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AUTOMATIC GENERATION AND ANALYSIS OF SOLAR CELL IV CURVES

ABSTRACT

A method of evaluating performance of solar panels (214), the method comprising: selectively providing power to a first current sensor (255) in a plurality of current sensors, wherein the plurality of current sensors comprises Hall Effect field sensors; sensing, using the first current sensor (255) while providing power to the first current sensor (255), current generated by a first string of solar panels in a plurality of strings of solar panels to generate a sensed current; selectively providing power to a second current sensor (256) in the plurality of current sensors instead of providing power to the first current sensor (255); sensing, using the second current sensor (256) while providing power to the second current sensor (256), current generated by a second string of solar panels in the plurality of strings of solar panels; and evaluating a performance of the first string of solar panels using the sensed current.

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AUTOMATIC GENERATION AND ANALYSIS OF SOLAR CELL IV CURVES

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TECHNICAL FIELD

[0002] Embodiments of the subject matter described herein relate generally to solar cells. More particularly, embodiments of the subject matter relate to generation and analysis of solar cell current-voltage (IV) curves.

BACKGROUND

[0003] Solar cells, also known as "photovoltaic cells," are well known devices for converting solar radiation to electrical energy. They may be fabricated on a semiconductor wafer using semiconductor processing technology. A solar cell includes P-type and N-type diffusion regions. Solar radiation impinging on the solar cell creates electrons and holes that migrate to the diffusion regions, thereby creating voltage differentials between the diffusion regions. In a backside contact solar cell, both the diffusion regions and the metal contact fingers coupled to them are on the backside of the solar cell. The contact fingers allow an external electrical circuit to be coupled to and be powered by the solar cell.

[0004] A solar cell may be characterized by its IV curve, which is a plot of the solar cell's output current for a given output voltage. The IV curve is indicative of the performance of the solar cell. FIG. 1 shows example IV curves of a solar panel, which comprises a plurality of interconnected solar cells mounted on the same frame. The IV curves of FIG. 1 show current-voltage characteristics with dependence on solar insolation and temperature of the solar panel.

[0005] Solar cell IV curves of a solar panel may be manually generated by technicians using appropriate test equipment. Typically, a technician may measure output current and voltage of a solar panel to get IV curves for the solar panel for that particular time of day. To generate IV curves for a new solar installation, which may comprise hundreds of solar panels, several technicians are needed for several days. After installation, new IV curves for the solar installation may need to be periodically generated to verify the performance of the solar panels in accordance with contractual obligations. The new IV curves are again manually generated by technicians.

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OBJECT OF THE INVENTION

[0006] It is an object of the present invention to at least substantially overcome or at least ameliorate the foregoing disadvantage.

BRIEF SUMMARY

[0007] In a first aspect, the present invention provides a method of evaluating performance of solar panels, the method comprising:

selectively providing power to a first current sensor in a plurality of current sensors, wherein the plurality of current sensors comprises Hall Effect field sensors;

sensing at a first instance, using the first current sensor while providing power to the first current sensor, current generated by a first string of solar panels in a plurality of strings of solar panels to generate a first sensed current;

sensing a solar insolation on the first string of solar panels at the first instance;

sensing a voltage generated by the first string of solar panels at the first instance; and

automatically generating a current-voltage (IV) curve of the first string of solar panels at the first instance using the first sensed current, the sensed solar insolation on the first string of solar panels at the first instance, and the sensed voltage generated by the first string of solar panels at the first instance; and

evaluating a performance of the first string of solar panels using the generated IV curve of the first string of solar panels at the first instance.

[0008] In a second aspect, the present invention provides a photovoltaic string monitoring system comprising:

a plurality of current sensors, the plurality of current sensors comprising Hall Effect field sensors;

a sensor to sense a solar insolation on a first string of solar panels in a plurality of solar panels;

a sensor to sense the voltage generated by the first string of solar panels;

a communications port;

a power source that receives power from the communications source; and

a microcontroller that selectively couples power from the power source to individual current sensors in the plurality of current sensors, the microcontroller being configured to select

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a first current sensor in the plurality of current sensors to receive power from the power source and to sense current generated by the first string of solar panels;

wherein the microcontroller automatically generates a current-voltage (IV) curve using the sensed current, the sensed insolation, and the sensed voltage.

[0009] In a third aspect, the present invention provides a method of evaluating performance of solar panels, the method comprising:

receiving a command through a communications port to selectively energize a first current sensor in a plurality of current sensors, wherein the plurality of current sensors comprises Hall Effect field sensors;

sensing, using the first current sensor while energizing the first current sensor, current generated by a first string of solar panels in a plurality of strings of solar panels;

sensing a solar insolation on the first string of solar panels;

sensing a voltage generated by the first string of solar panels; and

automatically generating a current-voltage (IV) curve of the first string of solar panels using the sensed current generated by the first string of solar panels, the sensed solar insolation on the first string of solar cells, and the sensed voltage generated by the first string of solar panels.

[0010] There is disclosed herein a method of automatically generating and analyzing solar cell current-voltage (IV) curves, the method comprising:

varying a direct current (DC) load presented to a first string of solar panels in a plurality of strings of solar panels to vary current generated by the first string of solar panels, each string of solar panels in the plurality of strings of solar panels comprising a plurality of serially-connected solar panels, each solar panel in the plurality of serially-connected solar panels comprising a plurality of serially-connected solar cells mounted on a same frame;

sensing current generated by the first string of solar panels responsive to the variation of the DC load presented to the first string of solar panels;

sensing voltage generated by the first string of solar panels responsive to the variation of the DC load presented to the first string of solar panels; and

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automatically generating a first IV curve of the first string of solar panels, the first IV curve indicating voltage generated by the first string of solar panels versus corresponding current generated by the first string of solar panels during variation of the DC load presented to the first string of solar panels,

wherein the current generated by the first string of solar panels responsive to the variation of the DC load presented to the first string of solar panels is sensed with a sensing device comprising a first field sensor adapted to sense current in the first string of solar panels.

[0011] A sensing device is also disclosed. The sensing device comprises a first current sensor adapted to non-invasively detect the current of a wire, a second current sensor adapted to non-invasively detect the current of a wire, a control device adapted to control the first and second field sensors, and a communications port controlled by the control device and adapted to receive

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and transmit signals and to receive power, wherein the first and second field sensors are powered by power from the communications port.

[0012] There is disclosed herein a photovoltaic panel string monitoring system comprising:

a first string of solar panels comprising a plurality of solar panels connected in series;

a second string of solar panels comprising a second plurality of solar panels connected in series;

a combiner box connecting the first and second strings of solar panels;

a sensing device comprising first and second current sensors, the first current sensor adapted to determine a first current in the first string of solar panels and the second current sensor adapted to determine a second current in the second string of solar panels;

a microcontroller configured to automatically generate a first IV curve of the first string of solar panels, the first IV curve indicating voltage generated by the first string of solar panels versus corresponding current generated by the first string of solar panels in response to variation of a direct current (DC) load presented to the first string of solar panels; and

a printed circuit board that includes the sensing device and the microcontroller.

[0013] These and other features of embodiments of the present invention will be readily apparent to persons of ordinary skill in the art upon reading the entirety of this disclosure, which includes the accompanying drawings.

Brief Description of Drawings

[0014] Preferred embodiments of the invention will be described hereinafter, by way of examples only, with reference to the accompanying drawings, wherein like reference numbers refer to similar elements throughout the figures.

[0015] FIG. 1 schematically shows example IV curves of a solar panel.

[0016] FIG. 2 schematically shows a photovoltaic (PV) system in accordance with an embodiment of the present invention.

[0017] FIG. 3 schematically shows a PV string in the PV system of FIG. 2, in accordance with an embodiment of the present invention.

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[0018] FIG. 4 schematically shows a data collection and control computer in the PV system of FIG. 2, in accordance with an embodiment of the present invention.

[0019] FIG. 5 shows a flow diagram of a method of automatic generation and analysis of solar cell IV curves in accordance with an embodiment of the present invention.

[0020] FIG. 6 schematically shows a string current monitor block in accordance with an embodiment of the present invention.

[0021] FIG. 7 schematically shows a diagram of a string current monitor block in accordance with an embodiment of the present invention.

[0022] FIG. 8 schematically shows current field sensors in accordance with an embodiment of the present invention.

[0023] FIG. 9 schematically shows a plurality of strings of solar panels and a string current monitor block in accordance with an embodiment of the present invention.

[0024] FIG. 10 shows a flow diagram of a method of automatic generation of solar cell IV curves in accordance with an embodiment of the present invention.

Description of Embodiments

[0025] In the present disclosure, numerous specific details are provided, such as examples of apparatus, components, and methods, to provide a thorough understanding of embodiments of the invention. Persons of ordinary skill in the art will recognize, however, that the invention can be practiced without one or more of the specific details. In other instances, well-known details are not shown or described to avoid obscuring aspects of the invention.

[0026] Techniques and technologies may be described herein in terms of functional and/or logical block components and with reference to symbolic representations of operations, processing tasks, and functions that may be performed by various computing components or devices. Such operations, tasks, and functions are sometimes referred to as being computer-executed, computerized, software-implemented, or computer-implemented. In practice, one or more processor devices can carry out the described operations, tasks, and functions by

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manipulating electrical signals representing data bits at memory locations in the system memory, as well as other processing of signals. The memory locations where data bits are maintained are physical locations that have particular electrical, magnetic, optical, or organic properties corresponding to the data bits. It should be appreciated that the various block components shown in the figures may be realized by any number of hardware, software, and/or firmware components configured to perform the specified functions. For example, an embodiment of a system or a component may employ various integrated circuit components, e.g., memory elements, digital signal processing elements, logic elements, look-up tables, or the like, which may carry out a variety of functions under the control of one or more microprocessors or other control devices.

[0027] "Coupled" – The following description refers to elements or nodes or features being "coupled" together. As used herein, unless expressly stated otherwise, "coupled" means that one element/node/feature is directly or indirectly joined to (or directly or indirectly communicates with) another element/node/feature, and not necessarily mechanically. Thus, although the schematic shown in FIG. 7 depicts one exemplary arrangement of elements, additional intervening elements, devices, features, or components may be present in an embodiment of the depicted subject matter.

[0028] FIG. 2 schematically shows a photovoltaic (PV) system 200 in accordance with an embodiment of the present invention. In the example of FIG. 2, the PV system 200 includes a plurality of PV strings 210, a PV inverter 220, and a data collection and control computer 201.

[0029] A PV string 210 may comprise a plurality of solar panels that are electrically connected in series. The direct current (DC) output of the PV string 210 is electrically coupled to a device that presents a DC load to the PV strings 210. In the example of FIG. 2, that device is the PV inverter 220, which converts the DC output of the PV strings 210 to sinusoidal alternating current (AC). The AC output of the PV inverter 220 may be applied to a power grid or power distribution of a customer structure (e.g., residential, commercial, industrial), for example. A PV string 210 may include a controller 211 configured to monitor and control solar panels in the string and to communicate with other components of the PV system 200. In one embodiment, a PV string 210 wirelessly communicates with the PV inverter 220 over a wireless mesh network. A PV string 210 may also communicate with the PV inverter 220 over other types of communications networks without detracting from the merits of the present invention.

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[0030] The computer 201 may comprise a computer configured to collect operational data from the PV system 200 including electrical current, voltage, temperature, solar insolation, and other information indicative of the performance and operational status of the PV system 200. The PV inverter 220 may include a communications module 221 for communicating with components of the PV system 200, including combiner boxes 212 (see FIG. 3), controllers 211, and the computer 201. The PV inverter 220 may communicate with the computer 201, combiner boxes 212, controllers 211, and other components of the PV system 200 over a wired or wireless computer network, which includes the Internet.

[0031] FIG. 3 schematically shows a PV string 210 in accordance with an embodiment of the present invention. In the example of FIG. 3, the PV string 210 includes a combiner box 212 and a plurality of solar panels 214. A controller 211 and environment sensors 216 allow for monitoring and control of the PV string 210.

[0032] A solar panel 214 comprises electrically connected solar cells mounted on the same frame. In one embodiment, each solar panel 214 comprises a plurality of serially-connected backside contact solar cells 215. Only some of the backside contact solar cells 215 have been labeled in FIG. 3 for clarity of illustration. Other types of solar cells, such as front contact solar cells, may also be employed.

[0033] Each PV string 210 comprises a plurality of serially-connected solar panels 214 coupled to a combiner box 212. The output of the PV string 210 is electrically connected to the PV inverter 220 by way of the combiner box 212. The output voltage of the PV string 210 may thus be sensed by a voltage sensing circuit at the PV inverter 220.

[0034] In the example of FIG. 3, the combiner box 212 includes sensor circuits 213. The sensor circuits 213 may comprise electrical circuits for sensing the amount of electrical current flowing through the solar panels 214 of the PV string 210 (and hence the output current of the PV string 210) and for sensing the output voltage of the PV string 210. The sensor circuits 213 may be implemented using conventional current and voltage sensing circuits. The sensor circuits 213 may be located in the combiner box 212 or integrated with a solar panel 214. The sensor circuits 213 may transmit current and voltage readings to the controller 211 of the PV string 210 over a wired or wireless connection. In another embodiment, the output voltage of a PV string 210 is directly sensed at the PV inverter 220.

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[0035] The environment sensors 216 may comprise an irradiance sensor and/or temperature sensor. The environment sensors 216 are shown collectively as outside the solar panels 214. In practice, an environment sensor 216 may be located in individual solar panels 214 or a location representing the PV string 210.

[0036] An irradiance sensor senses the amount of solar irradiance of insolation on one or more solar panels 214. The irradiance sensor may comprise a plurality of solar cells separate from those of the solar panels 214. The output current of the irradiance sensor solar cells is indicative of the amount of solar insolation on the panel, and is sensed by an associated electrical circuit and provided to the controller 211. An irradiance sensor may be mounted on individual solar panels 214 or a location representative of the location of the PV string 210.

[0037] The environment sensors 216 may also comprise a temperature sensor. The output of the temperature sensor is indicative of the temperature of a solar panel 214 or a location of the of the PV string 210 where the temperature sensor is located. The output of the temperature sensor may be provided to the controller 211.

[0038] The controller 211 may comprise control circuits, such as a maximum power point optimizer, and communication circuits for sending and receiving data between components of the PV string 210 and the PV system 200 in general. The controller 211 may receive sensor outputs from the sensor circuits 213 and environment sensors 216 over a wired or wireless connection. The controller 211 is configured to communicate the sensor outputs to the communications module 221 of the PV inverter 220, which provides the sensor outputs to the computer 201.

[0039] FIG. 4 schematically shows a data collection and control computer 201 in accordance with an embodiment of the present invention. The computer 201 may have less or more components to meet the needs of a particular application. The computer 201 may include a processor 401, such as those from the Intel Corporation or Advanced Micro Devices, for example. The computer 201 may have one or more buses 403 coupling its various components. The computer 201 may include one or more user input devices 402 (e.g., keyboard, mouse), one or more data storage devices 406 (e.g., hard drive, optical disk, USB memory), a display monitor 404 (e.g., LCD, flat panel monitor, CRT), a computer network interface 405 (e.g., network adapter, modem), and a main memory 408 (e.g., RAM). The computer network

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interface 405 may be coupled to a computer network, which in this example includes the Internet.

[0040] The computer 201 is a particular machine as programmed with software components 410 to perform its function. The software components 410 comprise computer-readable program code stored non-transitory in the main memory 408 for execution by the processor 401. The software components 410 may be loaded from the data storage device 406 to the main memory 408. The software components 410 may also be made available in other computer-readable medium including optical disk, flash drive, and other memory device. The software components 410 may include data collection and control, logging, statistics, plotting, and reporting software,

[0041] In one embodiment, the computer 201 is configured to receive data from the communications module 221, controller 211, and/or other components of the PV system 200. The computer 201 may receive sensor data from the PV strings 210 directly or by way of the inverter 220. The sensor data may include output current of a PV string 210, output voltage of a PV string 210, and environmental conditions (e.g., temperature, solar insolation) of a PV string 210.

[0042] The computer 201 may be configured to control the DC load presented to the PV strings 210. For example, the computer 201 may be configured to send a control signal to the inverter 220 such that the inverter 220 presents a particular DC load to the PV strings 210. A PV string 210 changes its output current based on to the DC load presented to it. By varying the DC load presented by the inverter 220, and receiving data indicating the corresponding output current and voltage generated by the PV string 210 for particular DC loads, the computer 201 is able to plot IV curves for the PV string 210 under various conditions and for different output current and voltage levels.

[0043] FIG. 5 shows a flow diagram of a method 500 of automatic generation and analysis of solar cell IV curves in accordance with an embodiment of the present invention. The method 500 is explained using the PV system 200 as an example. As can be appreciated, the method 500 may also be employed in other solar cell installations with a relatively large number of solar panels. The steps of the method 500 may be repeatedly performed to allow for real-time monitoring of the PV system 200.

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[0044] The method 500 includes sensing the output voltage (step 501) and corresponding output current (step 502) and insolation (step 506) of a PV string 210 in the PV system 200. The output current of the PV string 210 may be sensed by a current sensing circuit installed in a combiner box 212 or integrated in a solar panel 214. Similarly, the output voltage of the PV string 210 may be sensed by a voltage sensing circuit installed in the combiner box 212 or integrated in a solar panel 214. The output voltage of the PV string 210 may also be sensed at the PV inverter 220. Various output voltage-current pairs may be sensed over a relatively long period of time, or by varying the DC load presented to the PV string 210. Each current and voltage measurement may include solar insolation for that measurement.

[0045] The sensor data indicating the sensed output voltage, current, and solar insolation of the PV string 210 may be received by a controller 211 in the PV string 210, and then transmitted to the computer 201 directly or by way of the PV inverter 220. Sensor data for a particular PV string 210 may be collected periodically in real-time, such as every few minutes. The sensor data may include additional information, such as time and date stamps indicating when the output voltage and current were sensed and environmental conditions (e.g., solar insolation and temperature) at the time the output voltage and current were sensed.

[0046] The computer 201 may periodically receive sensor data of each of the plurality of PV strings 210. The computer 201 may generate IV curves for each PV string 210 using the sensor data (step 503). The IV curves may indicate output voltages, corresponding currents for particular PV strings 210, and dependence factors, such as corresponding solar insolation and/or temperature of the PV strings 210. As a particular example, each IV curve for a particular PV string 210 may indicate current and voltage at a solar insolation. The IV curves may be generated for sensor data taken over a period of time, such as over a week, month, or year. The sensor data for generating IV curves may be filtered based on collected solar insolation and/or temperature data. For example, the sensor data may be filtered such that only sensor data taken at particular solar insolation and/or temperature are used to generate IV curves.

[0047] In one embodiment, IV curves generated from sensor data are employed to evaluate the performance of a PV string 210 in real-time (step 504). For example, the computer 201 may compare an IV curve having recent current-voltage data against a baseline IV curve or a reference IV curve to determine if the PV string 210 meets performance standards. The baseline IV curve may be the IV curve of the PV string 210 as originally installed and the reference IV

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curve may be dictated by contractual requirements. The IV curve comparison may indicate whether the PV string 210 is degrading, e.g., lower output current at a particular output voltage, or still meets expected performance standards. Automatically sensing output voltages, output currents, and corresponding environmental conditions, and then automatically generating corresponding IV curves advantageously allow for evaluation of the performance of the PV string 210 in real-time. By comparing recent and past IV curves of the PV string 210, performance degradation trends may be detected before the degradation becomes a full blown failure.

[0048] In one embodiment, IV curves generated from sensor data are employed to detect and troubleshoot PV string failures (step 505). For example, the computer 201 may analyze a recent IV curve to detect a present or pending open circuit or short circuit condition. A short circuit condition is characterized by an IV curve where an output voltage is low for a corresponding high output current. A short circuit condition indicates that there is a short in the PV string 210 (e.g., a solar panel 214 is shorted or developing a short). An open circuit condition is characterized by an IV curve where an output voltage is high for a corresponding low output current. An open circuit condition indicates that the series connection of the solar panels 214 in the string is open. The threshold for low or high current or voltage may be set for particular installations. The computer 201 may compare current-voltage pairs of an IV curve to thresholds to determine if the PV string 210 presently or will soon have a short circuit condition or open circuit condition.

[0049] FIG. 6 illustrates an embodiment of a string current monitor block for use with PV system 200, described above. Unless otherwise described below, numerical indicators refer to similar components and elements described above. The sensor or sensor circuits 213 can include an embodiment of the string current monitor block, such as illustrated here. With additional reference to FIG. 7, the sensor 213 can include a printed circuit board (PCB) 250 supporting a plurality of current sensors 255. The current sensors 255 can be connected to or coupled to a microcontroller 260. The microcontroller 260 can also interoperate with, and the sensor 213 can also include, communication ports 270, a power source 275, and a sensor power switch 280, as well as other modules or processor devices such as a temperature sensor 299, or others not illustrated, such as memory devices, an analog-digital (A/D) converter, a translator device, an A/D converter reference, and so on. In certain embodiments, such as the illustrated embodiment of FIG. 7, one or more of such devices can be integrated, such as the

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microcontroller 260 which includes an A/D converter and communications module appropriate for receiving and providing signals using the communications ports 270.

[0050] The current sensors 255 can include Hall Effect field sensors adapted with sufficient sensitivity to determine current in a wire from a string of solar panels 210. There can be more than one current sensor 255 on each sensor 213, such as the twelve current sensors 255 illustrated in FIG. 6, and each current sensor 255 can be coupled to the microcontroller 260. In one embodiment, there is a current sensor 255 for each string of solar panels 210 which is connected in the combiner box 212, the sensor 213 additionally positioned within the combiner box 212. Therefore, as few as two current sensors or as many sensors as there are strings of solar panels, without limit, can be present on the sensor 213. The current sensors 255 can measure current in a wire associated with the current sensor 255 in a non-invasive manner, such as by not penetrating the wire. A Hall Effect field sensor can accomplish such a measurement.

[0051] A current sensor 255, like any of the sensors or sensing devices described herein, can provide to the microcontroller 260 any of a variety of signals, such as a voltage signal or a communications signal, which conveys information regarding the current being measured. Thus, for example, in one embodiment, the current sensor 255 can provide to the microcontroller a voltage level which is indicative of the current being measured by the current sensor 255. In such an embodiment, the voltage signal can be converted to a current measurement either by the microprocessor 260 or by another device to which the voltage level is provided. In another embodiment, the current sensor 255 can provide a signal which conveys a direct measurement of the current being measured by the current sensor 255.

[0052] FIG. 8 illustrates an example of wires 258 passing through a first 255 and second 256 current sensor, where the sensors are Hall Effect field sensors. By measuring the magnetic field surrounding the wires 258, the electric current flowing through the wires 258 can be separately determined by each of the first and second current sensors 255, 256 for each of the individual wires. There is no need for a direct electrical connection to the current in the wire to measure the current.

[0053] With reference again to FIGS. 6 and 7, the microcontroller 260 is shown as a single device integrated with an A/D converter, although the functions can be performed by different devices or modules in other embodiments. The microcontroller 260 can include a processing

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element, as well as digital memory storage, communications devices, or other elements or devices necessary to perform the functions described herein. Although the microcontroller 260 is illustrated coupled to various different elements of the sensor 213, such as the communications ports 270 and current sensors 255, in embodiments, the different components of the sensor 213 can be interconnected and coupled together in any manner which enables practice of the functions described herein.

[0054] Thus, the microcontroller 260 can, through coupling to the communications port 270, receive signals from the controller 211, inverter 220, or other device which controls the sensor 213. The microcontroller 260 can also provide response signals through the communications port 270, therefore enabling the sensor 213 to respond to a command from a remote controlling device to energize the current sensors 255, sense the current of one or more wires passing through the current sensors 255, and send a signal communicating the measurement to the remote controlling device. Additionally, the communications port 270 can be coupled to a power source 275 of the sensor 213. The power source 275 can be controlled by the microcontroller 260 to operate the various components of the sensor 213 using power received through the communications port 270. One such communications port can be a RS-485 connector, though other ports receiving power during communication can be used. Thus, in certain embodiments, the power source 275 can be coupled to a sensor power switch 280 for providing power from the communications port 270 to each current sensor 255. In certain embodiments, the sensor 213 can be arranged such that power, including electrical power, is supplied to each current sensor 255 simultaneously, whereas in other embodiments, power can be selectively supplied to each of the individual current sensors 255.

[0055] FIG. 9 illustrates an embodiment of the sensor 213 coupled to the controller 212. The sensor 213 is positioned such that wires 295 from each string of solar panels 210 passes through a current sensor 255. As shown, twelve current sensors 255 can be used with twelve strings of solar panels 210, where each string of solar panels 210 is combined in a combiner box. By powering the sensor 213 from a communications port, the sensor 213 can simultaneously determine the current through each of twelve strings of solar panels 210, increasing the ease of automation of IV curve generation. Moreover, because the power used to operate the sensor 213 can come from a communications line connected to one or more of the communications ports 270, a separate power line from either a PV string or the controller 212 is not necessary. In this

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way, multiple sensors can be powered from a single communications and control device, such as the controller 212.

[0056] FIG. 10 illustrates a flowchart of a method for using a sensor, such as sensor 213, to automatically generate IV curves. The various tasks performed in connection with process 600 may be performed by software, hardware, firmware, or any combination thereof. For illustrative purposes, the following description of process 600 may refer to elements mentioned above in connection with FIGS. 6-9. In practice, portions of process 600 may be performed by different elements of the described system, e.g., current sensor 255, microcontroller 260, or communications port 270. It should be appreciated that process 260 may include any number of additional or alternative tasks, the tasks shown in FIG. 10 need not be performed in the illustrated order, and process 600 may be incorporated into a more comprehensive procedure or process having additional functionality not described in detail herein.

[0057] One method of using a sensor, such as sensor 213 described above with reference to FIGS. 6-9 can be in response to receiving 610 a control signal using or with a communications port 270 of the sensor 213. In response, the microcontroller 260 or other control device can operate at least a first 620 and second 622 current sensor to sense the current in respective first and second strings of solar panels, or solar strings. In certain embodiments, the first and second current sensors 255 can be powered by power received through the communications port 270 of the sensor 213.

[0058] In some embodiments, it may be sufficient to determine only the IV curve of the first string of solar panels. In such an embodiment, the voltage of the first string of solar panels can also be measured 630. The solar insolation of the first string of solar panels can additionally be determined. From this information, a first IV curve can be determined 650 and communicated 660 via a response signal using the communications port 270. In certain embodiments, the IV curve need not be determined, and all sensed information can be directly reported, such as current information from the sensor 213, to a controller, including the controller 212, and the IV curve determined remotely.

[0059] In certain embodiments, after performing current sensing steps 620, 622, the second string of solar panels can have its voltage sensed 632 and solar insolation sensed 642 independently from the first solar string. This information can be used to generate 652 a second

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IV curve independent from the first IV curve. In such embodiments, the IV curves can be reported together in step 660. In some embodiments, however, the sensed information from each or any of steps 622, 632, and/or 642 can be provided via a communications signal to the controller 212. In this way, the sensor 213 can either provide the IV curve directly or information which can be coordinated with other inputs, such as the voltage and/or solar insolation information to determine an IV curve.

[0060] Methods and apparatus for automatic generation and analysis of solar cell IV curves have been disclosed. While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or embodiments described herein are not intended to limit the scope, applicability, or configuration of the claimed subject matter in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the described embodiment or embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope defined by the claims, which includes known equivalents and foreseeable equivalents at the time of filing this patent application.

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CLAIMS

1. A method of evaluating performance of solar panels, the method comprising:

selectively providing power to a first current sensor in a plurality of current sensors, wherein the plurality of current sensors comprises Hall Effect field sensors;

sensing at a first instance, using the first current sensor while providing power to the first current sensor, current generated by a first string of solar panels in a plurality of strings of solar panels to generate a first sensed current;

sensing a solar insolation on the first string of solar panels at the first instance;

sensing a voltage generated by the first string of solar panels at the first instance; and

automatically generating a current-voltage (IV) curve of the first string of solar panels at the first instance using the first sensed current, the sensed solar insolation on the first string of solar panels at the first instance, and the sensed voltage generated by the first string of solar panels at the first instance; and

evaluating a performance of the first string of solar panels using the generated IV curve of the first string of solar panels at the first instance.

2. The method of claim 1, further comprising:

sensing at a second instance, that is after the first instance using the first current sensor while providing power to the first current sensor, current generated by the first string of solar panels to generate a second sensed current;

sensing a solar insolation on the first string of solar panels at the second instance;

sensing a voltage generated by the first string of solar panels at the second instance; and

automatically generating an IV curve of the first string of solar panels at the second instance using the second sensed current, the sensed solar insolation on the first string of solar panels of the second instance, and the sensed voltage generated by the first string of solar panels at the second instance.

3. The method of claim 2, further comprising:

comparing the IV curve of the first string of solar panels at the first instance with the IV curve of the first string of solar panels at the second instance to evaluate the performance of the first string of solar panels.

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4. The method of claim 1, further comprising:

selectively providing power to a second current sensor in the plurality of current sensors instead of providing power to the first current sensor;

sensing, using the second current sensor while providing power to the second current sensor, current generated by a second string of solar panels in the plurality of strings of solar panels to generate a third sensed current;

sensing a solar insolation on the second string of solar panels;

sensing a voltage generated by the second string of solar panels; and

automatically generating an IV curve of the second string of solar panels using the third sensed current, the solar insolation on the second string of solar panels, and the sensed voltage generated by the second string of solar panels.

5. The method of claim 1, further comprising:

receiving, in a communications port of a sensing device that includes the plurality of current sensors, a command to selectively provide the power to the first current sensor.

6. The method of claim 5, wherein the sensing device receives power from the communications port.

7. The method of claim 1, wherein evaluating the performance of the first string of solar panels comprises detecting a pending open circuit condition of the first string of solar panels.

8. A photovoltaic string monitoring system comprising:

a plurality of current sensors, the plurality of current sensors comprising Hall Effect field sensors;

a sensor to sense a solar insolation on a first string of solar panels in a plurality of solar panels;

a sensor to sense the voltage generated by the first string of solar panels;

a communications port;

a power source that receives power from the communications source; and

a microcontroller that selectively couples power from the power source to individual current sensors in the plurality of current sensors, the microcontroller being configured to select a first current sensor in the plurality of current sensors to receive power from the power source and to sense current generated by the first string of solar panels;

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wherein the microcontroller automatically generates a current-voltage (IV) curve using the sensed current, the sensed insolation, and the sensed voltage.

9. The photovoltaic monitoring system of claim 8, wherein the microcontroller is configured to select a second current sensor instead of the first current sensor in the plurality of current sensors to receive power from the power source.

10. The photovoltaic monitoring system of claim 8, wherein the microcontroller is configured to receive a voltage indicative of the current generated by the first string of solar panels.

11. The photovoltaic monitoring system of claim 10, wherein the microcontroller comprises an analog to digital converter and is configured to convert the voltage indicative of the current generated by the string of solar panels into digital form.

12. The photovoltaic monitoring system of claim 8, wherein the microcontroller is configured to receive a command through the communications port to selectively provide power to the first current sensor in the plurality of current sensors.

13. A method of evaluating performance of solar panels, the method comprising:

receiving a command through a communications port to selectively energize a first current sensor in a plurality of current sensors, wherein the plurality of current sensors comprises Hall Effect field sensors;

sensing, using the first current sensor while energizing the first current sensor, current generated by a first string of solar panels in a plurality of strings of solar panels;

sensing a solar insolation on the first string of solar panels;

sensing a voltage generated by the first string of solar panels; and

automatically generating a current-voltage (IV) curve of the first string of solar panels using the sensed current generated by the first string of solar panels, the sensed solar insolation on the first string of solar cells, and the sensed voltage generated by the first string of solar panels.

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14. The method of claim 13, further comprising:

comparing the IV curve of the first string of solar panels to another IV curve to evaluate performance of the first string of solar panels.

15. The method of claim 14, wherein the performance of the first string of solar panels indicates a pending open circuit condition of the first string of solar panels.

16. The method of claim 13, further comprising:

energizing a second current sensor instead of the first current sensor in the plurality of current sensors; and

sensing, using the second current sensor while energizing the second current sensor, current generated by a second string of solar panels in the plurality of strings of solar panels.

17. The method of claim 16, further comprising:

sensing a solar insolation on the second string of solar panels;

sensing a voltage generated by the second string of solar panels; and

automatically generating an IV curve of the second string of solar panels using the sensed current generated by the second string of solar panels, the sensed insolation on the second string of solar cells, and the sensed voltage generated by the second string of solar cells.

18. The method of claim 13, further comprising:

receiving power from the communications port.

SunPower Corporation

Patent Attorneys for the Applicant/Nominated Person

SPRUSON & FERGUSON

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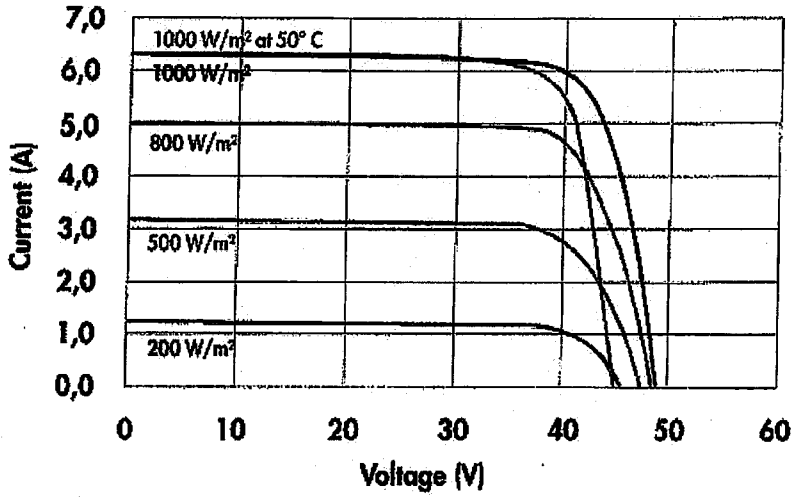


FIG. 1
(PRIOR ART)

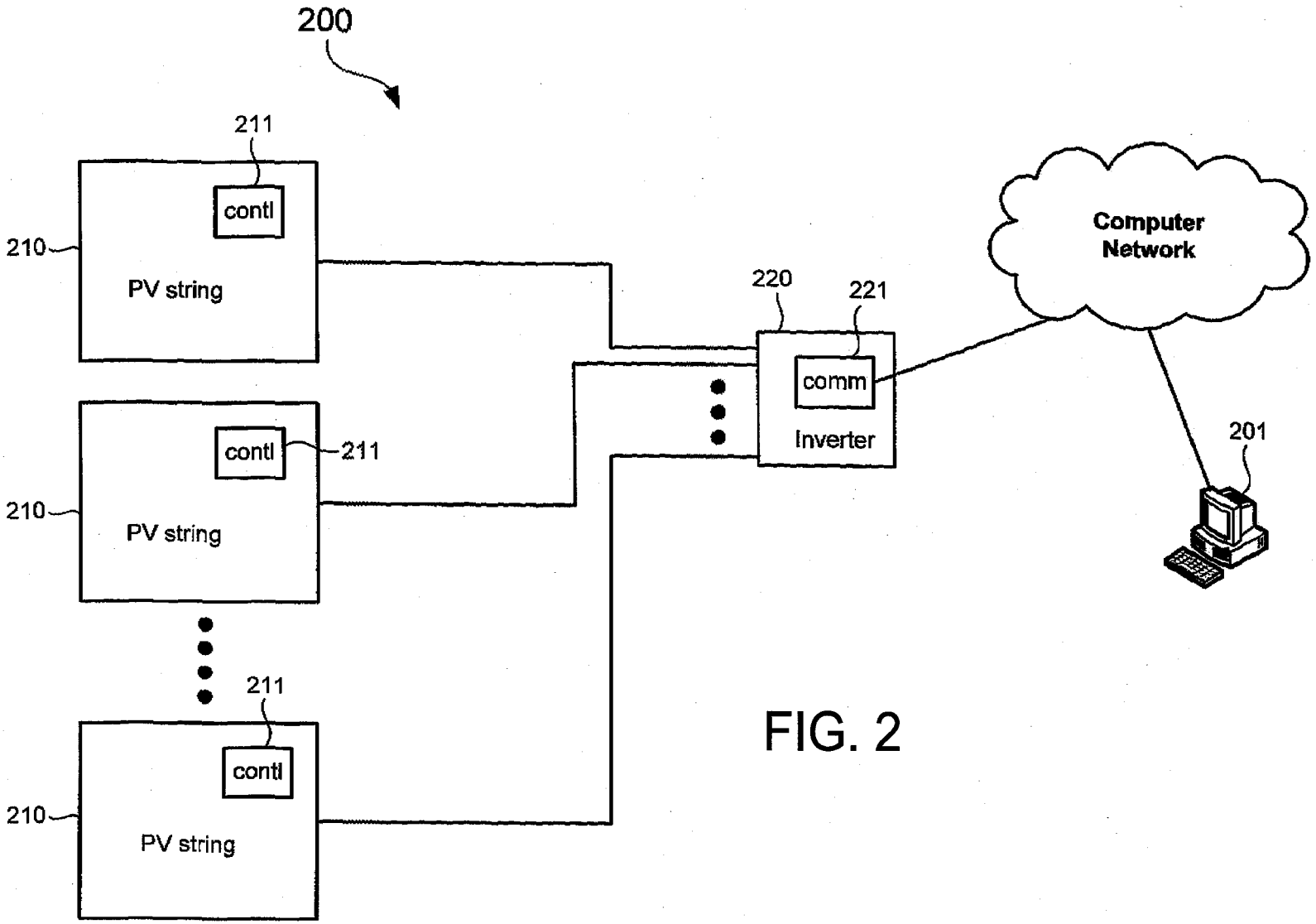

200
211
contl
210
PV string
211
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210
PV string
211
contl
210
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220
221
comm
Inverter
Computer Network
201

FIG. 2

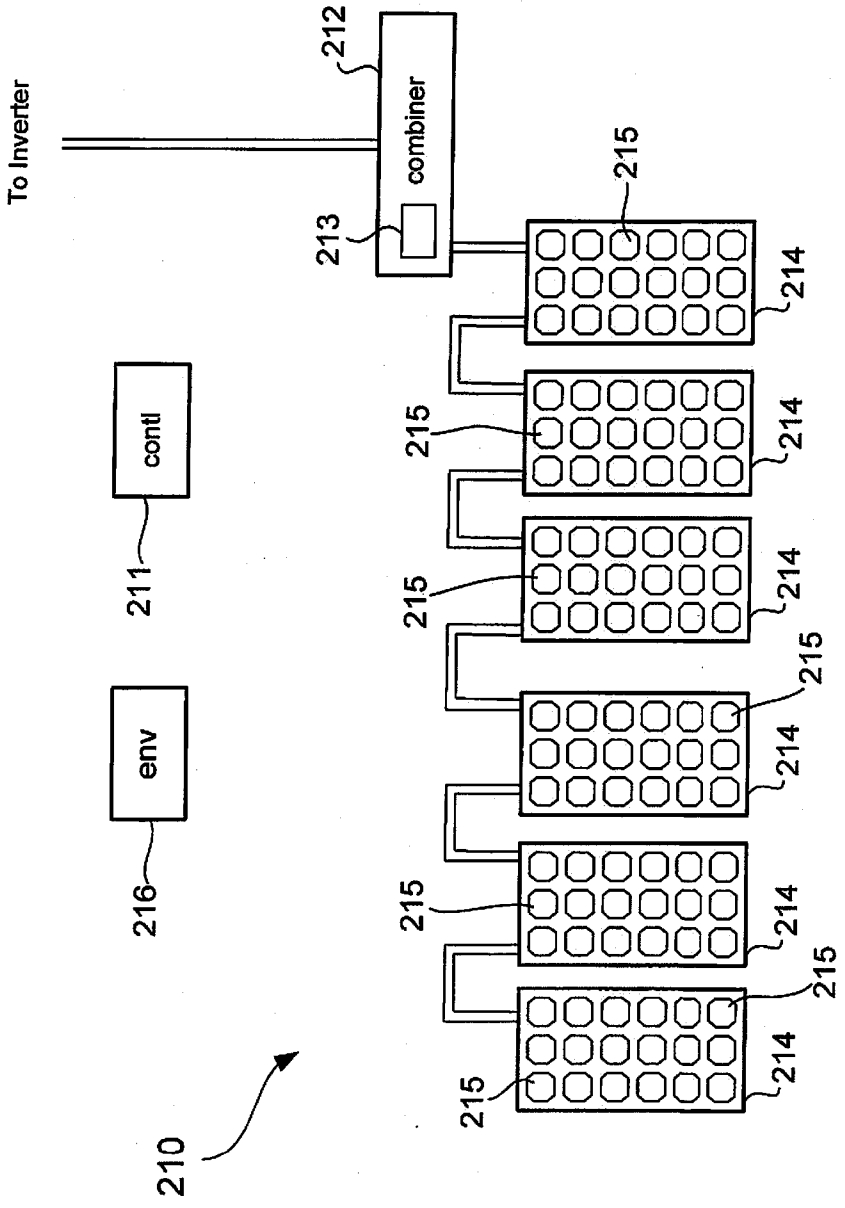


FIG. 3

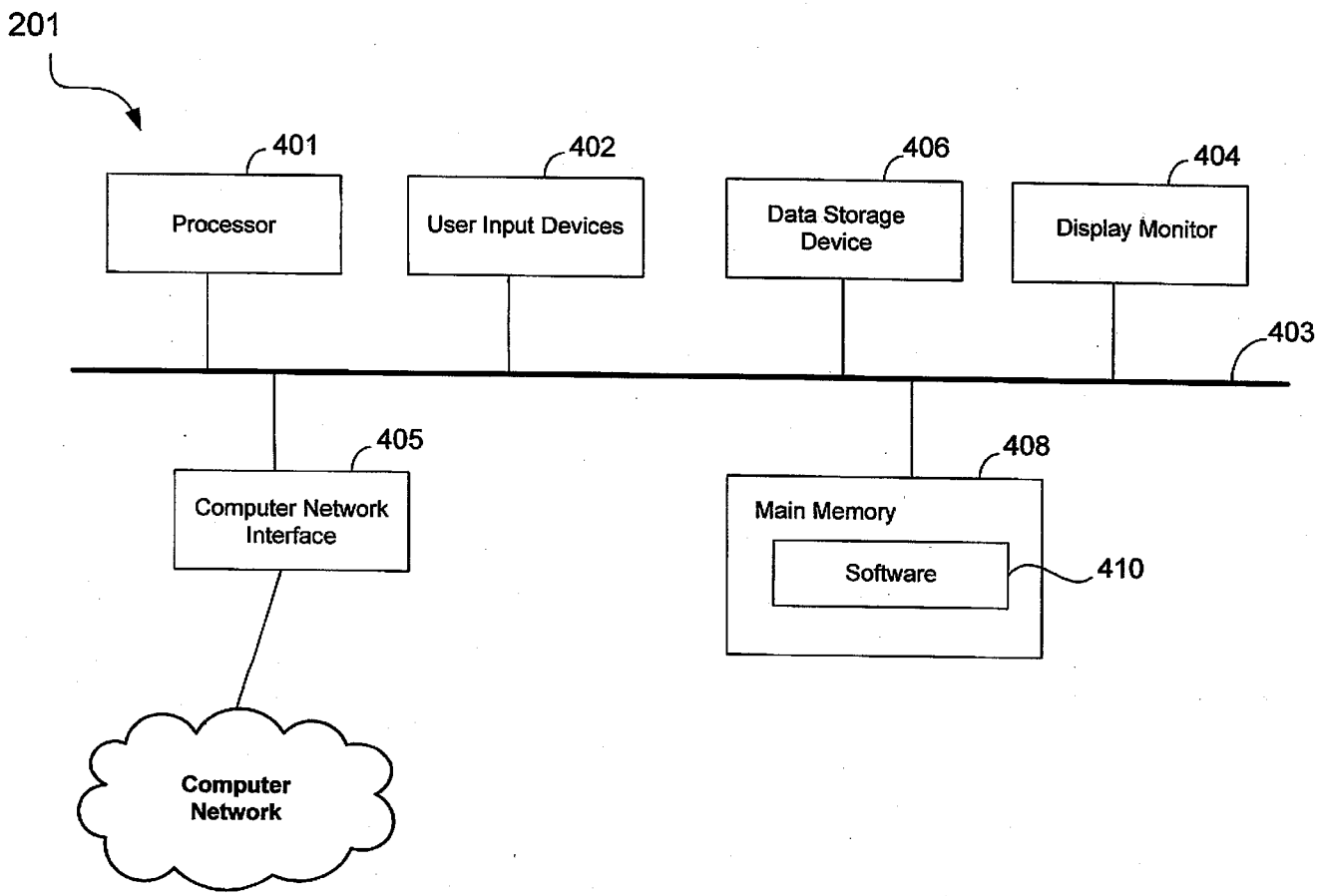

201
401
Processor
402
User Input Devices
406
Data Storage Device
404
Display Monitor
403
405
Computer Network Interface
408
Main Memory
Software
410
Computer Network

FIG. 4

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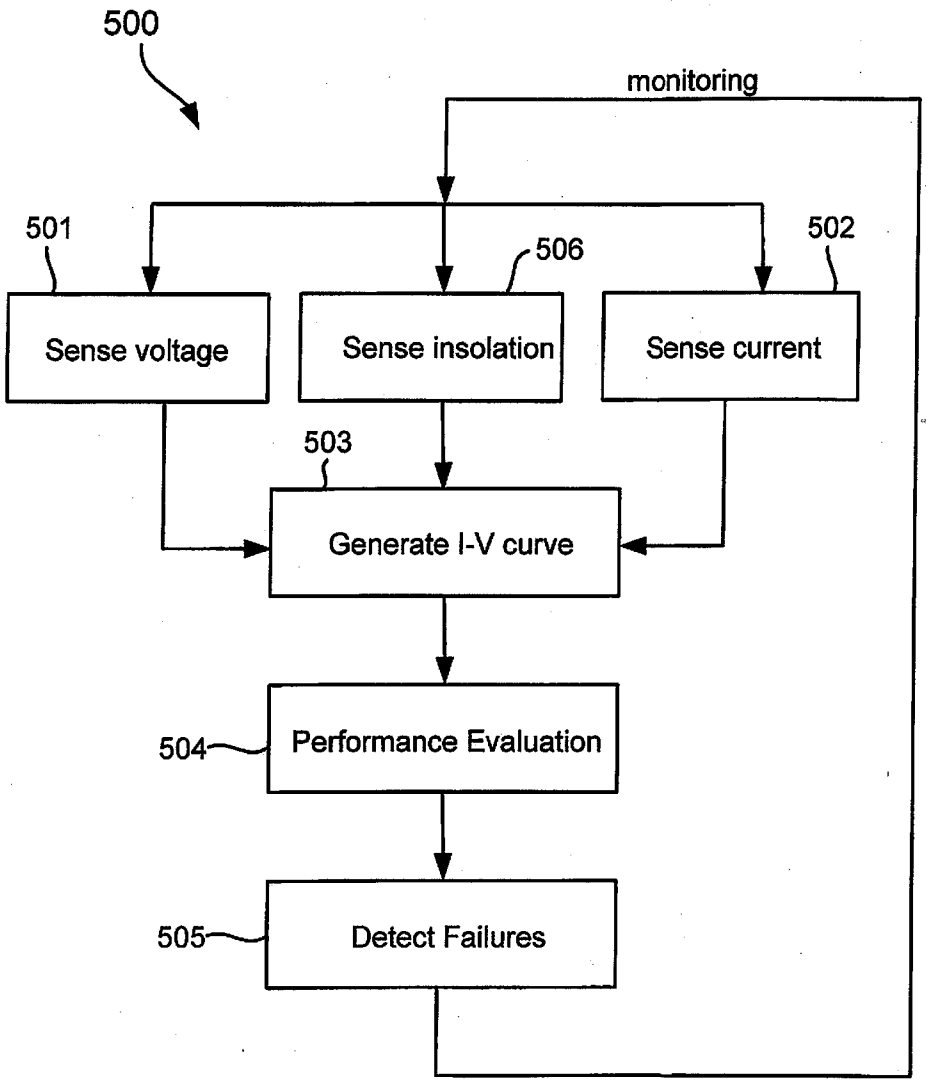


FIG. 5

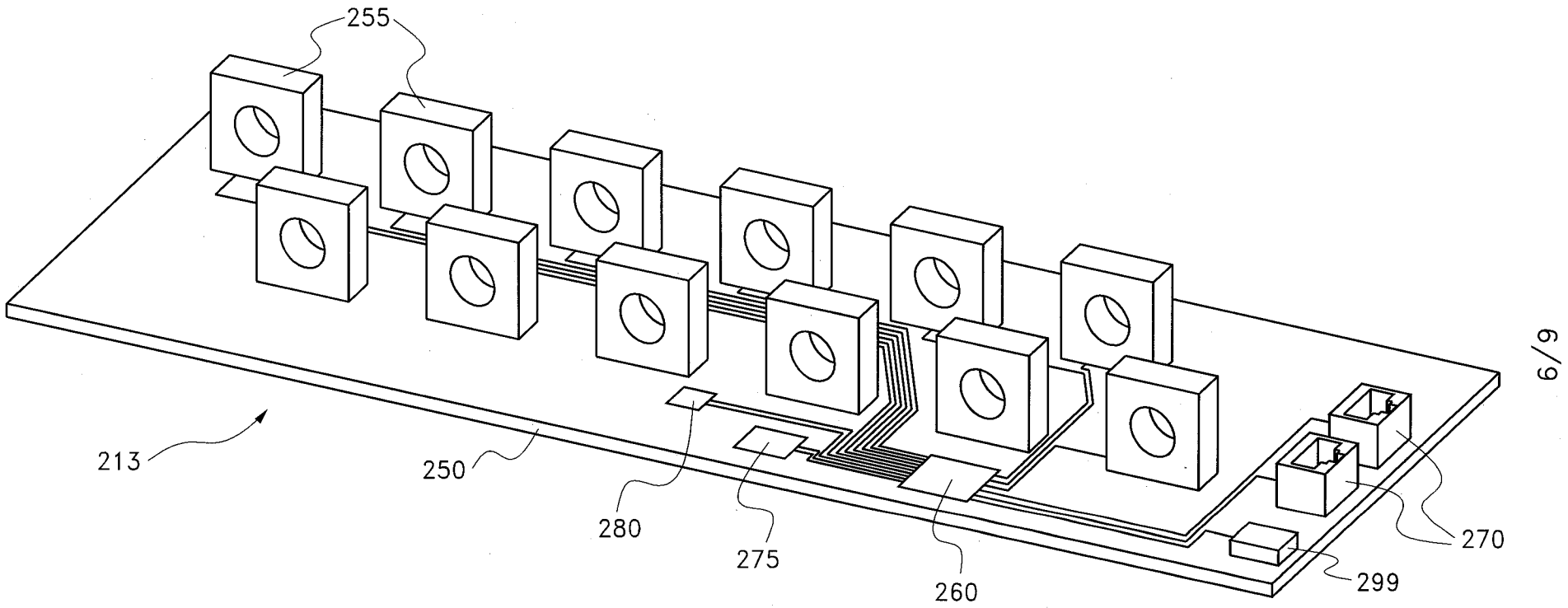


FIG. 6

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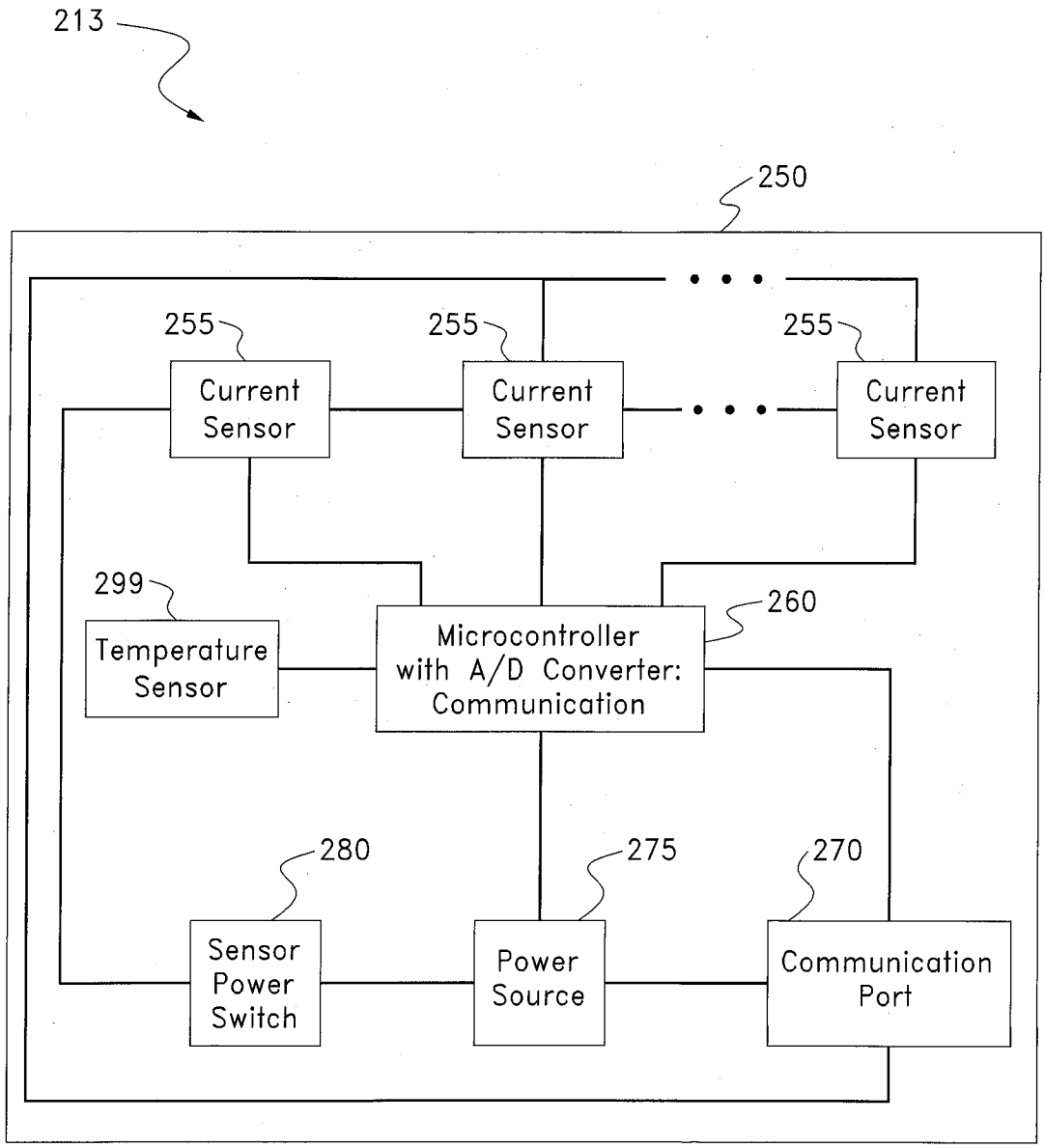


FIG. 7

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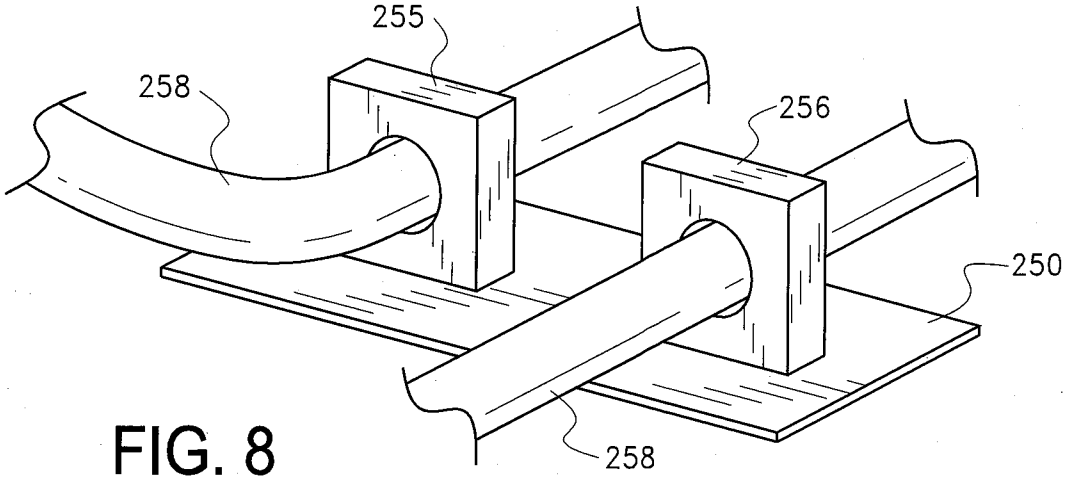


FIG. 8

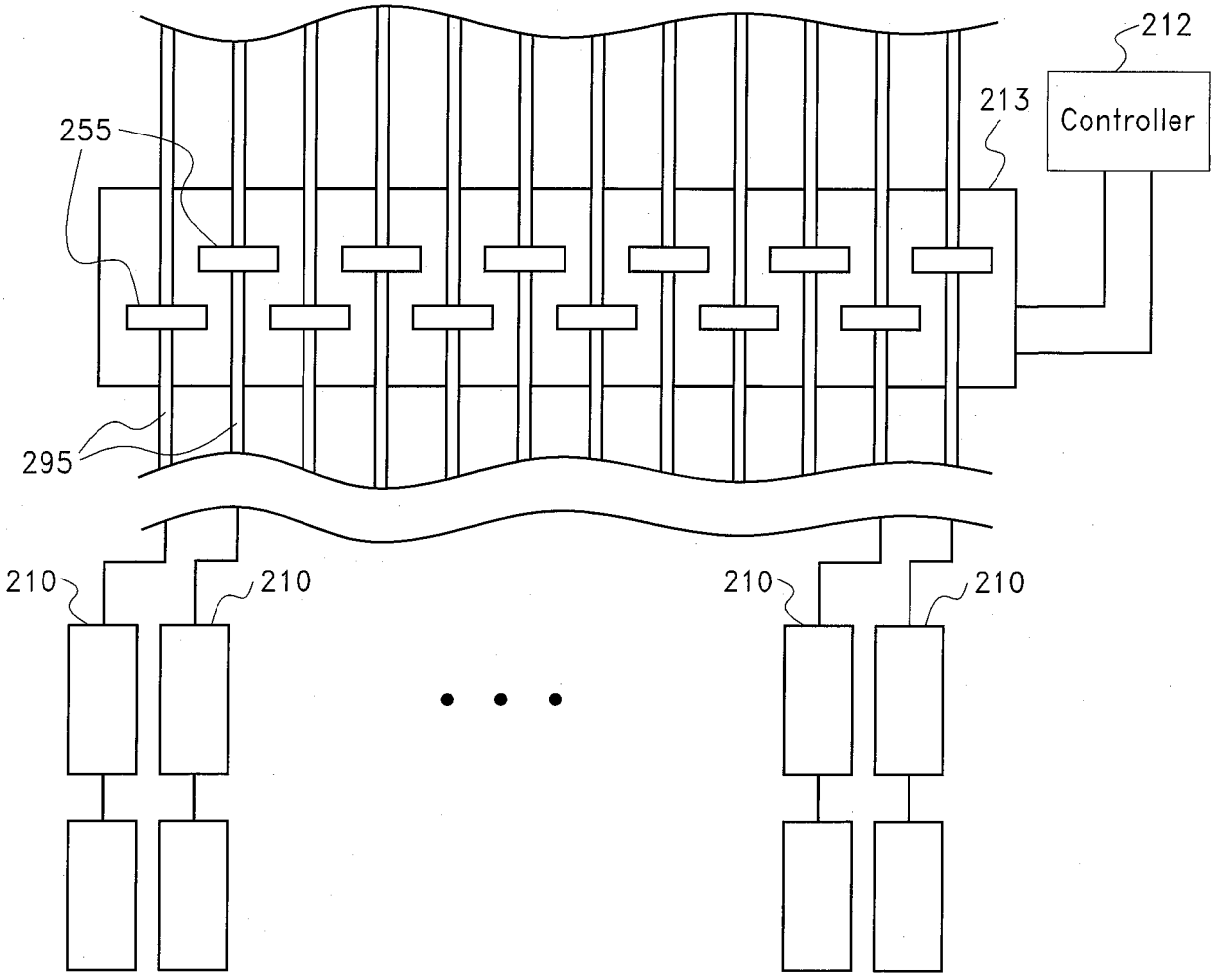


FIG. 9

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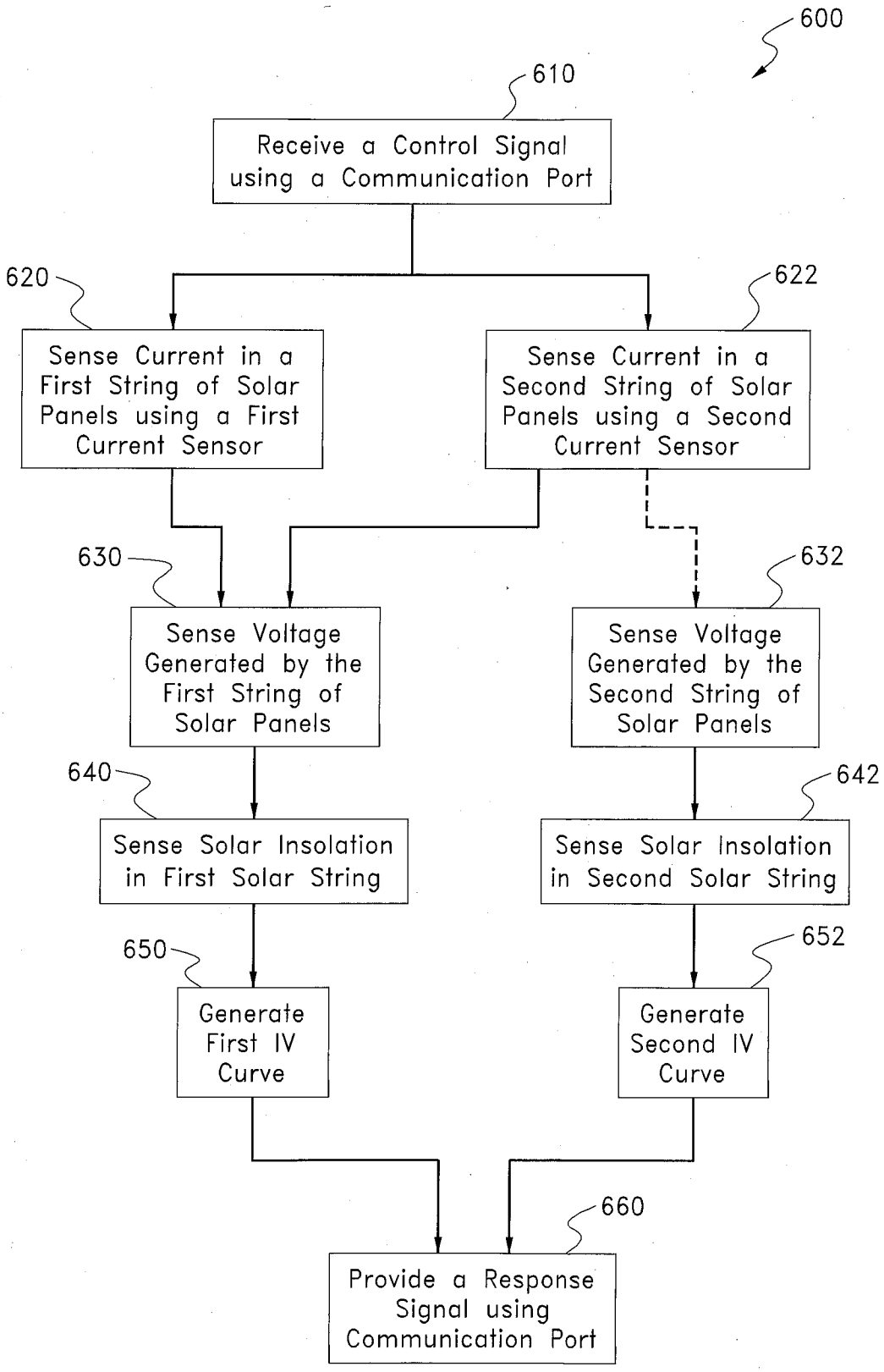


FIG. 10