Oct. 10, 1950 E. L. HARDER 2,525,485

OUT-OF-STEP PROTECTION OF TRANSMISSION SYSTEMS

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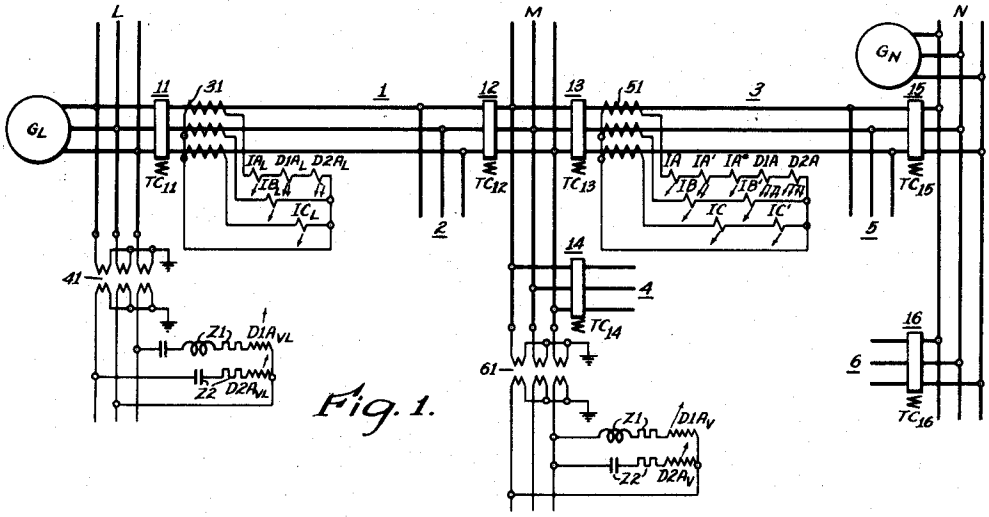


Fig. 1.

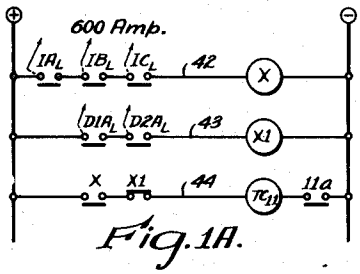


Fig. 1A.

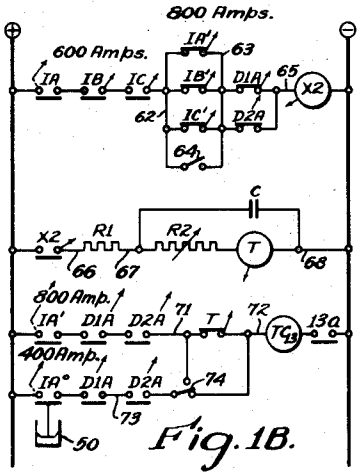


Fig. 1B.

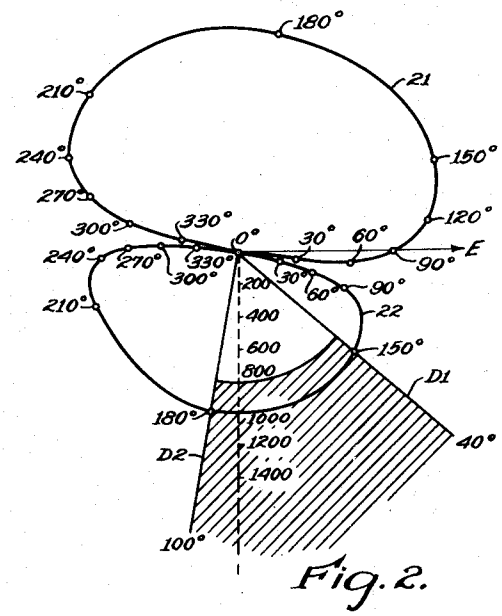


Fig. 2.

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OUT OF STEP PROTECTION OF TRANSMISSION SYSTEMS

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My invention relates to a simple and improved system and apparatus for protecting an alternating-current transmission-system against out-of-step or out-of-synchronism conditions, either for the purpose of blocking tripping at a point where an opening of the system would be disadvantageous, or for the purpose of causing a tripping-operation at a point where it is desired that the two out-of-step portions of the system should preferably be separated from each other by an opening-operation of the breakers.

Heretofore, several different out-of-step relaying systems have been known, including a system depending upon the use of carrier-current relaying, as described in my Patent 2,144,494 granted January 17, 1927; and a system having a complex dependence upon the successive operation of non-directional fault-detectors of different sensitivities, during the progress of an out-of-synchronism swing, as described in the Lewis Patent 2,210,680, granted August 6, 1940.

In addition to the foregoing previously known out-of-step protective relaying systems, a relaying system has been known, but not for out-of-step detection, in which the phase-angle zone in which all fault-currents will lie was blocked off by two directionally responsive modified-impedance relays, as shown in Fig. 4 of the Goldsborough Patent 2,386,209, granted October 9, 1945.

It is an object of my present invention to provide means for detecting an out-of-synchronism condition by the occurrence of a line-current of fault-magnitude at a phase-angle which is outside of the phase-angle zone in which fault-currents can occur. This out-of-step detection can either be utilized to cause tripping at the station where a separation of the out-of-step portions of the transmission system is desirable, or it can be utilized to block tripping at another station, and to continue said blocking action during the time when the line-current swings into the region of the phase-angle of fault-currents during an out-of-synchronism swing of the two portions of a transmission system.

A more specific object of my invention is to combine, with the foregoing out-of-step detection, a relaying response which insures that the 3-phase line-current is larger than a predetermined current-value higher than the maximum load-current value, but not much larger than this value; so as to further distinguish between an out-of-step swing-condition, in which the current-values gradually increase, and a fault-condition, in which the current substantially instantaneously reaches its fault-value; this provision being made in addition to the use of zoning directionally responsive elements for marking off the zone or phase-angle band in which fault-currents must lie.

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With the foregoing and other objects in view, my invention consists of the circuits, systems, combinations, parts and methods of design and operation, hereinafter described and claimed, and illustrated in the accompanying drawing, wherein

Fig. 1 is a simplified diagrammatic view of circuits and apparatus embodying my invention in an illustrative form of embodiment;

Fig. 1A is a simplified schematic diagram of the out-of-step detecting-apparatus such as would be utilized at the breaker 11 of the station L in Fig. 1, in case a separation of the system should be desirable at this point, under out-of-step conditions;

Fig. 1B is a similar view of apparatus such as would be used at the breaker 13 of the station M, in case it should be desirable to block out-of-step tripping at this point; and

Fig. 2 is a phase-angle diagram, in polar coordinates, showing the loci of the line-currents which are obtained during two possible different out-of-step conditions at the breaker 13 of the station M in Fig. 1, and also showing the phase-angle zone in which all three-phase fault-currents must lie.

In Fig. 1, I have illustrated one kind of transmission-system to which my present invention would be applicable. In Fig. 1, I show three substations of a 3-phase, 60-cycle transmission system in which out-of-step-responsive relays would be needed. The three geographically separated substations are indicated by the several 3-phase station-buses L, M and N, respectively. The system is indicated as having generating capacity connected thereto at the stations L and N, as indicated schematically by the synchronous generators G_L and G_N.

A 3-phase line-section 1 is indicated as joining the buses L and M, to which said line-section is connected by breakers 11 and 12, having trip-coils TC_{11} and TC_{12}, respectively. A 3-phase tie-line 2 is indicated as being connected to the line-section 1 near the end where the breaker 12 is located. The station M is further indicated as having two 3-phase line-sections 3 and 4 connected thereto, through breakers 13 and 14, having the trip-coils TC_{13} and TC_{14}, respectively. The line-section 3 is represented as connecting the station-bus M to the station-bus N, with a breaker 15 at the point of connection with the

bus N, said breaker having a trip-coil TC_{15}. The line-section 3 is also represented as having a 3-phase tie-line 5 connected thereto, near the end where the breaker 15 is located. The station-bus N is also represented as having another line or lines connected thereto, as symbolized by the 3-phase line 6, which is connected to the bus N through a breaker 16 having a trip coil TC_{16}.

In a transmission system such as has just been described, as shown in Fig. 1, it may be supposed that the generating-capacity which is available at the bus N is sufficient, in general, to carry the load at the bus M, in case of a failure or non-availability of the generating-capacity which is connected to the bus L, and it may also be assumed that the available generating-capacity at the bus L would not be sufficient to carry the load at M, in case of a failure or non-availability of the generating-capacity at the bus N. Such situations commonly arise, in interconnected transmission systems such as that which is shown in Fig. 1. It may also be assumed that the electrical center of the transmission system which is shown in Fig. 1 may be either to the right or left of the intermediate station M, depending upon the distribution of the generating-capacity which is connected to the system at various points, either at the buses L and N as shown, or at the bus M itself (not shown), or at the ends of the various tie-lines 2, 4, 5 and 6.

Fig. 2 is a phase-angle diagram, in polar coordinates, indicating line-current conditions, such as might exist at the breaker 13 at the intermediate station M, plotting the envelopes of the various possible line-currents with respect to the system-voltage E at the station M.

Under one set of system-conditions, the electrical center of the system is somewhere between the stations L and M, in which case the locus of the ends of the line-current vectors at the breaker 13 of the station M, during out-of-step system-conditions, might be as indicated by the curve 21 in Fig. 2. Each point in the curve 21 indicates the end of a current-vector which depicts, in polar coordinates, the magnitude and phase of the line-current at the breaker 13, with respect to the line-voltage E at the same place. The various angles which are marked on the curve 21 in Fig. 2 indicate the phase-angles between the voltage E at the bus M and the internal voltage of the generator G_L at the bus L.

During other system-conditions, it is possible that the electrical center of the system will fall somewhere between the buses M and N, in which case the locus of the ends of the line-current vectors at the breaker 13, when plotted with respect to the line-voltage E at the same place, may be something like that which is shown by the curve 22 in Fig. 2, in which case the various phase-angles which are indicated at different points around the curve 22, are the phase-angles between the voltage E at the bus M, and the internal voltage of the generator G_N at the bus N, in the course of a complete out-of-synchronism swing.

Fig. 2 also depicts a phase-angle zone for three-phase fault-currents, which is illustrated as lying between a 40° lagging phase-angle with respect to the station-M voltage E, and a 100° lagging phase-angle with respect to the same voltage, assuming that the line-section E has an impedance-angle of something like 70°, or somewhere near the middle of the phase-angle fault-zone which is included between the straight lines marked 40° and 100°, respectively, as indicated by the shaded zone in Fig. 2. Fig. 2 also shows the scale of current-magnitudes. To fix our ideas on something definite, it may be assumed that the full-load current flowing over the line-section 3 is somewhat less than 500 amperes.

In accordance with my present invention, I have provided two biased directional elements D1 and D2, that is, directional elements in which the zero-torque is biased, or at a different phase-angle, than in the directional elements such as have heretofore been commonly used, in connection with protective relays for transmission systems. Ordinarily, a directional element, as heretofore used, has had a zero-torque angle at a line-current phase-angle which is 90° displaced from the expected phase-angle of fault-currents. However, I displace this no-torque phase-angle of my directional elements, so that the no-torque current-angle of the element D1 is at 40° lagging, as indicated by the straight-line D1 in Fig. 2, while the no-torque current-angle of the second directional element D2 is at 100° lagging, as indicated by the straight line D2 in Fig. 2. These angles are just illustrative of any narrow angle-range, leading and lagging with respect to the line or zone in which it is expected that fault-currents will fall, with any desired margin of safety.

Fig. 1A shows a simplified schematic view of an out-of-step relaying system such as might be utilized at the breaker 11 at the bus L, in accordance with my invention, assuming that it is desired for the breaker 11 to be tripped in response to any out-of-step swing, so that the two portions of the transmission system will be broken apart from each other at this point, in any case of loss of synchronism. Fig. 1A shows just the means for responding to out-of-step conditions, and not the usual fault-responsive relays such as would be utilized at every relaying point.

For controlling the breaker 11 at the station L, as shown in Figs. 1 and 1A, I utilize three over-current relays IA_L, IB_L and IC_L, one for each of the line-phases A, B and C, and two directional elements, which I have indicated, by way of example, as phase-A elements marked $D1A_L$ and $D2A_L$. In addition, as shown in Fig. 1A, I utilize two auxiliary direct-current relays marked X and X1, in the out-of-step control of the breaker 11.

The various relays which make up my relaying system, as shown in the accompanying drawing, include various line-responsive relays and various direct-current 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 manner 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 coil or winding, or a polarizing 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. In addition, a

subscript L is added, to distinguish the line-responsive relays which are located at the station L.

The alternating-current connections for the various line-responsive relays are shown in Fig. 1. The overcurrent elements IA_L, IB_L and IC_L have similarly marked operating-coils which are energized from the various phases of a bank of line-current transformers **31**, as shown in Fig. 1. Each of these relays has a single make-contact, which is marked by the same symbols, as shown in Fig. 1A. The two phase-A directional elements $D1A_L$ and $D2A_L$ have similarly marked current-responsive coils which are connected in the phase-A circuit of the line-current transformers **31**, and each of these directional elements has a single make-contact which is similarly marked, in Fig. 1A. Each of these directional elements $D1A_L$ and $D2A_L$ is also provided with a voltage-coil, distinguished by the subscript V before the subscript L, in Fig. 1, and these two voltage-coils $D1A_{VL}$ and $D2A_{VL}$ are suitably energized from the B—C and A—C relaying-voltages which are supplied by potential-transformers **41** at the station L, as shown in Fig. 1, suitable leading impedances Z1 and Z2 being connected in series with the respective voltage-coils $D1A_{VL}$ and $D2A_{VL}$, or other equivalent means being used, to effect the necessary shifting of the no-torque phase-angle of the respective directional elements, so that, when both of the directional elements respond, the phase of the line-current will fall somewhere between the 40° line D1 and the 100° line D2 in Fig. 2.

The direct-current connections for the relaying equipment for the breaker **11** at the station L are shown in Fig. 1A. The first line of this figure shows how the three serially connected make-contacts IA_L, IB_L and IC_L are utilized to energize a conductor **42** from the positive bus (+). The operating coil of the auxiliary relay X is connected between the conductor **42** and the negative bus (—). The second line of Fig. 1A shows how the two serially connected make-contacts $D1A_L$ and $D2A_L$ are utilized to energize a conductor **43** from the positive bus (+), and how the operating coil of the second auxiliary relay X1 is connected between the conductor **43** and the negative bus (—). The last line in Fig. 3 shows the tripping-circuit connections, utilizing the make-contact X, in series with the back-contact X1, to energize the trip-circuit conductor **44**, which continues on, to energize the trip-coil TC_{11} of the breaker **11**, through the auxiliary make-contact **11***a* of the breaker, and thence to the negative bus (—).

Fig. 1B shows a much simplified schematic view of protective relaying apparatus for controlling the tripping of the breaker **13** at the station M, many parts being omitted in the interests of simplicity. In this equipment, as shown in Fig. 1B, the line-responsive relays include three overcurrent elements IA, IB and IC, marked, in Fig. 1B, as having a pick-up value of 600 amperes; three other overcurrent elements IA', IB' and IC', marked as having a pick-up value of 800 amperes; and a single phase-A time-delayed overcurrent element IA°, marked as having a pick-up value of 400 amperes, and as having a time-delay in its response, as symbolized by a dashpot **50**. In addition, the line-responsive relaying equipment, as shown in Fig. 1B, includes the two directional elements D1A and D2A which are similar to the direction elements $D1A_L$ and $D2A_L$ which are shown in Fig. 1A, except that the directional elements in Fig. 1B have back-contacts D1A and D2A, respectively, and two make-contacts D1A and D2A, as marked in accordance with the relay-designation.

The current-responsive coils of the several line-responsive relays of Fig. 1B are energized, as shown in Fig. 1, from a bank of line-current transformers **51**; while the voltage-coils $D1A_V$ and $D2A_V$ are energized, through the impedances Z1 and Z2, from a bank of potential-transformers **61** which are connected to the bus M as shown in Fig. 1.

In addition, as shown in Fig. 1B, I utilize two auxiliary direct-current relays marked X2 and T. The direct-current circuits, as shown in Fig. 1B, include the three serially connected make-contacts IA, IB and IC of the 600-ampere overcurrent relays, which are utilized to energize a conductor **62** from the positive bus (+). The three parallel connected back-contacts IA', IB' and IC' of the 800-ampere overcurrent relays are utilized to connect the conductor **62** to a conductor **63**, in Fig. 1B. In addition, a bypassing switch **64** is provided, whereby the conductors **62** and **63** may be directly connected, thus indicating that the 800-ampere relays IA', IB' and IC' need not always be utilized. The two back-contacts D1A and D2A of the directional elements are connected in parallel with each other, to join the conductor **63** to a conductor **65**, which is utilized to energize the operating coil of the auxiliary relay X2, which is connected between the conductor **65** and the negative bus (—).

Continuing the description of Fig. 1B, the second line of this figure shows the make-contact X2, of the auxiliary relay of the same designation, utilized to energize a circuit **66** from the positive bus (+), this circuit including a resistor R1, for energizing a circuit **67**, which continues on, through a variable resistor R2 and the operating coil of the auxiliary relay T, to a conductor **68** which is connected to the negative bus (—). Relay-coil T and the resistor R2 are shunted by a capacitor C which serves to provide a time-delay of the order of a second, or from $\frac{1}{10}$ of a second to a second or more, in the drop-out time of the relay T.

The third line of Fig. 1B shows the phase-A tripping-circuit connections, in which three serially connected make-contacts, IA', D1A and D2A, are utilized to energize a conductor **71** from the positive bus (+). A back-contact of the auxiliary relay T is utilized to connect the conductor **71** to the trip-circuit conductor **72**, from which the circuit continues on, through the trip-coil TC_{13}, and an auxiliary make-contact **13***a* of the breaker **13**, to the negative bus (—).

Fig. 1B also shows, by way of illustration of other tripping circuits, a back-up protective tripping-circuit connection, utilizing three serially connected contacts, IA°, D1A and D2A, to energize a circuit **73**, which may be connected, by a changeover switch **74**, either to the conductor **71** or the trip-circuit conductor **72**, so that in the first case, the auxiliary-relay back-contact T will be serially included in the tripping-circuit connections, whereas, in the second case, the back-contact T will not be included, thus indicating that the relay-contact T may, or may not, be included in all of the tripping circuits. It may be noted that the overcurrent contact IA° is a time-delayed contact, for back-up protection, and in many cases, its time-delay will be such that the auxiliary-relay contact T will not be needed in series with the back-up element IA°,

as will be obvious from the subsequent explanation.

In the operation of my apparatus, it will be noted that an out-of-synchronism swing requires a certain length of time, which may be a second or more, depending upon the time-constants of the particular electrical system. In other words, it takes time for the system to swing out of step sufficiently for the line-current to have a phase-angle within the zone which is confined between the response-phases of the two directional elements D1 and D2, as indicated in Fig. 2. The out-of-phase swing may start around the locus 22, for example, either clockwise or anti-clockwise, depending upon which end of the system is falling behind the other.

During the out-of-synchronism swing, the line-current gradually increases, reaching a maximum value near the 180° point of the swing, this maximum out-of-phase current being usually very considerably higher than the full-load line-current, and considerably higher than minimum fault-current. Long before the system swings as much as 150 degrees out of step, corresponding to current 40° lagging the voltage, the line-current between the out-of-phase generator-voltages will, in general, far exceed the maximum load-current value. In accordance with my invention, an out-of-step condition is detected by the occurrence of a current-magnitude higher than the full-load line-current, or, in general, the occurrence of a non-directional fault-condition indication of some kind, in any current-phase other than the restricted phase-angle zone which is included between the no-torque response-characteristics of the two directional elements, as shown in Fig. 2. If the first appearance of a current of fault-magnitude occurs within this restricted zone, that is, in the shaded area between the lines D1 and D2 in Fig. 2, then that circumstance indicates positively the existence of a fault-condition as distinguished from an out-of-step swing, but if the line-current builds up to fault-magnitude without falling within the phase-angle zone between the two lines D1 and D2 in Fig. 2, then this circumstance can, in general, be taken as a positive indication of an out-of-synchronism condition.

The operation of the Fig. 1A equipment for out-of-step tripping of the breaker 11 at the station L is as follows. Since an out-of-step condition is a 3-phase condition, a response is obtained, in Fig. 1A, to the simultaneous occurrence of a current higher than any load-current, in all three line-phases. Thus, at 600 amperes, which is higher than the full-load current, the overcurrent relays IA_L, IB_L and IC_L respond and energize the auxiliary relay X. If this overcurrent condition is the result of the beginning of an out-of-step swing, it will occur at a phase-angle outside of the narrow fault-current phase-angle zone between the two lines D1 and D2 in Fig. 2, which means that both of the biased directional relays $D1A_L$ and $D2A_L$ will not respond, thus failing to energize the circuit 43 which actuates the second auxiliary relay X1 in Fig. 1A. In the third circuit of Fig. 1A, therefore, the make-contact X will pick up, but the back-contact X1 will remain closed; thus energizing the trip-circuit, causing the breaker 11 to open, and segregating the two out-of phase portions of the transmission system.

If, however, the 3-phase overcurrent condition in Fig. 1A had been the result of a fault, the fault-current would have been within the restricted phase-angle zone between the lines D1 and D2 in Fig. 2, and both of the directional elements $D1A_L$ and $D2A_L$ would have immediately responded, picking up the auxiliary relay X1, and opening the tripping-circuit, at the back-contact X1 which opens faster than the closure of the make-contact X in the tripping-circuit. Tripping would thus have been blocked, insofar as concerns any action of my out-of-step tripping-equipment in Fig. 1A, thus leaving the fault to be taken care of by the usual fault-responsive relays (not shown in Fig. 1A), which can be designed and correlated to handle fault-conditions without any regard to out-of-step swings.

In the operation of the Fig. 1B equipment, which illustrates the control of the breaker 13 at the station M, it will be noted that it is desirable for a tripping-operation to be blocked, at this point, in the event of an out-of-step condition, so that the two separated portions of the transmission system may be better able to operate independently of each other, after the system has been cut in two by the operation of the breaker 11 at the station L.

In Fig. 1B, in the tripping-circuit 71—72, a back-contact T is included, which is normally closed, and which opens in response to out-of-synchronism conditions, after a brief time hesitation which may be of the order of 2 or 3 cycles. A time-hesitation, in the opening of the back-contact T, is desirable, although perhaps not always necessary, so as to provide that much additional safeguard against the possibility of an erroneous momentary response of the auxiliary relay T, under fault conditions. If there is a fault, the instantaneously operating fault-responsive relays, such as the 800-ampere overcurrent-relay IA', and both directional elements D1A and D2A, will quickly respond, establishing the trip-circuit, and initiating the opening-operation of the circuit breaker 13.

If there is an out-of-step condition, the relays of Fig. 1B will recognize this by a response of the three 600-ampere overcurrent relays IA, IB and IC, which will receive their minimum pick-up current before the line-current builds up to the 800-ampere setting of the relays IA', IB' and IC'. At the same time, since the overcurrent condition is now assumed to be the result of an out-of-synchronism swing, the phase-angle of the current will not be between the lines D1 and D2 of Fig. 2, and hence both of the directional elements D1A and D2A will not pick up, so that the back-contact of one of these elements will remain closed, thus completing the energization of the top circuit, 65, in Fig. 1B, and picking up the auxiliary relay X2, which has a response-time of the order of a cycle or a cycle-and-a-half, which is a usual time of response for a relay which is neither extraordinarily fast nor extraordinarily slow.

The picking up of the X2 relay-contact energizes the second circuit, in Fig. 1B, and picks up the second auxiliary relay T, which has a response-time similar to that of the X2 relay, making a total time hesitation of the order of two or three cycles before the back-contact T picks up, after the closure of the three 600-ampere overcurrent-contacts IA, IB and IC. This time-hesitation of two or three cycles is assumed to be too small for the 3-phase line-current to increase from 600 amperes to 800-amperes, in the course of an out-of-synchronism swing, under any expectable system-conditions, so that the trip-circuit 71—72 is blocked or opened, by the

opening of the back-contact T, prior to the closure of the 800-ampere overcurrent-relay contact IA' in the circuit 71.

The time-hesitation of two or three cycles is also much below the time required for the phase-angle of the line-current to swing to an angle which is within the shaded zone between the lines D1 and D2 in Fig. 2, during the course of any out-of-step swing, so that the back-contact T is opened, in the tripping-circuit 71—72 of Fig. 1B, long before both of the directional contacts D1A and D2A can be simultaneously closed, in this circuit 71. In this manner, a tripping-operation is blocked, in Fig. 1B, in response to an out-of-synchronism condition, but not blocked in response to a fault-condition which starts out with the D1A and D2A elements both responding.

In the Fig. 1B system, it is necessary for the blocking-contact T to remain open during the time when the system is swinging through the phase-angle zone between the lines D1 and D2 in Fig. 2, because, in this zone, both of the directional back-contacts D1A and D2A will be open, in the circuit 63—65, thus deenergizing the X2 relay which controls the actual blocking-relay T. Consequently, I provide any suitable means which will give the relay T the property of keeping its contact open, for a suitable time-delay period, after the opening of the X2-contact in its energizing-circuit 66. This time-delay period should be something of the order from 6 cycles to 60 cycles, or even more, depending upon the time-constant of the system. The required time-delay is the time required for the system to swing between the line-current phases indicated by the lines D1 and D2 in Fig. 2.

In the particular system shown in Fig. 1B, the dropout time-delay of the relay T is obtained by means of a sufficiently large capacitor C, which is shunted around the operating-coil T of the relay, and which discharges through the resistor R2 when the normal energizing-circuit 66 is interrupted by the falling out of the make-contact X2. The time required for the capacitor C to discharge, and hence the falling-out time-delay which is given to the relay T, can be controlled by proper adjustment of the discharging-resistance R2.

As previously indicated, the out-of-step blocking-contact T of Fig. 1B can be included in all, or, only a part, of the tripping-circuits for the trip-coil TC_{13}. It is necessary, of course, to utilize the out-of-step blocking-contact T in series with all trip-circuits which would be unable, by themselves, to distinguish between a real fault-condition and the spurious, or only apparent, fault-condition which occurs during an out-of-synchronism swing. In the case of back-up relay-protection, for example, as is illustrated in the case of the slow-acting 400-ampere over-current-element IA° in Fig. 1B, the inherent time-delay in the response of this 400-ampere relay IA° is usually or frequently longer than any time-delay which is necessary for the system to swing past the zone between the lines D1 and D2 in Fig. 2, and hence the circuit 73 of Fig. 1B may safely be connected directly to the circuit 72 through the proper manipulations of the changeover switch 74. However, in those systems in which the out-of-step blocking may be desired, even in the case of the slow-acting 400-ampere relay IA°, the changeover switch 74 may be moved to connect the circuit 73 to the circuit 71, so that the trip-blocking contact T will be included in the tripping-circuit of this slow-acting relay IA°.

It will be understood, from the foregoing description, that the 800-ampere back-contacts IA', IB' and IC' are frequently quite unnecessary, in the circuit 62—63 of Fig. 1B, and hence these contacts may be omitted, as by the closure of the switch 64 in said figure.

In Fig. 1B, I have not made any effort to show all of the protective relaying equipment, even in the case of the phase-A relays which are partially illustrated, and no effort has been made to show the usual phase-B or phase-C relays, which are controlled in the same manner as the phase-A relays.

It is to be understood that the foregoing and other changes may be made, in various details, without departing from the essential spirit of my invention. I desire, therefore, that the appended claims shall be accorded the broadest construction consistent with their language.

I claim as my invention:

1. Means for detecting an out-of-synchronism condition in an alternating-current line, comprising directionally responsive relaying-means for selectively responding only to line-currents in the region of the phase-angle of fault-currents, substantially non-directional current-responsive means for selectively responding only to line-currents of higher than load-magnitudes, and out-of-step-responsive relaying-means for responding to a response of said non-directional means and a simultaneous non-response of said directionally responsive relaying-means.

2. A fault-responsive protective relaying system for an alternating-current line, with provision for out-of-synchronism conditions, comprising fault-responsive relaying-means for selectively responding to certain fault-current conditions as distinguished from certain load-current conditions, directionally responsive relaying-means for selectively responding only to line-current in the region of the phase-angle of fault-currents, substantially non-directional current-responsive means for selectively responding only to line-currents of higher than load-magnitudes, means for promptly performing a protective relaying-operation in joint response to a predetermined response of said fault-responsive relaying-means and a response of said directionally responsive relaying-means, and blocking-means for blocking said protective relaying-operation in response to a response of said non-directional means and a simultaneous non-response of said directionally responsive relaying-means.

3. A fault-responsive protective relaying system for an alternating-current line, with provision for out-of-synchronism conditions, comprising fault-responsive relaying-means for selectively responding to certain fault-current conditions as distinguished from certain load-current conditions, directionally responsive relaying-means for selectively responding only to line-currents in the region of the phase-angle of fault-currents, substantially non-directional current-responsive means for selectively responding only to line-currents of higher than load-magnitudes, means for promptly performing a protective relaying-operation in joint response to a predetermined response of said fault-responsive relaying-means and a response of said directionally responsive relaying-means, blocking means for blocking and protective relaying-operation in response to a response of said non-directional means and a simultaneous non-

response of said directionally responsive relaying-means, and means for establishing a block-continuation which endures during the time when the line-current swings into the region of the phase-angle of fault-currents.

4. A fault-responsive protective relaying system for an alternating-current line, with provision for out-of-synchronism conditions, comprising fault-responsive relaying-means for selectively responding to certain fault-current conditions as distinguished from certain load-current conditions, directionally responsive relaying-means for selectively responding only to line-currents in the region of the phase-angle of fault-currents, means for promptly performing a protective relaying-operation under conditions involving a response of said directionally responsive relaying-means, blocking-means for blocking said protective relaying-operation in response to a predetermined response of said fault-responsive relaying-means and a simultaneous non-response of said directionally responsive means, and means for establishing a block-continuation which endures during the time when the line-current swings into the region of the phase-angle of fault-currents.

5. A fault-responsive protective relaying system for an alternating-current line, with provision for out-of-synchronism conditions, comprising one or more fault-responsive relaying-means for selectively responding to certain fault-current conditions as distinguished from certain load-current conditions, directionally responsive relaying-means for selectively responding only to line-currents in the region of the phase-angle of fault-currents, means for promptly performing a protective relaying-operation in joint response to a predetermined response of one or more of said fault-responsive relaying-means and a response of said directionally responsive relaying-means, blocking-means for blocking said protective relaying-operation in response to a predetermined response of one or more of said fault-responsive relaying-means and a simultaneous non-response of said directionally responsive means, and means for establishing a block-continuation which endures during the time when the line-current swings into the region of the phase-angle of fault-currents.

6. Means for detecting an out-of-synchronism condition in an alternating-current line, comprising abnormal-condition-responsive relaying-means for selectively responding to an abnormal operating-condition as distinguished from certain load-current conditions of said line, directionally responsive relaying-means for selectively responding only to line-currents in the region of the phase-angle of fault-currents, and out-of-step-responsive relaying-means for responding to a response of said abnormal-condition-responsive relaying-means, accompanied by a non-response of said directionally-responsive relaying means.

7. Means for detecting an out-of-synchronism condition in an alternating-current line, comprising two fault-responsive relaying-means for selectively responding respectively to a relatively mild and a relatively severe fault-current condition as distinguished from certain load-current conditions, directionally responsive relaying-means for selectively responding only to line-currents in the region of the phase-angle of fault-currents, and out-of-step-responsive relaying-means for responding to a response of said mild fault-responsive relaying-means, accompanied by a non-response of said severe fault-responsive relaying-means, and further accompanied by a non-response of said directionally-responsive relaying-means.

8. A fault-responsive protective relaying system for an alternating-current line, with provision for out-of-synchronism conditions, comprising two fault-responsive relaying-means for selectively responding respectively to a relatively mild and a relatively severe fault-current condition as distinguished from certain load-current conditions, directionally responsive relaying-means for selectively responding only to line-currents in the region of the phase-angle of fault-currents, means for promptly performing a protective relaying-operation under conditions involving a response of said directionally responsive relaying-means, blocking-means for blocking said protective relaying-operation in response to a response of said mild fault-responsive relaying-means, accompanied by a non-response of said severe fault-responsive relaying-means, and further accompanied by a non-response of said directionally-responsive relaying-means, and means for establishing a block-continuation which endures during the time when the line-current swings into the region of the phase-angle of fault-currents.

9. The invention as defined in claim 1, characterized by said directionally responsive relaying-means comprising two differently biased directional elements, one having a zero-torque angle at a line-current phase-angle slightly smaller than the fault-current phase-angle, and the other having a zero-torque angle at a line-current phase-angle slightly larger than the fault-current phase-angle, whereby both directional elements will respond only when the line-current has a phase-angle between the two zero-torque angles.

10. The invention as defined in claim 2, characterized by said directionally responsive relaying-means comprising two differently biased directional elements, one having a zero-torque angle at a line-current phase-angle slightly smaller than the fault-current phase-angle, and the other having a zero-torque angle at a line-current phase-angle slightly larger than the fault-current phase-angle, whereby both directional elements will respond only when the line-current has a phase-angle between the two zero-torque angles.

11. The invention as defined in claim 3, characterized by said directionally responsive relaying-means comprising two differently biased directional elements, one having a zero-torque angle at a line-current phase-angle slightly smaller than the fault-current phase-angle, and the other having a zero-torque angle at a line-current phase-angle slightly larger than the fault-current phase-angle, whereby both directional elements will respond only when the line-current has a phase-angle between the two zero-torque angles.

12. The invention as defined in claim 4, characterized by said directionally responsive relaying-means comprising two differently biased directional elements, one having a zero-torque angle at a line-current phase-angle slightly smaller than the fault-current phase-angle, and the other having a zero-torque angle at a line-current phase-angle slightly larger than the fault-current phase-angle, whereby both directional elements will respond only when the line-current

has a phase-angle between the two zero-torque angles.

13. The invention as defined in claim 5, characterized by said directionally responsive relaying-means comprising two differently biased directional elements, one having a zero-torque angle at a line-current phase-angle slightly smaller than the fault-current phase-angle, and the other having a zero-torque angle at a line-current phase-angle slightly larger than the fault-current phase-angle, whereby both directional elements will respond only when the line-current has a phase-angle between the two zero-torque angles.

14. The invention as defined in claim 6, characterized by said directionally responsive relaying-means comprising two differently biased directional elements, one having a zero-torque angle at a line-current phase-angle slightly smaller than the fault-current phase-angle, and the other having a zero-torque angle at a line-current phase-angle slightly larger than the fault-current phase-angle, whereby both directional elements will respond only when the line-current has a phase-angle between the two zero-torque angles.

15. The invention as defined in claim 7, characterized by said directionally responsive relaying-means comprising two differently biased directional elements, one having a zero-torque angle at a line-current phase-angle slightly smaller than the fault-current phase-angle, and the other having a zero-torque angle at a line-current phase-angle slightly larger than the fault-current phase-angle, whereby both directional elements will respond only when the line-current has a phase-angle between the two zero-torque angles.

16. The invention as defined in claim 8, characterized by said directionally responsive relaying-means comprising two differently biased directional elements, one having a zero-torque angle at a line-current phase-angle slightly smaller than the fault-current phase-angle, and the other having a zero-torque angle at a line-current phase-angle slightly larger than the fault-current phase-angle, whereby both directional elements will respond only when the line current has a phase-angle between the two zero-torque angles.

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