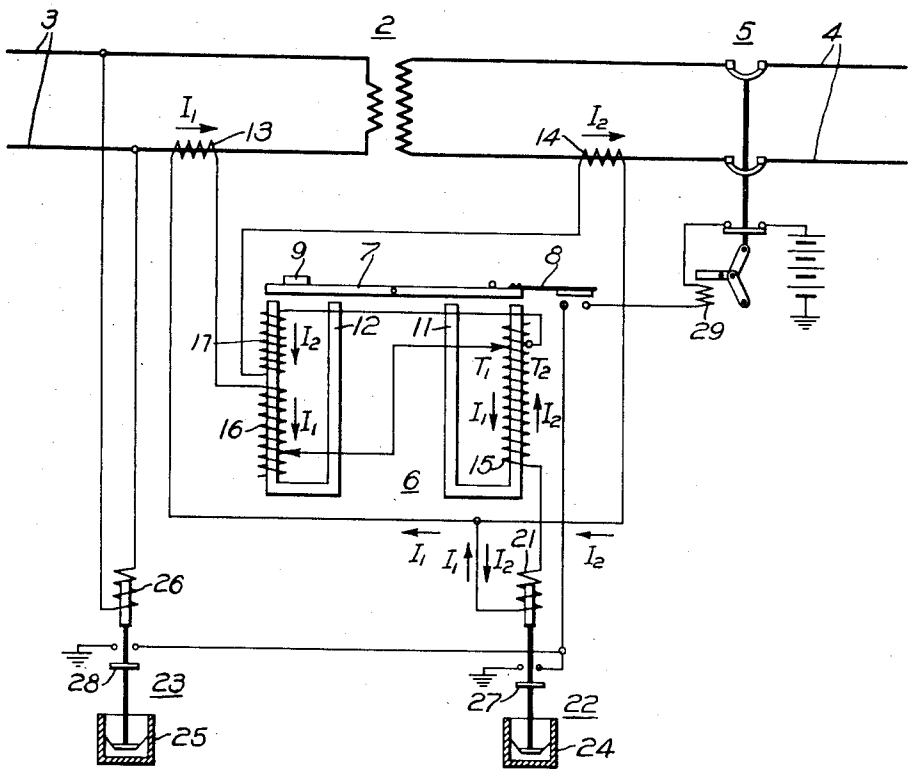
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HIGH SPEED DIFFERENTIAL RELAY

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## HIGH SPEED DIFFERENTIAL RELAY

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My invention relates to high-speed differential relays and it has particular relation to ratio-differential relays for transformer protection. Such relays are made to be as sensitive as possible and thus are usually made to respond more nearly to a predetermined departure, from a predetermined normal value, of the ratio of the input current to the output current, rather than responding to a predetermined difference between the currents themselves. When such relays are utilized to protect certain types of devices, notably transformers for power service, false operations are frequently obtained due to the magnetizing current surge, depending upon the point in the alternating-current cycle at which the transformer is first energized.

It is the object of my invention to provide suitable means for safeguarding against such faulty operation, in a differential protective relay system for a power transformer or the like, without sacrificing either the high speed or the extreme sensitivity of the balanced-type differential relay.

With the foregoing and other objects in view, my invention consists of the circuits, apparatus and systems hereinafter described and claimed and illustrated in the accompanying drawing, the single figure of which is a diagrammatic view of circuits and apparatus embodying my invention.

As shown in the drawing, my invention is utilized for the protection of a step-up transformer 2 receiving power from a generator bus 3 and transmitting power to a transmission line 4 through a circuit breaker 5. The transformer 2 is protected by a high-speed ratio-differential relay 6 comprising a balanced beam or armature 7 carrying a contact member 8 on one end and a counterbalancing weight 9 on the other, the counterbalancing weight being usually adjusted to slightly more than counterbalance the contact member so as to bias the relay toward its non-actuated position.

The balanced beam or armature 7 is acted upon by two magnetic circuits 11 and 12 which are energized, in a manner to be subsequently described, from two current transformers 13 and 14 which are responsive respectively to the input current and the output current of the transformer to be protected. The magnetic circuit 11 is energized by means of an operating coil 15 which is differentially excited from the two current transformers 13 and 14, whereby an operating force is developed in order to move the contact member 8 to its actuated position, in response to the difference between the input and output currents of the transformer 2. The magnetic circuit 12 is energized by two restraining coils 16 and 17 which are energized by the currents flowing in the secondary windings of the respective current transformers 13 and 14.

Under normal conditions, that is, when there is no internal fault in the transformer 2 to be protected, the two restraining coils 16 and 17 are so energized that their magnetomotive forces add, so as to normally provide a strong restraining force holding the contact member 8 in its non-actuated position. In the particular relay shown in the drawing, the contact member 8 is open in its non-actuated condition, and is closed when the relay responds to a predetermined change in the ratio of input and output currents of the transformer 2.

The current transformers 13 and 14 are usually chosen from a stock of standard current transformers, usually designed for a maximum current of about 5 amperes in the secondary circuit. In case there is any discrepancy in the available transformation-ratios of the current transformers 13 and 14, as compared with the transformation-ratio of the main transformer 2, such difference is compensated for by an adjustment of the number of turns traversed by either the input current or the output current in the operating coil 15 and also in one of the restraining coils, as 16.

In order to understand the operation of a device which is actuated by current transformers, it is convenient, when a single device is acted upon by two currents, to assume that each current flows through the device separately, this assumption being warranted because, in any divided circuit including current transformers, the effect of the current transformers is to fix the currents in the several paths in which they are located. Tracing the currents delivered by the two current transformers in the drawing, it will be noted that the input or primary current $I_1$ of the current transformer 13 passes through the restraining coil 16 and through the turns $T_1$ of the operating coil 15, returning to the current transformer through the operating coil 21 of a current-responsive timing device 22 to be subsequently described. The output or secondary current $I_2$ of the main transformer 2 passes through the timing-element coil 21, through the turns $T_2$ of the operating coil 15, and through the restraining coil 17. The ampere-turns $I_1T_1$ and $I_2T_2$ of the primary and secondary currents in the operating coil 15 are normally equal and opposite in

their effect, so that no pull is produced on the corresponding end of the balance beam 7 when there is no fault in the main transformer which is being protected.

When an internal fault occurs in the transformer being protected, there will be a decrease in the pull or effectiveness of the restraining coils 16 and 17, and at the same time there will be a strong flux developed by the operating coil 15 by reason of the fact that the ampere turns $I_1T_1$ and $I_2T_2$ are no longer equal and opposite to each other. It will be noted that, if the fault develops during light-load conditions, there will be only a very weak restraining force developed by the restraining coils 16 and 17, so that the total effective ampere-turns on the operating-coil side, necessary to tip over the balance beam 7, will be much less than the effective ampere-turns, or difference in currents, which is necessary to trip the beam when the fault occurs during heavy-load conditions. In this way, the relay responds to ratios rather than algebraic differences between currents, thus making the relay sensitive to small currents as well as large currents. It will be understood that the moving parts of the relay are made as light as practicable, in order to obtain substantially instantaneous response.

When a differential relay is made as quick in its action, and as sensitive in its operation, as the relay just described, it will trip, at least occasionally, upon the magnetizing current surges in the transformer 2, lasting for a considerable period of time, of the order of a second or more, after the transformer is first energized. These magnetizing current surges start with an initial maximum value, dependent upon the point in the cycle at which the transformer circuit was closed, and falling off, in accordance with a logarithmic curve, to their final values. If the differential relay is very quick and very sensitive, it may, and frequently does, trip in response to this initial magnetizing current.

In accordance with my invention, I prevent the possibility of such faulty operation of my differential relay by utilizing some sort of lock-out device for preventing the differential relay from performing its normal tripping function for a certain time after power is first applied to the main transformer which is being protected. Preferably, for this purpose, I utilize two timing elements which are indicated schematically in the drawing, at 22 and 23. The illustration of the timing elements in the drawing is intended to be purely schematic, so as to represent any known type of timing device, such as synchronous-motor devices, induction-motor devices, induction-disk devices, or solenoid devices operating against a time delay mechanism such as the dashpots 24 and 25. The timing mechanisms 22 and 23 are provided with operating coils 21 and 26, respectively, the former being energized in response to current, as previously described, and the latter being energized in response to the voltage appearing across one of the terminals of the transformer 2 to be protected.

The timing members 22 and 23 are provided with contact devices 27 and 28 respectively, which are connected in parallel to each other, and in series with the control device 8 of the differential relay, so that the differential relay does not become effective until either one or both of the timing members 22 and 23 have moved to their actuated position. As shown in the drawing, the contact member 8 of the differential relay is utilized to energize the tripping coil 29 of the circuit breaker 5.

Assuming that the generator bus 3 is deenergized and that the main transformer 2 is disconnected from a live transmission line 4 by means of the circuit breaker 5, it will be noted that all contacts will be open. If, now, the circuit breaker 5 is closed, thus energizing the main transformer 2, the high-speed differential contact member 8 may close substantially instantaneously on the magnetizing surge, but both of the timer contact members 27 and 28 are open, so that the circuit breaker 5 is not immediately tripped out. The voltage-responsive timer 23 will immediately start to close its contact member 28, and it is given such a time delay that, by the time said contact member 28 has closed, the differential contact member 8 will have reset due to the subsidence of the surge.

The voltage-responsive timer 23 keeps its contacts closed as long as there is voltage. If, now, while the main transformer is connected in operation, an internal fault should develop therein, the fault will, in general, cause a collapse of the voltage applied to the voltage-responsive timer 23, so that the latter will begin to open its contact member 28; but the quick-acting differential relay 6 is much faster, closing its contact member 8 before the trip circuit is open-circuited at the voltage-timer contact member 28, thus tripping the circuit breaker 5.

A current-responsive timer, as shown at 22, is preferably utilized also, in addition to the voltage-responsive timer 23, in order to afford protection in case the main transformer 2 is connected to a source of energy when it has an internal fault somewhere within the transformer. In such a case, the voltage timer will not operate, because of the collapse of voltage caused by the fault, and I make use of some sort of current-operated timer to close its contacts and thus trip out the circuit breaker 5. The current-responsive timer 22 can be given a high-current, short-time setting, so that the time necessary to clear, when closing in on a faulty transformer, is reduced to a minimum.

I preferably design the current-responsive timer 22 so that it will not close its contacts in response to the magnetizing current surge in the main transformer 2. This may be done by building the timer with a critical-current value so that it will not operate at all, when the current falls below a predetermined minimum value, or so that it will operate only very slowly when the current falls to a predetermined low value. As above pointed out, the value of the first inrush of magnetizing current depends upon the particular point in the cycle at which the main transformer is energized. Calculation and experience have shown that this first inrush of magnetizing current may be of the same order of magnitude as a fault current due to a fault in the transformer being protected. The magnetizing current falls off, however, very rapidly, ultimately becoming substantially zero, whereas a fault current does not fall off nearly so rapidly and does not ultimately become substantially zero. It is quite feasible, therefore, in most instances, to give the current-responsive timer a setting such that it will not close its contacts 27 in response to the magnetizing current surge, but so that it will close its contacts 27 in response to fault current. Moreover, the current-responsive timer 22 may be designed so that it will close its contacts 27 more quickly, in response to a fault current, than

the time required for the actuation of the voltage-responsive timer 23.

While I have shown my invention in single preferred form of embodiment and in a single application thereof, it will be obvious that many changes may be made by those skilled in the art without departing from the essential spirit of my invention. I desire, therefore, that the appended claims shall be accorded the broadest interpretation consistent with their language and the prior art.

I claim as my invention:

1. A differential protective relay system for protecting a power transformer or the like, comprising a sensitive high-speed differential relay and energizing means for adapting it to respond to a predetermined departure, from a predetermined normal value, of the ratio of input current to output current of said transformer, and two timing devices, in combination with means for so correlating said differential relay and said timing devices that one of said timing devices must be actuated before said differential relay can be effective to perform its relaying function, one of said timing devices being a voltage-responsive timer and the other being a current-responsive timer, and means for energizing said timers respectively in accordance with a voltage and a current derived from said transformer.

2. A differential protective relay system for protecting a power transformer or the like, comprising a sensitive high-speed differential relay and energizing means for adapting it to respond to the input current and the output current of said transformer, and two timing devices, in combination with means for so correlating said differential relay and said timing devices that one of said timing devices must be actuated before said differential relay can be effective to perform its relaying function, one of said timing devices being a voltage-responsive timer and the other being a current-responsive timer, and means for energizing said timers respectively in accordance with a voltage and a current derived from said transformer, the current-responsive timer being so designed that it will start to move on some magnetizing-current surges in the transformer, but will not complete such movement materially before the time required by the voltage-responsive timer, the current-responsive timer being also so designed that, for any fault-current obtaining as a result of a fault within the transformer, said current-responsive timer will complete its movement before the time required by the voltage-responsive timer.

3. A differential protective relay system for protecting a power transformer or the like, comprising a sensitive high-speed differential relay and energizing means for adapting it to respond to the input current and the output current of said transformer, and two timing devices, in combination with means for so correlating said differential relay and said timing devices that one of said timing devices must be actuated before said differential relay can be effective to perform its relaying function, one of said timing devices being a voltage-responsive timer and the other being a current-responsive timer, and means for energizing said timers respectively in accordance with a voltage and a current derived from said transformer, the current-responsive timer being so designed that it will start to move on some magnetizing-current surges in the transformer, but will stop before completing its movement on a magnetizing-current surge.

4. In an electrical system including a power transformer and a circuit-interrupter therefor, a differential protective relay system comprising a sensitive high-speed differential relay and energizing means for adapting it to respond to a predetermined departure, from a predetermined normal value, of the ratio of the input current to output current of said transformer, a voltage-responsive timing device, means for energizing said timing device only when the transformer is energized, said differential relay and said timing device each having a contact element, means for actuating said circuit-interrupter, and an energizing circuit for said actuating means, said energizing circuit comprising the contact elements of both said relay and said timing device in series.

5. In an electrical system including a power transformer and a circuit-interrupter therefor, a differential protective relay system comprising a sensitive high-speed differential relay and energizing means for adapting it to respond to a predetermined departure, from a predetermined normal value, of the ratio of input current to output current of said transformer, a current-responsive timing device, means for energizing said timing device in accordance with a current function of the transformer, said timing device being so designed that it will start to move on some magnetizing-current surges in the transformer, but will stop before completing its movement on a magnetizing-current surge, and means for actuating said circuit-interrupter in response to both said relay and said timing device.

6. In an electrical system including a power transformer and a circuit-interrupter therefor, a differential protective relay system comprising a sensitive high-speed differential relay and energizing means for adapting it to respond to a predetermined departure, from a predetermined normal value, of the ratio of input current to output current of said transformer, and two timing devices, in combination with means for so correlating said differential relay and said timing devices that one of said timing devices must be actuated before said differential relay can be effective to actuate said circuit-interrupter, one of said timing devices being a voltage-responsive timer and the other being a current-responsive timer, and means for energizing said timers respectively in accordance with a voltage and a current derived from said transformer, said current-responsive timer operating substantially faster than said voltage-responsive timer on fault-current conditions within said transformer but not on magnetizing-current surges in said transformer.

7. In an electrical system including a power transformer and a circuit-interrupter therefor, a differential protective relay system comprising a sensitive high-speed differential relay and energizing means for adapting it to respond to the input current and the output current of said transformer, said relay having a contact element adapted to be actuated substantially instantaneously, and two timing devices, in combination with means for so correlating said differential relay and said timing devices that one of said timing devices must be actuated before said differential relay can be effective to actuate said circuit-interrupter, each of said timing devices having a contact element adapted to be actuated with time relay, one of said said timing devices being a voltage-responsive timer and the other being a current-responsive timer, and means for energizing said timers respectively in accordance with a voltage and a current derived from

said transformer, the current-responsive timer being so adjusted that it will not keep its contact element in actuated position for normal load conditions on the transformer, and the voltage-responsive timer being adapted to keep its contact element in actuated position for normal voltage conditions on the transformer and to maintain said contact element in actuated position, after collapse of voltage due to a transformer fault, long enough for the substantially instantaneously operating differential relay to operate.

8. A differential protective relay system for protecting an electrical device, comprising a sensitive high-speed differential relay and energizing means for adapting it to respond to the input current and the output current of said electrical device, said relay having a contact element adapted to be actuated substantially instantaneously, a voltage-responsive timing device, and means for energizing said timing device in accordance with a voltage of said device to be protected, in combination with means for so correlating said differential relay and said timing device that the latter must be actuated before said differential relay can be effective to perform its relaying function, said voltage-responsive timing device having a contact element adapted to be actuated with time delay, said voltage-responsive timing device being adapted to keep its contact element in actuated position during normal voltage conditions on the device to be protected and to maintain said contact element in actuated position, after collapse of voltage due to an internal fault in the device to be protected, long enough for the substantially instantaneously operating differential relay to operate.

9. The invention as recited in claim 8, in combination with a current-responsive timing device operable selectively in response to fault-current conditions in the device to be protected and having a contact element adapted to be actuated faster than said voltage-timer contact element, in response to said fault-current conditions, and performing the function described for the voltage-timer contact element in making said differential relay effective to perform its relay function.

10. A protective system for a line to be protected, comprising a quick-acting current-responsive differential relay having differentially excited operating windings and additively excited restraining windings, a differentially excited current-responsive timing element, means for differentially exciting said operating windings and said timing element in response to the difference between the currents entering and leaving the line to be protected, means for additively exciting said restraining windings in response to the sum of the currents entering and leaving the line to be protected, and means responsive to an actuation of said timing element and performing a relaying operation only when said differential relay is also actuated.

11. A protective system for a line to be protected, comprising a quick-acting current-responsive differential relay having differentially excited operating windings, and two timing devices, in combination with means for so correlating said differential relay and said timing devices, that one of said timing devices must be actuated before said differential relay can be effective to perform its relaying function, one of said timing devices being a voltage responsive timer and the other being a differentially excited current-responsive timer, means for differentially exciting said operating windings and said current-responsive timer in response to the difference between the currents entering and leaving the line to be protected, and means for exciting the voltage-responsive timer in response to a voltage function of the line to be protected.

12. A differential protective relay system for protected an electrical device, comprising a sensitive high-speed differential relay having differentially excited current-responsive operating windings, exciting means therefor responsive differentially to the input current and output current of said electrical device, and two timing devices, in combination with means for so correlating said differential relay and said timing devices that one of said timing devices must be actuated before said differential relay can be effective to perform its relaying function, one of said timing devices being a voltage-responsive timer, exciting means therefore responsive to a voltage derived from said electrical device, and the other being a differentially excited current-responsive timer, and exciting means therefor responsive differentially to the input and the output current of said electrical device.

13. A differential protective relay system for protecting an electrical device, comprising a sensitive high-speed differential relay having differentially excited current-responsive operating windings, exciting means therefor responsive differentially to the input current of said electrical device, a voltage-responsive timing device, means for energizing said timing device only when the device to be protected is energized, means for performing a relaying function in response to both said differential relay and said voltage-responsive timing device, a differentially excited current-responsive auxiliary device having actuating windings, exciting means therefor responsive differentially to the input current and the output current of said electrical device, and means for performing a relaying function in response to both said differential relay and said current-responsive auxiliary device.

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