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PROTECTIVE RELAY SYSTEM

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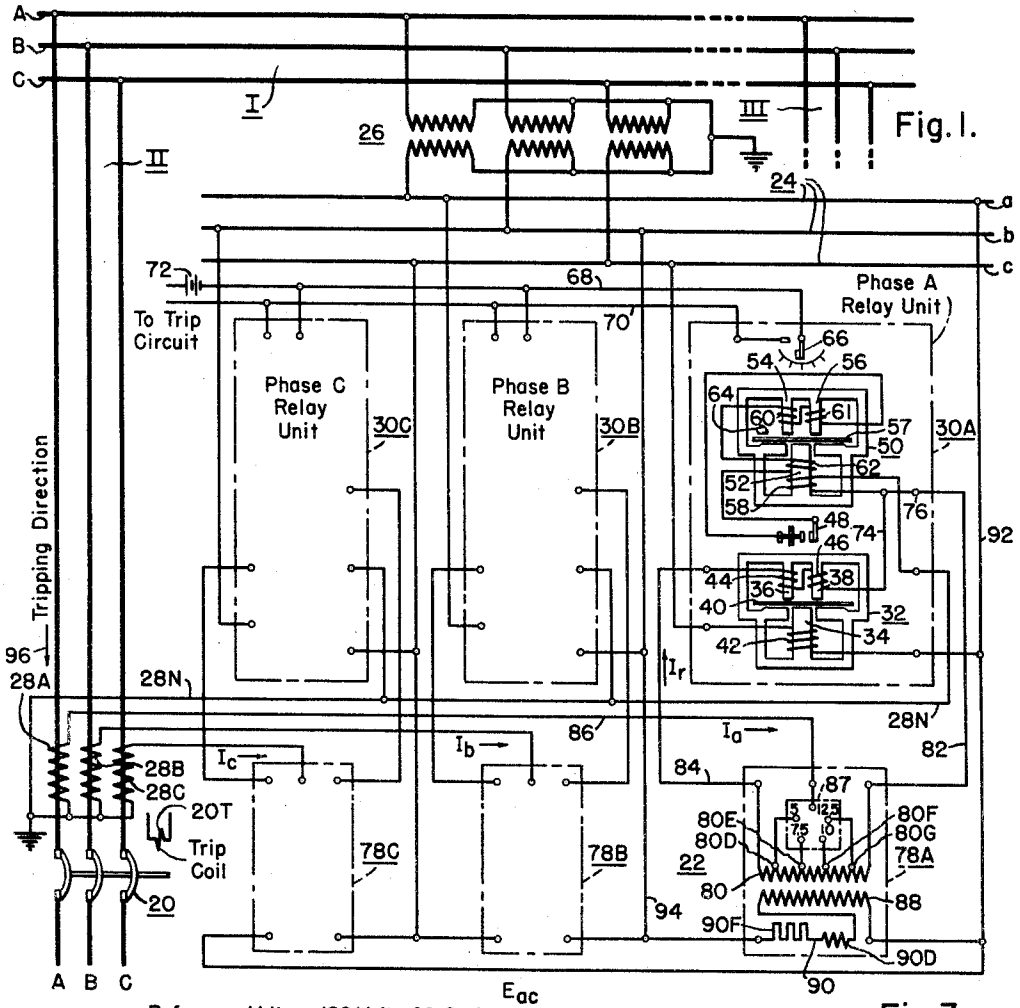


Fig. 1.

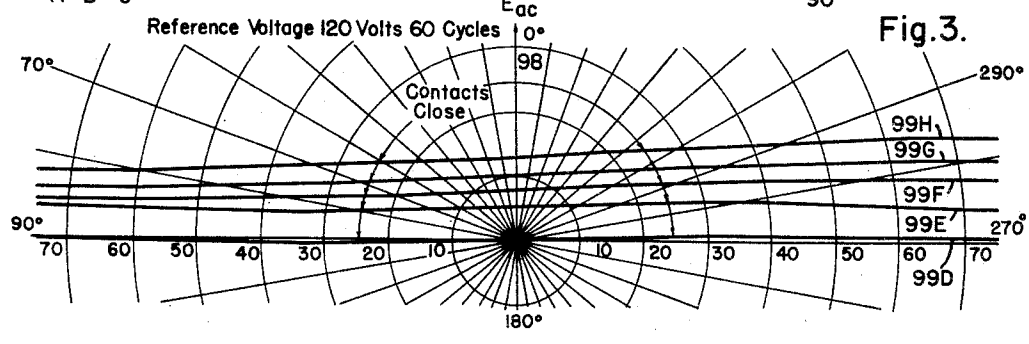


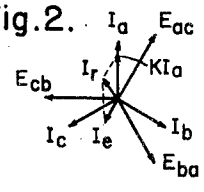
Fig. 3.

WITNESSES:

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Fig. 2.



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PROTECTIVE RELAY SYSTEM

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This invention relates to electrical systems having relays associated therewith, and it has particular reference to electrical systems employing directional protective relays.

In some relay units, a relay, which may be termed a "primary" relay, is employed for controlling the operativeness of another relay, which may be termed a "secondary" relay. As a specific example of such a relay unit, reference may be made to a directional relay unit which includes a directional relay as the primary relay and an overcurrent timing relay as the secondary relay. Relay units of this type are described in the Relay Handbook and Supplement published in 1931 by the National Electric Light Association, New York city, pages 1046 to 1051. The relay unit therein described is known as the Westinghouse type CR directional overcurrent relay.

Relay units of the type discussed in the preceding paragraph are provided with adjustable time delay. Several relay units may be employed in an electrical system and may be coordinated to provide different time delays in operation.

In order to facilitate the application of the relay units, it is desirable that a large range of adjustment be provided. The range of adjustment could be extended by adjusting the overcurrent timing relay to trip at values of current below the full load value of the associated system. However, in prior art relay units, such adjustment could not be employed for the reason that the relay unit would trip for conditions under which no tripping operation would be desired.

In accordance with the invention, the primary relay is restrained from operation until a condition arises wherein a tripping operation is desired. Under such conditions the secondary relay normally is inoperative and can be adjusted for operation at any desired value of energization. The primary relay may be restrained by a quantity which decreases or substantially vanishes when a condition arises necessitating a relay operation. For example, if the relay unit is associated with a polyphase system, a voltage may be selected which decreases or substantially vanishes under fault conditions requiring operation of the relay unit. If this voltage is employed for the purpose of restraining the primary relay, the occurrence of a fault requiring relay operation will result in removal of the restraint and in operation of the primary relay.

In a directional relay of the type described in the aforesaid handbook, the current winding may be energized not only in accordance with current flowing in the associated electrical system being protected but also by a restraining current derived from a voltage which decreases or substantially vanishes under conditions necessitating relay operation. Conveniently, one of the currents may be supplied to the current winding of the directional relay through a transformer. The other current may be supplied to the current winding through an energizing winding which is inductively coupled to the secondary winding of the transformer.

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It is, therefore, an object of the invention to provide a relay unit having a primary relay and a secondary relay responsive in part to the primary relay wherein the primary relay is restrained from operation until a condition arises wherein operation of the relay unit is required.

It is a further object of the invention to provide a directional relay having a voltage winding and a current winding wherein one of the windings is energized through a transformer and through an auxiliary winding inductively coupled to the secondary winding of the transformer.

It is a still further object of the invention to provide an electrical system wherein a relay unit is provided which includes a relay normally restrained from operation by a condition of the system which decreases or substantially vanishes upon the occurrence of a fault to which the relay unit should respond and which includes a second relay responsive in part to operation of the first relay for controlling the electrical system.

Other objects of the invention will be apparent from the following description taken in conjunction with the accompanying drawing, in which:

Figure 1 is a schematic view of an electrical system embodying the invention;

Fig. 2 is a vector diagram showing voltage and current relationships present in the system of Fig. 1; and

Fig. 3 is a polar diagram showing performance characteristics of a relay employed in the system of Fig. 1.

Referring to the drawing, Fig. 1 shows an electrical system which includes a circuit I to which are connected additional circuits II and III. The system may operate at any desired frequency and may have various numbers of phases. For the purpose of discussion, it will be assumed that it is a three-phase three-wire system operated at a frequency of 60 cycles per second. The circuits II and III may be substantially similar in construction. For this reason, a discussion of the circuit II suffices for the presentation of the invention.

The circuit II includes a circuit interrupter **20** of conventional construction for segregating portions of the circuit. The circuit interrupter includes a trip coil **20T** which is effective when energized for tripping the circuit interrupter. The phase conductors of the system are identified by the reference characters A, B and C.

In order to protect the system, a relay device **22** is associated with the system. For energizing the relay device, a voltage bus **24** having phase conductors *a*, *b* and *c* is energized from the circuit I through a voltage transformer **26** having primary and secondary windings connected in star. The neutrals of the star-connected primary and secondary windings are illustrated as grounded. The voltages between the phase conductors *a*, *b* and *c* correspond to the voltages between the phase conductors A, B and C but may be reduced or changed in magnitude, if desired, by suitable selection of the ratio of transformation of the transformer **26**.

Currents are supplied to the relay device **22** from current transformers **28A**, **28B** and **28C**, which are associated respectively with the phase conductors A, B and C of the circuit 11. These current transformers may be connected in star with their neutral connected to a neutral conductor **28N** and to ground. The output currents *Ia*, *Ib* and *Ic* of the three-current transformers correspond respectively to the line currents flowing in the associated conductors A, B and C but may be reduced or changed in magnitude by proper selection of the transformer ratio of the current transformers.

The relay device **22** includes three relay units **30A**, **30B** and **30C**, which are associated respectively with the three phases of the associated electrical system. Since these relay units are similar in construction, a discussion of the relay unit **30A** suffices for a presentation of the invention.

The relay unit **30A** includes a directional relay **32** which has a magnetic structure provided with a voltage pole **34** and two current poles **36** and **38**. The poles are spaced to define an air gap within which an electroconductive disc **40** is positioned for rotation. The voltage pole has a voltage winding **42** surrounding the pole, whereas the current poles **36** and **38** have current windings **44** and **46** therearound. When these windings are suitably energized, a shifting magnetic field may be produced in the air gap for the purpose of rotating the armature or disc **40**. Rotation of the disc **40** in one direction closes a pair of contacts **48**, whereas rotation of the disc in the opposite direction opens the contacts. The magnetic structure, disc **40** and contacts **48** comprise parts of a translator which is directionally responsive to the energization of the windings.

The relay unit **30A** also includes an overcurrent timing relay **50** which includes a magnetic structure similar to that of the directional relay **32**. The magnetic structure includes a main pole **52** and two auxiliary poles **54** and **56** which are spaced to define an air gap within which an electroconductive armature or disc **57** is disposed for rotation. The main pole **52** has a main winding **58** therearound through which the overcurrent relay is energized. This winding may have an adjustable number of turns. The auxiliary poles **54** and **56** have windings **60** and **61** thereabout, which are connected in series with each other and with a winding **62** through the contacts **48** of the directional relay.

It will be noted that the windings **58** and **62** are inductively coupled to each other. Consequently, if the winding **58** is energized by alternating current and if the contacts **48** are closed, the windings **60** and **61** are energized from the winding **62**.

Inasmuch as the relay **50** is employed for timing purposes, a damping magnet **64** (a fragment of which is shown) is associated with the disc **57** in a conventional manner.

The overcurrent relay is employed for controlling any desired translating device, such as the circuit interrupter **20**. The overcurrent relay **50** has a pair of contacts **66** normally biased open by a spring (not shown) which when closed connect a pair of conductors **68** and **70**. When these conductors are connected, they complete a circuit from a suitable source of energy, such as a battery **72** to the trip coil **20T** of the circuit interrupter.

By inspection of Fig. 1, it will be observed that the windings **44**, **46** and **58** are connected in series through a conductor **74**. The relay unit **30A**, as thus described, may be exactly similar to the type CR directional overcurrent relay described in the aforesaid handbook. In order to simplify the illustration, certain components, such as connection blocks and the torque compensator, have been omitted. The only change introduced herein is the provision of a terminal binding post **76** which is connected to the conductor **74**.

Inasmuch as the relay unit **30A** is associated with phase A of the electrical system, the voltage winding **42** is connected for energization across the conductors *a* and *c* of the voltage bus **24** for energization in accordance with the voltage E_{ac}. If prior art practice were to be followed, the windings **44**, **46** and **58** would be energized solely in accordance with the current I_a which represents the current flowing in the conductor A of the system. However, in accordance with the invention, the directional relay **32** also is energized by a restraining current which opposes operation of the relays.

The energization of the windings **44**, **46** and **58** conveniently may be obtained through an auxiliary unit **78A**. Similarly, units **78B** and **78C** are provided for the relay unit **30B** and the relay unit **30C** respectively.

The windings **44** and **46** are connected in series across the terminals of the secondary winding of a transformer **80**. This transformer may have separate primary and second windings, as in the conventional two-winding transformer. In the embodiment of Fig. 1 an autotransformer is employed. The circuit may be traced from the winding **44** through the winding **46**, the conductor **74**, the terminal binding post **76**, a conductor **82**, the secondary winding of the transformer **80** and a conductor **84** to the winding **44**.

The primary winding of the transformer is energized from the current transformer **28A** through one of a plurality of taps **80D**, **80E**, **80F** and **80G** on the primary winding. The energizing circuit for the primary winding of the transformer may be traced from the current transformer **28A** through a conductor **86**, a terminal block **87** through which the conductor **86** may be connected to any of the taps on the primary winding of the transformer, the selected portion of the primary winding, the conductor **82**, the terminal winding post **76**, the winding **58** of the overcurrent relay and the conductor **28N** to the remaining terminal of the secondary winding of the current transformer **28A**. Consequently, the primary winding of the transformer and the

winding 58 of the overcurrent relay are energized in accordance with the current I_a. This current flowing through the primary winding of the transformer produces a current KI_a in the secondary winding and the latter current KI_a flows through the windings 44 and 46 of the directional relay.

It will be recalled that a restraining current is supplied to the directional relay. This current is sufficient to provide the desired restraint during normal operation of the associated electrical system. When a fault occurs for which the relay unit 30A should operate, the restraining current should decrease or substantially vanish.

The phase A relay unit is intended to operate for a line fault involving the phases A and B of the associated electrical system, for a ground fault involving phases A and B of the associated electrical system and for a three-phase fault. For any of these fault conditions, the voltage between the phase conductors A and B is substantially reduced. Consequently, the voltage E_{ba} may be employed for producing the desired restraint for the directional relay. This voltage is employed for energizing a winding 88 which is inductively coupled to the secondary winding of the transformer 80. Consequently, the secondary winding of the transformer also serves as the secondary winding of a two-winding transformer wherein the winding 88 is the primary winding.

The energization of the winding 88 is effected through a suitable impedance 90. This impedance may be selected to produce the desired phase relationship between the voltage E_{ba} and the current supplied to the winding 88. For the purposes of illustration, it is assumed that the impedance 90 includes an inductive reactance represented by a coil 90D and a resistance represented by a resistor 90F connected in series. The entire energizing circuit for the winding 88 may be traced from the conductor *a* of the voltage bus 24 through a conductor 92, the winding 88, the impedance 90 and a conductor 94 to the conductor *b* of the voltage bus 24.

The operation of the relay unit 30A may be understood more clearly from a study of the vector diagram illustrated in Fig. 2. Conventional counterclockwise rotation of the vectors is assumed. The three voltages E_{ac}, E_{ba}, E_{cb} of the voltage bus 24 are shown in Fig. 2. It will be recalled that the voltage E_{ba} is employed for energizing the winding 88 to induce in the secondary winding of the transformer 80 a voltage which produces the current I_e. The impedance 90 is selected to provide a phase displacement between the current I_e and the associated voltage E_{ba} which brings the current substantially into phase opposition with the voltage E_{ac}. Inasmuch as the voltage E_{ac} is employed for energizing the voltage winding 42 of the directional relay, the current I_e in flowing through the windings 44 and 46 cooperates with the energization of the voltage winding to urge the disc 40 in a contact opening direction. Therefore, the current I_e is a restraining current which opposes operation of the directional relay. It will be recalled that this current decreases to a small value when a fault occurs for which operation of the relay unit 30A is desired.

The three currents I_a, I_b and I_c also are illustrated in Fig. 2. The current I_a energizes the winding 58 of the overcurrent relay. In addition, this current in flowing through the primary winding of the transformer 80 induces in the secondary winding of the transformer a current KI_a wherein K represents the transformer ratio of the transformer. The resultant current passing through the windings 44 and 46 of the directional relay then is represented by the current I_r which is the vector sum of the currents I_e and KI_a.

As long as the current I_e has a value sufficient to prevent operation of the directional relay 32, the contacts 48 of the directional relay are held open to maintain the overcurrent relay 50 in an inoperative condition. For this reason, the overcurrent relay may be adjusted to operate for a current corresponding to a value less than full load current of the associated system without fear of an incorrect operation of the overcurrent relay while the system is in normal operating condition. When a fault occurs for which the relay unit 30A should operate, the current I_e decreases to a value sufficiently small to permit operation of the directional relay 32. The resulting closure of the contacts 48 then places the overcurrent relay in operating condition, and the overcurrent relay operates with the proper time delay to close its contacts 66.

The directional relay operates only if the energy flowing in the associated system is in the proper direction. For example, it may be connected to close its contacts only for the direction of energy flow represented by the arrow 96.

It will be recalled that several taps are provided on the primary winding of the transformer 80. These taps control the sensitivity of the directional relay. For example, if the current I_a is in phase with the voltage E_{ac} (this corresponds to a 30° lagging power factor), the tap 80D may be so selected that five amperes flowing therethrough suffices to neutralize the restraining current I_e. Any increase in the current I_a above five amperes would result in operation of the directional relay. Similarly, the tap 80E may be so selected that under the assumed conditions 7½ amperes flowing through the primary winding of the transformer neutralizes the effect of the restraining current I_e in the directional relay. As further examples, the taps 80F and 80G, respectively, may require 10 and 12½ amperes to neutralize the restraining current I_e.

The characteristics of the relay unit 30A are illustrated in Fig. 3 by means of a conventional polar diagram. In this diagram the circles represent values of current, whereas the radial lines represent phase angle. The reference voltage employed for energizing the voltage winding 42 is illustrated by a vector 98. The curve 99D represents a conventional characteristic curve of the type CR relay described in the aforesaid handbook. Current vectors terminating above this curve result in closure of the contacts of the directional relay. The contacts remain open for current vectors which fall below the curve 99D. The curves 99E, 99F, 99G and 99H represent the characteristics of the directional relay, respectively, for the taps 80D, 80E, 80F and 80G. It will be observed that the change in shape of the characteristic curve is so small as to be virtually negligible for all relay applications.

In operation, the relay system is connected as illustrated in Fig. 1. The conductor 86 then is connected to the proper tap on the primary winding of the transformer 80 to provide the desired relay sensitivity. As a result of this connection, the overcurrent timing relay 50 may be adjusted to respond to any desired value of current, even though this current corresponds to a value below the full load current of the associated electrical

system. A greatly increased range of timing adjustment thus is available.

Although the invention has been described with reference to certain specific embodiments thereof, numerous modifications falling within the spirit and scope of the invention, are possible.

I claim as my invention:

1. In an electrical relay device, a directional relay having first and second windings arranged for independent energizations, a first source of energy for energizing the first winding, a second source of energy for energizing the first winding, a third source of energy for energizing the second winding, and a translator having a predetermined directional response to only a predetermined direction of energization of the first and second windings, the second source being connected to the first winding to cooperate with said energization of the second winding to oppose said directional response of the translator.

2. In an electrical relay device, a directional relay having first and second windings arranged for independent energizations, a first source of energy for energizing the first winding, a second source of energy for energizing the first winding, one of the sources comprising a transformer, and the other of the sources being connected to its associated winding through the secondary winding of the transformer, a third source of energy for energizing the second winding, and a translator having a predetermined directional response only to a predetermined direction of energization of the first and second windings, the second source being connected to energize the first winding to cooperate with said energization of the second winding to oppose said directional response of the translator.

3. In an electrical relay device, a directional relay having first and second windings arranged for independent energizations, a first alternating source of energy for energizing the first winding, a second alternating source of energy for energizing the first winding, one of the sources comprising a transformer having an adjustable primary winding and the other of the sources including a winding inductively coupled to the secondary winding of the transformer, a third source of alternating energy for energizing the second winding, and a translator having a predetermined directional response to a predetermined direction of energization of the first and second windings, the second alternating source being connected to energize the first winding in a direction cooperating with said energization of the second winding to oppose said directional response of the translator.

4. In a relay device, a directional relay having current and voltage windings, a normally inoperative protective relay, conditioning means responsive to operation of the directional relay for conditioning the protective relay for operation, connections connecting the current winding and the protective relay for energization in accordance with a first quantity, and connections for energizing the current winding in accordance with a second quantity, the connections being poled to cause the two energizations of the current winding operating in conjunction with the voltage winding when energized to act in opposition on the conditioning means.

5. In an electrical relay device, an over-current relay having windings normally ineffectively connected for operation, a directional relay having a voltage winding and a current winding, and effectuating means responsive to operation of the directional relay for connecting the windings of the overcurrent relay for operation, a transformer having a secondary winding connected for energizing the current winding, said transformer having a primary winding coupled to the secondary winding for supplying energy thereto, and a winding inductively coupled to the secondary winding of the transformer to form therewith a two-winding transformer for additionally energizing the current winding.

6. In an electrical relay device, an overcurrent timing relay having windings normally ineffectively connected for operation, a directional relay having a voltage winding and a current winding, and effectuating means responsive to operation of the directional relay for connecting the windings of the overcurrent relay for operation, an autotransformer having a secondary winding connected for energizing the current winding in accordance with energization of the primary winding of the autotransformer, a winding inductively coupled to the secondary winding of the autotransformer to form a two-winding transformer for additionally energizing the current winding, said autotransformer having an adjustable winding, and connections for energizing the overcurrent relay in accordance with the energization of the primary winding of the autotransformer.

7. In an electrical system, an electrical main circuit, a first relay connected to the circuit for response to a first predetermined fault condition of the circuit, a second relay, connections established in response to operation of the first relay for effectively connecting the second relay for response to a second condition of the circuit, connections establishing a local circuit responsive to a condition of the main circuit which substantially disappears upon occurrence of the predetermined fault condition on the main circuit for energizing the first relay to restrain operation of the first relay, and a translating device responsive to the second relay.

8. In an electrical system, an electrical polyphase circuit, a directional relay including a winding, connections energizing the relay including said winding from the circuit in accordance with a first phase voltage and a current of the circuit for response in accordance with the direction of energy flow in the circuit, and connections energizing said winding of the relay in accordance with a second phase voltage of the circuit for restraining operation of the relay, the second circuit phase voltage decreasing to a substantially greater extent than the first circuit phase voltage under a predetermined fault condition for which operation of the relay is desired, an overcurrent relay, connections completed in response to operation of the directional relay for energizing the overcurrent relay for operation in accordance with the current flowing in the circuit, and a translating device responsive to operation of the overcurrent relay.

9. In an electrical relay device, a directional relay having a voltage winding and a current winding, and an armature element responsive to a function of the product of the energizations of the voltage winding and the current winding, a current autotransformer having a secondary connected to supply first energy to the current winding, said autotransformer having primary terminals suitable for connection to a first source of electrical energy, and an auxiliary winding coupled to the secondary winding to constitute therewith a two-winding transformer, whereby

second energy may be supplied through the two-winding transformer to the current winding from a second source of electrical energy independent of the first source.

10. A relay device as claimed in claim 9 wherein the primary of the autotransformer has an adjustable number of turns.

11. A relay device as claimed in claim 9 in combination with a polyphase alternating-current circuit to be protected by the relay device, connections connecting the primary terminals for energization in accordance with current flowing in the polyphase alternating-current circuit, connections for energizing the voltage winding in accordance with a first voltage of the polyphase alternating-current circuit, and connections for energizing the auxiliary winding in accordance with a second voltage of the polyphase alternating-current circuit which decreases upon occurrence of a predetermined fault condition for which the relay device is to operate, said connections including impedance producing phase relations between the two energizations of the current winding respectively and the energization of the voltage winding which produce opposite forces

acting between the armature element and the relay windings.

12. The combination claimed in claim 11 in combination with an overcurrent relay, and connections completed by operation of the directional relay for operatively energizing the overcurrent relay in accordance with the current supplied to the primary terminals.

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