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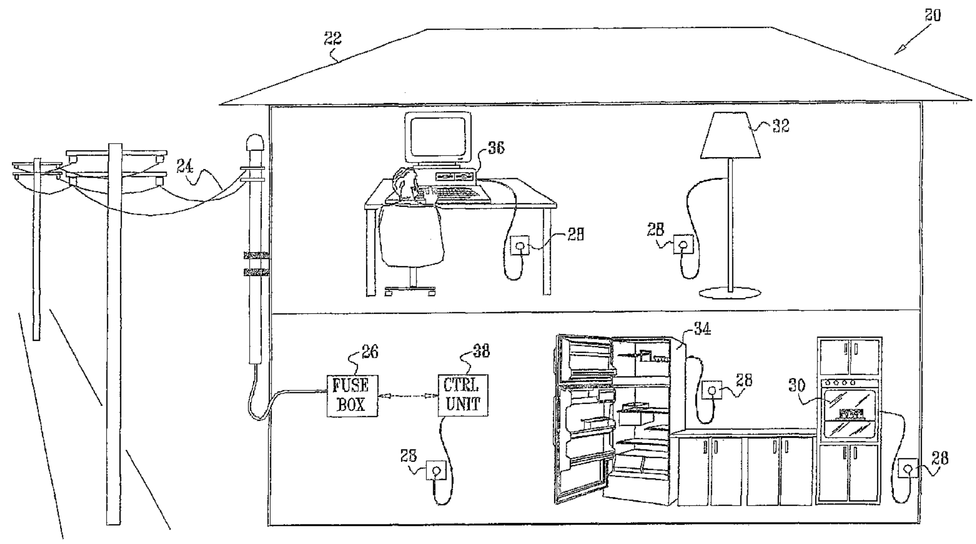

(57) Abstract: System for monitoring an electrical system of a facility includes one or more local sensing devices, each of which is adapted to be connected to the electrical system of the facility in proximity to a respective load that receives power from the electrical system so as to make local measurements of a voltage across the load continuity measurements of electrical-power presence at one or more points in the electrical system of said facility. A processing unit is adapted to receive and compare the local measurements to reference measurements of the voltage supplied to the facility, in order to detect a fault in the electrical system.

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SYSTEM, APPARATUS AND METHOD FOR DETECTION OF ELECTRICAL FAULTS

BACKGROUND OF THE INVENTION

The present invention relates to the field of electric safety. More particularly, the invention relates to a system and method providing an early and automatic detection of electrical faults in wiring systems and connected appliances.

Nearly all facilities that use electricity are equipped with a system containing fuses and / or circuit breakers, thus applied to cut off electrical supply when an electrical fault occurs. These devices operate by sensing excess current or other current-related phenomena, which typically occurs due to a short circuit, connection /disconnection of loads, short-term wiring disconnections or other electrical faults. (For example, arc-fault circuit interrupters detect current changes that are typical of arc-faults, while ground-fault circuit interrupters compare incoming current to outgoing current.) Despite the fact that modern buildings and other facilities are equipped with modern electric-fire prevention devices, improper power supply to loads in a facility are common and remain a severe hazard. According to the U.S. Fire Administration, for example, home electrical problems have recently accounted for 90,000 fires each year, causing over 700 deaths and $700 million in property losses. Such fires result from faulty wiring, from faults in appliances connected to the wiring, faults in the connections between the wiring itself or from any other part of the electrical system that conducts electrical current to the electrical loads. The electrical disturbance can be intermittent or fixed, thus leading to a time-to-time disturbance in the required operation of the electrical loads or preventing them from working at all.

Many electrical fires are a direct result of an electrical fault, in which the temperature of an electrical conductor significantly increases. The power dissipated by a piece of an electrical conductor is proportional to the voltage across the piece of conductor and the current through the conductor.

It is known in the art to measure the voltage and current consumed by a particular electrical appliance; such measurements indicate the total power supplied by a user and enable to bill him accordingly. Numerous attempts for an early detection of electrical faults have been made in recent years. Examples of existing electrical-fire prevention devices are the fuse, the circuit breaker and the Arc-Fault Circuit Interrupter. The fuse is a piece of wire designed to melt when the current through it exceeds a pre-defined level and as a result de-energize the circuit connected to it. The circuit breaker also checks whether the current passing through it for not exceeding a pre-defined level. The Arc-Fault Circuit Interrupter checks the current passing through it in order to find current changes which are indicative of an arc-fault, in addition to checking whether the current passing through it for not exceeding a pre-defined level . However, these devices are designed to treat all the resistance of the circuit as one equivalent resistor, and therefore have no indication of the amount of energy dissipation over each of the conductors, resistors, capacitors, coils, and other parts comprising the circuit. In addition, aging of the wiring within a facility creates "parasitic" resistors, which consume additional power. Existing devices lack the ability to measure power ratio between a desired load and a parasitic one. In some cases, the parasitic resistance acts as a current-limiter and prevents the current in the faulty circuit from being out of range of a pre-defined tripping level of the fuses or circuit-breakers that are in use in that circuit. These cases are typical to electrical circuits in which the intended load has a small resistance (e.g. a mechanically-stuck motor that exhibits very low DC resistance). Such cases can also be found in faulty wiring problems that create a short-circuit, whereas the series-connection with the parasitic resistance limits the current through the shortened circuit to be below the tripping level of the fuse or the circuit-breakers being used.

In other cases, the temperature increase over the parasitic resistance is itself a cause for a fire. These cases are typical to electrical circuits in which the intended load is a "pure resistance" load – like a baking oven. The increasing ratio of the parasitic resistance as part of the overall circuit resistance causes an increased percentage of the total circuit power to be dissipated by the parasitic resistance. This leads to a significant increase in the temperature of the parasitic loads of the electrical system and may ignite a fire.

In some devices, the checking process is performed by a bi-metal conductor that bends and cuts the electrical current when the current through it exceeds a predefined limit. In other devices – the checking process is performed by an electro-magnet that develops a magnetic power, whereas the magnetic power is proportional to the current passing through it. The existence of magnetic power affects the mechanical connection within the device and as a result the electrical current to the load is stopped. The protective device is implemented within the electrical circuit in such a manner that it is serially connected to appropriate load. As a result, current passing through the protection device causes dissipation of energy across the protection device itself. This leads to heating of that device and additional undesired phenomena such as corrosion, carbonization of conductors and mechanical deformation of the different parts comprising the protective device itself. Hence, the protection device's capability to detect an electrical-current fault is severely affected.

Furthermore, different checks are applied for detecting an electrical fault in a facility, whereas these checks can be due to regulations, a suspect of an electrical fault, due to indications of a fault whose location is not determined, for preventive-maintenance activities or similar circumstances. Among these tests are the infra-red photography of wiring, switch-panels and other appliances. Another test is the ultrasonic detection of wiring/appliances problems. However, these checks require special equipment, which does not operate constantly as part of the inspected facility. Therefore, these appliances can only detect a problem that occurs when such a specific test equipment is set to perform the tests.

Additional attempts include devices, which are provided for detecting an electrical fault by measuring current. Such devices include the AFCI (Arc-Fault Circuit Interrupter), which checks for indications of electrical-arcing in the wire, the ELCI (Equipment Leakage Circuit Interrupter), the GFCI (Ground-Fault Circuit Interrupter), which monitors the electricity flowing in a circuit and if the amount flowing into the circuit differs from the amount returning this interrupter shut off the current, the LCDI (Leakage Current Detection and Interruption), which is built as part of a power-plug, the ALCI (Appliance Leakage Circuit Interrupter), which is implemented as an integrated part within the appliance, and the IDCI (Immersion

Detection Circuit Interrupter), which detects immersion of an electrical appliance (like a hair-dryer) in water.

Prior art devices include U.S. Patent 6,445,188, whose disclosure is incorporated herein by reference, describes an intelligent, self-monitoring AC power plug, which contains current and voltage sensors. The plug includes a miniature printed circuit board, with a filtered power supply, microcontroller, and external interface. Based on the combined readings from the voltage sensor and the current sensor, an embedded program running on the microcontroller can determine the power being consumed by the loading device. The plug may be connected to a special interface connector in order for data to be exchanged with a computer. The interface also allows for networking of several plug devices to a central reader.

As another example, U.S. Patent 5,315,236 describes a power meter that plugs into an electric socket and has a socket for receiving the plug of an electric appliance. Alternatively, the power meter may be part of an electric wall switch or wall socket. U.S. Patent 5,869,960 describes a similar sort of device. Other references relating to voltage testing and power monitoring include U.S. Patents 4,672,555, 4,858,141, 4,884,022 and 5,196,982. The disclosures of all of these patents are incorporated herein by reference.

However, none of the existing methodologies propose an improved system for detecting an early electrical fault in an electrical system by monitoring voltage levels in parallel to loads within a facility.

It is thus an object of the invention to propose a system and method providing an early and automatic detection of electrical faults in a facility by monitoring local voltage levels (in parallel to the loads) and continuity measurements of electrical-power presence at one or more points in the electrical system of said facility.

It is yet another object of the present invention to further determine the type and specific location of the electrical fault which is most likely within the facility.

SUMMARY OF THE INVENTION

The present invention provides a system and method for monitoring local voltage levels and continuity measurements of electrical-power presence at one or more points in the electrical system of a facility, such as a home, business, vehicle, aircraft or ship. (In the context of the present patent application and in the claims, the electrical system is to be understood as comprising fixed wiring, such as wiring within the walls, ceiling and floors of the facility, fixed electrical-current conducting equipment and detachable wiring and circuits of electrical equipment that is powered by the system.) By measuring and tracking changes in the local voltage and continuity measurements regarding the presence of electrical-power, the system is able to detect changes and events that may be indicative of faults in the wiring, in the electrical current-conducting equipment or in electrical equipment that is powered by the wiring. In many cases, these voltage changes or discontinuities of electrical-power presence give a more reliable indication and earlier warning of such faults than is provided by systems known in the art.

In embodiments of the present invention, sensing devices are provided to sense voltage levels and measure the continuity of electrical-power presence by counting the time or number of alternating-current (AC) cycles passed since electrical-power was continually applied to the device. The sensing devices are deployed at different locations in the facility.

These devices are typically constructed as plug adapters, which are plugged in between the power plugs of different pieces of electrical equipment and the sockets that feed these power plugs. Alternatively or additionally, the local voltage level and / or continuity measurements devices may be contained within wall sockets or switches, or within the power plugs or in other parts of the powered equipment.

The local sensing devices typically communicate their local voltage readings and continuity measurements to a central control and monitoring station. Alternatively, one or more controllers may be collocated with respective sensing devices or otherwise distributed within the facility. Preferably, the local sensing devices and central station communicate by modulation of signals over the electrical wiring of the facility, so that no other communication network is required. Alternatively, other means of communication may be used, such as dedicated control lines, data-communication network or wireless communication links such as radio frequency (RF), infra-Red (IR) or acoustic links, as are known in the art.

The central station (or distributed processors) monitors the readings it receives, which are indicative of the voltage across the local loads to which the local sensing devices are connected. Typically, the voltage readings are compared to a non-loaded reference voltage value, which is measured by the central station or by another local sensing device near the point at which electrical mains power enters the facility. Alternatively, the reference voltage value may be provided from an external source, for example, by the utility company that supplies the electricity. In addition, the processing unit can analyze previous voltage levels sensed by the local sensing device, determine the expected voltage values and thus have a reference value computed with or without reference value from any other device.

The reference value may be just a voltage level – in case of a direct-current (DC) electrical-power, or a combination of amplitude and phase indications – in case of alternating-current (AC) electrical-power system. In an AC electric-power system the reference value may be time-dependent, since the voltage sensed by the sensing devices itself is time-dependent. By comparing the voltage readings to the reference value and/or the other values measured, the processing-units are able to detect the presence of faults, to distinguish actual voltage faults from fluctuations in the mains voltage and load variations that may occur in normal operation of certain appliances and, preferably, to identify the location of faults as they develop or occur in the electrical network. Alternatively or additionally, some fault conditions may be detected even without reference voltage information.

The processing units are further provided to store data and sensed values and perform calculations over time. These calculations include integration, averaging, standard deviation, Root-Mean-Square (RMS) calculations and/or any other statistical calculations and data-processing required to identify electrical fault.

In addition, the processing unit can analyze the time or AC-cycles passed since electrical-power was continually applied to the sensing devices. The processing unit compares this electrical-power continuity information with such information from other sensing devices, or from data stored in a non-volatile memory. In addition, the processing unit can include a local power source, such as a battery or capacitor for detecting external electrical-power discontinuities without being dependent on the external-power to perform this processing.

However, the implementation of an apparatus that displays the values measured and allows a person to analyze them is also applicable. Such an apparatus can be configured without any communication media at all and can therefore be very cheap and easy to implement and install.

There is therefore provided, in accordance with an embodiment of the present invention, a system for detecting faults in an electrical system of a facility having a main power supply, said system comprised of: at least one sensing device for measuring voltage levels and/or continuity measurements in proximity to a point of potential load, said potential load receiving power from said electrical system; and at least one processing unit for analyzing said voltage and continuity measurements to detect abnormal measurements on the basis of known range of values and historical measurements.

In a disclosed embodiment, the local sensing devices are adapted to be coupled to an electrical socket from which the respective load receives the power. Typically, at least one of the local sensing devices includes a plug adapter, including receptacles, which are configured to receive a power plug of the respective load, prongs, which are electrically connected to the receptacles and are configured for insertion into the electrical socket, and a voltage sensor, coupled to measure the voltage between the receptacles and the prongs as well as the time (or AC cycles) elapsed since electrical-power was continually applied to each of the sensing device.

In an aspect of the invention each of the local sensing devices includes a communication interface, for communicating with other parts of the system. Preferably, the communication interface is adapted to convey messages between a local sensing devices and any other processing or sensing device, whereas this communication is carried out by modulation of signals over power lines of the electrical system.

In an embodiment of the invention, each (or at least some) of the local sensing devices may include a circuit breaker, which is controllable to cut off the power to the respective load when the processor detects the fault. Alternatively, a relay that will generate a ground-fault may be used. This can be useful in facilities that have a ground-fault circuit-interrupter being part of them. An intentionally-generated such a ground-fault will cause the ground-fault circuit-interrupter to trip – and de-energize a larger part of the facility or even the whole facility. Such mechanism of electrical power disconnection in case of a fault-detection may be cheaper to implement and may provide better electrical-fire protection than disconnection of the faulty-load itself.

In some embodiments, the system includes a reference sensing device, which is adapted to make the reference measurements of the voltage supplied to the facility. Typically, the reference sensing device is connected to make the reference measurements in proximity to a point at which electrical mains power enters the facility.

The different processing units may be collocated with at least one of the local sensing devices, or may be included within a central control unit, which is adapted to receive the local measurements from the local sensing devices that are deployed at different locations in the facility.

In an aspect of the invention, the processor is adapted to compare the local measurements to the computed reference values in order to differentiate between electrical faults – internal to the facility or external to it. The processor is further adapted to locate the fault within the system. Additionally or alternatively, the processing units are adapted to learn a normal behavior pattern of the voltage level and continuity measurements in accordance with each of the local sensing devices, and to detect the fault in response to a deviation of the local measurements from the normal behavior pattern. Typically, the processing units are adapted to learn the normal behavior pattern during a learning phase of the system, and to detect the fault in the electrical system in response to a failure occurring during the continuous monitoring phase.

There is also provided, in accordance with an embodiment of the present invention, a method for monitoring an electrical system of a facility, the method includes connecting each of one or more local sensing devices to the electrical system of the facility in proximity to a respective load that receives power from the electrical system; making local voltage and continuity measurements across each of the loads using the local voltage sensing devices; computation of reference values; providing reference measurements of the voltage supplied to the facility; communicating at least one of the local measurements and the computed or measured reference values over a communication medium to one or more processing units; and comparing the local measurements to the reference values, using the processing units, in order to detect faults in the electrical system.

Making the reference measurements may include connecting a reference voltage sensing device in proximity to a point at which electrical mains power enters the facility, or alternatively, it may include sensing a reference voltage on mains external to the facility.

Making the reference measurements may also include obtaining electrical-power continuity information from any other such continuity devices in the facility or from a continuity device external to the facility.

In embodiments of the invention, communicating the at least one of the local measurements and the reference measurements includes conveying messages by modulation of signals over power lines of the electrical system, over a wireless medium, over dedicated lines, over data-communication network, over infra-red or over acoustic medium.

BRIEF DESCRIPTION OF THE DRAWINGS

These and further features and advantages of the invention will become more clearly understood in the light of the ensuing description of a preferred embodiment thereof, given by way of example only, with reference to the accompanying drawings, wherein-

Fig. 1 illustrates the implementation of the proposed system in accordance with a preferred embodiment of the present invention, depicting the electrical networking in a typical house.

Fig. 2 is an illustration of the proposed system in accordance with the present invention.

Figure 3 is an illustration of the implementation of a local sensing device, in accordance with a first embodiment of the present invention.

Figure 4 is an illustration of the implementation of a local sensing device, in accordance with a second embodiment of the present invention.

Figure 5 is an illustration of the implementation of a local sensing device, in accordance with a third embodiment of the present invention.

Figure 6 is a block diagram of the local sensing device in accordance with the present invention.

Figure 7 is an illustration of the implementation of a circuit breaker, in accordance with the present invention.

Fig. 8 is a flow chart illustrating the manner of operation of the Control Unit, in accordance with a preferred embodiment of the present invention, with relevant to the voltage level.

Fig. 9 is a flow chart illustrating the manner of operation of the Control Unit, in accordance with a preferred embodiment of the present invention, with relevant to continuity measurements.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The proposed system according to the present invention provides an early and automatic detection of electrical faults in wiring systems and / or in the loads connected to the system. The system can be implemented as a single apparatus, for performing local tests, or may be further implemented as a system and provide detection of electric faults on a plurality of wiring systems and connected loads. An early detection spares the need to immediately disconnect the system from the main power supply. The system is provided to monitor local voltage levels across electrical loads and continuity measurements since electrical-power was continually supplied to one or more points in the electrical system of a facility, such as a home, business, vehicle, aircraft or ship. By measuring and tracking changes in the local voltage and continuity measurements regarding the presence of electrical-power, the system is able to detect changes and events that may be indicative of faults in the wiring, in the electrical-current conducting equipment or in electrical equipment that is powered by the wiring.

Fig. 1 illustrates the implementation of the proposed system in accordance with a preferred embodiment of the present invention, depicting the electrical networking in a typical house. Although the facility shown in this figure is a house, this should not limit the scope of the invention, since the present invention can be implemented in similar facilities such as businesses, public buildings, automobiles, airplanes, ships and trucks. A main power supply [24], such as external power lines, is provided to supply electric power to the house [20]. The electric power is supplied to a fuse box [26], which is located in close proximity to the house. The fuse box contains fuses, circuit breakers and voltage and continuity sensing devices. The electric power is then distributed via a wiring to different wall sockets [28] located inside the house. The wall sockets are connected to various types of electric equipment, whereas this electric equipment has different load characteristics as follows:

Heating and lighting appliances, such as an electric oven [30] and a lamp [32], have resistive load characteristics. Motorized appliances, such as a refrigerator [34], exhibit inductive load characteristics. Electronic devices, such as a computer [36], are typically powered via a built-in transformer, and thus behave as a different sort of inductive load.

The proposed system includes local sensing devices [46] (see Fig.2), which are applied to continuously monitor the Alternating Current (AC) voltage level near each wall socket, transmit modulated signals to a central Control Unit [38], and as a result provide information regarding the operation of the different appliances in the house.

The sensing devices are typically constructed as plug adapters, which are plugged in between the power plugs of different pieces of electrical equipment and the sockets that feed these power plugs. These sensing devices may be further located in other parts of the wiring system (e.g. within wall sockets, switches and junction boxes) or directly integrated within the appliances themselves. The modulated signals are transmitted to the Control Unit over the electrical wiring itself using methods of power line communications known in the art. Alternatively, the local sensing device may communicate with the Control Unit by other means of communication known in the art, such as dedicated lines, data-communication network, wireless communication over Radio Frequency (RF), Infra-Red (IR) or acoustic links. The Control Unit receives continuous voltage variations of the sensing device's AC voltage level and then analyzes and compares these readings to a reference level, said reference level corresponding to the voltage initially provided by the main power supply [24]. The reference level may be just a voltage level – in case of a direct-current (DC) electrical-power, or a combination of amplitude and phase indications – in case of alternating-current (AC) electrical-power system. When the Control Unit detects an abnormal variation in the voltage readings of a sensing device in relative to the reference level, it informs the system by sending an alarm signal and may cut off the voltage supplied to appropriate wiring by triggering a circuit breaker in the fuse box or within the appliance itself. Furthermore, the Control Unit is configured in accordance with the present invention to detect electrical faults within the system independent of said reference level. Said configuration is essential for detection of electrical faults when no initial voltage samplings are available.

Fig. 2 is a block diagram of the proposed system in accordance with the present invention. A main wiring line [45] supplies alternating current (~) and provides Neutral connection (0). AC electrical power is distributed through the fuse box [26] and to the different loads [44], each loads created by a different appliance (e.g. electric oven, refrigerator, lamp, computer, etc.). The fuse box is an electric circuit including a main circuit breaker [42] and comprised of a plurality of parallel branches. Each branch includes a circuit breaker [40], operating in series with the main circuit breaker. The proposed system is based on a single AC phase. However, multiple AC phases may be further provided.

Each sensing device, which is located in proximity to the respective load [46], is parallel-connected to each load and is programmed to continuously transmit modulated signals of appropriate AC voltage level to the central Control Unit [38].

The wiring is designed to have low electrical resistance and therefore the impedance of each load is much higher than the wiring. Hence, these sensing devices enable to measure local load voltage that is only slightly lower than the reference level measured by a reference sensing device [48].

A number of different causes may lead to a substantial voltage drop measured by any one of the sensing devices. These causes include a short circuit or other malfunction in a load which reduces the effective impedance of the load, a loose connection or other fault in the wiring causes an increase in the impedance of said wiring, and an independent voltage drop in the main supply. An unexpected increase in the local load voltage, occurring rapidly or gradually over time, may also indicate an electrical fault.

The Control Unit identifies the type of each load [44] – resistive or inductive, preferably distinguishing, as well, between inductive motor coils and transformer windings. This unit additionally learns the normal operating pattern of each load, such as the characteristic on/off cycling of heaters, ovens and other appliances, and spikes that commonly occur when inductive loads are switched on.

As noted above, the Control Unit tracks and analyzes the voltage measurements made by each sensing device, including instantaneous and past measurements, and then proceeds to compare these measurements to a baseline voltage level measured by the reference sensing device.

In addition, independent of measuring voltage, the Control Unit is configured to analyze continuity measurements made by each sensing device, said measurements define (in terms of time units or AC cycles) the elapsed time since power was continually applied to each sensing device and appropriate load, and then detects the location of a power cut-off within the system. Continuously-increasing measurements of a specific sensing device indicate that power is continually supplied to said device.

On the opposite, repetitively-restarting measurements indicate frequent intermissions in the electrical power which is supplied to said device. Based on these measurements, the Control Units detects unintentional disconnected power wiring in the system and an absence of power supply to the load and to the sensing devices themselves. For example, the Control Unit may detect that an appliance monitored by a particular sensing device does not operate continuously for more than a certain period of time. This input information enables the Control Unit to detect hazard conditions that are not immediately reflected by abnormal voltage changes, such as an oven that has been left on, presumably unattended, for several hours. For this purpose, control unit [38] may comprise a communication interface to a personal computer or other computing device. Such an interface also enables data that has been recorded by the control unit or sensing devices [46] to be uploaded to the computer for further processing, analysis and display. Hence, the Control Unit is able not only to detect anomalies that may be indicative of faults in the loads or wiring, but also to determine the type and specific location of the electrical fault which is most likely.

Reference is now made to Figure 3, illustrating an implementation of a local sensing device, in accordance with a first embodiment of the present invention. An adapter [50], located between an AC power plug [52] and a wall socket [54], is comprised of a first set of receptacles [56] for inserting its prongs [58] to the power plug. These receptacles are wired via the adapter to a second set of receptacles [62] for inserting its prongs [60] to the wall socket. The sensing device [46], situated within the housing of the adapter, is coupled in parallel to the first set of receptacles [56] and to the prongs [60] of the adapter.

The configuration of the adapter according to the first embodiment of the present invention enables to install the proposed system within a facility simply by attaching or plugging in adapters of this type at desired sockets in the facility.

Figure 4 illustrates an implementation of a local sensing device, in accordance with a second embodiment of the present invention. The device, according to the second embodiment, is situated within the AC power plug [70].

Figure 5 illustrates an implementation of a local sensing device, in accordance with a third embodiment of the present invention. The sensing device, according to the third embodiment, is situated within the wall socket [74].

Figure 6 is a block diagram of the local sensing device, in accordance with the present invention. AC wiring lines [80] and [82] are connected to the main wiring line [45]. A power supply [84] receives AC power from these wiring lines and generates a low DC voltage that powers the other parts in the circuit. The power supply further includes a local power source [94], which may be a capacitor or any type of battery (optionally rechargeable battery), provided for independently supplying electric energy to only specific sensing devices in the circuit when no electric power is supplied from the power lines.

The electric circuit comprising the sensing device further includes an Analog-to-Digital converter [86], for performing measurements of the voltage level between lines [80] and [82] and transmit a digital signal of said voltage level to a processor unit [88]. These measurements are received without the need to apply similar electrical operations required to measure and determine the voltage level and phase at any particular moment, such as frequency-domain filtering or amplitude scaling. The processing units are further provided to store data and sensed values and to perform calculations over time. These calculations include integration, averaging, standard deviation, Root-Mean-Square (RMS) calculations and/or any other statistical calculations and data-processing required to identify electrical fault.

A Continuity meter device [92] is provided to measure the time or AC cycles that elapsed since power was continually supplied to the sensing device, whereas a discontinuity of electrical power at lines [45] restarts the counting procedure of said continuity metering device. The processor compares these time measurements with measurements obtained from other continuity devices in the proposed system and transmit them (along with a unique identification code) via a communication interface [90] to the Control Unit [38] (see figure 1). Said procedure enables to detect abnormal power behavior of a specific sensing device. A series of restarts indicate a disconnecting wiring connection, while continuous readouts indicate no disconnection. Hence, applying such time measurements enables to detect the presence of an electrical fault in relation with a specific sensing device.

In addition, this continuity device may be comprised of several sub-counters of different powering and resetting schemes. For example, one counter may be adopted to restart its counting in case a discontinuity of power supply has occurred in wires [80] and [82], while another counter is provided to count the time electric power is supplied to the sensing device regardless of the presence of electric power in the wires.

The proposed system may further comprise an analog modulation circuit known in the art, such as a Voltage-Controlled-Oscillator (VCO). By applying the VCO, which is a voltage-to-frequency converter, the Control Unit [38] senses the analog modulation on the main wiring line [45] (see figure 1) in order to determine if electric power is supplied to the sensing device.

The implementation of the local sensing device [46] includes a plurality of functional blocks. However, this device may be implemented in a single semiconductor chip or in a set of two or three chips as follows:

According to one implementation, the processor comprises a microcontroller with limited firmware instructions, thus invoking the microcontroller to periodically transmit voltage and time measurements at fixed intervals for analysis by the Control Unit.

According to yet another implementation, the processor comprises a microprocessor, which analyzes the voltage and time measurements received from the Analog-to-Digital converter [86] and Continuity-meter [92]. This microprocessor is provided to detect abnormal fluctuations in the voltage level and counting indications - and transmit a signal to the Control Unit indicating a possible electrical fault.

Applying a two-way communication interface [90], through which a particular sensing device communicates with other such devices, enables each processor to locally perform and analyze all the required measurements.

Furthermore, the sensing device may itself comprise a simple user interface and set of alarms. Hence, such a sensing device performs all the voltage and time measurements required for detecting an electrical fault, whereas the need to implement a separate

Control Unit is obviated entirely. This implementation is equivalent to disturbing the Control Unit's functionality at different locations within the facility and is useful particularly when the reference measurements are made at some external point, closer to the supplier of the electrical energy, for use by a number of facilities.

Figure 7 illustrates an implementation of a circuit breaker, in accordance with the present invention. The proposed adapter [100] is comprised of a first set of receptacles [56] and prongs [60], a sensing device [102] and an internal circuit breaker [104]. The electrical faults may be either detected by the microprocessor within the sensing device, as described above or by the Control Unit [38], signaling the sensing device via a communication interface to trip the circuit breaker accordingly.
The circuit breaker is a protection device, including both one-time fuses and/or switches. These are provided to reset automatically or manually after they are tripped. Said protection device is designed to disconnect at least one conductor in the receptacles in order to de-energize the electrical system connected to the wire lines of the second set of receptacles [60]. In addition, the device may be applied to generate an intentional connection between the alternating wiring (~) and ground connection of a facility. This connection enables a central Ground-Fault-Circuit-Interrupter (GFCI) to trip and disconnect numerous appliances from the electrical power.

Figure 8 and 9 are flow charts that schematically illustrate the operation of control unit [38], in accordance with an embodiment of the present invention. As noted above, some or all of these functions of the Control Unit may alternatively be performed by processors [88] in local sensing devices [46] or [102]. Therefore, although the functions shown in Figure 8 and 9 are described herein below as being carried out by Control Unit [38], it will be understood that these functions may be distributed in any suitable fashion between processors in the Control Unit and in the local sensing devices.

Reference is now made to Figure 8. In an initial learning phase [110], the Control Unit receives and monitors voltage signals from each of the local sensing devices in order to establish a pattern of normal behavior for each local sensing device. This phase may be invoked by a user, for example, via a user interface of the Control Unit, or it may be initiated automatically when a sensing device is plugged into the power network. The pattern behavior recorded at this stage is meant to be indicative of the behavior of wiring lines [45] and of loads [44] in the absence of any malfunction, although irregularities involving abnormal voltage behavior may be further detected even in this initial phase. During phase [110] the Control Unit [38] records normal voltage drop behavior at each local sensing device [46] with relevance to reference voltage measurements performed either locally or by a main reference sensor [48] near the point at which electrical power enters the facility.

During the receiving phase [113], after the completion of phase [110], the Control Unit [38] receives voltage measurements from sensing devices [46], whereas these measurements define the voltage values read by local and remote sensing devices [46] in the facility.

At step [114] these voltage measurements are recorded in a database for subsequent review and possibly for the purpose of modifying the learned voltage behavior recorded at step [110].

Step [115] analyzes the pattern of the voltage measurements made by each sensing device [46] over time and computes the voltage level of each sensor.

Step [116] computes reference voltage measurements. These reference values may be directly generated by a main reference sensor [48], provided from an external source or concluded from measurements performed on each sensing device individually.

At step [118] the Control Unit [38] compares the actual reference voltage measurements readings to predefined upper and lower voltage limits. The voltage limits define the normal range of lines voltage that is expected to be supplied to a specific facility. If the measured voltage is out of the normal range, the Control Unit proceeds to step [120].

Step [120] checks the voltage readings of sensing devices [46]. This step is applied only in case a reference sensing device [48] is provided (see Figure 2). If these readings have similarly increased or decreased in a manner that reflects the increase or decrease in the reference voltage (step [122]), the Control Unit concludes that there is a problem in the voltage input from the main power supply. In this case, the Control

Unit may issue an audible or visible alarm. It may further instruct fuse box [26] or sensing devices [46] within the facility to shut off the electrical power in order to prevent damage to existing appliances. Alternatively at step [124], if the control unit finds at step [120] that the readings of sensing devices [46] are behaving normally and have not changed along with the reference voltage reading, the Control Unit concludes that there is a fault associated with the reference sensor [48] itself. For example, the wiring to the reference sensor may be disconnected or otherwise faulty. The Control Unit may, in this case, set an alarm to indicate that a fault condition is suspected.

Note, that steps [120] through [124] are applied only in case a main reference sensing device is provided. However, if this is not the case (i.e. reference voltage readings are concluded from measurements performed on each sensing device individually), then steps [120] through [124] are skipped.

At step [118], the Control Unit [38] checks whether the reference voltage) found at step [115]) is within the proper range, Control Unit [38] proceeds to step [128]. At step [128] the Control Unit compares the value of the voltage measurement made by each sensing device to predefined upper and lower voltage limits. Note that this step is performed for each of sensing devices [46] in turn or in parallel. If the value measured at each sensing device is in the acceptable range, the Control Unit returns to step [113] and cycles indefinitely through the process that has been described above.

Otherwise, (i.e. if the value measured by any of the sensing devices is out of the normal range indicated by these limits), the Control Unit concludes that a fault has occurred in one of loads [44] or in wiring [45]. Based on the identity of the sensing device reporting the anomalous voltage readings, the Control Unit identifies the location of the fault (step [130]). The control unit may also analyze the pattern of the readings reported by the sensing devices in order to assess the type of fault that has occurred, for example, to determine whether the fault is in wiring [45] or in one of loads [44]. At step [132] the Control Unit issues an alarm, indicating the fault location. The Control Unit may also instruct the appropriate circuit breaker [40] (in fuse box [26]) or [104] (as in sensing device [100]) to shut off the power supplied to the faulty circuit.

Reference is now made to Figure 9. In an initial learning phase [140], the Control Unit receives and monitors continuity behavior from each of the local sensing devices in order to establish a pattern of normal behavior for each local sensing device. During this phase the Control Unit [38] records normal continuity behavior of each local sensing device [46] (in terms of time units or AC cycles).

During the data-collection phase [142], the Control Unit receives continuity time measurements from local and remote sensing devices [46], whereas these measurements define the elapsed time since electrical power was continually applied to each sensing device and appropriate load within the facility.

At step [144] these continuity measurements are recorded in a database for subsequent review and possibly for the purpose of modifying the learned continuity behavior recorded at step [140].

Step [146] analyzes these continuity values over time.

At step [148] the Control Unit [38] compares continuity measurement readings of remote sensing devices to predefined upper and lower continuity limits. The continuity limits define the normal range of elapsed time that is expected since electrical power was continually applied to each sensing device. If the continuity values of the remote sensing devices are within the normal range, the Control Unit proceeds to step [154].

At step [154] the Control Unit [38] compares continuity measurement readings of local sensing device to predefined upper and lower continuity limits. If the continuity values of said sensing devices are within the normal range, the Control Unit returns to step [142] and cycles indefinitely through the process that has been described above. Otherwise, the Control Unit issues an alarm indicating the location of the electrical fault (step [156]). The Control Unit may also instruct the appropriate circuit breaker [40] (in fuse box [26]) or [104] (as in sensing device [100]) to shut off the power supplied to the faulty circuit.

If the continuity values of the remote sensing devices compared in step [148] are out of the normal range, the Control Unit proceeds to step [150].

At step [150] the Control Unit concludes that a fault has occurred in one of loads [44] or in wiring [45]. Based on the identity of the sensing device reporting the continuity readings, the Control Unit identifies the location of the fault (step [150]).
At step [152] the Control Unit transmits an electric signal, notifying other sensing devices in the facility the existence of such an electrical fault.

Although the embodiments described above refer to monitoring of AC lines voltage, and specifically to monitoring functions carried out in a typical house, the methods and devices described herein are similarly applicable, *mutatis mutandis*, to detection of faults in the electric systems of other facilities. As noted above, the term "facility" as used in the preferred embodiments and claims according to the present invention should be understood broadly to include not only buildings, but also outdoor facilities and vehicles, such as airplanes, ships and trucks. The principles of the present invention may likewise be applied to monitoring of DC voltage levels supplied in such facilities.
In addition, the sensing device may be further implemented within the electric appliance itself or connected to other switches and junction boxes, whereas the connection to the power network may either be a fixed-connection or applied via a detachable power plug.
However, the implementation of a system that displays the values measured and allows a person to analyze them is also applicable. Such a system can be configured without any communication media between parts of the system and can therefore be very cheap and easy to implement and install.

While the above description contains many specifities, these should not be construed as limitations on the scope of the invention, but rather as exemplifications of the preferred embodiments. Those skilled in the art will envision other possible variations that are within its scope. Accordingly, the scope of the invention should be determined not by the embodiment illustrated, but by the appended claims and their legal equivalents.

What is claimed is:

1. A system for detecting faults in an electrical system of a facility having a main power supply, said system comprised of:
   - At least one sensing device for measuring voltage in proximity to a point of potential load, said potential load receiving power from said electrical system.
   - At least one processing unit for analyzing said voltage measurements to detect abnormal measurements on the basis of known range values and historical measurements.

2. The system according to claim 1, wherein the local voltage sensing devices are adapted to be coupled to an electrical socket from which the respective load receives the power.

3. The system according to claim 2, wherein at least one of the local voltage sensing devices comprises a plug adapter, comprising:
   - receptacles, which are configured to receive a power plug of the respective load;
   - prongs, which are electrically connected to the receptacles and are configured for insertion into the electrical socket; and
   - a voltage sensor, coupled to measure the voltage between the receptacles and the prongs.

4. The system according to claim 1, wherein each of the local voltage sensing devices comprises a communication interface, for communicating with the processor.

5. The system according to claim 4, wherein the communication interface is adapted to convey messages between the local voltage sensing devices and the processors via wired communication means or wireless communication means.

6. The system according to claim 1, wherein each of at least some of the local voltage sensing devices comprises a circuit breaker, which is controllable by

the processor to cut off the power to the respective load when the processor detects the fault.

7. The system according to claim 1, further comprising a reference sensing device, which is adapted to make the reference measurements of the voltage and elapsed time supplied to the facility.

8. The system according to claim 7, wherein the reference sensing device is connected to make the reference measurements in proximity to a point at which electrical mains power enters the facility.

9. The system according to claim 1, wherein the processor is collocated with at least one of the local voltage sensing devices.

10. The system according to claim 1, wherein the processor comprises a central control unit, which is adapted to receive the local measurements from the local voltage sensing devices that are deployed at different locations in the facility.

11. The system according to claim 1, wherein the processor is adapted, by comparing the local measurements to the reference measurement, to differentiate between electrical faults internal and external to the facility.

12. The system according to claim 1, wherein the processor is adapted to learn a normal behavior pattern of each of the local voltage sensing devices, and to detect the fault in response to a deviation of the local measurements from the normal behavior pattern.

13. The system according to claim 12, wherein the processor is adapted to learn the normal behavior pattern during a learning phase of the system, wherein irregularities involving abnormal voltage behavior in the electrical system can be detected during the learning phase.

14. The system according to claim 1, further comprising at least one continuity sensor for measuring discontinuities of electrical-power presence.

15. The system according to claim 14, wherein the continuity sensor is counting the time or number of alternating-current (AC) cycles passed since electrical-power was continually applied to the device.

16. The system according to claim 14, wherein the processor check the continuity sensor measurement in comparison to reference continuity sensor measurements or other continuity sensor measurement.

17. A method for monitoring an electrical system of a facility, said electrical system including at least one sensing devices, said method comprising the steps of:
   - making local measurements of a voltage across each of the loads using the local voltage sensing devices;
   - making reference measurements of the voltage supplied to the facility;
   - communicating at least one of the local measurements and/or the reference measurements over a communication medium to a processor; and
   - analyzing the local measurements based on known range values and historical measurements, using a processor, in order to detect a fault in the electrical system.

18. The method according to claim 17, wherein local voltage sensing devices are connected by coupling at least one of the local sensing devices to an electrical socket from which the respective load receives the power.

19. The method according to claim 17, wherein the at least one of the local voltage sensing devices comprises a plug adapter, comprising:
   - receptacles, which are configured to receive a power plug of the respective load;
   - prongs, which are electrically connected to the receptacles and are configured for insertion into the electrical socket; and
   - a voltage sensor, coupled to measure the voltage between the receptacles and the prongs.

20. The method according to claim 17, wherein communicating the at least one of the local measurements and the reference measurements comprises conveying messages via wired communication means or wireless communication means.

21. The method according to claim 17, wherein communicating the at least one of the local measurements and the reference measurements comprises conveying messages over a wireless medium.

22. The method according to claim 17, and comprising, responsively to detecting the fault, using one of the local voltage sensing devices to cut off the power to the respective load.

23. The method according to claim 17, wherein making the reference measurements comprises connecting a reference voltage sensing device in proximity to a point at which electrical mains power enters the facility.

24. The method according to claim 17, wherein making the reference measurements comprises sensing a reference voltage on mains external to the facility.

25. The method according to claim 17, wherein comparing the local measurements to the reference measurement comprises differentiating between electrical faults internal and external to the facility based on a comparison of the measurements.

26. The method according to claim 17, and comprising learning a normal behavior pattern of each of the local voltage sensing devices, wherein comparing the local measurements to the reference measurements comprises detecting the fault in response to a deviation of the local measurements from the normal behavior pattern.

27. The method according to claim 26, wherein learning the normal behavior pattern comprises observing the normal behavior during a learning phase, and comprising detecting the fault in the electrical system in response to a failure occurring during the learning phase.

28. The method according to claim 17, further comprising the step of measuring discontinuities of electrical-power presence by at least one continuity sensor.
29. The method according to claim 28 wherein continuity measurement include counting the time or number of alternating-current (AC) cycles passed since electrical-power was continually applied to the device.
30. The method according to claim 28 wherein the processor checks the continuity sensor measurement in comparison to reference continuity sensor measurements or other continuity sensor measurements.
31. An apparatus for detecting faults in an electrical system of a facility having a main power supply, said apparatus comprised of:
    - at least one sensing means for measuring voltage in proximity to a point of potential load, said potential load receiving power from said electrical system.
    - at least one processing unit for analyzing said voltage measurements to detect abnormal measurements on the basis of known range values and historical measurements.

32. The apparatus of claim 31 further comprising continuity sensor for measuring discontinuities of electrical-power presence

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Fig 1

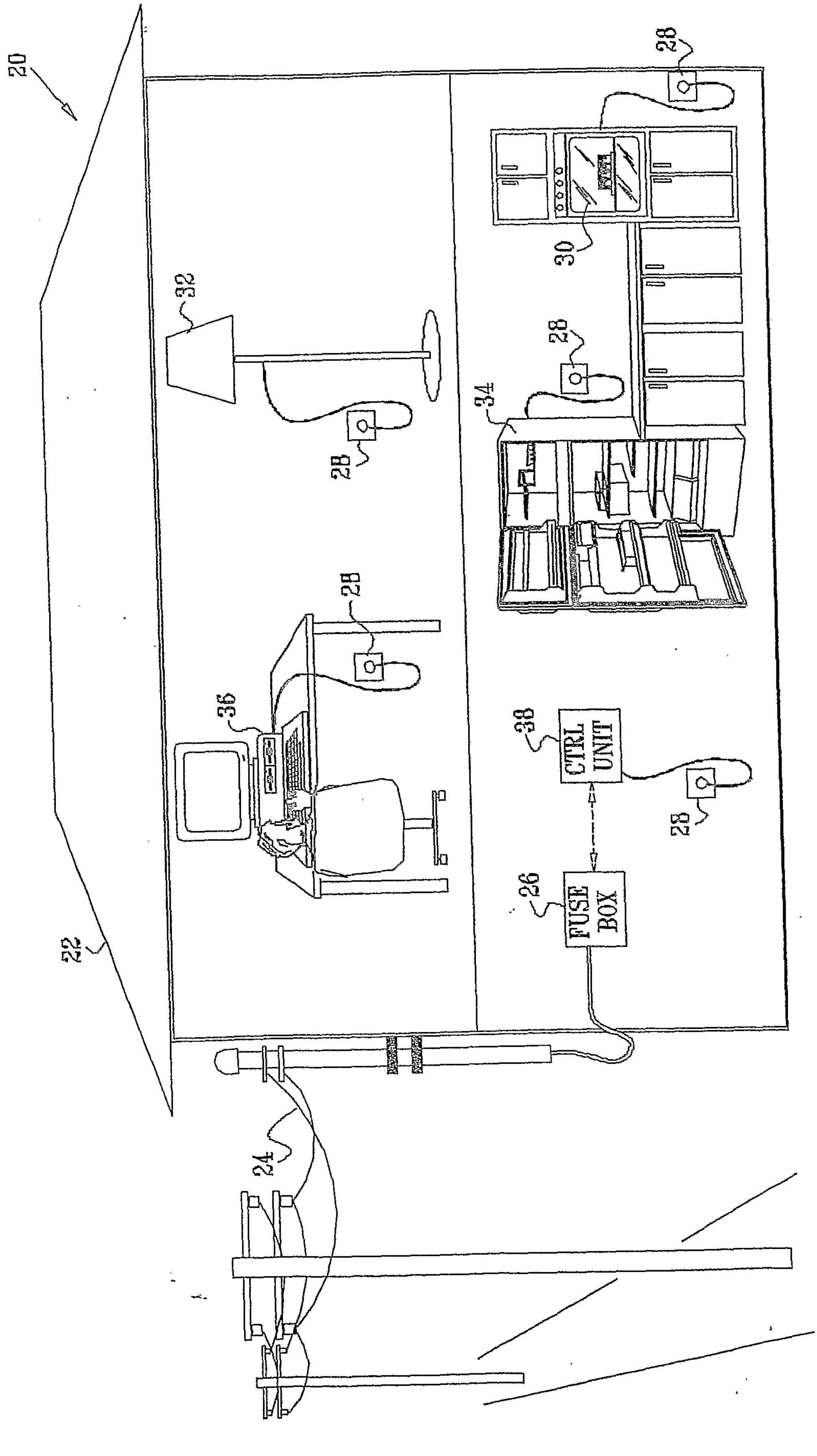

Fig. 2

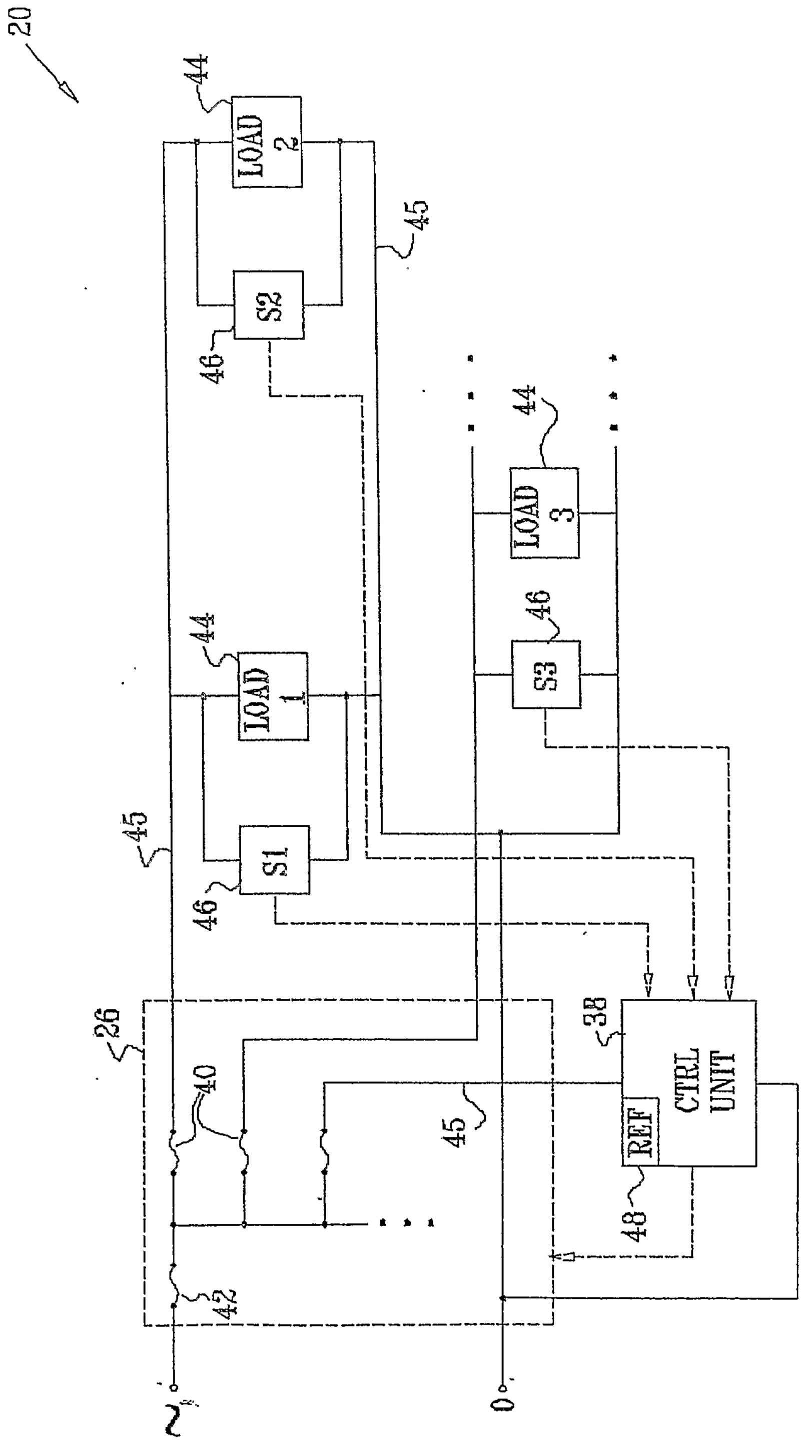
20
LOAD 2
44
45
S2
46
LOAD 3
44
S3
46
LOAD 1
44
S1
46
45
26
40
42
38
CTRL UNIT
REF
48
45

Fig 3

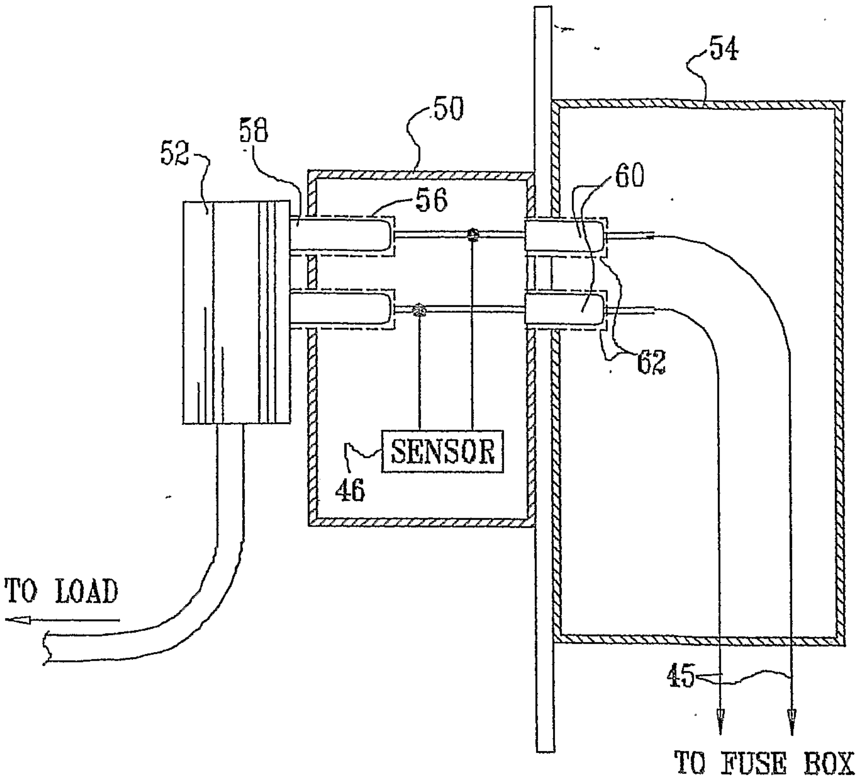
54
50
58
52
56
60
62
SENSOR
46
TO LOAD
45
TO FUSE BOX

FIG. 4

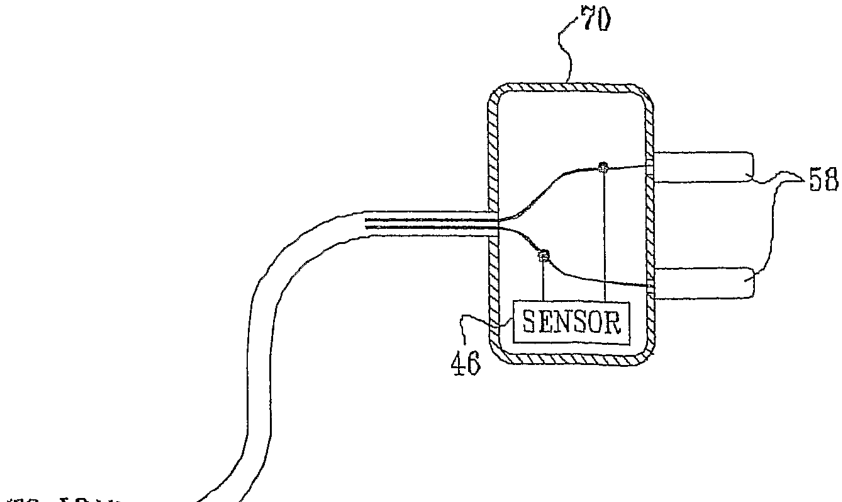
70
58
SENSOR
46
TO LOAD

Fig 5

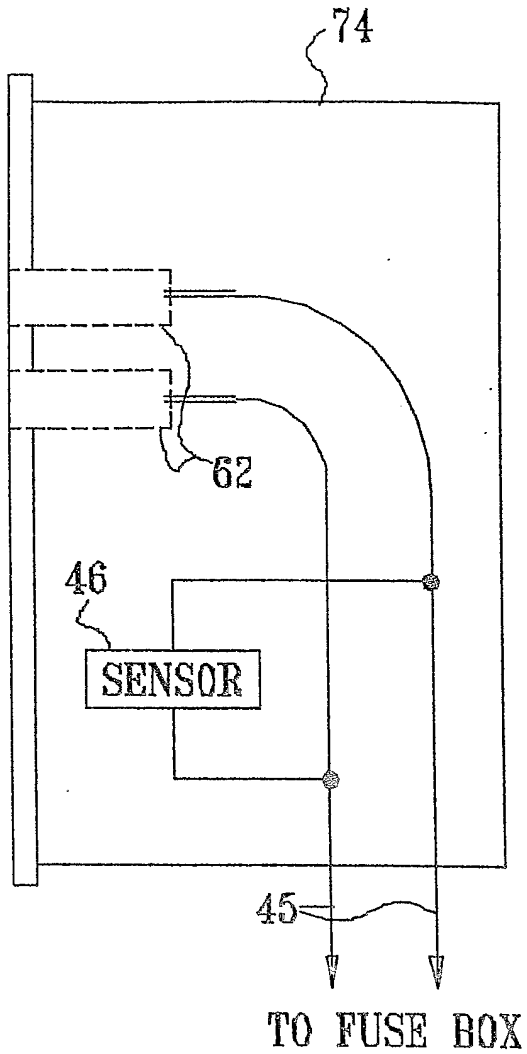

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Fig 6

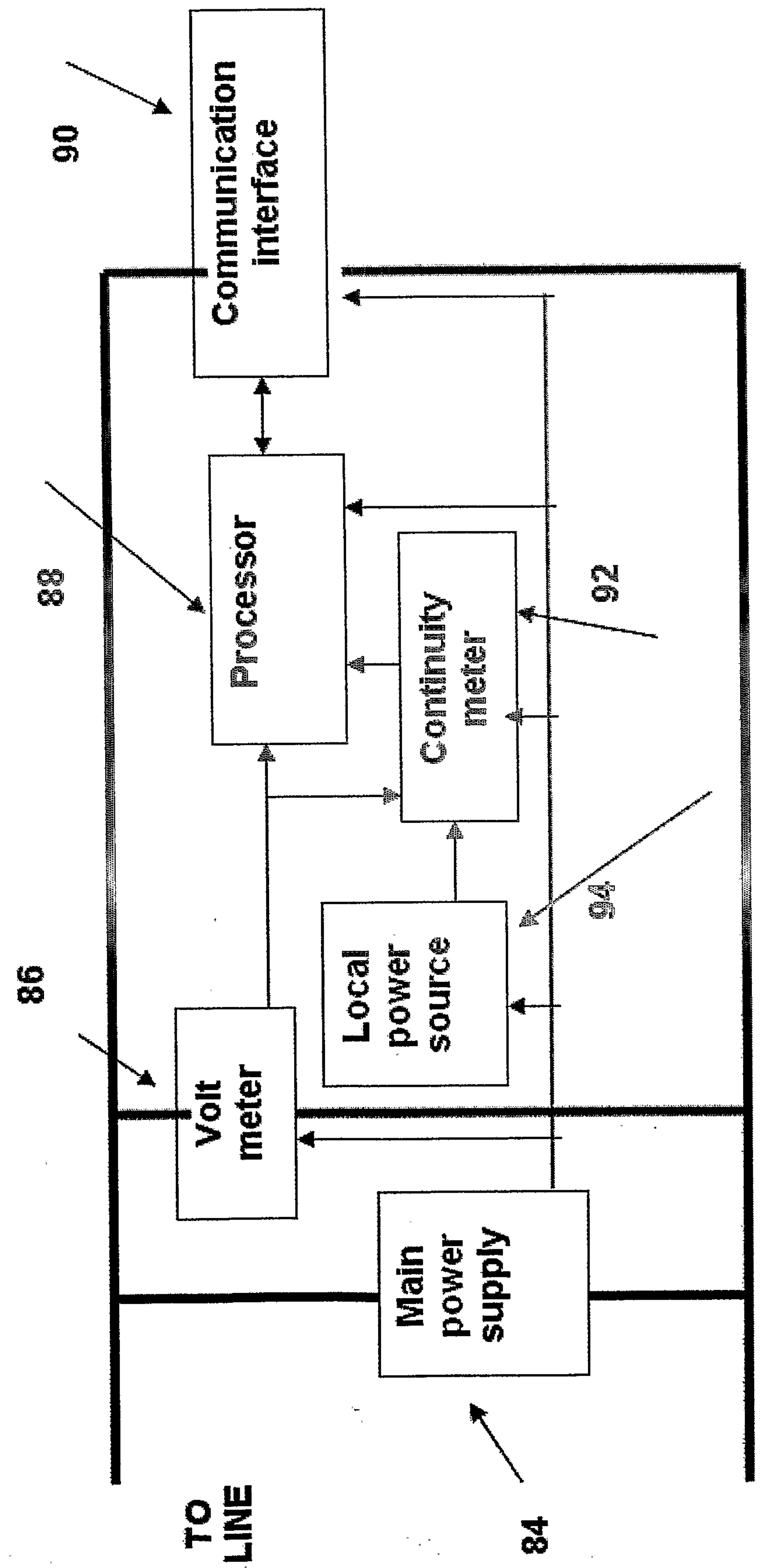
90
Communication interface
88
Processor
92
Continuity meter
94
Local power source
86
Volt meter
Main power supply
TO LINE
84

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Fig 7

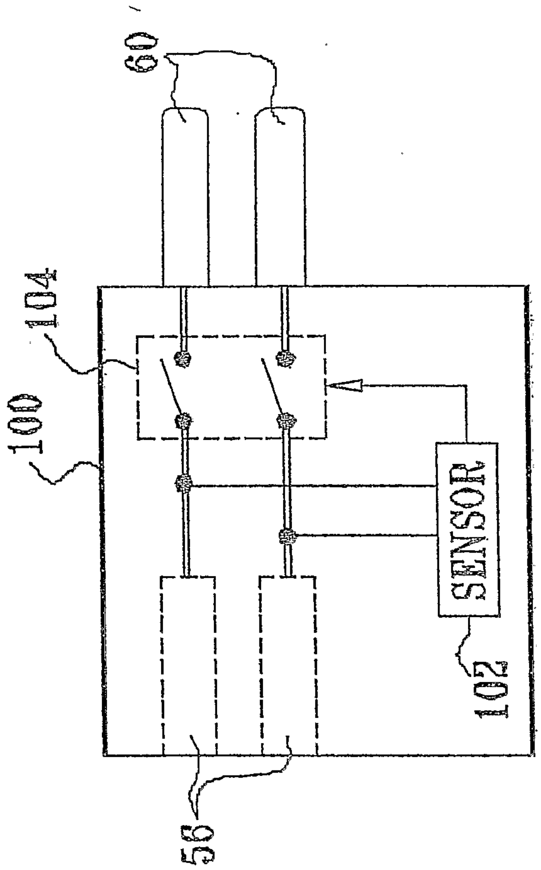


FIG. 8

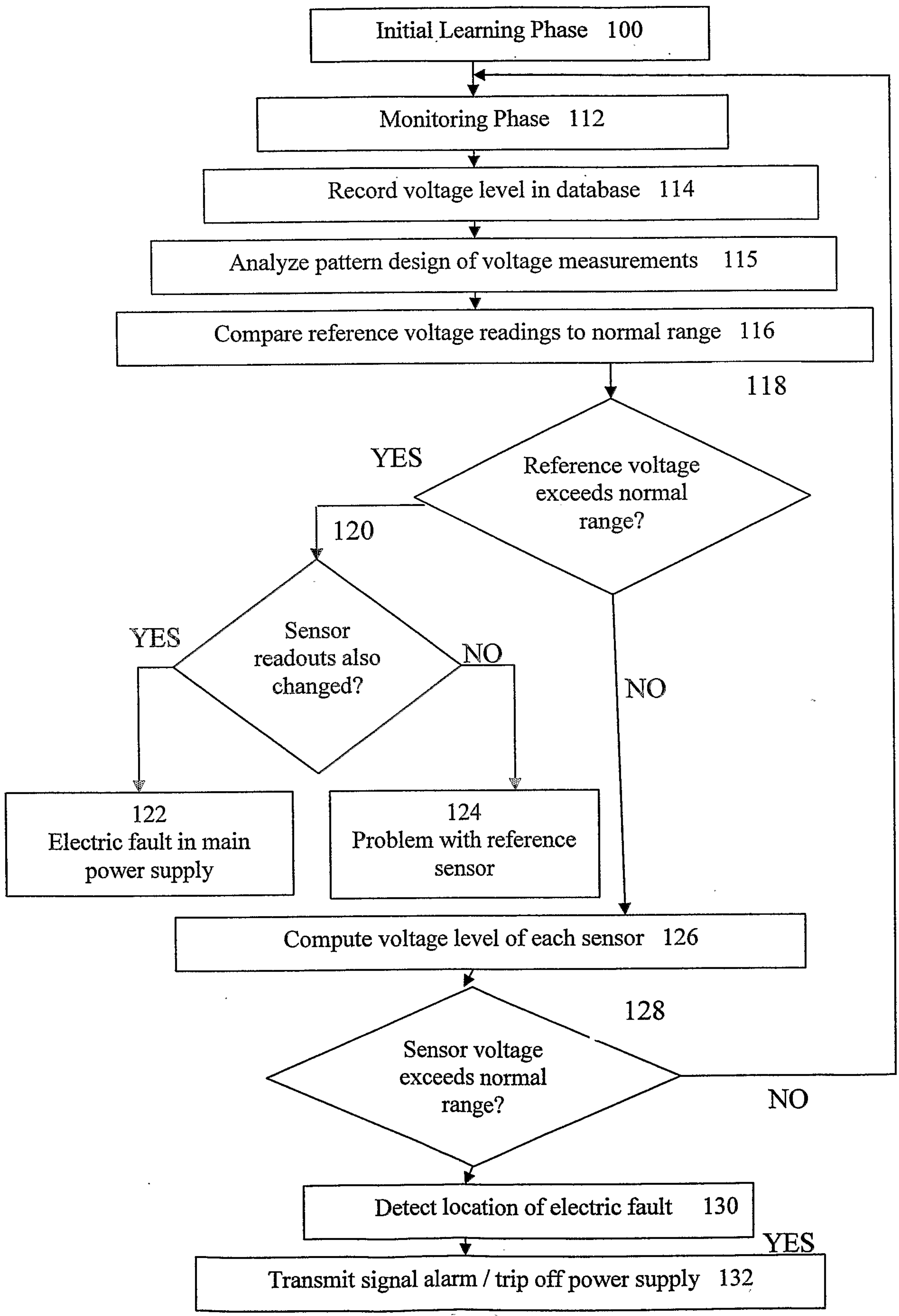
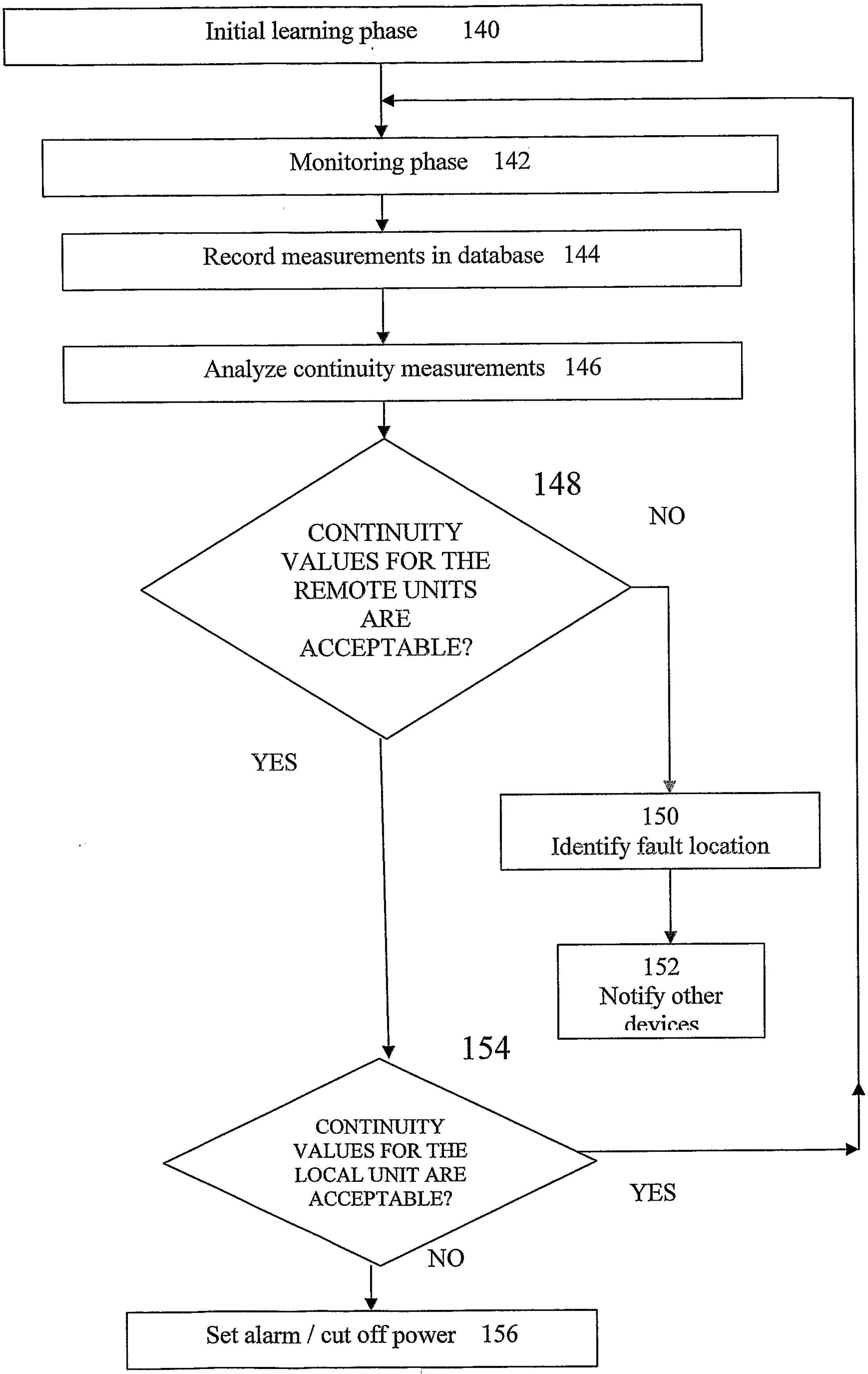

Initial Learning Phase 100
Monitoring Phase 112
Record voltage level in database 114
Analyze pattern design of voltage measurements 115
Compare reference voltage readings to normal range 116
118
Reference voltage exceeds normal range?
YES
NO
120
Sensor readouts also changed?
YES
NO
122
Electric fault in main power supply
124
Problem with reference sensor
Compute voltage level of each sensor 126
128
Sensor voltage exceeds normal range?
NO
YES
Detect location of electric fault 130
Transmit signal alarm / trip off power supply 132

FIG. 9


Initial learning phase 140
Monitoring phase 142
Record measurements in database 144
Analyze continuity measurements 146
148
CONTINUITY VALUES FOR THE REMOTE UNITS ARE ACCEPTABLE?
NO
YES
150
Identify fault location
152
Notify other devices
154
CONTINUITY VALUES FOR THE LOCAL UNIT ARE ACCEPTABLE?
YES
NO
Set alarm / cut off power 156