

[54] **TRANSFORMER INTERNAL FAULT
DETECTOR**

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[58] Field of Search **317/14 R, 14 C, 14 D**

[56] **References Cited**

UNITED STATES PATENTS

3,754,163 8/1973 Sykes **317/14 D**

Primary Examiner—**L. T. Hix**

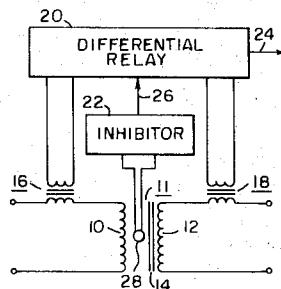
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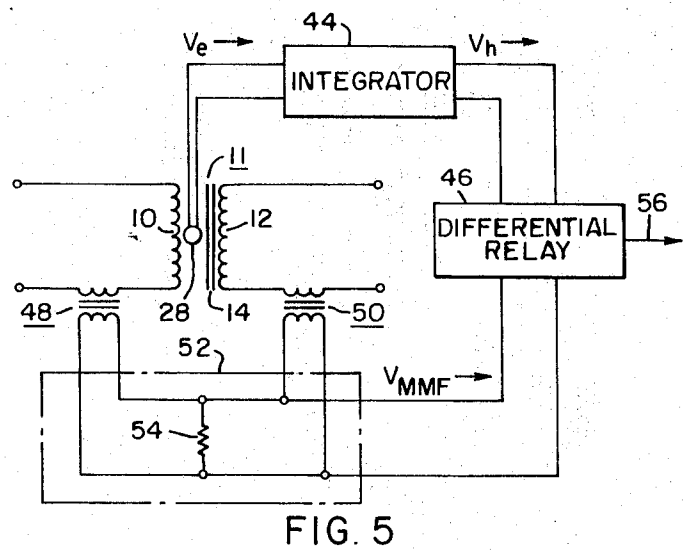
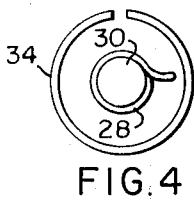
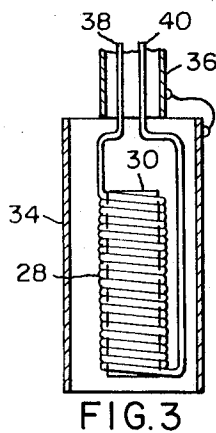
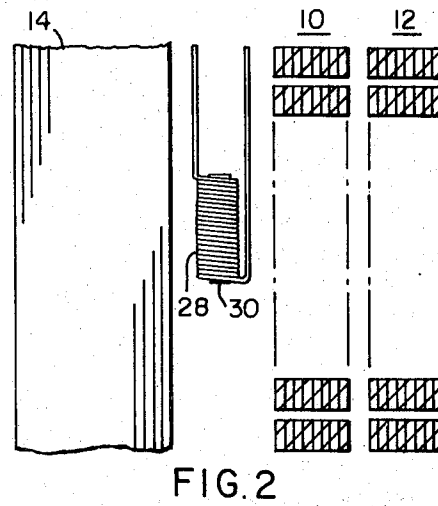
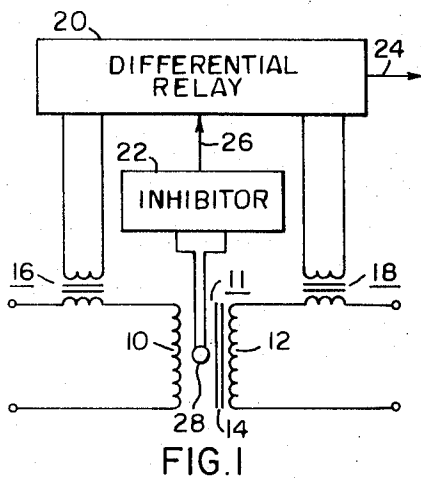
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ABSTRACT

A fault detector for power transformers which quickly indicates an internal fault condition. In one embodiment, the current in the primary and secondary windings are compared by a differential relay which may be restrained by a voltage developed during magnetizing inrush current conditions. This voltage is provided by a pick-up coil which is located between the primary winding and the magnetic core leg. The coil is oriented so that the voltage induced therein is relatively large when the core leg is saturated by an inrush current. In another embodiment, a first voltage from a similarly positioned pick-up coil is integrated and applied to a differential relay. A second voltage which is proportional to the difference between the magnetomotive forces in the primary and secondary windings is also applied to the differential relay. The differential relay compares the integrated voltage and the second voltage and is activated when an internal fault changes the normal ratio of these two voltages.

9 Claims, 6 Drawing Figures





TRANSFORMER CONDITION	MEASURED MAGNETIC FIELD	NET MAGNETOMOTIVE FORCE
NORMAL	O	O
OVERLOADED	O	O
INTERNAL FAULT	O	X
INRUSH CURRENT	Y	Y
INTERNAL FAULT & INRUSH CURRENT	Y	X+Y

FIG. 6

TRANSFORMER INTERNAL FAULT DETECTOR**BACKGROUND OF THE INVENTION****1. Field of the Invention**

This invention relates, in general, to electrical inductive apparatus and, more specifically, to transformer fault detectors.

2. Description of the Prior Art

Differential relays are used to detect an internal fault in a power transformer and to initiate the removal of the transformer from its energizing voltage. Current transformers in the primary and secondary windings of the transformer develop voltages which are applied to the differential relay. The current transformers and the differential relay are suitably constructed to make the proper comparison of the voltages. Without any internal faults or saturation of the core, the magnetomotive forces in the primary and secondary windings are substantially equal. Since the turns ratio is constant, the ratio between the primary and secondary currents is substantially constant in power transformers during normal operation. An internal fault changes the current ratio from its normal value and causes the differential relay to be activated.

Power transformers are subjected to magnetizing inrush currents usually when the transformer is first connected to the energizing voltage and to "sympathetic" inrush currents when another power transformer is first connected to the same energizing voltage. Inrush currents are characterized by their pulsating DC waveform which decays after a period of time. Before decay, the peak value of the inrush current may be several times the normal full load current. The actual value of the inrush current is limited only by the air-core impedance of the energized winding since the magnetic core is in saturation.

Since inrush currents flow mainly in the energized or primary winding, an abnormal primary to secondary current ratio exists for the duration of the inrush current. Thus, to prevent the inaccurate detection of an internal fault during inrush current conditions, some means must be used to prevent activation of the differential relay during the duration of the inrush current. Most prior art arrangements for reducing the effects of inrush currents employ an electrical or mechanical inhibiting means which restrains or prevents activation of the differential relay by the unbalance created during the inrush current condition.

Inrush current contains a high second order harmonic content. Many prior art restraining arrangements filter the second harmonic current from the fundamental primary current. When no harmonic current is detected, the primary current is not due to any inrush current. Thus, no restraint is provided and the differential relay will be activated if the primary to secondary current ratio is not proper. When harmonic current is detected, an abnormal primary to secondary current ratio is detected but activation of the differential relay is restrained due to the voltage provided by the second harmonic filtering system.

There are several disadvantages characteristic to prior art inrush current restraining arrangements. Filtering second harmonic current from the fundamental current requires a tuned filter network. The response time required for the filter to satisfactorily segregate the harmonic current component makes it necessary to

provide a permanent restraint in the differential relay which persists until the harmonic current restraining means can develop its own restraining action. Such a lag in response time of the differential relay, even if only for a few cycles, can allow large currents produced by internal faults to damage the power transformer or associated equipment. Therefore, it is desirable, and it is an object of one embodiment of this invention to provide a differential relay restraining means which responds substantially instantaneously to inrush currents.

Conventional restraining means also restrains the operation of the differential relay during inrush current conditions regardless of the existence of an internal fault current. This characteristic of responding only to inrush currents instead of internal fault current when they both exist simultaneously drastically reduces the usefulness of such a protective device during current conditions which are very probable considering the nature and causes of the excessive currents. Therefore, it is also desirable, and it is an object of another embodiment of this invention, to provide a fault detecting system wherein internal fault produced currents can be detected and corrective action taken even when an inrush current is present.

SUMMARY OF THE INVENTION

There is disclosed herein transformer internal fault detectors which can respond quickly to internal faults within the transformer. In one embodiment, a pick-up coil is located between the primary winding and the magnetic core. An inrush current saturates the core and develops a relatively large magnetic field which is oriented in a direction which induces a voltage into the pick-up coil. The induced voltage in the pick-up coil is used to restrain the activation of the differential relay connected to the primary and secondary windings of the transformer. Since the induced voltage is developed during the first cycle of the inrush current, the restraining means of the differential relay can be constructed to activate quickly since there is no requirement to delay activation to allow for the response time of the restraining means. Thus, the differential relay can respond quickly to the internal fault conditions, therefore reducing the possibility of further internal or external apparatus destruction.

In another embodiment of the invention, the induced voltage in the pick-up coil is applied to an integrating circuit. The integrating circuit provides a voltage which is proportional to the magnetic field which exists between the primary winding and the magnetic core and which is oriented in a direction to induce voltage into the pick-up coil. The magnitude of this voltage is substantially equal to zero when no inrush currents are present. When an inrush current is present, the magnitude of the voltage from the integrator is relatively large and is applied to a differential relay. The differential relay compares the integrated voltage from the pick-up coil and a voltage produced by a difference in the magnetomotive forces in the primary and secondary windings. The two voltages are equal except during an internal fault condition, regardless of the presence of inrush currents. Thus, quick and accurate response to an internal fault condition may be accomplished with a differential relay which does not require a restraining means. In addition, since the voltages compared by the differential relay are different during

a combined inrush and fault condition, detection of a fault condition during an inrush current condition may be achieved.

BRIEF DESCRIPTION OF THE DRAWING

Further advantages and uses of this invention will become more apparent when considered in view of the following detailed description and drawings, in which:

FIG. 1 is a schematic diagram of a fault detector constructed according to an embodiment of this invention and connected to a power transformer;

FIG. 2 is a partial sectional view of a power transformer with a pick-up coil positioned and constructed according to this invention;

FIG. 3 is an elevational view, in section, of a pick-up coil constructed according to this invention with an electrostatic shield positioned therearound;

FIG. 4 is a bottom view of the pick-up coil and the shield shown in FIG. 3;

FIG. 5 is a schematic diagram of a fault detector constructed according to another embodiment of this invention and connected to a power transformer; and

FIG. 6 is a table representing the relative voltage magnitudes existing in the circuit of FIG. 5 during specific operating conditions.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Throughout the following description, similar reference characters refer to similar elements or members in all the figures of the drawing.

Referring now to the drawing, and to FIG. 1 in particular, there is shown an internal fault detector associated with a power transformer 11. The transformer 11 includes the primary winding 10, the secondary winding 12, and the magnetic core 14. Current transformers 16 and 18 are connected to provide a voltage proportional to the current in the primary and secondary windings 10 and 12, respectively. The differential relay 20 properly compares the voltages from the current transformers 16 and 18 and, depending on the comparison made and the signal 26 from the inhibitor 22, may provide an output signal 24 which normally disconnects the transformer 11 from its energizing voltage. Differential relays with various inhibiting arrangements are shown in U.S. Pat. Nos. 3,144,590; 3,160,787; 3,218,516 and 3,414,772, all of which are assigned to the assignee of this invention.

The general function of the differential relay 20 is to compare the voltages produced by the current transformers 16 and 18. This indicates whether the current in the primary winding 10 is substantially proportional to the current in the secondary winding 12. The turns ratio of each current transformer may be selected to provide equal voltages for winding currents having a ratio corresponding to the primary-secondary winding turns ratio of the transformer 11. Other turns ratio compensating techniques may be used, such as a voltage divider or a tapped relay coil in the differential relay 20.

The inhibitor signal 26 restrains activation of the differential relay 20. Various mechanical, electrical and magnetic inhibiting arrangements have been disclosed and used in the prior art to restrain activation of the differential relay 20. The inhibitor is responsive to a voltage developed by the pick-up coil 28. The pick-up coil

is located in the magnetic field between the energizing or primary winding 10 and the magnetic core 14. During most normal fault and overloaded operating conditions of the transformer 11 the voltage developed by the pick-up coil 28 is very small. Thus, the signal 26 from the inhibitor 22 does not function to restrain activation of the differential relay 20 should an internal fault occur which produces an abnormal ratio of primary to secondary winding current.

FIG. 2 is a partial sectional view of a transformer and winding assembly with the pick-up coil 28 positioned therein. The pick-up coil 28 is wound around a rod 30 which is constructed of a suitable material. This material may have magnetic properties when the voltage provided by the pick-up coil 28 can have a non-linear relationship to the magnetic field. The pick-up coil 28 is located between the core 14 and the primary winding 10. The axis of the coil 28 is substantially parallel to the axis of the primary winding 10 and of the secondary winding 12. It is emphasized that it is within the scope of this invention that the secondary winding 12 may be connected to the energizing voltage instead of primary winding 10.

The location of the coil 28 between the core 14 and the primary winding 10 is important in order to keep unwanted magnetic fields from inducing a voltage into the pick-up coil 28. In general, the pick-up coil 28 should not be located near the ends of the primary winding 10 where leakage flux, which would not be perpendicular to the coil 28 would induce a voltage into the coil 28. Preferably, the coil 28 should not be located adjacent to a portion of the primary winding 10 which has tap leads connected thereto since, during some tapping arrangements, distorted flux patterns may induce a voltage into the coil 28.

During the normal operation of the transformer 11, the magnetic core 14 does not become saturated. Also, the core rarely becomes saturated under "normal" overloaded conditions. Consequently, the drop in the magnetic potential along the magnetic core 14 is small during unsaturated conditions. The net component of the flux in the direction parallel to the axis of the coil 28 is zero. Hence, negligible voltage is induced into the coil 28 when the core 14 is not saturated.

When the core 14 becomes saturated, the drop in the magnetic potential along the core 14 becomes appreciable and the net component of the flux in the direction parallel to the axis of the coil 28 has a finite value. This flux induces a voltage into the coil 28 which varies with the magnetomotive force for the core.

Magnetizing inrush current is unique in its ability to saturate the magnetic core 14. By sensing the presence of a saturated core, the presence of an inrush current component in the currents applied to the differential relay 20 can be detected, and the proper relay restraining action provided.

For a typical power transformer operating normally, and not in saturation, a flux density of up to approximately 20,000 gauss can be developed by a magnetic field intensity of approximately 200 oersteds. When an inrush current starts to saturate the core, at approximately 21,000 gauss, the magnetic field intensity required is approximately 800 oersteds. The magnetic field intensity increases rapidly after saturation and, with possible values of magnetizing inrush currents, a magnetic field intensity of approximately 40,000 oersteds may be developed. Thus, the magnetic field inten-

sity between the core 14 and the primary winding 10 increases very rapidly when a magnetizing inrush current is present.

An electrostatic shield may be used to prevent current from being established in the coil 28 due to the electric field between the winding 10 and the core 14. The electric field is especially strong when the voltage from a lightning stroke is developed across the winding 10. FIG. 3 shows one arrangement of an electrostatic shield which may be used. The sleeve 34 is coaxially positioned around the coil 28 and is electrically connected to the sleeve 36 which surrounds the leads 38 and 40 of the coil 28. The sleeves 34 and 36 are connected to ground potential. This effectively removes the coil 28 and the leads 38 and 40 from the electric field and prevents false restraining signals due to large electric fields.

The sleeve 34 may be constructed of a rigid metallic tube, a conducting foil wrapped around the coil 28, a conducting coating disposed on an insulating cylinder, or of any other suitable material. As shown in FIG. 4, the sleeve 34 must be discontinuous around the coil 28 to prevent the formation of a shorted turn in the magnetic field.

The internal fault detector described thus far has used the voltage from the pick-up coil 28 to restrain the operation of a differential relay during magnetizing inrush current conditions. As shown in FIG. 5, the voltage from the pick-up coil 28 may also be used directly in detecting an internal fault in the transformer 11. Definite relationships between the magnetomotive forces and the magnetic field intensity within the winding exist in power transformers. Without internal fault currents, the net sum of the magnetomotive forces in the primary winding 10 and in the secondary winding 12 equals zero and the net magnetic field which is oriented to induce a voltage into the pick-up coil 28 is zero. These same conditions also exist generally when the power transformer 10 is moderately overloaded.

The equality between the net magnetomotive force and the magnetic field is utilized by the circuit of FIG. 5 to detect any potentially destructive abnormal conditions in the transformer 11. When an internal fault occurs, the net magnetomotive force will not be zero although the inducing magnetic field around the pick-up coil 28 will remain equal to zero. Therefore, the equality between the net magnetomotive force and the inducing magnetic field is not maintained. When a magnetizing inrush current exists, the net magnetomotive force is not zero nor is the inducing magnetic field zero. Since the net magnetomotive force due to inrush currents is proportional to the magnetic field detected, the equality still exists. These relationships between the magnetic field adjacent to the magnetic core 14 and the net magnetomotive force of the windings 10 and 12 may be used to directly indicate the existence of a destructive condition within the transformer 11.

FIG. 6 is a table illustrating the relative magnitude of quantities compared for detection of a destructive condition in a transformer. In normal and overloaded conditions, the quantities are equal to zero. During an internal fault condition, the net magnetomotive force is some value X which is different than zero. These quantities are also different when both fault and inrush currents are present. During inrush current conditions, the magnetic field Y and the net magnetomotive force Y are different than zero but equal to each other.

The magnetic field "h," in oersteds, adjacent to the core 14 is equal to the flux density "B," in gauss, in the pick-up coil 28. Therefore, the equation

$$V_e = N10^{-8} A(dB/dt) = N10^{-8} A(dh/dt)$$

properly determines the voltage, in volts, which is induced into the pick-up coil 28 having "N" turns and a pick-up area of "A" square centimeters. The integrator 44 shown in FIG. 5 integrates the voltage V_e from the pick-up coil 28 and provides an output voltage V_h which is proportional to the magnetic field which induces the voltage into the pick-up coil 28. The voltage V_h which is proportional to the magnetic field is one quantity of the conduction equalities and is applied to the differential relay 46.

The circuit shown within the box 52 provides a means for comparing the voltages produced by the current transformers 48 and 50. The voltages from the current transformers 48 and 50 are effectively applied in series across the resistor 54. By connecting the voltages 180° out of phase, there is not any voltage developed across the resistor 54 when the voltages from the current transformers are equal. When they are unequal, a voltage is developed across the resistor 54. The voltage V_{MMF} across the resistor 54 may also be considered as equal to the product of the difference between the currents in the secondary windings of the current transformers 16 and 18 and the resistance of the resistor 54. The turns ratios of the current transformers 48 and 50 may be selected to correspond with the turns ratio of the power transformer 11 to provide equal voltages 90° currents, when the primary and secondary currents in the transformer 11 have the normal relationship. Thus, the voltage V_{MMF} is proportional to the net magnetomotive force in the primary winding 10 and the secondary winding 12.

By applying voltages V_h and V_{MMF} to the differential relay 46, it can be determined when an internal fault exists within the transformer 11. When the voltages are not equal, the differential relay 46 is activated and an output signal 56 generally mechanical or electrical, is produced for the proper control of associated equipment. The magnitude of the actual voltages developed can be changed by conventional circuit arrangements to provide any desired ratio of the voltages without disturbing their proportional relationship during normal, overloaded, and inrush current operating conditions.

The internal fault detectors described herein provide quick, accurate, and reliable protection for power transformers without any significant delay required by the effects of magnetizing inrush currents. Although described generally in a single phase system, the invention is equally applicable to multiple phase systems. Since numerous changes may be made in the above described apparatus, and since different embodiments of the invention may be made without departing from the spirit thereof, it is intended that all of the matter contained in the foregoing description, or shown in the accompanying drawing, shall be interpreted as illustrative rather than limiting.

I claim as my invention:

1. An internal fault detector for transformers having primary and secondary windings disposed around a leg of a magnetic core, comprising:
 - means for measuring the current in the primary winding;

means for measuring the current in the secondary winding;

differential means responsive to predetermined ratios of the measured currents in the primary and secondary windings; and

a pick-up coil positioned between the primary winding and the magnetic core leg, said pick-up coil developing a predetermined voltage thereon when the magnetic core becomes saturated, with the predetermined voltage being used to prevent activation of the differential means.

2. The internal fault detector of claim 1 wherein the pick-up coil is aligned with its longitudinal axis parallel to the longitudinal axis of the primary winding.

3. The internal fault detector of claim 1 wherein the pick-up coil has an electrostatic shield disposed therearound.

4. The internal fault detector of claim 1 wherein the pick-up coil is wound around a non-magnetic rod.

5. The internal fault detector of claim 1 wherein the pick-up coil is wound around a magnetic rod.

6. An internal fault detector for transformers having primary and secondary windings disposed around a leg of a magnetic core, comprising:

a first current transformer which provides a first voltage proportional to the current in the primary winding;

a second current transformer which provides a second voltage proportional to the current in the secondary winding;

a differential relay responsive to predetermined ratios of the first and second voltages, said relay including inhibiting means which restrains activation of the differential relay when a restraining voltage applied to the inhibiting means exceeds a first predetermined value; and

a pick-up coil connected to apply the restraining voltage to the inhibiting means and positioned between the primary winding and the magnetic core leg with the axis of said pick-up coil being parallel to the axis of the primary winding;

said pick-up coil providing a restraining voltage to the inhibiting means which exceeds a first predetermined value when the magnetic field between the primary winding and the leg of the magnetic core exceeds a second predetermined value, said second predetermined value being substantially greater than the value of the magnetic field produced between the primary winding and the leg of the magnetic core when magnetizing inrush current is not flowing in the primary winding.

7. An internal fault detector for transformers having primary and secondary windings disposed around a leg of a magnetic core, comprising:

means for comparing the magnetomotive forces in the primary and secondary windings and providing a first voltage responsive to the comparison;

means for providing a second voltage responsive to the magnetic field between the primary winding and the core leg produced upon saturation of the core leg;

means for integrating the second voltage and providing a third voltage proportional to the integral of the second voltage; and

differential means responsive to predetermined ratios of the first and third voltages.

8. The internal fault detector of claim 7 wherein the means for comparing the magnetomotive forces includes:

means for measuring the current in the primary winding;

means for measuring the current in the secondary winding; and

means for comparing the ratio of the currents in the primary and secondary windings.

9. The internal fault detector of claim 7 wherein the means for providing the second voltage includes a pick-up coil positioned between the primary winding and the magnetic core leg with the axis of said pick-up coil being substantially parallel to the axis of said primary winding.

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