases of the line-voltages E_A, E_B and E_C. Fig. 2 also shows two different fault-current conditions. One current is a single-phase ground-fault current, which is characterized by equal components of positive, negative, and zero-sequence components, all in phase with each other, as indicated at I_1, I_2 and I_0. Such a fault is assumed to be on phase-A. The other fault-current condition, indicated on Fig. 2, is for a double ground-fault, which is assumed to be on phases B and C, for a two-phase-to-ground fault, with the fault-currents I_B and I_C, respectively. It should be understood, of course, that the single-phase and the double-phase fault-currents do not exist at the same time. They are for different fault-conditions. The symmetrical-component resolution of the two-phase fault-currents B and C of Fig. 2, with no phase-A current, is shown in Fig. 3.

The operation of my specially energized ground-directional relay DO can thus be understood by reference to Figs. 2 and 3.

In the event of a single-phase ground-fault, say on phase-A, the phase-A selector SA will energize the CSA auxiliary relay, and this will apply the phase-C line-to-ground voltage to the voltage-coil DO_V of the ground-directional element DO. Reference to Fig. 2 will show that the zero-sequence current-component I_0, which energizes the current-coil DO of the ground-directional relay, is in a proper direction to make the relay respond when its voltage-coil DO_V is energized with the phase-C voltage E_C, the response-area under such circumstances being when the zero-sequence current-vector extends to the right of the dotted line **24**, as indicated in Fig. 2. Under such circumstances, the ground-directional relay DO responds, and closes its make-contact DO in the tripping-circuit, which results in a trip-

ping operation if the ground-fault is within the limiting distance to which the ground-reactance relay XO responds.

In the event of a two-line-to-ground fault, involving, say, phase-conductors B and C, two different conditions may prevail. If there is no neutral resistance or fault resistance, the phase-selector SA, for the sound phase, will erroneously respond, and neither of the two faulted-phase selectors SB or SC will respond. The response of the sound-phase selector SA energizes the CSA auxiliary relay, and applies the sound-phase line-to-ground voltage to the ground-reactance element XO, causing the latter to overreach, which would involve erroneous tripping-operations if tripping were not otherwise blocked. Under such circumstances, however, the CSA auxiliary contactor applies the phase-C line-to-ground voltage E_C to the ground-directional element DO, as shown in Fig. 2, but Fig. 3 shows that the zero-sequence components I_{OA}, I_{OB}, I_{OC} are almost 180° out of phase with the single-fault zero-sequence current I_0 in Fig. 2, so that the zero-sequence current-component is now in a phase which results in no response of the ground-directional relay DO when it is energized with the phase-C voltage E_C. Thus the ground-directional contacts DO do not close in the tripping-circuit, and no tripping results.

In case the double ground-fault on phases B and C is accompanied by either neutral or fault resistance, the phase-selector SB for the leading faulted phase B may pick up (if the resistance is sufficient), in addition to the sound-phase selector SA. Under such circumstances, the opening of the SB back-contact prevents the energization of the auxiliary relay CSA, while the phase-B auxiliary relay CSB will pick up in response to the closure of the SB make-contact. One of the CSB make-contacts applies the phase-B line-to-ground voltage to the ground-reactance element XO, which makes it underrespond, which is a safe condition. Another CSB make-contact applies the sound-phase voltage E_A of Fig. 2 to the voltage-coil DO_V of the ground-directional element. Comparison of Figs. 2 and 3 will show that the phase of the zero-sequence component of the two-phase fault-currents I_B and I_C is somewhere near the border-line between a response and a non-response of the ground-directional relay DO, when energized with the phase-A voltage E_A. If the ground-directional relay DO does not respond, there will be no tripping-action in response to the ground-reactance element XO, which is all right because a double ground fault will be properly taken care of by the phase-fault relays, which are always provided, and which constitute no part of my present invention. If the ground-directional relay DO does respond, under the circumstances just described, again no harm is done, because the ground-reactance relay DO underresponds because of its energization with the voltage of the leading faulted phase B.

It will thus be seen that my special energization of the ground-directional relay DO enables it to properly supervise the ground-reactance or distance-responsive element XO, so that my ground-responsive relaying-apparatus always responds properly, on single-phase ground-faults, and it either does not respond at all, or underresponds, in the event of a two-phase-to-ground fault, which is a safe condition, leaving such faults to be handled by the phase-fault relays (not shown).

In Fig. 4, I have shown another means for supervising the ground-fault relays, so that they will not improperly operate, in the event of two-phase-to-ground faults having little or no neutral resistance or fault resistance. As explained in connection with the Fig. 1 embodiment of my invention, such a fault results in an erroneous response of the sound-phase phase-selector, such as the selector SA for a B-to-C ground-fault; and the operation of the SA selector results in applying the phase-A line-to-ground voltage to the distance-responsive ground-reactance element DO, which causes it to overreach, enabling it to respond to faults which are too far away. In Fig. 1, an erroneous tripping-response was prevented by a special line-to-ground voltage-energization of the ground-directional element DO, causing the latter to also falsely respond, cancelling the false response of the phase-selector SA, and thus preventing the overreaching response of the ground-reactance element XO, in the tripping circuit.

In Fig. 4, instead of providing this special line-to-ground voltage-energization of the ground-directional element DO, I energize the voltage-coil DO_V of the ground-directional relay DO in response to the zero-sequence line-voltage component, in the conventional manner, as, for example, by utilizing a bank of auxiliary potential transformers 27, which are energized from the potential transformers 6, for providing the response to the zero-sequence voltage-component. This makes the ground-directional element DO respond correctly for all ground-faults, including double ground-faults, whether with or without resistance.

In Fig. 4, instead of utilizing auxiliary relays CSA, CSB and CSC, to respond to the picking up of the respective selector-relays SA, SB and SC, whenever the next lagging phase of the selector-relays does not pick up, I utilize the respective front and back contacts of the selector-relays, in the same pairs as before, in the corresponding phases of the line-to-ground voltages which are applied to the relaying bus 11, these selector-relay contacts being in lieu of the auxiliary contacts 21 of the contactor-switches CSA, CSB and CSC in Fig. 1.

To prevent faulty response, or overreaching, of the ground-reactance relay XO, in Fig. 4, in the event of a resistanceless double-phase ground-fault, which energizes only the sound-phase, phase-selector SA, for example, I provide contactor-switch back-contacts CSB, CSC and CSA, respectively, in the phase-A, phase-B and phase-C voltage-circuits, responsively, and I energize the operating-coils of the auxiliary relays CSA, CSB and CSC in response to the correspondingly lettered third-zone phase-fault impedance relays Z3A, Z3B and Z3C of the phase-fault relaying equipment. Any transmission system which warrants the expense of distance-type ground-fault relaying, will, in general, also have distance-type phase-fault relays, among which will be included third-zone phase-fault distance-relays Z3A, Z3B and Z3C, for the three line-phases A, B and C, respectively. These third-zone phase-relays may be, for example, of a differential type, having operating windings Z3A, Z3B and Z3C, energized from the respective phases of the line-currents, and having restraining windings ZA_V and ZB_V and ZC_V, energized from the corresponding phase-voltages of the line.

In the operation of the system shown in Fig. 4, whenever there is a double phase-to-ground resistanceless fault, involving, say, phases B and C,

within the reach of the ground-fault relay XO, the phase-B third-zone phase-fault distance-element Z3B will always respond, thus energizing the phase-B auxiliary relay CSB, which opens its back-contact CSB which is in series with the make-contact of the phase-A selector-relay SA. As previously described, this phase-A selector-relay SA erroneously responds to such a resistanceless double ground-fault, and no other selector-relay responds under such circumstances. Hence, neither one of the three alternative voltage-circuits which are connected to the auxiliary relay-bus 11 is energized, which means that the ground-reactance relay XO is not energized, and there is no ground-fault tripping-operation under such circumstance.

In the case of a double ground-fault having resistance, the phase-C third-zone phase-fault relay Z3C may sometimes pick up, in which case it would block the operation of the ground-reactance relay XO, but this will do no harm, as the phase-fault relays properly take care of faults involving two phases of the line-conductors, through phase-fault tripping-circuits which I have not shown, as they are, or may be, conventional.

In the event of a single-phase ground-fault, say on phase-A, in the Fig. 4 embodiment of my invention, the phase-B third-zone phase-fault relay Z3B cannot respond to a fault involving only phase-A; and any possible response of the phase-A phase-fault relay Z3A would not block my phase-A ground-fault tripping.

While I have shown my invention in two illustrative forms of embodiment, I desire it to be understood that my invention is not limited to these precise forms, and that the appended claims are to be accorded the broadest construction consistent with their language.

I claim as my invention:

1. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault reactance-responsive relaying-means for responding to the line-reactance of a predetermined phase of the line-conductors, said distance-measuring response being accurate only if a single ground-fault occurs on said predetermined phase, in combination with ground-fault phase-selector means for making a selection of an apparently ground-faulted phase, said phase-selector means being operative to properly select the faulted phase in the event of a single ground-fault, and being operative to select only the leading one of the two faulted phases in the event of a double ground-fault having adequate resistance, and being operative to erroneously select the sound phase in the event of a resistanceless double ground-fault, said phase-selection of the phase-selector means being made without an accurate determination of the distance of the fault by said phase-selector means, means for obtaining an indication of a joint response of said distance-measuring relaying-means in said predetermined phase, and a selection of that same phase by said phase-selector means, and means for blocking said indication in response to a double ground-fault of predeterminably low resistance.

2. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means energized from line-derived quantities including a phase-to-ground line-voltage and the zero-sequence line-current, in combination with ground-fault phase-selector means for making a selection of an apparently ground-faulted phase, said phase-selector means being operative to properly select the faulted phase in the event of a single ground-fault, and being operative to select only the leading one of the two faulted phases in the event of a double ground-fault having adequate resistance, and being operative to erroneously select the sound phase in the event of a resistanceless double ground-fault, said phase-selection of the phase-selector means being made without an accurate determination of the distance of the fault by said phase-selector means, means for obtaining a joint indication of a phase-selection and a distance-response to the phase-to-ground voltage of the selected phase, and means for blocking said indication in response to a double ground-fault of predeterminably low resistance.

3. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means, means for supplying said ground-fault distance-measuring relaying-means with a relaying-current dependent upon the zero-phase-sequence line-current, means for supplying said ground-fault distance-measuring relaying-means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, ground-fault phase-selector means for selecting and applying one of said relaying-voltages to said distance-measuring relaying-means, means for performing a line-protective operation in response to said distance-measuring relaying-means, and means for blocking said line-protective operation in response to a double ground-fault of predeterminably low resistance.

4. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault reactance-responsive relaying-means for responding to the line-reactance of a predetermined phase of the line-conductors, said distance-measuring response being accurate only if a single ground-fault occurs on said predetermined phase, in combination with a plurality of ground-fault phase-selector relays, one for each phase, each being directionally responsive to its own phase of the negative and zero phase-sequence components of a three-phase quantity derived from the line, means for obtaining an indication of a joint response of said distance-measuring relaying-means in said predetermined phase, a response of the phase-selector relay for that phase, and a non-response of the phase-selector relay for the next lagging phase, and means for blocking said indication in response to a double ground-fault of predeterminably low resistance.

5. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means, means for supplying said ground-fault distance-measuring relaying-means with a relaying-current dependent upon the zero-phase-sequence line-current, means for supplying said ground-fault distance-measuring relaying-means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, a plurality of ground-fault phase-selector relays, one for each phase, each being directionally responsive to its own phase of the negative and zero phase-sequence components of a three-phase quantity derived from the line, means for selecting and applying one of said relaying-voltages to said distance-measuring relaying-means in accord-

ance with the phase selected by the response of any phase-selector relay, means for blocking said voltage-application in response to a simultaneous response of the phase-selector relay for the next lagging phase, means for performing a line-protective operation in response to said distance-measuring relaying-means, and means for blocking said line-protective operation in response to a double ground-fault of predeterminably low resistance.

6. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault reactance-responsive relaying-means for responding to the line-reactance of a predetermined phase of the line-conductors, said distance-measuring response being accurate only if a single ground-fault occurs on said predetermined phase, in combination with ground-fault phase-selector means for making a selection of an apparently ground-faulted phase, said phase-selector means being operative to properly select the faulted phase in the event of a single ground-fault, and being operative to select only the leading one of the two faulted phases in the event of a double ground-fault having adequate resistance, and being operative to erroneously select the sound phase in the event of a resistanceless double ground-fault, said phase-selection of the phase-selector means being made without an accurate determination of the distance of the fault by said phase-selector means, a ground-directional relaying-means energized from line-derived quantities including a phase-to-ground line-voltage and the zero-phase-sequence line-current, and means for obtaining an indication of a joint response of said distance-measuring relaying-means in said predetermined phase, and a selection of that same phase by said phase-selector means, and a ground-directional response to the phase-to-ground voltage which leads the phase selected by the phase-selector means.

7. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means energized from line-derived quantities including a phase-to-ground line-voltage and the zero-sequence line current, in combination with ground-fault phase-selector means for making a selection of an apparently ground-faulted phase, said phase-selector means being operative to properly select the faulted phase in the event of a single ground-fault, and being operative to select only the leading one of the two faulted phases in the event of a double ground-fault having adequate resistance, and being operative to erroneously select the sound phase in the event of a resistanceless double ground-fault, said phase-selection of the phase-selector means being made without an accurate determination of the distance of the fault by said phase-selector means, a ground-directional relaying-means energized from line-derived quantities including a phase-to-ground line-voltage and the zero-phase-sequence line-current, and means for obtaining an indication of a joint response of said distance-measuring relaying-means in said predetermined phase, and a selection of that same phase by said phase-selector means, and a ground-directional response to the phase-to-ground voltage which leads the phase selected by the phase-selector means.

8. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means, means for supplying said ground-fault distance-measuring relaying-means with a relaying-current dependent upon the zero-phase-sequence line-current, means for supplying said ground-fault distance-measuring relaying-means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, a ground-directional relaying-means, means for supplying said ground-directional relaying-means with a relaying current dependent upon the zero-phase-sequence line-current, means for supplying said ground-directional relaying means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, ground-fault phase-selector means for selecting and applying one of said relaying-voltages to said distance-measuring relaying-means, and for applying the phase-to-ground voltage of the next leading phase to said ground-directional relaying-means, and means for performing a line-protective operation jointly in response to said distance-measuring relaying-means and said ground-directional relaying-means.

9. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault reactance-responsive relaying-means for responding to the line-reactance of a predetermined phase of the line-conductors, said distance-measuring response being accurate only if a single ground-fault occurs on said predetermined phase, in combination with a plurality of ground-fault phase-selector relays, one for each phase, each being directionally responsive to its own phase of the negative and zero phase-sequence components of a three-phase quantity derived from the line, a ground-directional relaying-means energized from line-derived quantities including a phase-to-ground line-voltage and the zero-phase-sequence line-current, and means for obtaining an indication of a joint response of said distance-measuring relaying-means in said predetermined phase, a response of the phase-selector relay for that phase, a non-response of the phase-selector relay for the next lagging phase, and a response of said ground-directional relaying-means in the phase leading said predetermined phase.

10. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means, means for supplying said ground-fault distance-measuring relaying-means with a relaying-current dependent upon the zero-phase-sequence line-current, means for supplying said ground-fault distance-measuring relaying-means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, a ground-directional relaying-means, means for supplying said ground-directional relaying-means with a relaying-current dependent upon the zero-phase-sequence line-current, means for supplying said ground-directional relaying means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, a plurality of ground-fault phase-selector relays, one for each phase, each being directionally responsive to its own phase of the negative and zero phase-sequence components of a three-phase quantity derived from the line, means for selecting and applying one of said relaying-voltages to said distance-measuring relaying-means, and for applying the

phase-to-ground voltage of the next leading phase to said ground-directional relaying-means, in accordance with the phase selected by the response of any phase-selector relay, means for blocking said voltage-applications in response to a simultaneous response of the phase-selector relay for the next lagging phase, and means for performing a line-protective operation jointly in response to said distance-measuring relaying-means and said ground-directional relaying-means.

11. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault reactance-responsive relaying-means for responding to the line-reactance of a predetermined phase of the line-conductors, said distance-measuring response being accurate only if a single ground-fault occurs on said predetermined phase, in combination with ground-fault phase-selector means for making a selection of an apparently ground-faulted phase, said phase-selector means being operative to properly select the faulted phase in the event of a single ground-fault, and being operative to select only the leading one of the two faulted phases in the event of a double ground-fault having adequate resistance, and being operative to erroneously select the sound phase in the event of a resistanceless double ground-fault, said phase-selection of the phase-selector means being made without an accurate determination of the distance of the fault by said phase-selector means, a phase-fault relaying-means which is responsive to predeterminably severe faults on the two phases of the line-conductors other than said predetermined phase, and means for obtaining an indication of a joint response of said distance-measuring relaying-means in said predetermined phase, and a selection of that same phase by said phase-selector means, and a non-response of said phase-fault relaying-means.

12. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means energized from line-derived quantities including a phase-to-ground line-voltage and the zero-sequence line-current, in combination with ground-fault phase-selector means for making a selection of an apparently ground-faulted phase, said phase-selector means being operative to properly select the faulted phase in the event of a single ground-fault, and being operative to select only the leading one of the two faulted phases in the event of a double ground-fault having adequate resistance, and being operative to erroneously select the sound phase in the event of a resistanceless double ground-fault, said phase-selection of the phase-selector means being made without an accurate determination of the resistance of the fault by said phase-selector means, a phase-fault relaying-means which is responsive to predeterminably severe faults on the two phases of the line-conductors other than said predetermined phase, and means for obtaining an indication of a joint response to said distance-measuring relaying-means in said predetermined phase, and a selection of that same phase by said phase-selector means, and a non-response of said phase-fault relaying-means.

13. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means, means for supplying said ground-fault distance-measuring relaying-means with a relaying-current dependent upon the zero-phase-sequence line-current, means for supplying said ground-fault distance-measuring relaying-means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, ground-fault phase-selector means for selecting and applying one of said relaying-voltages to said distance measuring relaying-means, means for performing a line-protective operation in response to said distance-measuring relaying-means, and means for blocking said line-protective operation in response to a predeterminably severe double-phase fault on the two phases of the line-conductors other than the phase selected by said phase-selector means.

14. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault reactance-responsive relaying-means for responding to the line-reactance of a predetermined phase of the line-conductors, said distance-measuring response being accurate only if a single ground-fault occurs on said predetermined phase, in combination with a plurality of ground-fault phase-selector relays, one for each phase, each being directionally responsive to its own phase of the negative and zero phase-sequence components of a three-phase quantity derived from the line, means for obtaining an indication of a joint response of said distance-measuring relaying-means in said predetermined phase, a response of the phase-selector relay for that phase, and a non-response of the phase-selector relay for the next lagging phase, and means for blocking said indication in response to a predeterminably severe double-phase fault on the two phases of the line-conductors other than said predetermined phase.

15. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means, means for supplying said ground-fault distance-measuring relaying-means with a relaying-current dependent upon the zero-phase-sequence line-current, means for supplying said ground-fault distance-measuring relaying-means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, a plurality of phase-fault fault-detector means, one for each pair of phases, a plurality of ground-fault phase-selector relays, one for each phase, each being directionally responsive to its own phase of the negative and zero phase-sequence components of a three-phase quantity derived from the line, means for selecting and applying one of said relaying-voltages to said distance-measuring relaying-means in accordance with the phase selected by the response of any phase-selector relay, means for performing a line-protective operation in response to said distance-measuring relaying-means, and means for blocking said line-protective operation in response to an operation of either the phase-selector relay for the next lagging phase or the phase-fault fault-detector means for a fault on the two phases other than the phase selected by said response of a phase-selector relay.

16. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault reactance-responsive relaying-means for responding to the line-reactance of a predetermined phase of the line-conductors, said distance-measuring response being accurate only if

a single ground-fault occurs on said predetermined phase, being under-responsive if a double ground-fault occurs on said predetermined phase and the next lagging phase of the line, and being over-responsive if a double ground-fault occurs on any other combination of two line-phases, in combination with selective-phase-sequence-responsive ground-fault selector-means for so responding to double ground-faults as to render said distance-measuring ground-fault reactance-responsive relaying-means ineffectual upon the occurrence of any double ground-fault other than one which involves said predetermined phase and the next lagging phase of the line.

17. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault reactance-responsive relaying-means for responding to the line-reactance of a predetermined phase of the line-conductors, selective-phase-sequence-responsive ground-fault selector-means for responding to ground-faults so as to permit effectual operation of said distance-measuring relaying-means only when said predetermined phase is responded to by said selector-means and when the next lagging phase is not responded to by said selector-means, and means for rendering said distance-measuring relaying-means ineffectual in response to a double ground-fault of predeterminably low resistance.

18. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means energized from line-derived quantities including a phase-to-ground line-voltage and the zero-sequence line-current, in combination with selective-phase-sequence-responsive ground-fault selector-means for so responding to double ground-faults as to render said distance-measuring ground-fault reactance-responsive relaying-means ineffectual upon the occurrence of any double ground-fault other than one which involves said phase-to-ground line-voltage and the next lagging phase of the line.

19. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means, means for supplying said ground-fault distance-measuring relaying-means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, in combination with selective-phase-sequence-responsive ground-fault selector-means for responding to ground-faults so as to select and apply, to said distance-measuring relaying-means, the relaying-voltage dependent upon the faulted line-phase in the event of a single ground-fault, and so as to either select and apply, to said distance-measuring relaying-means, the relaying-voltage dependent upon the leading faulted line-phase or to render said distance-measuring relaying-means ineffectual in the event of a double ground-fault, depending upon the neutral resistance and the fault-resistance.

20. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means, means for supplying said ground-fault distance-measuring relaying-means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, in combination with selective-phase-sequence-responsive ground-fault selector-means for responding to ground-faults so as to select and apply, to said distance-measuring relaying-means, the relaying-voltage dependent upon the line-phase responded to by the selector-means, provided that the next lagging line-phase is not also responded to by the selector-means, and means for rendering said distance-measuring relaying-means ineffectual in response to a double ground-fault of predeterminably low resistance.

21. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault reactance-responsive relaying-means for responding to the line-reactance of a predetermined phase of the line-conductors, a ground-directional relaying-means for responding to a predetermined direction of a ground-fault line-quantity in the phase next leading said predetermined phase, and means for performing a line-protective operation jointly in response to said distance-measuring relaying-means and said ground-directional relaying-means.

22. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means energized from line-derived quantities including a phase-to-ground line-voltage and the zero-sequence line-current, a ground-directional relaying-means energized from line-derived quantities including the zero-sequence line-current and the phase-to-ground line-voltage next leading the phase which is applied to said distance-measuring relaying-means, and means for performing a line-protective operation jointly in response to said distance-measuring relaying-means and said ground-directional relaying-means.

23. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means, a ground-directional relay-means, means for supplying said ground-fault distance-measuring relaying-means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, means for supplying said ground-directional relaying means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, selective-phase-sequence-responsive ground-fault selector-means for responding to ground-faults so as to select and apply, to said distance-measuring relaying-means, the relaying-voltage dependent upon the line-phase responded to by the selector-means, provided that the next lagging line-phase is not also responded to by the selector-means, and so as to apply, to said ground-directional relaying-means, the relaying voltage dependent upon the line-phase which next leads the phase which is applied to the distance-measuring relaying-means, and means for performing a line-protective operation jointly in response to said distance-measuring relaying-means and said ground-directional relaying-means.

24. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault reactance-responsive relaying-means for responding to the line-reactance of a predetermined phase of the line-conductors, selective-phase-sequence-responsive ground-fault selector-means for responding to ground-faults so as to permit

effectual operation of said distance-measuring relaying-means only when said predetermined phase is responded to by said selector-means and when the next lagging phase is not responded to by said selector-means, and phase-fault relaying-means, sensitively responsive to phase-faults involving the line-phase next lagging said predetermined phase, for rendering said distance-measuring ground-fault relaying-means ineffectual.

25. Relaying apparatus for ascertaining ground-faults on a three-phase line, comprising a single-phase distance-measuring ground-fault relaying-means, means for supplying said ground-fault distance-measuring relaying-means with any one of a plurality of relaying-voltages dependent upon the different phase-to-ground line-voltages respectively, in combination with selective-phase-sequence-responsive ground-fault selector-means for responding to ground-faults so as to select and apply, to said distance-measuring relaying-means, the relaying-voltage dependent upon the line-phase responded to by the selector-means, provided that the next lagging line-phase is not also responded to by the selector-means, and phase-fault relaying-means, sensitively responsive to phase-faults involving the line-phase next lagging said line-phase responded to by the selector-means, for rendering said distance-measuring ground-fault relaying-means ineffectual.

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