

May 28, 1968

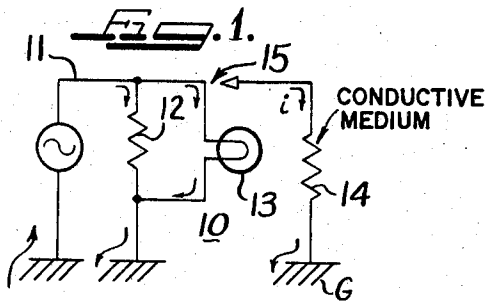
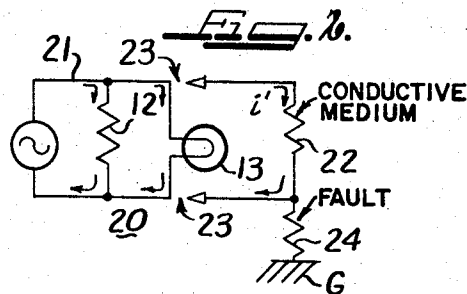
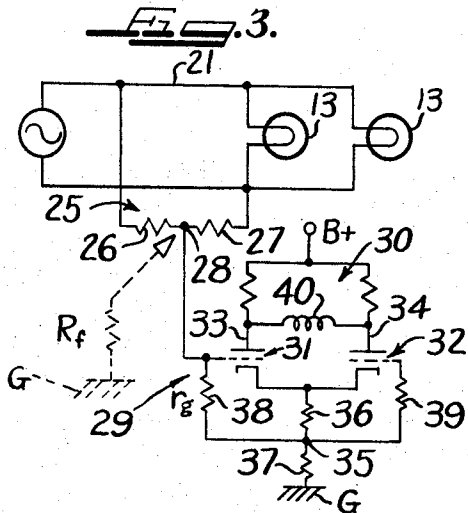
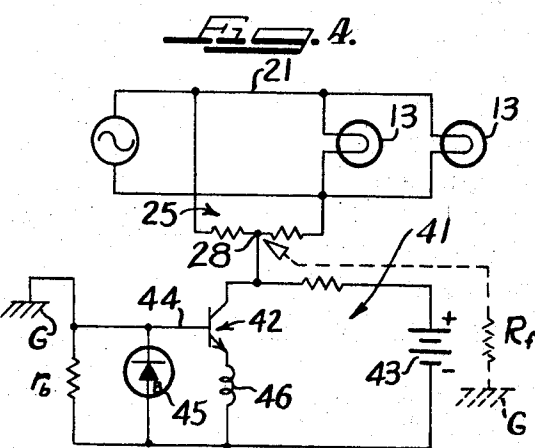
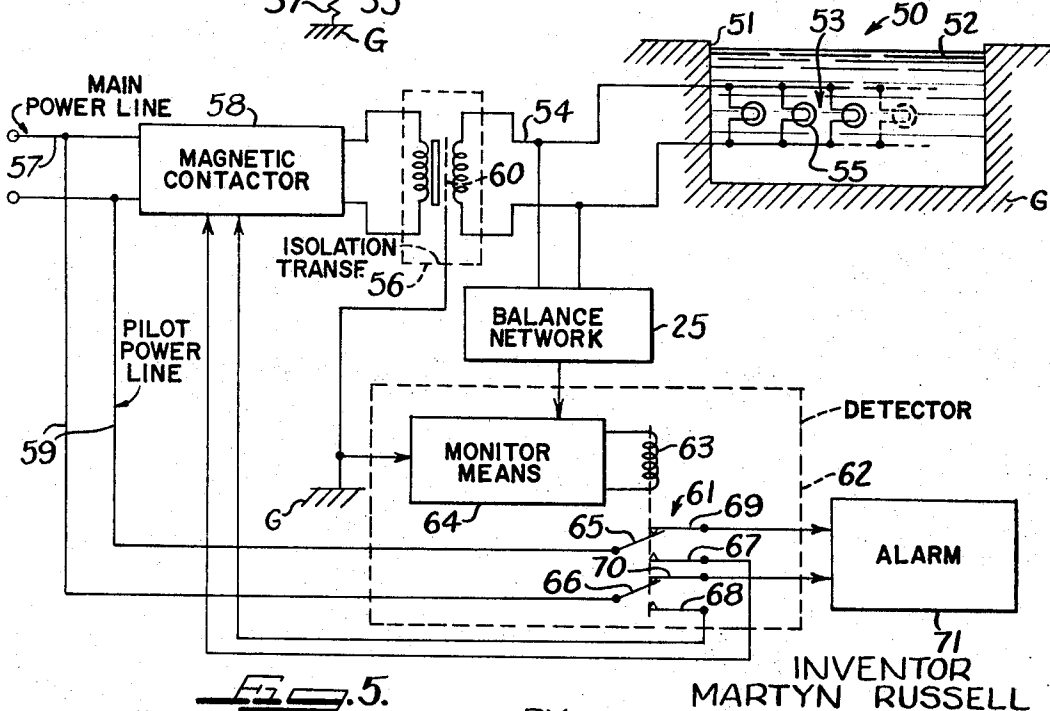
M. RUSSELL

3,386,002

GROUND FAULT DETECTOR

Filed Aug. 2, 1965

3 Sheets-Sheet 1



INVENTOR
MARTYN RUSSELL
BY *Singer Stern & Culberg*
Attys.

May 28, 1968

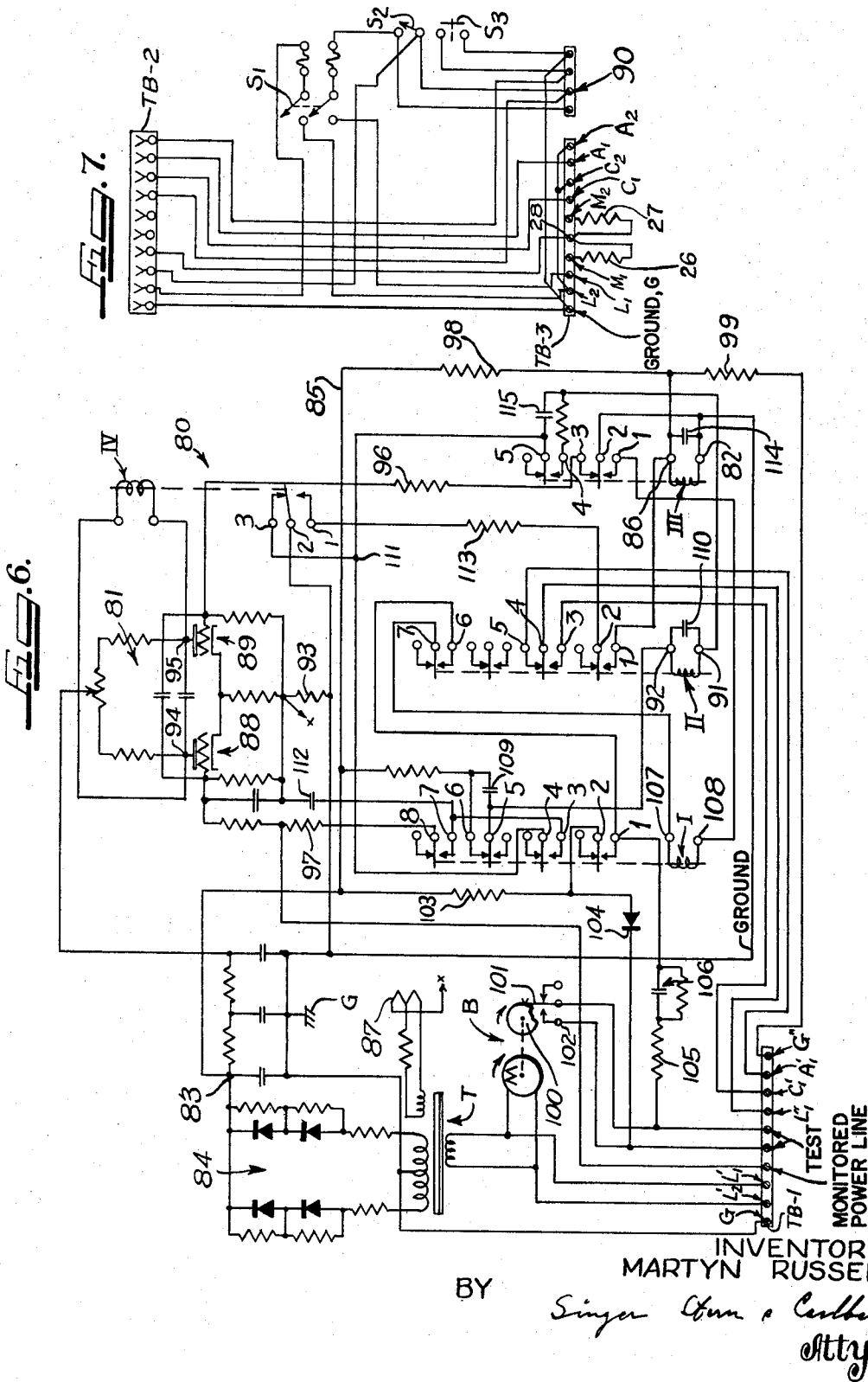
M. RUSSELL

3,386,002

GROUND FAULT DETECTOR

Filed Aug. 2, 1965

3 Sheets-Sheet 2



May 28, 1968

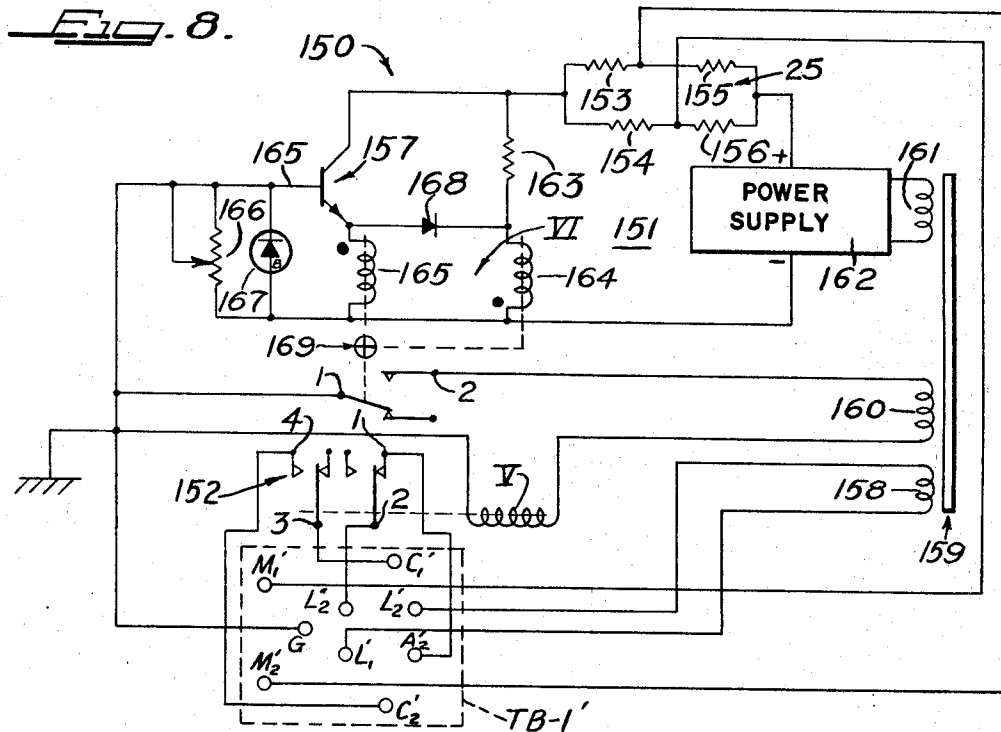
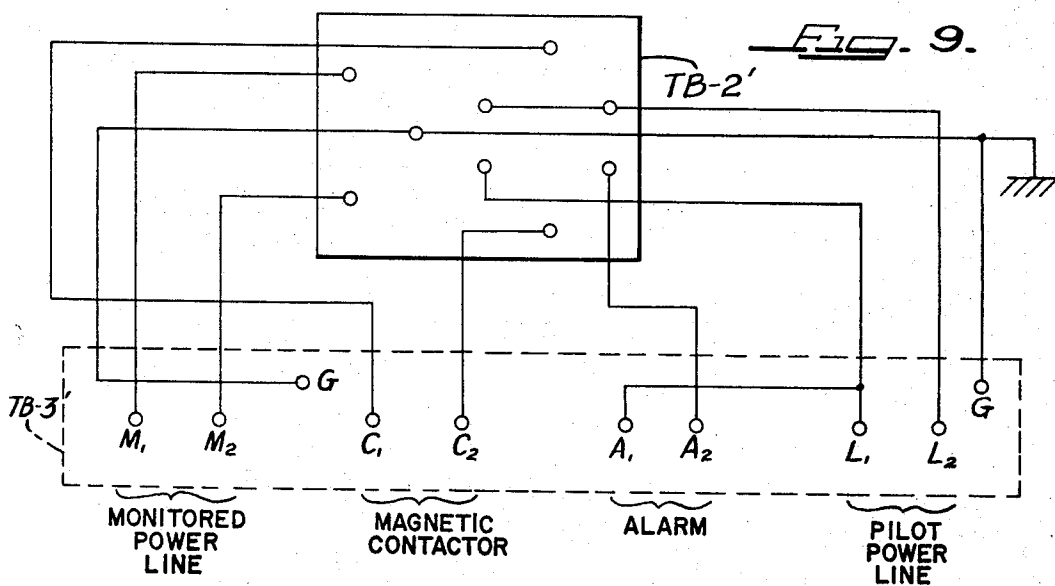
M. RUSSELL

3,386,002

GROUND FAULT DETECTOR

Filed Aug. 2, 1965

3 Sheets-Sheet 3



BY

INVENTOR
MARTYN RUSSELL

Singer Stern & Carlsberg
Attys.

1

3,386,002

GROUND FAULT DETECTOR

Martyn Russell, Elgin, Ill., assignor to Water Conditioning Products Company, St. Charles, Ill., a corporation of Illinois

Filed Aug. 2, 1965, Ser. No. 476,456
12 Claims. (Cl. 317-10)

ABSTRACT OF THE DISCLOSURE

Means for protecting against dangerous electrical shocks due to current leaking from a power line through a conducting medium by detecting and responding to such leakage by disconnecting power from the power line rapidly enough to prevent injury to human life, said means in one embodiment being capable of testing the ability of component parts to respond to dangerous conditions such that the failure of these components to pass the test causes power to be disconnected from the power line.

The present invention relates to means for protecting against dangerous electrical shocks due to current leaking from a power line through a conducting medium.

In the illustrative embodiment of the invention, the conducting medium is water in a swimming pool, and the power line is associated with the underwater lighting system for the pool. It is possible for the underwater power system to have a defect not visually apparent to an observer such that a dangerous amount of current leaks into the water. In such case, a person entering the water unaware of this situation is likely to become immobilized on contact with the water due to the paralyzing effect the leakage current has on human muscles, and is subject to serious injury and possible death if power is not disconnected from the lighting system in a very short time. It is possible, of course, to provide a sensitive circuit breaker arrangement in the lighting system power supply such that the occurrence of dangerous values of leakage currents would automatically disconnect power to the lights, and this expedient may suffice to protect would-be bathers before they enter the pool. Not so fortunate, however, is a person already in the water at the instant a defect in the lighting system occurs, because serious injury will generally result before the circuit breaker can respond and disconnect power to the lighting system. So far as is known, no circuit breaker has a sensitivity and response time capable of reliably protecting a bather against lethal leakage currents that flow upon the occurrence of a defect in an underwater power system associated with a swimming pool.

It is therefore the primary object of the present invention, to provide means by which the initiation of the flow of leakage current from a power line through a conducting medium in an amount likely to be dangerous to human safety is detected and responded to by disconnecting power from the power line rapidly enough to prevent injury to human life. It is a further object to provide a device that operates in the manner described, and is capable of testing the ability of component parts to respond to dangerous conditions such that the failure of these components to pass the test causes power to be disconnected from the power line.

The invention is based on a recognition that a grounded conducting medium establishes a reference potential (e.g., ground) to which the potential of a power line can be referred if the latter is isolated from ground. More specifically, the presence of leakage current from an isolated power line through a grounded conducting medium

2

means that a current path exists between the isolated power line and ground. Associatable with this current path is an impedance with a value related to the amount of leakage current. The invention, therefore, provides for monitoring this impedance with a circuit capable of rapidly disconnecting power from the isolated power line when the impedance decreases below a preselected level. The impedance between the isolated power line and ground, when of a value less than a preselected value, is sometimes referred to hereinafter as a "fault," so that the occurrence of a fault means that the impedance has decreased below a preselected value and a dangerous amount of current leakage exists. The term "rapidly," as applied to the speed with which power is disconnected from the isolated power line, means fast enough to prevent injury to human life.

The monitoring aspect of the invention involves, generally, providing a power supply or reference voltage source that is connected between ground and the isolated power line, such that the impedance between the latter and ground furnishes a current path that establishes a bias on an active element. When such impedance reaches the preselected value that constitutes a fault to be protected against, the bias on the active element reaches a level at which conduction of the active element changes rapidly. This change in conduction is sensed, amplified, and used to rapidly disconnect power from the isolated power line. In one form of the invention, the active element is one side of a balanced differential amplifier. The bias control of this side of the amplifier is connected to the isolated power line, so that when a fault occurs, the amplifier becomes sufficiently unbalanced to produce a control signal that can be used to rapidly disconnect power from the isolated power line. In another form of the invention, the active element is a transistor to which bias is furnished when a breakdown diode conducts. Here, the existence of a fault completes a circuit between a power supply and the breakdown diode such that the latter conducts furnishing bias to the transistor whose conduction is caused to change rapidly producing the desired control signal.

The more important features of this invention have thus been outlined rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contribution to the art may be better appreciated. There are, of course, additional features of the invention that will be described hereinafter and which will also form the subject of the claims appended hereto. Those skilled in the art will appreciate that the conception upon which this disclosure is based may readily be utilized as a basis for designing other structures for carrying out the several purposes of this invention. It is important, therefore, that the claims to be granted herein shall be of sufficient breadth to prevent the appropriation of this invention by those skilled in the art.

In the drawings:

FIG. 1 is a schematic wiring diagram of a conventional grounded power supply;

FIG. 2 is a schematic wiring diagram of a floating or isolated power supply;

FIG. 3 is a schematic wiring diagram showing one embodiment of a device for monitoring the impedance to ground of a floating power line;

FIG. 4 is a schematic wiring diagram showing another embodiment of a device for monitoring the impedance to ground of a floating power line;

FIG. 5 is a block diagram showing an isolated underwater lighting system monitored by a device for detecting and indicating when a fault occurs;

FIG. 6 is a detailed schematic diagram of a detector similar to that shown in FIG. 3;

FIG. 7 is a diagram showing the wiring configuration of a plug that can be mated with the connector shown in FIG. 6;

FIG. 8 is a detailed schematic diagram of a detector similar to that shown in FIG. 4; and

FIG. 9 is a diagram showing the wiring configuration of a z plug that can be mated with the connector shown in FIG. 8.

In order to provide a background for understanding and appreciating details of this invention, a brief reference is made to two highly idealized models for the purpose of illustrating the origin of the parameter that is monitored to detect the existence of dangerous leakage currents in a conducting medium; and two devices used in the invention to monitor such parameter are discussed briefly. Referring now to FIG. 1, reference numeral 10 designates a model representative of a conventional grounded A.C. power line 11 supplying power to a load associated with a conducting medium grounded at G. Specifically, the load is composed of elements 12 and 13; and resistor 14 represents the impedance seen by leakage current due to defect 15 in the power line. Note that the leakage current i flows through the conductive medium (represented by resistor 14) to ground G. It is this leakage current that has a lethal effect upon a human in contact with the conducting medium.

In FIG. 2, reference numeral 20 designates a model representative of an isolated or floating A.C. power line 21 supplying power to a load associated with a conducting medium grounded at G. Again, the load is designated at 12 and 13, and resistor 22 represents the impedance seen by leakage current due to defect 23 in power line 21. Note that the leakage current i' flows through the conductive medium as before. However, because the medium is conductive and grounded at G, the medium provides a current path between the isolated power line and ground. The impedance of this path is represented by fault resistor 24. In other words, in the absence of defect 23, the impedance to ground is infinite; but once a defect occurs, the conducting medium establishes some finite impedance to ground. It is the monitoring of this impedance that constitutes the end toward which the method and means of the invention are directed, since the existence of an impedance below a preselected value (e.g., the existence of a fault) is indicative of a defect in the power supply that results in a dangerous current leakage into the conducting medium. Note that monitoring the magnitude of impedance 14 will not provide any indication that a person's body accidentally bridges power line 21 (like load element 12) unless the person is also a part of the same ground as the pool water. However, the probability that a fault will occur is far greater than the probability that a person will accidentally come into direct contact with the power line; and the purpose of the invention is to detect faults as they occur and remove power from the power line rapidly enough to prevent injury.

Before describing now the two embodiments of circuits by which the impedance between the power line and the system ground is monitored, consideration must be given to the A.C. characteristics of the monitored power line. Particularly where a bridge circuit is used to monitor the impedance, it is desirable to reduce the residual A.C. voltage that appears at the point at which connection to the power line is made. To this end, a resistive balancing network may be used. As shown in FIGS. 3 and 4, such network is composed of a pair of resistors connected across the isolated power line, with the result that the induced voltage at the junction between the resistors is substantially independent of the A.C. input to the power line. The junction floats at some potential dependent on the capacitance of the isolated line to ground, etc., and the effect of a fault, when one occurs, can be visualized as a grounding of the junction through a "fault resistor" designated R_f for convenience.

Referring now to FIG. 3, the A.C. power line to be

monitored is designated at 21 and supplies power to load 13, 13, and to balancing network 25 composed of resistors 26 and 27 whose junction is designated at 28. Visualizing the occurrence of a fault as the connection of a resistor R_f between the junction 28 and ground, R_f constitutes an impedance of less than the preselected value whose existence is to be detected by detector bridge circuit 29. The latter may comprise a differential amplifier 30 comprising a pair of similar vacuum tubes 31, 32 connected in the configuration shown. In the absence of a fault (R_f is infinite), both tubes conduct equally and the voltage at plate 33 of tube 31 is the same as the voltage at plate 34 of tube 32. The voltage at the junction 33 between the cathode resistors 36 and 37 due to conduction of the tubes is the reference voltage referred to previously and is coupled, via grid resistors 38, 39, to the respective control grids of the two tubes. In such condition, the differential amplifier is balanced since the input to each tube is identical. However, when a fault occurs, which can be visualized as connecting R_f to junction 28, a fraction of the reference voltage (e.g., r_g/R_f+r_g) is suddenly connected to the grid of tube 31. This reduction in the input to this tube as compared to the voltage at the input to tube 32 causes the differential amplifier to have an output. In other words, the plate voltage of tube 31 increases by an amount proportional to the decrease in voltage at the grid of the tube, and the voltage at junction 35 in the common cathode circuit, and the voltage at the plate of tube 32 decreases. As a consequence, the voltage at the plate of tube 31 is higher than the voltage at the plate of tube 32 and current flows through the output circuit designated by relay coil 40. The resultant change in state of the switching network (not shown) associated with relay 40 may be used to cause power to be removed from isolated power line 21. As will be appreciated by those skilled in the art, the selection of component resistor values in the cathode and grid circuits of the differential amplifier plus the value of current required for activation of the switching network associated with relay coil 40, will determine the maximum value of R_f that will be sensed. Proper selection of component values will permit differential amplifier 29 to monitor the impedance between the isolated power line and ground G, and detect when such impedance decreases below a preselected level that constitutes a fault.

The above described approach to monitoring the impedance between the isolated power line and ground utilizes the broad idea of using the fault as part of a voltage divider network (note that the value of r_g is preferably of the same order of magnitude as the maximum value of impedance between the isolated power line and ground that is to constitute a fault to provide a substantial change in voltage in comparison to the reference voltage at junction 35). In FIG. 4, however, the fault is shown used in a somewhat different manner. Detector circuit 41 is essentially a single transistor 42 which can conduct only when the impedance between junction 28 of network 25 and ground G has less than a preselected value (specified as R_f in the drawing). Transistor 42 is connected as an emitter follower in FIG. 4, with power supply 43 providing the proper reverse bias across the collector-base junction of the transistor. In the absence of a fault, base 44 is open circuited since breakdown diode 45 connected across the input to the transistor cannot conduct. Note that base 44 is grounded so that the impedance between junction 28 and ground provides a current path between base 44 of the transistor and the power supply 43. When a fault occurs, a fraction of the power supply voltage is connected across breakdown diode 45 (essentially r_b/R_f+r_b). The value of r_b is selected such that any value of the impedance to ground less than the preselected value will cause a voltage to be impressed across diode 45 that exceeds the breakdown voltage. Thus, when a fault occurs, diode 45 conducts furnishing base current to transistor 42, which amplifies this current, and fur-

ishes emitter current to load 46 in the form of a relay coil or the like. In this embodiment, the load current is independent of the value of fault impedance achieving reliable operation over a wide range of impedances to ground. Since this circuit is meant to be illustrative of how load current is supplied to a relay coil or the like, which itself causes power to be disconnected from the isolated power line, no showing is made of the various expedients known to those skilled in the art for protecting the transistor against transient over-voltage between collector and emitter when the fault is removed, or providing temperature compensation, etc.

FIG. 5 is a block diagram showing how monitor means, like that shown in schematic form in FIGS. 3 and 4, can be incorporated into a detector associated with the underwater lighting system for a swimming pool. The latter is indicated schematically at 50, as an excavation 51 that defines the system ground G. Water 52 contained in excavation 51 defines a conducting medium. Associated with pool 50 is an underwater lighting system 53 comprising power line 54 and a plurality of underwater lights 55. Power line 54 is isolated from ground by the use of an isolation transformer 56 to whose secondary the power line is connected. Additional isolation is provided by grounding shield 60 between the primary and secondary of power transformer 56. The power line 54 is connected to a power source in the form of magnetic contactor 58, which, in the case illustrated, connects the main power line 57 to the primary of transformer 56 only when relay coils (not shown) in contactor 58 are energized by a pilot power line 59. When this occurs, the power source is said to be enabled. When it is disabled, power is disconnected from line 54.

In the absence of a fault, the first switching network 61 contained in detector 62 is in a first state established by the condition of relay coil 63 associated with monitor means 64 to which is connected the system ground G, and the output of balancing network 25. That is to say, in the absence of a fault, network 61 has a state wherein contact arms 65 and 66 are engaged in the contacts 67 and 68 respectively whereby the power source is enabled due to the connection of the pilot power supply to the relay coils (not shown) of magnetic contactor 58. When a fault occurs, monitor means 64 reacts by causing a change in the flow of current through coil 63, such change establishing network 61 in a second state, wherein contact arms 65 and 66 are engaged with contacts 69 and 70, respectively. This state is shown in FIG. 5, and causes pilot power line 59 to be applied directly to alarm 71. The change in state of network 61 also disables the power source by removing the pilot power line from magnetic contactor 58 with the result that power is disconnected from isolated power line 54.

I. FIRST EMBODIMENT

The first embodiment of the detector, shown in FIG. 6 and designated by reference numeral 80, has two basic modes of operation: a monitoring mode in which the isolated power line is monitored to detect the occurrence of a fault, and a self-analysis or auto-testing mode in which the various components of the detector are tested for their operability. A timing mechanism periodically shifts the operation of the detector from the monitoring mode to the testing mode; and if one of the components tested is not in a condition to respond to a fault, should one occur in the monitoring mode, the power source is disabled and power is removed from the isolated power line.

The portion of the detector concerned with detecting faults includes monitor means like that illustrated in FIG. 3 wherein a balanced bridge or differential amplifier is provided such that a reference D.C. voltage above ground is applied to the line being monitored through an impedance of substantially the same order of magnitude as the maximum value of the fault to which the cir-

cuit must respond. Any leakage associated with the monitored line will result in a change in the voltage on the grid of one tube of the differential amplifier resulting in an unbalance in the plate voltage of one tube relative to the plate of the other tube. When the leakage reaches a degree that establishes the existence of a fault, the unbalanced plate voltages will be such as to energize a polarized latching relay which will disconnect the isolated power line from the main power supply, and at the same time cause an alarm to be actuated. The main components of the detector involved in the monitoring mode of operation are: differential amplifier 81, and relays II, III, and IV with their associated contact networks.

The testing mode involves all of these components and in addition, relay I and its associated contact network, and timer B. The latter causes an impedance of the same value as the fault to be detected to be applied periodically between the monitored line and ground. Each time this impedance is applied, the contact networks sequence through a number of states determined by the operation of each of the main components previously identified. In the event of failure of any of these components, a state is established that causes power to be disconnected from the isolated power line and prevents the monitor means from being reset so that operation cannot be restored until the failed component is replaced. The balanced nature of the monitor means results in a device of considerable sensitivity with respect to occurrence of faults, and considerable insensitivity to ambient factors such as line voltage fluctuations, etc. In addition, the two modes of operation provide a detector which is virtually fail-safe.

Amplifier 81, relays I, II, III and IV and timer B, all of which make up detector 80, are contained in a unitary waterproof housing (not shown) with all leads brought out to terminal board TB-1. Plug TB-2 (FIG. 7) mates with board TB-1, and terminal board TB-3 connects to the external components indicated. The symbols associated with the terminals on TB-3, identify the leads connected thereto:

Terminal on TB-3:	Identity of lead
Ground -----	System ground, G.
L ₁ -----	One side of main power line.
L ₂ -----	Other side of main power line.
M ₁ -----	One side of isolated power line.
M ₂ -----	Other side of isolated power line.
C ₁ -----	One side of line that enables or disables power source.
C ₂ -----	Other side of line that enables or disables power source.
A ₁ -----	One side of power line to alarm.
A ₂ -----	Other side of power line to alarm.

Note that for convenience in achieving balancing of the A.C. signal produced by the isolated power line, a balance network made up of resistors 26 and 27 is externally located between M₁ and M₂ on TB-3 so that junction 28 defines a connection to the monitored line. Also, with regard to TB-3, note that terminals A₂ and C₂ are connected to terminal L₂. Thus, the alarm will be actuated only when terminal A₁ is connected by the switching networks of detector 80 to terminal L₁; and the magnetic contactor will be able to furnish power to the primary of the isolation transformer (power source enabled) only when terminal C₁ is connected to L₁. Since A₁ and C₁ on TB-3 are connected via leads shown in FIG. 7 to terminals A₁' and C₁' respectively at TB-1 (when TB-2 is mated with TB-1), and since L₁ on TB-3 is connected via switches S₁ and S₂ to terminals L₁' and L₁'' on TB-1, the switching networks of detector 80 must connect terminal L₁'' only to terminal A₁' when the alarm should be actuated, and only to terminal C₁' when power should be applied to the primary of the isolation transformer. These two events are mutually exclusive and hence L₁'' need be connected to only one at a time of

either C_1' and A_1' . With this in mind, the operation of the device shown in FIG. 6 will be related to the interconnection of terminals on TB-1 for the most part, it being assumed that the leads associated with the terminals on TB-3 are all connected as indicated, and S_1 and S_2 are open.

To facilitate understanding the operation of the device shown in FIG. 6, the description thereof is divided into four categories: condition prior to start-up, start-up, monitor mode, and testing mode of operation.

(A) Prior to start-up (S_1 and S_2 open)

The primary of transformer T is open, and relays I, II, III, and IV are deenergized. The made contacts in the networks associated with the relays are shown in the following chart:

Relay:	Made contacts
I -----	5-6
II -----	4-5
III -----	2-3
IV -----	2-3

Note that with the networks in this state, ground G is connected to terminal 82 of the coil of relay III, and output terminal 83 of full wave rectifier 84 is connected via lead 85 to terminal 86 of the coil of relay III.

(B) Start-up (S_1 and S_2 are closed)

Since L_1 and L_2 at TB-3 are connected via S_1 and S_2 to L_1' and L_2' at TB-1, power is applied to the primary of transformer T causing rectifier 84 to produce a D.C. voltage at 83 thus energizing relay III and causing contacts 1-2 and 4-5 to be made, and contacts 2-3 to be broken. Simultaneously, the filtered output of rectifier 84 is applied as B+ to differential amplifier 81 as the filaments 87 of the triodes 88 and 89 begin to heat. Also, simultaneously with the closing of S_1 and S_2 , the alarm is actuated because L_1 is connected through the lower leg (see FIG. 7) of S_1 , through S_2 to common terminal 90, to terminal L_1'' ; and L_1'' is connected to A_1' by way of made contacts 4-5 of relay II that is still deenergized.

With contacts 4-5 now made at energized relay III, ground G is applied to terminal 91 of relay II through these made contacts and through made contacts 2-3 of relay IV. Relay II is now energized because terminal 92 is connected to output terminal 83 of rectifier 84 via made contacts 5-6 of relay I. The energization of relay II breaks contacts 4-5 thereof, and makes contacts 1-2, 3-4 and 6-7. Since contacts 3-4 are made, L_1'' on TB-1 is disconnected from A_1' and is now connected to C_1' . Thus, the alarm is deactuated and power is applied to the holding relay (not shown) of magnetic contactor 58 causing power to be applied to the primary of the isolation transformer associated with the underwater lighting system. The device is now ready to enter its monitor mode.

(C) Monitor mode

(1) No fault (only relays II and III energized).

Amplifier 81 is now fully operational with tubes 88 and 89 conducting equally causing current to flow in grounded cathode resistor 93 establishing a reference voltage above ground at the point x. This reference voltage is applied to the grids of each tube through identical grid resistors. Since the amplifier is balanced, the voltage at plate terminal 94 of tube 88 equals the voltage at plate terminal 95 of tube 89 and no current flows through the coil of relay IV. Note that because relay III is energized and contacts 2-3 are broken, resistor 96 connected to the grid of tube 89 floats; and that because relay I is not energized, and contacts 7-8 are broken, resistor 97 connected to the grid of tube 88 also floats.

(2) Fault occurs.

The occurrence of a fault, as described previously, amounts to grounding terminal 28 on TB-3 through an impedance of less than some preselected value. Since ter-

terminal 28 is connected via a terminal on TB-1 to the grid of tube 88, the voltage at this grid drops to a fraction of its former value. As previously explained, the voltage at plate 94 increases and the voltage at plate 95 decreases; and current flows through the coil of relay IV from plate 94 to plate 95. This energization of relay IV breaks contacts 2-3 thereof, and makes contacts 1-2.

Recalling that terminal 91 of the coil of relay II was grounded through made contacts 2-3 of relay IV, the occurrence of a fault, and, in consequence, the energization of relay IV, opens the ground return circuit of relay II with the result that it is deenergized. The consequent deenergization of relay II breaks contacts 3-4 thereof, interrupting power to the relays of magnetic contactor 58 and causing power to be disconnected from the primary of the isolation transformer associated with the underwater lighting system. Furthermore, contacts 4-5 of relay II are now made connecting power to the alarm, thus causing its actuation. At this point, only relays III and IV are energized.

Relay IV is a polarized latching relay, which means that its contact network has two stable states which can change only by causing operating current to flow through the relay coil in a direction opposite to the direction in which it flowed to establish the state. Hence, if S_1 and S_2 are now opened, the state of the contacts 1-2 (e.g., made) established by the occurrence of a fault does not change and reclosing S_1 and S_2 will not permit power to be applied to the primary of the isolation transformer since relay II cannot be energized with the contact network associated with relay IV in the state established by occurrence of a fault (contacts 2-3 broken).

(3) Resetting after fault has occurred.

To reset the monitor means after a fault has occurred and been corrected, it is necessary to cause operating current to flow through the coil of relay IV from plate 95 to plate 94. This is accomplished with reset switch S_3 . Assume that the fault has been corrected and S_1 and S_2 are then closed. When amplifier 81 reaches operating condition the voltages at terminals 94 and 95 are the same, relay IV is deenergized with contacts 2-3 broken, relay III is energized with contacts 1-2 and 4-5 made, relay II is deenergized (because terminal 91 is disconnected from ground by broken contacts 2-3 of relay IV), and relay I is deenergized. If key S_3 (see FIG. 7) is now closed, ground is connected to terminal G' of TB-1. Resistors 98 and 99 (see lead 85), now act as a voltage divider connected between terminal 83, which is the output of rectifier 84, and ground. As a result, the voltage at terminal 86 decreases to a level which will not permit operating current to flow through the coil of relay III and the latter is essentially deenergized. This causes contacts 2-3 of relay III to be made, in effect grounding the grid of tube 89 through impedance 96. The latter causes the voltage at the grid of this tube to drop, and the voltage at the plate (terminal 95) to increase. Also, the voltage at plate 94 decreases, and as can be seen, grounded impedance 96 appears as a "fault" applied to tube 89. Consequently, operating current flows through relay IV and reestablishes the original state of the contact network associated therewith, namely contacts 2-3 made. Upon reopening S_3 , ground is removed from terminal G', relay III is energized, and contacts 2-3 of the latter relay are broken removing ground from resistor 96. Amplifier 81 then returns to its balanced condition and is ready to operate in its monitor mode.

If the fault is not corrected and S_3 is closed, the grids of both tubes 88 and 89 will be grounded through impedances R_f and 96, which, at worst, would be substantially equal and prevent operating current from flowing through the coil of relay IV. At best, impedance 96 would be greater than the fault, and current would flow through the coil of relay IV from terminal 94 to 95 in a direction that tends to establish the same state of the contact network, namely contacts 1-2 made and 2-3

broken. Thus, energization of relay II cannot occur and the alarm remains actuated as long as S_1 and S_2 are closed.

(D) Testing Mode of Operation

Assume that the device of FIG. 6 is operating in the monitoring mode and a fault has not occurred. In such case, only relays II and III are energized, and contacts 2-3 of relay IV are made. The components to be described now are concerned with causing the operation of the device to shift from its monitoring mode to its testing mode, and back to its monitoring mode if the testing is successful. What is required, basically, is to cycle each important component, whose operation is required to detect a fault, through a test procedure without interrupting the power supply to the primary of the isolation transformer and actuating the alarm, if the test procedure is a success. This requires relay II to remain energized during the testing mode of operation which should take place periodically during the use of the detector device.

The periodic shift in the mode of operation from monitoring to testing, from testing back to monitoring, as well as the duration of the testing mode, are controlled by timing switch B. The latter comprises synchronous motor M which shunts the primary of transformer T and operates during the time the transformer is active. Attached to the rotatable with the shaft of motor M, is disc 100 containing a notch into which spring arm 101 is seated during a limited portion of each revolution of the disc. When seated in the notch, arm 101 establishes contact with contactor arm 102. The initial contact triggers the switch from monitoring to testing mode, the latter lasting for a portion of the time required for the motor M to rotate disc 100 to a position where arm 101 rides out of the notch and breaks contact with arm 102.

When arm 101 initially contacts arm 102, relay I is energized by a pulse of current as follows: Voltage at terminal 83 of rectifier 84 is applied through resistor 103, diode 104, made contacts 101-102, resistor 105, pulse trigger network 106 and made contacts 6-7 of relay II to terminal 107 of the coil of relay I; and ground is applied through made contacts 1-2 of relay III to terminal 108 of the coil of relay I. Upon this initial energization of relay I, contacts 1-2 thereof are made bypassing diode 104, resistor 105 and trigger network 106, and permitting relay I to be held in as long as ground is furnished to terminal 108 through made contacts 1-2 of relay III. Energization of relay I interrupts the primary power path to relay II, establishes an alternate ground path for relay II that shunts contacts 2-3 of relay IV, and causes a fault to be simulated. The primary power path to relay II is through contacts 5-6 of relay I which breaks when the latter is energized. However, relay II is not deenergized because capacitor 109 begins to charge through the coil of relay II and capacitor 110, shunting the coil, begins to discharge thereinto. This furnishes sufficient current to maintain relay II energized until the primary power path is restored upon deenergization of relay I (provided all components are operating properly). An alternate ground path to node 111 (which is at ground potential) is provided by cathode resistor 93, capacitor 112, and made contacts 3-4 of relay I. A fault is simulated because fault resistor 97, connected to the grid of tube 88, is grounded to node 111 through made contacts 7-8 and 3-4 of relay I. Note that contacts 2-3 of relay IV are still made at this time, connecting node 111 directly to ground. Just prior to energization of relay IV, the state of the detector is as follows: Relay I is energized, relay II remains energized due to its alternate power and ground paths, and relay III is energized.

When relay IV is energized, contacts 2-3 thereof are broken, and contacts 1-2 are made. The result is to deenergize relay III, deenergize relay I, and to lower the grid voltage on tube 89 causing relay IV to be energized in the opposite direction again making contacts 2-3 and reestab-

lishing the detector in the same state it had prior to the initial closing of contacts 101-102. Relay III is deenergized because resistor 113 is shunted across the coil of relay III by made contacts 1-2 of relay IV, and made contacts 1-2 of relay II. Capacitor 114, shunting the coil of relay III, discharges into resistor 113 causing the current in the coil of relay III to drop below its operating value, whereupon contacts 1-2 and 4-5 of relay III are broken and contacts 2-3 are made. The breaking of contacts 1-2 on relay III disconnects terminal 108 from ground, and relay I deenergizes. Simultaneously with the breaking of contacts 1-2 of relay III, contacts 2-3 are made, thus connecting resistor 96 between the grid of tube 89 and ground. This energizes relay IV in the opposite direction breaking contacts 1-2 thereof and making contacts 2-3. Also simultaneously with the breaking of contacts 1-2 of relay III, contacts 4-5 of relay III are broken connecting terminal 91 of relay II to ground through capacitor 115, and resistor 113 is removed from a shunting connection across the coil of relay III. Relay IV is still energized due to made contacts 2-3 of relay III.

The state of the device of FIG. 6 is now as follows: relay I is deenergized (contacts 1-2 of relay III having been broken), relay II is energized (primary power path is restored and the ground path includes capacitor 115 which charges), relay III is deenergized but about to be energized (shunt resistor 113 has been removed), and relay IV is energized but about to be deenergized, and contacts 2-3 thereof are made. Since shunt resistor 113 is removed from across the coil of relay III, the latter is energized making contacts 4-5 of this relay and reestablishing the original ground path for terminal 91 of the coil of relay II. Also, ground is removed from resistor 96 and relay IV is deenergized. The detector has now returned to the state associated with monitoring the isolated power line, having passed through a cycle in which relay II was maintained in its energized state by providing temporary power and ground paths, while other components, namely tubes 88 and 89, relay IV and relay III were each sequenced through their operations. Note that the temporary paths for power and ground to relay II are time dependent since they employ the charging or discharging of capacitors in a D.C. circuit. Note also that the failure of any component being sequenced to perform properly will interrupt the sequence and fail to restore the primary power and ground paths to relay II. In such case, relay II would become deenergized, thus removing power from the magnetic contactor device, which disconnects power from the isolated power line, and applying power to the alarm. In this situation, the alarm indicates component failure.

The time constants associated with the various capacitors that provide temporary current paths are chosen such that the testing cycle referred to above occurs within the period that contacts 101-102 are made. In fact, provision can be made for covering a fixed number of testing cycles to occur independently of the duration that contacts 101-102 are made. This is the function served by diode 104, resistor 105 and trigger network 106. The capacitor of the network 106 is initially uncharged (due to the shunting resistance) when contacts 101-102 are initially made. The first current surge through network 106 that energizes relay I, and permits breaking contacts 1-2 to become effective in furnishing a primary power path to the coil of relay I, charges the capacitor of network 106; and diode 104 maintains the charge on the capacitor during the time contacts 101-102 are made.

At the completion of the first cycle described above, and when relay I is deenergized, contacts 101-102 are still made and a second current surge through diode 104 and trigger network 106 occurs again energizing relay I and initiating another test cycle like the one just described. However, the second current surge serves to further charge the capacitor of network 106 with the result that

less initial current passes from terminal 83 of rectifier 84, into the coil of relay I during the second current surge than during the first current surge that preceded the first test cycle. In the preferred embodiment, the time constant of network 106 and the operating current requirements of the coil of relay I are such as to limit the number of test cycles to three, all of which occur during the time that contacts 101-102 are made. After the three cycles are completed, the detector again operates in the monitor mode despite the fact that contacts 101-102 remain made. Eventually, motor M drives the disc until arm 101 is unseated from the notch in the disc and contacts 101-102 are broken. The capacitor of network 106 then discharges through its shunt resistor, and the device is made ready to shift out of the monitoring mode and into the testing mode the next time arm 101 is seated in the notch in disc 100. Note that three cycles of operation define the testing mode, but the number mentioned is only by way of example, and could be more or less than three.

II. SECOND EMBODIMENT

The detector means 150 shown in FIG. 8 includes monitor means 151, which utilizes a single active element instead of a pair of active elements as in the case with the monitor means of FIG. 6, and switching network 152, which is concerned with enabling and disabling the power source by which power is connected to or disconnected from the primary of the isolation transformer. Switching network 152 also differs slightly from the corresponding network shown in FIGS. 5 and 6. Here, the relay coils (not shown) of the magnetic contactor are assumed to be connected directly to the main power line through a switch (contacts 3-4) located in the detector. Otherwise, the basic operation of the detector with regard to enabling the power source in the absence of a fault (and simultaneously disabling an alarm), and disabling the power source when a fault occurs (and simultaneously actuating an alarm) is substantially the same.

Detector means 150 is contained in a unitary waterproof housing (not shown) with all leads brought out to terminal board TB-1'. Plug TB-2' (FIG. 9) mates with board TB-1', and terminal board TB-3' connects to the external components indicated by the terminal identification, the latter being specified in the chart contained in the portion of this description relating to FIG. 6. Note that in this embodiment, C₁ and C₂ constitute a part of a circuit whose completion causes the power source to be enabled, and whose breaking causes the power source to be disabled. Note also, that the A.C. balance network 25' is internal to the detector means and comprises resistors 153, 154, 155 and 156. That is to say, the induced voltage at the node between resistors 153 and 154 is substantially the same as the induced voltage at the node between resistors 155 and 156. As far as the monitor circuit 151 is concerned, balance network 25' is merely an impedance in the collector circuit of transistor 157 which is connected in an emitter-follower configuration.

(A) State prior to start-up

Prior to start-up, plug TB-2' is mated with board TB-1' and no power is yet applied to terminals L₁ and L₂ of TB-3'. All the other terminals of TB-3' have the proper leads connected thereto. The state of detector 150 is as follows: primary 158 of transformer 159 has no power applied; secondary winding 160 on transformer 159 is not energized; A.C. relay V is not energized with the result that its contacts 1-2 are made and contacts 3-4 are broken; secondary winding 161 on transformer 159 is not energized with the result that power supply 162 is dormant; split-coil relay VI is not operative, and its contacts 1-2 are broken. Note that terminal A₁ is connected to L₁ on TB-3', and that A₂ is connected to A₂', the latter being connected to L₂' through made contacts 1-2 of

relay V. Since L₂' is connected to L₂, terminals A₁ and A₂ are connected directly across the pilot power line when relay V is not energized. Note also that C₁ is connected to C₁', and C₂ to C₂'; but broken contacts 3-4 of relay V prevent connection of C₁' with C₂'. Hence, while relay V is deenergized, the power source is disabled and the alarm is actuated (when power is supplied to L₁ and L₂). As is now apparent, the energization of relay V breaks contacts 1-2 and makes contacts 3-4 with the result that the power source is enabled and the alarm is deactuated.

(B) Operation—No fault

When power is applied to L₁ and L₂, power is applied to primary 158 of transformer 159. Although power is now applied to the alarm, the detector responds so rapidly to the application of power to the primary in comparison to the response of the alarm, that the latter will, in general, not be actuated before the state of the detector 150 has changed. For this reason, it may be desirable to insert a time delay between terminals L₁', L₂' and the primary 158 so that upon start-up, the alarm will be actuated for the purpose of testing it.

In any event, the voltage induced in secondary 161 is furnished to power supply 162, which rectifies the A.C. voltage and produces a sufficiently steady D.C. voltage compatible with transistor operation. Power supply 162 is shunted by the parallel resistance of resistors 153-156, resistor 163 and coil 164 of the split-coil of relay VI. Operating current thus flows through coil 164 causing contacts 1-2 of relay VI to be made. Operating current does not yet flow in the other coil 165 of relay VI because, as will be explained later, transistor 157 is cut off. With contacts 1-2 of relay VI made, a complete circuit is formed between the coil of A.C. relay V and secondary 160. Consequently, relay V is energized breaking contacts 1-2 thereof, and making contacts 3-4. Thus, terminal C₁' is connected by made contacts 3-4 of relay V to terminal C₂', and the power source is enabled. Note also, that L₂' is disconnected from A₂' so that the alarm is not actuated.

Returning now to the state of transistor 157, it can be seen that the latter is shunted by the series combination of resistor 163 and coil-half 164, and that the collector-base junction is reverse biased. However, the base 165 is returned to the negative side of the power supply through a parallel combination of adjustable resistor 166 and breakdown diode 167. For the n-p-n transistor shown in the drawing, there is no base-emitter bias to initiate transistor action, and the only current flow through the emitter circuit and through coil-half 165 is the leakage current I_{co}. This current is on the order of microamperes under usual conditions, and even though the polarity of the windings defining coil-half 165 is opposite to the polarity of the windings defining coil-half 164, the transistor leakage current has little effect on the total magnetic field applied to the armature of relay VI that is connected to the movable contact arm electrically connected to terminal 1 of the contact network.

(C) Operation—Fault occurs

Note that base 165 of the transistor is grounded, as is the cathode of breakdown diode 167. Hence, the occurrence of a fault establishes a current path between the parallel impedance 153-156 and base 165 of the transistor. Visualizing this as an impedance R_b, a fraction of the power supply voltage is coupled across breakdown diode 167, reverse biasing the latter by an amount equal to at least its breakdown voltage. Diode 167 now operates as a battery with a potential equal to the breakdown voltage that forward biases the base-emitter junction and initiates transistor action. That is to say, base current flows, current amplification occurs, and operating current flows in coil-half 165. The effect of this current flow cancels the effect of operating current flow in coil-half 164, and

the situation is the same as if current did not flow in either coil-half. Hence, the state of contacts 1-2 of relay VI changes from made to broken, and relay V is deenergized. The state of its contact network reverts from 3-4 made and 1-2 broken, to 3-4 broken and 1-2 made. Thus, the power source is disabled and the alarm is actuated when a fault occurs.

Before mentioning the split-coils of relay VI again, it is pointed out that diode 168 interconnecting the coil-halves is provided for the purpose of limiting transient effects on transistor 157 due to rapid changes in the current flow through the respective coil-halves. In the absence of diode 168, temporary over-voltages would be imposed on the transistor that would damage the same. As shown by the polarity dots in the drawing, coils 164 and 165 are wound in opposite senses on a common core so that the net magnetic flux is the difference between the flux due to each coil. The fact that algebraic addition of the fluxes takes place is illustrated by the symbol designated by numeral 169. The net flux, of course, controls the movable contact arm connected to terminal 1 of relay VI so that the state of the contact network relative to current flow through coils 164, 165 can be summarized as follows:

Fault	Operating Current Flow		Relay VI		Relay V
			State of Contacts		
	Coil 164	Coil 165	1-2	1-2	3-4
(1)-----	No-----	No-----	Broken-----	Made-----	Broken.
No-----	Yes-----	No-----	Made-----	Broken-----	Made.
Yes-----	Yes-----	Yes-----	Broken-----	Made-----	Broken.

¹ Power supply 162 is not operative prior to turn-on.

Note that the state of the contact network associated with each of relays V and VI is the same in two situations: no current through either coil-half, or operating current through each. This provides an essentially fail-safe operation, since the power source connecting power to the isolated line is enabled, and the alarm is deactivated, only when operating current flows in coil 164 and less than operating current flows in coil 165.

Application of the invention

The basic principles of the present invention, namely isolating a power line from ground, monitoring the impedance between the isolated power line and ground, and providing a circuit capable of removing power from the isolated line rapidly enough to prevent a dangerous electric shock when the impedance decreases below a preselected value, can be utilized for purposes other than monitoring an underwater lighting system in a swimming pool. For example, the isolated power line could be the main power line in a house or factory in which case a magnetic contactor arrangement, or the like, would be somewhat permanently installed after the electric meter and would control the power input to the primary of an isolation transformer from whose secondary all of the power furnished to the house or factory would be drawn. Thus, each electrical outlet in the home or factory would be floating. Any defect, either in the wiring, or in the electrical device plugged into the outlet, that connects the outlet to ground would be sensed by the detector. In such case, the latter would be effective to immediately disconnect power from the primary of the isolation transformer. This approach would provide protection against any situation grounding the lighting system, an electric stove, toaster, immersion heaters, space heaters, etc. It would also protect against a grounding defect in hand appliances such as electric drills, hedge trimmers, lawn mowers, mixers, well and sump pumps, etc. Protection would be afforded also to grounding defects with potentially dangerous devices like battery chargers, whirlpool bath pumps, air conditioners, television sets, radios, electrical toys, garbage disposal units, automatic washers and dryers, Christmas tree lights, etc. In an industrial applica-

tion, the above-described use of the detector could be used effectively in connection with operating rooms, pressurized rooms, etc.

The device illustrated schematically in FIG. 5 could also be made portable, in which case the main power line would be a plug that mates with a suitable electrical receptacle; and the output of the secondary could be a receptacle into which an electrical appliance could be plugged. The transistorized version of the detector is small enough to make the whole device easily portable.

While a magnetic contactor has been shown as part of the power source by which power is connected to the isolated line, it is believed apparent that other devices, such as solid state switching means could be used. In such case, their response would be triggered by the control signal developed by the monitor means in response to the occurrence of a fault.

What is claimed is:

1. An electrical system comprising: an environment that defines the system ground; a monitored power line isolated from said ground; and fault detector means to monitor the impedance between said power line and the system ground for detecting and indicating when said impedance decreases below a preselected value and constitutes a fault; and said detector means being provided with self-testing means effective, while said detector means is monitoring said power line, to test whether component parts are in operable condition to detect occurrence of a fault, to remove power from said power line in the event one of said component parts is not in said operable condition, and to prevent the re-application of power to said power line after a fault occurs and until the fault is corrected.

2. An electrical system comprising: an environment that defines the system ground; a monitored power line isolated from said ground; and fault detector means to monitor the impedance between said power line and the system ground for detecting and indicating when said impedance decreases below a preselected value and constitutes a fault; a first switching network having a first state established by the occurrence of a fault; a power source effective to connect power to said monitored power line only when said power source is enabled; said detector means being constructed and arranged to disable said power source when said first switching network is in said first state whereby power is disconnected from said monitored power line when a fault occurs, a pilot power line; an alarm actuatable only when said pilot power line is connected thereto; and said detector means being further constructed and arranged to cause said pilot power line to be connected to said alarm when said first switching network is in said first state whereby said alarm is actuated when a fault occurs.

3. An electrical system comprising: an environment that defines the system ground; a monitored power line isolated from said ground; and fault detector means to monitor the impedance between said power line and the system ground for detecting and indicating when said impedance decreases below a preselected value and constitutes a fault; a first switching network having a first state established by the occurrence of a fault; a power source effective to connect power to said monitored power line only when said power source is enabled; said detector means being constructed and arranged to disable said power source when said first switching network is in said first state whereby power is disconnected from said monitored power line when a fault occurs; said first switching network having a second state established by the absence of a fault; said detector means being further constructed and arranged to enable said power source when said first switching network is in said second state whereby power is connected to said monitored power line in the absence of a fault; said detector means including at least one active element whose conduction is caused to change when a fault occurs; such change in conduction of said one active

15

element causing said first switching network to switch from its second state to its first state; said detector means including a power supply, the occurrence of a fault providing a current path from said power supply to said one active element that changes the bias on the latter and causes its conduction to change; and a breakdown diode establishing the bias on said one active element when said power supply is connected across said breakdown diode, the current path provided by the occurrence of a fault effecting the connection of said power supply across said breakdown diode.

4. An electrical system comprising: an environment that defines the system ground; a monitored power line isolated from said ground; and fault detector means to monitor the impedance between said power line and the system ground for detecting and indicating when said impedance decreases below a preselected value and constitutes a fault; a first switching network having a first state established by the occurrence of a fault; a power source effective to connect power to said monitored power line only when said power source is enabled; said detector means being constructed and arranged to disable said power source when said first switching network is in said first state whereby power is disconnected from said monitored power line when a fault occurs; said first switching network having a second state established by the absence of a fault; said detector means being further constructed and arranged to enable said power source when said first switching network is in said second state whereby power is connected to said monitored power line in the absence of a fault; said detector means including at least one active element whose conduction is caused to change when a fault occurs; such change in conduction of said one active element causing said first switching network to switch from its second state to its first state; a power supply connected to said active element; a pair of coils, one of which is connected to said power supply whereby operating current flows through said one coil, and the other of which is connected in the output circuit of said active element; said detector means being constructed and arranged so that said active element does not conduct until a fault occurs whereby operating current is caused to flow through said other coil upon such occurrence; and means associating said pair of coils with said first switching network such that the flow of operating current through said one coil accompanied by the flow of less than operating current through said other coil establishes said second state of said first switching network, and the flow of operating current through both coils establishes said first state.

5. The system of claim 4 wherein said coils are wound on a common core such that the net effect of current flow through both coils is substantially the same as when no current flows through either coil.

6. The system of claim 4 wherein said pair of coils is a part of a second switching network having a first state established by the flow of current through both coils and a second state established by the flow of operating current through said one coil accompanied by the flow of less than operating current through said other coil, and means are provided for causing said first switching network to have a state corresponding to the state of said second switching network.

7. An electrical system comprising: an environment that defines the system ground; a monitored power line isolated from said ground; and fault detector means to monitor the impedance between said power line and the system ground for detecting and indicating when said impedance decreases below a preselected value and constitutes a fault; said fault detector means comprising at least one active element whose conduction is dependent on a bias voltage applied thereto; a breakdown diode connected to said active element and effective to furnish, when a breakdown voltage is applied to said diode, a bias voltage to said active element that causes the conduction

16

of the latter to change; a power supply connected to said active element and to said monitored power line; and means connecting said diode to said ground such that the occurrence of a fault between said monitored power line and said ground provides a path by which said power supply applies a breakdown voltage to said diode whereby conduction of said active element changes upon the occurrence of a fault.

8. The system of claim 7 wherein said breakdown diode is shunted with a resistance element whose magnitude determines the preselected value of the impedance between said power line and said ground that defines the occurrence of a fault.

9. The system of claim 7 wherein said one active element is a transistor that does not conduct until a fault occurs.

10. An electrical system comprising: an environment that defines the system ground; a monitored power line isolated from said ground; and fault detector means to monitor the impedance between said power line and the system ground for detecting and indicating when said impedance decreases below a preselected value and constitutes a fault; a first switching network having a first state established by the occurrence of a fault; a power source effective to connect power to said monitored power line only when said power source is enabled; a pilot power line; an alarm actuable only when said pilot power line is connected thereto; and said detector means being further constructed and arranged to cause said pilot power line to be connected to said alarm when said first switching network is in said first state whereby said alarm is actuated when a fault occurs.

11. An electrical system comprising: an environment that defines the system ground; a monitored power line isolated from said ground; and fault detector means to monitor the impedance between said power line and the system ground for detecting and indicating when said impedance decreases below a preselected value and constitutes a fault; a first switching network having a first state established by the occurrence of a fault; a power source effective to connect power to said monitored power line only when said power source is enabled; said first switching network having a second state established by the absence of a fault; said detector means including at least one active element whose conduction is caused to change when a fault occurs; said detector means including a power supply, the occurrence of a fault providing a current path from said power supply to said one active element that changes the bias on the latter and causes its conduction to change; and a breakdown diode establishing the bias on said one active element when said power supply is connected across said breakdown diode, the current path provided by the occurrence of a fault effecting the connection of said power supply across said breakdown diode.

12. An electrical system comprising: an environment that defines the system ground; a monitored power line isolated from said ground; and fault detector means to monitor the impedance between said power line and the system ground for detecting and indicating when said impedance decreases below a preselected value and constitutes a fault; a first switching network having a first state established by the occurrence of a fault; a power source effective to connect power to said monitored power line only when said power source is enabled; said first switching network having a second state established by the absence of a fault; said detector means including at least one active element whose conduction is caused to change when a fault occurs, such change in conduction of said one active element causing said first switching network to switch from its second state to its first state; a power supply connected to said active element; a pair of coils, one of which is connected to said power supply whereby operating current flows through said one coil, and the

other of which is connected in the output circuit of said active element; said detector means being constructed and arranged so that said active element does not conduct until a fault occurs whereby operating current is caused to flow through said other coil upon such occurrence; and means associating said pair of coils with said first switching network such that the flow of operating current through said one coil accompanied by the flow of less than operating current through said other coil establishes said second state of said first switching network, 10

and the flow of operating current through both coils establishes said first state.

References Cited

UNITED STATES PATENTS

3,253,188 5/1966 Nissel ----- 317—10

MILTON O. HIRSHFIELD, *Primary Examiner*.

J. D. TRAMMELL, *Assistant Examiner*.