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(54) **SAFETY MECHANISMS, WAKE UP AND SHUTDOWN METHODS IN DISTRIBUTED POWER INSTALLATIONS**

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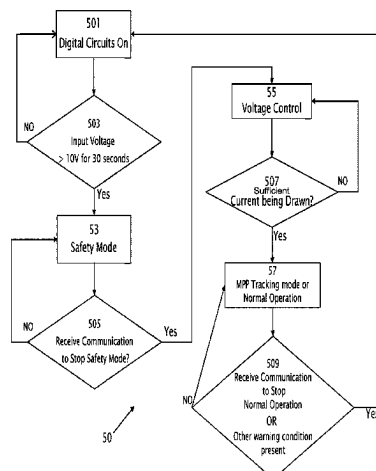
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(57) **ABSTRACT**

A distributed power system including multiple DC power sources and multiple power modules. The power modules include inputs coupled respectively to the DC power sources and outputs coupled in series to form a serial string. An inverter is coupled to the serial string. The inverter converts power input from the serial string to output power. A signaling mechanism between the inverter and the power module is adapted for controlling operation of the power modules. Also, for a protection method in the distributed power system, when the inverter stops production of the output power, each of the power modules is shut down and thereby the power input to the inverter is ceased.

**24 Claims, 15 Drawing Sheets**



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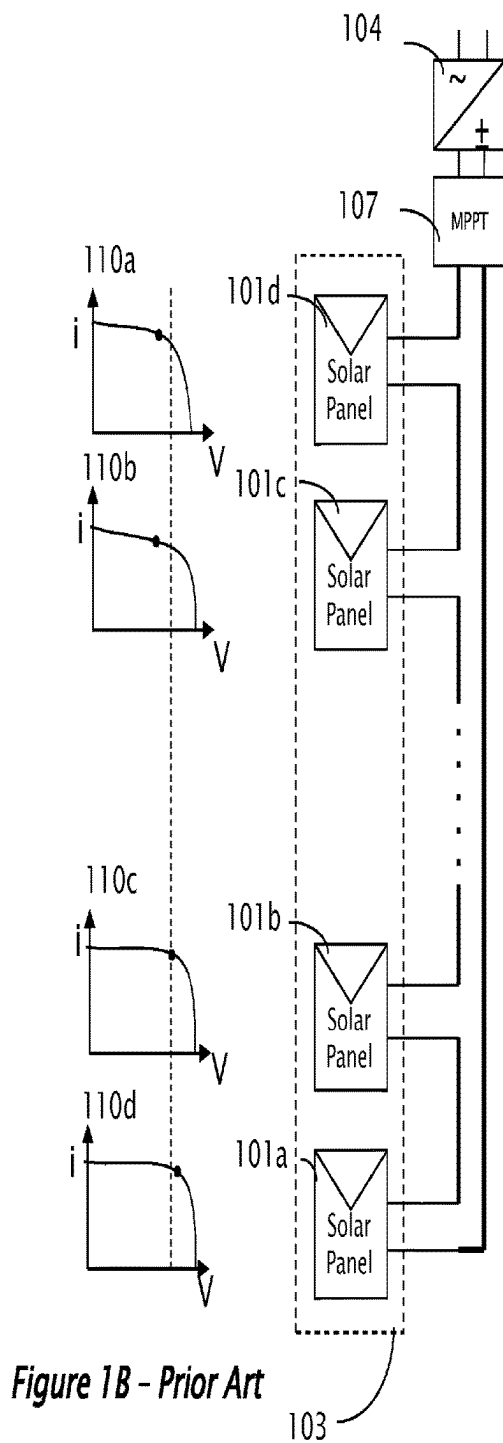
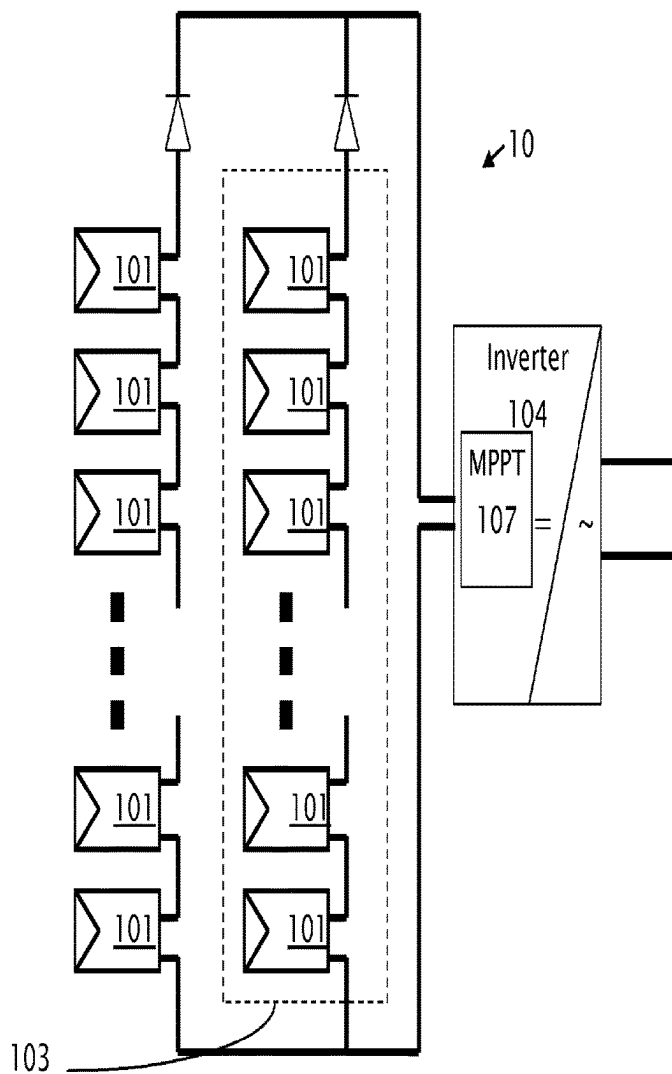
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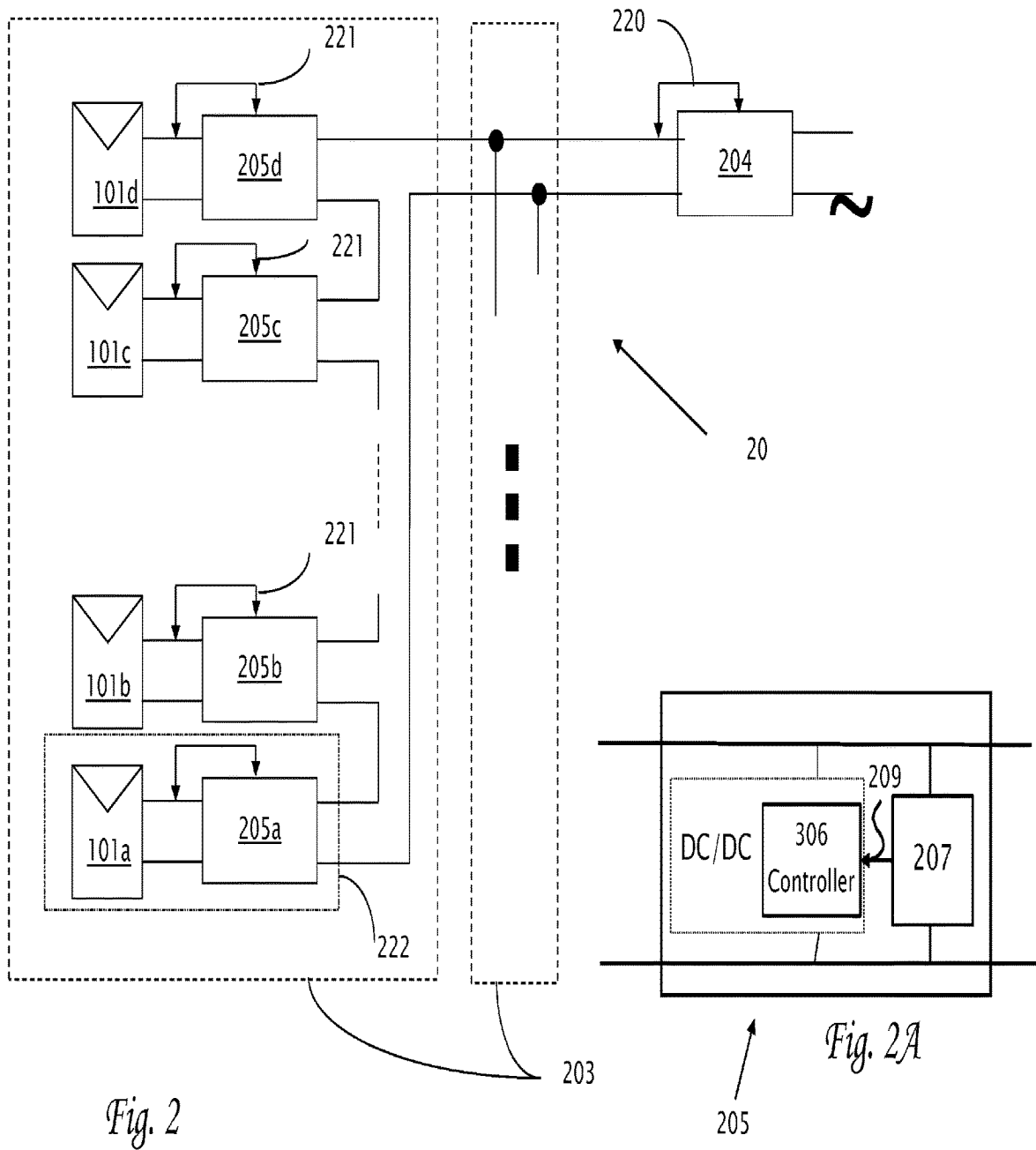
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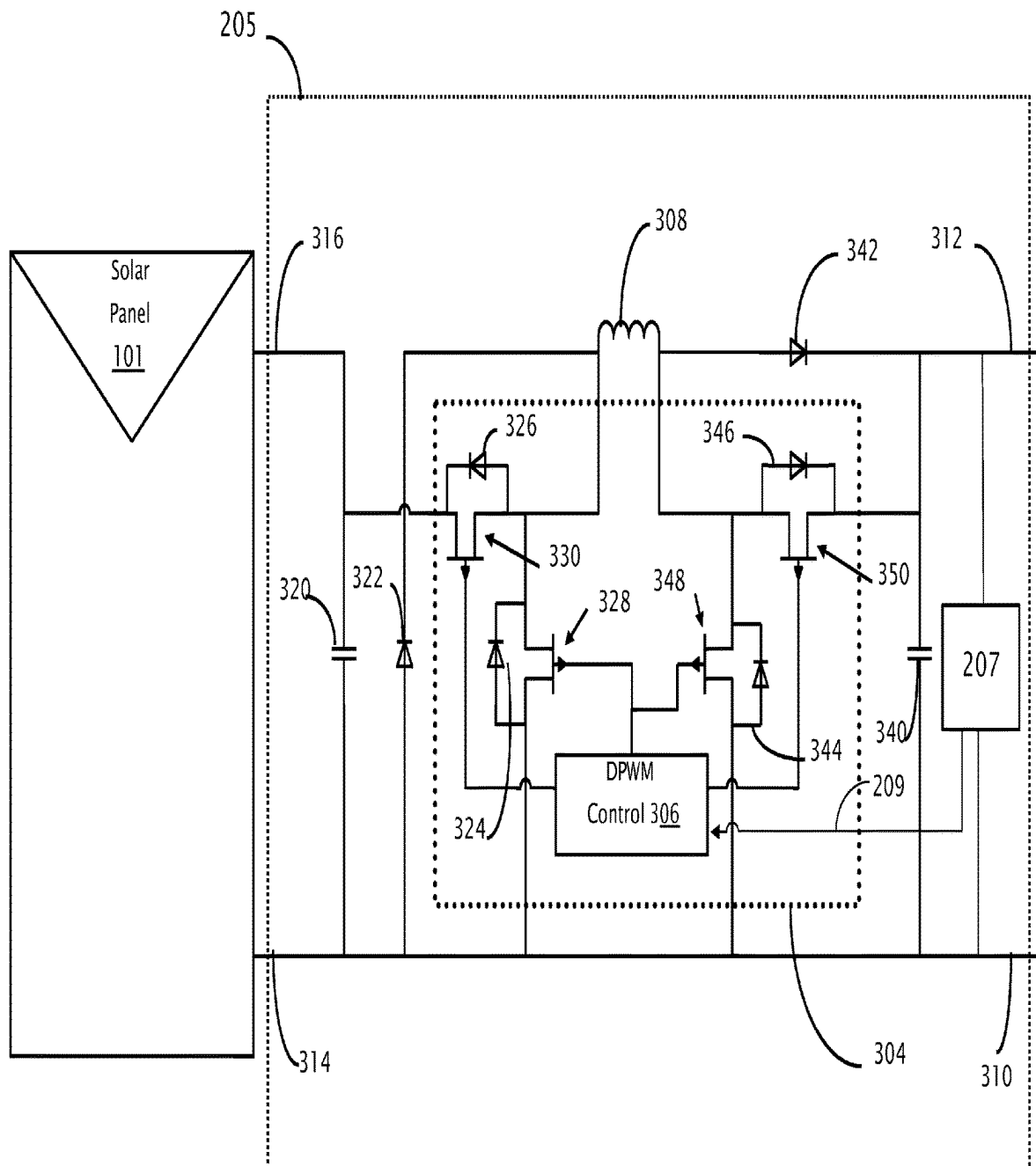
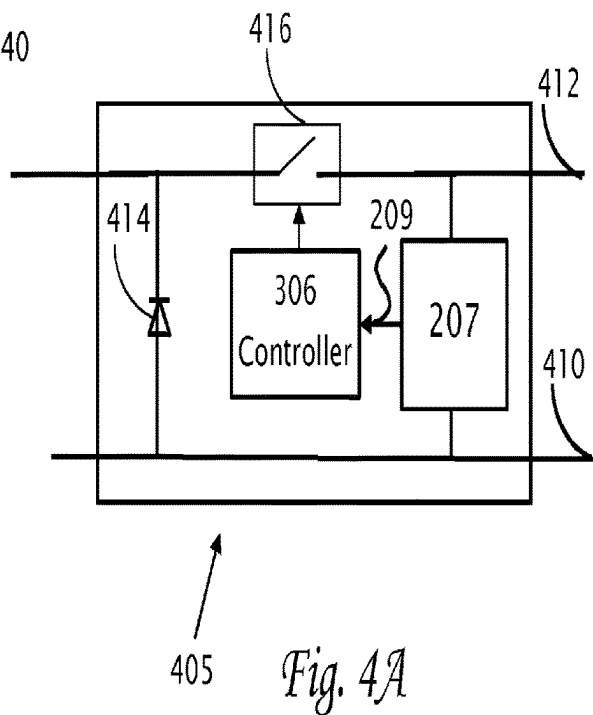
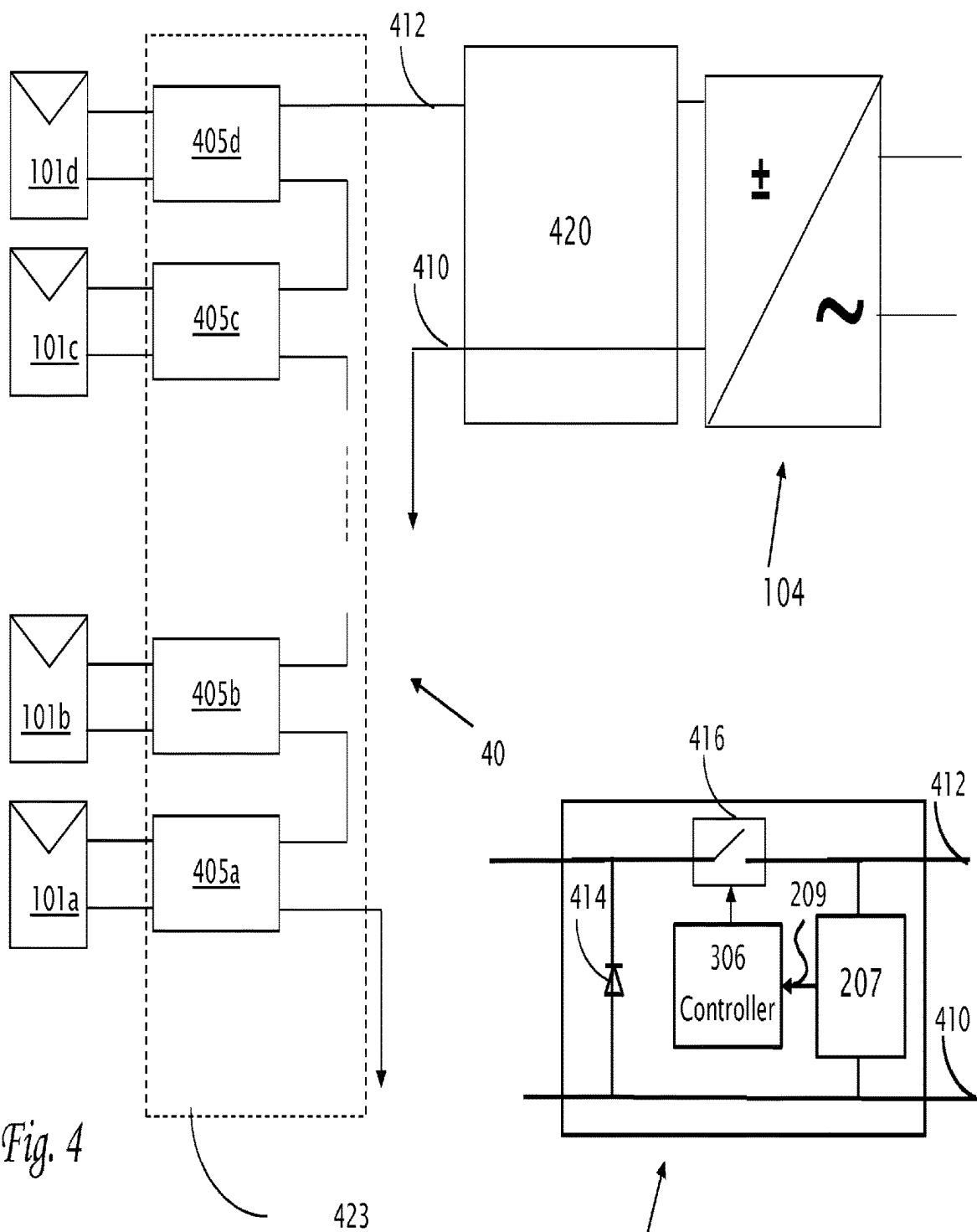


Fig. 3



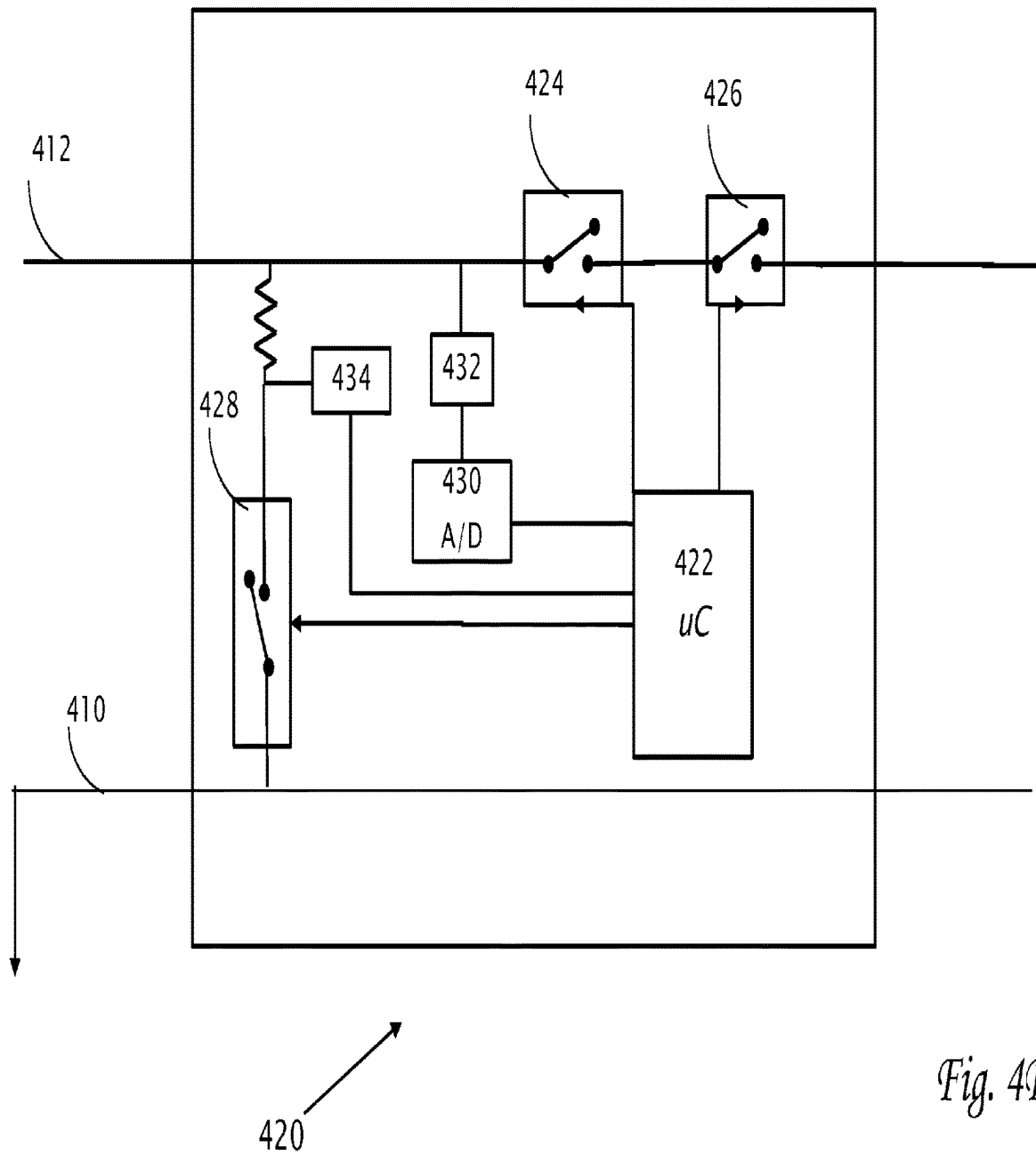
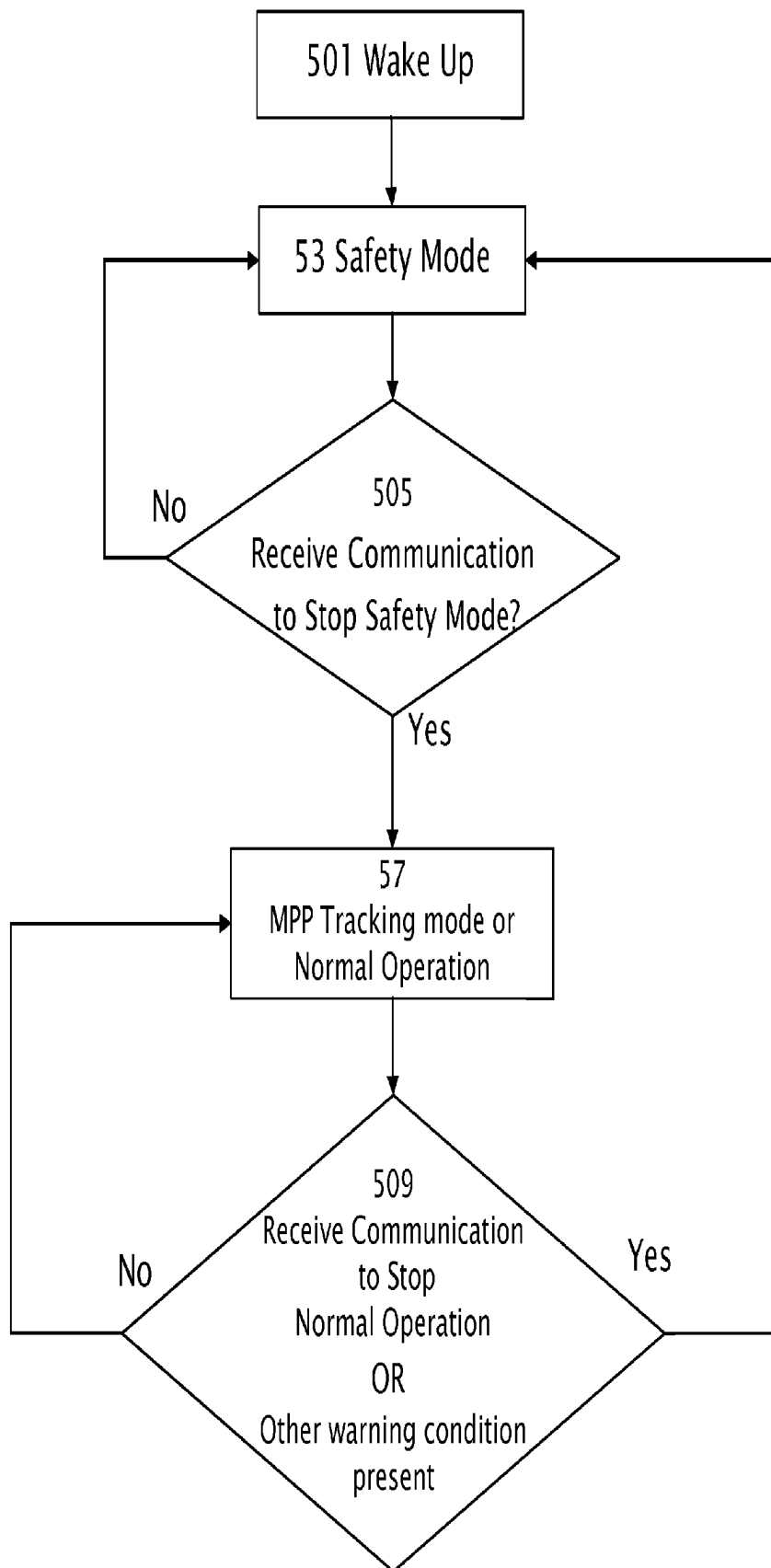
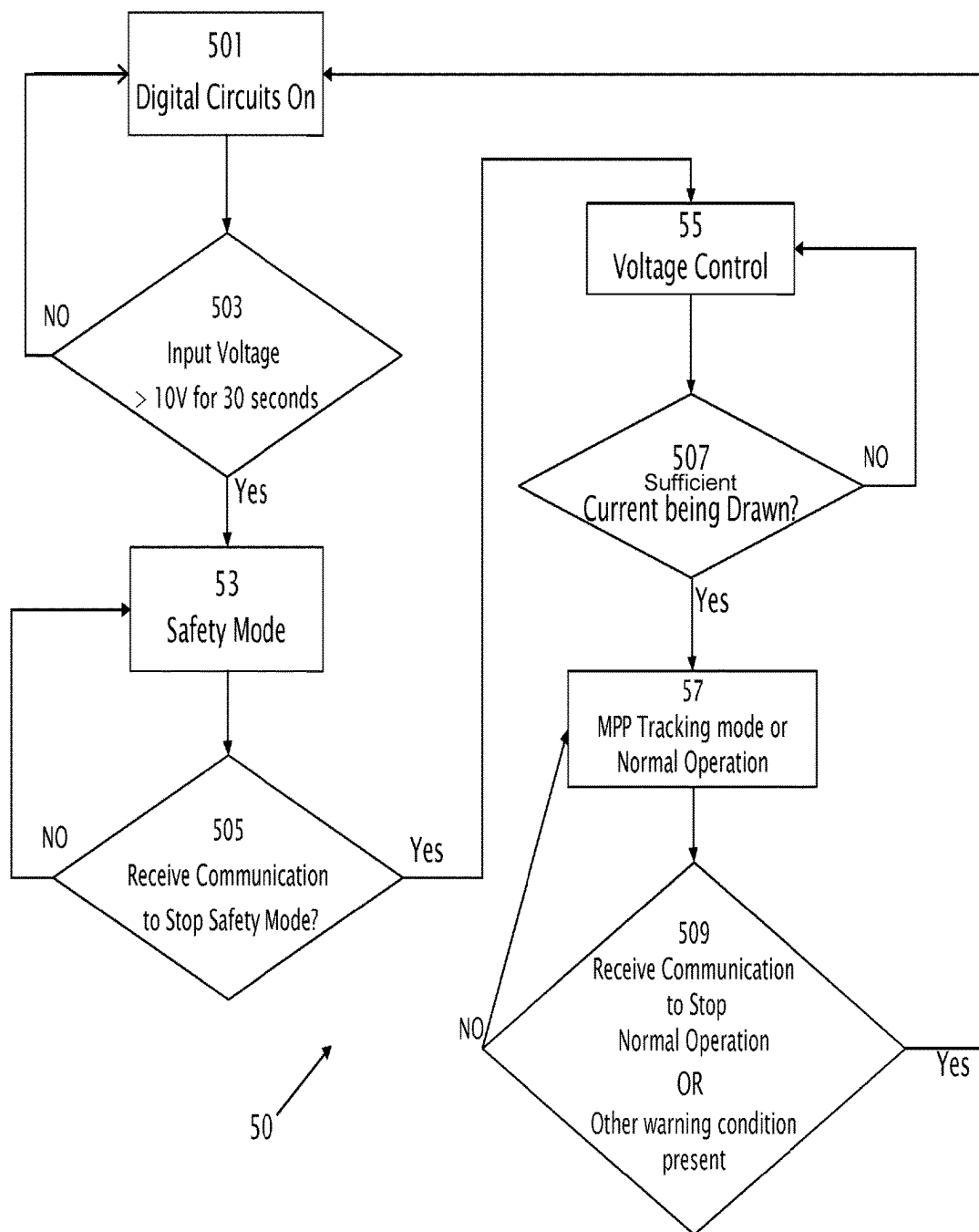


Fig. 4B

*Fig. 5*



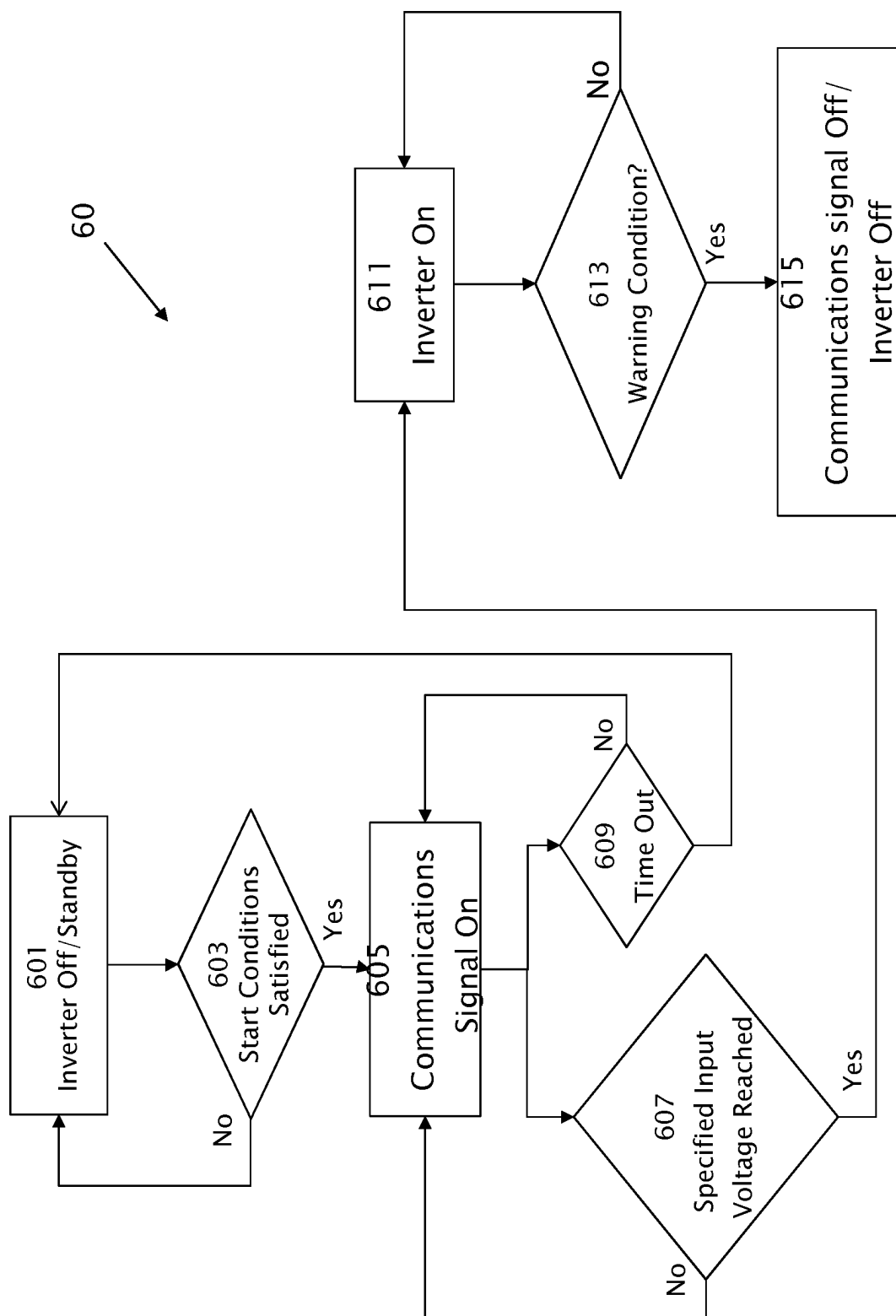
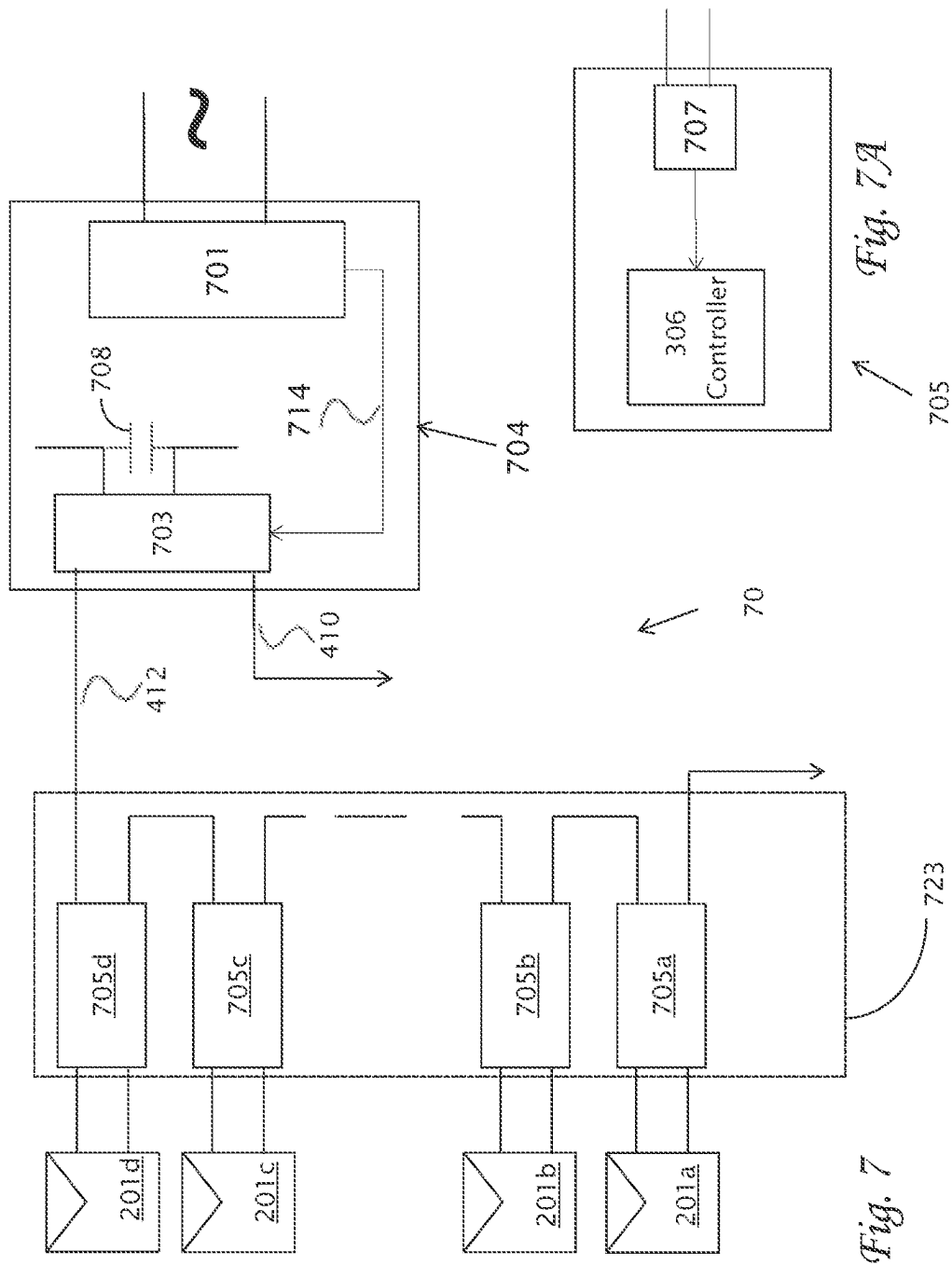


Fig. 6





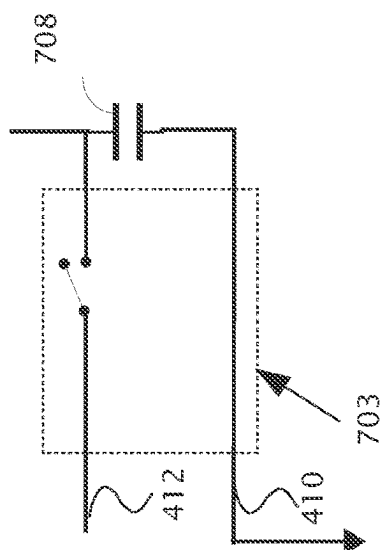


Figure 7B

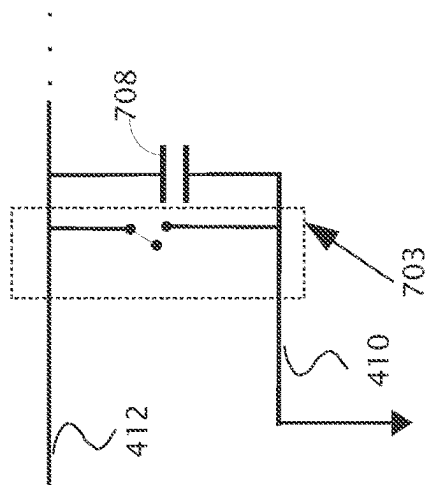


Figure 7C

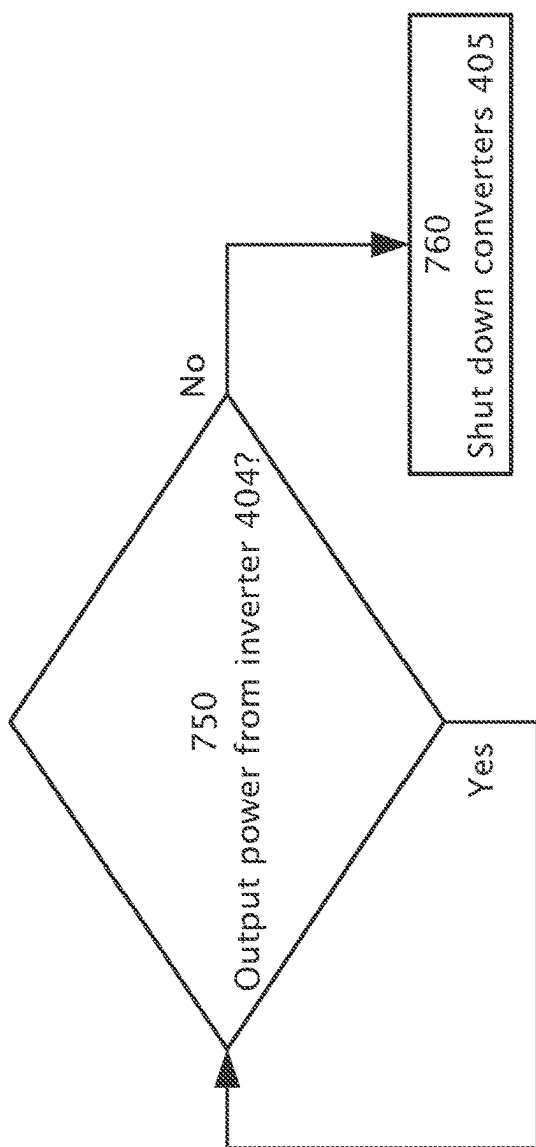
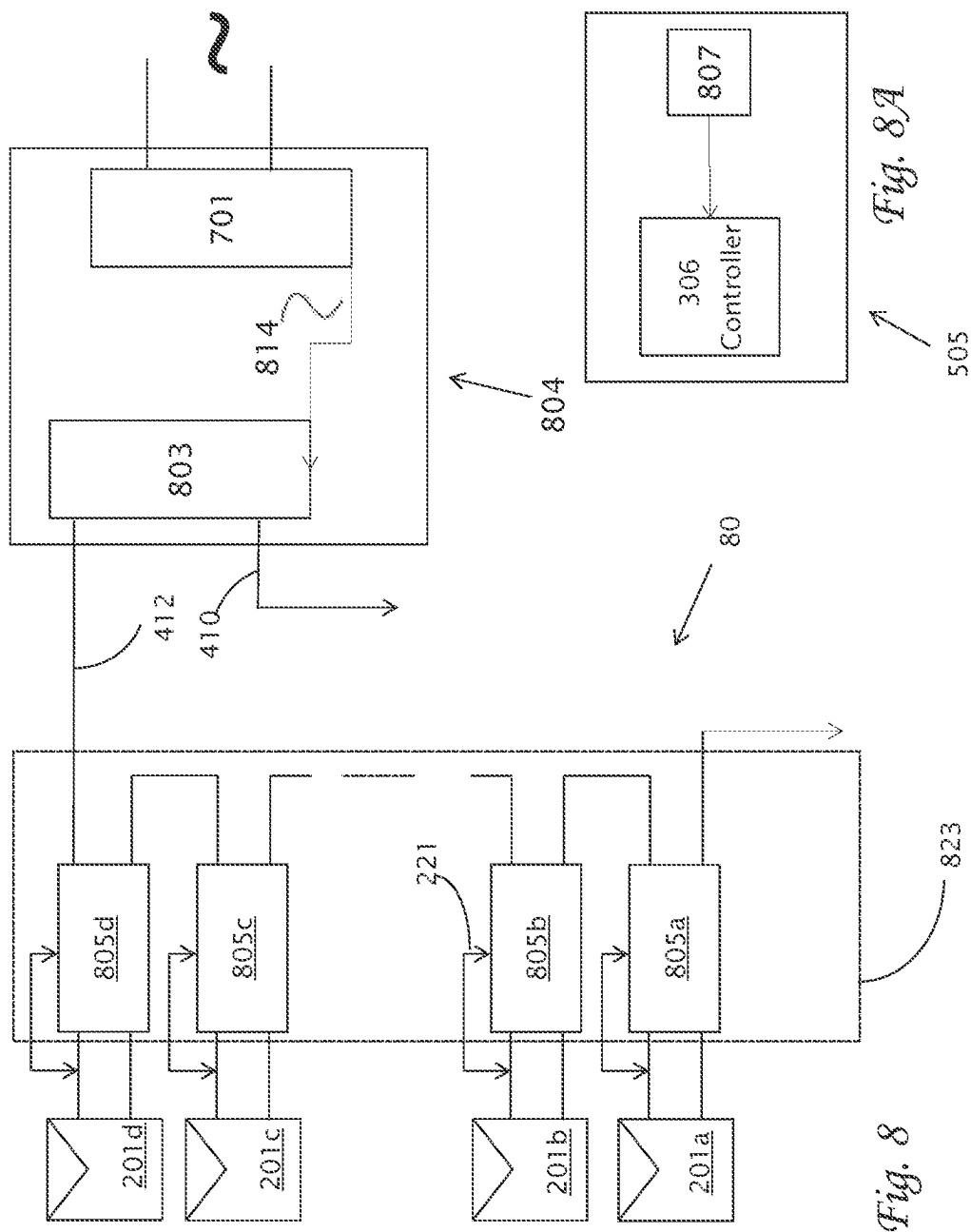


Fig. 7D



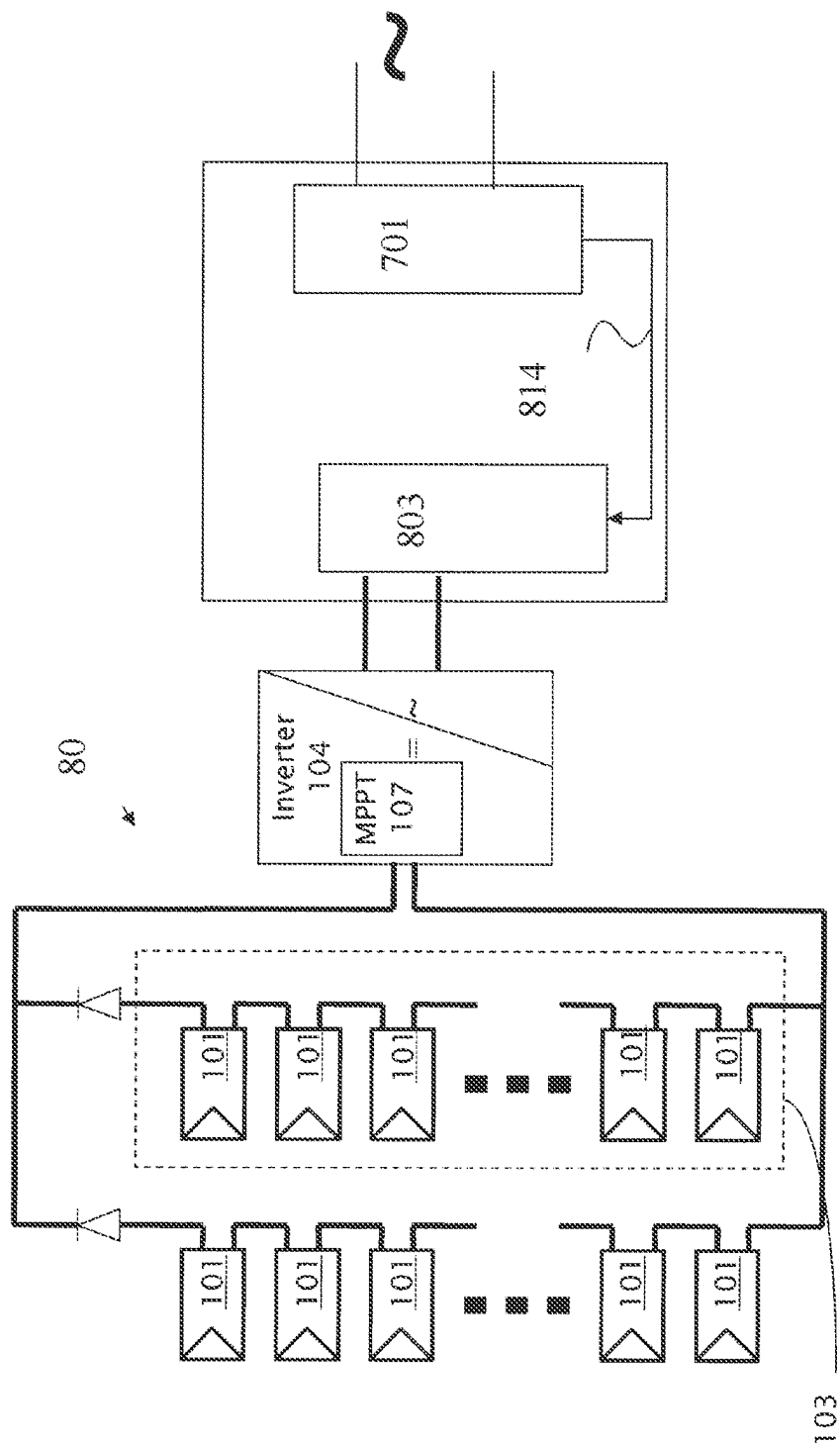
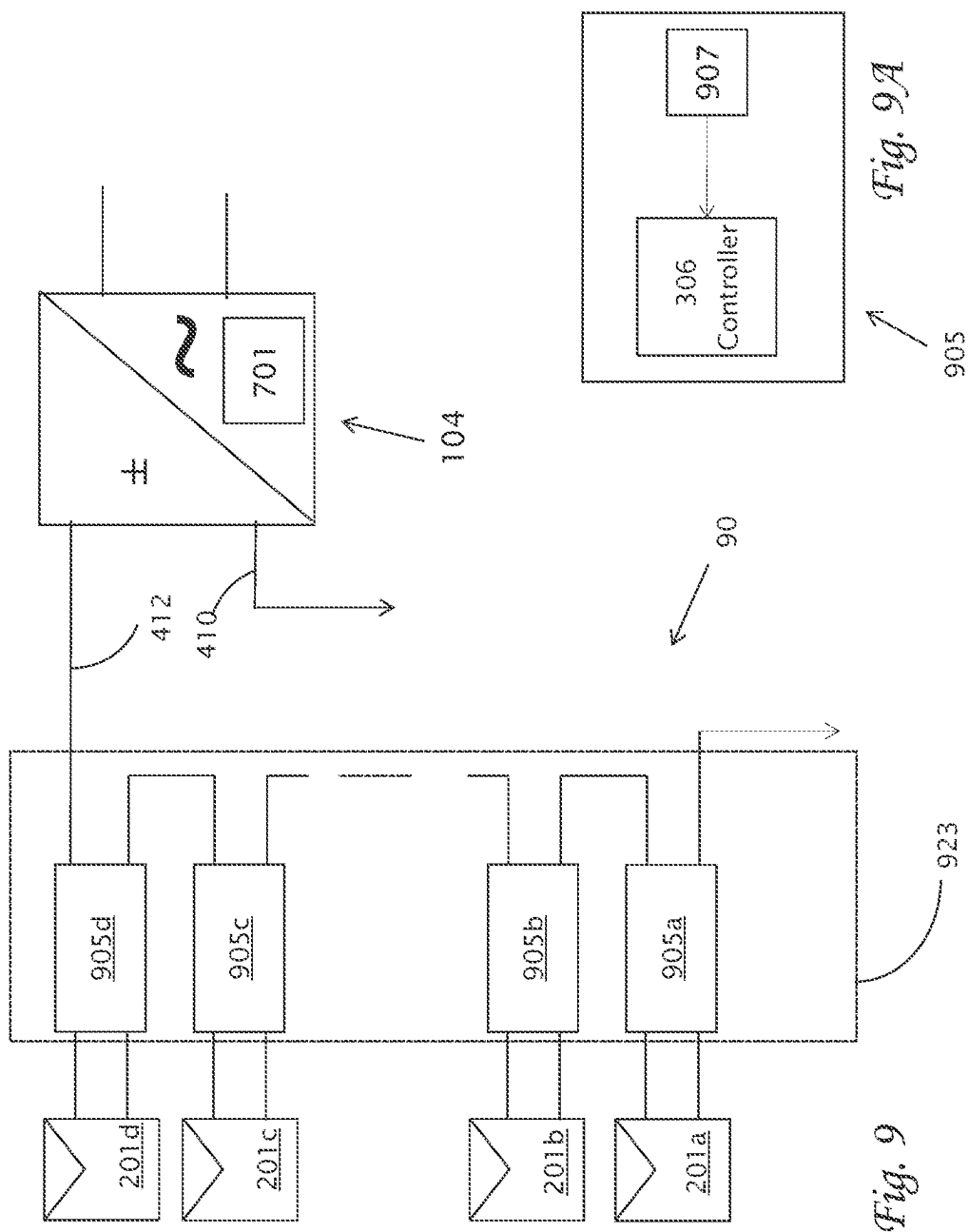


Figure 8B



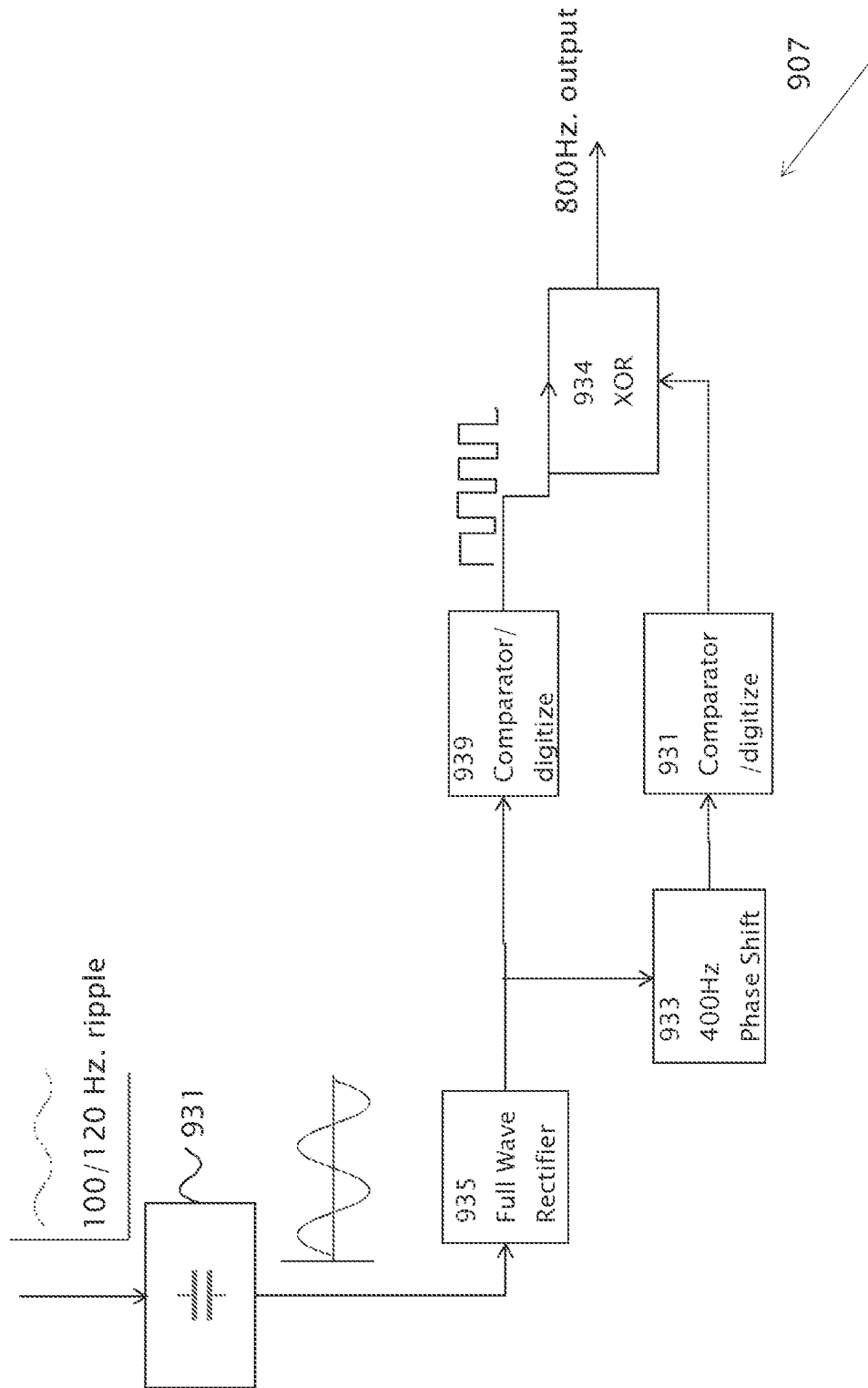
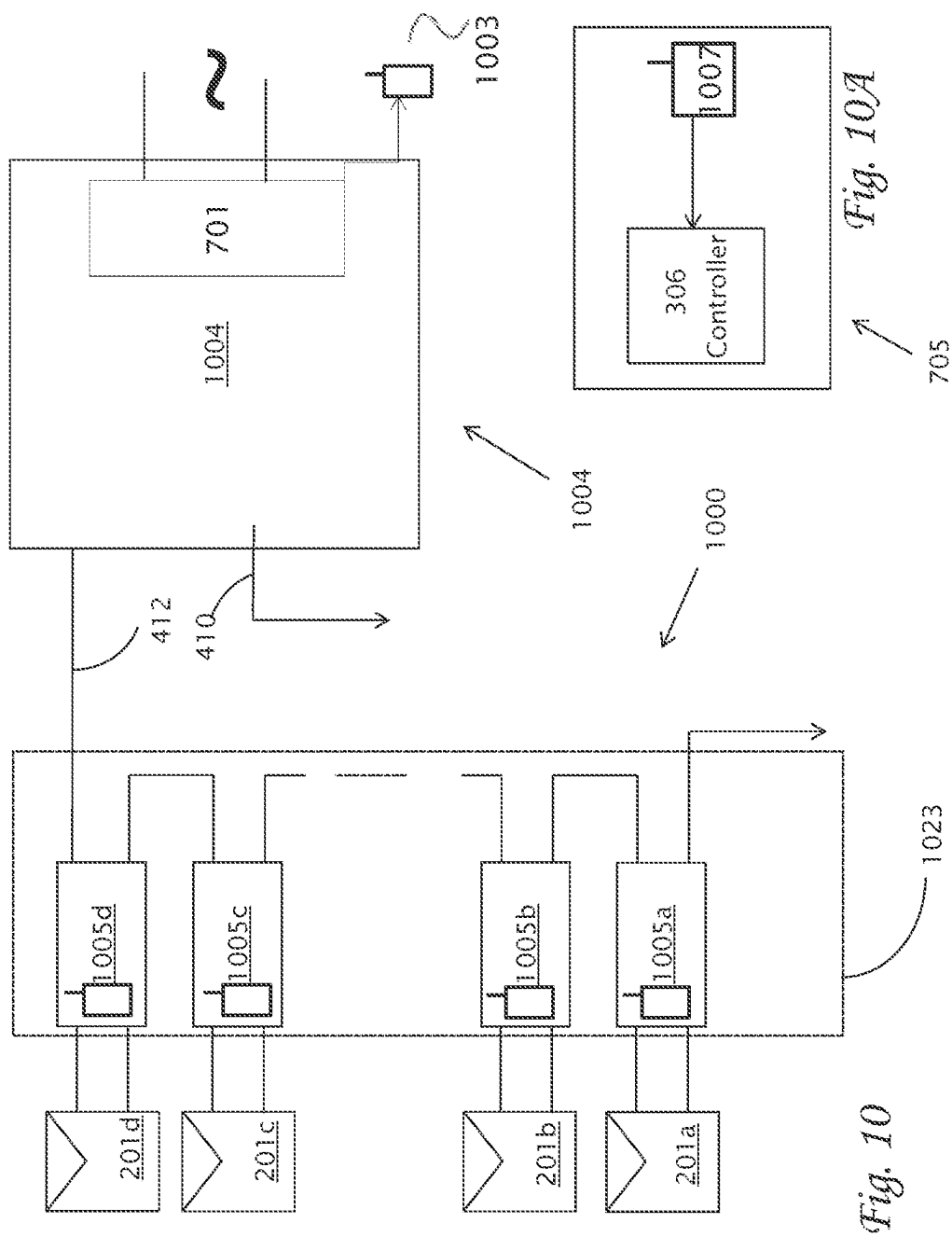


Fig. 9B



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# SAFETY MECHANISMS, WAKE UP AND SHUTDOWN METHODS IN DISTRIBUTED POWER INSTALLATIONS

## CROSS REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of U.S. application Ser. No. 15/369,881, filed Dec. 5, 2016, which is a continuation-in-part of U.S. application Ser. No. 13/372,009, filed Feb. 13, 2012 (now U.S. Pat. No. 9,590,526), which is a continuation of U.S. application Ser. No. 12/329,525, filed Dec. 5, 2008 (now U.S. Pat. No. 8,531,055), which claims the benefit of U.S. Provisional Application Ser. No. 60/992,589, filed Dec. 5, 2007. U.S. application Ser. No. 12/329,525, filed Dec. 5, 2008 is a continuation-in-part of U.S. application Ser. No. 11/950,271, filed Dec. 4, 2007 (now U.S. Pat. No. 9,088,178), which claims the benefit of each of U.S. Provisional Application Ser. No. 60/916,815, filed May 9, 2007, U.S. Provisional Application Ser. No. 60/908,095, filed Mar. 26, 2007, U.S. Provisional Application No. 60/868,962, filed Dec. 7, 2006, U.S. Provisional Application No. 60/868,851, filed Dec. 6, 2006, and U.S. Provisional Application No. 60/868,893, filed Dec. 6, 2006. U.S. application Ser. No. 15/369,881 also is a continuation-in-part of U.S. application Ser. No. 14/323,531, filed Jul. 3, 2014 (now U.S. Pat. No. 9,960,667), which is a continuation of U.S. application Ser. No. 12/328,742, filed Dec. 4, 2008 (now U.S. Pat. No. 8,816,535), which is a continuation-in-part of U.S. application Ser. No. 11/950,271, filed Dec. 4, 2007. Each of the above-mentioned disclosures are incorporated herein by reference in their entireties and for all purposes.

## FIELD AND BACKGROUND

The present invention relates to distributed power systems and, more particularly, wake-up and shutdown algorithms for the photovoltaic distributed power systems. The present invention also relates to anti-islanding in a distributed power system and, more particularly, system and method for protection of photovoltaic distributed power equipment and personnel during anti-islanding.

Utility networks provide an electrical power system to utility customers. The distribution of electric power from utility companies to customers utilizes a network of utility lines connected in a grid-like fashion, referred to as an electrical grid. The electrical grid may consist of many independent energy sources energizing the grid in addition to utility companies energizing the grid, with each independent energy source being referred to as a distributed power (DP) generation system. The modern utility network includes the utility power source, consumer loads, and the distributed power generation systems which also supply electrical power to the network. The number and types of distributed power generation systems is growing rapidly and can include photovoltaics, wind, hydro, fuel cells, storage systems such as battery, super-conducting flywheel, and capacitor types, and mechanical devices including conventional and variable speed diesel engines, Stirling engines, gas turbines, and micro-turbines. These distributed power generation systems are connected to the utility network such that they operate in parallel with the utility power sources.

One common problem faced by modern utility networks is the occurrence of islanding. Islanding is the condition where a distributed power generation system is severed from the utility network, but continues to supply power to por-

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tions of the utility network after the utility power supply is disconnected from those portions of the network. All photovoltaic systems must have anti islanding detection in order to comply with safety regulations. Otherwise the photovoltaic installation may shock or electrocute repairmen after the grid is shut down from the photovoltaic installation generating power as an island downstream. The island condition complicates the orderly reconnection of the utility network and poses a hazard also to equipment. Thus, it is important for an island condition to be detected and eliminated.

Several techniques have been proposed to guard against islanding. For example, one method involves the monitoring of auxiliary contacts on all circuit breakers of the utility system between its main source of generation and DP systems. The auxiliary contacts are monitored for a change of state which represents an open circuit breaker on the utility source. The utility circuit breaker is typically monitored and tripped by external protective relays. When a loss of utility is detected by the change in state of the auxiliary contact of a circuit breaker, a transferred trip scheme is employed to open the interconnection between the utility and the distributed power system. A transferred trip scheme uses the auxiliary contacts of the utility source being monitored. The auxiliary contacts are connected in parallel with other devices which can trigger the trip of the local interconnection breaker. When the auxiliary contacts change state, a trip is induced on the local interconnection breaker. This prevents an island condition from occurring. The drawback of such a method is that often the point of utility isolation (the point at which the utility circuit breaker opens) is of such a distance from the local distributed power system that running a contact status signal back to the local distributed power system control system is not practical.

Anti-islanding schemes presently used or proposed include passive schemes and active schemes. Passive schemes are based on local monitoring of the grid signals, such as under or over voltage, under or over frequency, rate of change of frequency, phase jump, or system harmonics, for example. Active schemes are based on active signal injection with monitoring of the resulting grid signals, such as impedance measurement for example, or active signal injection with active controls, such as active frequency shifting or active voltage shifting for example. With active schemes, some distortion may occur in the output current waveform, thereby resulting in a tradeoff between islanding detection time and waveform distortion, with faster detection typically resulting in higher total harmonic distortion.

A conventional installation of a solar distributed power system **10**, including multiple solar panels **101**, is illustrated in FIG. 1. Since the voltage provided by each individual solar panel **101** is low, several panels **101** are connected in series to form a string **103** of panels **101**. For a large installation, when higher current is required, several strings **103** may be connected in parallel to form overall system **10**. The interconnected solar panels **101** are mounted outdoors, and connected to a maximum power point tracking (MPPT) module **107** and then to an inverter **104**. MPPT **107** is typically implemented as part of inverter **104** as shown in FIG. 1. The harvested power from DC sources **101** is delivered to inverter **104**, which converts the direct-current (DC) into alternating-current (AC) having a desired voltage and frequency, which is usually 110V or 220V at 60 Hz, or 220V at 50 Hz. The AC current from inverter **104** may then be used for operating electric appliances or fed to the power grid.

As noted above, each solar panel **101** supplies relatively very low voltage and current. A problem facing the solar



array designer is to produce a standard AC current at 120V or 220V root-mean-square (RMS) from a combination of the low voltages of the solar panels. The delivery of high power from a low voltage requires very high currents, which cause large conduction losses on the order of the second power of the current  $i^2$ . Furthermore, a power inverter, such as inverter **104**, which is used to convert DC current to AC current, is most efficient when its input voltage is slightly higher than its output RMS voltage multiplied by the square root of 2 (which is the peak voltage). Hence, in many applications, the power sources, such as solar panels **101**, are combined in order to reach the correct voltage or current. A large number of panels **101** are connected into a string **103** and strings **103** are connected in parallel to power inverter **104**. Panels **101** are connected in series in order to reach the minimal voltage required for inverter **104**. Multiple strings **103** are connected in parallel into an array to supply higher current, so as to enable higher power output.

FIG. **1B** illustrates one serial string **103** of DC sources, e.g., solar panels **101a-101d**, connected to MPPT circuit **107** and inverter **104**. The current versus voltage (IV) characteristics is plotted (**110a-110d**) to the left of each DC source **101**. For each DC power source **101**, the current decreases as the output voltage increases. At some voltage value, the current goes to zero, and in some applications the voltage value may assume a negative value, meaning that the source becomes a sink. Bypass diodes (not shown) are used to prevent the source from becoming a sink. The power output of each source **101**, which is equal to the product of current and voltage ( $P=i*V$ ), varies depending on the voltage drawn from the source. At a certain current and voltage, close to the falling off point of the current, the power reaches its maximum. It is desirable to operate a power generating cell at this maximum power point (MPP). The purpose of the MPPT is to find this point and operate the system at this point so as to draw the maximum power from the sources.

In a typical, conventional solar panel array, different algorithms and techniques are used to optimize the integrated power output of system **10** using MPPT module **107**. MPPT module **107** receives the current extracted from all of solar panels **101** together and tracks the maximum power point for this current to provide the maximum average power such that if more current is extracted, the average voltage from the panels starts to drop, thus lowering the harvested power. MPPT module **107** maintains a current that yields the maximum average power from system **10**.

However, since power sources **101a-101d** are connected in series to single MPPT **107**, MPPT **107** selects a maximum power point which is some average of the maximum power points of the individual serially connected sources **101**. In practice, it is very likely that MPPT **107** would operate at an I-V point that is optimum for only a few or none of sources **101**. In the example of FIG. **1B**, the selected point is the maximum power point for source **101b**, but is off the maximum power point for sources **101a**, **101c** and **101d**. Consequently, the arrangement is not operated at best achievable efficiency.

The present applicant has disclosed in co-pending U.S. application Ser. No. 11/950,271 entitled "Distributed Power Harvesting System Using DC Power Sources", the use of an electrical power converter, e.g., DC-to-DC converter, attached to the output of each power source, e.g., photovoltaic panel. The electrical power converter converts input power to output power by monitoring and controlling the input power at a maximum power level. This system may be used also to address the anti-islanding issue.

The term "signaling" or "signaling mechanism" as used herein refers to either a signal modulated on an electromagnetic carrier signal or a simple unmodulated signal such as an on/off signal "keep alive" signal or "dry contact" signal. For a modulated signal, the modulation method may be by any such method known in the art by way of example, frequency modulation (FM) transmission, amplitude modulation (AM), FSK (frequency shift keying) modulation, PSK (phase shift keying) modulation, various QAM (Quadrature amplitude modulation) constellations, or any other method of modulation.

The term "leakage" as used herein refers to electrical power which is radiated or conducted into an electrical signal line typically at low levels and typically because of insufficient isolation.

The term "power module" as used herein includes power converters such as a DC-DC power converter but also includes modules adapted to control the power passing through the module or a portion of the power, whether by switching or other means.

## SUMMARY

The following summary of the invention is included in order to provide a basic understanding of some aspects and features of the invention. This summary is not an extensive overview of the invention and as such it is not intended to particularly identify key or critical elements of the invention or to delineate the scope of the invention. Its sole purpose is to present some concepts of the invention in a simplified form as a prelude to the more detailed description that is presented below.

According to an aspect of the present invention, there is provided a distributed power system including a DC power source and a power module. The power module includes an input coupled respectively to the DC power source and an output. An inverter is coupled to the output. The inverter converts power input from the output of the power module to output power. A signaling mechanism between the inverter and the power module is adapted for controlling operation of the power module. During operation of the distributed power system, in some embodiments, the signaling mechanism may superimpose a signal on the output of the power module. The signaling mechanism may include a switch integrated with the inverter, the switch modulating the signal onto the output of the power module. A receiver integrated with the power modules receives the signal from the inverter. Alternatively a detection mechanism in the power module detects a signal at the frequency of the electrical grid. Alternatively, a signal from the electrical grid is detected in the output of the power module at a higher frequency up-converted from the frequency of the electrical grid. Alternatively, a detection mechanism in the power module detects a switching frequency of the inverter. The power modules are may be configured for operation in a safety mode, and during the safety mode, the power at the output of the power module, the voltage across the output of the power module, and/or the current flowing through it, are limited so as not to endanger personnel. The power module may include a detection mechanism wherein during operation of the distributed power system, the detection mechanism detects a signal from the inverter. Based on the signal, the operation of the power module is varied from the safety mode of operation to a normal mode of operation for converting power of the DC power source from the input to the output of the power module.

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According to another aspect of the present invention there is provided a method for operating a distributed power system. The system includes a DC power source and a power module. The power module includes an input coupled to the DC power source. The power module includes an output. An inverter is coupled to the output of the power module. The inverter converts a power output from the power module to an output power. The method includes operating the power modules in a safety mode by limiting the power output from the power module. The safety mode is characterized by having less than a predetermined amount (e.g. ten milliamperes) of current flow and/or less than a predetermined amount (e.g. 2 Volts) through the output of the power module. A signal from the inverter is preferably monitored and upon detecting the signal from the inverter, the power input to the inverter is increased by operating the power module in a normal mode of operation for converting power of the DC power source from the input to the output of the power module. Upon detecting the signal and prior to the operation of the power module in the normal mode of operation, the voltage of the output of the power module is preferably ramped up slowly. The normal mode of operation of the power module may include controlling a maximum peak power at the input coupled to the DC power sources.

According to an aspect of the present invention, there is provided in a distributed power system multiple DC power sources and multiple power modules which include inputs coupled respectively to the DC power sources. The power modules each include outputs coupled in series to form a serial string. An inverter is coupled to the serial string. The inverter converts power input from the string and produces output power. A protection mechanism in the power modules shuts down the power modules and ceases the power input to the inverter when the inverter stops producing the output power. Typically, the inverter is connected to the electrical grid. A monitoring mechanism is attached to the electrical grid which monitors one or more electrical parameters of the electrical grid. A shutdown mechanism is attached to the monitoring mechanism which when one or more of the electrical parameters is out of predetermined specification, the inverter stops the production of the output power or disconnects from the grid. A switch is preferably disposed between the serial string and the inverter. The switch is activated by the shutdown mechanism and the protection mechanism senses a change in current flowing through the serial string when the switch is activated. When the switch is connected serially with the serial string, the protection mechanism senses that current less than a previously specified minimal threshold current in the serial string; or when the switch is connected in parallel with the serial string the protection mechanism senses a current greater than a previously specified maximal threshold current in the string. Alternatively a signal-providing mechanism is attached to the inverter which provides a signal based on the shutdown mechanism. Multiple receivers are attached respectively to the power modules. The receivers receive the signal and multiple enabling mechanisms, which are attached respectively to the receivers, enable the respective power modules to supply the input power to the inverter based on the presence of the signal or absence thereof. When the signal is a keep-alive signal, the enabling mechanisms enable the respective power modules to supply the input power to the inverter based on the presence of the keep-alive signal. When the signal is a shut-down signal, the enabling mechanism disables the respective power modules and stops supply of the input power to the inverter based on the presence of the shut-down signal. The signal in the serial

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string is optionally from the electrical grid and detected at the frequency of the electrical grid or detected at a higher frequency up converted from the frequency of the electrical grid. The signal in the serial string is optionally from the inverter or the output power therefrom, and detected at a switching frequency of the inverter. The signal is optionally superimposed on the power input to the inverter from the serial string. The signal may be wirelessly transmitted by the signal-providing mechanism, and the receiver in each of the power modules, receives the wirelessly transmitted signal.

According to another aspect of the present invention, there is provided a protection method in a distributed power system including DC power sources and multiple power modules each of which include inputs coupled to the DC power sources. The power modules each include outputs coupled in series to form a serial string. An inverter is coupled to the serial string. The inverter converts power input from the string and produces output power. When the inverter stops production of the output power, each of the power modules is shut down and thereby the power input to the inverter is ceased. When the inverter is connected to and supplies the output power to the electrical grid, one or more electrical parameters of the grid are monitored. When the one or more electrical parameters of the grid are out of a predetermined specification, the inverter is shut down and thereby production of the output power is stopped or the inverter is disconnected from the grid. When the inverter is shut down, a switch disposed between the serial string and the inverter is activated. When the switch is activated a change in current flowing through the serial string is sensed. Alternatively a signal is provided based on the shutdown mechanism. Multiple receivers are attached respectively to the power modules. The receivers receive the signals which enable the respective power modules to supply the input power to the inverter based on the presence of the signal or absence thereof. When the signal is a keep-alive signal, the respective power modules supply the input power to the inverter based on the presence of the keep-alive signal. When the signal is a shut-down signal, the respective power modules stop supply of the input power to the inverter based on the presence of the shut-down signal. The signal may be based on current in the serial string from the electrical grid and detected at the frequency of the electrical grid or detected at a higher frequency up converted from the frequency of the electrical grid. The signal in the serial string is optionally from the inverter or the output power therefrom, and detected at a switching frequency of the inverter. The signal is optionally actively superimposed on the power input to the inverter from the serial string. The signal may be wirelessly transmitted, and the receiver in each of the power modules, receives the wirelessly transmitted signal.

The foregoing and/or other aspects will become apparent from the following detailed description when considered in conjunction with the accompanying drawing figures.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, exemplify embodiments of the present invention and, together with the description, serve to explain and illustrate principles of the invention. The drawings are intended to illustrate various features of the illustrated embodiments in a diagrammatic manner. The drawings are not intended to depict every feature of actual embodiments nor relative dimensions of the depicted elements, and are not necessarily drawn to scale.

The invention is herein described, by way of example only, with reference to the accompanying drawings, wherein:

FIG. 1 is a block diagram of a conventional power harvesting system using photovoltaic panels as DC power sources;

FIG. 1B illustrates current versus voltage characteristic curves for one serial string the DC power sources of FIG. 1;

FIG. 2 is a simplified block diagram illustrating a distributed power harvesting circuit, based on the disclosure in U.S. application Ser. No. 11/950,271, according to an aspect of the present invention;

FIG. 2A is a simplified block diagram of a DC-to-DC converter, including a feature of the present invention;

FIG. 3 illustrates an exemplary DC-to-DC converter, is a simplified block diagram illustrating in more detail;

FIG. 4 is a simplified block diagram of another exemplary system, according to an embodiment of the present invention;

FIG. 4A is a simplified block diagram illustrating in more detail, a power module according to the embodiment of FIG. 4;

FIG. 4B is a simplified block diagram illustrating in more detail, a signaling mechanism attached to a conventional inverter, according to embodiments of the present invention;

FIG. 5 is a simplified flow diagram illustrating a method for wake-up and shutdown of a power harvesting system with a safety mode, according to a feature of the present invention;

FIG. 5A is a flow diagram illustrating methods for wake-up and shutdown of a power harvesting system, according to embodiments of the present invention, the flow diagram including method steps performed by the power converters/modules;

FIG. 6 is another flow diagram illustrating methods for wake-up and shutdown of a power harvesting system, according to embodiments of the present invention, the flow diagram including method steps performed by the inverter of FIG. 2 or signaling block of FIG. 4B;

FIGS. 7 and 7A illustrate a system for protection during an islanding condition, in accordance with aspects of the present invention;

FIGS. 7B and 7C illustrate in more detail the system of FIGS. 7 and 7A;

FIG. 7D illustrates a method, according to an aspect of the present invention using the system of FIGS. 7 and 7A;

FIGS. 8 and 8A, illustrate a system for protection during an islanding condition in accordance with other aspects of the present invention;

FIG. 8B illustrates an example wherein a system according to an embodiment of the invention is applied as a retrofit to a prior art system, such as the system of FIG. 1;

FIGS. 9, 9A and 9B illustrate a system for protection during an islanding condition, according to still other aspects of the present invention; and

FIGS. 10 and 10A, illustrate a system for protection during an islanding condition, according to yet other aspects of the present invention.

#### DETAILED DESCRIPTION

Reference will now be made in detail to embodiments of the present invention, examples of which are illustrated in the accompanying drawings, wherein like reference numerals refer to the like elements throughout. The embodiments are described below to explain the present invention by referring to the figures.

It should be noted, that although the discussion herein relates primarily to wake-up and shutdown methods in photovoltaic systems and more particularly to those systems previously disclosed in U.S. application Ser. No. 11/950,271, the present invention may, by non-limiting example, alternatively be configured as well using conventional photovoltaic distributed power systems and other distributed power systems including (but not limited to) wind turbines, hydroturbines, fuel cells, storage systems such as battery, super-conducting flywheel, and capacitors, and mechanical devices including conventional and variable speed diesel engines, Stirling engines, gas turbines, and micro-turbines.

By way of introduction, it is important to note that aspects of the present invention have important safety benefits. While installing or performing maintenance on photovoltaic systems according to certain aspects of the present invention, installers are protected from danger of shock or electrocution since systems according to embodiments of the present invention do not output potentially dangerous high voltage and/or currents such as when solar panels are exposed to sunlight when an operational inverter is not connected during installation and maintenance procedures. Similarly, firefighters, even after they shut down the main electrical switch to a burning building can safely break into the burning building or hose the roof of the building with water without fear of high voltage DC conduction through the water, since high voltage direct current feeding the inverter is safely turned off.

Before explaining embodiments of the invention in detail, it is to be understood that the invention is not limited in its application to the details of design and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

Reference is now made to FIG. 2 which illustrates a distributed power harvesting circuit 20, based on the disclosure in U.S. application Ser. No. 11/950,271. Circuit 20 enables connection of multiple distributed power sources, for example solar panels 101a-101d, to a single power supply. Series string 203 of solar panels 101 may be coupled to an inverter 204 or multiple connected strings 203 of solar panels 101 may be connected to a single inverter 204. In configuration 20, each solar panel 101a-101d is connected individually to a separate power converter circuit or a module 205a-205d. Each solar panel 101 together with its associated power converter circuit 205 forms a power generating element 222. (Only one such power generating element 222 is marked in FIG. 2.) Each converter 205a-205d adapts optimally to the power characteristics of the connected solar panel 101a-101d and transfers the power efficiently from input to output of converter 205. Converters 205a-205d are typically microprocessor controlled switching converters, e.g. buck converters, boost converters, buck/boost converters, flyback or forward converters, etc. The converters 205a-205d may also contain a number of component converters, for example a serial connection of a buck and a boost converter. Each converter 205a-205d includes a control loop 221, e.g. MPPT loop that receives a feedback signal, not from the converter's output current or voltage, but rather from the converter's input coming from solar panel 101. The MPPT loop of converter 205 locks the input voltage and current from each solar panel 101a-101d at its optimal power point, by varying one or more duty cycles of the switching conversion typically by pulse width modula-

tion (PWM) in such a way that maximum power is extracted from each attached panel **101a-101d**. The controller of converter **205** dynamically tracks the maximum power point at the converter input. Feedback loop **221** is closed on the input power in order to track maximum input power rather than closing a feedback loop on the output voltage as performed by conventional DC-to-DC voltage converters.

As a result of having a separate MPPT circuit in each converter **205a-205d**, and consequently for each solar panel **101a-101d**, each string **203** may have a different number or different specification, size and/or model of panels **101a-101d** connected in series. System **20** of FIG. **2** continuously performs MPPT on the output of each solar panel **101a-101d** to react to changes in temperature, solar radiance, shading or other performance factors that effect one or more of solar panels **101a-101d**. As a result, the MPPT circuit within the converters **205a-205d** harvests the maximum possible power from each panel **101a-101d** and transfers this power as output regardless of the parameters effecting other solar panels **101a-101d**.

The outputs of converters **205a-205d** are series connected into a single DC output that forms the input to inverter **204**. Inverter **204** converts the series connected DC output of converters **205a-205d** into an AC power supply. Inverter **204**, regulates the voltage at the input of inverter **204**. In this example, an independent control loop **220** holds the voltage input to inverter **204** at a set value, say 400 volts. The current at the input of inverter **204** is typically fixed by the power available and generated by photovoltaic panels **101**.

In order to legally be allowed to connect to the grid in each country, inverter **104,204** is preferably designed to comply with local electrical regulations. Electrical regulations typically dictate, among other things, the minimal and maximal voltages of the grid e.g. **220-260** root mean squares voltage V, and a range of permitted frequency, e.g. 45-55 Hz. Whenever the grid deviates from allowed values inverter **104,204** is required to disconnect from the grid. Disconnection from the grid is typically performed using software controlling inverter **104, 204** and control circuitry which constantly monitors grid parameters, e.g. voltage, frequency.

In system **10**, solar panels **101** are directly connected (e.g. in series-parallel) to inverter **104**. When an islanding condition is detected, inverter **104** is disconnected from the grid. Hence, inverter **104** stops drawing current and therefore panels **101** output a relatively high open circuit voltage typically 25% higher than the normal operating voltage. An open circuit voltage 25% higher than nominal working voltage is typically safe, (less than the allowed 600 VDC in the USA and 1000 VDC in Europe) which are typical ratings for inverters **104** designed to be able to handle the higher open circuit voltage.

In system **20**, there are power converters **205** which "push" power to the output of converters **205**. Under an islanding condition which has been detected by inverter **204**, inverter **204** is shut down and current is not flowing between converters **205** and inverter **204**. Consequently, in system **20**, the open circuit voltage at the input to inverter **204**, reaches dangerous voltages, higher than the open circuit maximum voltage ratings of inverters **104, 204**.

According to a feature of the present invention, information regarding wakeup or shut-down may be conveyed from inverter **204** to converters **205**. The information may be transmitted using any of the methods well known to those experienced in the art. According to certain embodiments, a modulation method may be used, by way of example, frequency modulation (FM) transmission, amplitude modulation (AM), FSK (frequency shift keying) modulation, PSK

(phase shift keying) modulation, various QAM (Quadrature amplitude modulation) constellations, or any other method of modulation. Alternatively, inverter **204**, while converting power from its input to its output, actively creates a frequency ripple in serial string **203**. During normal operation, the 100 Hz (or 120 Hz in USA) ripple is detectable in serial string **203** since the capacitors of inverter **204** do not entirely block the alternating current (AC), and an additional signaling mechanism is not required to produce the 100/120 Hz signal in serial string **203**. Alternatively or in addition, one or more switching frequencies of inverter **204**, typically 16 KHz or 32 KHz may be detectable as leakage or provided intentionally to serial string **203**.

Reference is now made to FIG. **2A** which illustrates a feature of the present invention. In FIG. **2A**, converter **205** is shown in more detail. Integrated with power converter **205** is a detector/receiver **207**, according to a feature of the present invention which is configured to receive, optionally amplify and detect the signal, e.g. at 100/120 Hz originating in inverter **204**.

Controller **306** preferably either polls a signal input **209** from receiver/detector **207** or uses signal input **209** as an interrupt so that only when detector/receiver **207** detects the 100/120 Hz signal, is module **205** in a normal operating mode converting power from its input to its output. Receiver **207** is alternatively configured to detect the 16/32 KHz inverter switching frequency and provides an enabling signal to controller on signal input **209** while inverter **204** is operating.

Reference is now made to FIG. **3** which illustrates an exemplary DC-to-DC converter **205**, according to a feature of the present invention. DC-to-DC converters are used to either step down or step up a DC voltage input to a higher or a lower DC voltage output, depending on the requirements of the output circuit. However, in the embodiment of FIG. **3** the DC-DC converter **205** is used as a power converter, i.e., transferring the input power to output power, the input voltage varying according to the MPPT at the input, while the output current is dictated by the constant input voltage to inverter **104, 204**. That is, the input voltage and current may vary at any time and the output voltage and current may vary at any time, depending on the operating condition of DC power sources **101**.

Converter **205** is connected to a corresponding DC power source **101** at input terminals **314** and **316**. The converted power of the DC power source **101** is output to the circuit through output terminals **310, 312**. Between the input terminals **314, 316** and the output terminals **310, 312**, the converter circuit includes input and output capacitors **320, 340**, backflow prevention diodes **322, 342** and a power conversion circuit including a controller **306** and an inductor **308**.

Diode **342** is in series with output **312** with a polarity such that current does not backflow into the converter **205**. Diode **322** is coupled between the positive output lead **312** through inductor **308** which acts a short for DC current and the negative input lead **314** with such polarity to prevent a current from the output **312** to backflow into solar panel **101**.

A potential difference exists between wires **314** and **316** due to the electron-hole pairs produced in the solar cells of panel **101**. Converter **205** maintains maximum power output by extracting current from the solar panel **101** at its peak power point by continuously monitoring the current and voltage provided by panel **101** and using a maximum power point tracking algorithm. Controller **306** includes an MPPT circuit or algorithm for performing the peak power tracking. Peak power tracking and pulse width modulation (PWM) are

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performed together to achieve the desired input voltage and current. The MPPT in controller 306 may be any conventional MPPT, such as, e.g., perturb and observe (P&O), incremental conductance, etc. However, notably the MPPT is performed on panel 101 directly, i.e., at the input to converter 205, rather than at the output of converter 205. The generated power is then transferred to the output terminals 310 and 312. The outputs of multiple converters 205 may be connected in series, such that the positive lead 312 of one converter 205 is connected to the negative lead 310 of the next converter 205.

In FIG. 3, converter 205 is shown as a buck plus boost converter. The term “buck plus boost” as used herein is a buck converter directly followed by a boost converter as shown in FIG. 3, which may also appear in the literature as “cascaded buck-boost converter”. If the voltage is to be lowered, the boost portion is substantially shorted. If the voltage is to be raised, the buck portion is substantially shorted. The term “buck plus boost” differs from buck/boost topology which is a classic topology that may be used when voltage is to be raised or lowered, and sometimes appears in the literature as “cascaded buck-boost”. The efficiency of “buck/boost” topology is inherently lower than a buck or a boost. Additionally, for given requirements, a buck-boost converter will need bigger passive components than a buck plus boost converter in order to function. Therefore, the buck plus boost topology of FIG. 3 has a higher efficiency than the buck/boost topology. However, the circuit of FIG. 3 continuously decides whether it is bucking or boosting. In some situations when the desired output voltage is similar to the input voltage, then both the buck and boost portions may be operational.

The controller 306 may include a pulse width modulator, PWM, or a digital pulse width modulator, DPWM, to be used with the buck and boost converter circuits. Controller 306 controls both the buck converter and the boost converter and determines whether a buck or a boost operation is to be performed. In some circumstances both the buck and boost portions may operate together. That is, the input voltage and current are selected independently of the selection of output current and voltage. Moreover, the selection of either input or output values may change at any given moment depending on the operation of the DC power sources. Therefore, in the embodiment of FIG. 3, converter 205 is constructed so that at any given time a selected value of input voltage and current may be up converted or down converted depending on the output requirement.

In one implementation, an integrated circuit (IC) 304 may be used that incorporates some of the functionality of converter 205. IC 304 is optionally a single ASIC able to withstand harsh temperature extremes present in outdoor solar installations. ASIC 304 may be designed for a high mean time between failures (MTBF) of more than 25 years. However, a discrete solution using multiple integrated circuits may also be used in a similar manner. In the exemplary embodiment shown in FIG. 3, the buck plus boost portion of the converter 305 is implemented as the IC 304. Practical considerations may lead to other segmentations of the system. For example, in one aspect of the invention, the IC 304 may include two ICs, one analog IC which handles the high currents and voltages in the system, and one simple low-voltage digital IC which includes the control logic. The analog IC may be implemented using power FETs which may alternatively be implemented in discrete components, FET drivers, A/Ds, and the like. The digital IC may form controller 306.

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In the exemplary circuit 205 shown, the buck converter includes input capacitor 320, transistors 328 and 330, diode 322 positioned in parallel to transistor 328, and inductor 324, 326. Transistors 328, 330 each have a parasitic body diode 324, 326. The boost converter includes inductor 308, which is shared with the buck converter, transistors 348 and 350 a diode 342 positioned in parallel to transistor 350, and output capacitor 340. Transistors 348, 350 each have a parasitic body diode 344, 346.

System 20 includes converters 205 which are connected in series and carry the current from string 203. If a failure in one of the serially connected converters 205 causes an open circuit in failed converter 205, current ceases to flow through the entire string 203 of converters 205, thereby causing system 20 to stop functioning. Aspects of the present invention provide a converter circuit 205 in which electrical components have one or more bypass routes associated with them that carry the current in case of an electrical component failing within one of converters 205. For example, each switching transistor of either the buck or the boost portion of the converter has its own diode bypass. Also, upon failure of inductor 308, the current bypasses the failed inductor 308 through parasitic diodes 344, 346.

In FIG. 3, detector/receiver block 207 is shown which is configured to provide an enable signal 209 to microcontroller 306 when the communications signal originating in inverter 104, 204 is detected.

Reference is now made to FIGS. 4, which illustrate system 40, according to an embodiment of the present invention. For simplicity, a single string 423 is shown of distributed power sources, e.g. solar panels 101a-101d connected to respective power modules 405a-d. Serial string 423 is input to conventional inverter 104 through wires 412 and 410. The output of inverter 104 is connected to and supplies electrical power to the electrical grid. At the input of inverter 104, is connected a signaling mechanism 420 which superimposes a signal on serial string 423 through wires 412 and 410 when inverter 104 is converting power to the grid.

Reference is now also made to FIG. 4B which illustrates in more detail signaling mechanism 420. Signaling mechanism 420 includes a relay 428 which is normally open and controlled by a microcontroller 422. Relay 428 is switched at a given rate, e.g. 100 Hz, and the signal is superimposed by action of relay 428 onto serial string 423 over wires 410 and 412. Microcontroller 422 typically provides the control of the signal, e.g. 100 Hz, during normal operation of distributed power system 40. Microcontroller 422 is typically connected to one or more sensors in order to monitor the operation of inverter 104. In the example of FIG. 4B, microcontroller 422 monitors over-voltage of the input DC voltage to inverter 104. The example shown in FIG. 4B includes an input DC voltage tap 432 connected to an analog to digital converter (A/D) 430, the output of which is provided to microcontroller 422. The tap 432 may be, e.g., a Hall-effect sensors, series connected resistor across which the voltage drop is measured, etc. In one embodiment, an over-voltage condition as measured by microcontroller 422, results in microcontroller 422 stopping the signaling through relay 428 and/or opening one or more protective relays 424, 426 in series with the input DC voltage to inverter 104. Note that one switch 424 or 426 may be enough for performing the required action, and two switches in series are shown solely for the purpose of illustration that double protection might be required by some regulatory bodies. A power

management block **434** taps voltage for powering micro-controller **422** and any other active electronics components (not shown) in block **420**.

Reference is now made to FIG. **4A** which illustrates in more detail certain aspects of power module **405**. Integrated with power module **405** is detector/receiver **207** which is configured to receive, optionally amplify and detect the signal, e.g. at 100 Hz, produced by signal mechanism **420**. Controller **306** preferably either polls signal input **209** or uses signal input **209** as an interrupt so that only when detector/receiver **207** detects the 100 Hz signal, is module **405** operating in a normal operating mode. Power module **405** is shown to include a bypass diode **414**. Optionally, power module **405** may include a conventional DC/DC switching converter with a control loop based on output power. Power module **405** includes at least one switch **416** controlled by controller **306** which functions to stop normal operation of power from the input of module **405** to the output of **405** when signal input **209** is absent indicating that inverter **104** is not transferring power to the electrical grid.

Reference is now made to FIG. **5** which illustrates a simplified method for safe operation of system **40**, according to an aspect of the present invention. In step **501**, active control circuits, e.g. microcontroller **306**, are turned on. Module **205, 405** begins operation (step **53**) in a safety mode. In safety mode, output current and/or voltage from module **405** is limited, for instance output voltage is limited to 2 volts and output current is limited to 10 mA so that a person can touch the wires of serial string **203, 423** without any danger of electrocution.

Controller **306** maintains safety mode operation (step **53**) until a communications signal, e.g. 100 Hz, is received (decision box **505**) by receiver/detector **207** from inverter **204** or signaling block **420**. When the communications signal is received (decision block **505**) indicating inverter **104** or **204** is connected and converting power, safety mode (step **53**) of operation ends. When the communications signal is received (decision block **505**), module **405** preferably enters a normal operation mode (step **57**), typically with maximum power point tracking. The normal operation of transferring power is maintained as long as the communications signal, e.g. 100 Hz is received from inverter **204** or signal mechanism **420**, and no other warning condition is present. If the communications signal is not detected, or another warning condition is present, the normal mode (step **57**) is typically ended and power conversion of modules **405** is typically turned off. If in decision box **509**, the communications signal is not detected, or another warning condition is present, the normal mode (step **57**) is typically ended and power conversion of modules **405** is typically turned off.

Reference is now made to FIG. **5A**, which illustrates a method **50** for wake-up and shutdown of module **405**, according to embodiments of the present invention. Method **50** is applicable to both systems **20** and **40**. In step **501**, active control circuits, e.g. microcontroller **306**, are turned on. Active control circuits are typically turned on (step **501**) in the early morning when there is sufficient light to power the active control circuits typically with voltage of DC voltage source **101** reaching three volts. In decision block **503**, when voltage output—or power output—from DC voltage source **101** is sufficiently high and stable (e.g. voltage input to module **405** is ten volts for a period of 30 seconds), then module **205,405** begins operation (step **53**) in a safety mode. In safety mode, output current and/or voltage from module **405** is limited, for instance output voltage is limited to 2 volts and output current is limited to 10 mA so that a person can touch the wires of serial string **203,423**

without any danger of electrocution. Note also, that in this case even if 25 modules are connected in series, the maximum output voltage of the string doesn't exceed 50V—which means the string voltage is still safe. Referring back to FIG. **3**, safety mode may be achieved by controller **306** in module **405** by turning on FET **330** and turning off FETS **328, 348, and 350**. Output wire **412** is held close to zero volts. Alternatively, the controller **306** may alternate the switches (e.g. switches **324 & 326** of buck converter) at a low duty-cycle in order to maintain a low output voltage.

Referring back to FIG. **5A**, controller **306** maintains safety mode operation (step **53**) until a communications signal, e.g. 100 Hz, is received by receiver/detector **207** from inverter **204** or signaling block **420**. When the communications signal is received (decision block **505**) indicating inverter **104** or **204** is connected and converting power, safety mode (step **53**) of operation ends. When the communications signal is received (decision block **505**), module **405** preferably enters a voltage control mode (step **55**) and voltage output between wires **412,410** is slowly ramped up. Voltage continues to ramp up, typically as high as +60V until module **205,405** detects that current is being drawn by the inverter **104, 204** (step **507**). When sufficient current is drawn (step **507**), module **205, 405** begins normal operation, (step **57**) e.g. for module **205**, the normal mode is the maximum power point (MPP) tracking mode of converting DC power from its input to its output by maintaining maximum power at its input. The normal operation of transferring power is maintained as long as the communications signal, e.g. 100 Hz is received from inverter **204** or signal mechanism **420**, and no other warning condition is present. If the communications signal is not detected, or another warning condition is present, the normal mode (step **57**) is typically ended and power conversion of modules **405** is typically turned off. Exemplary warning conditions in decision box **509**, which cause module **205,405** to end normal mode (step **57**) and to stop transferring power to its output include: (i) input voltage less than predetermined value, e.g. about 10 volts for 5 seconds, (ii) rapid change in output voltage, for instance greater than 20% in 100 milliseconds, (iii) reception of signal requesting to stop producing power, (iv) not receiving a signal to produce power (in the case where recurring “allow production” signals are required for the converter to function), or (v) output exceeds over voltage threshold caused for instance when multiple modules **205** in string **203** are converting power (step **57**) and one of modules **205** of string **203** shuts down, then the other modules **205** of string **203** have a raise of output voltage.

Reference is now made to FIG. **6**, which illustrates a method **60** performed by inverter **204** or signaling block **420** attached at the input of inverter **104**. In step **601**, inverter **104** is off or inverter **204** is on standby, and not converting power to its output. In decision box **603**, start conditions for turning on inverter **104,204** are determined. Typically, as a safety requirement, inverter **104** delays operation (converting power to its output) until after at least 5 minutes of connection to a functioning AC-grid at its output. This safety requirement may be achieved using microcontroller **422** and at least one of relays **424** and **426** in signaling block **420**. In inverter **204**, a minimum voltage is required at the input to inverter **204** (e.g. if the safety output voltage of each module is 2V, and the minimal-length string allowed contains 5 modules, the inverter will wait until at least 10V are present at its DC input) and only thereafter does inverter **204** begin to charge its input, typically to a specified standard input of 400V.

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In step 605, communications signal, e.g. 100 Hz, is superimposed on serial string 203,423 either from signaling mechanism 420 or from inverter 204 for instance when at least a 50 Watt load is attached to the output of inverter 204. In decision box 607, when the specified input voltage is reached, e.g. 400V for inverter 204, inverter 204 is turned on or inverter 104 is attached to serial string 423 by mechanism 420. In decision box 609, if a time out occurs before the minimum specified input voltage is reached of inverter 204,404 then inverter is returned to the off or standby state (step 601). Otherwise inverter 204,404 is connected or turned on in step 611. Inverter 204, 404 remains on and connected unless a warning condition (decision box 613) occurs. Possible warning conditions include, (i) disconnection from the electrical grid, (ii) electrical grid stops producing power (islanding), (iii) less than 50 Watts transferred in the last minute, (iv) input voltage to inverter 204,404 is over the maximum limit, and (v) input power is over the maximum limit. If a warning condition occurs (decision box 613) communications signal is turned off (step 615) for inverter 404 or inverter 204 is turned off or put into standby.

Reference is now made to FIG. 7 which illustrates a system 70 for protection during an islanding condition, in accordance with embodiments of the present invention. For simplicity, a single string 723 is shown of distributed power sources, e.g. solar panels 201 a-201 d connected to respective power converters 705 a-d. Serial string 723 is input to inverter 704 through wires 412 and 410. The output of inverter 704 is connected to and supplies electrical power to the electrical grid. Inverter 704, typically includes a monitoring, and detection mechanism 701 which monitors one or more parameters of the electrical grid such as voltage and/or frequency. If one or more of the grid parameters is out of specification indicating an islanding condition, monitoring and detection mechanism 701 typically causes inverter 704 to be shut down or inverter 704 is disconnected from the grid so that output power is no longer supplied by inverter 704 to the grid. At the same time, a signal 714 is transmitted to a switch mechanism 703 which may be located at the input of inverter 704 before input capacitor 708. Switch mechanism 703 is optionally packaged with inverter 704 or may be integrated with inverter 704 and packaged separately. In this example, signal 714 activates switch mechanism 703 so that when switch 703 is activated, the current flowing through serial string 723 and wires 410, 412 varies abruptly.

Reference is now also made to FIG. 7A which illustrates in more detail converter 705. Converter 705 is equipped with a current sensing mechanism 707 which upon sensing a variation in current through serial string 723 signals controller 306 to shut down and stop converting power. Typically, current sensing mechanism 707 includes an analog/digital converter which continuously feeds data to controller 306. Controller 306 detects a shutdown in current and decides to shut down the converters 705 accordingly.

Reference is now also made to FIGS. B and C which illustrate schematically switch mechanism 703 in more detail. FIG. 7B illustrates switch mechanism 703 in a serial configuration in which switch 703 is connected in series with the serial string 723 and FIG. 7C illustrates a parallel configuration in which switch 703 is connected in parallel with serial string 723. In the serial configuration (FIG. 7B) switch 703 is closed during normal operation of inverter 704. When an island condition is detected, serial switch 703 opens during shut down of inverter 704. Current sensing mechanism 707 upon sensing zero current signals controller 306 that output current is less than a previously specified minimum value and controller 306 shuts down power con-

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version in converter 705. In the parallel configuration (FIG. 7C), switch 703 is open during normal operation of inverter 704. When an island condition is detected, parallel switch 703 closes during shut down of inverter 704. With all the current of serial string 723 flowing through the switch 703 at minimal load, the current increases to above a previously specified maximum current. Current sensing mechanism 707 upon sensing a current maximum signals controller 306 that output current is above maximal previously specified value and controller 306 shuts down power conversion. Switch mechanism 703 in different embodiments may be embodied by a mechanical switch or a solid state switch with current and voltage ratings appropriate to the present application. Switch mechanism 703 is preferably selected by one skilled in the art of power electronics so that arcing across its open terminals is avoided while practicing some embodiments of the present invention.

Reference is now made FIG. 7D which illustrates a method, according to an embodiment of the present invention. In decision block 750, output power from inverter 104, 204 is constantly monitored. If output power is stopped, power converters 705 are shut down.

Reference is now made to FIG. 8, illustrating a system 80 according to other embodiments of the present invention for protection during an islanding condition. For simplicity, a single string 823 is shown of distributed power sources, e.g. solar panels 201 a-201 d connected to respective power converters 805 a-d. Serial string 823 is input to inverter 804 through wires 412 and 410. The output of inverter 804 is connected to and supplies electrical power to the electrical grid. Inverter 804, typically includes a monitoring and detection mechanism 701 which monitors one or more parameters of the electrical grid such as voltage and/or frequency. If one or more of the grid parameters is out of specification indicating an islanding condition, monitoring/detection mechanism 701 typically shuts down inverter 804 or disconnects from the grid, so that output power is no longer supplied by inverter 804 to the grid. During normal operation, a line communications transmitter 803 superimposes a keep-alive signal, for instance between 1 kilohertz to 100 Megahertz on direct current (DC) input lines 410 and 412 attached to serial string 823.

Reference is now also made to FIG. 8A which illustrates converter 805 in more detail. The keep-alive signal is constantly monitored and detected by a line communications receiver 807. Only while receiver 807 senses the keep-alive signal does receiver 807 provide an enable signal to controller 306. When controller 306 doesn't receive an enabling signal from receiver 807, controller 306 shuts down power conversion of converter 805.

Alternatively, instead of a "keep-alive" signal, a stop signal 814 which is first generated by monitoring and detection mechanism 701 when an islanding condition is detected, is transmitted to receiver 807. The stop signal is transmitted over line communications by superimposing a varying (e.g. 10 Khz to 100 Mhz) signal over the power lines of serial string 823. Receiver 807 receives the stop signal and relays the stop signal to controller 306 using, e.g., a single disable bit. Controller 306 on receiving a disable signal, stops converting power to the output of converter 805. Typically, when converters 805 are disabled they go into a bypass mode which allows current from other converters 805 to pass through. Hence, the stop signal may be continued until all power stops being supplied on string 823 by all of converters 805.

It should be noted that one skilled in the art would realize that although in system 80, converters 805 are shown to have



feedback loop 221, as in controller 205 of system 20, embodiments of the present invention as illustrated in system 70 using switch mechanism 703 and/or in system 80 using line communications, to the serial string may be applied to and find benefit in other distributed power systems using converters without feedback loops 221 as applied to prior art system 10. Similarly, conventional inverters 104 may be used instead of inverter 804 with communications transmitter 803 added to inverter 104 either by the inverter manufacturer or as a retrofit. For example, FIG. 8B illustrates a system according to an embodiment of the invention applied as a retrofit to a prior art system, such as the system of FIG. 1. In this example, detection mechanism 701 and switch mechanism 703 are installed between the grid and the conventional inverter 104. Of course, detection mechanism 701 and switch mechanism 703 may be incorporated into the inverter, e.g., for original installation, rather than a retrofit. Also, other implementations described herein may be used instead of detection mechanism 701 and switch mechanism 703. Advantages of incorporation of monitoring and detection mechanism 701 and one of switch mechanism 703 or communications transmitter 803 into system 10 is beneficial during installation, maintenance, and firefighting.

Reference is now made to FIG. 9 which illustrates system 90, according to another embodiment of the present invention for protection during an islanding condition. For simplicity, a single string 923 is shown of distributed power sources, e.g. solar panels 201 a-201 d connected to respective power converters 905a-d. Serial string 923 is input to conventional inverter 104 through wires 412 and 410. The output of inverter 104 is connected to and supplies electrical power to the electrical grid. Inverter 104, typically includes a monitoring and detection mechanism 701 which monitors one or more parameters of the electrical grid such as voltage and/or frequency. If one or more of the grid parameters is out of specification indicating an islanding condition, monitoring and detection mechanism 701 typically shuts down inverter 104 so that output power is no longer supplied by inverter 104 to the grid. During normal operation, a 100 Hz (or 120 Hz. in USA) ripple current is detectable between lines 410, 412 and in serial string 923 since capacitors of inverter 104 do not block entirely the alternating current (AC), or the 100/120 Hz is intentionally leaked into serial string 923 through lines 410, 412.

Reference is now also made to FIG. 9A which illustrates converter 905 in more detail. The 100/120 Hz leakage is constantly monitored and detected by a receiver 907. Only while receiver 907 senses the leakage from the grid does receiver 907 provide an enable signal to controller 306. When controller 306 doesn't receive an enabling signal from receiver 907, controller 306 shuts down power conversion of converters 905.

Alternatively or in addition, one or more switching frequencies of inverter 104, typically 16 KHz or 32 KHz. may be detected as leakage or provided intentionally to serial string 923 along lines 412, 410. Receiver 907 is configured to detect the 16/32 KHz inverter switching frequency and provides an enabling signal to controller while inverter 104 is operating.

Reference is now made to FIG. 9B, showing a simplified block diagram according to an embodiment of the present invention for up conversion of 100/120 Hz. into a higher frequency in order to enable faster detection in receiver 907 of leakage from the grid. The 100 Hertz or 120 Hertz signal is AC coupled by capacitor 931 to remove the direct current component in serial string 923 and lines 410 and 412. The 100/120 Hz. signal is optionally amplified and rectified by a

full wave rectifier 935 so that a 100 Hz or 120 Hz unipolar DC ripple is achieved. The 100/120 Hz unipolar signal is split. One portion of the 100/120 Hz. unipolar ripple is converted to a square wave, such as in a comparator/digitize circuit 939. A second portion of the 100/120 Hz unipolar ripple undergoes a known phase shift, e.g. of 400 Hz. in a phase shifter 933 and output to a second comparator/digitizing circuit 931. The two outputs of two digitizing circuits 939, 931 undergo an exclusive OR in a XOR circuit 933 which outputs a signal at a much higher frequency, e.g. 800 Hz.

Reference is now made to FIG. 10, illustrating a system 1000 according to other embodiments of the present invention for protection during an islanding condition. For simplicity, a single string 1023 is shown of distributed power sources, e.g. solar panels 201 a-201 d connected to respective power converters 1005 a-d. Serial string 1023 is input to inverter 1004 through wires 412 and 410. The output of inverter 1004 is connected to and supplies electrical power to the electrical grid. Inverter 1004, typically includes a monitoring and detection mechanism 701 which monitors one or more parameters of the electrical grid such as voltage and/or frequency. If one or more of the grid parameters is out of specification indicating an islanding condition, monitoring, and detection mechanism 701 typically shuts down inverter 1004 or disconnects inverter 1004 from the grid so that output power is no longer supplied by inverter 1004 to the grid. During normal operation, a wireless transmitter 1003 transmits wirelessly a signal, for instance between 100 Megahertz-10 Gigahertz.

Reference is now also made to FIG. 10A which illustrates converter 1005 in more detail. The wireless signal is received and constantly monitored by a wireless receiver 1007. Only while receiver 1007 senses the wireless signal does receiver 1007 provide an enable signal to controller 306. When controller 306 doesn't receive an enabling signal from receiver 1007, controller 306 shuts down power conversion of converter 1005.

The present invention has been described in relation to particular examples, which are intended in all respects to be illustrative rather than restrictive. Those skilled in the art will appreciate that many different combinations of hardware, software, and firmware will be suitable for practicing the present invention. Moreover, other implementations of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. Various aspects and/or components of the described embodiments may be used singly or in any combination in the server arts. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.

While the invention has been described with respect to a limited number of embodiments, it will be appreciated that many variations, modifications and other applications of the invention may be made.

The invention claimed is:

1. A method comprising:

receiving power from a direct current (DC) power source at an input of a power converter;

performing, with a controller, the following steps:

operating one or more switches of the power converter in a safety mode by limiting output voltage at an output of the power converter below a predetermined voltage;

detecting, while limiting the output voltage in the safety mode, receipt of a communication signal;



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responsive to the detecting receipt of the communication signal, transitioning from the safety mode to a voltage control process including:  
 operating the one or more switches of the power converter to cause increases of the output voltage, and  
 detecting, for each of the increases of the output voltage, an amount of current being drawn from the output of the power converter;  
 after detecting that the amount of current being drawn exceeds a preexisting level, the controller transitioning the power converter from the voltage control process to a maximum power point tracking mode;  
 maintaining, by the controller and after the transitioning from the voltage control process, the output voltage to be below a maximum output voltage of the power converter while simultaneously remaining in the maximum power point tracking mode; and  
 responsive to an interruption in receipt of the communication signal, transitioning from the maximum power point tracking mode to the safety mode.

2. The method of claim 1, further comprising:  
 responsive to a different interruption in receipt of the communication signal, transitioning from the voltage control process to the safety mode.

3. The method of claim 1, wherein the DC power source comprises one or more solar cells.

4. The method of claim 1, wherein the detecting receipt of the communication signal comprises detecting receipt of the communication signal from a signaling mechanism integrated in an inverter.

5. The method of claim 1, wherein the power converter comprises a direct current to direct current (DC/DC) converter.

6. The method of claim 1, wherein the detecting receipt of the communication signal comprises one of:  
 detecting the communication signal at a frequency of an electrical grid;  
 detecting the communication signal at a second frequency, wherein the second frequency is up-converted from the frequency of the electrical grid; and  
 detecting the communication signal at a frequency of an inverter.

7. The method of claim 1, wherein the detecting receipt of the communication signal comprises one of:  
 detecting the communication signal delivered over an electrical conductor; and  
 detecting the communication signal delivered over a wireless medium.

8. The method of claim 1, wherein the detecting receipt of the communication signal is based on a change in voltage, current, or power corresponding to an inverter or a power grid.

9. An apparatus comprising:  
 a power converter comprising:  
 an input configured to receive power from a direct current (DC) power source,  
 an output terminal, and  
 a controller, wherein the controller is further configured to:  
 operate one or more switches of the power converter in a safety mode by limiting output voltage at the output terminal of the power converter below a predetermined voltage;  
 detect, while limiting the output voltage in the safety mode, receipt of a communication signal;

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responsive to the detecting receipt of the communication signal, transition from the safety mode to a voltage control process including:  
 operating the one or more switches of the power converter to cause increases of the output voltage, and  
 detecting, for each of the increases of the output voltage, an amount of current being drawn from the output terminal of the power converter;  
 after detecting the amount of current being drawn exceeds a preexisting level, the controller transitioning the power converter from the voltage control process to a maximum power point tracking mode;  
 maintain, by the controller and after the transitioning from the voltage control process, the output voltage to be below a maximum output voltage of the power converter while simultaneously remaining in the maximum power point tracking mode; and  
 responsive to an interruption in receipt of the communication signal, transition from the maximum power point tracking mode to the safety mode.

10. The apparatus of claim 9, wherein the voltage control process further includes:  
 responsive to a different interruption in receipt of the communication signal, transitioning from the voltage control process to the safety mode.

11. The apparatus of claim 9, wherein the DC power source comprises one or more solar cells.

12. The apparatus of claim 9, wherein the controller is further configured to detect receipt of the communication signal by detecting receipt of the communication signal from a signaling mechanism integrated in an inverter.

13. The apparatus of claim 9, wherein the power converter comprises a direct current to direct current (DC/DC) converter.

14. The apparatus of claim 9, wherein the controller is further configured to detect receipt of the communication signal by one of:  
 detecting the communication signal at a frequency of an electrical grid;  
 detecting the communication signal at a second frequency, wherein the second frequency is up-converted from the frequency of the electrical grid; and  
 detecting the communication signal at a frequency of an inverter.

15. The apparatus of claim 9, the controller is further configured to detect receipt of the communication signal by one of:  
 detecting the communication signal delivered over an electrical conductor; and  
 detecting the communication signal delivered over a wireless medium.

16. The apparatus of claim 9, wherein the controller is further configured to detect receipt of the communication signal based on a change in voltage, current, or power corresponding to an inverter or a power grid.

17. A method comprising:  
 receiving power from a direct current (DC) power source at an input of a power converter;  
 performing, with a controller, the following steps:  
 operating one or more switches of the power converter in a safety mode by limiting output voltage at an output of the power converter below a predetermined voltage;  
 detecting, while limiting the output voltage in the safety mode, receipt of a communication signal;

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responsive to the detecting receipt of the communication signal, transitioning from the safety mode to a voltage control process including:

- operating the one or more switches of the power converter to cause increases of the output voltage, and
- detecting, for each of the increases of the output voltage, an amount of current being drawn, from the output of the power converter;

after detecting the amount of current being drawn exceeds a preexisting level, and responsive to continuously detecting receipt of the communication signal, the controller transitioning the power converter from the voltage control process to a maximum power point tracking mode; and

responsive to an interruption in receipt of the communication signal, transitioning from the voltage control process to the safety mode.

18. The method of claim 17, further comprising:

- after transitioning to the maximum power point tracking mode and responsive to a different interruption in receipt of the communication signal, transitioning from the maximum power point tracking mode to the safety mode.

19. The method of claim 17, wherein the DC power source comprises one or more solar cells.

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20. The method of claim 17, wherein the detecting receipt of the communication signal comprises detecting receipt of the communication signal from a signaling mechanism integrated in an inverter.

21. The method of claim 17, wherein the power converter comprises a direct current to direct current (DC/DC) converter.

22. The method of claim 17, wherein the detecting receipt of the communication signal comprises one of:

- detecting the communication signal at a frequency of an electrical grid;

- detecting the communication signal at a second frequency, wherein the second frequency is up-converted from the frequency of the electrical grid; and

- detecting the communication signal at a frequency of an inverter.

23. The method of claim 17, wherein the detecting receipt of the communication signal comprises one of:

- detecting the communication signal delivered over an electrical conductor; and

- detecting the communication signal delivered over a wireless medium.

24. The method of claim 17, wherein the detecting receipt of the communication signal is based on a change in voltage, current, or power corresponding to an inverter or a power grid.

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