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[54] **SENSOR FOR GROUND FAULT INTERRUPTER APPARATUS**

[72] Inventors: **Fred C. Butler**, 12812 Bubbling Well Rd., Santa Ana, Calif. 92705; **Nathaniel M. Johnson**, 312 West Hill Drive, Los Gatos, Calif. 95030; **Clifford G. Wallace**, 1208 Saint Charles, Alameda, Calif. 94501

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[58] **Field of Search**........336/84, 173, 174, 175, 212, 336/83, 73

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Primary Examiner—Thomas J. Kozma
Attorney—John W. Graham

[57] **ABSTRACT**

Sensor apparatus for a ground fault interrupter operative to open or interrupt an electric circuit in response to the occurrence of a ground fault therealong. The sensor apparatus is operative to detect differences in the mangitudes of the currents respectively flowing in the entrance and return paths of an electric power circuit having at least a pair of conductors providing such paths; and it includes magnetic and electrostatic shield structure adapted to pass such conductors therethrough to form the primary winding of a differential transformer, and it further includes a transformer core coaxially related to the shield structure and equipped with a secondary winding to define a differential transformer in conjunction with the power conductors.

10 Claims, 3 Drawing Figures

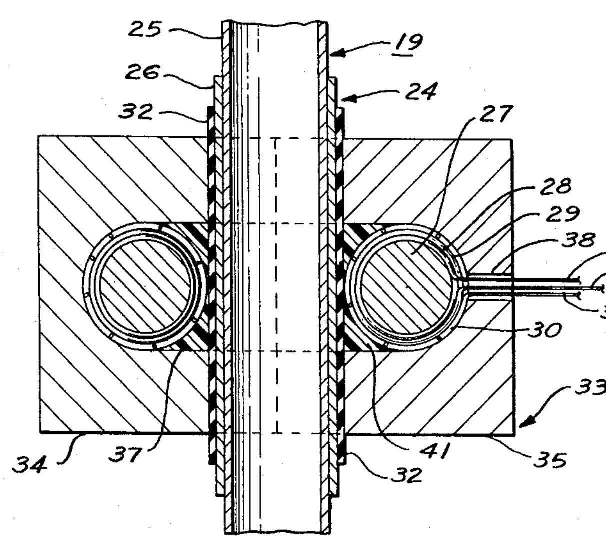

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FIG. 1

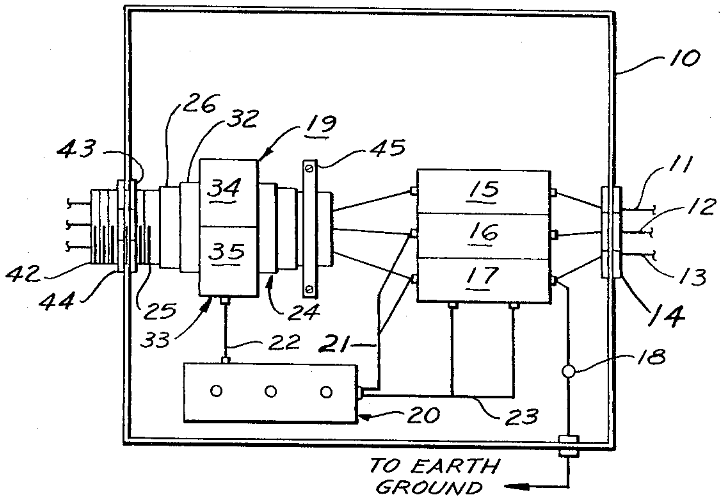
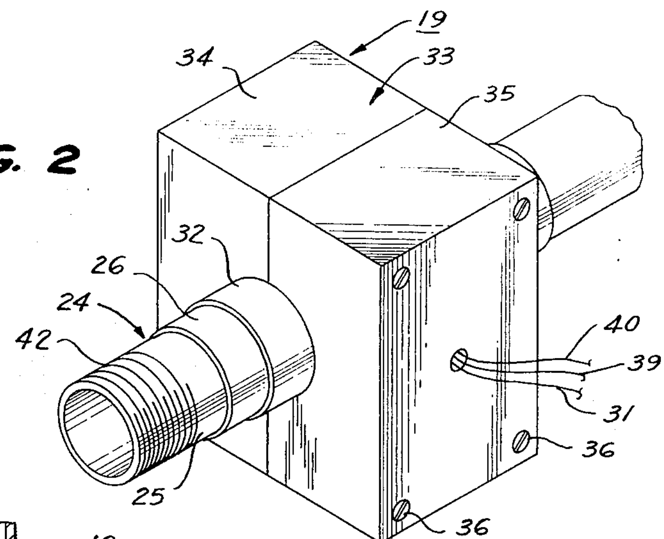


FIG. 2



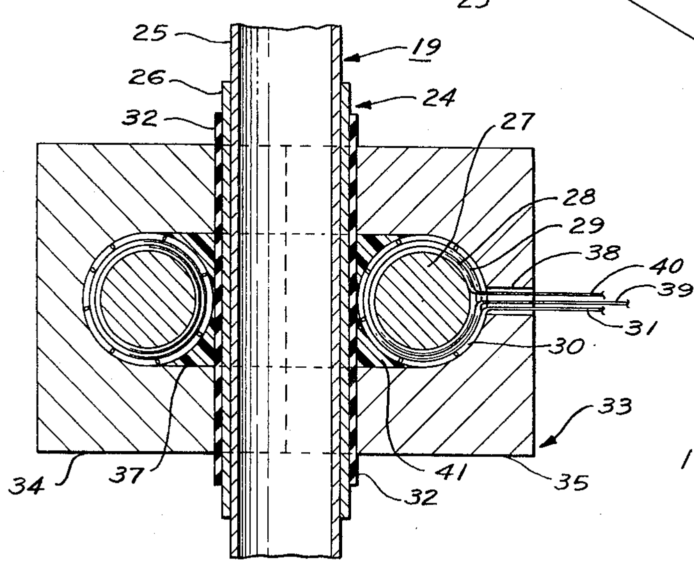


FIG. 3

INVENTORS:
FRED C. BUTLER
NATHANIEL N. JOHNSON
CLIFFORD G. WALLACE
BY: John W. Graham
ATTORNEY

SENSOR FOR GROUND FAULT INTERRUPTER APPARATUS

This invention relates generally to apparatus for interrupting an electric circuit in response to the occurrence of a fault or malfunction therealong, and it relates more particularly to the sensor or detector assembly for ground fault interrupter apparatus operative to open a circuit protected thereby in the event of a short to ground occurring therealong.

Although ordinary residential and industrial electric circuits are routinely protected against excessive current loads by fuses or other circuit breakers which interrupt the circuit in response to a current overload therein, such circuits are typically unprotected against shorts to ground which may have sufficient resistance to limit the magnitude of the current flow therethrough to a value much less than that required to actuate the excess-current circuit breakers, but which value is nevertheless sufficiently high to cause shock, severe injury and often death to humans or to cause fire which may damage or destroy structures housing the faulty circuit. An exemplary instance of such a short circuit path to ground is an ungrounded home appliance that becomes defective with a short or current-leakage path from the "hot" conductor of the energizing circuit of the appliance to the chassis thereof, and whenever the appliance is touched by someone who is grounded via the house plumbing, direct earth ground, etc., a ground fault occurs through such person who therefore experiences an electric shock.

The hazards attendant ground faults in electric circuits have long been recognized and as respects appliances, manufacturers thereof now provide a special conductor effective to ground the chassis of the appliances provided that the power distribution circuit to which the appliance is connected is a properly grounded power circuit. If so, the occurrence of a ground fault involving the chassis may not result in shock or fire because the current path to ground will be through the low resistance path provided for this purpose rather than through any higher resistance path such as the human body. It is very easy, however, to connect any such appliance to a power distribution circuit (i.e., any convenience outlet thereof) that is not grounded, thereby voiding the protective benefits otherwise derived from the special grounding conductor, and this avoidance is almost always practiced in older residential buildings not having the more modern grounded power distribution systems.

In any case, a defective appliance is only one manner in which a ground fault can occur, and it is well recognized that there is no way to protect against all possible ground faults by means of properly grounded three-conductor power distribution systems having only current-overload circuit breakers therein (the difficulty of protection is evidenced by considering the common instance of one accidently touching the "hot" conductor or terminal of a convenience outlet while in contact with a water line, thereby creating a ground fault often passing sufficient current to injure or cause death but not sufficiently large to actuate the overload circuit breaker). As a consequence, apparatus has been developed which is intended to afford more general protection against ground faults of all types, and such apparatus is typically referred to as ground fault interrupters.

Such ground fault interrupter apparatus is intended to sense very small ground fault currents (a fractional part of an ampere) and in response thereto, quickly (a fractional part of a second) energize a circuit breaker to interrupt the circuit having the ground fault therein. So far as is known, the practical realization of this intended result in devices heretofore proposed has not been attained, and prominent among the deficiencies of all such devices is that they are characterized by "-nuisance tripping" of the circuit breakers energized thereby because they cannot differentiate between actual ground faults and spurious current signals present in the circuit from time-to-time, and/or they are not sufficiently rapid in their response to completely protect against the hazard of electric shock.

It is believed that one of the major reasons for these deficiencies is that ground fault interrupter devices, being current sensitive, must respond to very minute ground fault currents in the presence of massive current loads, the ratio therebetween, by way of example, might be a fault current of the order of several milliamperes in the presence of a load current in excess of 100 amperes — a ratio, say, of 1 to 10,000 or more. That the requirement for response to small currents is necessary, it may be considered that many authorities in the field assert that an energy level in excess of about 50 joules (joules being determined by the formula $W=I^2 RT$, where W is the energy level in watt seconds or joules, I is the current in amperes at an assumed voltage value of 120 volts, RMS, R is the human body resistance in ohms, and T is the elapsed time in seconds) will cause ventricular fibrillation or death in the average human, which level is the equivalent, for example, of 100 milliamperes for a period of 4.2 seconds. An energy level below about 0.25 joules (about 10 milliamperes) is considered to be a mild shock, and any energy level slightly above the 0.25 joule — 10 milliampere value is painful and produces muscular contraction preventing release of the current-carrying conductor. Evidently, as the energy level of any electric shock increases from the 0.25 to the 50 joule value, the consequences of the shock progressively become more severe.

In order to reduce the ratio of load or environmental current to fault current, it has been customary to use conventional ground fault interrupter apparatus only in branch circuits of a power distribution system rather than in the main circuit thereof, but such restriction in use has not contributed appreciably to the reliability and utility of these devices. We have determined that it is possible to provide very discrete resolution of small fault currents or signals in an environment of large load currents such as may exist in the main circuit of a power distribution system and, depending upon the particular system, may exceed several hundred amperes; and an object of this invention is to provide improved ground fault interrupter apparatus having this capability.

Another and more particular object of this invention is that of providing a sensor or detector for ground fault interrupter apparatus, and which sensor comprises as a part thereof both shielding and magnetic field suppression arrangements that make possible the aforementioned resolution of small fault signals.

Further objects, among others, of the present invention are in the provision of an improved sensor of the character described that is easy to install and can be used readily with both new and old power distribution systems; that permits one installation in association with the main circuit of a power distribution system to protect the entire system, thereby obviating the necessity of a multiplicity of devices respectively arranged with branch circuits of such system; that provides high fault-signal sensitivity and resolution, thereby enabling ground fault interrupter apparatus embodying the same to have a fast reaction time to the occurrence of a ground fault (for example, disconnecting a faulty circuit within about 16 milliseconds in response to a fault current of about 4 milliamperes — thus limiting the energy absorbed by a victim through which the fault current is flowing to about 0.0076 joules which causes no more than a mild sensation); that is operative over a wide temperature range without compromise of the sensitivity, resolution and reaction time attributable thereto, and is not adversely affected by stray electric and magnetic fields; that is essentially frequency insensitive and immune to transient or stray signals such as those attributable to load switching, residual ground-leakage currents, and transient-load phase shifts all of which otherwise could lead to false or nuisance tripping; and that includes magnetic and electrostatic shield structure effective to suppress the magnetic field caused by large load currents flowing through the power circuit protected thereby to obviate "shorted-turn" effects in a differential transformer winding forming a part of the sensor, and to generally isolate or protect against internally and externally generated electrostatic and magnetic fields so as to optimize sensitivity to and resolution of minute fault signals in the presence of large load currents.

Additional objects and advantages of the invention, especially as concerns particular features and characteristics thereof, will become apparent as the specification continues.

An embodiment of the invention is illustrated in the accompanying drawing, in which:

FIG. 1 is a front view in elevation, somewhat diagrammatic, of a ground fault interrupter installation in association with a three-wire power distribution system;

FIG. 2 is a perspective view of the sensor assembly forming a part of such installation; and

FIG. 3 is a broken longitudinal sectional view of the sensor assembly.

The sensor or detector assembly embodying the present invention is intended for use in ground fault interrupter apparatus operative to interrupt a power circuit in response to the occurrence of a ground fault therealong. A ground fault current is usually considered to be any current from an alternating current source that passes through a load and returns to the source via a path other than the path provided for this purpose which, in a three-conductor power distribution system, is the neutral conductor thereof. Interrupter apparatus embodying the present invention is useful with a great variety of multiple-conductor power distribution systems including both two-conductor and three-conductor systems, the latter being illustrated in FIG. 1 in functional association with a ground fault interrupter embodying the present invention. The power distribution system per se forms no part of the present invention and may be completely conventional except as to the manner in which the conductors thereof are related to the sensor assembly of the interrupter apparatus.

A typical installation is illustrated in FIG. 1 which depicts the interrelationship of the ground fault interrupter apparatus with the conductors of a power distribution system being effected within a metal casing **10** which, in the usual instance, will have a cover (not shown) pivotally movable between open and closed positions to enable the casing to provide a complete enclosure about the components located within the interior thereof. As indicated hereinbefore, the particular power distribution system being considered is a three-wire 240 volt alternating current system having two load or hot conductors **11** and **12** and a neutral conductor **13**. Accordingly, two 120 volt circuits are established, one between the conductors **11** and **13** and the other between the conductors **12** and **13**. The conductors **11**, **12**, and **13** define the main circuit of the power distribution system rather than a branch circuit thereof, although as heretofore indicated, the sensor and ground fault interrupter apparatus being considered is equally useful with branch circuits but is in no sense limited to the relatively low current loads usually represented thereby.

The three conductors **11**, **12**, and **13** enter the casing **10** through a knock-out or other opening therein that may be provided with an insulating grommet **14**, and within the interior of the casing the conductors are respectively connected to the input terminals of circuit breakers **15**, **16**, and **17** which are ordinarily closed to complete the circuits therethrough to the output terminals thereof, but when energized interrupt such circuits to prevent current transmission therethrough. As respects the present invention, the circuit breakers **15**, **16**, and **17** may be completely conventional and are actuated in the ordinary manner in response to an energizing current delivered thereto. The neutral conductor **13** is bonded or electrically connected to the casing **10**, as indicated at **18**, and passes through an opening provided therefor in the casing to enable the neutral conductor to be connected to earth ground as, for example, by electrically connecting the conductor to the plumbing (usually water pipes) of the building structure in which the assemblage is located.

The conductors **11**, **12**, and **13** continue from the output terminals of the respectively associated circuit breakers **15**, **16**, and **17** through the sensor or detector assembly located for the most part within the casing **10** and denoted in its entirety with the numeral **19**. Exteriorly of the casing **10**, the conductors continue to the distribution panel of the power system through the usual wiring duct or conduit, not shown. Also located within the casing **10** is an electric module **20** that together with the sensor assembly **19** and circuit breakers **15**, **16**, and **17** form a complete ground fault interrupter apparatus for the power distribution system defined by the conductors **11**, **12**, and **13**. A detailed description of the electric module **20** including the components comprising the same and function thereof is unnecessary as respects an understanding of the present invention and is not included. For purposes hereof, it is sufficient to note that the module **20** is operative to process any fault current or signal detected by the sensor assembly **19** and to actuate the circuit breakers **15**, **16**, and **17** in response thereto so as to open or interrupt the power circuits. In this respect, the power supply of the module **20** is connected with the conductors **12** and **13** via a cable **21**, ground fault signal currents are delivered to the module through a cable **22**, and output signals developed in response to the presence of a ground fault current are delivered via a cable **23** to the circuit breakers **15**, **16**, and **17** which may be ganged so as to function simultaneously.

The sensor assembly **19**, as illustrated most clearly in FIGS. **2** and **3**, includes inner magnetic shield structure **24** having an opening therein adapted to pass the conductors **11**, **12**, and **13** therethrough in the manner shown in FIG. **1**. In more particular terms, the inner magnetic shield structure **24** includes a pair of inner shields **25** and **26** located one within another. In the particular embodiment of the invention illustrated, the shield **25** is an axially elongated hollow tube, and the shield **26** is also a hollow elongated tube coaxially circumjacent the shield tube **25**. The shield **25** is a low permeability, high saturation magnetic shield which serves primarily to suppress the high density magnetic fields attributable to the large current flows through the conductors **11**, **12**, and **13**. The shield **26** is a high permeability, low saturation magnetic shield that further suppresses the internally developed magnetic fields to isolate the electrical components of the sensor assembly **19** therefrom. The shields **25** and **26** also serve to positionally locate the magnetic field generated by current flow through the conductors **11**, **12**, and **13**, thereby making the sensor apparatus essentially independent of the dress or location of the conductors within the shield structure **24**. The shield **25** is usually formed of a soft iron such as cold rolled steel (ordinary black pipe, for example), and the shield **26** is usually formed of mu-metal.

The sensor assembly **19** further includes a transformer core **27** which is equipped with a secondary winding **28** to define a differential current transformer in conjunction with the power conductors **11**, **12**, and **13** which provide the primary winding of such transformer. The core **27** and winding **28** are in the form of a toroid surrounding the shield structure **24** intermediate the ends thereof. The core **27** may be fabricated from ferrite, and the winding **28** is ordinary copper magnet wire comprising approximately **100** turns in one particular embodiment of the invention. An insulator is usually provided intermediate the core **27** and winding **28** as is customary, and it may be a coating of insulating enamel on the core **27**. A test winding **29** may be included in the assembly, and in the particular apparatus being considered, it is defined by one or more turns overlying the secondary winding **28**.

Enclosing the core **27** and windings **28** and **29** is an electrostatic shield **30** effective to isolate or shield the aforesaid secondary winding **28** from externally developed electrostatic fields. The electrostatic shield **30** is connected at its center by means of a conductor **31** to the DC or electronic ground of the interrupter apparatus, thereby providing a bipolar shield that balances any capacitive coupling to the secondary winding **28**. In the embodiment of the sensor apparatus **19** being considered, the electrostatic shield **30** constitutes a thin copper foil backed with an insulator (Mylar, for example) wound about the core **27** and windings **28** and **29** in a touch-lap configuration. In one particular embodiment of the invention, about **15** to **20** turns of a Mylar-backed copper foil approximately three-eighths of an inch wide are touch-lap wound about the toroidal core and windings mounted thereon. Although the shield **30** may enclose both the windings **28** and **29** as shown, there is little advantage in so shielding the test winding **29** which, then, is wound over the shield **30** in certain embodiments of the invention.

For purposes of insulating the electrostatic shield **30** from the inner magnetic shield structure **24**, and particularly from the shield **26** thereof, an insulator **32** is interposed between the outer surface of the shield **26** and exposed adjacent surface of the shield **30**. In the form shown, the insulator **32** is a hollow tubular sleeve somewhat shorter than and coaxially circumjacent the shield **26**. The insulator **32** may be a length of phenolic tubing having a thickness of about one thirty-seconds of an inch.

Enclosing the toroidal core and coil combination is an outer magnetic shield structure **33** effective to shield the transformer assembly from externally developed magnetic fields, thereby essentially performing a function analogous to the inner shield structure **24** which isolates the transformer assembly from internally developed magnetic fields. It will be observed that the axial length of the outer magnetic shield **33** is somewhat less than the axial length of the insulating sleeve **32** which thereby serves to electrically isolate the outer and inner shield structures from each other so as to prevent shorted turns therebetween. The outer shield **33** may be constructed in any conventional manner so as to effect the desired shielding, and in the exemplary form illustrated, it is constructed of separable sections **34** and **35** secured to each other by a plurality of screw fasteners **36** and provided with an internal annulus **37** adapted to accommodate the toroidal configuration of the transformer assembly. Should a shield **33** be desired having a more ideal magnetic circuit path, it can take the form of an integral cylinder enclosing the transformer assembly with end caps soldered or otherwise integrated therewith after the transformer is in position.

The annulus **37** is centrally disposed, and the shield section **35** is provided with a small bore or passage **38** through which the various conductor arrangements **31**, **39**, and **40** comprising the aforementioned cable **22** (FIG. **1**) extend between from the electric module **20** to the windings **28** and **29** and to the electrostatic shield **30**. For maximum resolution efficiency, the transformer assembly is centered about the longitudinal axis of the inner shield structure **24**, and the transformer assembly may be supported in the desired position by an ordinary potting material **41**, as illustrated in FIG. **3**. In this same sense, a snug fit is defined between the tubular shields **25** and **26** and the tubular insulator **32**, these components being additionally crimped, adhesively connected, or otherwise fixed one to another to constrain the same against relative longitudinal or axial displacements.

As shown in FIG. 1, the lower end portion of the shield **25** may be provided with external threads **42**, thereby enabling the assembly **19** to be fixedly secured to the casing **10** by means of inner and outer nuts **43** and **44**. The assembly **19** is additionally stabilized with respect to the casing **10** by an insulating collar **45** that surrounds the shield **25** adjacent the upper end thereof, and which collar is bolted or otherwise fixedly secured to the casing. The assembly **19** and, in particular, the shield **25** thereof is bonded or electrically connected to the casing **10** usually adjacent the inner nut **43**.

The various components comprising the sensor **19** are assembled into the configuration illustrated in FIGS. **2** and **3** as a factory operation and may be distributed as an integer or, in the ordinary case, will constitute a part of an entire ground fault interrupter apparatus mounted within a casing **10**, as illustrated in FIG. **1**. In any event, installation thereof requires power distribution conductors to be inserted through the inner shield structure **24** so as to extend longitudinally therealong through the tubular shield **25**. Such power conductors are discontinuous and are connected to the opposed terminals of the circuit breakers **15, 16** and **17** which are selectively operative to complete or interrupt circuit continuity therethrough.

Referring specifically to the arrangement shown in FIG. **1**, the conductors **11** and **12** define the entrance paths of the electric power distribution system and are the hot or load conductors. The conductor **13** defines the return path for the system and is the neutral conductor. Ordinarily, all of the current delivered through the entrance conductors **11** and **12** to the load on the power distribution system returns from the load via the neutral conductor **13**, and as a consequence thereof there is no net flux present in the transformer assembly to produce a current in the secondary winding **28** of the differential transformer, it being understood that each of the power conductors **11, 12** and **13** defines a primary winding for such differential transformer. Thus, since there is no current induced in the secondary winding **28**, no fault signal current is transmitted via the cable **22** to the electric module **20** for processing thereby.

In the event of a ground fault occurring on the load side of the sensor **19** in one of the entrance conductors **11** or **12**, a portion of the current flowing to the load through the conductors **11** and **12** will not return to the source via the neutral conductor **13** and will return thereto through the ground fault. This inequality in the current flows through the entrance and return paths of the power conductors will result in a flux imbalance at the sensor **19**, thereby creating a net magnetic flux which induces a current flow in the secondary winding **28** of the differential transformer. Such induced current constitutes a fault signal delivered via the cable **22** to the electric module **20** which is operative to produce an energizing signal on the cable **23** which actuates the circuit breakers **15, 16** and **17** to interrupt the power distribution system.

As indicated hereinbefore, the sensor assembly **19** is able to detect and resolve very minute fault currents in the presence of comparatively large load currents, thereby enabling ground fault interrupter apparatus embodying the sensor to very quickly interrupt a power distribution circuit having a ground fault therealong. As a result, such detection of a ground fault current and interruption of the power circuit might occur, for example, in a time of about one-half cycle where the alternating current source involved has a frequency of 60 cycles per second. As a result, and in accordance with the energy example set forth hereinbefore, a faulty circuit might be interrupted in a time of about 16 milliseconds in response to a fault current of about 4 milliamperes so that a person forming a part of the fault circuit would experience little more than a mild sensation as a consequence of the energy he would absorb (about 0.0076 joules).

The ability to respond to such minute fault currents in largely attributable to the isolation of the secondary winding **28** of the differential transformer from both internally and extenerally generated magnetic fields and because the position or dress of the conductors **11, 12** and **13** relative to the inner magnetic shield **25** is not critical as a result of the function of the inner shield structure **24** and especially the shield **25** in positionally locating the large flux field developed internally of the sensor **19** as a consequence of the large load currents flowing through the power distribution system. The electrostatic shield **30** effectively isolates the secondary winding **28** from any electrostatic fields, principally of external origin, and therefore, might be omitted should the sensor **19** be used in environments not having electrostatic fields present therein.

The sensor **19** is essentially a current device so that the input impedance into which it feeds is not critical but is advantageously as low as possible, preferably zero, in contrast to voltage devices in which a high load impedance is necessary, as in the case of known ground fault interrupters. The sensor **19** may be said to be insensitive to load current variations and responds only to changes in the relative magnitudes of the currents flowing in the entrance and return paths of the electric power circuit monitored thereby, i.e., fault currents.

While in the foregoing specification an embodiment of the invention has been set forth in considerable detail for purposes of making a complete disclosure thereof, it will be apparent to those skilled in the art that numerous changes may be made in such details without departing from the spirit and principles of the invention.

What is claimed is:

1. A sensor for a ground fault interrupter or the like operative to detect differences in the magnitudes of the currents flowing in the entrance and return paths of an electric power circuit having at least a pair of conductors providing such paths, comprising inner magnetic shield structure having an opening therein adapted to pass such conductors therethrough to form the primary winding of a differential transformer, and a transformer core circumjacent said inner magnetic shield and equipped with a secondary winding to define a differential transformer in conjunction with such conductors, said inner magnetic shield structure including a pair of inner shields located one within another, one of said inner shields being a low permeability high saturation shield and the other thereof being a high permeability low saturation shield.

2. The sensor of claim 1 in which each of said inner shields is an axially elongated hollow tube greater in axial dimension than said core.

3. The sensor of claim 2 in which each of said inner shields and said core is substantially continuous perimetrically and said secondary winding is symmetrically disposed about said core, whereby a substantially symmetrical structural assemblage is provided about the longitudinal axis through said sensor.

4. The sensor of claim 3 and further comprising an electrostatic shield enclosing said core and secondary winding to protect the same from electrostatic fields.

5. The sensor of claim 1 and further comprising outer magnetic shield structure enclosing said core and secondary winding to protect the same from stray external magnetic fields.

6. The sensor of claim 5 in which said outer magnetic shield structure is a high permeability low saturation shield structure.

7. The sensor of claim 6 in which each of said inner shields is an axially elongated hollow tube greater in axial dimension than said core, and in which each of

said inner shields and said core is substantially continuous perimetrically and said secondary winding is symmetrically disposed about said core, whereby a substantially symmetrical construction is provided about the longitudinal axis of said sensor.

8. The sensor of claim 7 and further comprising an electrostatic shield enclosing said core and secondary winding to protect the same from electrostatic fields.

9. The sensor of claim 1 in which each of said inner shields and said core is substantially continuous perimetrically and said secondary winding is symmetrically disposed about said core, whereby a substantially symmetrical structural assemblage is provided about the longitudinal axis through said sensor.

10. The sensor of claim 1 and further comprising an electrostatic shield enclosing said core and secondary winding to protect the same from electrostatic fields.

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