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CONFIRMATION NO. 5948

Tigo Energy, Inc.  
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Los Gatos, CA 95032-1833

## FILING RECEIPT



Date Mailed: 10/22/2009

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Power of Attorney: None

If Required, Foreign Filing License Granted: 10/19/2009

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 61/276,753**

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Early Publication Request: No

**\*\* SMALL ENTITY \*\***

### Title

System and method for enhanced watch dog in solar panel installations

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16179

PTO/SB/16 (12-08)

Approved for use through 06/30/2010. OMB 0651-0032

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**PROVISIONAL APPLICATION FOR PATENT COVER SHEET – Page 1 of 2**

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EH 763433276 US

U.S. PTO

61/276753

09/16/2009

| INVENTOR(S)                            |                        |                                                         |
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|                                        |                        |                                                         |
|                                        |                        |                                                         |
|                                        |                        |                                                         |

Additional inventors are being named on the \_\_\_\_\_ separately numbered sheets attached hereto.

**TITLE OF THE INVENTION (500 characters max):**

System and Method for Enhanced Watch Dog in Solar Panel Installations

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OR

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**ENCLOSED APPLICATION PARTS (check all that apply)**

|                                                                                                                 |                                                     |
|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|
| <input type="checkbox"/> Application Data Sheet. See 37 CFR 1.76                                                | <input type="checkbox"/> CD(s), Number of CDs _____ |
| <input type="checkbox"/> Drawing(s) Number of Sheets _____                                                      | <input type="checkbox"/> Other (specify) _____      |
| <input checked="" type="checkbox"/> Specification (e.g. description of the invention) Number of Pages <b>50</b> |                                                     |

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**METHOD OF PAYMENT OF THE FILING FEE AND APPLICATION SIZE FEE FOR THIS PROVISIONAL APPLICATION FOR PATENT**

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PROVISIONAL APPLICATION COVER SHEET

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Date 09/16/2009

TYPED or PRINTED NAME Ella Revzin

REGISTRATION NO. \_\_\_\_\_  
(if appropriate)

TELEPHONE 408 3640150

Docket Number: \_\_\_\_\_

# **System and Method for Enhanced Watch Dog in Solar Panel Installations**

Inventors Sam Ardit, Ron Hadar  
TGY027 CIP of TGY002, TGY010

## **Background**

### ***Background TGY002***

When a photovoltaic panel or laminate is exposed to direct or diffuse light, a lethal voltage potential may be present. In the United States the possible voltage could be as high as 600 volts, while in Europe and the rest of the world this voltage could approach a kilovolt.

Because of this potential danger from electrical shock, solar panel manufacturers and code and standards development organizations have made some recommendations to minimize or eliminate this danger.

One suggestion has been to cover the photovoltaic panel with an opaque material such as a tarpaulin. However, this approach proposes its own safety risk from having the wind catch the tarpaulin and pull installation personnel off the roof as they try to control the unstable sheet material against the wind.

Another recommendation is to install and/or service the photovoltaic panels at night when there is minimal risk of the panels being energized. This approach presents the potential safety risks associated from working in a poorly lighted environment.

In addition to the potential personnel safety issues there are also significant risks to equipment and hardware. Connecting or disconnecting energized plugs can cause arcing and damage to these connectors, junction boxes, and other electrical components.

### ***Background TGY010***

Solar system installers take a large guard band (or safety margin) to make sure the voltages don't cross the 600V or 1000V limits in the United States and the European Union, respectively. That limitation inhibits them from installing more solar panel modules, often referred to as "modules" or "panels," in series to reduce the cost of combiner boxes or string inverters. When solar modules are connected in series or in mesh configurations, there can be a problem in which weaker modules not only produce less energy but also affect other modules' capabilities to deliver energy in the same string or wiring section.

## ***Background TGY027 New Matter***

In solar panel installations it is often desirable to have additional safety for the operating environment and for personnel involved with maintenance, etc. Of particular concern are certain portions of the wiring. If certain wires are disconnected, through theft, vandalism, accident, natural forces, or any other cause, voltages may rise to an unacceptable, even dangerous, level.

## **Description of the Embodiment**

### ***Description TGY002***

The following description and drawings are illustrative and are not to be construed as limiting. Numerous specific details are described to provide a thorough understanding. However, in certain instances, well known or conventional details are not described in order to avoid obscuring the description. References to one or an embodiment in the present disclosure are not necessarily references to the same embodiment; and, such references mean at least one.

One embodiment of the disclosure provides a method and system to reduce the safety risks during the shipment, installation and/or maintenance of photovoltaic systems, without introducing the risks associated with other approaches, such as covering them with an opaque material or working on them at night.

In one embodiment, safety protection is provided via the inclusion of a normally closed switch integral to the panel junction box or integral to the panel module when alternating current (AC) or direct current (DC) modules are used.

Figure TGY002-1 illustrates a solar panel having a safety switch according to one embodiment. In Figure TGY002-1, a solar panel 10 (e.g., a photovoltaic panel) includes at least one solar cell 12 (e.g., a photovoltaic cell) to generate power when exposed to direct or diffuse light, in some cases a voltage module 14 to adjust or regulate the output voltage (or in some other cases a current module to regulate current), and a switch 16 to selectively isolate the solar cell 12 from the output connectors of the solar panel. In yet other cases, the switch may be incorporated into regulator modules, such as voltage module 14.

In one embodiment, the switch 16 is a normally closed switch. During the shipment, installation and/or maintenance, the switch 16 is placed in an open state to isolate the solar cell 12 from the output. After the installation or maintenance, the switch 16 is placed into a closed state to allow the solar cell 12 to

energize the output connectors of the solar panel and to supply power through the output connectors of the solar panel.

The switch 16 and the voltage module can be integrated into the junction box of the solar panel. In some embodiment, the switch 16 is integrated with the voltage module 14 as a panel module.

Figures TGY002-2 through TGY002-5 illustrate a spring loaded safety switch for a photovoltaic panel according to one embodiment. In Figures TGY002-2 through TGY002-5, the switch includes two contactors 102 and 103 made of a conductive metal or plated hybrid. The contactors 102 and 103 are normally made of a spring alloy metal or have an integral spring plunger design (not shown). The contactors 102 and 103 are positioned or fixed in such a way that the two contacts 102 and 103 are spring loaded toward each other to maintain electrical continuity between the two contactors 102 and 103. Thus, the switch is normally closed (NC) and not in a safe mode for installation or maintenance.

In Figure TGY002-2, a safe mode for installation or maintenance is achieved when the blade 104 is inserted between the two contactors 102 and 103. The blade 104 is manufactured from a dielectric material and when inserted between the two contactors 102 and 103 there is no electrical continuity between the contactors 102 and 103.

As illustrated in Figure TGY002-2, the blade 104 may also have a flag 105 attached. The flag 105 could be red or some other highly visible color, to provide a visual indicator of the state of the panel.

In one embodiment, the panels and/or panel with integral modules would come shipped from the factory with the blade 104 and the flag 105, where the blade 104 is inserted between the two contactors 102 and 103. The panels would be installed and integrated with the blade 104 present and flag 105 visible. The installer would mount, secure, and plug in all of the connections in the system, including the grounding.

As illustrated in Figure TGY002-3, once the installation is completed the installer would remove the blades 104 at all those places indicated by the flags 105. Once the blade 104 is removed, the spring loaded contactors 102 and 103 contact each other to provide an electric path from the photovoltaic cells to the output connectors of the photovoltaic panel.

If additional work or troubleshooting were needed, the blade(s) 104 and flag(s) 105 could be reinserted, aided by the tapered section 207 of the blade 104, thereby breaking the electrical continuity between the contactors 102 and 103 at point 206.

In some embodiments, there is symmetry in contactors 102 and 103. In other embodiments, the contactors 102 and 103 are not identical or even similar. The contactors 102 and 103 are made of electrically conductive material and configured to be in physical contact with each so that an electrically conductive path 206 is maintained, after the blade 104 is removed. In at least some embodiments, the electrical conductive path 206 is maintained without the blade 104 being inserted between the contactors 102 and 103, then disrupted by the blade 104 inserted between the contactors 102 and 103, and then reestablished by the reinsertions of a dielectric device such as the blade 104.

In addition to the visual indication of the modes of the panels provided by the flag(s) 105, the flags could also provide information in the form of text, such as, for example, "Remove before operation" or a warning of potentially lethal voltage.

Figure TGY002-4 illustrates a configuration of a spring loaded switch integrated with a junction box 308 of a photovoltaic panel. The junction box 308 includes a connector to connect the solar power generated by the photovoltaic panel to a load (e.g., an inverter, a voltage bus, etc.) via a cable 307. Thus, when the blade 104 is inserted into the switch, with the flag 105 visible, the voltage generated by the solar cells is isolated from the connector for the cable 307; and thus it is safe to install the photovoltaic panel or to perform maintenance operations on the photovoltaic panel.

Figure TGY002-5 shows the components of the spring loaded switch and the junction box of a photovoltaic panel. As illustrated in Figure TGY002-5, the junction box 308 has an opening 409, which provides access to remove the blade 104 and/or to re-insert the blade 104. The contactors 103 of the switch can be attached to the junction box 308 via fastening the portion 401 to a supporting member of the junction box 308, such as a printed circuit board (PCB).

Figures TGY002-6 through TGY002-7 illustrate a junction box with a reed switch for a photovoltaic panel according to one embodiment. Figure TGY002-6 shows an assembly of a reed switch 510 and magnets for integrated into the photovoltaic junction box 308. Figure TGY002-7 shows a cut-away section illustrating the reed switch 510 and the magnets 511 and 512 installed within the portion 509 of the junction box 308.

In Figure TGY002-7, a reed switch 510 is made normally closed by integrating a stationary biasing magnet 511 into the junction box 308 in close proximity to the normally open reed switch, so that the

switch 510 is closed in absence of the magnet 512.

In one embodiment, the magnet 512 is inserted into the junction box well 509 so that the reversed polarity cancels the magnetic lines of force and the reed switch 510 opens.

In one embodiment, the magnet 512 is installed in the junction box well 509 at the factory; and a flag 105 (not shown in Figures TGY002-6 and TGY002-7) is attached to the magnet 512. The magnet 512 is removable and/or re-insertable via the junction box well 509.

In other embodiments, normally closed (NC) reed contacts can be used to replace the normally open (NO) reed contacts 510 and the magnet 511, avoiding the need for the additional stationary magnet.

Once the installation and integrations are complete the magnet 512 is removed and may be discarded. The power leads of the junction box 308 can then be energized via the semiconductor switch or relay (not shown), when the reed switch 512 is in the closed state.

In some cases, a semiconductor switch (not shown in Figure TGY002-7) can be used to energize the power leads of the junction box 308. The panel junction box 308 or inverter (not shown in Figure TGY002-7) may include a controller unit with a watchdog circuit configured to send a signal periodically (e.g., every time interval  $t$ ) to maintain the connection of the panel outputs to the string. When this signal is timed-out or is absent, the panel outputs of the panel are disconnected via a semiconductor switch device (not shown).

Figure TGY002-8 illustrates an optical sensor to control a safety switch for a photovoltaic panel according to one embodiment. In Figure TGY002-8, an optical sensor unit 700 with an optical sensor 701 is mounted on a printed circuit board (PCB) 711. Additionally, springs 702 and 712 hold a separator 703 in place that can be removed in direction of arrow 704 using a pull-tab similar to the flag 105 discussed earlier. Not shown in Figure TGY002-8 is the exterior enclosure that would contain the mechanical elements such as the cable connections and the guide elements for guiding separator 703 in and out of the unit.

In one embodiment, additional circuitry (not shown in Figure TGY002-8) will be on the side of the PCB 711, such as a control circuit to affect an on/off switching either in some cases by FET (Field-Effect Transistor) transistors or using, in other cases, a relay, such as a bi-stable relay or another suitable circuit. The operational power may be drawn from the solar system itself, or it may be brought up by auxiliary

wiring.

In yet some other embodiments, a relay can be simply remote controlled by an auxiliary wire to close or open the circuit. The advantage of this approach is that no pull-tabs (flags or blades) can be forgotten on the roof.

In one embodiment, a mechanism and/or circuitry is integrated in the panel to identify the load from the inverter and connect the panel to the panel outputs when the load is detected. When no load is present the panel outputs is disconnected. This functionality would also be implemented using a semiconductor switch device or other suitable device (such as a relay), and some sensor circuitry, allowing an automatic reconnect when the loop appears to be closed and a load connected.

Figure TGY002-9 illustrates a solar panel having a safety switch controlled via auxiliary wiring according to one embodiment. In Figure TGY002-9, a separate wire is connected to control the switch 16 from a remote location. For example, the switch may be controlled via a signal from a watchdog circuit, from a remote switch or controller, etc.

In the foregoing specification, the disclosure has been described with reference to specific exemplary embodiments thereof. It will be evident that various modifications may be made thereto without departing from the broader spirit and scope as set forth in the following claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.

### ***Description TGY010***

The following description and drawings are illustrative and are not to be construed as limiting. Numerous specific details are described to provide a thorough understanding. However, in certain instances, well known or conventional details are not described in order to avoid obscuring the description. References to one or an embodiment in the present disclosure are not necessarily references to the same embodiment; and, such references mean at least one.

When solar modules are connected in series or mesh configuration, there can be a problem in which weaker modules not only produce less energy but also affect other modules in the same string or wiring section. By measuring one can determine that a few modules are weaker than the others in most commercially installed strings. Thus, the string is generating less power than the sum available at each module if modules were operated separately.

At least one embodiment of the present disclosure provides methods and systems to switch on and off weak modules in the string in a way that the current on the string bus from the good modules won't be affected by the weak modules.

Figures TGY010-1 through TGY010-3 illustrate local management units according to some embodiments. In Figures TGY010-1 through TGY010-3, local management units (101) are used to switch on and off the solar module (102) periodically to improve the energy production performance of the photovoltaic systems connected, at least in part, in series.

In Figure TGY010-1, a management unit (101) is local to the solar module (102) and can be used to periodically couple the solar module (102) to the serial power bus (103) via the switch Q1 (106), to improve the total power output for the string of solar modules connected to the serial power bus in series.

The local management unit (LMU) (101) may include a solar module controller to control the operation of the solar module (102) and/or a link module unit to provide connectivity to the serial power bus (103) for energy delivery and/or for data communications.

In one embodiment, the command to control the operation of the switch Q1 (106) is sent to the local management unit (101) over the photovoltaic (PV) string bus (power line) (103). Alternatively, separate network connections can be used to transmit the data and/or commands to/from the local management unit (101).

In Figures TGY010-1 and TGY010-2, the inputs (104a, 104b, 104c) to the local management unit (101) are illustrated separately. However, the inputs (104a, 104b, 104c) are not necessarily communicated to local management unit (101) via separate connections. In one embodiment, the inputs are received in the local management unit via the serial power bus (103).

In Figure TGY010-1, the solar module (102) is connected in parallel to the capacitor C1 (105) of the local management unit (101). The diode D1 (107) of the local management unit (101) is connected in series in the serial power bus (103) which may or may not be part of an overall mesh configuration of solar modules. The switch Q1 (106) of the local management unit can selectively connect or disconnect the solar module (102) and the capacitor C1 (105) from a parallel connection with the diode D1 (107) and thus connect or disconnect the solar module (102) from the serial power bus (103).

In Figure TGY010-1, a controller (109) of the local management unit (101) controls the operation of

the switch (106) according to the parameters, such as duty cycle (104a), phase (104b) and synchronization pulse (104c).

In one embodiment, the controller (109) receives the parameters (104a, 104b, 104c) from a remote management unit via the serial power bus (103) or a separate data communication connection (e.g., a separate data bus or a wireless connection). In some embodiment, the controller (109) may communicate with other local management units connected on the serial power bus (103) to obtain operating parameters of the solar modules attached to the serial power bus (103) and thus compute the parameters (e.g., 104a and 104b) based on the received operating parameters. In some embodiment, the controller (109) may determine the parameter (e.g., 104a and 104b) based on the operating parameters of the solar module (102) and/or measurements obtained by the controller (109), without communicating with other local management units of other solar modules, or a remote system management unit.

In Figure TGY010-2, a system (100) has a local management unit (101) coupled to the solar module (102). The local management unit (101) is connected between the solar module (102) and the string bus (103) to improve the total power output for the whole string on the serial power bus (103). Commands to the local management unit (101) can be sent over the photovoltaic (PV) string bus (power line) (103). To make the figure more clear, the inputs (104a, 104b, 104c) to the controller (109) of the local management unit (101) were drawn separately, which does not necessarily indicate that the inputs (104a, 104b, 104c) are provided via separate connections and/or from outside the local management unit (101). For example, in some embodiments, the controller (109) may compute the parameters (104a, 104b, 104c) based on measurements obtained at the local management unit (101), with or without data communications over the serial power bus (103) (or a separate data communication connection with other management units).

In Figure TGY010-2, the local management unit (101) is connected in one side to the solar module (102) in parallel and on the other side in series to a string of other modules, which may or may not be part of an overall mesh configuration. The local management unit (101) may receive, among others, three inputs or types of input data, including a) requested duty cycle (104a), which can be expressed as a percentage (e.g., from 0 to 100%) of time the solar module (102) is to be connected to the serial power bus (103) via the switch Q1 (106), b) a phase shift (104b) in degrees (e.g., from 0 degree to 180 degree) and c) a timing or synchronization pulse (104c). These inputs (e.g., 104a, 104b and 104c) can be supplied as

discrete signals, or can be supplied as data on a network, or composite signals sent through the power lines or wirelessly, and in yet other cases, as a combination of any of these input types.

In Figure TGY010-2, the local management unit (101) periodically connects and disconnects the solar module (102) to and from the string that forms the serial power bus (103). The duty cycle (104a) and the phase (104b) of the operation of the switch Q1 (106) can be computed in a number of ways to improve the performance of the system, which will be discussed further below.

In Figure TGY010-2, the local management unit (101) includes a capacitor C1 (105) and a switch Q1 (106), as well as a diode D1 (107). In Figure TGY010-2, the diode D1 (107) is supplemented with an additional switch Q2 (108), which acts as a synchronous rectifier to increase efficiency. In one embodiment, the additional switch Q2 (108) is open (turned off) when the switch Q1 (106) is closed (turned on) to attach the solar module (102) (and the capacitor C1 (105)) to the serial power bus (103).

In some cases, a filter (not shown), including a serial coil and a parallel capacitor, is also used. The filter may be placed at the local management unit or placed just before the fuse box or inverter, or be part of either one of those.

In Figure TGY010-2, the controller (109) is used to process the input signals (e.g., 104a, 104b, 104c) and drive the switches Q1 (106) and Q2 (108). In one embodiment, the controller (109) is a small single chip micro controller (SCMC). For example, the controller (109) may be implemented using Application-Specific Integrated Circuit (ASIC) or Field-Programmable Gate Array (FPGA). The controller (109) can even be implemented in discrete, functionally equivalent circuitry, or in other cases a combination of SCMC and discrete circuitry.

In one embodiment, the controller (109) is coupled to the solar module (102) in parallel to obtain power for processing; and the controller (109) is coupled to the serial power bus (103) to obtain signals transmitted from other management units coupled to the serial power bus (103).

By switching the module (102) (or groups of cells, or a cell) on and off to the string periodically, the local management unit (101) may lower the voltage reflected to the string bus (103) (e.g., a lower average voltage contributed to the string bus) and can cause the current reflected to the string bus (103) to be higher, nearer the level it would be if the module was not weak, generating a higher total power output.

In one embodiment, it is preferable to use different phases to operate the switches in different local

management units on a string to minimize voltage variance on the string.

In Figure TGY010-3, the local management unit (101) provides two connectors (112 and 114) for serial connections with other local management unit (101) to form a serial power bus (103). The controller (109) controls the states of the switches Q1 (106) and Q2 (108).

In Figure TGY010-3, when the controller (109) turns on the switch (106), the panel voltage and the capacitor C1 (105) are connected in parallel to the connectors (112 and 114). The output voltage between the connectors (112 and 114) is substantially the same as the output panel voltage.

In Figure TGY010-3, during the period the switch (106) is turned off (open), the controller (109) turns on (closes) the switch (108) to provide a path around the diode D1 (107) to improve efficiency.

In Figure TGY010-3, when the switch (106) is turned off (open), the panel voltage charges the capacitor C1 (105), such that when the switch (106) is turned on, both the solar panel and the capacitor (105) provides currents going through the connectors (112 and 114), allowing a current larger than the current of the solar panel to flow in the string (the serial power bus (103)). When the switch (106) is turned off (open), the diode D1 (107) also provides a path between the connectors (112 and 114) to sustain the current in the string, even if the switch (108) is off for some reasons.

In one embodiment, the controller (109) is connected (not shown in Figure TGY010-3) to the panel voltage to obtain the power for controlling the switches Q1 (106) and Q2 (108). In one embodiment, the controller (109) is further connected (not shown in Figure TGY010-3) to at least one of the connectors to transmit and/or receive information from the string. In one embodiment, the controller (109) includes sensors (not shown in Figure TGY010-3) to measure operating parameters of the solar panel, such as panel voltage, panel current, temperature, light intensity, etc.

Figure TGY010-4 illustrates a photovoltaic system (200) according to one embodiment. In Figure TGY010-4, the photovoltaic system 200 is built from a few components, including photovoltaic modules (201a, 201b, ..., 201n), local management unit units (202a, 202b, ..., 202n), an inverter (203), and a system management unit (204).

In one embodiment, the system management unit (204) is part of the inverter (203), the combiner box (206), a local management unit, or a stand-alone unit. The solar modules (201a, 201b, ..., 201n) are connected in parallel to the local management unit units (202a, 202b, ..., 202n) respectively, which are

connected in series to form a string bus (205), which eventually is connected to an inverter (203) and the management unit (204).

In Figure TGY010-4, the string bus (205) can be connected to the inverter (203) directly or as part of a mesh network or combiner boxes or fuse boxes (not shown). An isolated local management unit can be used as a combiner box (206) to adjust all voltages before connecting to the inverter (206); or, a single or multi-string inverter can be used. To limit the changes in the voltage of the bus, the management unit (204) may assign a different phase for each of the local management units (202a, 202b, ..., 202n). In one embodiment, at any given time, a maximum of a predetermined number of solar modules (e.g., one single solar module) are disconnected from the string bus (205).

In one embodiment, beyond the module connection the local management units can have the signal inputs, including but not limited to duty cycle (104a), phase (104b) and synchronization pulse (104c) (e.g., to keep the local management units synchronized). In one embodiment, the phase (104b) and the synchronization pulse (104c) are used to further improve performance, but the local management unit (101) can work without them.

In one embodiment, the local management unit may provide output signals. For example, the local management unit (101) may measure current and voltage at the module side and optionally measure current and voltage in the string side. The local management unit (101) may provide other suitable signals, including but not limited to measurements of light, temperature (both ambient and module), etc.

In one embodiment, the output signals from the local management unit (101) are transmitted over the power line (e.g., via power line communication (PLC)), or transmitted wirelessly.

In one embodiment, the system management unit (204) receives sensor inputs from light sensor(s), temperature sensor(s), one or more each for ambient, solar module or both, to control the photovoltaic system (200). In one embodiment, the signals may also include synchronization signals. For example, a maUsing the described methods the local management unit can be a very non-expensive and reliable device that can easily increase the throughput of a photovoltaic solar system by a few (e.g., signal or low double digits) percentage points. These varied controls also allow installers using this kind of system to control the VOC (open circuit voltage) by, for example by shutting off some or all modules. For example, by using the local management units of the system, a few modules can be disconnected from a string if a string is

getting to the regulatory voltage limit, thus more modules can be installed in a string.

In some embodiments, local management units can also be used within the solar panel to control the connection of solar cells attached to strings of cells within the solar panel.

Figure TGY010-5 illustrates a solar panel according to one embodiment. In one embodiment, the solar panel (300) has a few strings of solar cells (e.g., three solar cell strings per module). In Figure TGY010-5, a local management unit (101) can be applied to a group of cells (301) within a string of an individual solar panel (300), or in some cases to each cell (301) in a solar panel (300).

In Figure TGY010-5, a group of solar cells (301) that are attached to a local management unit (101) may be connected to each other in series, in parallel, or in a mesh configure. A number of local management units (101) connect the groups of the solar cells (301) in a string to provide output for the solar panel (300).

Some embodiments of the disclosure includes methods to determine the duty cycles and/or phases for local management units connected to a string or mesh of solar modules.

In some embodiments, the duty cycle of all local management units in a string or mesh can be changed, to increase or decrease the string voltage. The duty cycles may be adjusted to avoid exceeding the maximum voltage allowed. For example, the maximum voltage may be limited by the combiner box (206), the inverter (203), or any other load connected to the string bus (205), or limited by any regulations applicable to that system. In some embodiments, the duty cycles are adjusted to align the voltage of multiple strings.

In some embodiments, the duty cycle of one local management unit (101) in a string can be changed to cause higher current in that local management unit (101) and overall higher power harvesting.

In one embodiment, the duty cycles are computed for the solar modules that are connected to a string via the corresponding local management units. The duty cycles can be calculated based on the measured current and voltages of the solar modules and/or the temperatures.

After an initial set of duty cycles is applied to the solar modules, the duty cycles can be further fine tuned and/or re-adjusted to changes, such as shifting shading etc., one step a time, to improve power performance (e.g., to increase power output, to increase voltage, to increase current, etc.). In one embodiment, target voltages are computed for the solar modules, and the duty cycles are adjusted to drive

the module voltage towards the target voltages.

The methods to compute the duty cycles of the solar modules can also be used to compute the duty cycles of the groups of solar cells within a solar module.

Figures TGY010-6 through TGY010-8 show methods to improve performance of a photovoltaic system according to some embodiments.

In Figure TGY010-6, at least one operating parameter of a solar energy production unit coupled to a string via a management unit is received (401) and used to identify (403) a duty cycle for the management unit to connect the solar energy production unit to string. The solar energy production unit may be a solar module, a group of solar cells within a solar module, or a single solar cell in a string in a solar module. The duty cycle is adjusted (405) to optimize the performance of the solar energy production unit and/or the string.

For example, the duty cycle can be adjusted to increase the current in the string and/or the solar energy production unit, to increase the output power of the string and/or the solar energy production unit, to increase the voltage of the solar energy production unit, etc.

In Figure TGY010-7, the operating voltages of a plurality of solar panels connected in series are received (421) and used to identify (423) a second solar panel having the highest operating voltage (highest output power) in the string.

In Figure TGY010-7, a duty cycle of a first solar panel is computed (425) based on a ratio in operating voltage between the first and second solar panels. Alternatively, the duty cycle can be computed based on a ratio in output power between the first and second solar panels. Alternatively, the duty cycle can be computed based on a ratio between the first and second solar panels in estimated/computed maximum power point voltage. Alternatively, the duty cycle can be computed based on a ratio between the first and second solar panels in estimated/computed maximum power point power.

The duty cycle of the first solar panel is adjusted (427) to improve the performance of the first solar energy production unit and/or the string, until a decrease in the operating voltage of the second solar panel is detected. For example, the duty cycle of the first solar panel can be adjusted to increase the total output power of the string, to increase the current of the string, to increase the current of the first solar panel, to drive the voltage of the first solar panel towards a target voltage, such as its maximum power point voltage

estimated based on its current operating parameters, such as temperature or a voltage calculated using its estimated maximum power point voltage.

In Figure TGY010-7, in response to the detected decrease in the operating voltage of the second solar panel which had the highest operating voltage, the adjustment in the duty cycle of the first solar panel that causes the decrease is undone/reversed (429).

In Figure TGY010-7, the duty cycle of the second solar panel is optionally decreased (431) to increase the operating voltage of the second solar panel. In some embodiments, the strongest solar panel (or strong panels within a threshold from the strongest panel) is not switched off line (e.g., to have a predetermined duty cycle of 100%).

In one embodiment, the duty cycle of the second solar panel is repeatedly decreased (429) until it is determined (431) that the decrease (429) in the duty cycle of the second solar panel cannot increase the voltage of the second solar panel.

In Figure TGY010-8, operating parameters of a plurality of solar panels connected in a string are received (441) and used to identify (443) a first maximum power point voltage of a first solar panel. A second solar panel having the highest operating voltage (or output power) in the string is identified. A second maximum power point voltage of the second solar panel is identified (447) based on the received operating parameters and used to compute (449) a target voltage for the first solar energy production unit. In one embodiment, the target voltage is a function of the first and second maximum power point voltages and the highest operating voltage identified (445) in the second solar panel in the string. The duty cycle of the first solar energy production unit is adjusted to drive the operating voltage of the first solar panel towards the target voltage.

Alternatively, the target voltage may be set as the first maximum power point voltage of the first solar panel.

In one embodiment, to adjust voltage a same factor is applied to all modules in that string. For example, in a case of a first module A1 that is producing only 80%, and the voltage of the whole string needs to be 5% lower, the duty cycle of A1 is 80% multiplied the duty cycle applied to the whole string (which is Y in this example) so module A1 then has  $Y \times 0.8$  as duty cycle.

In some embodiments, the system management unit (204) and/or the local management units (e.g.,

202a, 202b, ..., 202n) are used solely or in combination to determine the parameters to control the operations of the switches.

For example, in one embodiment, a system management unit (204) is the “brain” of the system, which decides on the duty cycle and phase parameters.

For example, in another embodiment, each local management unit broadcasts information to the other local management units on the string to allow the individual local management units to decide their own duty cycle and phase parameters.

In some embodiment, a local management unit may instruct one or more other local management units to adjust duty cycle and phase parameters. For example, the local management units on a string bus (205) may elect one local management unit to compute the duty cycle and phase parameters for other local management units on the string.

For example, in some embodiment, the system management unit (204) may determine one or more global parameters (e.g., a global duty cycle, the maximum power on the string, the maximum voltage on the string, etc.), based on which individual local management units adjust their own duty cycles.

In some embodiments, a local management unit may determine its own duty cycles without relying upon communicating with other management units. For example, the local management unit may adjust its duty cycle for connecting its solar module to the string to operate the solar module at the maximum power point.

In one embodiment, module voltage are measured by the local management units in the same string at substantially/approximately the same time and used to identify the strongest solar module. A strongest solar module provides the most power in the string. Since the modules are connected in series, the solar module having the highest module voltage in the string can be identified as the strongest solar module. In some embodiment, the operating voltage and current of the solar module are measured to determine the power of the solar module.

In one embodiment, after the highest module voltage  $V_m$  in the string is identified, the duty cycle for each module can be computed as a function of a ratio between the module voltage  $V$  of the module and the highest module voltage  $V_m$ . For example, the duty cycle for a module can be computed as  $1 - ((V_m - V)/V_m) = V/V_m$ .

In one embodiment, the system management (204) may identify the highest module voltage from the module voltages received from the local management units (202a, 202b, ..., 202n), and compute the duty cycles for the corresponding local management units (202a, 202b, ..., 202n).

In one embodiment, the local management units (202a, 202b, ..., 202n) may report their module voltages on the string bus (205) to allow individual local management units (202a, 202b, ..., 202n) to identify the highest module voltage and compute the duty cycles, without relying upon the system management unit (204).

In one embodiment, one of the local management units (202a, 202b, ..., 202n) may identify the highest module voltage and/or compute the duty cycles for the other local management units (202a, 202b, ..., 202n).

In one embodiment, the duty cycles are determined and/or adjusted periodically.

In one embodiment, after the duty cycles for the solar modules on the string are set based on the module voltage ratio relative to the highest module voltage in the string, the duty cycles can be fine tuned to increase the power performance. The duty cycles can be fine tuned one step a time, until a decrease of voltage of the module with the highest power is detected. In response to the detected decrease, the last change that caused the decrease can be reversed (undone). The fine tuning of the duty cycles can be used to reach the peak performance point (e.g., for maximum power point tracking).

In one embodiment, after the strongest module is identified, the duty cycles of the solar modules on the string are adjusted until the module with the highest power in the string decrease its voltage. Since decreasing the duty cycle of a solar module decreases the time period the module is connected to the string and thus increases its voltage, the duty cycle of the module with the highest power in the string can be decreased to increase its voltage, in response to the decrease in its voltage caused by the adjustment to the duty cycles of other solar modules on the string. For example, the duty cycle of the module with the highest power in the string can be decreased until its voltage is maximized.

In one embodiment, the local management unit measures module and ambient temperatures for some methods to determine the duty cycles. For example, the operating parameters measured at the local management units (e.g., 202a, 202b, ..., 202n), such as module temperature, can be used compute the estimated voltages of the solar modules at their maximum power points. For example, a formula presented

by Nalin K. Gautam and N.D. Kaushika in “An efficient algorithm to simulate the electrical performance of solar photovoltaic arrays”, Energy, Volume 27, Issue 4, April 2002, pages 347-261, can be used to compute the voltage  $V_{mp}$  of a solar module at the maximum power point. Other formulae can also be used. Once the maximum power point voltage  $V_{mp}$  of a solar module is computed or estimated, the duty cycle of the solar module connected to a string can be adjusted to drive the module voltage to the computed/estimated maximum power point voltage  $V_{mp}$ , since decreasing the duty cycle of a solar module normally increases its voltage.

In one embodiment, a local management unit may adjust the duty cycle of the solar module connected to the local management unit to change the module voltage to the computed/estimated maximum power point voltage  $V_{mp}$ , without having to communicating with other management units.

In one embodiment, a local management unit (or a system management unit) may adjust the duty cycle of the solar module connected to the local management unit to perform maximum power point tracking.

In one embodiment, after identifying the strongest module and computing/ estimating the maximum power point voltage  $V_{mpm}$  of the strongest module, the duty cycle for each module on a string can be computed as a function of a ratio between the maximum power point voltage  $V_{mp}$  of the module and the maximum power point voltage  $V_{mpm}$  of the strongest module. For example, the duty cycle for a module can be computed as  $1 - ((V_{mpm} - V_{mp})/V_{mpm}) = V_{mp}/V_{mpm}$ . The duty cycle can be periodically updated, based on the current operating parameters measured, and/or fine tuned until a decrease in the voltage of the strongest module is detected.

Alternatively, a target voltage for each module on the string can be computed as a function of a ratio between the maximum power point voltage  $V_{mp}$  of the module and the maximum power point voltage  $V_{mpm}$  of the strongest module. For example, the target voltage for a module can be computed as  $V_m - V_{mp}/V_{mpm}$ , where  $V_m$  is the measured voltage of the strongest module. The duty cycle of the module can be changed to drive the module voltage of the module towards the target voltage.

In one embodiment, after identifying the strongest module and computing/ estimating the maximum power point power  $P_{mpm}$  of the strongest module, the duty cycle for each module on a string can be computed as a function of a ratio between the maximum power point power  $P_{mp}$  of the module and the

maximum power point power  $P_{mpm}$  of the strongest module. For example, the duty cycle for a module can be computed as  $1 - ((P_{mpm} - P_{mp})/P_{mpm}) = P_{mp}/P_{mpm}$ . The duty cycle can be periodically updated, based on the current operating parameters measured, and/or fine tuned until a decrease in the voltage of the strongest module is detected, since decreasing the duty cycle normally increases the module voltage.

In one embodiment, a target voltage for each module on the string can be computed as a function of a ratio between the maximum power point power  $P_{mp}$  of the module and the maximum power point power  $P_{mpm}$  of the strongest module. For example, the target voltage for a module can be computed as  $V_m - P_{mp}/P_{mpm}$ , where  $V_m$  is the measured voltage of the strongest module. The duty cycle of the module can be changed to drive the module voltage of the module towards the target voltage, since decreasing the duty cycle normally increases the module voltage.

In one embodiment, the duty cycle for each local management unit is changed to increase the current of the solar module attached to the local management unit (e.g., based on the measurement of the voltage and current of the solar module), until the maximum current is achieved. This method assumes that string maximum power can be achieved with some accuracy by driving each local management unit to maximum current. In one embodiment, the voltages and currents of the solar modules are measured for tuning the duty cycles for maximum power point tracking for the string. The measurements of the voltages and currents of the solar modules also enable the local management units to additionally serve as a module level monitoring system.

The duty cycles can be adjusted by the system management unit (e.g., 204) based on the measurements reported by the local management units (e.g., 202a, 202b, ..., 202n), or adjusted directly by the corresponding local management units (e.g., 202a, 202b, ..., 202n).

In one embodiment, during the process of setting and/or tuning the duty cycles, the maximum power point tracking operation by the inverter (203) is frozen (temporarily stopped). Light intensity at the solar modules is monitored for changes. When the light intensity at the solar modules stabilizes, the voltage and current of the solar modules are measured for the determination of the duty cycles. Then normal operation resumes (e.g., unfreezing of maximum power point tracking operation).

In one embodiment, the local management units measure the voltages and currents of the solar

modules to determine the power of the solar modules. After identifying the highest power  $P_m$  of the solar module on the string, the duty cycles of the solar modules on the string are determined by the power ratio relative to the highest power  $P_m$ . For example, if a module produces 20 percent less power, it will be disconnected from the string bus about 20 percent of the time. For example, if a module produces power  $P$ , its duty cycle can be set to  $1 - ((P_m - P)/P_m) = P/P_m$ .

In one embodiment, a predetermined threshold is used to select the weak modules to apply duty cycles. For example, in one embodiment, when a module produces power less than a predetermined percent of highest power  $P_m$ , a duty cycle is calculated and applied to the solar module. If the module is above the threshold, the module is not disconnected (and thus having a duty cycle of 100%). The threshold may be based on the power, or based on the module voltage.

In one embodiment, the system management unit (204) finds the duty cycles for the local management units (202a, 202b, ..., 202n) and transmits data and/or signals representing the duty cycles to the local management units (202a, 202b, ..., 202n) via wires or wireless connections. Alternatively, the local management units (202a, 202b, ..., 202n) may communicate with each other to obtain the parameters to calculate the duty cycles.

In one embodiment, the system management unit (204) knows all the different duty cycles indicated for the local management units (202a, 202b, ..., 202n).

In one embodiment, during power fine tuning, the system management unit (204) sends the appropriate data/signal to the appropriate local management units (202a, 202b, ..., 202n), and then the system management unit (204) calculates the total power of the string and corrects the duty cycle to produce maximum power. Once maximum power is achieved, the duty cycles for the local management units (202a, 202b, ..., 202n) may be saved in a database and serve as a starting point for the corresponding local management units (202a, 202b, ..., 202n) at the same time of day on the next day. Alternatively, a local management may store the duty cycle in its memory for the next day.

The stored duty cycles can be used when there is a fixed shade on the modules, such as a chimney, a tree, etc., which will be the same shade on any day at the same time. Alternatively, historical data may not be saved, but may be recalculated from scratch on each run, for example every 30 minutes.

In one embodiment, the light intensity at the solar modules is monitored for changes. The duty cycles

are calculated when the light intensity does not change significantly. If there are changes in sun light radiation at the solar modules, the system will wait until the environment stabilizes before applying or adjusting the duty cycles.

[In one embodiment, the system management unit (204) can communicate with the inverter as well. When the environment is not stable (e.g., when the sun light radiation is changing), the inverter may stop maximum power point tracking. In such a situation, the inverter can be set up for its load, instead of tracking for maximum power point. Instead of using the inverter to perform maximum power point tracking, the system management unit (204) and the local management units (202a, 202b, ..., 202n) are used to set the operating parameters and balance the string.

Alternatively, when the environment is not stable but measurements and calculation are done faster than the MPPT is working, there may be no need to stop the MPPT on the inverter. Alternatively, when the environment is not stable, measurements can be taken few times for the same radiation until a stable result is achieved.

Many variations may be applied to the systems and methods, without departing from the spirit of the invention. For example, additional components may be added, or components may be replaced. For example, rather than using a capacitor as primary energy store, an inductor may be used, or a combination of inductor and capacitor. Also, the balance between hardware and firmware in the micro controllers or processors can be changed, without departing from the spirit of the invention. In some cases, only some problematic modules may have a local management unit, for example in a shaded or partially shaded or otherwise different situation. In yet other cases, local management units of strong modules may be virtually shut off. The methods for determining the duty cycles for the solar modules can also be used to determine the duty cycles of groups of cells connected via local management units in a string within a solar panel/module.

In the foregoing specification, the disclosure has been described with reference to specific exemplary embodiments thereof. It will be evident that various modifications may be made thereto without departing from the broader spirit and scope as set forth in the following claims. The specification and drawings are, accordingly, to be regarded in an illustrative sense rather than a restrictive sense.

### **Description TGY027 New Matter**

What is needed is a system and method for an enhanced “watch dog” device that can implement an emergency shut down of the solar panel system when it detects a problem at the head end or in the wiring, thus maintaining the system in a safe condition.

Figure TGY027-1 shows an overview of an exemplary photo voltaic power system 100 known to the inventors. Photovoltaic solar panel (PVSP) 101 typically connects via wires 103, such pigtail wires, to a junction box 102, which in turn connects the wiring 104 to the wiring system, typically as part of a string of panels, or a high voltage box, to a combiner box (essentially a wiring panel) and from there on to an inverter feeding the power grid.. In this example the watch dog is in junction box 102; in other cases the watch dog may be in other locations in the wiring further down the line, such as, for example, in the combiner box that combines wires of multiple panels and/or strings, or it may be in an inverter box that combines multiple wirings and the inverter.

Figure TGY027-2 shows an overview of an exemplary photo voltaic power system 200 that is known to the inventors. Wires from the panel 103 feed into converter or adaptor 203. A controller 204 is also present, which controller communicates with a central controller 109 (shown in Figure TGY010-1) as indicated by arrow 206, in some cases via a wire line and in other cases wirelessly. Often a diode 205 may be included for reversal of the panel, or if the panel has weak cells, to avoid reversal of the panel. The configuration shown in Figure TGY027-2 is typical of a string configuration, but similarly it may apply in ac or other similar configurations, or high-voltage bus configurations, all of which are known to the inventors. It is clear that in the case of an ac configuration, diode 205 would not be included in the system, because it would create serious problems.

Figure TGY027-3 shows an overview of an exemplary system 300 according to one embodiment of the current invention. System 300 is essentially an enhancement of system 200, wherein the controller 204 now has additional code 308, which code performs the shut-down function of the current invention. Also shown are several normally open or normally closed switches. Not all the switches are necessarily in all embodiments of the current invention. For example, switch 305 is used to short a panel that has shown, in some cases, to extend the life of the panel, as is known to inventors. <<SAM, RON, Attorney: this links to case TGY020 >> In this example it is shown as a normally open switch, controlled by controller 204

(control line not shown). However, rather than a mechanical switch, the on/off device could be typically a suitable semiconductor device, including but not limited to a FET or MOSFET, or it could be an IGBT type of transistor that can take the current and short the panel. Also, in some cases, rather than shorting the panel, the on/off device would create an active load to the panel and would allow a voltage to continue feed to the controller, as is shown by the feeding line, even though the inverter or converter 203 may be shut off. Also shown is a switch 304, which is normally closed. Again, rather than a mechanical switch, this could be a FET, MOSFET, or other similar suitable type of semiconductor switch. It is normally closed to allow the power of the inverter to flow out into the wiring; however, it could go into a normal open state and thus disconnect the panel. In some cases, the converter or inverter 203 may achieve the same function internally by managing switching devices already inside a converter accordingly. Also, in some cases, switch 307 may short the panel bypass. In particular, in the case of an ac system, where there is no diode, a bypass may be desirable. In other cases, no bypass is desired, or, in the case of a high-voltage system a bypass may even be not desirable. The shut-off may be triggered by, for example, the absence of a regular signal from the main controller (not shown). In other cases, for example, a fault in the wiring, which can be detected by controller 204 by comparing different voltages, etc., may also automatically trigger a disconnect. In yet other cases, additionally, for example, the plus or the minus may be connected to ground to add security. In some cases, system 300 may have a local capacitor or battery to power the unit even after loss of power from both sides.

Figure TGY027-4 shows an exemplary process 400 for implementation of the watch dog code 308 according to one embodiment of the present invention. In step 402 parameters are initialized based on data from a storage 401 that would typically be an E2PROM in the device itself, and hence it could even survive loss of power. After initialization, in step 403 the software executes local checks, which checks may include checking that the wiring, voltages, and other components are correct and all signals present as they should be for normal operation. In step 404 the software waits for a ping from the main controller. In some cases, the software may not wait for an incoming ping, but rather, it may issue a challenge and receive a response to that challenge. Other, similar well known methods of two-way verification may be used. At step 405, the process branches. If the software receives a response it moves to step 407 to determine whether the response is a shut-down signal. If the response is not a shutdown signal (negative), the

software loops back to step 403. If the response is a shut-down signal, the software moves to step 408, where it shuts down the system and, in step 409, waits for a restart signal, after which it returns to step 402. If, in step 405, the software does not receive a ping or other expected response within an allotted time, it moves to step 406, where it checks the number of allowed skips. Depending on the circumstances, a certain number of skips may be allowed, particularly if the "heartbeats" of the ping are set at a high rate, such as 100 or even 1000 per second. In such cases, the software may allow two, five, or even 100 skips (this limit is drawn from data store 401) before it moves to step 410, where the process again branches. If the software receives a response before the limit is reached (-), the process loops back to step 407 and continues as described above. If the software receives no response by the time/count the skip limit is reached (+), the process moves to step 408 and proceeds as described above. If the device has a battery, as mentioned above, it may remain in shut-down mode until it either receives a restart signal or until the battery runs down, in which case it does a complete shut-down.

It is clear that many modifications and variations of this embodiment may be made by one skilled in the art without departing from the spirit of the novel art of this disclosure. These modifications and variations do not depart from the broader spirit and scope of the invention, and the examples cited here are to be regarded in an illustrative rather than a restrictive sense.

## Illustrations TGY002

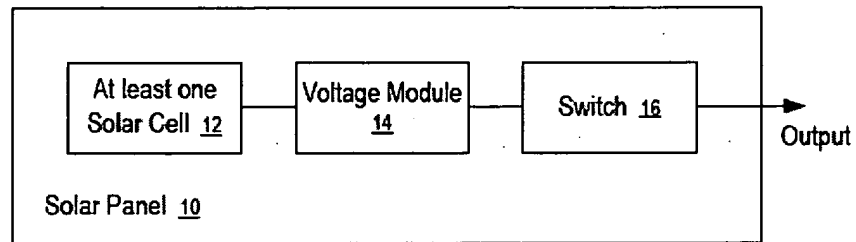


FIG. 1

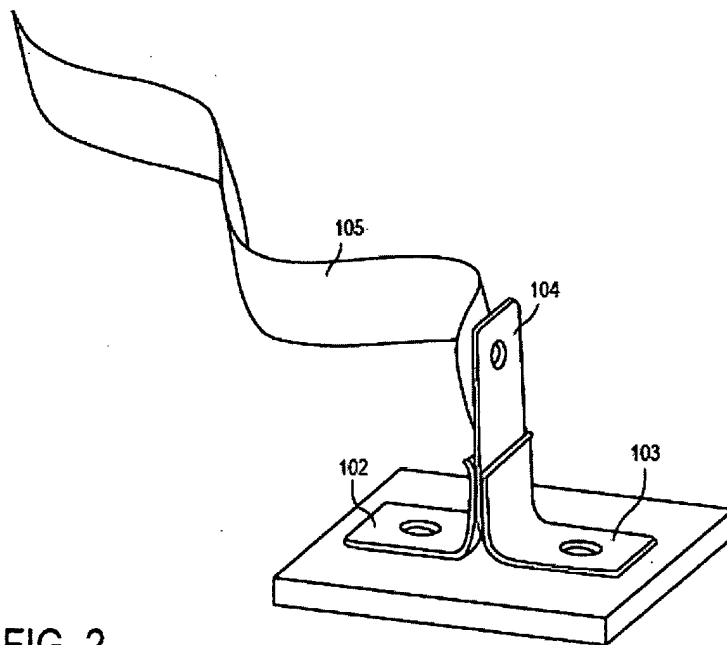


FIG. 2

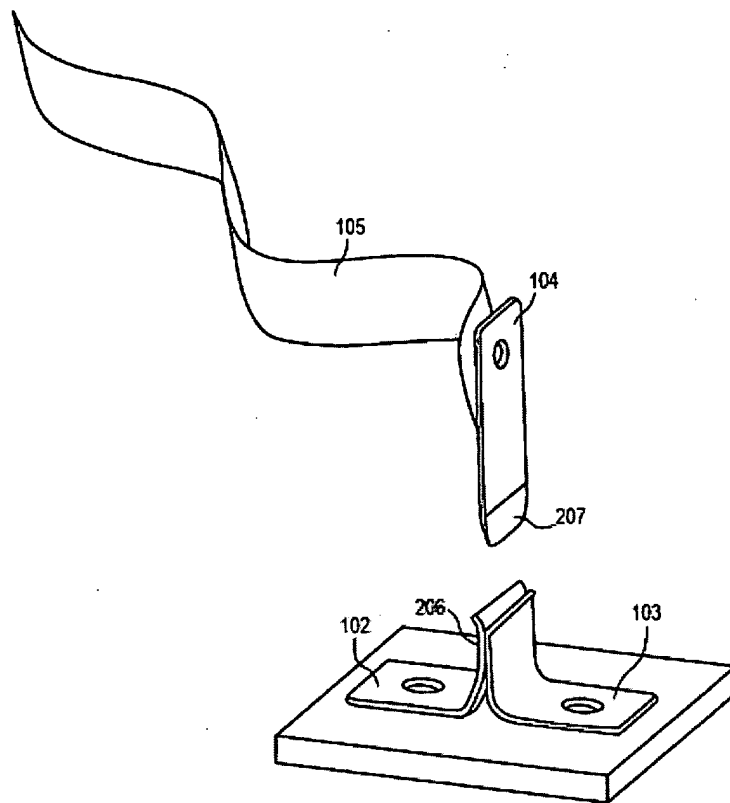


FIG. 3

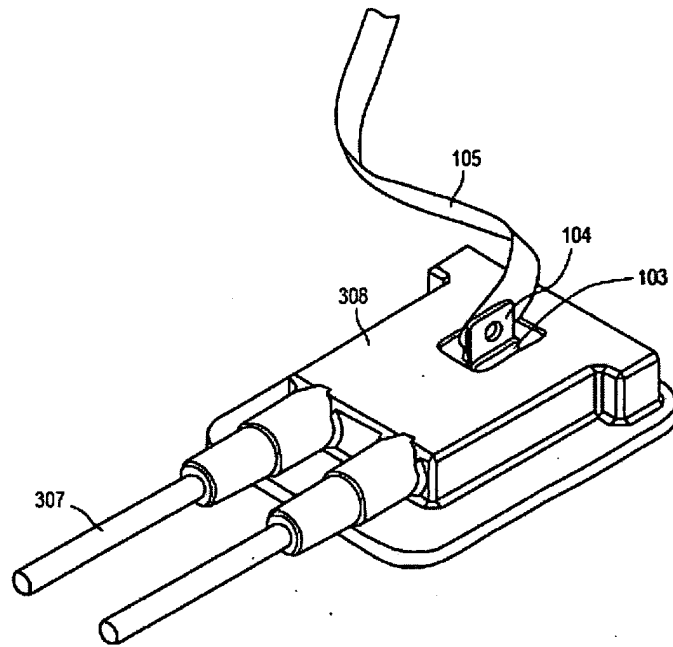


FIG. 4

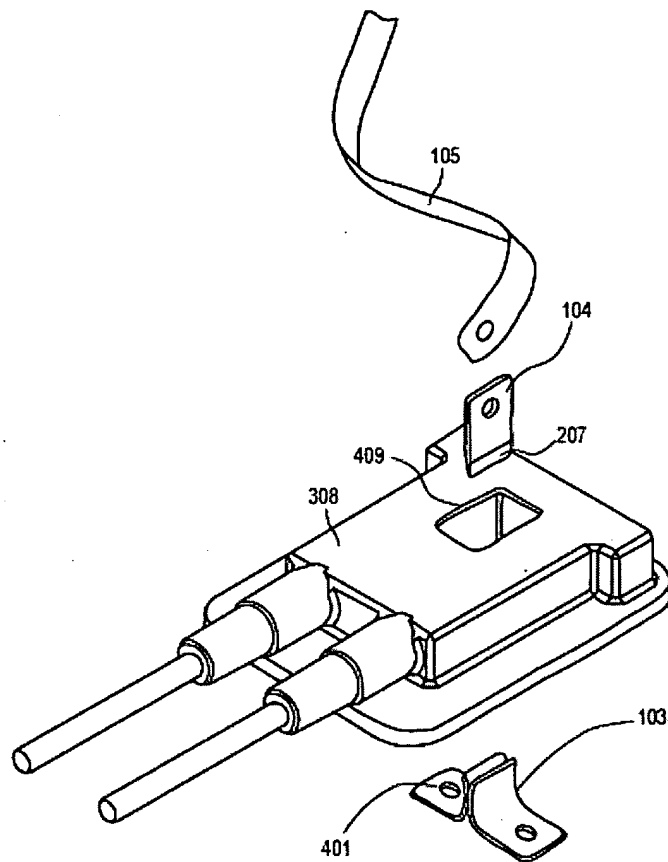


FIG. 5

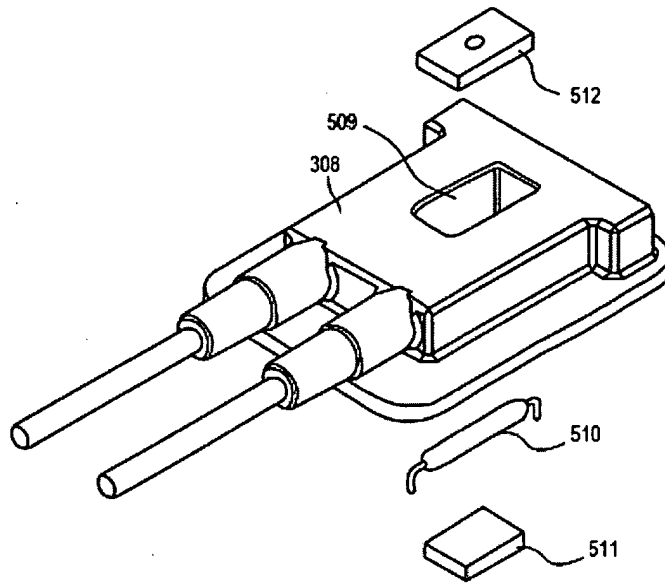


FIG. 6

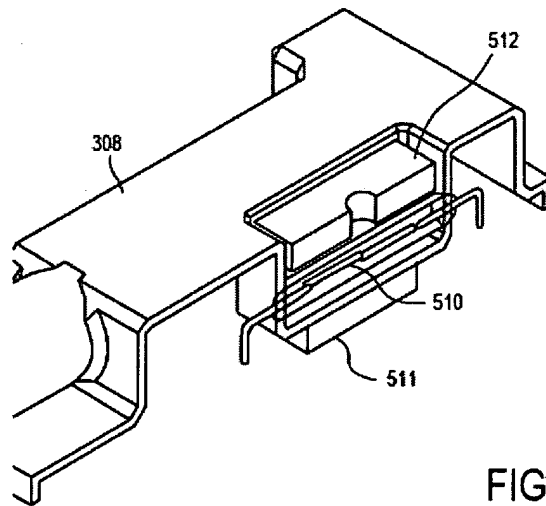


FIG. 7

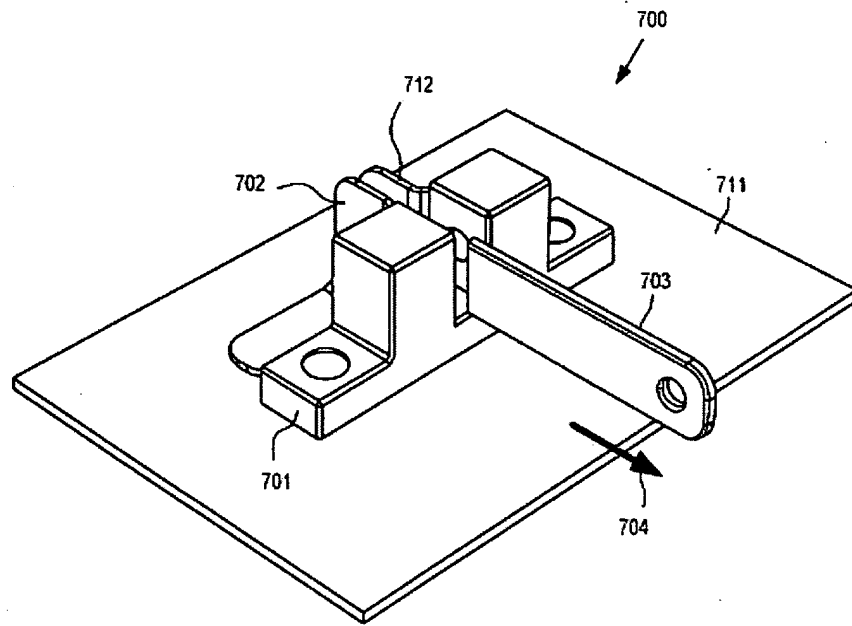


FIG. 8

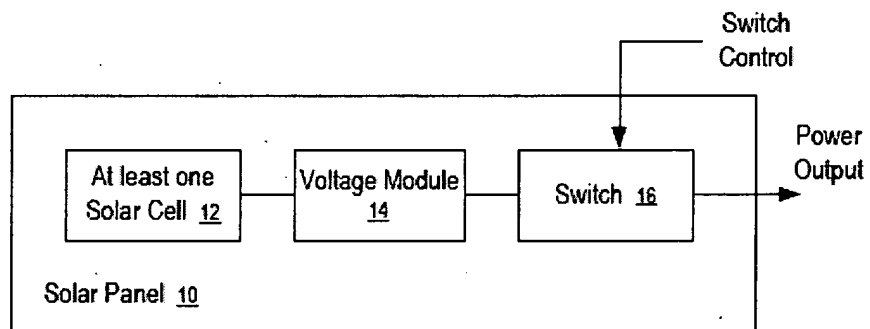


FIG. 9

## Illustrations TGY010

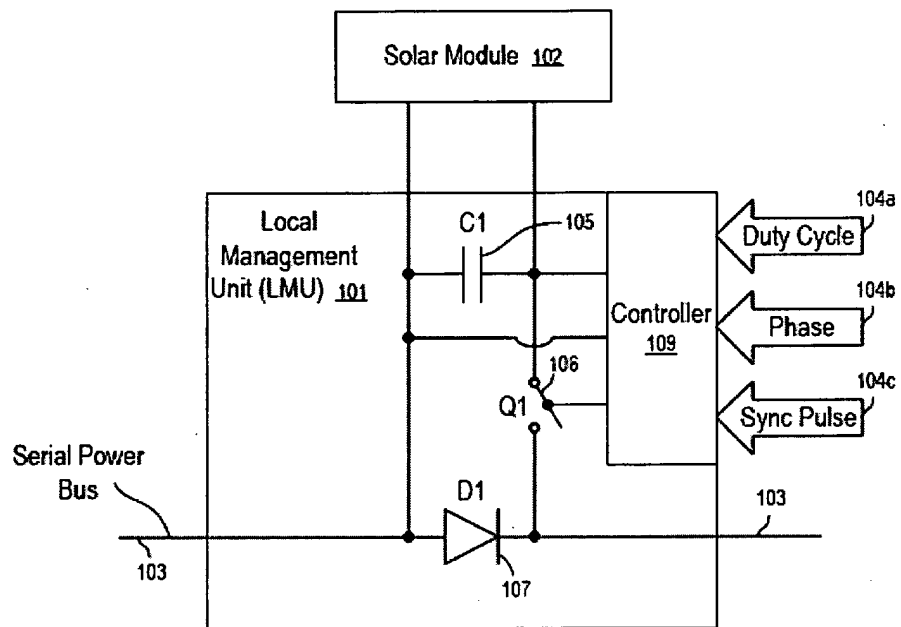


FIG. 1

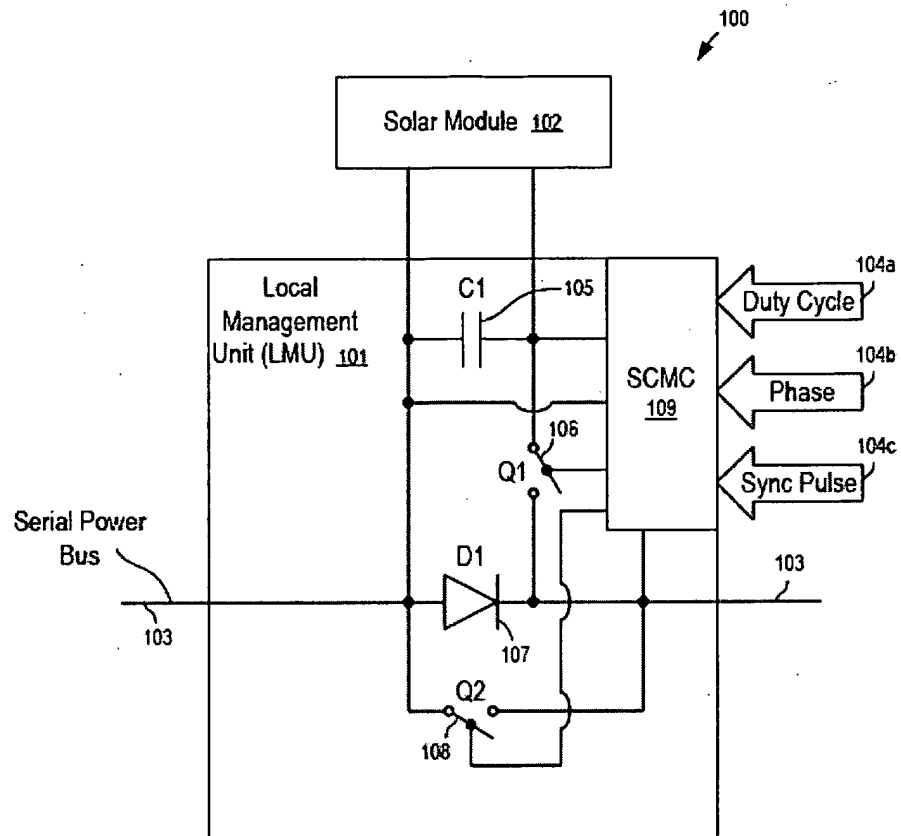


FIG. 2

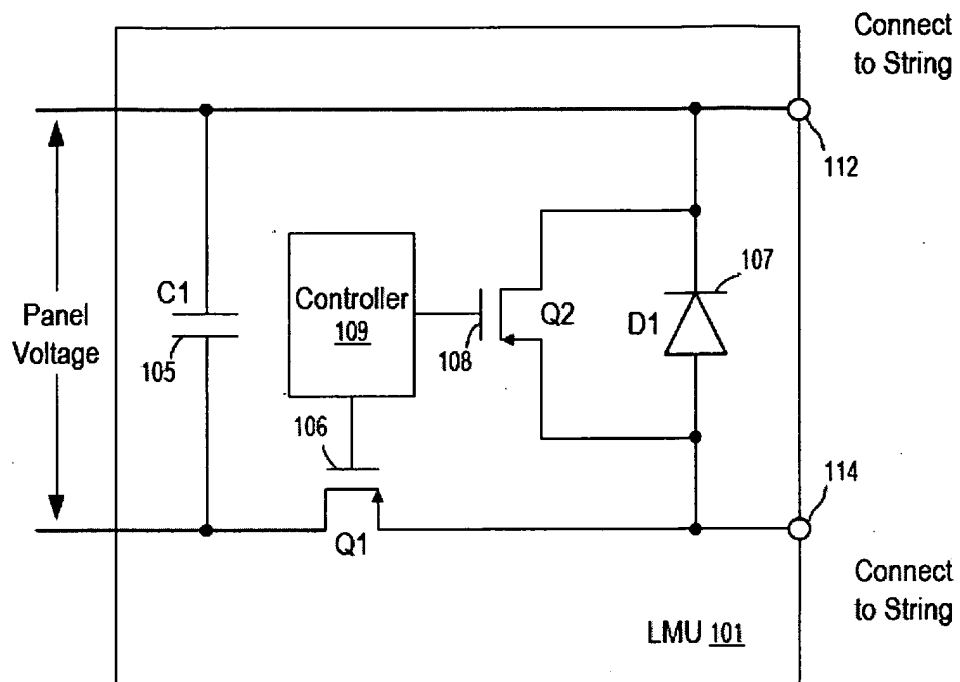


FIG. 3

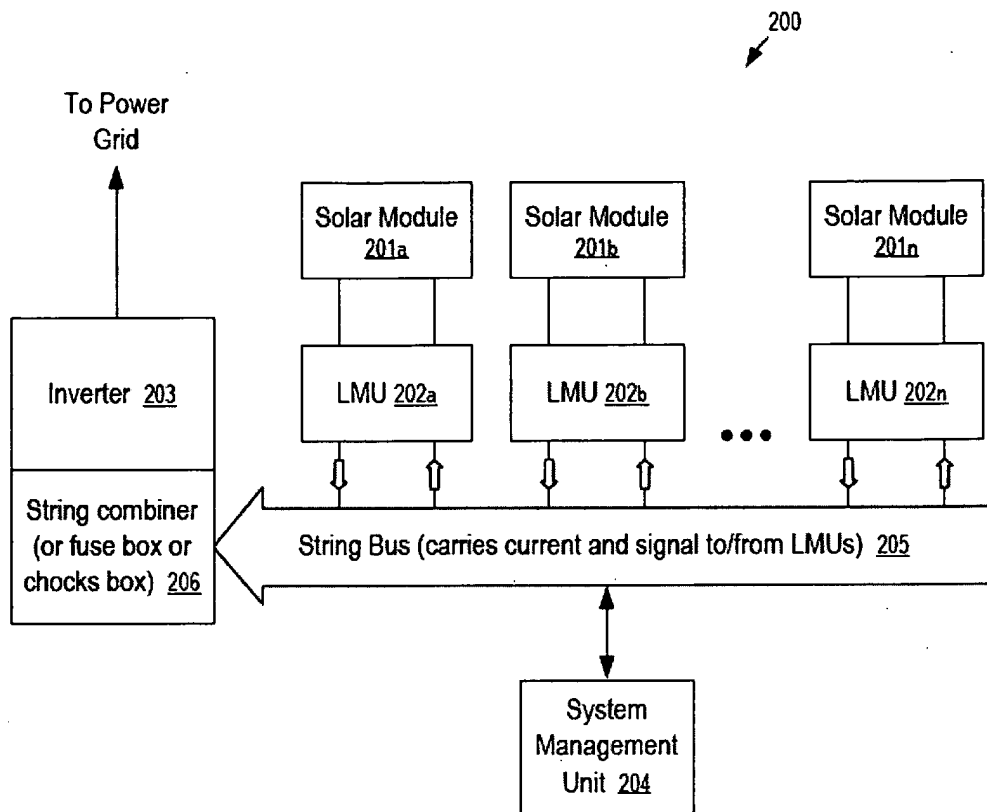


FIG. 4

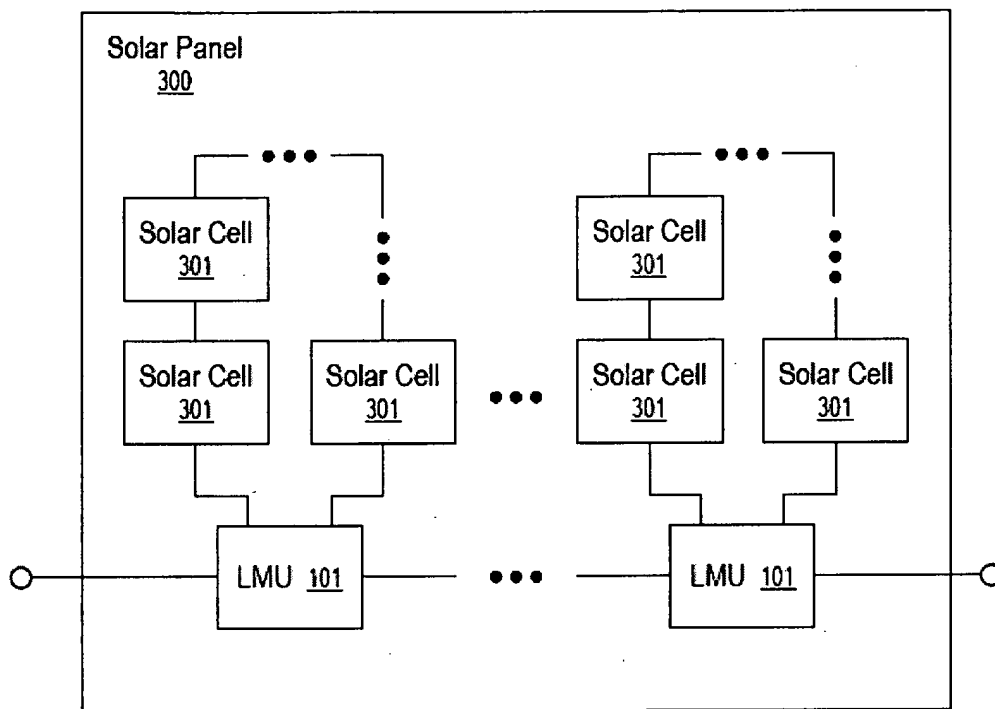


FIG. 5

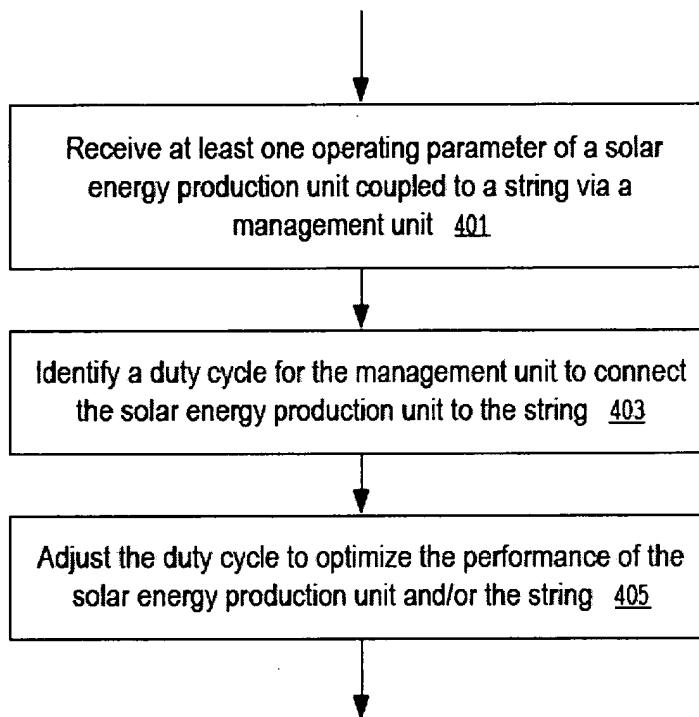


FIG. 6

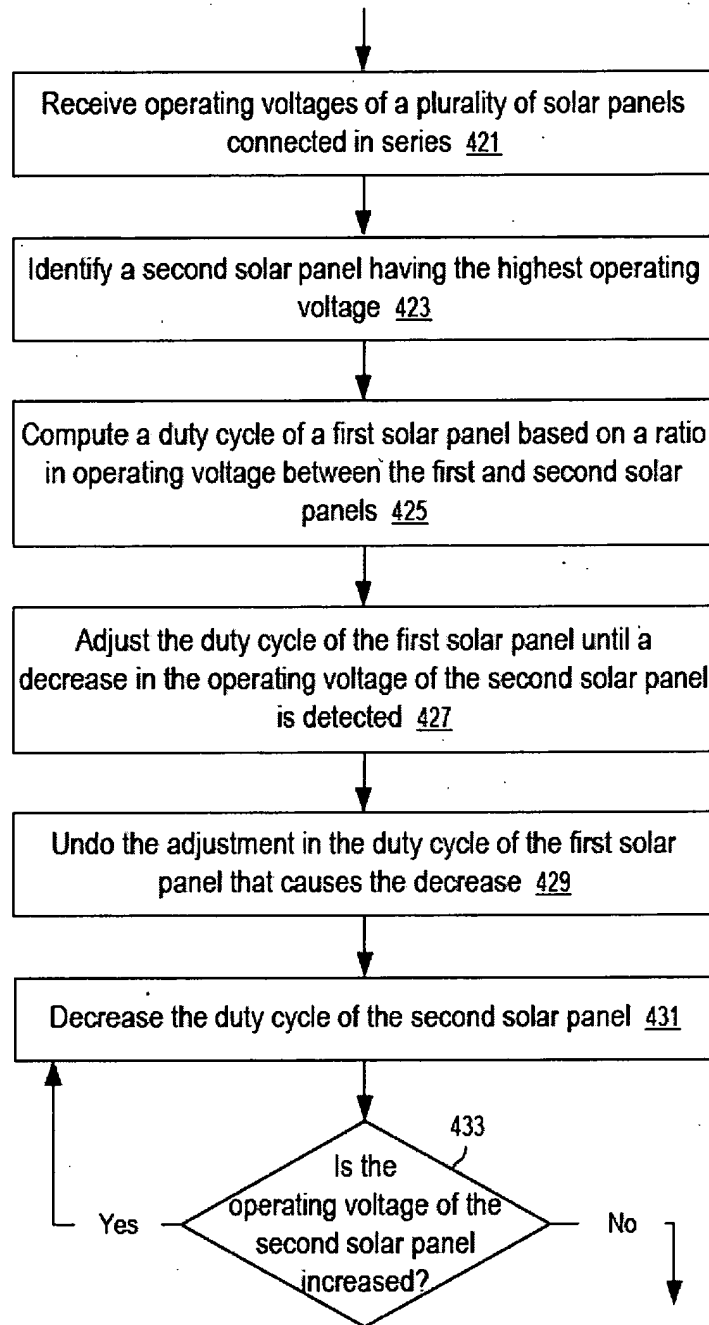


FIG. 7

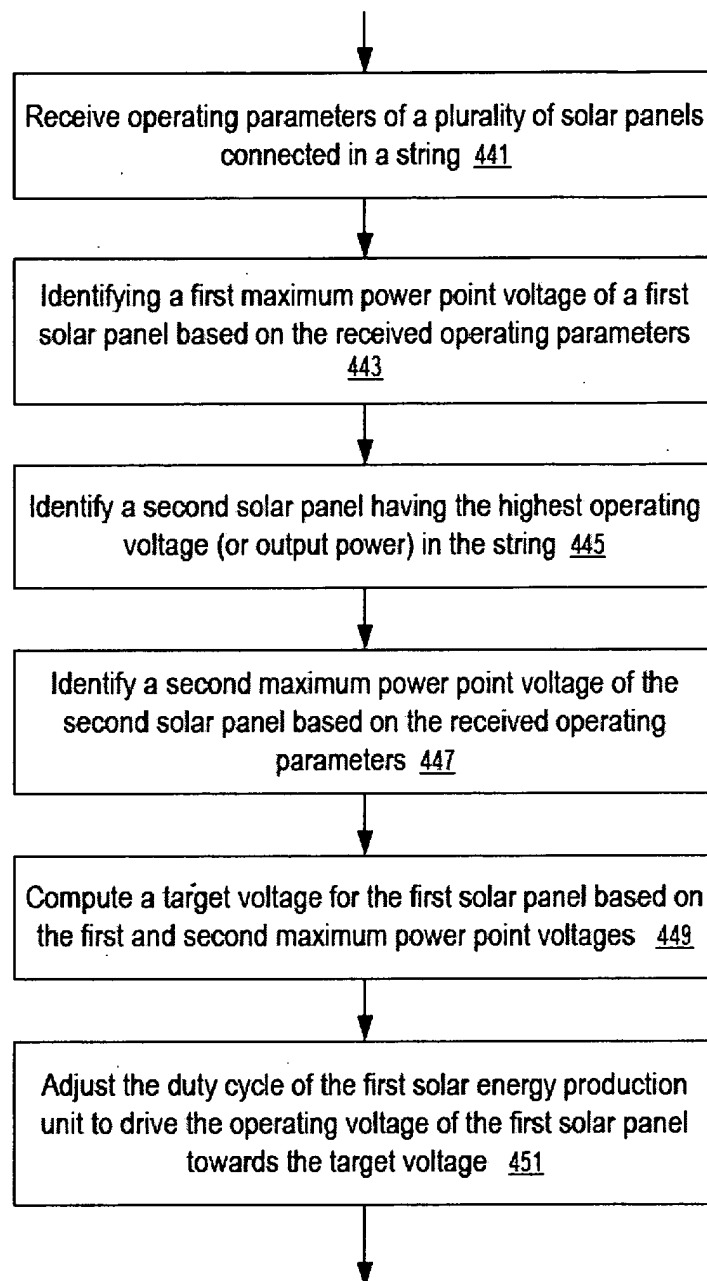


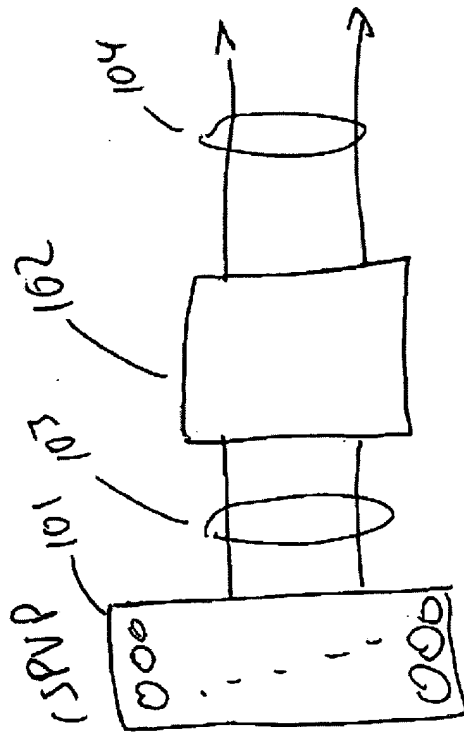
FIG. 8

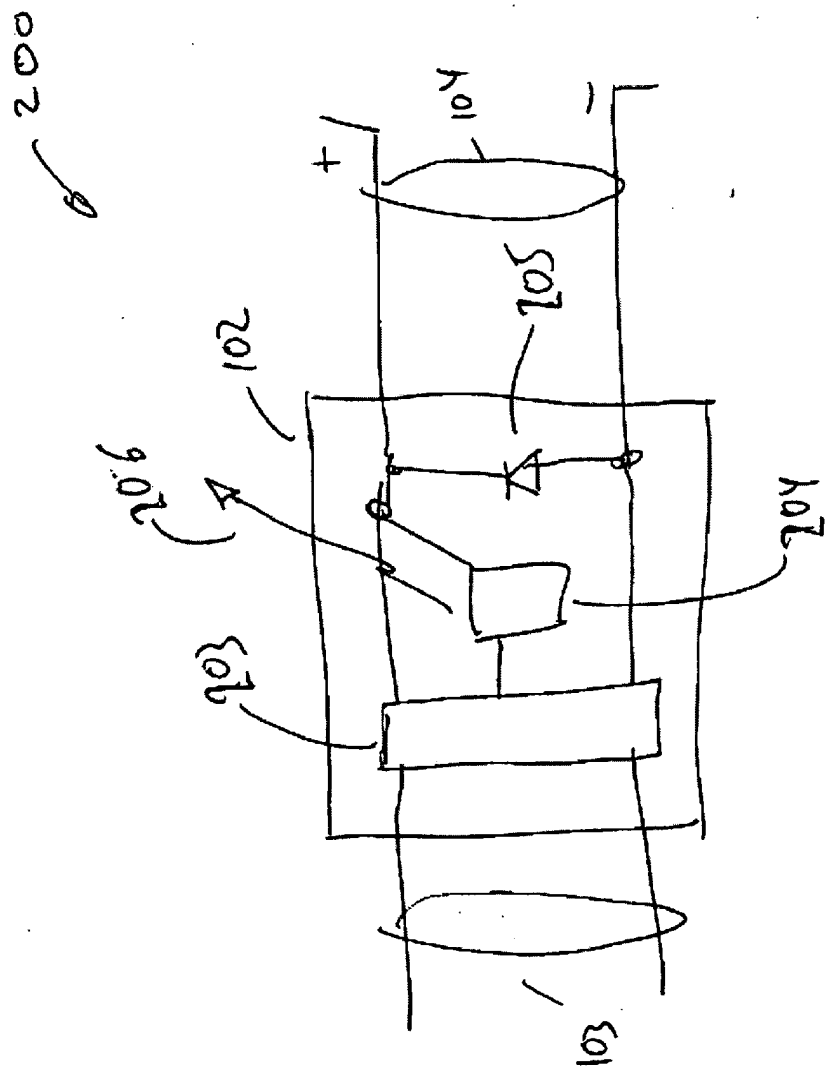
Illustrations TGY027

TGY027

Fig. 1

100





TGY 027



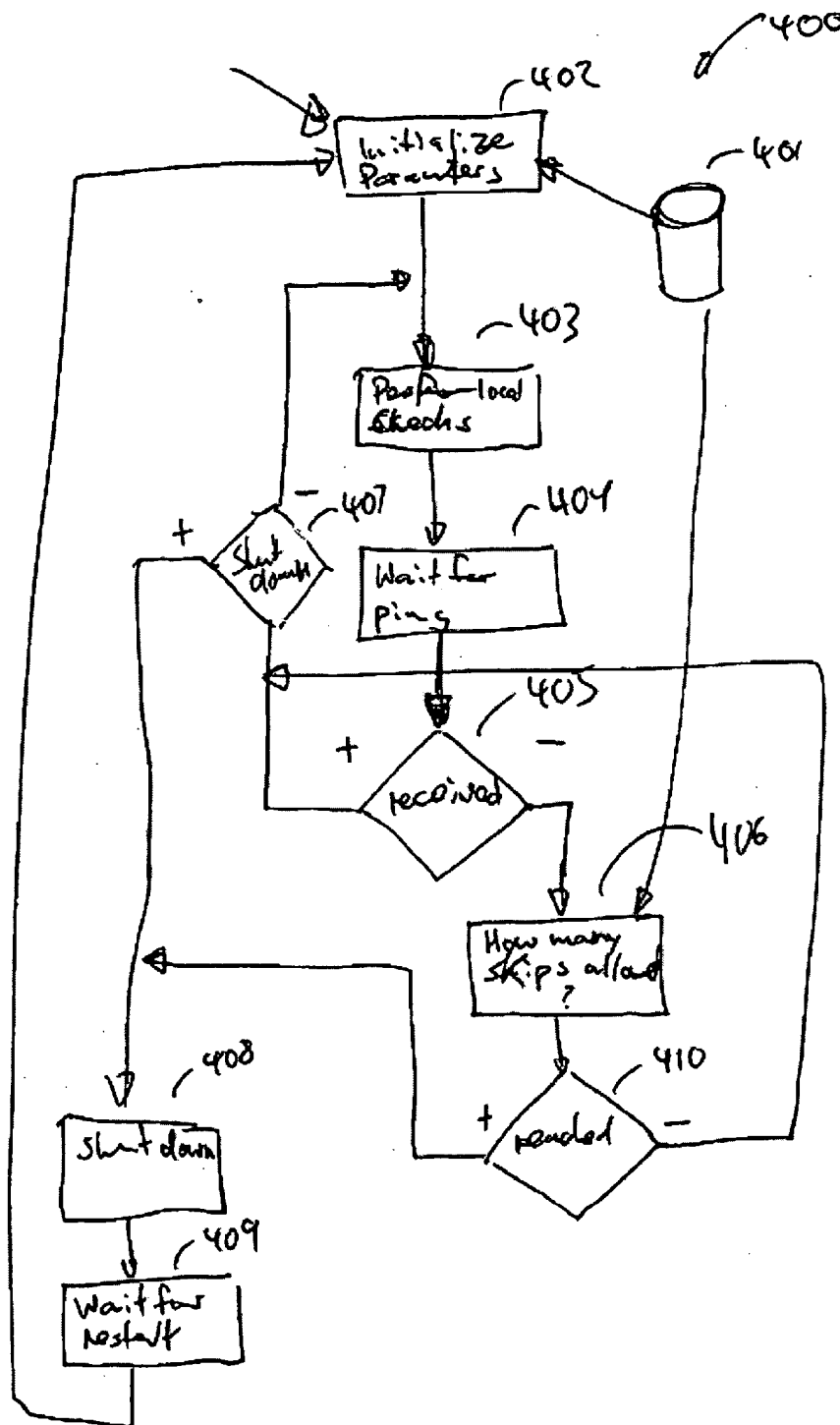


Fig. 4 TGY021

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