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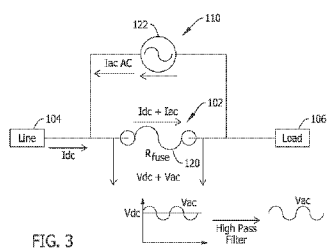


FIG. 3

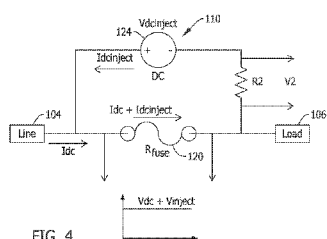


FIG. 4

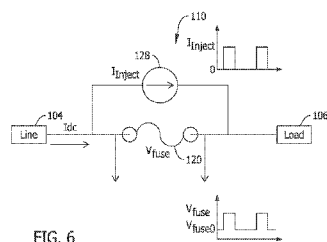


FIG. 6

(57) Abstract: Electrical current sensing and monitoring methods include connecting a compensation circuit across a conductor having a non-linear resistance such as a fuse element. The compensation circuit injects a current or voltage to the conductor that allows the resistance of the conductor to be determined. The current flowing in the conductor can be calculated based on a sensed voltage across the conductor once the resistance of the conductor has been determined.



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ELECTRIC FUSE CURRENT SENSING SYSTEMS AND MONITORING METHODS

BACKGROUND OF THE INVENTION

[0001] The field of the invention relates generally to electrical power distribution systems, and more specifically to systems and methods of sensing and monitoring electrical current flow through a conductor in an electrical circuit.

[0002] In electrical products and systems of various types, current sensing is performed for a variety of reasons. Current sensing and monitoring facilitates oversight and control of equipment and processes in various aspects, as well as facilitates circuit protection functionality. Various different types of contact and non-contact current sensors are presently used today, including but not necessarily limited to resistance shunts, current transformers (CTs), hall-effect sensors and fiber-optic current sensors (FOCS) that use the magneto-optic effect (Faraday effect).

[0003] In many residential-type electrical power systems where current sensing is required, the relative cost of conventional current sensors is high and as such the use of current sensors has been limited for residential applications. For electrical products including current sensing capability, the cost of the current sensor components can account for as much as 50% of the total product cost. For industrial and commercial-type products requiring current sensing, the sensing components can account for as much as 20% of the total system cost. The relatively high cost of presently utilized current sensor technology is an impediment to otherwise beneficial adoption of current sensing on a broader scale in the electrical industry. Lower cost and/or simpler current sensing solutions are accordingly desired.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Non-limiting and non-exhaustive embodiments are described with reference to the following Figures, wherein like reference numerals refer to like parts throughout the various drawings unless otherwise specified.

[0005] Figure 1 is a partial circuit schematic of a portion of an electrical power system illustrating a conventional current sensing technique.

[0006] Figure 2 is a partial circuit schematic of a portion of an electrical power system illustrating a first exemplary current sensing technique according to an embodiment of the present invention.

[0007] Figure 3 is a partial circuit schematic of a portion of an electrical power system illustrating a second exemplary current sensing technique according to an embodiment of the present invention.

[0008] Figure 4 is a partial circuit schematic of a portion of an electrical power system illustrating a third exemplary current sensing technique according to an embodiment of the present invention.

[0009] Figure 5 is a partial circuit schematic of a portion of an electrical power system illustrating a fourth exemplary current sensing technique according to an embodiment of the present invention.

[0010] Figure 6 is a partial circuit schematic of a portion of an electrical power system illustrating a fifth exemplary current sensing technique according to an embodiment of the present invention.

[0011] Figure 7 schematically represents a first exemplary current sensing system according to an embodiment of the present invention.

[0012] Figure 8 schematically represents a second exemplary current sensing system according to an embodiment of the present invention.

[0013] Figure 9 schematically represents a third exemplary current sensing system according to an embodiment of the present invention.

[0014] Figure 10 schematically illustrates compensation circuitry for the current sensing techniques and systems shown in Figures 2-9.

[0015] Figure 11 is a method flowchart illustrating exemplary processes associated with the current sensing techniques, systems, and circuitry shown in Figures 2-10.

DETAILED DESCRIPTION OF THE INVENTION

[0016] Figure 1 is a partial circuit schematic of a portion of an electrical power system 100 illustrating a conventional current sensing technique sometimes referred to as shunt based current sensing.

[0017] As shown in Figure 1, the power system 100 includes an electrical fuse 102 connected between line side circuitry 104 and load side circuitry 106. The fuse 102 includes a housing and a conductive fuse element that is structurally configured to melt, disintegrate, vaporize or otherwise structurally fail in response to a predetermined overcurrent condition and effectively create an open circuit between the line side circuitry 104 and the load side circuitry 106. The load side circuitry 106 is therefore protected by the fuse 102 and its fuse element that electrically isolates the load side circuitry 106 when the fuse element is exposed to overcurrent conditions as the fuse element fails to conduct electrical current any longer through the fuse 102, thereby preventing otherwise damaging current from flowing to the line side circuitry 106. The opening of the fuse element in response to the overcurrent condition is permanent and the fuse 102 must be replaced with another fuse 102 to restore the electrical connection between the line side circuitry 104 and the load side circuitry 106.

[0018] As also shown in Figure 1, a resistive shunt 108 is connected in series with the fuse 102 in the electrical power system 100. By monitoring or sensing a voltage V_{sense} across the shunt 108, the current I_{sense} flowing through the fuse 102 can be easily determined from Ohm's law ($V = I/R$). Ideally, the resistive shunt 108 has a broad linear resistance band allowing for direct conversion of the voltage V_{sense} to the current I_{sense} . The broad linear resistance band in the resistive shunt 108, which is typically not available in other components in the electrical system, is highly desired and accordingly the resistive shunt 108 is rated for full current and is

manufactured with high precision. The resistive shunt 108 is therefore a relatively expensive, although effective current sensing solution. In an electrical power system 100 including many electrical fuses 102, the costs of providing resistive shunts are multiplied and can be substantial.

[0019] Other current sensors are known that may be utilized in lieu of the resistive shunt 108 described, including those mentioned above, but they tend to be bulkier and/or more expensive than the resistive shunt 108 and therefore have not completely met the need for compact and lower cost solutions.

[0020] Exemplary embodiments of systems and methods are described hereinbelow that facilitate a compact, reliable and cost effective current sensing, monitoring and control functions and advanced capabilities in electrical power systems. This is achieved, as explained in detail below, by connecting a compensation circuit across a conductor having a non-linear resistance such as a fuse element. The compensation circuit injects a current or voltage to the conductor that allows the resistance of the conductor to be determined. The current flowing in the conductor can be calculated based on a sensed voltage across the conductor once the resistance of the conductor has been determined. Method aspects will be in part apparent and in part explicitly discussed in the following description.

[0021] Figure 2 illustrates a first exemplary current sensing technique according to an embodiment of the present invention. Comparing Figures 1 and 2, it is seen that the resistive shunt 108 is eliminated and the voltage V_{sense} is derived directly across the fuse 102 and the current I_{sense} may likewise be determined without involving a relatively expensive series-connected shunt 108 as shown in Figure 1. The elimination of the resistive shunt 108, as afforded by the present invention, is advantageous beyond cost reduction. Elimination of the resistive shunt also saves physical space, and in applications where many fuses are utilized in a common location, including but not limited to combiner boxes, the size of the combiner box can be reduced. Likewise, a size of a panelboard or fuse block can be reduced via elimination of resistive shunts while still providing current sensing capability and advanced fuse status features, abnormal fuse detection and alarms, etc.

[0022] Sensing the voltage V_{sense} directly across the fuse 102 to determine the current I_{sense} introduces complications that are addressed by compensation circuitry 110. Specifically, the fuse element in the fuse 102 exhibits a non-linear resistance that unlike the resistive shunt 108 (Figure 1) precludes a simple and direct application of Ohm's law to calculate the current I_{sense} because the resistance of the fuse element in the fuse 102 is not constant in use.

[0023] The compensation circuitry 110 may accordingly include a controller 112 that measures the fuse element resistance at periodic intervals to account for variations in fuse resistance. Alternatively, the controller 112 may be provided in a sub-metering module (SMM) in, for example a combiner box including the fuse 102. That is, the controller 112 need not be a part of the compensation circuitry 110 itself in all embodiments, but instead may be separately provided. The voltage V_{sense} in some embodiments may be input to another optional controller 114 that calculates the current I_{sense} . It is understood, however, that the functionality of the controllers 112, 114 shown may be combined into a single controller if desired.

[0024] The controllers 112 and/or 114 may be processor-based control devices. As used herein, the term "processor-based" shall refer not only to controller devices including a processor or microprocessor, but also to other equivalent elements such as microcomputers, programmable logic controllers, reduced instruction set (RISC) circuits, application specific integrated circuits and other programmable circuits, logic circuits, equivalents thereof, and any other circuit or processor capable of executing the functions described below. The processor-based devices listed above are exemplary only, and are thus not intended to limit in any way the definition and/or meaning of the term "processor-based".

[0025] The technique shown in Figure 2 recognizes that the fuse 102, as are all electrical fuses, is essentially a calibrated resistor. Because a resistor drops a voltage during operation, knowing the resistance of the fuse element in the fuse 102 (as determined by one of the controllers 112, 114) and also knowing the voltage V_{sense} , the current I_{sense} can be calculated using relationships derived from Ohms Law while achieving a relatively smaller and more cost effective current sensing system

than that shown in Figure 1. The current sensing technique shown in Figure 2, and also further described below in exemplary implementations in Figures 3-6 can be applied on practically any type of fuse with advantageous effect.

[0026] In contemplated embodiments, algorithms are utilized to translate the non-linear response of the fuse element into accurate current readings. Unique non-linear fuse coefficients can then be coded onto or into the individual fuse 102 with, for example, an RFID tag or bar code label. As also described below, a fuse reader may alternatively be integrated into a housing of a fuse holder or a housing of a disconnect switch, sometimes referred to as a base, along with current monitor electronics. Since the fuse 102 introduces non-linear resistance aspects to the current monitoring equation, electronic circuit assisted sensing or acquisition is proposed along with algorithms to compensate for non-linear fuse resistance.

[0027] While the concepts described are illustrated in the context of the fuse 102 being utilized to sense current, the concept illustrated in Figure 2 could alternatively be applied to other conductive elements besides a fuse. The use of circuit elements like fuses, circuit breaker contacts, electrical connections and all other components that introduce series resistance into the circuit can be effectively applied with an accompanying compensation circuit operating. Since each circuit element used for current sensing can have its own unique and individual variables and properties, a scheme for coding these unique variables and properties with the circuit element is required for proper and accurate translation of the resistor voltage to a current measurement. A coding scheme may include, as mentioned above, RFID tagging and or bar code labeling. It shall be understood that the proposed concept shown in Figure 2 can be used for both direct current (DC) and alternating current (AC) current sensing and measurement as illustrated in the examples below.

[0028] Those in the art will appreciate that the electronic circuitry proposed requires an appropriate isolation scheme to isolate the system voltage of the electrical power system 100 from the electronics. Once determined, current data can be transmitted to a remote location, via, for example, optical or wireless

communication systems, although other types of communication are possible if desired.

[0029] Figure 3 is a partial circuit schematic of a portion of an electrical power system illustrating a second exemplary current sensing technique according to an embodiment of the present invention.

[0030] As shown in Figure 3, line side circuitry 104 delivers an input I_{dc} to the fuse 102 including a fuse element 120. The circuit 110 is connected in electrical parallel with the fuse element 120, and the circuit 110 includes a current source 122 that injects an AC current injection I_{ac} at a preset frequency. Applying Ohm's law, the following relationships apply:

$$R_{fuse} = \frac{V_{ac}}{I_{ac}}$$

$$I_{dc} = \frac{V_{dc}}{R_{fuse}}$$

The current flowing through the fuse element 120 is the sum of I_{dc} and I_{ac} , and the sensed voltage across the fuse element 120 is the sum of V_{ac} and V_{dc} . As seen in Figure 3, the sensed voltage may be subjected to a high pass filter to obtain the voltage V_{ac} . R_{fuse} can now be determined as V_{ac} and I_{ac} are both known. Once R_{fuse} is known, I_{dc} can be calculated since V_{dc} is known. The relationships and calculations may be repeated at any desired time interval to account for non-linear resistance behavior of the fuse element over time.

[0031] Figure 4 is a partial circuit schematic of a portion of an electrical power system illustrating a third exemplary current sensing technique according to an embodiment of the present invention.

[0032] As shown in Figure 4, line side circuitry 104 delivers an input current I_{dc} to the fuse 102 including a fuse element 120. The circuit 110 is connected in electrical parallel with the fuse element 120, and the circuit 110 includes a voltage source 124 with known voltage $V_{dcinject}$ and generating current $I_{dcinject}$. A voltage

dividing resistor R_2 is also present and a voltage V_2 is sensed across the resistor R_2 . Applying Ohm's law, the following relationships apply to sense and determine the current I_{dc} :

$$I_{dcinject} = \frac{V_2}{R_2}$$

$$R_{fuse} = \frac{V_{dcinject} - V_2}{I_{dcinject}}$$

$$V_{dc} = V_{fuse} - V_{inject} = V_{fuse} - R_{fuse} * I_{dcinject}$$

$$I_{dc} = \frac{V_{dc}}{R_{fuse}}$$

The relationships and calculations may be repeated at any desired time interval to account to non-linear resistance behavior of the fuse element over time.

[0033] Figure 5 is a partial circuit schematic of a portion of an electrical power system illustrating a fourth exemplary current sensing technique according to an embodiment of the present invention.

[0034] As shown in Figure 5, line side circuitry 104 delivers an input current I_{dc} to the fuse 102 including a fuse element 120. The circuit 110 is connected in electrical parallel with the fuse element 120, and the circuit 110 includes a DC current source 126 providing current $I_{dcinject}$ and generating voltage $V_{dcinject}$. A voltage dividing resistor R_2 is also present and a voltage V_2 is sensed across the resistor R_2 . Applying Ohm's law, the following relationships apply to sense and determine the current I_{dc} :

$$R_{fuse} = \frac{V_{dcinject} - V_2}{I_{dcinject}}$$

$$V_{dc} = V_{fuse} - V_{inject} = V_{fuse} - R_{fuse} * I_{dcinject}$$

$$I_{dc} = \frac{V_{dc}}{R_{fuse}}$$

The relationships and calculations may be repeated at any desired time interval to account to non-linear resistance behavior of the fuse element over time.

[0035] Figure 6 is a partial circuit schematic of a portion of an electrical power system illustrating a fifth exemplary current sensing technique according to an embodiment of the present invention.

[0036] As shown in Figure 6, line side circuitry 104 delivers an input current I_{dc} to the fuse 102 including a fuse element 120. The circuit 110 is connected in electrical parallel with the fuse element 120, and the circuit 110 includes a pulsed current source 128 providing current I_{inject} . Applying Ohm's law, the following relationships apply to sense and determine the current I_{dc} :

When pulse current is zero, then

$$V_{fuse0} = R_{fuse} * I_{dc}$$

When pulse current is I_{inject} , then

$$V_{fuse} = R_{fuse} * (I_{dc} + I_{inject})$$

So

$$\frac{V_{fuse}}{V_{fuse0}} = \frac{I_{dc} + I_{inject}}{I_{dc}}$$

$$I_{dc} = \frac{V_{fuse0} * I_{inject}}{V_{fuse} - V_{fuse0}}$$

The relationships and calculations may be repeated at any desired time interval to account to non-linear resistance behavior of the fuse element over time.

[0037] Figure 7 schematically represents a first exemplary current sensing system 140 according to an embodiment of the present invention. The system 140 includes the fuse 102 including the fuse element 120 and the circuitry 110 connected in parallel with the fuse element 120 inside a fuse housing 142. The fuse

housing 142 is provided with fuse terminals T_1 and T_2 for establishing electrical connection with the line side circuitry 104 and the load side circuitry 106.

[0038] The fuse element 120 may be provided in any structural shape and configuration desired and may be designed to open in response to any overcurrent condition desired. The housing 142 may likewise be provided in any shape desired, including but not necessarily limited to round cylindrical shapes and rectangular shapes, and may be filled with an arc-extinguishing media. The fuse terminals T_1 and T_2 may be any known fuse terminal shape and configuration, including but not necessarily limited to end caps or ferrules, knife blade contacts, or terminal blades. In some contemplated embodiments the fuse 102 may be configured as a CUBEFuse[®] modular fuse of Bussmann by Eaton, St. Louis, Missouri having a rectangular housing and terminal blades projecting from a common side of the rectangular housing. Regardless, and as shown in Figure 7, the compensation circuit 110 is embedded in the fuse construction. That is, the circuit 110 and electronics such as those described above are inside the fuse housing 142 and are accordingly built-in to the fuse.

[0039] A reader device 144 is shown as a separately provided device in the system 150. The reader device 144 may be a portable device in some embodiments or may be mounted stationary in other embodiments. In some embodiments the reader device 144 may be hand-held device. The reader device 144 may be a processor-based device and may communicate wirelessly with the circuitry 110 to receive the sensed voltage information or other data needed to analyze or calculate the current being sensed in the manner described above. While wireless communication between the circuitry 110 and the reader device 144 is beneficial in a large electrical power system 100, it is not in all cases strictly necessary and the reader device 144 may instead be hard-wired to the circuitry 110 via connecting ports and terminals in the fuse 102 if desired.

[0040] The reader device 144 in a contemplated embodiment may be configured as an RFID reader or interrogator device. In such an embodiment, once the information is obtained from a corresponding RFID element in the circuit 110, the current of interest can be calculated by the reader device 144, or in an embodiment

wherein the current is calculated within the electronics embedded in the fuse 102, the calculated current can simply be communicated to the reader device 144.

[0041] As previously mentioned, the fuse 102 may be provided with an RFID label or bar code label 143 on the housing 142 of the fuse 102. The label 143 may include encoded information to be communicated to a reader device 144. The reader device 144 may accordingly be a multi-functional device including multiple means of communicating with elements of the fuse. The RFID label or bar code label may include identifying information for the fuse 102, rating information for the fuse 102, and coded information facilitating the calculation of the sensed current. As such, by reading the label or bar code on the fuse housing, the reader device 144 can know which one of multiple predetermined algorithms to use to calculate the current, and the reader device may also obtain any coefficients that may be unique the fuse 102 for use in the algorithm. In such a scenario, the reader device 144 is an intelligent device that can distinguish different types of fuses and select one of a variety of predetermined algorithms to calculate the sensed current.

[0042] Once obtained, the information obtained by the reader device 144, including the calculated current, can further be communicated to a remote device 146 via any desired communication network. The remote device 146 may facilitate monitoring and oversight of the electrical power system 100 and any related processes. The remote device 146 may, for example, be part of a Supervisory Control and Data Acquisition (SCADA) system monitoring aspects of an industrial facility and processes as those in the art may appreciate.

[0043] It is appreciated that in some embodiments the sensed current could actually be calculated by the remote device 146 at the remote location if desired, with the reader device 144 supplying only the information needed to make the calculation. Varying degrees of sophistication and complexity in the reader device 144 can be provided in the system 140 proposed at varying cost.

[0044] Figure 8 schematically represents a second exemplary current sensing system 150 according to another embodiment of the present invention. The

system 150 includes a fuse holder or fuse block 152 including a housing 154 provided with terminals T_{1H} and T_{2H} respectively configured to structurally establish electrical connection to the line-side and load-side circuitry 104, 106. The terminals T_{1F} and T_{2F} of the fuse 102 are configured to structurally mate with the terminals T_{1H} and T_{2H} of the fuse holder or fuse block 152 such that an electrical connection between the line-side and load-side circuitry is established through the fuse element 120.

[0045] Unlike the system 140 (Figure 7), the circuitry 110 is not provided in the housing 142 of the fuse, but is instead provided on or in the housing 154 of the fuse holder or fuse block 152. As such, the circuitry 110 in this embodiment is embedded in the fuse block 152 instead of in the fuse 102. The operation of the circuitry 110, however, remains the same, and the label 143 and reader 144 may also be provided as described above with similar effect.

[0046] In an alternative embodiment wherein the circuitry 110 is embedded in the fuse 102 as described above in the system 140, the reader 144 could be embedded in the fuse block or housing 152.

[0047] The fuse holder or fuse block housing 154 may be provided with multiple sets of terminals T_{1H} and T_{2H} such that multiple sets of fuses 102 can be accommodated in the fuse housing or fuse block 152. The housing 154 may be provided in a single piece or in multiple pieces, and may be provided in modular pieces that may be attached to one another. The housing 154 may be configured as an open-style fuse block or may partly or completely enclose the fuse(s) 102 as desired.

[0048] The terminals T_{1H} and T_{2H} provided on the housing 154 may include resilient spring clips that are structurally configured to receive and retain the terminals T_{1F} and T_{2F} of the fuse 102. The fuse terminals T_{1F} and T_{2F} may be provided in any shape and structural configuration, including but not necessarily limited to end caps or ferrules, knife blade contacts, or terminal blades. The terminals T_{1H} and T_{2H} on the fuse holder or fuse block housing may accordingly be varied to mate with the terminals T_{1F} and T_{2F} of the fuse 102. Fuse rejection features may be

built-in to the terminals T_{1F} and T_{2F} of the fuse 102 and/or may be incorporated into the housing 154 to prevent installation of an incompatible fuse.

[0049] The terminals T_{1H} and T_{2H} provided on the housing 154 also include terminal features such as box lugs, spring clamps, or other terminals configured to accept and retain an end of a wire utilized to establish the line and load-side electrical connections to the fuse block or housing 152. Alternatively, panel mount clips and the like, as well as another terminal structure to establish mechanical and electrical connection to the line and load circuitry 104, 106 may be provided.

[0050] Figure 9 schematically represents a third exemplary current sensing system 160 according to an embodiment of the present invention. The system 160 includes a fusible disconnect switch device 162 including a housing or base 164 provided with terminals T_{1L} and T_{2L} respectively configured to structurally establish electrical connection to the line-side and load-side circuitry 104, 106. A switch 166 is provided in the housing or base 164 that may be selectively opened or closed to make or break the current path through the disconnect switch device 162, and when the fuse 102 is installed and the switch 166 is closed, the fuse element 120 of the fuse 102 completes an electrical connection between the line and load-side circuitry 104, 106. The base 164 may in some embodiments be configured as a Compact Circuit Protector (CCP) of Bussmann by Eaton, St. Louis, Missouri. As can be seen in the schematic of Figure 9, the disconnect switch device 162 does not include an in-line circuit breaker and is accordingly smaller than conventional in-line circuit breaker and fuse combinations.

[0051] The terminals T_{1F} and T_{2F} of the fuse 102 are configured to structurally mate with complementary terminals of the base 164 such that an electrical connection may be established through the fuse element 120. The complementary terminals of the base 164 may include resilient spring clips that are structurally configured to receive and retain the terminals T_{1F} and T_{2F} of the fuse 102. The fuse terminals T_{1F} and T_{2F} may be provided in any shape and structural configuration, including but not necessarily limited to end caps or ferrules, knife blade contacts, or terminal blades. The complementary terminals on the fuse holder or fuse block

housing may accordingly be varied to mate with the terminals T_{1F} and T_{2F} of the fuse 102. Fuse rejection features may be built-in to the terminals T_{1F} and T_{2F} of the fuse 102 and/or may be incorporated into the housing 154 to prevent installation of an incompatible fuse. When the fuse 102 is installed, the switch 166 may be operated to connect or disconnect the electrical connection through the fuse element 120 and between the line-side and load-side circuitry 104, 106. As such, the switch 166 provides a connection and disconnection of the circuit path through the device 162 while the fuse 102 remains in place.

[0052] In the embodiment shown in Figure 9, the circuitry 110 is not provided in the housing 142 of the fuse 102, but is instead provided on or in the base 164 of the switch disconnect device 162. As such, the circuitry 110 in this embodiment is embedded in the base 162 instead of in the fuse 102. The operation of the circuitry 110, however, remains the same, and the label 143 and reader 144 may also be provided as described above with similar effect.

[0053] In an alternative embodiment wherein the circuitry 110 is embedded in the fuse 102 as described above in the system 140, the reader 144 could be embedded in the base 164.

[0054] The base 164 may be provided with multiple sets of terminals such that multiple sets of fuses 102 can be accommodated. The base 164 may be provided in a single piece or in multiple pieces, and may be provided in modular pieces that may be attached to one another. The base 164 may partly or completely enclose the fuse(s) 102 as desired.

[0055] Terminals T_{1L} and T_{2L} provided on the base 164 also include terminal features such as box lugs, spring clamps, or other terminals configured to accept and retain an end of a wire utilized to establish the line and load-side electrical connections to the disconnect switch device 162. Alternatively, panel mount clips and the like, as well as another terminal structure to establish mechanical and electrical connection to the line and load circuitry 104, 106 may be provided.

[0056] Figure 10 schematically illustrates the compensation circuitry 110 discussed in the embodiments above. The circuitry 110 includes a voltage/current source 170 and a power source or power supply 172. In the exemplary embodiments described, the voltage/current source corresponds to the element 122 (Figure 3), the element 124 (Figure 4), the element 126 (Figure 5), or the element 128 (Figure 6). In different embodiments, the power source 172 may be derived from the line-side of the electrical system 100, the power source 172 may be a stand-alone power-supply (e.g., and energy storage element such as a battery or supercapacitor), or the power supply 172 may correspond to a self-powered, power harvesting device. The power source 172 may optionally be coupled to the controller 112.

[0057] The controller 112 as shown includes a processor 174 and a memory storage 176 wherein executable instructions, commands, and control algorithms, as well as other data and information required to satisfactorily sense and calculate the current flowing the fuse 102 are stored. The memory 176 of the processor-based device may be, for example, a random access memory (RAM), and other forms of memory used in conjunction with RAM memory, including but not limited to flash memory (FLASH), programmable read only memory (PROM), and electronically erasable programmable read only memory (EEPROM).

[0058] As described above, when the controller 112 is provided an input for the voltage V_{sense} across the fuse 102 as shown and described in Figure 2 and in the more specific implementations shown and described in Figures 3-6, and optionally when the controller 112 is provided the input V_2 shown and described in the embodiments of Figures 4 and 5, the relationships derived from Ohm's law can be evaluated and applied in algorithmic form to determine the current I_{sense} as shown and described in Figure 2 and in the more specific implementations shown and described in Figures 3-6. It is understood, however, that as discussed above, the controller 112 in the circuitry 110 is optional when another controller, such as the controller 114 shown and described in Figure 2, is available to receive the voltage input(s) and make the calculations. It is likewise understood that in some embodiments the current

calculation is made by another processor-based entirely, such as the reader 144 or remote device 146 described above.

[0059] Figure 11 is a method flowchart illustrating exemplary processes associated with the current sensing techniques, systems, and circuitry shown in Figures 2-10.

[0060] As shown in Figure 11, the method includes at step 180 determining the algorithm to calculate the resistance, and also the current flowing through a non-linear resistance element such as the fuse element 120 in the embodiments described above. Exemplary relationships that may be implemented in algorithms are described above in relation to Figures 2-6. The embodiments described herein are, however, merely examples that are provided for the sake of illustration rather than limitation. Other relationships than those described can be used with circuitry other than that specifically described herein in further and/or alternative embodiments of the invention.

[0061] Once the algorithm is determined 182, it can be programmed in a processor-based device such as those described above. Having now described various specific implementation circuitry and relationships for exemplary algorithms, those in the art could implement and program the algorithm without further explanation. A plurality of algorithms are contemplated for specific use with respectively different types of fuses and different types of circuitry utilized to implement the measuring and calculation of the fuse element resistance.

[0062] At step 184, the current or voltage in the circuitry 110 is applied, which injects current or voltage that can be used to calculate the fuse resistance and the current as explained above.

[0063] At step 186, the voltage is sensed across the fuse element, and at step 188 the current may be calculated based on the sensed voltage utilizing the appropriate algorithm determined at step 182. In some cases, a second voltage such as the voltage V_2 shown and described in relation to the embodiments of Figures 4

and 5 may also be sensed and utilized to calculate the current. The actual calculation can be made by any of the processor-based devices described above.

[0064] As optionally shown at step 190, the method may further include reading a label 190 to obtain identifying information for the fuse and any information needed to make the calculation. Also, optionally shown as step 192 the method may include selecting the appropriate algorithm 192 based on information received from reading the label. In contemplated embodiments, the steps 190 and 192 may be performed by the reader device 140 and/or the remote device 146 described above. The steps 184, 186, 188, 190 and 192 may be repeated at regular or irregular time intervals to account for the non-linear resistance behavior of the fuse element.

[0065] As shown at step 194, the sensed voltage data may optionally be communicated to another device such as the reader device as described above. The calculated current may likewise be communicated at step 194 to another device such as the reader device or to a remote device according to the examples described above. Variations of the examples described are possible, however, as well as alternative embodiments that are extensions of the concepts disclosed herein.

[0066] The advantages and benefits of the invention are now believed to have been amply demonstrated in the exemplary embodiments disclosed.

[0067] An embodiment of an electrical current sensing system has been disclosed including: a conductor having a non-linear resistance when connected to an electrical power system; a compensation circuit connected in parallel with the conductor and configured to introduce at least one of a voltage and a current to the conductor; and a processor receiving a first voltage sensed across the conductor, the processor configured to determine a current flowing through the conductor based on the received first voltage.

[0068] Optionally, the conductor may be a fuse element. The fuse element may be contained in a fuse housing, and the compensation circuit may also be contained in the fuse housing. The sensing system in one embodiment may further include a fuse holder, and the compensation circuit may be provided on the fuse

holder. The sensing system in another embodiment may further include a disconnect switch, and the compensation circuit may be provided on the disconnect switch. The sensing system may include a reader device configured to communicate with the compensation circuitry, and may also include a label associated with the conductor, with the reader device configured to read the label and utilize information from the label to determine the current flowing through the conductor.

[0069] As further options, the compensation circuitry may include a stand-alone power supply, and the compensation circuit may be configured to introduce an alternating current to the conductor. The compensation circuit may include a voltage dividing resistor, wherein the processor receives a second voltage sensed across the voltage dividing resistor, and the processor device is configured to determine a current flowing through the conductor based on the received first and second voltages.

[0070] Another embodiment of an electrical current sensing system has been disclosed including: an electrical fuse including a housing, first and second terminal elements, and a fuse element having a non-linear resistance when connected to an electrical power system; a compensation circuit connected in parallel with the fuse element and configured to introduce at least one of a voltage and a current to the fuse element; and a processor receiving a first voltage sensed across the fuse element, the processor configured to determine a current flowing through the fuse element based on the received first voltage.

[0071] Optionally, the compensation circuit is contained in the fuse housing. The sensing system may further include a fuse holder, and the compensation circuit may be provided on the fuse holder. The electrical current sensing system may also include a disconnect switch, and the compensation circuit may be provided on the disconnect switch. The electrical current sensing system may further include a reader device configured to communicate with the compensation circuitry, and a label may be associated with the electrical fuse, the reader device configured to read the label and utilize information from the label to determine the current flowing through the conductor. The compensation circuit may include a voltage dividing resistor, wherein

the processor receives a second voltage sensed across the voltage dividing resistor, and the processor device is configured to determine a current flowing through the fuse element based on the received first and second voltages.

[0072] A method of sensing current in an electrical power system has also been disclosed. The method includes: providing a conductor having a non-linear resistance when connected to an electrical power system; connecting a compensation circuit in electrical parallel with the conductor; injecting one of a voltage or current to the conductor with the compensation circuit; sensing the voltage across the conductor; and calculating the current flowing through the conductor based on the sensed voltage across the conductor.

[0073] Optionally, providing the conductor having a non-linear resistance when connected to an electrical power system includes providing an electrical fuse including a fuse element, and wherein connecting the compensation circuit in electrical parallel with the conductor comprises connecting the compensation circuit in electrical parallel with the fuse element. The fuse may include a fuse housing, and connecting the compensation circuit in electrical parallel with the fuse element may include connecting the compensation circuit inside the fuse housing.

[0074] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims. E

WHAT IS CLAIMED IS:

1. An electrical current sensing system comprising:
 - a conductor having a non-linear resistance when connected to an electrical power system;
 - a compensation circuit connected in parallel with the conductor and
 - 5 configured to introduce at least one of a voltage and a current to the conductor; and
 - a processor receiving a first voltage sensed across the conductor, the processor configured to determine a current flowing through the conductor based on the received first voltage.
2. The electrical current sensing system of claim 1, wherein the conductor is a fuse element.
3. The electrical current sensing system of claim 2, wherein the fuse element is contained in a fuse housing, and the compensation circuit is also contained in the fuse housing.
4. The electrical current sensing system of claim 2, further comprising a fuse holder, and the compensation circuit provided on the fuse holder.
5. The electrical current sensing system of claim 2, further comprising a disconnect switch, and the compensation circuit provided on the disconnect switch.
6. The electrical current sensing system of claim 1, further comprising a reader device configured to communicate with the compensation circuit.
7. The electrical current sensing system of claim 6, further comprising a label associated with the conductor, the reader device configured to read the label and utilize information from the label to determine the current flowing through the conductor.

8. The electrical current sensing system of claim 1, wherein the compensation circuit includes a stand-alone power supply.

9. The electrical current sensing system of claim 1, wherein the compensation circuit is configured to introduce an alternating current to the conductor.

10. The electrical current sensing system of claim 1, wherein the compensation circuit includes a voltage dividing resistor, wherein the processor receives a second voltage sensed across the voltage dividing resistor, and the processor device is configured to determine a current flowing through the conductor
5 based on the received first and second voltages.

11. An electrical current sensing system comprising:

an electrical fuse including a housing, first and second terminal elements, and a fuse element having a non-linear resistance when connected to an electrical power system;

5 a compensation circuit connected in parallel with the fuse element and configured to introduce at least one of a voltage and a current to the fuse element; and

a processor receiving a first voltage sensed across the fuse element, the processor configured to determine a current flowing through the fuse element based on the received first voltage.

12. The electrical current sensing system of claim 11, wherein the compensation circuit is contained in the housing.

13. The electrical current sensing system of claim 11, further comprising a fuse holder, and the compensation circuit provided on the fuse holder.

14. The electrical current sensing system of claim 11, further comprising a disconnect switch, and the compensation circuit provided on the disconnect switch.

15. The electrical current sensing system of claim 11, further comprising a reader device configured to communicate with the compensation circuit.

16. The electrical current sensing system of claim 15, further comprising a label associated with the electrical fuse, the reader device configured to read the label and utilize information from the label to determine the current flowing through the fuse element.

17. The electrical current sensing system of claim 11, wherein the compensation circuit includes a voltage dividing resistor, wherein the processor receives a second voltage sensed across the voltage dividing resistor, and the processor device is configured to determine a current flowing through the conductor
5 based on the received first and second voltages.

18. A method of sensing current in an electrical power system, the method comprising:

providing a conductor having a non-linear resistance when connected to an electrical power system;

5 connecting a compensation circuit in electrical parallel with the conductor;

injecting one of a voltage or current to the conductor with the compensation circuit;

sensing the voltage across the conductor; and

10 calculating the current flowing through the conductor based on the sensed voltage across the conductor.

19. The method of claim 18, wherein providing the conductor having a non-linear resistance when connected to an electrical power system comprises providing an electrical fuse including a fuse element, and wherein connecting the

compensation circuit in electrical parallel with the conductor comprises connecting
5 the compensation circuit in electrical parallel with the fuse element.

20. The method of claim 19, wherein the fuse includes a fuse housing,
and wherein connecting the compensation circuit in electrical parallel with the fuse
element comprises connecting the compensation circuit inside the fuse housing.

1/6

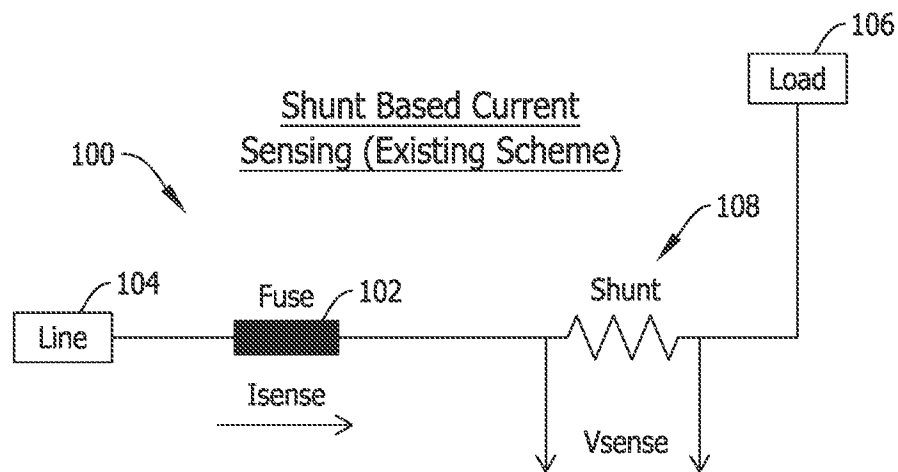


FIG. 1
Prior Art

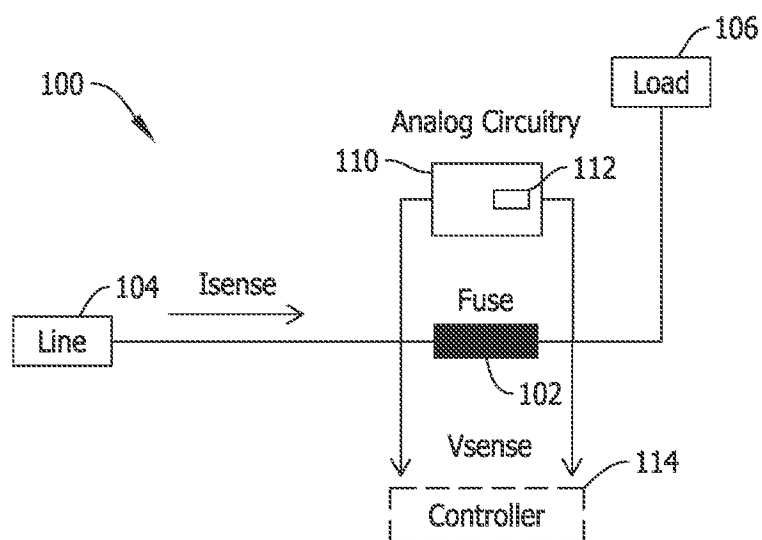


FIG. 2

2/6

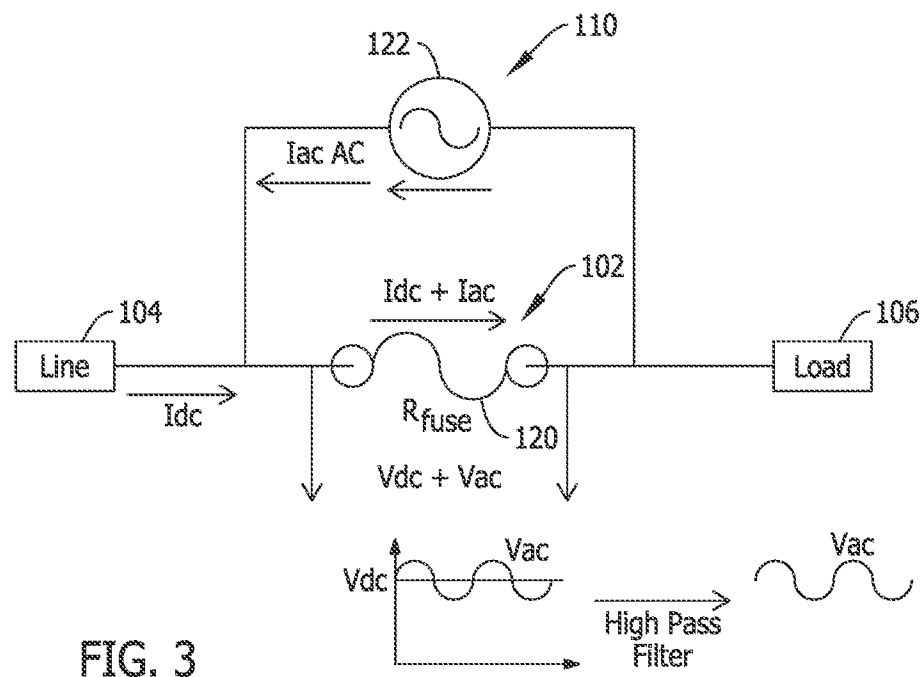


FIG. 3

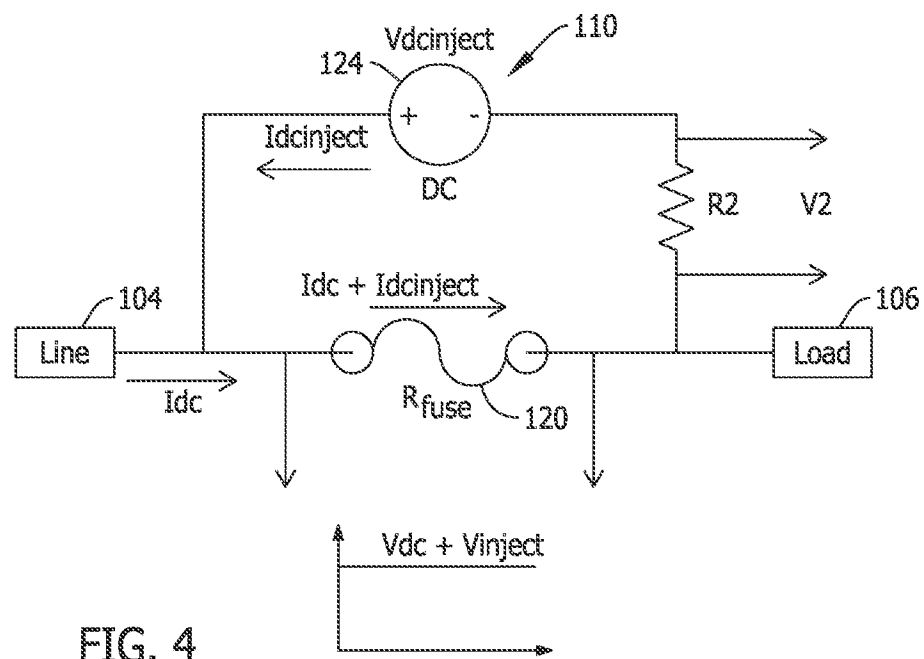


FIG. 4

3/6

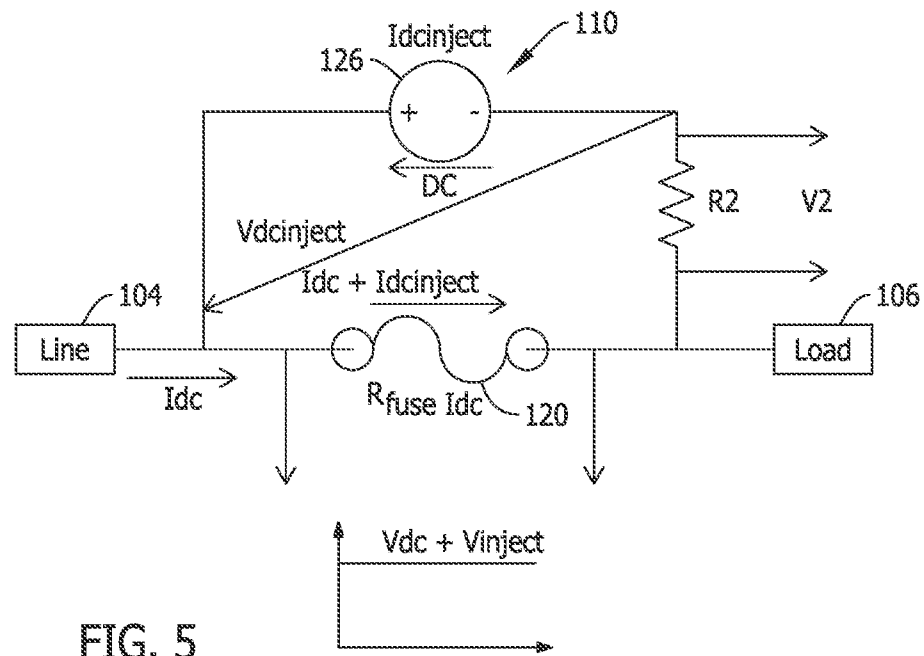


FIG. 5

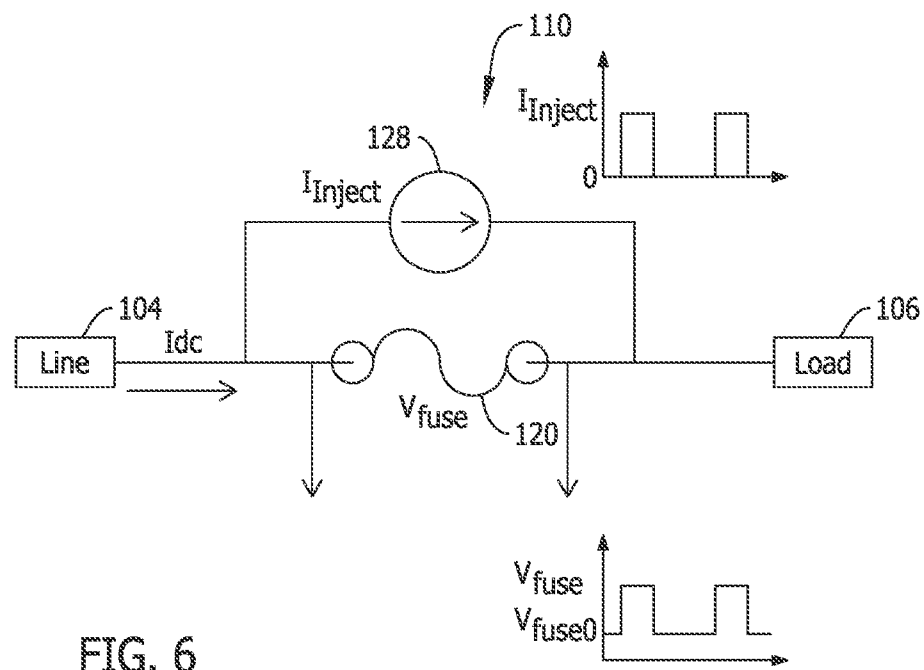


FIG. 6

4/6

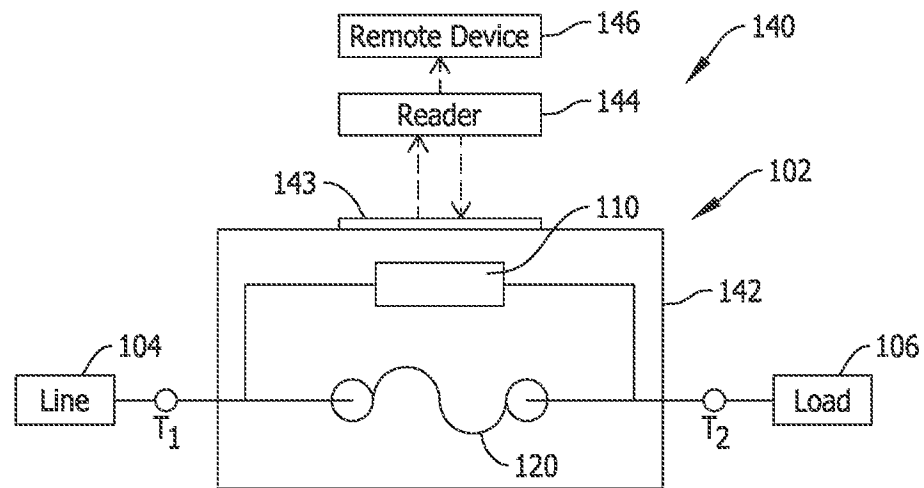


FIG. 7

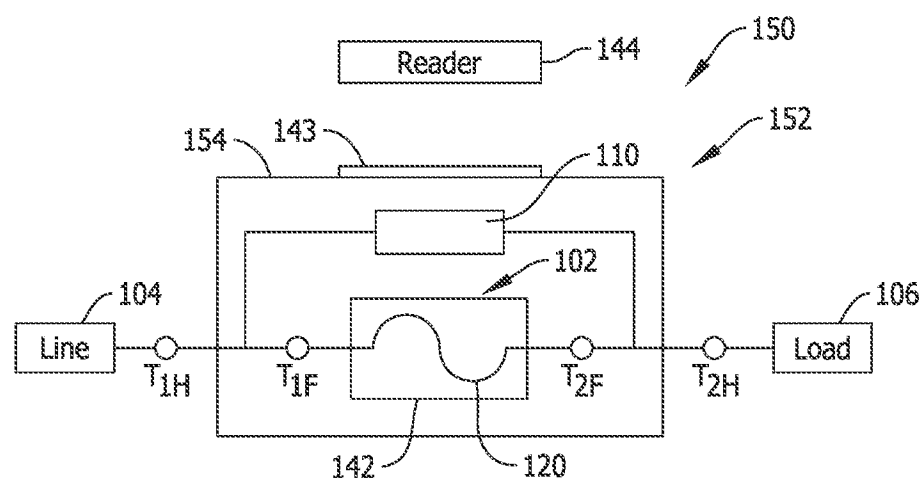


FIG. 8

5/6

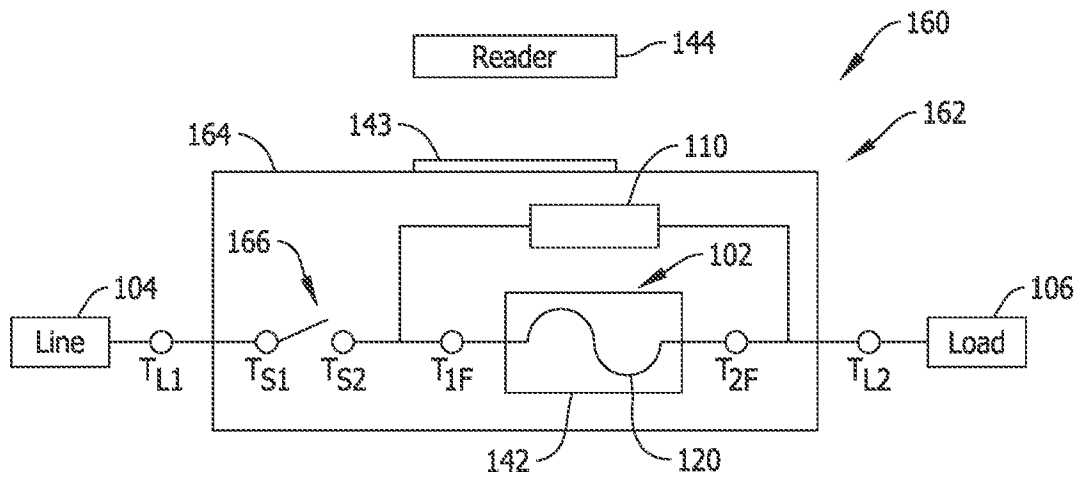


FIG. 9

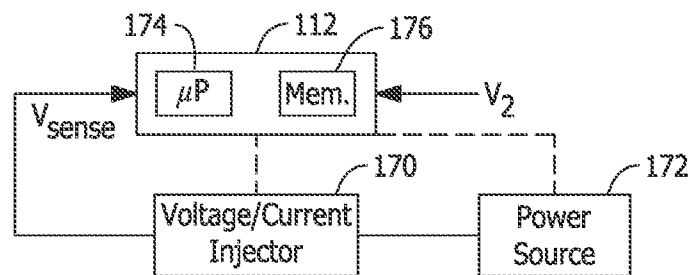


FIG. 10

6/6

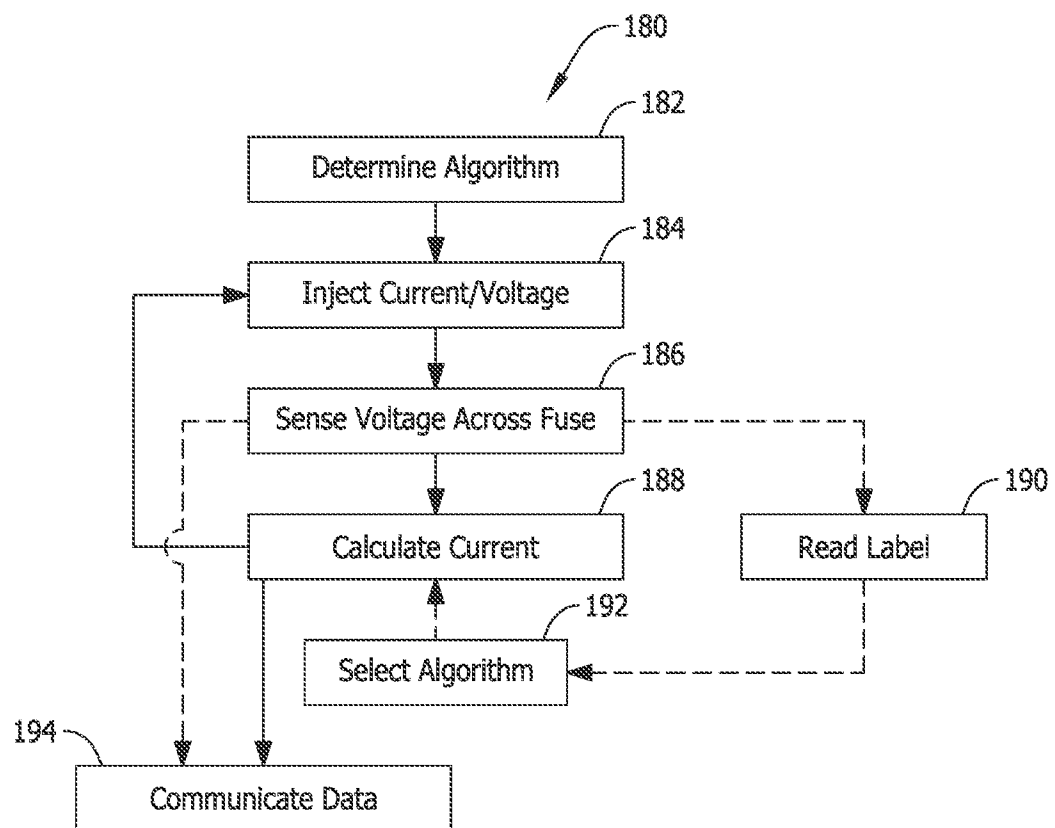


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/041458

A. CLASSIFICATION OF SUBJECT MATTER INV. G01R27/16 G11C29/02 G11C29/50 G01R1/04 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) G01R G11C		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data, INSPEC		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010/283491 A1 (ZUREK STANISLAW [GB] ET AL) 11 November 2010 (2010-11-11) abstract; claims 1-17; figures 1-14b paragraph [0012] - paragraph [0031] paragraph [0032] - paragraph [0051] paragraph [0069] - paragraph [0105] -----	1-20
X	US 2005/280405 A1 (BRAY DAVID M [GB]) 22 December 2005 (2005-12-22) abstract; claims 1-20; figures 1-12 paragraph [0005] - paragraph [0014] paragraph [0028] - paragraph [0059] -----	18-20
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 17 October 2016		Date of mailing of the international search report 28/10/2016
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Nadal, Rafael

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2016/041458

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2010283491	A1	11-11-2010	EP 2249169 A1 10-11-2010
			EP 2249170 A1 10-11-2010
			US 2010283491 A1 11-11-2010

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