June 10, 1969 H. G. FISCHER ET AL 3,449,633

ELECTRICAL TRANSFORMER

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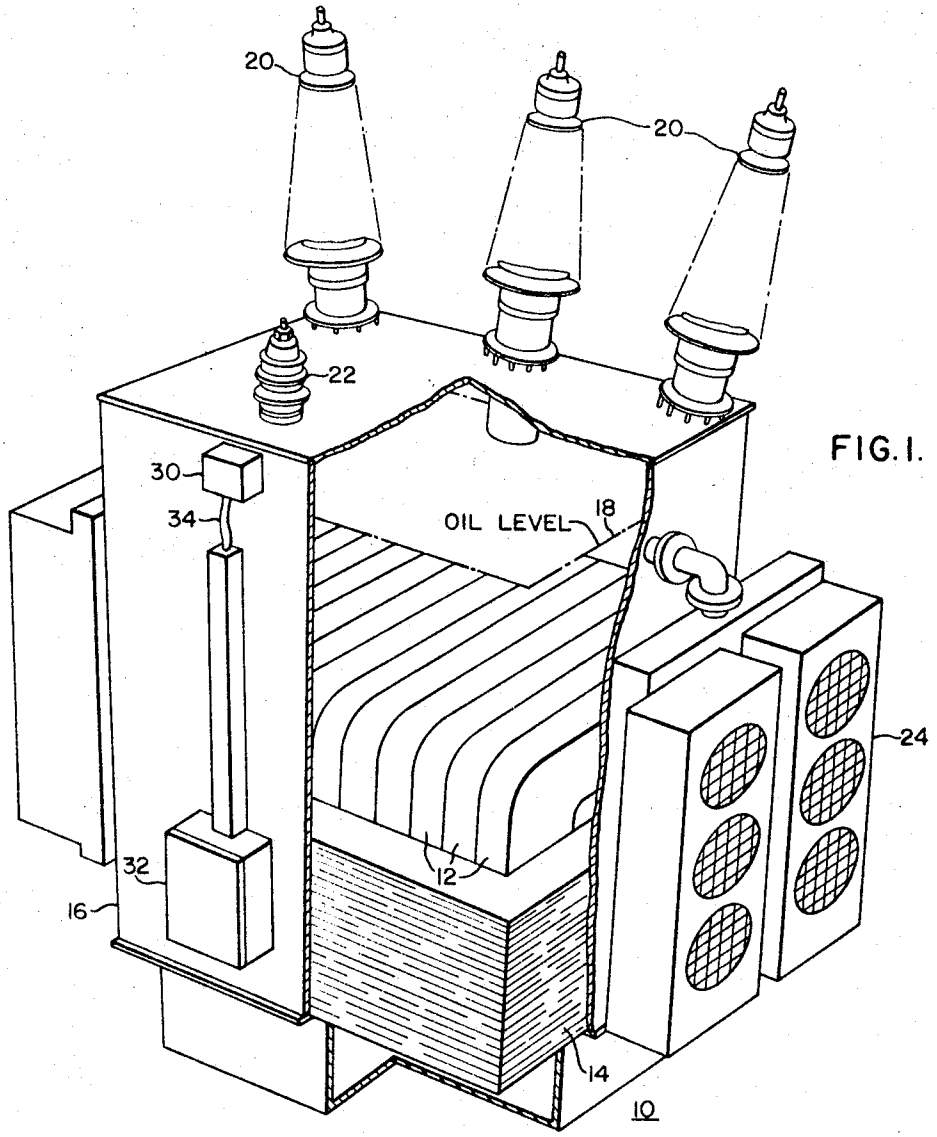


FIG. 1.

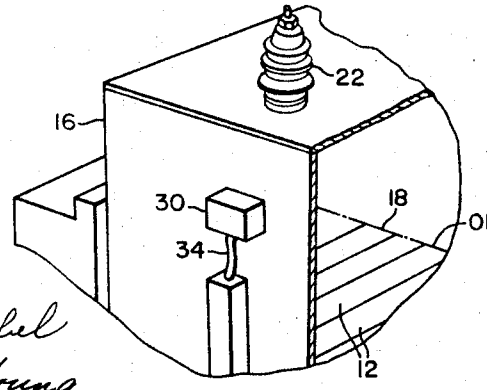


FIG. 1A.

WITNESSES

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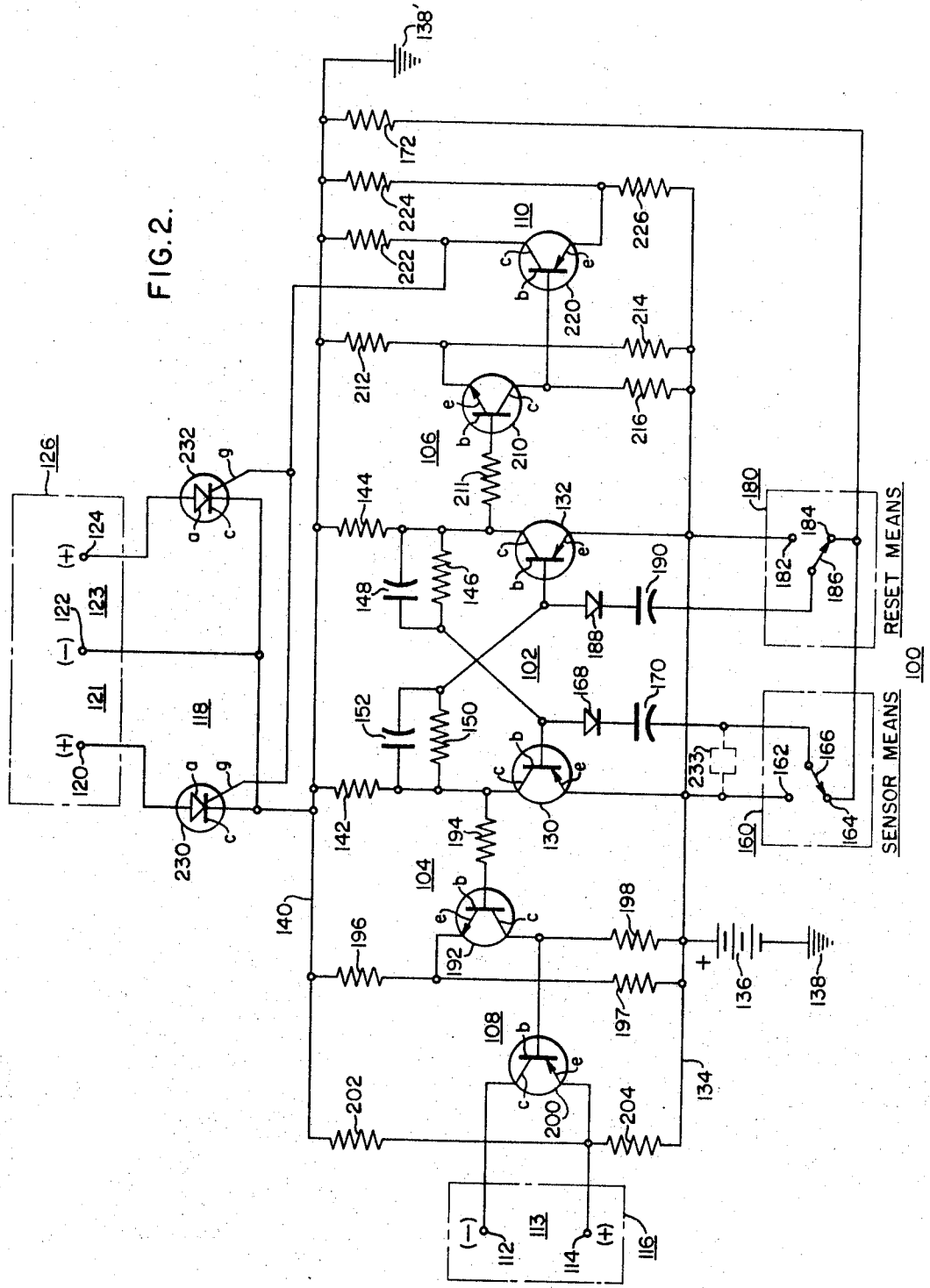
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ELECTRICAL TRANSFORMER

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FIG. 2.



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ELECTRICAL TRANSFORMER

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U.S. Cl. 317—14 5 Claims

ABSTRACT OF THE DISCLOSURE

A power transformer having a magnetic core-winding assembly disposed within a casing which contains an insulating dielectric fluid, sensing means disposed to sense the rate of change of pressure within the casing, and a solid state relay which has a flip-flop circuit responsive to the sensing means. The flip-flop circuit controls static switches which are adapted for connection in protective and alarm circuits for the transformer.

When a transformer experiences an internal electrical fault, the energy released in the fault causes a very rapid increase in the internal tank pressure of the transformer. In the prior art, this sudden increase in tank pressure is detected by a bellows type sensor disposed in the gas space above the fluid dielectric, which activates a solenoid driven seal-in relay having contacts which are used to energize alarm and protective circuits.

Since the amount of damage caused by an internal fault in a transformer is usually dependent upon the time interval between the start of the internal fault, and the time when the tarnsformer is removed from the electrical system by its protective apparatus, it is of the utmost importance that the relay which is responsive to the sensor means be extremely fast acting. Further, since it is not desirable to have nuisance tripping by the transformer's protective apparatus, the relay must be very reliable, actuating the protective apparatus only upon the detection of an internal fault by the sensor means. Efforts to increase the operating speed, and thus reduce the operating time of the mechanical relay, however, result in making the relay shock sensitive, causing the relay to vibrate and momentarily close its contacts upon an accidental blow to the relay, or the cabinet within which the relay is mounted. Further, the contact bounce associated with the closing of mechanical contacts is undesirable, as it introduces a further time delay between the start of a fault and the actuation of protective apparatus.

Accordingly, it is an object of the invention to provide a transformer having a new and improved pressure responsive protective system.

Another object of the invetnion is to provide a transformer having a new and improved pressure responsive protective system which has a substantially faster response time than relay ystems of the prior art.

Still another object of the invention is to provide a transformer having a new and improved pressure responsive protective system which has a substantially faster response time than prior art relay systems, has no contact bounce, and is not shock sensitive.

A still further object of the invention is to provide a new and improved pressure responsive protective system for electrical transformers which includes a solid state relay having both normally open and normally closed contacts, which substantially eliminates the relay as a source of time delay in the operating time of the protective system, and which is not sensitive to shock and vibration.

Briefly, the invention accomplishes the above-cited objects by providing an electrical tarnsformer with a pressure sensor disposed to be responsive to the pressure in

the air space above the liquid dielectric, or in the liquid dielectric itself, which provides a signal upon a sudden change in the pressure within the tarnsformer tank. This signal may be the closing of contacts on a bellows type pressure sensor, or a voltage signal provided by an electronic type transducer. The relay which is responsive to the signal from the pressure sensor is of solid state construction, and includes a bistable flip-flop circuit which operates static switching means. A reset switch flips the circuit into a first predetermined stable operating mode, in which the conductive side of the flip-flop circuit operates static normally "closed" switching means, and the non-conductive side of the flip-flop circuit is connected to operate static normally "open" switching means. Upon receiving a signal from the pressure sensor, the flip-flop circuit switches to the second of its two stable operating conditions, which effectively opens the static normally closed switching means, and closes the static normally open switching means. The normally open and normally closed switching means may be connected to operate alarm circuits, circuit breakers, and devices which perform other desired functions. The relay, being solid state, operates in micro-seconds, which effectively eliminates its response time from the total system operating time, and since there are no mechanical contacts to vibrate in the relay, it is essentially unaffected by shock and vibration, and has no contact bounce.

Further objects and advantages of the invention will become apparent from the following detailed description, taken in connection with the accompanying drawings, in which:

FIGURE 1 is a pictorial view of a transformer, partially cut away, illustrating an embodiment of the invention;

FIG. 1A is a fragmentary view of the transformer shown in FIG. 1, which illustrates another embodiment of the invention; and

FIG. 2 is a schematic diagram of a solid state relay constructed according to the teachings of the invention, which may be used in the protective system for the transformer shown in FIGS. 1 and 1A.

Referring now to the drawings, and FIG. 1 in patricular, there is shown a pictorial view of a transformer **10** of the type which may advantageously utilize the teachings of the invention. Transformer **10** includes a plurality of electrical coils **12** connected to provide high and low voltage windings, with the coils being disposed in inductive relation with a magnetic core 14. The magnetic core-winding assembly is disposed within a casing or tank **16**, which is shown partially cut away, with the tank **16** being filled to a predetermined level **18** with an insulating and cooling liquid dielectric, such as oil. The tank **16** includes high and low voltage bushings **20** and **22**, respectively, for connecting the windings with an external electrical system and electrical load, and heat exchanger means **24** for cooling the liquid dielectric.

When a short circuit or fault occurs in the electrical windings, the sudden release of energy in the fault causes a rapid increase of pressure within both the liquid dielectric, and in the air space disposed above the liquid dielectric. This sudden pressure increase, as opposed to gradual pressure changes do to ambient temperature changes and loading induced changes, is used to operate the protective apparatus associated with the transformer.

The pressure responsive protective system includes pressure sensor means, and a relay which is responsive to a signal from the pressure sensor means. The relay contains switching circuits which initiate protective and alarm circuits. Sensor means for providing a signal in response to a rapid increase in the internal tank pressure is shown in FIG. 1 at **30**, and the relay may be disposed in a con-

trol panel **32**, connected to the sensor means through electrical leads **34**. It will be noted that in the embodiment of the invention shown in FIG. 1, the pressure sensor means **30** is disposed to be responsive to the pressure in the gas space disposed above the liquid dielectric. This may be accompanied by obtaining access to the gas space through a small opening in the tank wall, which is in sealed communication with the sensor means. Any suitable type of pressure sensor may be used. For example, the pressure sensor may be of the bellows type which contains a pressure chamber in sealed communication with the gas space above the liquid dielectric, with the bellows closing mechanical contacts upon a sudden change in tank pressure, which contacts are connected to the relay. Gradual pressure changes in tank **16**, such as those due to loading factors and ambient temperatures, leak through a small opening in the pressure chamber without actuating the bellows. The opening is insufficient to dissipate a rapid pressure change, associated with internal faults within the transformer, thus moving the bellows and actuating the relay, which seals-in until manually reset.

Sensor means **30**, instead of being disposed to be responsive to the pressure in the gas space, may be disposed to be responsive to the pressure in the liquid dielectric itself, as shown in FIG. 1A. In transformers which have a gas space within the main transformer tank, disposed over the liquid dielectric, the pressure sensor is usually disposed to monitor the pressure of the gas space. In certain transformers, however, such as extra high voltage transformers (EHV), the transformers is completely filled with liquid dielectric, with a separate tank being used for expansion of the liquid dielectric due to ambient and loading factors. In this instance, the sensor would be disposed to be responsive to the pressure in the liquid dielectric. Instead of using a bellows type sensor disposed in the liquid dielectric, it would be preferable to utilize an electronic pressure transducer which provides an output voltage only when the rate of change of pressure within the liquid exceeds a predetermined value. The electronic type pressure transducer would also provide less delay in the operation of the transformer's protective system, than a mechanical bellows type system, as the speed of operating the mechanical bellows depends upon the rate of change of pressure.

The relays which are conventionally used to initiate the operation of the protective apparatus, in response to a signal from the pressure sensor means, are solenoid operated, mechanical relays, which contain contacts connected to energize the protective apparatus. Mechanical relays, in this application, have certain disadvantages. Since the internal fault in the transformer may cause extensive damage, it is important to remove the transformer from the electrical system as soon as possible, in order to minimize damage to the transformer. Fast operating mechanical relays still require one-half cycle, or more, on a 60 Hz. system, to pickup, and in addition have the disadvantage of being shock sensitive. Since it is undesirable to disconnect the transformer from an electrical system, unless absolutely necessary, the tendency of the mechanical relay to vibrate and momentarily close its contacts when subjected to shock is a distinct disadvantage.

These disadvantages are overcome, in both the embodiments shown in FIG. 1 and FIG. 1A, by using the solid state relay **100** shown in FIG. 2, which may be actuated by either the closing of contacts by a mechanical type sensor, or by a voltage signal from an electronic type transducer. The operating time of the relay is in the order of micro-seconds, and thus, for all practical purposes is eliminated from the system as far as adding to the delay of the protective system. Further, there are no mechanical contacts to vibrate and accidentally close due to shock, making relay **100** essentially shock proof. Still further, contact bounce has been eliminated.

In general, relay **100** includes a bistable flip-flop circuit **102**, first amplifier means **104**, second amplifier means **106**, first static switching means **108**, and second static switching means **110**. The static switching means **108** may be used directly to provide a normally closed contact **113** between terminals **112** and **113**, as shown, which terminals are connected to protective means **116**; or, static switching means **108** may be used to provide a signal for operating one of more additional static switching devices which are connected to the protective means.

Static switching means **110** may be used directly to provide a normally open contact, in the same manner as switching means **108**, or it may be used to provide gating signals for one of more additional static switching means **118**. In this instance, static switching means **118** provides a normally open contact **121** between terminals **120** and **122**, and a normally open contact **123** between terminals **124** and **122**. These terminals are connected to protective means **126**. Protective means **116** and **126** may be alarms, circuit breakers, and any other devices which provide functions which it is desirable to activate, or deactivate, upon a fault in transformer **10**.

More specifically, relay **100** includes a bistable flip-flop circuit **102**, which includes first and second transistors **130** and **132**, respectively. Transistors **130** and **132** may be of the PNP junction type, each having base, emitter and collector electrodes *b*, *e* and *c*, respectively. The emitter electrodes *e* of transistors **130** and **132** are connected to a conductor or bus **134**, which is connected to the positive terminal of a source **136** of direct current potential, represented by a battery in FIG. 2, but which may be a bridge rectifier connected to a source of alternating potential, if desired. The negative terminal of direct current source **136** may be connected to ground **138**. The collector electrodes *c* of transistors **130** and **132** are connected to bus **140** through resistors **142** and **144**, respectively, and bus **140** is grounded at **138'**. The base electrode *b* of transistor **130** is connected to the collector electrode *c* of transistor **132** through the parallel connected resistor **146** and capacitor **148**, and the base electrode *b* of transistor **132** is connected to the collector electrode *c* of transistor **130** through the parallel connected resistor **150** and capacitor **152**.

Transistor **130** is also connected to sensor means **160**, which is the pressure sensor means **30** shown in FIG. 1, and in this instance, is illustrated as being of the mechanical switch type which includes stationary contacts **162** and **164**, and a movable contact **166**. The base electrode *b* of transistor **130** is connected to movable contact **166** through diode **168** and capacitor **170**, with the anode electrode of diode **168** being connected to the base electrode *b* of transistor **130**. Stationary contact **162** is connected to positive bus **134**, and stationary contact **164** is connected to ground **138'** through resistor **172**. Sensor means **160** is illustrated in FIG. 1 with movable contact **166** on stationary contact **164**, which is the normal position for sensor means **160**. Upon a sudden increase in pressure, movable contact **166** will move to momentarily engage stationary contact **162**.

Transistor **132** is also connected to reset means **180**, which is a switch having stationary contacts **182** and **184**, and movable contact **186**. The base electrode *b* of transistor **132** is connected to movable contact **186** through diode **188** and capacitor **190**, with the anode electrode of diode **188** being connected to the base electrode *b* of transistor **132**. Stationary contact **182** is connected to the positive bus **134**, and stationary contact **184** is connected to ground **138'** through resistor **172**.

In describing the operation of the flip-flop circuit **102**, assume that transistor **132** is conducting and transistor **130** is cut-off or non-conducting. To place relay **100** in readiness for a signal from sensor means **160**, transistor **130** should be conducting and transistor **132** should be cut-off. This is accomplished by moving movable contact **186** of reset means **180** to engage stationary contact **182**. Movable contact **186** should then be returned to stationary contact

184, in order to ready the reset means for the next reset operation. The return of movable contact **186** may be automatic by spring means which urges the movable contact **186** into engagement with the stationary contact **184**. When movable contact **186** contacts stationary contact **182**, the base electrode *b* of transistor **132** becomes positive, and transistor **132** switches to its non-conductive state. The collector electrode *c* of transistor **132** thus becomes negative, which makes the base electrode *b* of transistor **130** negative, and switches transistor **130** to its conductive condition.

In the operation of relay **100**, the flip-flop circuit **102** will stay in the previously described stable mode of operation, with transistor **130** being conductive and transistor **132** being non-conductive, until sensor means **160** detects a sudden increase in pressure within the tank **16** of the transformer **10** shown in FIG. 1, at which time movable contact **166** will momentarily engage stationary contact **162**. This causes the base electrode *b* of transistor **130** to become positive, biasing transistor **130** to cut-off, and simultaneously making the base electrode *b* of transistor **132** negative with respect to its emitter electrode *e*, which switches transistor **132** to its conductive condition.

The switching of transistors **130** and **132** to their conductive condition is used as signals to operate static switching devices connected in series circuit relation with protective circuits, and thus functions as normally closed and normally open contacts, depending upon which end of the flip-flop circuit they are located. The output signal from transistor **130**, when it is in its conductive state, is amplified by amplifier **104**, which may be NPN junction type transistor **192** having base, collector and emitter electrodes *b*, *c* and *e*, respectively. The base electrode *b* of transistor **192** is connected through resistor **194** to the collector electrode *c* of transistor **130**, the emitter electrode *e* is connected to the voltage divider provided by resistors **196** and **197**, which are connected between buses **134** and **140**, and its collector electrode *c* is connected to the positive bus **134** through resistor **198**. Thus, when transistor **130** is conductive, the base electrode *b* of transistor **192** will be more positive than its emitter electrode *e*, biasing transistor **192** into its conductive state. When transistor **130** switches to its non-conductive state, the base electrode *b* of transistor **192** will be negative with respect to its emitter electrode *e*, switching transistor **192** to its non-conductive state. Transistor **192**, in addition to amplifying the low level output of transistor **130**, provides isolation for the flip-flop circuit **102**, preventing leakage current from switching means **108** from affecting the operation of the flip-flop circuit.

The output of transistor **192** is used to switch static switching means **108** to its conductive state. Static switching means **108** may be a PNP junction type transistor **200** having base, collector, and emitter electrodes *b*, *c* and *e*, respectively, with its base electrode *b* being connected to the collector electrode *c* of transistor **104**, its emitter electrode *e* being connected to terminal **114**, and to the voltage divider provided by resistors **202** and **204**, which are connected between buses **134** and **140**, and its collector electrode *c* is connected to terminal **112**. When transistor **192** is conductive, the base electrode *b* of transistor **200** is more negative than its emitter electrode *e*, which biases transistor **200** to its conductive state, and in effect provides a closed contact for any apparatus connected to terminals **112** and **113**. Thus, any apparatus which is serially connected with a direct current power supply to terminals **112** and **114**, with the polarity of the power supply being as indicated at terminals **112** and **114**, will be energized while relay **100** is awaiting a signal from sensor means **160**.

Transistor **200** is a power transistor which is selected to carry the current and voltage demanded by the connected apparatus. As will hereinafter be explained, transistor **200**, instead of being a power transistor, may be a less costly transistor which is used to provide gating signals for one or more high power devices which are less costly than power transistors for comparable ratings, such as silicon controlled rectifiers.

Transistor **192** may drive more than one power transistor **200**, if more than one circuit is desired which provides a closed contact in the absence of a fault in the transformer.

When a fault occurs within the casing of the transformer and transistor **132** switches to its conductive state, its output is amplified by amplifier **106**, which may include an NPN junction type transistor **210** having base, collector and emitter electrodes *b*, *c* and *e*, respectively. The base electrode *b* of transistor **210** is connected to the collector electrode *c* of transistor **132** through resistor **211**, its emitter electrode *e* is connected to the voltage divider comprising resistors **212** and **214**, which are connected between buses **134** and **140**, and its collector electrode *c* is connected to bus **134** through resistor **216**. Transistor **210** also isolates the flip-flop circuit **102** from being affected by leakage current from static switching means **110**.

Static switching means **110**, which may be a PNP junction type transistor **220** having base, collector and emitter electrodes *b*, *c* and *e*, respectively, has its base electrode *b* connected to the collector electrode *c* of transistor **210**, its collector electrode *c* connected to bus **140** through resistor **222**, and its emitter electrode *e* connected to the voltage divider which includes resistors **224** and **226**, which are connected between buses **134** and **140**.

In this instance, instead of making transistor **220** a power transistor capable of handling the current of the protective devices, transistor **220** is used to provide switching signals for switching means **118**, which may be a silicon controlled rectifier, a silicon controlled switch, or any other suitable static switching means.

Switching means **118** is shown with two static switching devices **230** and **232**, but any number may be connected in parallel, in order to provide the desired number of normally open contacts. Device **230**, which is shown as a semiconductor controlled rectifier, such as a silicon controlled rectifier, has anode, cathode and gate electrodes *a*, *c* and *g*, respectively, with its anode electrode being connected to terminal **120**, its cathode electrode being connected to terminal **122** and to ground **138'**, and its gate electrode being connected to the collector electrode *c* of transistor **110**. Device **232**, which is also shown as a silicon controlled rectifier, has anode, cathode and gate electrodes *a*, *c* and *g*, respectively, with its anode electrode *a* being connected to terminal **124**, its cathode electrode *c* being connected to terminal **122** and ground **138'**, and its gate electrode *g* being connected to the collector electrode *c* of transistor **110**. Thus, when sensor means **160** provides a signal which switches the flip-flop circuit into providing an output from transistor **132**, which is amplified by transistor **210** and applied to transistor **220**, to cause it to switch to its conductive state, a signal will be continuously applied to the gate electrodes *g* of switching devices **230** and **232**. Since the gate signal is continuous, the electrical potential which is serially connected with each of the switching devices, to terminals **120** and **122**, and to terminals **122** and **124**, along with a protective device in each series circuit, may be an alternating potential, and switching devices **230** and **232** will allow the positive half cycles of the current to flow through its associated protective device. If the electrical potential connected to each of the switching devices **230** and **232** is a direct current potential, the direct current potential should be connected according to the polarities marked on terminals **120**, **122** and **124**, in FIG. 2. Also, if the electrical potential is a direct current potential, the reset means **180** should contain switching means which momentarily interrupts the circuits of the switching devices **230** and **232**, in order to allow their gate electrodes to regain control.

Relay **100** thus has two stable operating conditions, with the first operating condition being the "normal" con-

dition, triggered into this condition by reset means **180**, and the second operating condition being the "alarm" condition, triggered into this condition by a signal from sensor means **160**. Relay **100** has static switches, some of which are conductive during the normal condition, and some of which are nonconductive, with the static switches switching to their opposite operating modes when the relay is driven into its alarm condition.

In the embodiment of the invention shown in FIG. 2, the signal from sensor means **160**, which triggers relay **100**, is the closing of mechanical contacts. The potential for triggering the relay action is derived from the direct current source associated with the relay which is indicated as battery **136**. The relay circuit may easily be modified for use with an electronic transducer sensor, which supplies a direct current potential upon a sudden increase of pressure, by connecting a transducer **233**, shown in dotted outline in FIG. 2, to reverse bias transistor **130**, when the transducer **233** provides an output potential. The mechanical sensor means **160**, in this embodiment, would be eliminated.

Thus, in the complete operation of the protective system, suitable sensor means will be disposed to be responsive to the pressure within the casing **16** of transformer **10**, either in the air space above the liquid dielectric level **18**, as shown in FIG. 1, or in the liquid itself, as shown in FIG. 1A. The sensor means is connected to the static relay **100**, which is disposed in a suitable control panel **32**, and relay **100** has its normally open switching circuits and normally closed switching circuits connected to appropriate alarm and protective means. Reset means **180** would be manually actuated to "set" the relay in its normal operating condition, in which transistors **130**, **192**, and **200** are conductive, and transistors **132**, **210** and **220** are non-conductive. Thus, contacts **112** and **114** may be connected to an alarm circuit **116**, which is energized only when transistor **200** is conductive, which is during the normal operating period of the relay. Contacts **112** and **114** may be connected to an alarm circuit which will automatically indicate a malfunction of relay **100**, in those instances where alarm circuit **116** provides an alarm, without operation of the protective apparatus **126**. Contacts **120**, **122** and **124** may be connected to protective and alarm apparatus **126**, which may be a circuit breaker, alarm, and/or other apparatus which provides the desired functions.

The protective system shown and described herein is substantially faster than similar systems of the prior art, with any time delay between the transformer fault and the operation of the protective devices being almost wholly due to the time lag in the sensor means. If the sensor means is an electronic transducer, instead of a mechanical bellows type arrangement, the time from fault detection to operation of the protective apparatus could be reduced still more. Further, relay **100** is rugged, compact, unaffected by thermal changes within the operating temperature range of normal transformer operation, and is not subject to contact bounce, or to false tripping due to vibration and shock, as there are no moving contacts subject to vibration.

Since numerous changes may be made in the above-described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it isintended that all matter contained in the foregoing description or shown in the accompanying drawings, shall be interpreted as illustrative, and not in a limiting sense.

We claim as our invention:

1. An electrical transformer comprising

a magnetic core,

electrical windings disposed in inductive relation with said magnetic core,

a casing,

said electrical windings and magnetic core being disposed within said casing,

fluid insulating means disposed in said casing,

sensing means for sensing rate of change of pressure, said sensing means being disposed to sense the pressure within said casing, said sensing means providing a signal when the rate of change of pressure in said casing exceeds a predetermined magnitude,

reset means, and solid state relay means, said solid state relay means including a bistable flip-flop circuit having first and second output terminals, first and second amplifier means connected to said first and second output terminals, respectively, and first and second static switching means connected to said first and second amplifier means, respectively,

said reset means being connected to said flip-flop circuit, causing said flip-flop circuit to switch its output from its second to its first output terminal when said reset means is activated, to switch said first static switching means to its conductive state and said second static switching means to its non-conductive state,

said sensing means being connected to said flip-flop circuit, causing said flip-flop circuit to switch its output from its first to its second output terminal when said sensing means provides a signal, to switch said second static switching means to its conductive state and said first static switching means to its non-conductive state,

the switching of said first and second static switching means in response to said flip-flop circuit providing normally open and normally closed static contacts adapted for connection to protective apparatus.

2. The electrical transformer of claim **1** wherein said fluid insulating means is an insulating liquid disposed to a predetermined level in said casing, which provides a predetermined air space above said insulating liquid, and said sensing means is disposed to sense the pressure in said air space.

3. The electrical transformer of claim **2** wherein the signal provided by said sensing means is the closing of a mechanical contact, which triggers said bistable flip-flop circuit to provide an output signal at its second output terminal.

4. The electrical transformer of claim **1** wherein said fluid insulating means is an insulating liquid and said sensing means is disposed to sense the pressure within said lquid.

5. The electrical transformer of claim **4** wherein the signal provided by said sensing means is an electrical potential, which triggers said bistable flip-flop circuit to provide an output signal at its second output terminal.

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