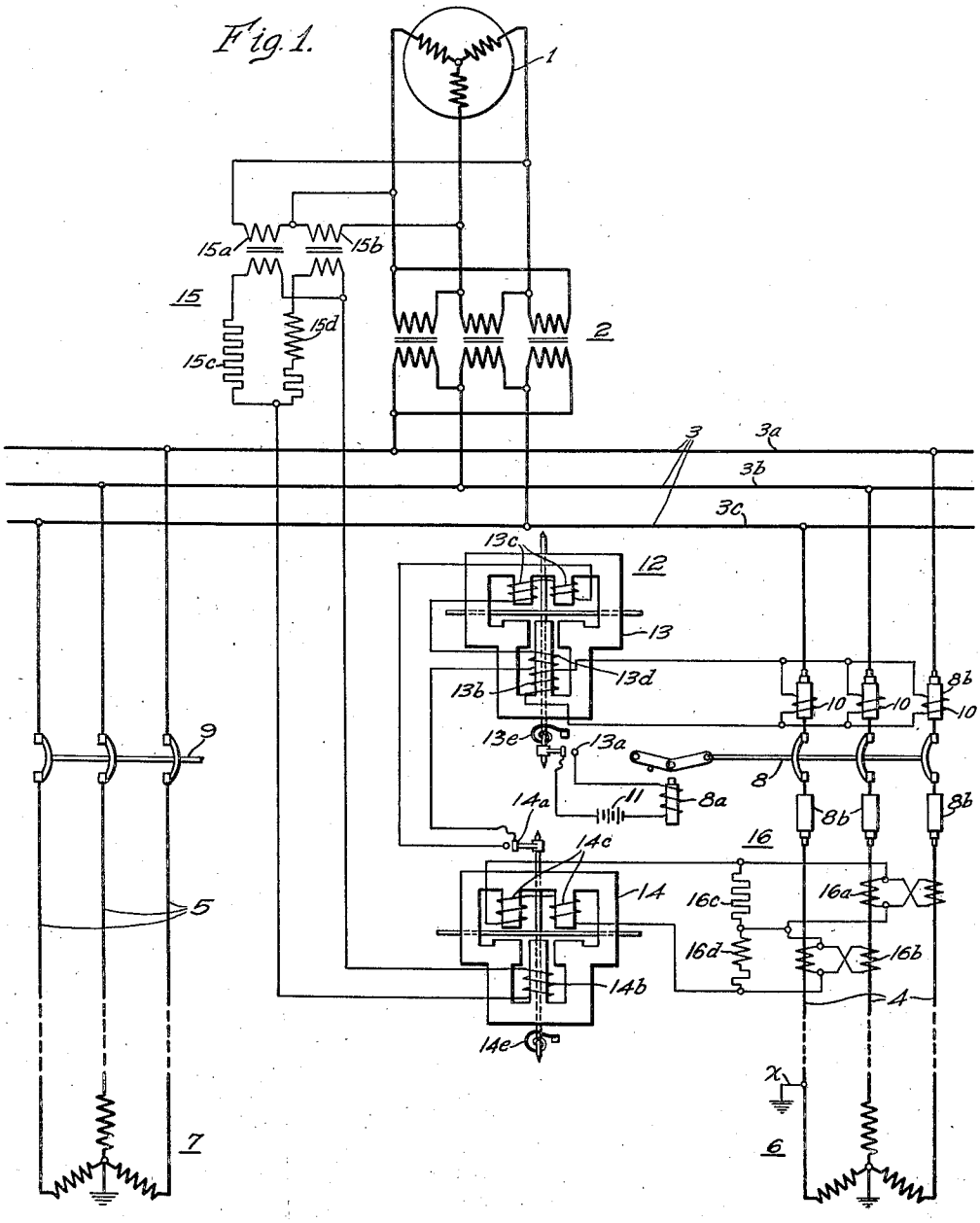
Jan. 5, 1937. R. D. EVANS 2,066,932

DIRECTIONAL GROUND RELAY

Filed Dec. 28, 1933 2 Sheets-Sheet 1

Fig. 1.



WITNESSES:
C. J. Weller,
Geo. O. Harrison.

INVENTOR
Robert D. Evans.
BY J. C. Saltzman
ATTORNEY

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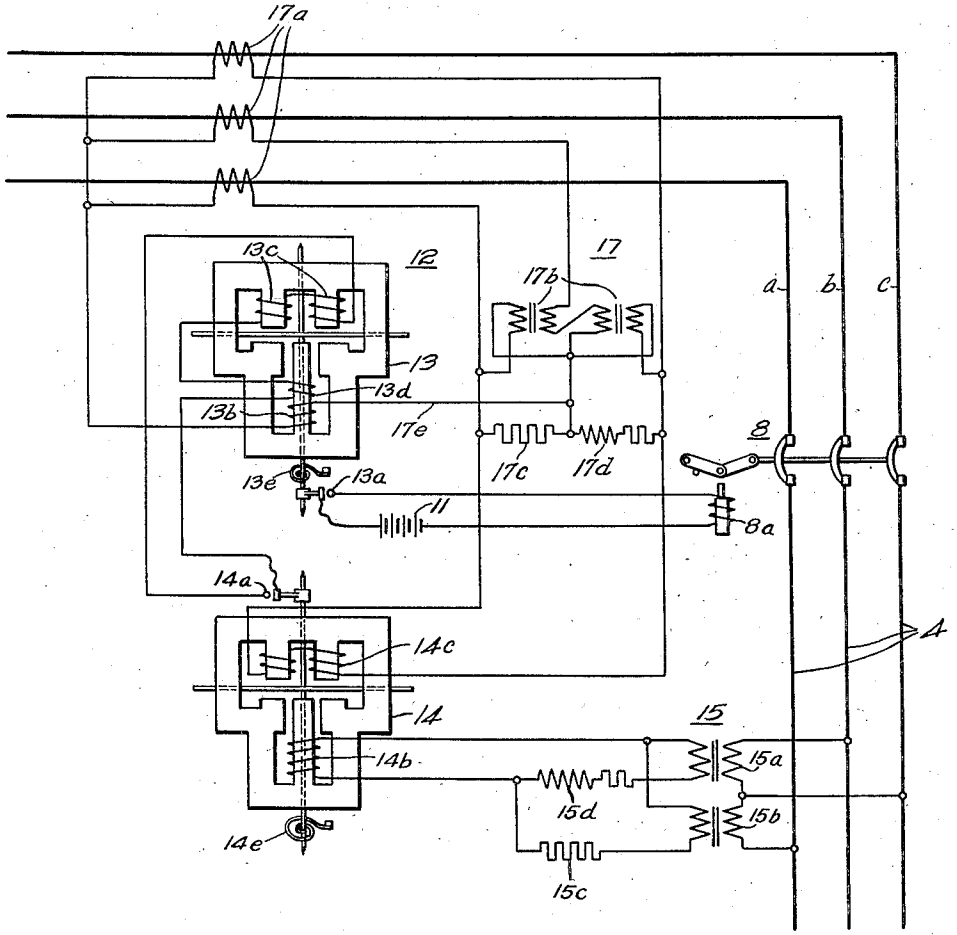
Fig. 2.



WITNESSES:

C. J. Weller.

Geo. O. Harrison

INVENTOR

Robert D. Evans.

BY W. Waltzman

ATTORNEY

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DIRECTIONAL GROUND RELAY

Robert D. Evans, Swissvale, Pa., assignor to Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., a corporation of Pennsylvania

Application December 28, 1933, Serial No. 704,310

8 Claims. (Cl. 175—294)

My invention relates to protective apparatus for electric circuits and particularly to directional ground relays for polyphase alternating current transmission and distribution circuits.

Although not limited thereto, my invention is particularly applicable to ground relays of the type consisting of independent power-directional and current responsive elements as usually applied for clearing ground faults in polyphase circuits having at least one neutral point grounded solidly or through a reactor or resistor. In such relays as commonly constructed, the power directional element is energized in accordance with a vector product of zero sequence voltage and zero sequence current, or in accordance with a residual power product of the protected circuit.

In order to obtain the zero sequence voltage necessary for the power directional element of such relays, either of two connections may be used dependent upon the type of power apparatus available at the point at which the relay is applied. If a polyphase transformer or bank of transformers having star connected high voltage windings with neutral grounded and delta connected low voltage windings is available, the equivalent of zero sequence voltage may be obtained by a single current transformer connected in the neutral ground conductor of the high voltage windings. If no such star-delta apparatus is available, three insulating potential transformers must be used to obtain the zero sequence voltage.

As the cost of an insulating potential transformer for use at transmission voltages is of the order of 10 to 15 times the cost of a directional ground relay and approximately double the cost of an insulating current transformer of the same voltage rating, it will be apparent that the overall cost of a ground relay installation may be considerably reduced by eliminating one or more of the three insulating potential transformers ordinarily used.

It is accordingly an object of my invention to provide a novel directional ground relay for three-phase circuits which shall require a maximum of two insulating potential transformers.

Another object of my invention is to provide a novel directional ground relay having a potential winding which may be energized from the low voltage side of any polyphase transforming apparatus available at the relaying point.

Another object of my invention is to provide a novel directional ground relay which shall respond to unsymmetrical line-to-line faults as well as ground faults.

A further object of my invention is to provide a novel directional ground relay having a directional element energized in accordance with variables which may pass delta connected transformer windings.

Other objects of my invention will become evident from the following detailed description taken in conjunction with the accompanying drawings, in which

Figure 1 is a diagrammatic view of a relay embodying my invention as applied to a high-voltage power system, and

Fig. 2 is a diagrammatic view of a modification of the relay shown in Fig. 1.

Referring to Fig. 1 in detail, a generator 1 is connected by means of any suitable transforming apparatus, shown as a delta-delta connected bank of transformers 2 to a high voltage bus 3. A pair of transmission circuits or high voltage feeders 4 and 5, for supplying power to any suitable receiving apparatus 6 and 7 respectively, indicated as grounded-neutral star connected transformer windings, are connected to the high voltage bus 3 by means of a pair of circuit breakers 8 and 9, respectively.

The circuit breaker 8 may be of any suitable high voltage type having a trip coil 8*a* and condenser type or oil filled type bushings 8*b* for insulating the high voltage circuit breaker parts, in a manner well understood in the art. One set of the bushings 8*b* is provided with a set of bushing type current transformers, shown diagrammatically at 10, the purpose of which will be hereinafter explained. The circuit breaker 9 may be of the same general construction as the circuit breaker 8, but for simplicity is shown in more diagrammatic form.

The trip coil 8*a* is connected in a trip circuit with any suitable source of tripping current, indicated as a battery 11 and the contact members 13*a* of a directional ground relay 12, constructed in accordance with my invention. The ground relay 12 comprises an overcurrent element 13 and a power directional element 14, which may be mounted in the same case in the usual manner.

The overcurrent element 13 is preferably of the induction disc type having a lower pole winding 13*b* and a pair of upper pole windings 13*c* mounted upon angularly displaced pole members in the usual manner. The upper pole windings 13*c* are normally deenergized but may be connected to an auxiliary winding 13*d* to be in-

ductively energized in accordance with the lower pole flux, by means of contact members 14a of the power directional element 14.

The power directional element 14 is also preferably of the induction disc type and has a potential winding 14b and a pair of current windings 14c arranged in a well known manner.

A pair of biasing springs 13e and 14e are provided for normally maintaining the contact members 13a and 14a in open circuit positions. Many other structural details of the elements 13 and 14, which are known in the art and which would be used in practice, but which are not necessary to an understanding of my invention, have for simplicity been omitted from the drawings and description.

The lower pole winding 13b is connected in a neutral return circuit for the star connected windings of the bushing transformers 10, to be energized in accordance with the zero sequence current or residual current of the circuit 4. It will be understood that the connection of the bushing transformers 10 is merely one of a number of expedients known in the art for separating zero sequence current components from a system of polyphase currents, and that my invention may be practiced with any equivalent of the specific connections shown.

The potential winding 14b is connected to a negative sequence voltage filter 15 of any suitable type, to be energized in accordance with a negative symmetrical component of the polyphase voltage of the generator 1. In the form shown, the filter 15 comprises a pair of potential transformers 15a and 15b having their primary windings connected in open V to the terminals of the generator 1 and their secondary windings connected in parallel circuits which include a resistor 15c and a reactor 15d, respectively. The impedance of the parallel circuit which includes the reactor 15d is equal to the impedance of the parallel circuit which includes the resistor 15c, rotated through a phase angle of 60° in the lagging direction. As explained in the copending application of W. A. Lewis, Serial No. 704,308, filed December 28, 1933, and assigned to the Westinghouse Electric and Manufacturing Company, the efficiency of the filter 15 may be made a maximum by making the absolute impedance of each of the parallel circuits mentioned above 1.73 times as large as the absolute impedance of the potential winding 14b. It will be assumed that the filter 15 is designed to satisfy this relationship also.

The current windings 14c are connected to a negative phase sequence current filter 16 to be energized in accordance with a negative symmetrical component of the polyphase current of the circuit 4. The current filter 16 consists of two pairs of insulating current transformers 16a and 16b, having their secondary windings connected in opposition to eliminate zero sequence current, a reactor 16d and a resistor 16c. The impedance of the reactor 16d is equal to that of the resistor 16c rotated through a phase angle of 60° in the lagging direction. For maximum efficiency of the current filter 16, the absolute impedances of the resistor 16c and reactor 16d are made equal to .866 times the impedance of the current windings 14c, in series, as explained in the above mentioned application of W. A. Lewis.

Assuming that the phase relationship of star voltages and star currents of the system is as indicated by the subscripts *a*, *b* and *c* of the conductors 3a, 3b and 3c, and that the impedance relationships of the phase sequence filters 15 and 16 and the windings 14b and 14c are as stated above, it may be shown that the currents which flow in the windings 14b and 14c are proportional to negative sequence voltage and negative sequence current, respectively. It will therefore be obvious that the torque of the power directional element 14 is a function of a vector product of negative sequence current and negative sequence voltage. By selecting a potential winding 14b of suitable phase angle as compared with the phase angle of the current windings 14c, the directional element 14 may be made to respond to negative sequence real power, negative sequence reactive power or to any intermediate negative sequence power product. In order to obtain negative sequence real power response of the directional element 14, the phase angle of the potential winding 14b is made 60° greater than the phase angle of the current windings 14c. The 60° shift of potential pole flux together with a 30° displacement resulting from the constants of the filters 15 and 16 gives a 90° displacement of potential pole and current pole fluxes and therefore maximum torque of the directional element 14, when the negative sequence current of the circuit 4 is in phase with the negative sequence voltage of the generator 1.

In many applications it is desirable to cause the power directional element 14 to respond to a lagging negative sequence power product rather than real negative sequence power. This may be accomplished by choosing a potential winding 14b having a phase angle of less than 60° greater than the phase angle of the current windings 14c, or by inserting external resistance in series with the potential winding 14b.

The operation of the apparatus shown in Fig. 1 may be set forth as follows: It is assumed that initially the generator 1 is in operation, the circuit breakers 8 and 9 are closed as shown in the figure, and that power is flowing from the generator 1 through the high voltage circuits 4 and 5 to the receiving apparatus 6 and 7. If the power flow in the circuits 4 and 5 is balanced, no negative sequence power flows in the system. If there is an unbalance in the polyphase power flow in either circuit 4 or 5, negative sequence power flows from the unbalanced receiving apparatus 6 or 7 to the generator 1 to be absorbed in the generator damper winding in well known manner. The magnitude of this negative sequence power flow is small as compared with that which may flow under fault conditions and will be assumed as less than the minimum value to which the directional element 14 is adjusted to respond.

If an unbalanced ground fault occurs at point *x* on the circuit 4, negative sequence power of large magnitude flows from the fault in both directions to any apparatus having negative phase-sequence admittance connected to the system. The flow of this power to the generator 1 and receiving apparatus 7 causes the directional element 14 to close.

At the same time, zero sequence power flows from the fault in both directions to any apparatus having zero phase sequence admittance or ground connections. As the zero sequence power cannot pass the delta-connected windings of transformer bank 2, it flows to ground through the grounded receiving apparatus 6 and 7. In response to the flow of zero sequence current,

the overcurrent element 13 closes to trip the circuit breaker 8.

If an unsymmetrical fault occurs on the high voltage circuit 5, the direction of negative sequence power flow at the relaying point is opposite to that described above and the direction element 14 remains open.

It will be apparent that negative sequence power flow and zero sequence current occur under the following fault conditions: single phase-to-ground faults, double phase-to-ground faults at the same location, and three-phase-to-ground faults where the fault impedances are unsymmetrical. For phase-to-phase faults, there may be considerable flow of negative phase sequence power, but no zero phase-sequence current flow. For three-phase symmetrical faults, both the negative sequence and zero sequence power flow are zero. It will therefore be seen that the relay 12 operates under substantially the same fault conditions as ground relays of the usual zero sequence directional type.

In the system described above, the voltage of the generator 1 may be of medium value such as 6600 or 13,200 volts, whereas the voltage of the bus 3 and circuits 4 and 5 may be a transmission voltage such as 66 KV. The voltage filter 15 is connected on the low voltage side of the transformer bank 2 in order to avoid the use of high voltage insulating potential transformers. As negative sequence voltage is transmitted by delta, star, open V or Scott connected transformer windings, the connection shown in Fig. 1 may be used where power transformer banks connected in any usual manner are available. Insulating current transformers 16*a* and 16*b* are used in preference to bushing type current transformers to supply the filter 16, as the volt-ampere capacity of the former type is higher than that of the latter, and the burden imposed by the filter impedances is comparatively large. It will be obvious however, that the circuit shown may be modified in many ways.

Referring to Fig. 2, which shows a modification of my invention employing a current phase sequence filter of the type disclosed in the copending application of W. A. Lewis mentioned above, a relay 12 having an overcurrent element 13 and a power directional element 14, constructed in the same manner as the relay 12 of Fig. 1, is arranged to control a high voltage circuit 4 by means of a circuit breaker 8 and battery 11 as in Fig. 1.

The power directional element 14 is energized by means of a negative sequence voltage filter 15 which may be of the same type as the filter 15 of Fig. 1, and a negative sequence current filter 17.

The filter 17 comprises a bank of insulating current transformers 17*a* having their secondary windings connected in star to a pair of 5:5 ratio low voltage current transformers 17*b*, a resistor 17*c* and a reactor 17*d*. The primary windings of the current transformers 17*b* are connected in series with the secondary winding of one of the current transformers 17*a*, and the secondary windings of the current transformers 17*b* are connected in reversed open V across the star circuits, beyond the primary windings of the current transformers 17*b*. The resistor 17*c* and the reactor 17*d* are connected in parallel to the secondary windings of the current transformers 17*b*. The impedance of the reactor 17*d* is equal to the impedance of resistor 17*c* rotated through 60° in the lagging direction, and for maximum efficiency is equal to .866 times the impedance of the current windings 14*c* of the power directional element 14, as in Fig. 1. A neutral return conductor 17*e* is connected in the manner shown to include the lower pole winding 13*b* of the overcurrent element 13.

The normal phase relationship of star currents and voltages of the circuit 4 for power flow in the normal direction is indicated by reference characters *a*, *b*, and *c*. As explained in the copending application of W. A. Lewis mentioned above, a filter constructed in the manner described above produces zero sequence current in the neutral return conductor 17*e* and negative sequence current in the current windings 14*c*. The phase position of the negative phase sequence current output of the filter 17 is the same as that of the current filter 16 of Fig. 1.

The operation of the apparatus shown in Fig. 2 will be obvious from that described above in connection with Fig. 1.

I do not intend that the present invention shall be restricted to the specific structural details, arrangement of parts or circuit connections herein set forth as various modifications thereof may be effected without departing from the spirit and scope of my invention. I desire therefore that only such limitations shall be imposed as are indicated in the appended claims.

I claim as my invention:

1. In an alternating current system of transmission and distribution having a first polyphase power circuit and a second polyphase power circuit connected by power transformer apparatus, said transformer apparatus having polyphase windings connected to pass positive sequence power components and prevent the passage of zero sequence power components, ground fault protective means for said first circuit including a directional element having potential coil means energized in accordance with potential of sequence other than zero derived from said second circuit and current coil means energized in accordance with current of said sequence other than zero derived from one of said power circuits.

2. In an alternating current system of transmission and distribution having a first polyphase power circuit and a second polyphase power circuit connected by power transformer apparatus, said transformer apparatus having polyphase windings connected to pass positive sequence power components and power components of a different sequence, ground fault protective means for said first circuit including a directional element having potential coil means energized in accordance with potential of said different sequence derived from said second circuit and current coil means energized in accordance with current of said different sequence derived from one of said circuits, and an overcurrent element energized in accordance with an unbalanced current condition derived from said first circuit.

3. In a directional ground relay for polyphase alternating current circuits, a directional element responsive to a vector product of negative phase-sequence current and negative phase-sequence voltage, and an overcurrent element responsive to zero phase-sequence current, said elements being connected to effect a control operation only when said vector product is in a predetermined directional condition and a zero phase-sequence component of current exceeds a predetermined value.

4. In a directional ground relay for polyphase alternating current circuits, a directional element of the watt responsive type having a potential winding and a current winding, means for energizing said potential winding in accordance with a negative symmetrical voltage component, means for energizing said current winding in accordance with a negative symmetrical current component, an overcurrent element, and means for energizing said overcurrent element in accordance with ground current, said elements being connected to effect a control operation only when said watt element is energized in a predetermined direction and a ground current condition exceeds a predetermined value.

5. In protective apparatus for a polyphase alternating current circuit, a circuit breaker, a relay element responsive to a vector product of negative phase-sequence current and negative phase-sequence voltage of said circuit, said element having contact members operable in response to a predetermined directional value of said product, an overcurrent element having contact members operable in response to a predetermined current condition, means controlled by said first-mentioned contact members for energizing said overcurrent element in accordance with the zero phase sequence current of said circuit, and means including said contact members of said overcurrent element for operating said circuit breaker.

6. In an alternating current system of transmission and distribution having a three-phase high voltage circuit, directional ground protective apparatus for said circuit comprising a circuit breaker, a power directional relay element having a potential winding and a current winding, a pair of insulating potential transformers connected to said circuit, energizing means for said potential winding including a negative phase-sequence voltage filter energized from said potential transformers, means for energizing said current winding in accordance with the negative phase-sequence current of said circuit, an overcurrent relay element responsive to the zero phase-sequence current of said circuit, and means including said relay elements for operating said circuit breaker in response to simultaneous directional energization of said directional element and energization of said overcurrent element above a predetermined degree.

7. In an alternating current system of transmission and distribution having a three-phase high voltage circuit and having polyphase power transforming means including high voltage windings connected to said circuit and low voltage windings, directional ground protective apparatus for said circuit comprising a circuit breaker, a directional relay element having a potential winding and a current winding, energizing means for said potential winding including a negative phase-sequence voltage filter energized from said low voltage windings, means for energizing said current winding in accordance with the negative phase-sequence current of said circuit, an overcurrent relay element, means for energizing said overcurrent relay element in accordance with the zero phase sequence current of said circuit, and means including said relay elements for operating said circuit breaker in response to simultaneous directional operation of said directional element and energization of said overcurrent element above a predetermined degree whereby said high voltage circuit is protected against unsymmetrical ground faults in a predetermined direction without the use of high voltage insulating potential transformers.

8. In protective apparatus for a polyphase alternating-current circuit, a circuit breaker, a directional relay element having contact members, an overcurrent relay element having contact means, energizing means for said relay elements including means for energizing said directional relay element in accordance with a vector product of negative sequence current and negative sequence voltage of said circuit, said energizing means including means controlled by said contact members for energizing said overcurrent element in accordance with a current condition derived from said circuit, and means controlled by said contact means for causing said circuit breaker to open when said vector product is in a predetermined directional condition and said current condition exceeds a predetermined value.

ROBERT D. EVANS.