(54) Title: RESIDUAL CURRENT DEVICE

FIG. 3

(57) Abstract: A residual current device comprises a circuit (CT, 10, 12) for detecting a current imbalance in an AC supply to a load indicative of a residual current and providing a corresponding output. A relay RLA has contacts SW1 in the AC supply to the load. The relay contacts SW1 automatically close when a closing current is passed through the relay and is thereafter maintained closed so long as a holding current, less than the closing current, passes through the relay. A capacitor C1 is connected to the AC supply in parallel with the relay RLA such that, upon application of power from the AC supply, current flows to the charge storage device. An electronic switch SCR2 in series with the relay is turned on when the voltage on the capacitor exceeds the breakover voltage of a Zener diode ZD2 to allow discharge of the capacitor through the relay to provide a current exceeding the closing current, the AC supply thereafter providing a holding current for the relay at least when the supply is at a certain minimum voltage. An output from the current imbalance detecting circuit opens contacts SW3 in series with the relay to interrupt the current flow through the relay.

1

Residual Current Device

BACKGROUND OF THE INVENTION

5 1. FIELD OF THE INVENTION

This invention relates to residual current devices.

2. PRIOR ART

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Residual current devices (RCDs) detect earth fault currents,
which are also known as residual currents. The principle of
operation of RCDs is very well known.

15 RCDs can be grouped into two broad categories - voltage
independent (VI) and voltage dependent (VD) types. The VI
types use the detected residual current as the source of
energy to enable them to operate. The VD types use the mains
supply as the source of energy to enable them to operate. The
20 VI types are commonly referred to as electromechanical types,
and VD RCDs are often referred to as electronic types.

RCDs can also be divided into two other categories - those
that are mechanically or magnetically latched (ML) to enable
25 them to be closed and remain closed (these include VD and VI
types), and those that are electrically latched (EL) in that
they require the mains supply to enable them to be closed and
to remain closed.

30 The EL types can be further subdivided into those that open
automatically on loss of supply and remain open on restoration
of the supply (for convenience here referred to as ELRO -
electrically latched remains open), and those that open
automatically on loss of supply but reclose automatically on

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2

restoration of the supply (for convenience here referred to as
ELAR - electrically latched auto recloses).

These four RCD types are summarised as follow

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VIML   voltage independent mechanically latching
VDML   voltage dependent mechanically latching
VD-ELRO   voltage dependent electrically latching - remains
          open
10   VD-ELAR   voltage dependent electrically latching - auto
             recloses

All of these RCDs have advantages and disadvantages which
users can take into consideration when selecting an RCD for a
15   particular application. For example, the VI type can operate
down to virtually zero volts, but can be disabled under a
double grounded neutral fault condition. The VDML uses
electronic circuitry to provide for enhanced performance such
as detection of pulsating DC fault currents, but can be
20   disabled in the event of loss of supply neutral when used on a
single phase supply. It should be noted that the risks
involved in both of the above cases are generally considered
to be very low and have not precluded the extensive use of
such RCDs worldwide. The ELRO also uses electronic circuitry
25   to provide for enhanced performance, and can protect motors
from burn out under conditions of low supply voltage by auto
tripping under these conditions. However, ELRO devices have
to be manually reclosed on restoration of the supply, which
can be an inconvenience. The ELAR uses electronic circuitry
30   to provide for enhanced performance, and can protect motors
from burn out under conditions of low supply voltage by auto
tripping under these conditions, and also auto recloses on
restoration of supply.

3

From the above, the ELAR would appear to be the ideal RCD.
Unfortunately, the need to enable such RCDs to open
automatically on loss of supply and reclose automatically on
restoration of the supply has to date required very
5   sophisticated and bulky electronic circuitry and components to
provide this functionality. These problems are seriously
compounded by the additional requirement for these RCDs to
remain open after opening in response to a residual current,
even if the mains supply is temporarily removed and restored
10   after such opening.

Figure 1 is an example of a simple ELAR RCD. In Figure 1, an
AC mains supply is fed to a load L via two contacts SW1 of a
relay RLA, the live and neutral mains conductors L, N passing
15   through a current transformer CT en route to the load. The
output of the CT is fed to an RCD integrated circuit (IC) 10.
The function of the CT and IC 10 is to detect a current
imbalance in the AC supply to the load indicative of a
residual current, and when such an imbalance is detected to
20   provide a high output voltage on the line 12 sufficient to
turn on a silicon controlled rectifier SCR1. The construction
and operation of such components are well known. The IC 10
may be a type WA050, supplied by Western Automation Research &
Development and described in US Patent 7068047. The RCD is
25   powered from the mains via a bridge rectifier X1. The IC 10 is
supplied with current via resistor R2.

A solenoid SOL, a capacitor C1 and the relay RLA are connected
in parallel to the bridge rectifier X1 via a resistor R1.
30   The SCR1, which is normally held in a non-conducting state by
a low voltage on the line 12 from the IC 10, is connected in
series with the solenoid SOL. The relay contacts SW1 are
normally open. An example of a suitable relay RLA is shown in
Figure 2.

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RLA comprises a bobbin 14 with a coil (not shown) wound on it.
A ferromagnetic pole piece 16 extends through the bobbin, the
top of the pole piece being positioned below a ferromagnetic
element 18 fixed within a moving contact carrier 20. The
5   contact carrier 20 and the moving contacts 22 are biased
towards an open position away from fixed contacts 24 by a
spring 26, so that a substantial air gap exists between the
pole piece 16 and the ferromagnetic element 18. The coil has
a relatively large number of turns in its winding so as to
10   maximise the ampere turns providing electromagnetic energy.

Prior to the application of power to the RCD, the relay RLA is
de-energised and its contacts 22, 24 are open, so the mains
supply is disconnected from the load L (the moving and fixed
15   contacts 22, 24 constitute the contacts SW1 of Figure 1).
When power is applied to the RCD the current through R1 will
initially flow primarily to C1 to charge it up. As C1
acquires charge, more of the R1 current will be diverted into
the RLA coil to establish an electromagnetic field which will
20   be concentrated in the pole piece 16 and thereby provide an
attracting force on the ferromagnetic element 18. At a
certain threshold of ampere-turns known as the closing ampere
turns the bias of the spring 26 will be overcome by the
magnetic attraction between the pole piece 16 and the
25   ferromagnetic element 18 and the contact carrier 20 will move
automatically towards the pole piece 16 with the result that
the contacts SW1 will close and thereby provide power to the
load. Thereafter, C1 will sustain the RLA coil with current
during the low voltage troughs of the rectified mains supply.
30   A Zener diode ZD1 clamps the voltage on capacitor C1 to a safe
level for the capacitor and the relay coil.

In the event of a sufficient reduction in the level of the
mains supply voltage, the current through the RLA coil will be
35   insufficient to keep the contact carrier 20 in the closed

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position, and the contact carrier and the contacts SW1 will automatically revert to the open position. If the mains voltage then increases to a sufficiently high level so as to reach or exceed the closing ampere turns current level, the
5   relay RLA will be re-energised and its contacts SW1 will reclose automatically as before.

The RLA coil will have a relatively large number of turns to enable it to achieve the required number of ampere turns to
10   cause automatic closing of the contacts SW1. This results in the RLA coil having a relatively high impedance, typically a few thousand ohms. In contrast the solenoid SOL will have a relatively low impedance, typically less than 200 ohms, because it will only be energised momentarily as will be
15   described later.

In the event of a residual current of sufficient magnitude, the output of the CT will cause the IC 10 to turn on SCR1 via output line 12, which in turn will cause the solenoid SOL to
20   be energised and open associated solenoid contacts SW2. This in turn will result in removal of supply to C1 and also cause C1 to discharge through the relatively low impedance of the solenoid SOL. The resultant discharge of C1 will cause the relay RLA to de-energise and its contacts to open. It is
25   generally a requirement of RCD product standards that the resetting means must be a trip free type which ensures that the solenoid and load contacts cannot be held closed if the RCD trips in response to a residual current. The solenoid mechanism is therefore designed such that when its contact
30   opens it remains open until manually reset. This adds to the complexity of the design of the resetting means. The design of Figure 1 has a number of drawbacks, as follows.

- The current required to close the relay RLA will be quite
35   large, typically about 15 - 20mA. This results in

6

considerable power dissipation in R1 and RLA, which have to
be suitably rated to handle this power.

- The level of AC supply voltage at which RLA automatically
5   closes and opens is highly dependent on the value and
     tolerance of C1 and the efficiency of RLA, resulting in
     variances in these values from one RCD to the next.

- The solenoid SOL has to be suitably rated to handle the
10   relatively high operating voltage and current required to
     ensure reliable opening of the solenoid contacts SW2.

- The solenoid contacts are fitted in the high voltage part of
     the circuit, giving rise to problems of voltage rating and
15   dielectric strength, etc.

- SCR1 has to be suitably rated to withstand the relatively
     high operating voltage and current to which it is exposed.

20   - The circuit requires a full wave bridge rectifier to ensure
     adequate supply current under all conditions.

It is an object of the present invention to provide an RCD
which mitigates one or more of the above disadvantages.
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SUMMARY OF THE INVENTION

According to the present invention there is provided a
residual current device comprising: a circuit for detecting a
30   current imbalance in an AC supply to a load indicative of a
residual current and providing a corresponding output, a relay
having contacts in the AC supply to the load, means for
providing a current flow through the relay sufficient to
maintain the relay contacts closed at least when the supply is
35   at a certain minimum voltage, and at least one further contact

7

in series with the relay, the further contact being opened in
response to an output from the current imbalance detecting
circuit to interrupt the current flow through the relay and
thereby disconnect the load.

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The invention also provides a residual current device
comprising: a circuit for detecting a current imbalance in an
AC supply to a load indicative of a residual current and
providing a corresponding output, a relay having contacts in
10   the AC supply to the load, the relay contacts automatically
closing when a current greater than a predetermined closing
current is passed through the relay and being maintained
closed by passing a holding current, less than the closing
current, through the relay, the relay contacts automatically
15   opening if the current through the relay falls below the
holding current, a charge storage device connected to the AC
supply in parallel with the relay such that, upon application
of power from the AC supply, current flows to the charge
storage device to charge the latter up, and an electronic
20   switch in series with the relay, the switch being turned on
when the voltage on the charge storage device exceeds a
predetermined threshold thereby to allow discharge of the
charge storage device through the relay to provide a current
exceeding the closing current, the AC supply thereafter
25   providing a holding current for the relay at least when the
supply is at a certain minimum voltage, wherein the residual
current device includes at least one further contact in series
with the relay, the further contact being opened in response
to an output from the current imbalance detecting circuit to
30   interrupt the current flow through the relay and thereby
disconnect the load.

Preferably the residual current device comprises a permanent
magnet relay which is energised in response to an output from
35   the current imbalance detecting circuit to open contacts in

8

series with the firstmentioned relay to cut off the current
flow through the latter.

In a preferred embodiment the permanent magnet relay is
5   connected to the supply in parallel with the firstmentioned
relay and has a normally-off further electronic switch in
series therewith which is switched on by the output from the
current imbalance detecting circuit to energise the permanent
magnet relay.
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BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described, by way of
example, with reference to the accompanying drawings, in
15   which:

Figure 1, previously described, is a circuit diagram of a
typical ELAR type RCD.

20   Figure 2, previously described, are schematic end and side
views of the relay RLA used in the circuit of Figure 1.

Figure 3 is a circuit diagram of an ELAR type RCD according to
a first embodiment of the invention.
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Figure 4 is a schematic diagram of a permanent magnet relay
used in the circuit of Figure 3.

Figure 5 is a circuit diagram of an ELAR type RCD according to
30   a second embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The embodiment shown in Figure 3 mitigates the drawbacks of
35   the arrangement of Figure 1, and provides additional benefits.

9

In Figure 3 the RCD is powered via a diode D1 rather than a
bridge rectifier. The solenoid SOL has been replaced by a
permanent magnet relay PMR. The PMR contacts SW3 and a second
5   silicon controlled rectifier SCR2 are connected in series with
the relay RLA. A Zener diode ZD2 is connected between C1 and
the gate of SCR2. The remainder of the circuit is
substantially the same as that shown in Figure 1. A schematic
diagram of the PMR is shown in Figure 4.
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The PMR comprises a bobbin 30 and a coil 32 wound on the
bobbin. A ferromagnetic plunger 34 passes through the bore of
the bobbin. One end of the plunger 34 is fitted with a reset
button 36 which is biased downwardly (as seen in Figure 4) by
15   a reset spring 42. The other (upper) end of the plunger 34
faces a permanent magnet 44 to which is fixed a moving contact
38, the moving contact 38 being biased into an open position
away from a fixed contact 40 by a biasing means such as a
spring, not shown. A more detailed description of a PMR of
20   this type is given in US Patent 6975191. The moving and fixed
contacts 38, 40 constitute the contacts SW3 of Figure 3.

When the reset button 36 is pushed upwardly against the bias
of the spring 42, the top of the plunger 34 is presented to
25   the magnet 44 and the two become magnetically entrained. When
the reset button 36 is released, the magnet 44 and moving
contact 38 are drawn downwards by the spring 42 until the
moving contact 38 engages the fixed contact 40. The PMR is
now in the latched state. When a current of sufficient
30   magnitude and polarity is passed through the coil 32, the
magnetic holding force of the permanent magnet 44 will be
reduced due to the flux produced by an opposing
electromagnetic field with the result that the magnet 44 will
be released from the plunger 34 and the magnet 44 and its

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moving contact 38 will revert to the open position. The PMR
contacts SW3 can only be reclosed by manual means.

Referring back to Figure 3, when mains power is initially
5   applied to the RCD, the capacitor C1 will charge up via R1 as
before. However, at this stage, no current will flow through
the RLA coil because SCR2 will be in its non conducting state.
When the voltage on C1 reaches a certain level, the breakover
voltage of ZD2 will be exceeded and current will flow into the
10   gate of SCR2, at which point it will turn on. At that
instant, a large current (greater than the closing current)
will flow from C1 through the RLA coil resulting in an
electromagnetic field of sufficient strength as to cause
automatic closing of RLA contacts SW1 and thereby provide
15   power to the load L. Provided the supply voltage remains at
or above a certain minimum value, the resistor R1 and the
remaining charge on C1 will maintain a current flow through
the RLA coil less than the closing current but greater than
the holding current so as to keep RLA contacts SW1 closed.
20   However, if the supply voltage is sufficiently reduced, the
current flow through the RLA coil will be reduced to a level
at which it can no longer hold the RLA in the closed state, at
which point the RLA contacts SW1 will open. When the supply
voltage is sufficiently restored, the RLA contacts SW1 will
25   automatically reclose.

ZD2 provides a triggering means to facilitate automatic and
controlled energisation of RLA and resultant closing of SW1
contacts. This triggering means may be achieved by other
30   suitable devices, for example a diac.

In the event of a residual current of sufficient magnitude,
the output of the CT will cause the IC 10 to turn on SCR1 via
output line 12, which in turn will cause C1 to discharge via
35   the PMR coil 32, causing the PMR contacts SW3 to open as

previously described. The interruption in current flow
through the relay coil will cause the relay RLA to be de-
energised and its contacts SW1 to open. It should be noted
that in addition to determining the closing voltage for the
5   relay RLA, ZD2 also limits the voltage on C1 to a safe level.

The arrangement of Figure 3 provides considerable benefits and
features over and above the arrangement of Figure 1.

10   It is well known that the current required to close a relay of
the type shown in Figure 2 (the closing current) is
substantially greater than the current required to maintain
the relay in the closed position (the holding current). This
is because in the open state, a substantial air gap will exist
15   between the relay pole piece and the ferromagnetic element
coupled to the moving contacts, and this air gap will result
in a high level of magnetic reluctance or resistance. The
current flow through the relay coil in the open state has to
generate sufficient electromagnetic force to overcome this
20   reluctance and draw the ferromagnetic element to the closed
position. Once the relay is in the closed state, the air gap
will be substantially reduced with the result that magnetic
reluctance will also be reduced. Because of this, it is
possible to substantially reduce the current flow through the
25   relay coil before the relay will revert to the open state. The
difference between the closing current and the holding current
can be greater than 80%.

The arrangement of Figure 3 takes advantage of this effect.
30   In Figure 3, when power is applied to the circuit, current
flows through R1 to charge up C1. However, because SCR2 is in
the off state, no current will flow initially through the RLA
coil. When the voltage on C1 exceeds the breakover voltage of
ZD2, SCR2 will turn on with the result that there will be an
35   immediate surge of current from C1 through the RLA coil. The

12

component values are chosen to ensure that under this
condition, the RLA contacts SW1 close automatically and
thereby provide power to the load L. The standing current
flow through R1 is just sufficient to maintain RLA in the
5 closed state and to provide C1 with a charge so that C1 can
keep RLA closed during low levels of the AC supply voltage.
Thus, the current flow in the circuit of Figure 3 will be
substantially less that that of the arrangement of Figure 1,
thereby resulting in a substantially reduced level of power
10 dissipation. R1 size and rating can thereby be optimised
solely for the purpose of providing RLA with its holding
current.

The voltage level at which RLA closes is largely determined by
15 ZD2, which in turn ensures that the contacts can close at a
consistent level of AC supply voltage. By drawing only the
holding current from the mains supply, a diode can be used
instead of a bridge rectifier. However, a bridge rectifier may
be used to facilitate the use of an alternative relay and
20 associated electronic components.

The PMR has a stored energy device in the form of the
permanent magnet 44 with the result that the PMR contacts 38,
40 can be latched by a very simple arrangement obviating the
25 need for complex mechanical coupling, etc. The reset spring 42
provides the effective contact pressure, and the strength of
the reset spring can be brought to a level just below the
holding force of the permanent magnet. As a result, the
energy required to open the PMR contacts will be very low and
30 just sufficient to cause the permanent magnet to release its
contact. Furthermore, the PMR contacts are located in a low
voltage part of the circuit, mitigating problems of contact
rating, dielectric strength, etc. In addition to minimising
stress and improving the reliability of the contact releasing

13

means, additional benefits accrue from the PMR in terms of its
design, size and cost.

Key features of new design of Figure 3 are:

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- The closing current for the relay RLA is not directly
  derived from the mains supply, but rather from a charge
  stored in C1.

10   - Zener diode ZD2 acts as a voltage clamp on C1, but also acts
  as the trigger to cause auto closing of RLA.

- Because the PMR has a permanent magnet, it has stored energy
  which keeps its contact closed, but furthermore it is only
15   necessary to weaken the PM holding force by a small amount
  to cause automatic opening of the PMR contact and auto
  opening of RLA.

- Because the PMR contact is in the RLA coil current path,
20   opening of the PMR contact completely removes any current
  flow through RLA coil, causing faster de-energizing of RLA
  and faster opening of the load contacts than can occur in
  Figure 1.

25   In an alternative embodiment, Figure 5, with a sufficiently
  efficient PMR it is possible to dispense with the SCR1 and
  drive the PMR directly from the IC 10 via output 12. In this
  case, the PMR would not be directly dependent on any current
  flow from C1 or via R1. Capacitor C2 acquires a charge via
30   R2, and provides the current flow through the PMR coil when
  the IC 10 output goes high.

The invention is not limited to the embodiments described
herein which may be modified or varied without departing from
35   the scope of the invention.

The claims defining the present invention are as follows:

1.   A residual current device comprising:

a circuit (10) for detecting a current imbalance in an AC supply (L,N) to a load (L)
indicative of a residual current and providing a corresponding output,

a relay (RLA) having contacts (SW1) in the AC supply to the load, the relay contacts
automatically closing when a current greater than a predetermined closing current is passed
through the relay being maintained closed by passing a holding current, less than the
closing current, through the relay, the relay contacts automatically opening if the current
through the relay falls below the holding current, and

at least one further contact (SW3) in series with the relay, the further contact being opened
in response to an output from the current imbalance detecting circuit (10) to interrupt the
current flow through the relay and thereby disconnect the load characterized by

a charge storage device (C1) connected to the AC supply in parallel with the relay such
that, upon application of power from the AC supply, current flows to the charge storage
device to charge the latter up, and

an electronic switch (SCR2) in series with the relay, the switch being turned on when the
voltage on the charge storage device exceeds a predetermined threshold thereby to allow
discharge of the charge storage device through the relay to provide a current exceeding the
closing current, the AC supply thereafter providing a holding current for the relay at least
when the supply is at a certain minimum voltage.

2.   A residual current device as claimed in claim 1, comprising a permanent magnet
relay (PMR) which is energised in response to an output from the current imbalance
detecting circuit to open the further contact.

3.   A residual current device as claimed in claim 2, wherein the permanent magnet
relay is connected to the supply in parallel with the firstmentioned relay and has a further
electronic switch (SCR1) in series therewith which is switched on by the output (12) from
the current imbalance detecting circuit to energise the permanent magnet relay.

4.   A residual current device as claimed in claim 3, wherein the permanent magnet relay is energised directly by the output (12) from the current imbalance detecting circuit.

5.   A residual current device as claimed in any preceding claim, wherein the firstmentioned electronic switch (SCR2) is turned on when 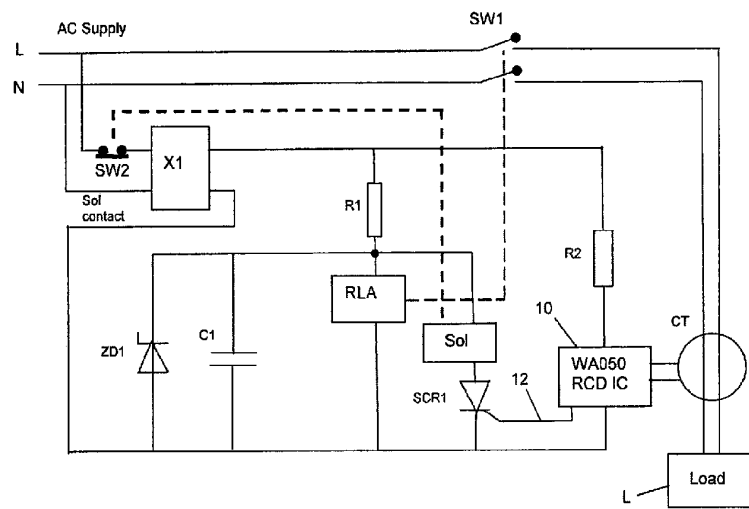the voltage on the charge storage device (C1) exceeds the breakover voltage of a triggering means connected between the charge storage device and the switch.

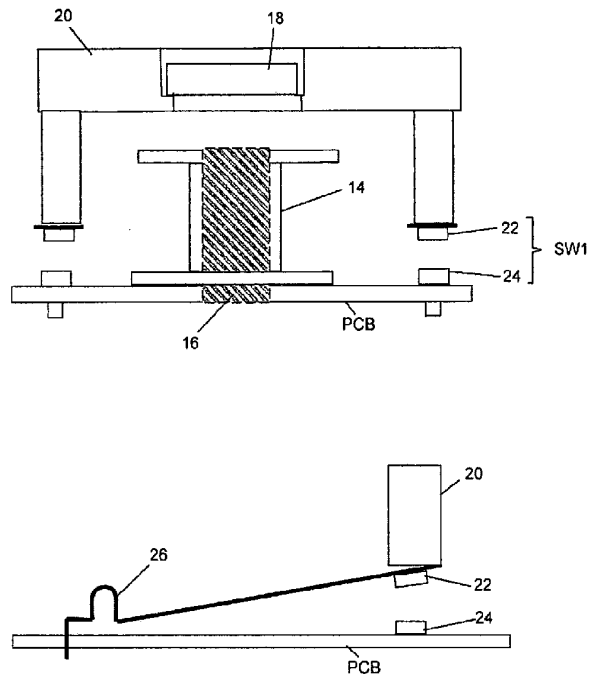6.   A residual current device as claimed in any preceding claim, wherein the firstmentioned electronic switch is an SCR.
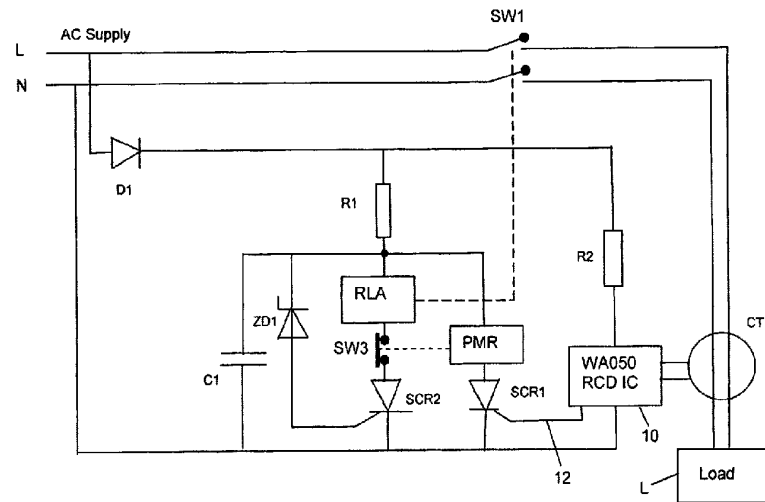
FIG. 1

(Prior Art)
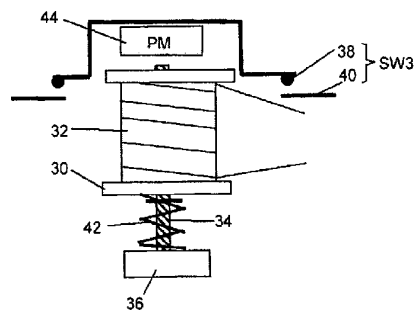
FIG. 2

(Prior Art)

FIG. 3

FIG. 4

FIG. 5