PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H02H 9/02 — A2

(11) International Publication Number: WO 98/56095

(43) International Publication Date: 10 December 1998 (10.12.98)

(21) International Application Number: PCT/US98/11123

(22) International Filing Date: 2 June 1998 (02.06.98)

(30) Priority Data:
08/867,682 2 June 1997 (02.06.97) US
08/958,808 28 October 1997 (28.10.97) US

(71) Applicant: RAYCHEM CORPORATION [US/US]; 300 Constitution Drive, Mail Stop 120/6600, Menlo Park, CA 94025-1164 (US).

(72) Inventors: WYNN, Craig; 4207 Manuela Avenue, Palo Alto, CA 94306 (US). NICKOLS, St. Elmo, III; 222 Nicholson Avenue, Los Gatos, CA 95030 (US).

(74) Agents: RICHARDSON, Timothy, H., P. et al.; Raychem Corporation, Intellectual Property Law Dept., 300 Constitution Drive, Mail Stop 120/6600, Menlo Park, CA 94025-1164 (US).

(81) Designated States: JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: OVERCURRENT PROTECTION CIRCUIT

(57) Abstract

Circuit protection systems employing arrangements of PTC devices and mechanical switches. The PTC device is not involved in the circuit until a fault is sensed. In one embodiment, a current sensing relay senses an overcurrent and directs the current to the PTC device. As the voltage across the PTC device increases, a parallel arrangement of voltage sensing relays completes the operation of the protection system, and disconnects the load until the protection system is reset. The protection system may be reset manually or remotely.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	**ES**	Spain	**LS**	Lesotho	**SI**	Slovenia
AM	Armenia	**FI**	Finland	**LT**	Lithuania	**SK**	Slovakia
AT	Austria	**FR**	France	**LU**	Luxembourg	**SN**	Senegal
AU	Australia	**GA**	Gabon	**LV**	Latvia	**SZ**	Swaziland
AZ	Azerbaijan	**GB**	United Kingdom	**MC**	Monaco	**TD**	Chad
BA	Bosnia and Herzegovina	**GE**	Georgia	**MD**	Republic of Moldova	**TG**	Togo
BB	Barbados	**GH**	Ghana	**MG**	Madagascar	**TJ**	Tajikistan
BE	Belgium	**GN**	Guinea	**MK**	The former Yugoslav Republic of Macedonia	**TM**	Turkmenistan
BF	Burkina Faso	**GR**	Greece			**TR**	Turkey
BG	Bulgaria	**HU**	Hungary	**ML**	Mali	**TT**	Trinidad and Tobago
BJ	Benin	**IE**	Ireland	**MN**	Mongolia	**UA**	Ukraine
BR	Brazil	**IL**	Israel	**MR**	Mauritania	**UG**	Uganda
BY	Belarus	**IS**	Iceland	**MW**	Malawi	**US**	United States of America
CA	Canada	**IT**	Italy	**MX**	Mexico	**UZ**	Uzbekistan
CF	Central African Republic	**JP**	Japan	**NE**	Niger	**VN**	Viet Nam
CG	Congo	**KE**	Kenya	**NL**	Netherlands	**YU**	Yugoslavia
CH	Switzerland	**KG**	Kyrgyzstan	**NO**	Norway	**ZW**	Zimbabwe
CI	Côte d'Ivoire	**KP**	Democratic People's Republic of Korea	**NZ**	New Zealand		
CM	Cameroon			**PL**	Poland		
CN	China	**KR**	Republic of Korea	**PT**	Portugal		
CU	Cuba	**KZ**	Kazakstan	**RO**	Romania		
CZ	Czech Republic	**LC**	Saint Lucia	**RU**	Russian Federation		
DE	Germany	**LI**	Liechtenstein	**SD**	Sudan		
DK	Denmark	**LK**	Sri Lanka	**SE**	Sweden		
EE	Estonia	**LR**	Liberia	**SG**	Singapore		

OVERCURRENT PROTECTION CIRCUIT

This invention relates to electrical circuit overcurrent protection.

PTC circuit protection devices are well known. Particularly useful PTC devices contain a PTC element which is composed of a PTC conductive polymer, i.e. a composition which comprises (1) an organic polymer, and (2) dispersed, or otherwise distributed, in the polymer, a particulate conductive filler, preferably carbon black. PTC conductive polymers and devices containing them are described, for example in U.S. Patent Nos. 4,237,441, 4,238,812, 4,315,237, 4,317,027, 4,426,633, 4,545,926, 4,689,475, 4,724,417, 4,774,024, 4,780,598, 4,800,253, 4,845,838, 4,857,880, 4,859,836, 4,907,340, 4,924,074, 4,935,156, 4,967,176, 5,049,850, 5,089,801 and 5,378,407.

International Publication No. WO 97/10637 discloses overcurrent protection systems which are particularly useful when a circuit is to be protected from relatively small overcurrents. In those systems, a control element and a circuit interruption element are placed in series with the load. The control element is functionally linked to the circuit interruption element, so that, when the current in the circuit exceeds a predetermined amount, the control element senses the overcurrent and causes the circuit interruption element to change from a relatively conductive state to a relatively non-conductive state (including a completely open state). In the development of systems of the type described in International Publication No. WO 97/10637, we have discovered novel electrical systems which can be connected between an electrical power supply and an electrical load to form an operating circuit, and which when so connected protect the circuit from overcurrents. The novel systems fall into two overlapping categories which will be described separately below as the first and second aspects of the invention.

FIRST ASPECT OF THE INVENTION

The systems of the first aspect of the invention comprise:

(1) a current sensing means having

(a) a current deenergized state, when the current passing through it does not exceed a normal current, I_{NORMAL}, by a predetermined current amount, and

(b) a current energized state, when the current passing through it has exceeded the normal current, I_{NORMAL}, by the predetermined current amount;

(2) a first circuit switch which is coupled with the current sensing means and which is

(a) closed when the current sensing means is in the current deenergized state, and

(b) open when the current sensing means is in the current energized state;

(3) a voltage sensing means having

(a) a voltage deenergized state when the voltage across the voltage sensing means does not exceed a predetermined voltage amount, and

(b) a voltage energized state when the voltage across the voltage sensing means exceeds the predetermined voltage amount;

(4) a PTC device; and

(5) a second circuit switch which is coupled with the voltage sensing means and which is

(a) closed when the voltage sensing means is in the voltage deenergized state, and

(b) open when the voltage sensing means is in the voltage energized state;

the first circuit switch and the PTC device being connected in parallel with each other;

the second circuit switch being connected in series with the parallel combination of the first circuit switch and the PTC device; and

the voltage sensing means being connected in parallel with the series combination of (i) the second switch and (ii) the parallel combination of the first circuit switch and the PTC device.

An example of a circuit including such a system is shown in FIG. 1 of the accompanying drawings. The novel system is similar to the system shown in FIG. 2c of International Publication No. WO 97/10637, but, has the advantage that opening of the second circuit switch transfers the system voltage to the voltage sensing means. This ensures that the second circuit switch continues to open and remains open. The system shown in FIG. 2c of International Publication No. WO 97/10637 has the disadvantage that opening of the second circuit switch removes the voltage from the voltage sensing means. This may cause the contacts of a conventional relay to "chatter" and necessitate the use of some measure to prevent this, e.g. the use of a make-before-break relay.

The level (current or voltage, as the case may be) at which a relay energizes (e.g., switches from a normally open position to a closed position, or from a normally closed position to an open position, as the case may be) is often referred to as the "pull-in" level. Similarly, the level (current or voltage, as the case may be) at which a relay deenergizes (e.g. switches from a closed position to a normally open position, or from an open position to a normally closed position, as the case may be) is often referred to as the "drop-out" level.

It is preferred in a system of this kind that the current sensing relay (or other sensing means) have a pull-in level which is not far above the maximum operating current level (e.g., not more than 5 times, particularly not more than 3 times, especially not more than 2 times) to provide the desired overcurrent protection. It is also preferred in a system of this kind that the current sensing relay (or other sensing means) have a drop-out level which is not far above the maximum operating current level of the circuit to avoid triggering the protection system on short transient overcurrents. This is illustrated in the curves shown in FIGs. **2A** and **2B**. In the curve shown in FIG. **2A**, the drop-out level of the current sensing means is below the normal operating level of the circuit. Thus, in the event of a transient, such as is depicted in FIG. **2A**, the current sensing means will pull-in when the transient exceeds the pull-in level, but, since the normal operating current level is above the drop-out level, the current sensing means will not drop-out, and thus will remain energized. In protection systems of this kind, such would cause the PTC device the heat up and increase its resistance, thereby causing the voltage sensing relay (or other second circuit switch) to open.

In order to avoid this situation, i.e. to prevent triggering on such transients, the pull-in and drop-out levels of the current sensing relay may have relationships as depicted in FIG. **2B**. In the curve shown in FIG. **2B**, the drop-out level of the current sensing means is above the normal operating level of the circuit. Thus, in the event of a transient, such as is depicted in FIG. **2B**, the current sensing relay will pull in when the transient exceeds the pull-in level, but will then quickly drop-out when the current falls back below the drop-out level. With the current sensing relay pulled-in for a very brief time, the PTC device will not heat up sufficiently to cause the voltage sensing relay to open. Hence, the protection system should not trigger on transients.

It has been found that there is a danger that, after the current sensing relay contacts have opened, the PTC device will reduce the current to a level below the drop-out level of the current sensing relay before the voltage across the PTC device reaches the level required to pull-in the voltage sensing relay. With the current sensing relay dropping-out, the contacts reclose, thereby restoring the fault current, and the cycle of opening and reclosing of the current sensing relay contacts may repeat continuously. This "bussing" or "chattering" can cause the contacts to fuse together. This problem cannot be overcome by using a single voltage sensing relay having a sufficiently low pull in voltage (while also meeting the drop-out level requirement described above) because the coil in such a relay must be made with very fine wire which can melt when exposed to the normal system voltage or to surges induced by lightning or by inductive coupling to switching transients in parallel AC power lines.

Preferred embodiments of the first aspect of the invention provide a solution to this problem.

In one embodiment, the voltage sensing relay is a latching relay with a pull-in voltage low enough to ensure that the voltage contacts open before the current in the circuit drops below the drop-out current of the current relay; and a second latching relay is placed in parallel with the first relay, the second relay having a higher pull-in voltage than the first relay and controlling contacts which disconnect both relays. At least one, and preferably both, of the latching relays are DC relays, because latching DC relays are more readily available than latching AC relays. This solution not only prevents chattering of the current relay contacts, but also isolates the downstream circuit and the voltage relays; this makes the circuit safer for field personnel and ensures that neither the protection system nor the other circuit components can be damaged by lightning or other surges.

Another, less preferred, embodiment is to add a plurality of additional voltage relays, each in parallel with the voltage relay and each other, and with progressively higher pull-in voltages. The voltage relay with the highest pull-in voltage has a coil which will not be damaged by the normal system voltage. Each additional voltage relay controls a switch which will completely disconnect the "original" voltage relay and the additional voltage relay or relays having a lower pull-in voltage.

The first aspect of the invention is illustrated in Figures 1 to 5 of the accompanying drawings, in which FIGs. 1, 3, 4 and 5 are circuit diagrams of circuits in accordance with the first aspect of the invention, and FIGs. 2a and 2b are curves which illustrate the effect of different pull-in and drop-out levels of the current sensing relay in response to a transient condition.

FIG. 1 shows a circuit which includes a PTC device **18**, a current sensing relay **14** and a first voltage sensing relay **22**. The current sensing relay **14** is coupled to a first set of contacts **16**, and the first voltage sensing relay **22** is coupled to a second set of contacts **24**. The current sensing relay **14** performs the function of sensing the current in the circuit. When it detects an overcurrent condition, it opens the first set of contacts **16**, thus diverting the current to the PTC device **18**. Normally the resistance of the PTC device **18** is smaller than the resistance of the first voltage sensing relay **22**, so most of the current flows through the PTC device **18**. The PTC device **18** increases in resistance, thereby limiting the current in the circuit **10**, and applies a voltage across the first voltage sensing relay **22**. When the voltage across the first voltage sensing relay **22** reaches the level necessary to energize the first voltage sensing relay **22**, the first voltage sensing relay **22** opens the second set of contacts **24**. This transfers the system voltage to the voltage relay coil, thus ensuring that the contacts **24** continue to open and remain open so long as the voltage coil is energized. The current continues to flow through the load and the first voltage sensing relay **22**, but is limited by the resistance of voltage relay **22**. The circuit can be reset by interrupting the current through the voltage coil, which can be done by means of a manual reset mechanism or a reset coil which can be operated remotely (neither being shown in FIG. 1).

The circuit in FIG. **3** employs two voltage sensing relays **22,28** coupled in parallel. A first latching voltage sensing relay **22** has a pull-in voltage low enough to ensure that the second set of contacts **24** open before the current in the circuit drops below the drop-out level of the current sensing relay **14**. A second voltage sensing relay **28** has a higher pull-in voltage than the first voltage sensing relay **22** and controls a third set of contacts **32** which disconnects both voltage sensing relays **22,28** from the circuit.

An alternative circuit is shown in FIG. **4**, in which three (or more, three shown in FIG. **4**) voltage sensing relays **22,42,44** are coupled in parallel. Each succeeding voltage sensing relay coil has a higher pull-in voltage than the previous, and, as the voltage across the parallel assembly increases, the relay coils energize in sequence, with each succeeding relay disconnecting the previous relay from the circuit. Thus, only that last relay in the assembly need carry the full system voltage.

In the circuit shown in FIG. **5**, a first latching DC voltage relay **76** is used in place of the voltage relay **22** of FIG. **3**. The first latching DC voltage relay **76** has two coils **52,54**, a first set coil **52** for switching the first latching DC voltage relay contacts **24** to the open position, and a first reset coil **54** for returning the first latching DC voltage relay contacts **24** to the closed position. The bridge circuit **72** converts AC to rectified DC. When the voltage across the PTC device **18** increases to the pull-in voltage of the first set coil **52**, the first set coil **52** energizes causing the first latching DC voltage relay contacts **24** to switch to the open circuit position. The first latching DC voltage relay **76** latches in this position.

A second latching DC voltage relay **78** also has two coils **56,58**, a second set coil **56** for switching two sets of contacts **68,74**, and a second reset coil **58** for resetting the two sets of contacts **68,74**. The second set coil **56** has a higher pull-in voltage than the first set coil **52**. When the first latching DC voltage relay contacts open **24**, the voltage across the bridge circuit **72** rises. As the voltage rises, the pull-in voltage of the second set coil **56** is reached, and the second set coil **56** energizes. The two sets of contacts **68, 74** switch, disconnecting the bridge circuit **72** from the AC input, and thereby deenergizing the set coils **52,56** of both relays. A first capacitor **82** completes the switching action after the system voltage has been removed.

At the conclusion of the switching event, the contacts **24,68,74** of both voltage sensing relays **76,78** are open, and zero current flows from input to output. No power is dissipated when the circuit is in the tripped state, and the downstream load is electrically isolated from the system voltage. This presents a less hazardous condition for field personnel, and protects delicate coil windings from lightning and other transient sources.

When the two sets of contacts **68,74** switch to their set position, the first and second reset coils **54,58** are connected to the bridge circuit **72**. The circuit may be reset manually, for example by means of a push button **64**, or remotely by means of an additional relay coil **62** and associated contacts **66**. Resetting by either means connects power through the bridge circuit **72** to the first and second reset coils **54,58**. A resistor **84** may be included to prevent an overvoltage condition which might cause arcing or damage to the relay coils.

SECOND ASPECT OF THE INVENTION

The specific current sensing means disclosed by way of preferred example in the above description of the first aspect of the invention is a current sensing relay. We have found that under some circumstances, a current sensing relay is not the preferred current sensing means. For example, if the fault condition produces intermittent or repetitive current surges, this can result in the current relay being rapidly energized and deenergized in a way which is not satisfactory. In accordance with the second aspect of the invention, we have discovered an alternative current sensing means, which can be used in all the circuits disclosed in the above description of the first aspect of the invention, and is particularly useful when there is a possibility that the fault condition will produce intermittent or repetitive current surges. This current sensing means is responsive not only to the size, but also the duration of the current (for example so that it will not convert the first circuit switch from the closed to the open position unless the current exceeds a predetermined level for more than 1 millisecond) and thus ensures that the current to the load is cut off or reduced only when some function of the size and the duration of the current exceeds a predetermined value.

In accordance with the second aspect of the invention, we have also discovered that, providing the second switch will latch in the open position, the components (1) to (5) can be arranged in a different configuration, namely with the first circuit switch, the PTC device and the voltage sensing means connected in parallel; and the second circuit switch, and the parallel combination of the first circuit switch, the PTC device and the voltage sensing means, being connected in series.

In one embodiment, the second aspect of the invention provides an electrical protection system which can be connected in series between an electrical power supply and an electrical load to form an operating circuit, and which when so connected protects the circuit from overcurrents, the system having a normal operating condition and a fault condition, and comprising :

(1) a current sensing means having
   (a) a current deenergized state, when a function of the size of the current passing through the load does not exceed a predetermined value, and
   (b) a current energized state, when an overcurrent causes said function to exceed said predetermined value;

(2) a first circuit switch which
   (a) has an open state and a closed state, and
   (b) is coupled to the current sensing means so that, when the first circuit switch is in a closed position and said function increases from below to above said predetermined value, the first circuit switch is converted to the open state;

(3) a voltage sensing means having
   (a) a voltage deenergized state when the voltage across the voltage sensing means does not exceed a predetermined voltage amount, and

(b) a voltage energized state when the voltage across the voltage sensing means exceeds the predetermined voltage amount;

(4) a PTC device; and

(5) a second circuit switch which

(a) has an open state and a closed state, and

(b) is coupled to the voltage sensing means so that, when the second circuit switch is in the closed state, and the voltage sensing means is converted from the voltage deenergized state to the voltage energized state, the second circuit switch is converted from the closed state to the open state;

the components (1) to (5) being connected so that

(A) the second circuit switch is connected in series with the parallel combination of the first circuit switch and the PTC device; and the voltage sensing means is connected in parallel with the series combination of (i) the second switch and (ii) the parallel combination of the first circuit switch and the PTC device; or

(B) the first circuit switch, the PTC device and the voltage sensing means are connected in parallel with each other; and the second circuit switch, and the parallel combination of the first circuit switch, the PTC device and the voltage sensing means, being connected in series, the second circuit switch being a switch which latches in the open position.

In another embodiment, the second aspect of the invention provides electrical circuits comprising an electrical power supply, an electrical load and an electrical protection system according to the first embodiment of the second aspect of the invention.

The second aspect of the invention is illustrated in Figures 6 to 10 the accompanying drawings, in which Figures 6 and 7 are circuit diagrams of circuits of the invention, and Figures 8, 9 and 10 are circuit diagrams of parts of circuits of the invention.

In one preferred embodiment of the second aspect of the invention, the current sensing means comprises

(i) a voltage output which provides a signal voltage related to said function of the current passing through the load;

(ii) a voltage source which supplies a reference voltage; and

(iii) a comparator which makes a comparison between the signal voltage and the reference voltage, and provides an output which reflects the result of that comparison.

The signal voltage can for example be the voltage across a resistor through which flows a current proportional to the current through the load, or the voltage from a current transformer coupled to a conductor through which flows a current proportional to the current through the load, or the voltage from a magneto resistive device coupled to a conductor through which flows a current proportional to the current through the load.

In the simplest embodiment of the second aspect of the invention, the function of the current passing through the load is simply the magnitude of that current (subject to the inherent property of all current sensing means, namely that an overcurrent pulse can be so short that it is not recognized by the current sensing means as having a magnitude greater than a predetermined minimum). In another embodiment, the function is a function of (i) the size of the current passing through the load, and (ii) the duration of the current passing through the load, with the function being something other than that inherent in the current sensing means itself (for example, a function such that the predetermined value cannot be exceeded when the duration of the overcurrent is less than 1 millisecond, or less than 25 milliseconds, or less than 50 milliseconds, or less than 100 milliseconds). Alternatively or additionally, the current sensing means can be one which can be programmed to change the predetermined value and/or which is adaptive, i.e. which observes the current (or another variable) over a period and sets the predetermined value in response to the current (or the other variable) during the period of observation..

In various embodiments of the second aspect of the invention, one of the first and second switches is a switch which latches in the open position and the other is a non-latching switch; or both are latching switches; or both are non-latching switches. In one embodiment, the components (1) to (5) are connected in accordance with paragraph (A) above, and the second circuit switch does not latch in the open state when it is converted into the open state. This has the advantage that if the cause of the overcurrent is removed, the circuit reverts to normal operation. In another embodiment, the components (1) to (5) are connected in accordance with paragraph (B) above, and each of the first and second circuit switches latches in the open state when it is converted from the closed state to the open state. This has the advantage that no current flows through the load after the overcurrent has triggered the protection system, but the disadvantage that the switches must be reset, even after the cause of the overcurrent has been removed, before normal operation can be restored. However, when the system employs a current sensing means which has a reference voltage, and/or is programmable and/or is adaptive, it is not difficult to design a system in which the switches can be reset remotely, e.g. by means of an electrical signal, thus removing the need for manual resetting.

A preferred protection system of the second aspect of the invention comprises

(1) a current sensing means having

(a) a current deenergized state, when a function of (i) the size of the current passing through the load, and (ii) the duration of the current passing through the load, does not exceed a predetermined value, and

(b) a current energized state, when an overcurrent causes said function to exceed said predetermined value,

and the current sensing means comprising

(i) a voltage output which generates a signal voltage related to said function,

(ii) a voltage source which supplies a reference voltage, and

(iii) a comparator which makes a comparison between the signal voltage and the reference voltage, and provides an output which reflects the result of that comparison;

(2) a first circuit switch which

(a) has an open state and a closed state, and

(b) is coupled to the current sensing means so that, when the first circuit switch is in the closed state and said function increases from below to above said predetermined value, the output from the comparator converts the first circuit switch from the closed state to the open state;

(3) a voltage sensing means having

(a) a voltage deenergized state when the voltage across the voltage sensing means does not exceed a predetermined voltage amount, and

(b) a voltage energized state when the voltage across the voltage sensing means exceeds the predetermined voltage amount;

(4) a PTC device; and

(5) a second circuit switch which

(a) has an open state and a closed state, and

(b) is coupled to the voltage sensing means so that, when the second circuit switch is in the closed position and the voltage sensing means is converted from the voltage deenergized state to the voltage energized state, the second circuit switch is converted from the closed state to the open state and latches in the open state;

the first circuit switch, the PTC device and the voltage sensing means being connected in parallel with each other; and the parallel combination of the first circuit switch, the

PTC device and the voltage sensing means, and the second circuit switch, being connected in series with each other. In this circuit, it is preferred that

(a) the first circuit switch is a first relay which is normally closed and which latches in the open state;

(b) the second circuit switch is a second relay which is normally closed and which latches in the open state;

(c) the output from the comparator, when said function increases from above to below said predetermined value, closes a third relay which is normally open and does not latch in a closed state, thus causing flow of a current which opens the first circuit switch; and

(d) the voltage sensing means

 (i) comprises a fourth relay which is normally open and which latches in the closed state, and

 (ii) when it is converted from the voltage deenergized state to the voltage energized state, closes the fourth relay, thus causing flow of a current which opens the second circuit switch.

Referring now to the drawings, Figure 6 shows a circuit which includes a power source **12**, a load **26**, first and second circuit switches **16** and **24**, a PTC device **18**, a current sensing means **14** and a voltage sensing means **22**. The current sensing means **14** is coupled to the first circuit switch **16**, and the voltage sensing means **22** is coupled to the second circuit switch **24**. The current sensing means **14** senses the current in the circuit. When it detects an overcurrent condition, it opens the first circuit switch **16**, which latches in the open position, thus diverting the current to the PTC device **18** which is connected in parallel with the first circuit switch 16. Normally the resistance of the PTC device **18** is smaller than the resistance of the voltage sensing means **22**, so most of the current flows through the PTC device 18. The PTC device **18** increases in resistance, thereby limiting the current in the circuit, and applies a voltage across the voltage sensing means **22**. When the voltage across the voltage sensing means 22 reaches a predetermined level, it opens the second circuit switch 24, which latches in the open position.

Figure 7 is a somewhat more detailed version of Figure 6. The current sensing means comprises a voltage output **141** which provides a signal voltage proportional to a function of the current flowing through the load. The signal voltage is sent to a comparator **142** which compares the voltage signal to a predetermined reference voltage, and provides a current output which reflects the result of that comparison and which is passed to a relay coil **143** which controls normally open relay contacts **144**. When the output from the comparator reflects the fact that the function of the load current has exceeded the predetermined level, the relay contacts **144** close, causing current to flow through a relay coil **145**, which in turn opens the first circuit switch **16**, which latches in the open position. The voltage sensing means comprises a relay coil **221** which controls normally open relay contacts **222**. When the voltage across the relay coil reaches the predetermined voltage amount, the relay contacts **222** close, causing current to flow through a relay coil **223**, which in turn opens the second circuit switch **24**, which latches in the open position. Since the first circuit switch latches open, the predetermined voltage amount can be at any appropriate level, typically a level below the interrupt rating of the second circuit switch **24**.

A current sensing means of the kind in Figure 7 is electronic, rather than electromagnetic (as in a current relay). The use of an electronic sensing means makes it possible to adjust the system, e.g. through the use of capacitors and resistors, to produce a wide variety of different results; for example to obtain whatever averaging time constant is desired for the current. For example, if a fault current has surges which are repetitive with a period of 16 milliseconds, a current relay will respond with repetitive opening and closing with the same period, producing an oscillating "buzzing" sound, and potentially damaging the contacts. An electronically controlled sensing method can be selected to average the surges over a longer time-period, such as 100 milliseconds. The output will then be a smoothed value, which can be easily compared with a reference value. Another advantage is precise operation of the circuit. With an electronic current sensing method, the trigger current for operation may be selected much more precisely than is possible with a current relay, given the variation in fitting together the mechanical components of a relay. Nor is it necessary to worry about matching pull-in and drop-out currents, as discussed in the parent application.

Another advantage of electronically controlled current sensing is that there is low power dissipation associated with latching contacts. Operation of these contacts requires an input signal, which can then be removed, since the contacts will remain in their latched position. This means that, in normal operation, the circuit requires no power dissipation other than a low value associated directly with the resistance of the contacts, typically near 100 milliohms. Once the circuit has operated and the contacts are latched in their open position, again there is no ongoing power required to maintain their position.

Another advantage is that the time-averaging constant can be selected to ensure that lightning surges do not trigger the protection system. Another advantage is that the system can be designed so that, in the "tripped" or open state, all current paths are interrupted by open contacts, including paths between the high-voltage or "hot" conductor and neutral (ground) and between the input and output of the "hot" conductor.

Two features of the type of current sensor shown in Figure 7 need to be recognized. The first is the requirement of contact with the neutral (ground) conductor in order to power the latching relays. Usually this is not a difficult requirement, since a ground or low-voltage contact is available from the power supply. The second is the requirement for a minimum system voltage. If the system voltage (the voltage difference between the "hot" conductor and neutral) is below the minimum operating voltage of the first and second circuit switches, these relay switches will not operate and the circuit will remain in the conducting state, even though fault current may be flowing.

This means that this type of protection may be used in cases where the system voltage does not drop below the operating voltage of the relays in the case of an overcurrent fault, e.g., between a utility electric supply and a downstream power supply, but should not be used, for example, on the secondary side of transformers whose output voltage may collapse when shorted.

Figures 8 and 9 show circuit diagrams for the voltage output suitable for use in Figure 7. In Figure 8, the signal voltage is the voltage across a precisely known resistor **1411**. In Figure 9, the voltage output comprises a current transformer **1412** coupled to a conductor which carries the circuit current, and the induced voltage is supplied to a circuit containing a capacitor **1413** and a resistor **1414** which average the current over a desired time period to provide the desired voltage signal.

Figure 10 shows a circuit diagram for a comparator suitable for use in Figure 7. The comparator makes use of a 3-volt power supply (or a similar low voltage) which may be derived from the principal power source **12** or from a battery. Resistors **1424** and **1425** determine the reference voltage for an op-amp **1426**; if desired one or both of resistors **1424** and **1425** can be a variable resistor, so that the reference voltage can be changed if desired. When the signal voltage exceeds the reference voltage, the op-amp turns on a transistor FET, causing current to flow through relay coil **143** (which must operate with the reference voltage).

CLAIMS

1. An electrical system which can be connected between an electrical power supply and an electrical load to form an operating circuit, and which when so connected protects the circuit from overcurrents, the system having a normal operating condition and a fault condition, and comprising :

(1) a current sensing means having

(a) a current deenergized state, when the current passing through it does not exceed a normal current, I_{NORMAL}, by a predetermined current amount, and

(b) a current energized state, when the current passing through it has exceeded the normal current, I_{NORMAL}, by the predetermined current amount;

(2) a first circuit switch which is coupled with the current sensing means and which is

(a) closed when the current sensing means is in the current deenergized state, and

(b) open when the current sensing means is in the current energized state;

(3) a voltage sensing means having

(a) a voltage deenergized state when the voltage across the voltage sensing means does not exceed a predetermined voltage amount, and

(b) a voltage energized state when the voltage across the voltage sensing means exceeds the predetermined voltage amount;

(4) a PTC device; and

(5) a second circuit switch which is coupled with the voltage sensing means and which is

(a) closed when the voltage sensing means is in the voltage deenergized state, and

(b) open when the voltage sensing means is in the voltage energized state;

the first circuit switch and the PTC device being connected in parallel with each other;

the second circuit switch being connected in series with the parallel combination of the first circuit switch and the PTC device; and

the voltage sensing means being connected in parallel with the series combination of (i) the second switch and (ii) the parallel combination of the first circuit switch and the PTC device.

2. A system according to claim 1 wherein:

a. the current sensing means comprises a current sensing relay coil;

b. the first circuit switch comprises a first set of contacts coupled with the current sensing relay coil;

c. the voltage sensing means comprises a voltage sensing relay coil; and

d. the second circuit switch comprises a second set of contacts coupled with the voltage sensing relay coil.

3. A system according to claim 2 wherein the combination of the current sensing relay coil and the first set of contacts has a drop-out current which is above I_{NORMAL} and a pull-in current which is not more than P times I_{NORMAL}, where P is 3.

4. A system according to claim 2 or 3 in which said voltage relay coil and said second set of contacts have a first pull-in voltage and latch open when the voltage across the coil exceeds the first pull-in voltage; and which further comprises

(6) an auxiliary voltage sensing relay coil which is connected in parallel with said voltage sensing relay coil, and

(7) an auxiliary set of contacts which is

(a) coupled with the auxiliary voltage sensing relay coil, and

(b) when it is open, disconnects said voltage relay coil and the auxiliary voltage sensing relay coil;

the auxiliary voltage sensing relay coil and the auxiliary set of contacts having a second pull-in voltage which is higher than the first pull-in voltage and latching open when the voltage across the auxiliary voltage sensing relay coil exceeds the second pull-in voltage.

5. A system according to claim 3 which further comprises a plurality of additional voltage relay coils, each having an associated set of contacts coupled thereto; the additional voltage coils and the associated sets of contacts having different pull-in voltages, each of the pull-in voltages being higher than the pull-in voltage of said voltage relay coil and said second set of contacts; and each of the associated sets of contacts, when open, completely disconnecting said voltage relay and any additional voltage coil having a lower pull-in voltage.

6. An electrical protection system which can be connected in series between an electrical power supply and an electrical load to form an operating circuit, and which when so connected protects the circuit from overcurrents, the system having a normal operating condition and a fault condition, and comprising :

(1) a current sensing means having

(a) a current deenergized state, when a function of the size of the current passing through the load does not exceed a predetermined value, and

(b) a current energized state, when an overcurrent causes said function to exceed said predetermined value;

(2) a first circuit switch which

(a) has an open state and a closed state, and

(b) is coupled to the current sensing means so that, when the first circuit switch is in a closed position and said function increases from below to above said predetermined value, the first circuit switch is converted to the open state;

(3) a voltage sensing means having

(a) a voltage deenergized state when the voltage across the voltage sensing means does not exceed a predetermined voltage amount, and

(b) a voltage energized state when the voltage across the voltage sensing means exceeds the predetermined voltage amount;

(4) a PTC device; and

(5) a second circuit switch which

(a) has an open state and a closed state, and

(b) is coupled to the voltage sensing means so that, when the second circuit switch is in the closed state, and the voltage sensing means is converted from the voltage deenergized state to the voltage energized state, the second circuit switch is converted from the closed state to the open state;

the components (1) to (5) being connected so that

(A) the second circuit switch is connected in series with the parallel combination of the first circuit switch and the PTC device; and the voltage sensing means is connected in parallel with the series combination of (i) the second switch and (ii) the parallel combination of the first circuit switch and the PTC device; or

(B) the first circuit switch, the PTC device and the voltage sensing means are connected in parallel with each other; and the second circuit switch, and the parallel combination of the first circuit switch, the PTC device and the voltage sensing means, being connected in series, the second circuit switch being a switch which latches in the open position.

7. A system according to claim 6 wherein the current sensing means comprises

(i) a voltage output which provides a signal voltage related to said function;

(ii) a voltage source which supplies a reference voltage; and

(iii) a comparator which makes a comparison between the signal voltage and the reference voltage, and provides an output which reflects the result of that comparison.

8. A system according to claim 7 wherein the signal voltage is the voltage across a resistor through which flows a current proportional to the current through the load.

9. A system according to any one of claims 6 to 8 wherein the current sensing means comprises (a) a current transformer coupled to a conductor through which flows a current proportional to the current through the load, or (b) a magneto resistive device coupled to a conductor through which flows a current proportional to the current through the load.

10. A system according to any one of claims 6 to 9 wherein said function is a function of (i) the size of the current passing through the load, and (ii) the duration of the current passing through the load, and said predetermined value cannot be exceeded when the duration of the overcurrent is less than 1 millisecond.

11. A system according to claim 10 wherein said function is an integral of the current passing through the current sensing means over a period of at least 1 millisecond.

12. A system according to claim 10 wherein said function is an integral of the current passing through the current sensing means over a period of at least 50 milliseconds.

13. A system according to any one of claims 6 to 9 wherein said function is a function of (i) the size of the current passing through the load, and (ii) the duration of the

current passing through the load, and the current sensing means can be programmed to change said predetermined value.

14. A system according to any one of claims 6 to 9 wherein said function is a function of (i) the size of the current passing through the load, and (ii) the duration of the current passing through the load, and the current sensing means is adaptive.

15. A system according to claim 6 wherein the components (1) to (5) are connected in accordance with paragraph (A) and the second circuit switch does not latch in the open state when it is converted into the open state.

16. A system according to claim 6 wherein the components (1) to (5) are connected in accordance with paragraph (B), and each of the first and second circuit switches latches in the open state when it is converted from the closed state to the open state.

17. An electrical protection system which can be connected in series between an electrical power supply and an electrical load to form an operating circuit, and which when so connected protects the circuit from overcurrents, the system having a normal operating condition and a fault condition, and comprising:

(1) a current sensing means having

(a) a current deenergized state, when a function of (i) the size of the current passing through the load, and (ii) the duration of the current passing through the load, does not exceed a predetermined value, and

(b) a current energized state, when an overcurrent causes said function to exceed said predetermined value,

and the current sensing means comprising

(i) a voltage output which generates a signal voltage related to said function,

(ii) a voltage source which supplies a reference voltage, and

(iii) a comparator which makes a comparison between the signal voltage and the reference voltage, and provides an output which reflects the result of that comparison;

(2) a first circuit switch which

(a) has an open state and a closed state, and

(b) is coupled to the current sensing means so that, when the first circuit switch is in the closed state and said function increases from below to above said predetermined value, the output from the comparator converts the first circuit switch from the closed state to the open state;

(3) a voltage sensing means having

(a) a voltage deenergized state when the voltage across the voltage sensing means does not exceed a predetermined voltage amount, and

(b) a voltage energized state when the voltage across the voltage sensing means exceeds the predetermined voltage amount;

(4) a PTC device; and

(5) a second circuit switch which

(a) has an open state and a closed state, and

(b) is coupled to the voltage sensing means so that, when the second circuit switch is in the closed position and the voltage sensing means is converted from the voltage deenergized state to the voltage energized state, the second circuit switch is converted from the closed state to the open state and latches in the open state;

the first circuit switch, the PTC device and the voltage sensing means being connected in parallel with each other; and the parallel combination of the first circuit switch, the PTC device and the voltage sensing means, and the second circuit switch, being connected in series with each other.

18. A circuit according to claim 17 wherein

(a) the first circuit switch is a first relay which is normally closed and which latches in the open state;

(b) the second circuit switch is a second relay which is normally closed and which latches in the open state;

(c) the output from the comparator, when said function increases from above to below said predetermined value, closes a third relay which is normally open and does not latch in a closed state, thus causing flow of a current which opens the first circuit switch; and

(d) the voltage sensing means

(i) comprises a fourth relay which is normally open and which latches in the closed state, and

(ii) when it is converted from the voltage deenergized state to the voltage energized state, closes the fourth relay, thus causing flow of a current which opens the second circuit switch.

19. An electrical circuit which comprises an electrical power supply, an electrical load and an electrical protection system as defined in any one of the preceding claims.

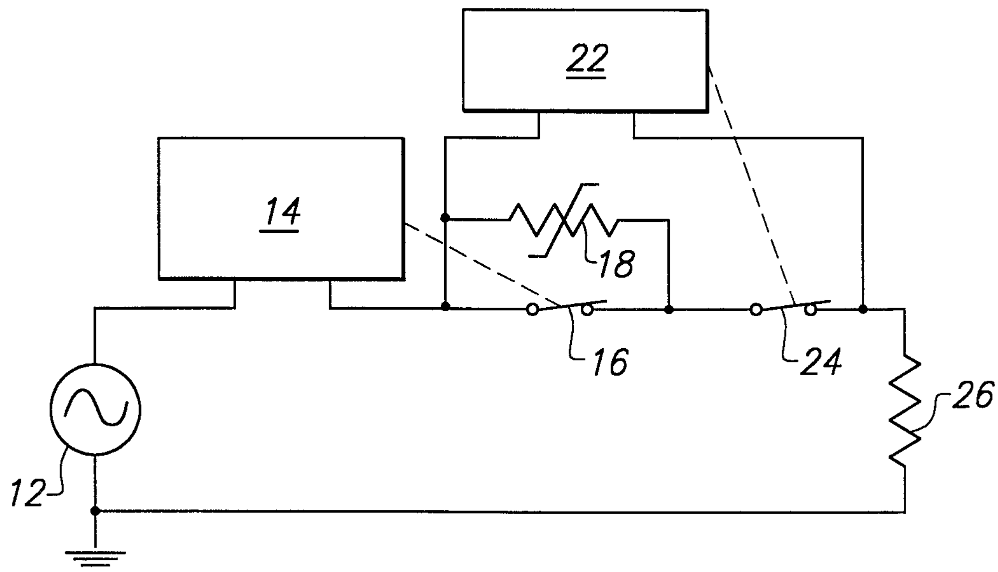

FIG. 1

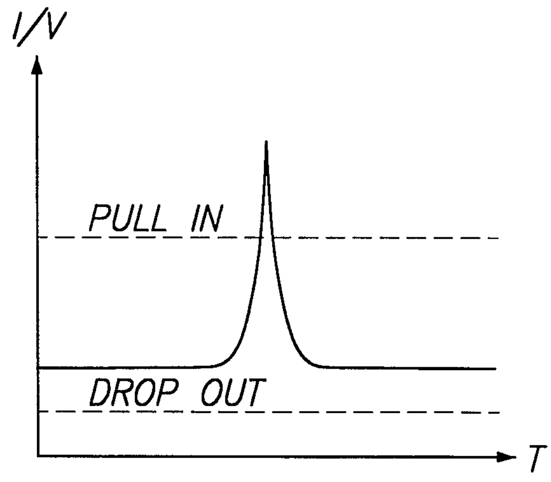

FIG. 2A

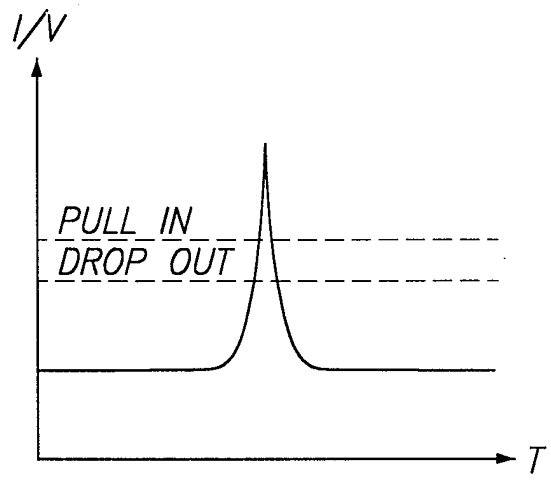

FIG. 2B

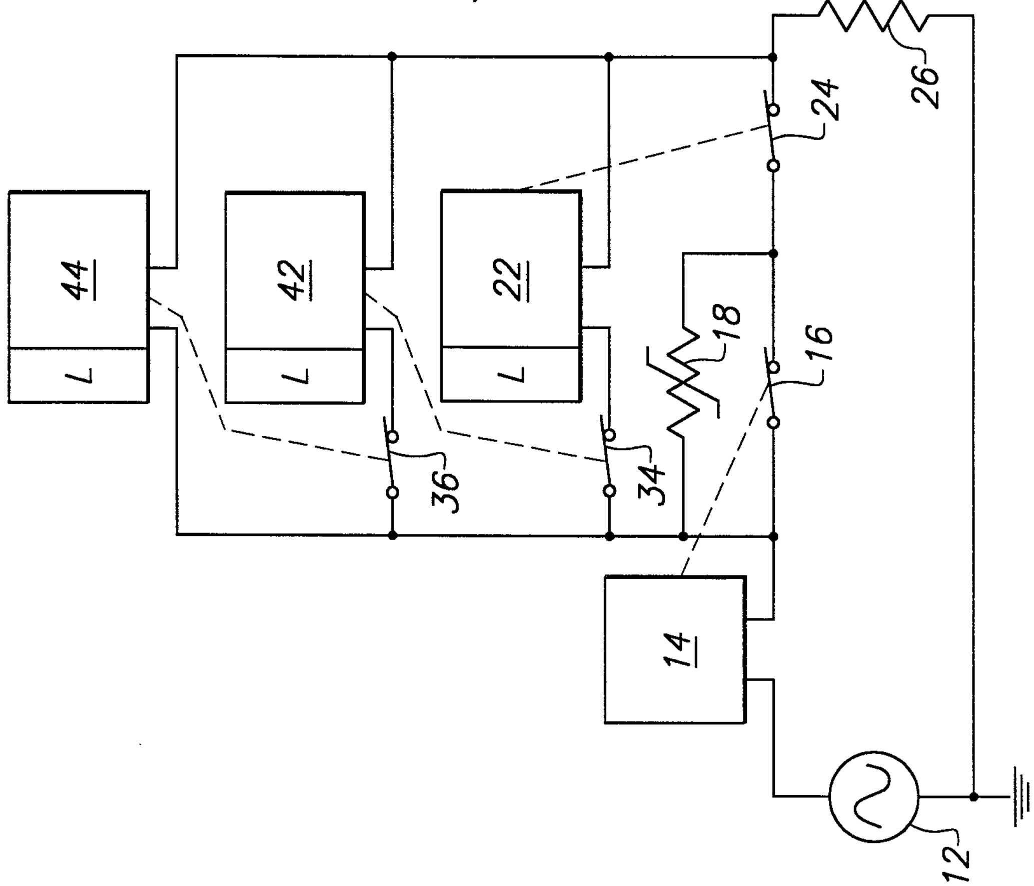

FIG. 4

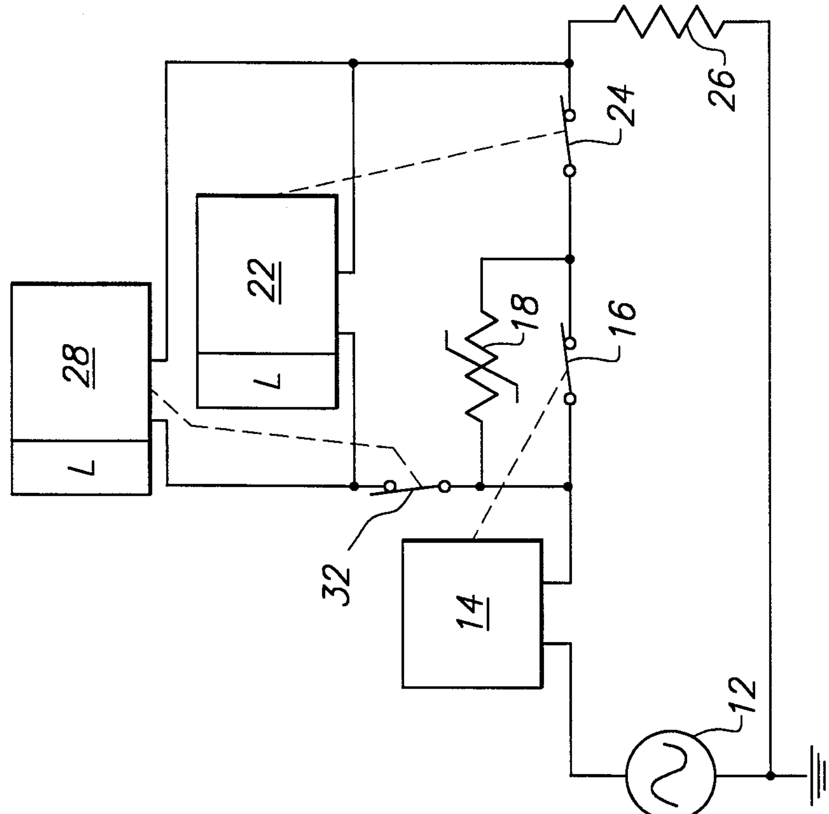

FIG. 3

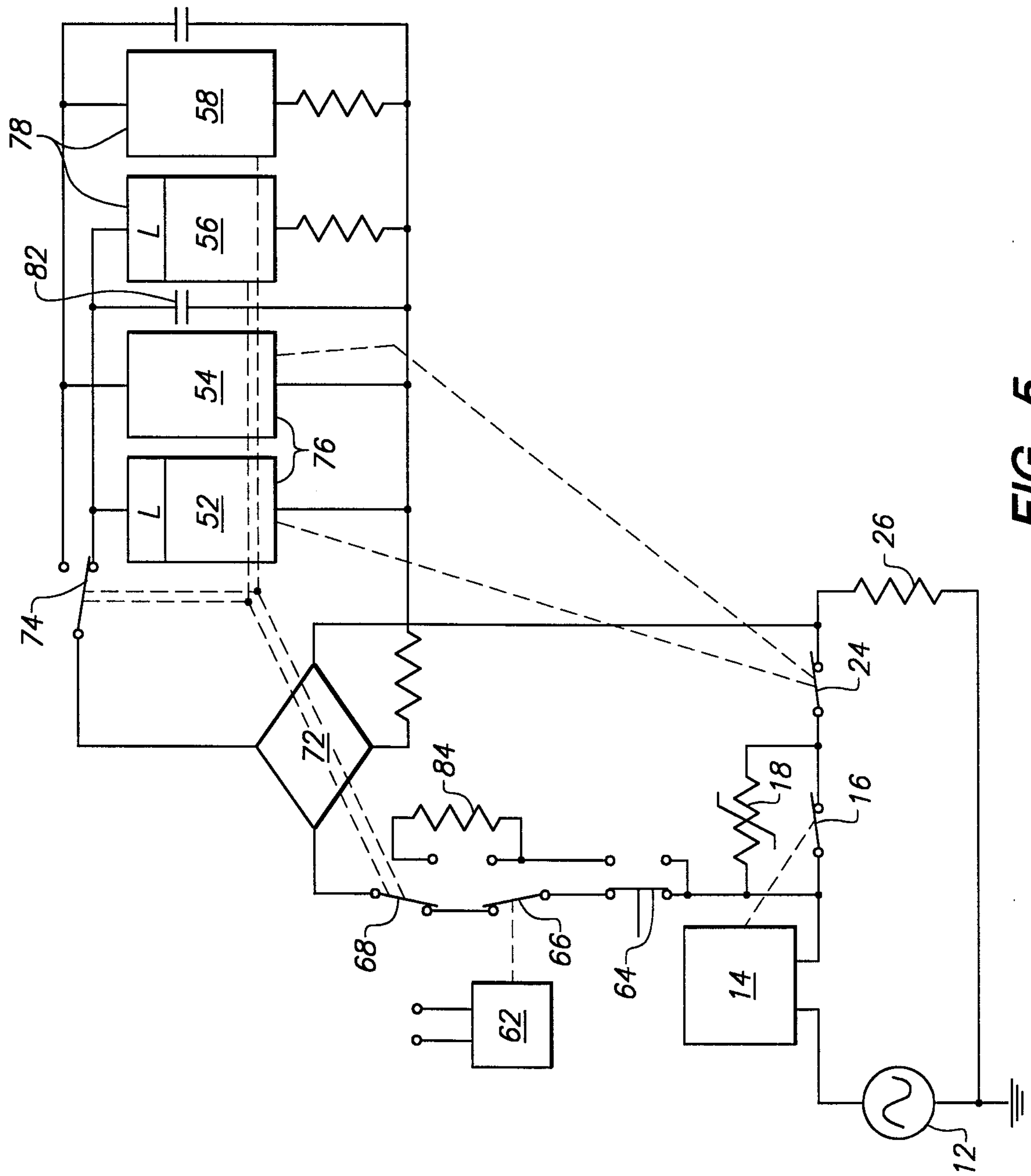

FIG. 5

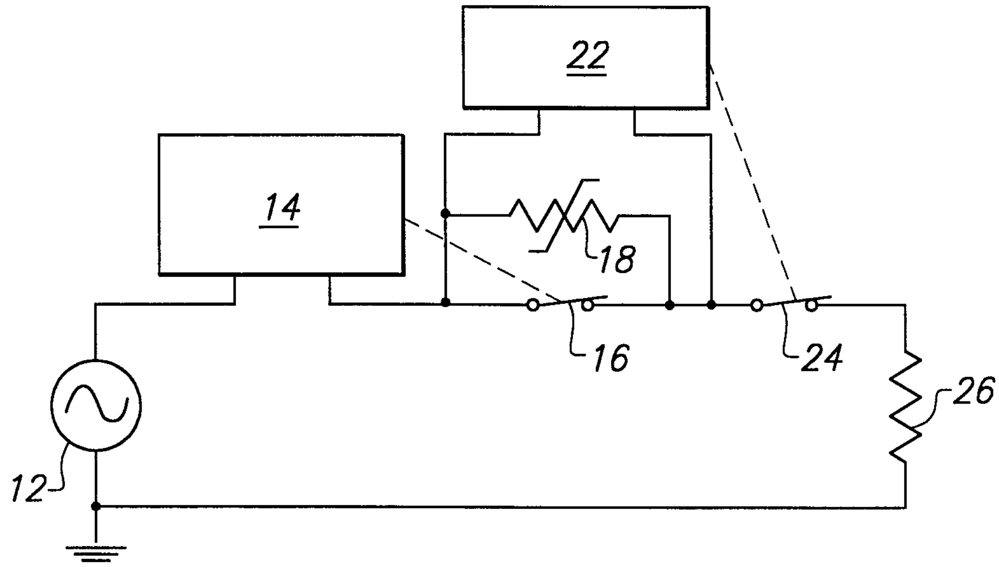

FIG. 6

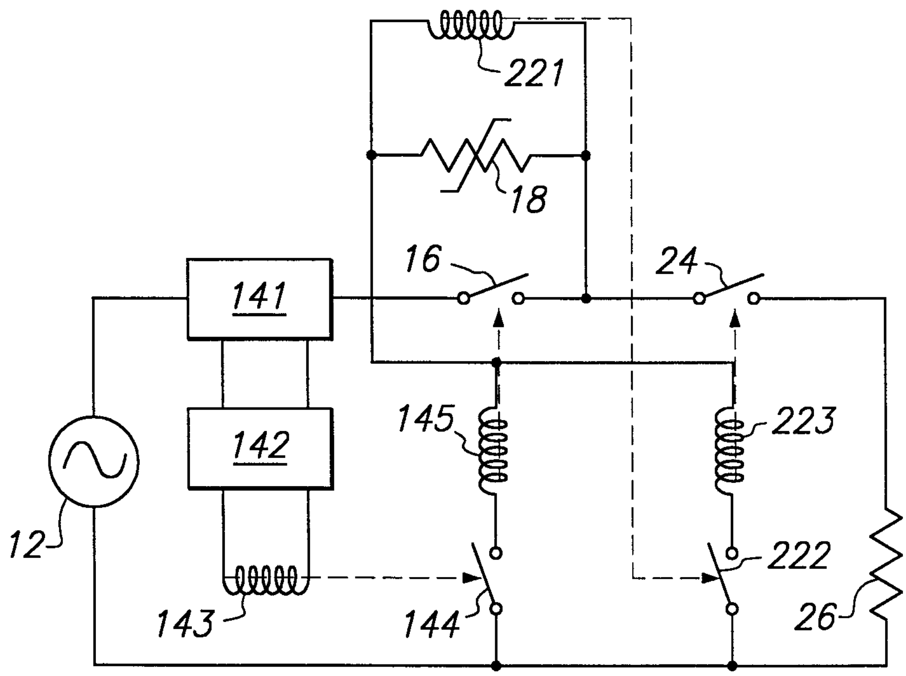

FIG. 7

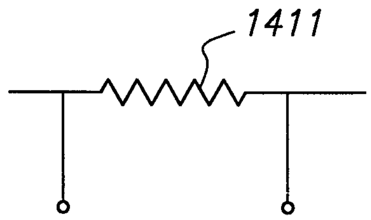

FIG. 8

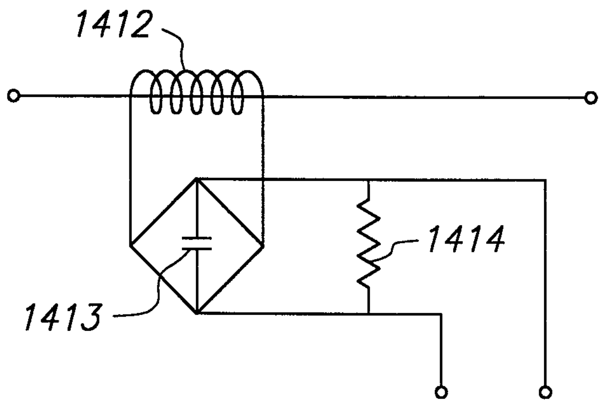

FIG. 9

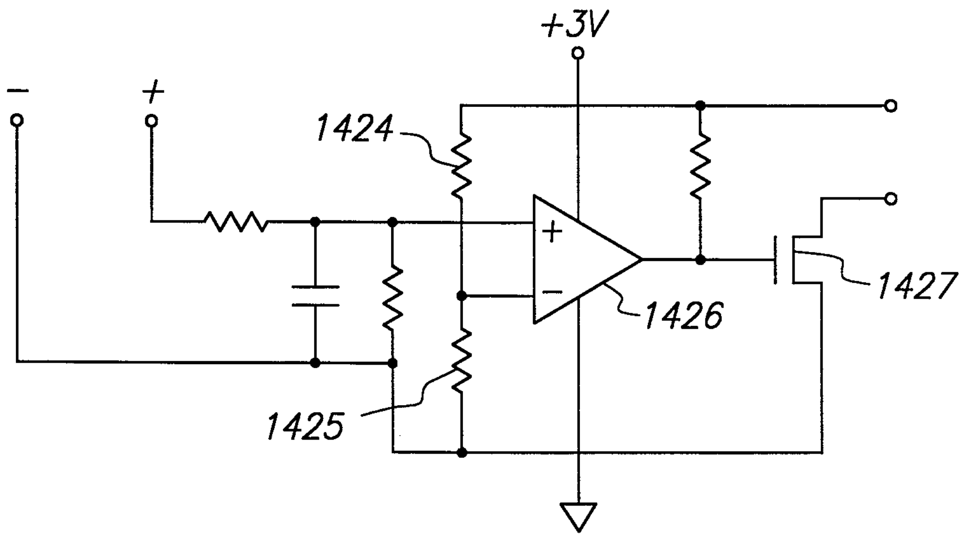

FIG. 10