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GB 2476508 A **JP 110318042 A**
JP 2004194500 A **US 5530335 A**

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(54) Title of the Invention: **Maximizing power in a photovoltaic distributed power system**
Abstract Title: **Maximising power in a photovoltaic distributed power system**

(57) A power harvesting system 30a includes multiple parallel-connected photovoltaic strings 109, each photovoltaic string including a series-connection of photovoltaic panels 101. Voltage compensation circuits 307 are connected in series with the photovoltaic strings. The voltage compensation circuits are configured to provide respective compensation voltages Vc to the photovoltaic strings to maximize power harvested from the photovoltaic strings. The voltage compensation circuits may include respective inputs which may be connected to a source of power Vs and respective outputs which may be connected in series with the photovoltaic strings.

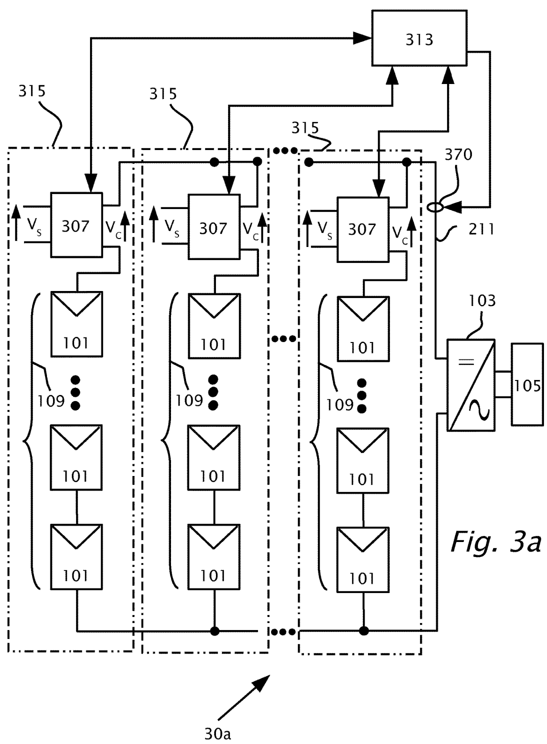

Fig. 3a

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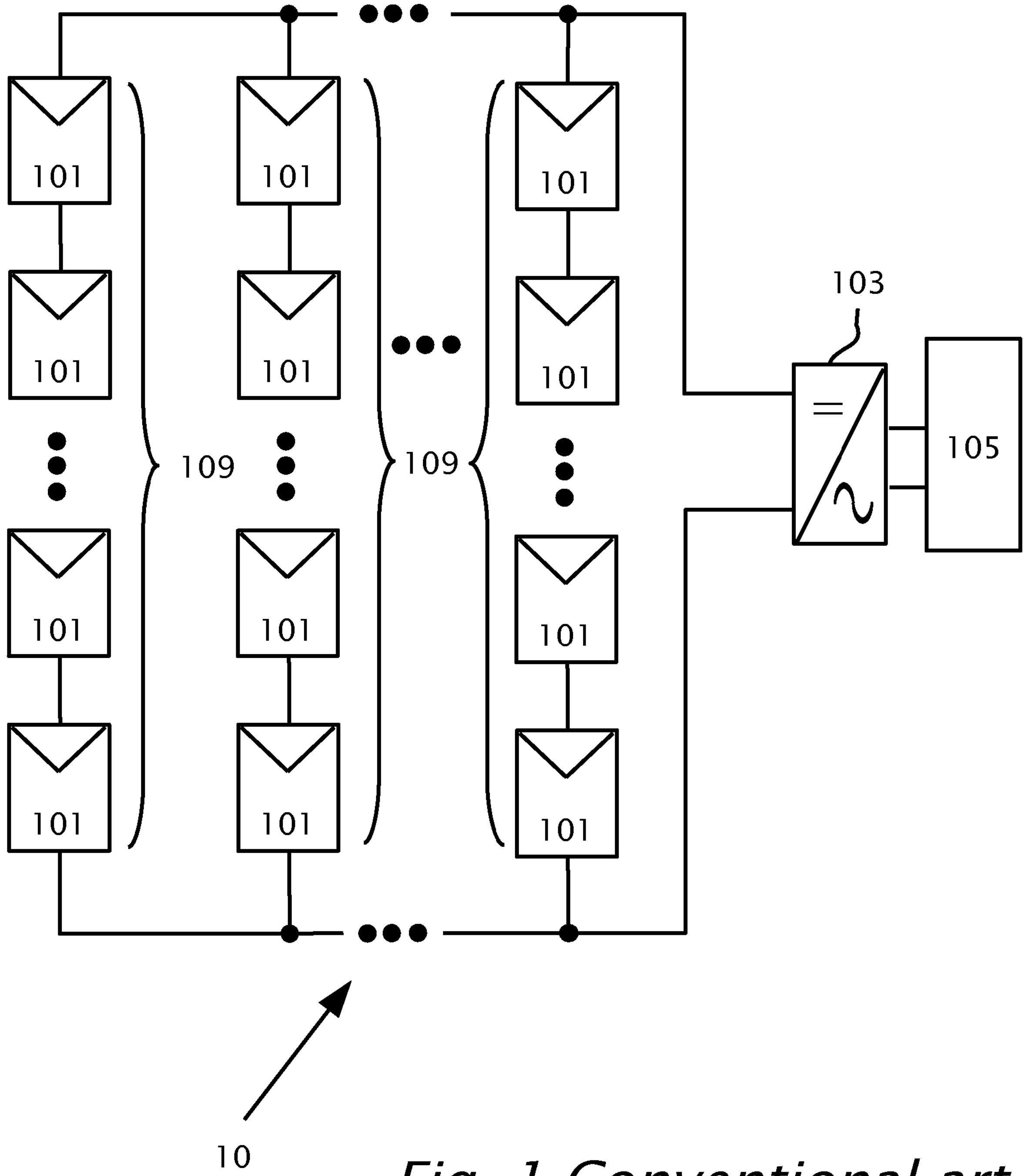

Fig. 1 Conventional art

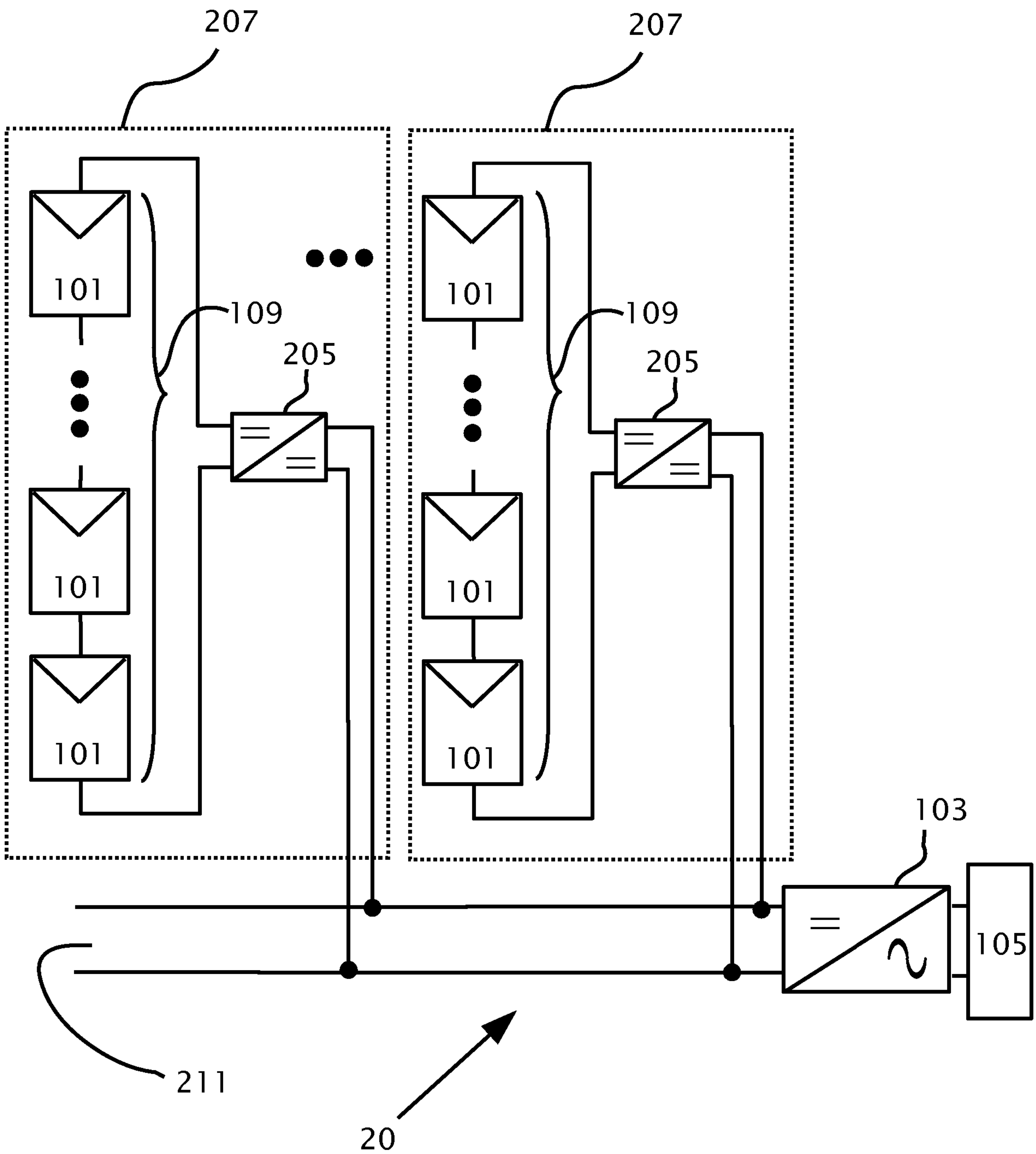

Fig. 2
Conventional art

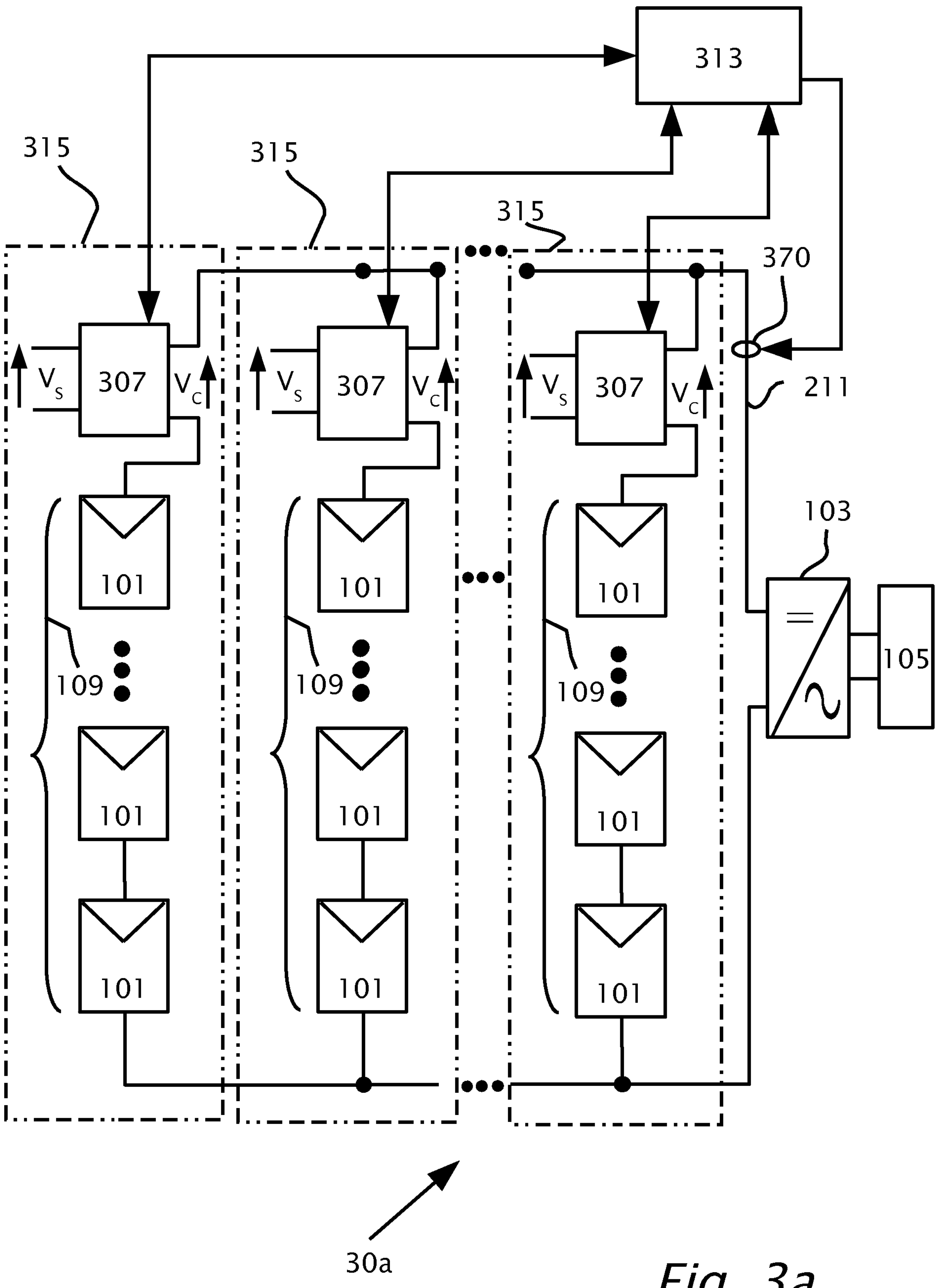

Fig. 3a

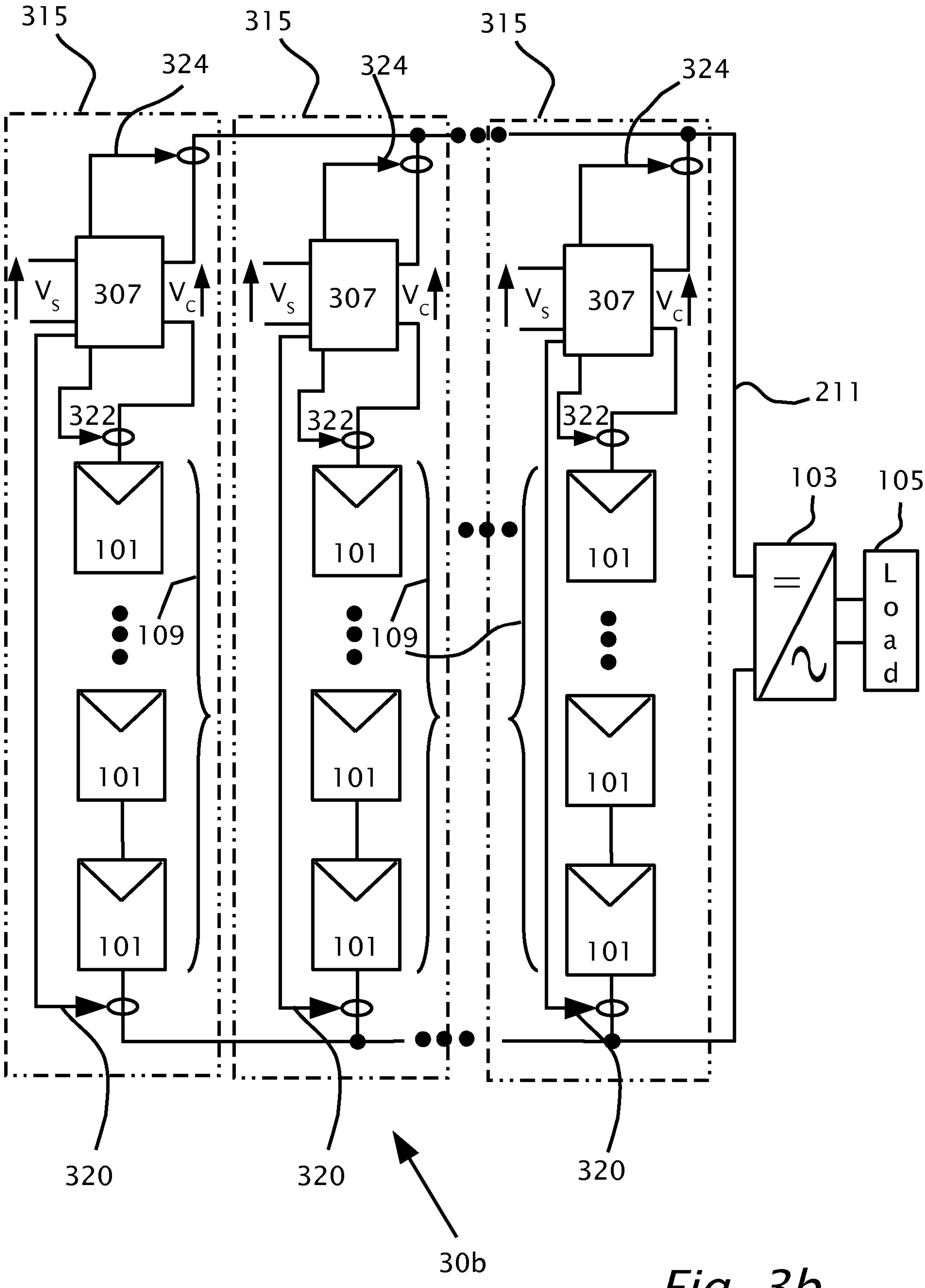
315
315
315
324
324
324
V S
307
V C
322
101
109
211
103
105
L o a d
320
320
320
30b

Fig. 3b

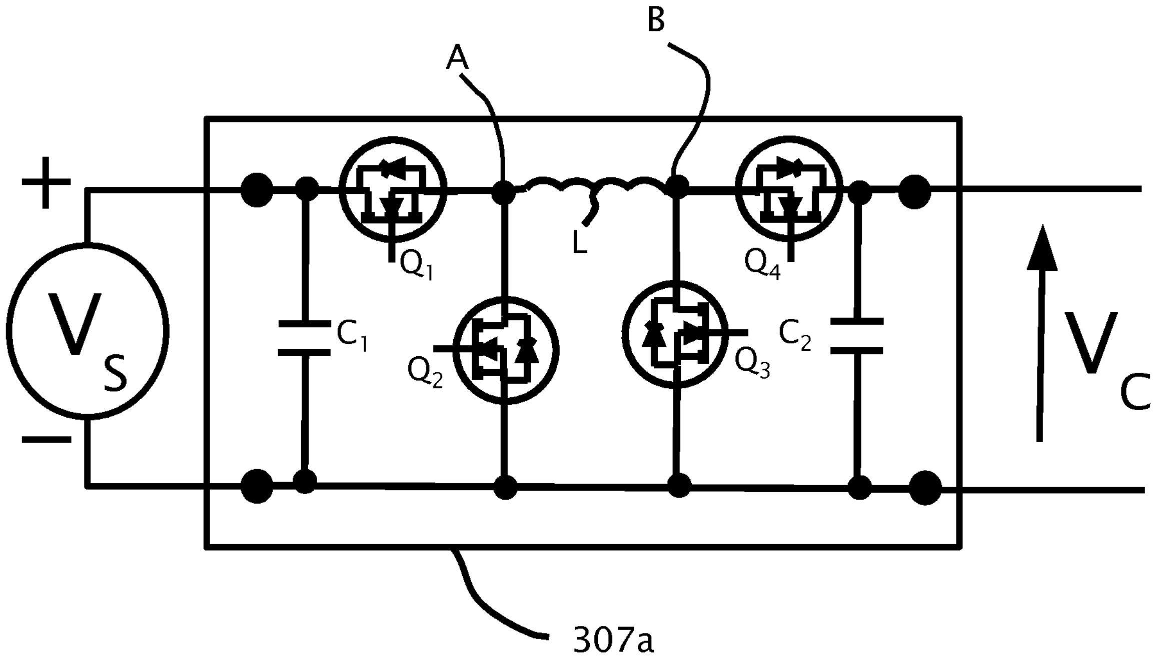

Fig. 3c

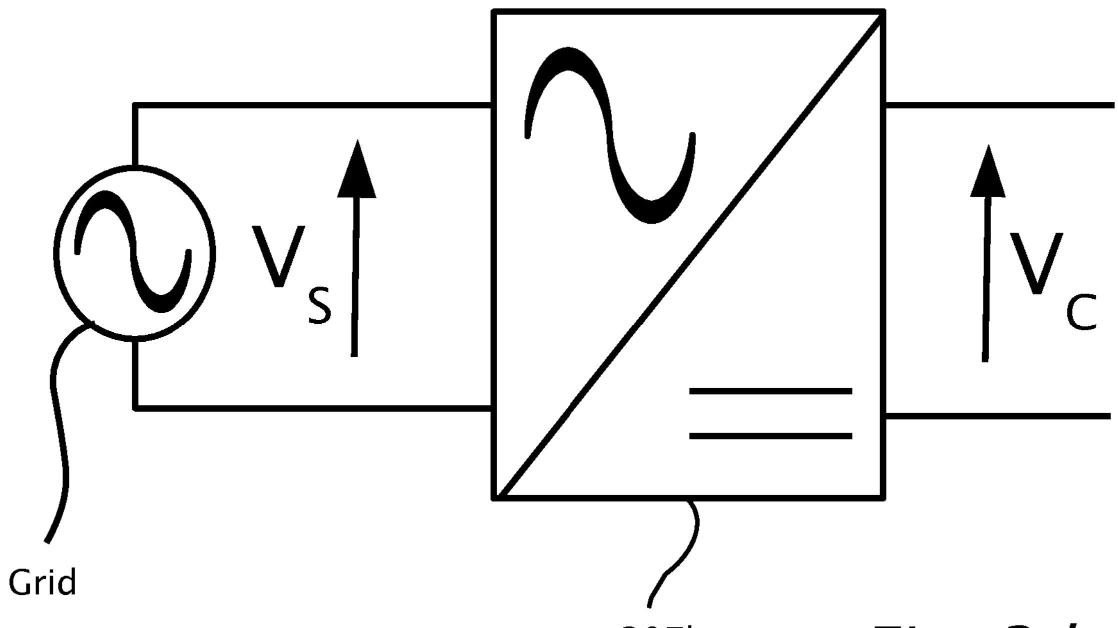

Fig. 3d

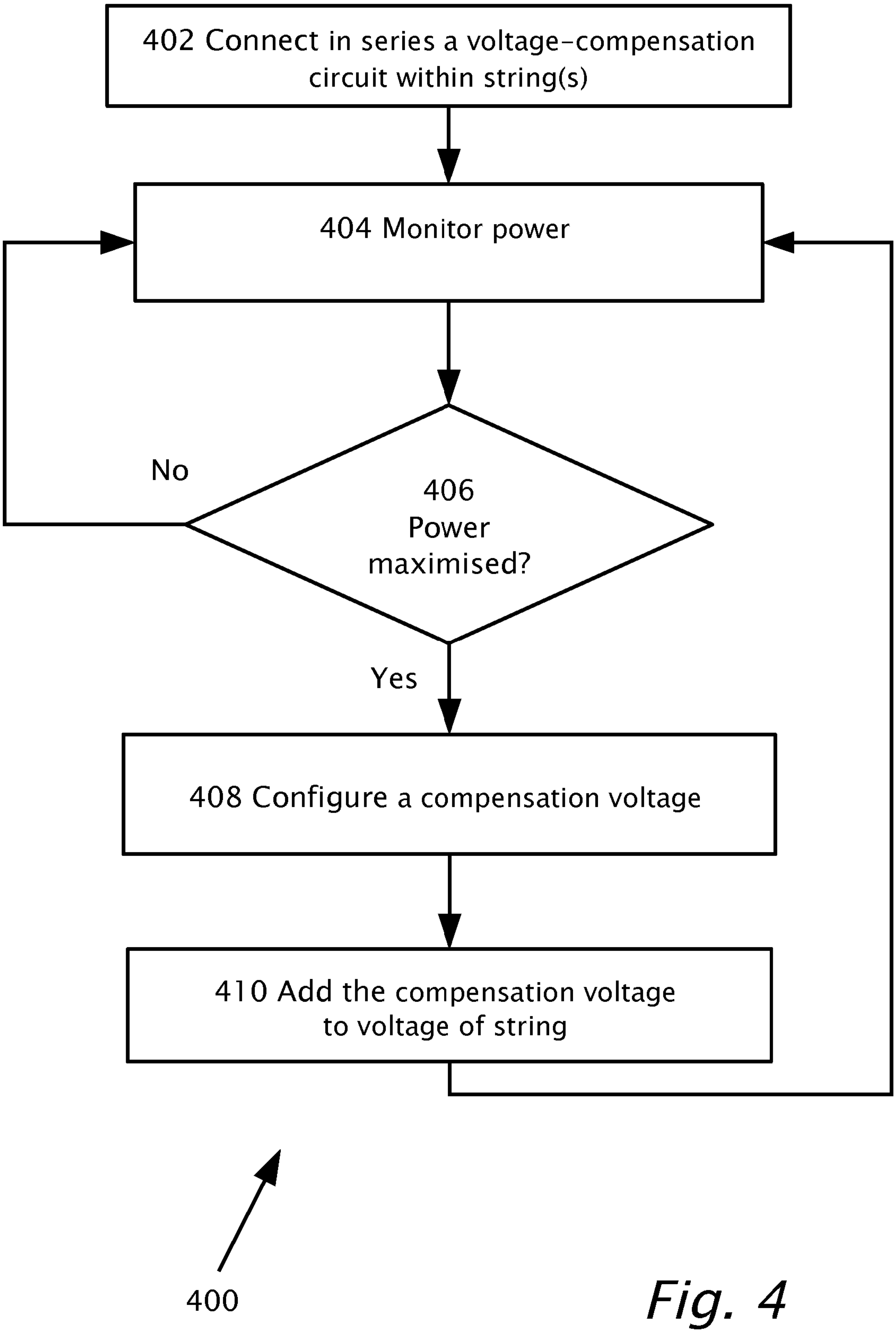
402 Connect in series a voltage-compensation circuit within string(s)
404 Monitor power
No
406 Power maximised?
Yes
408 Configure a compensation voltage
410 Add the compensation voltage to voltage of string
400

Fig. 4

MAXIMIZING POWER IN A PHOTOVOLTAIC DISTRIBUTED POWER SYSTEM

BACKGROUND

1. Technical Field

The exemplary features presented relate to a photovoltaic power harvesting system including multiple photovoltaic strings and, more particularly to system and method for maximizing power in each photovoltaic string. .

2. Description of Related Art

Reference is made to Figure 1 which shows a photovoltaic power harvesting system **10** according to conventional art. A photovoltaic string **109** includes a series connection of photovoltaic panels **101**. Photovoltaic strings **109** may be connected in parallel to give a parallel direct current (DC) power output. The parallel DC power output connects to the input of a direct current (DC) to alternating current (AC) inverter **103**. The AC power output of inverter **103** connects across an AC load **105**. AC load **105** may be an AC load such as an AC motor or may be an electrical power grid.

By way of a simplified numerical example, three strings **109** may be used with an inverter **103**. If two strings **109** are equally irradiated such that each string operates with a string voltage of 600 volts (V) and string current of 10 amperes (A); each of the two strings generates (10 A · 600 V) 6 kilowatts (kW). It is also assumed that the two equally irradiated strings **109** may be operating at maximum power.

If however, one string **109** is partially shaded or if one or more panels **101** is under performing, there may still be a string voltage of 600V as set by the other two equally irradiated strings **109,** however, the string current in the one under performing string **109** may only be only 6 amperes. The under performing string **109** is not operating at maximum power point. For instance, it may be that the under performing string **109** has a maximum power point of 550 volts for a current of 10 amperes. In this situation, the power lost by the under performing string **109** is 1.9kW (550V·10A – 600V·6A). The under performing string **109,** therefore, produces 3.6kW (600V·6A). Overall power harvested from system **10** is, therefore 15.6kW (3.6kW + 2 · 6kW).

Reference is now made to Figure 2 which shows another power harvesting system **20** according to conventional art, according to international patent application publication WO2010002960. System **20** is directed to reduce power losses compared to the losses of system **10**. Each photovoltaic string **109** includes a series connection of photovoltaic panels **101.** Each photovoltaic string **109** is connected in parallel to an input of a DC-to-DC converter **205**. The output of converter **205** connects to a DC bus **211**. The DC voltage generated by photovoltaic string **109** is converted by converter **205** to the voltage of DC bus **211.** Each photovoltaic string **109** together with the respective DC-DC converter **205** forms a photovoltaic string module **207**. A number of modules **207** with outputs from respective DC-to-DC converters **205** may be connected in parallel to DC bus **211.** The parallel combined outputs of modules **207** may be also connected to an input of a direct current (DC) to alternating current (AC) inverter **103** via DC bus **211**. Inverter **103** converts the combined DC power outputs of modules **207** to an alternating current power at an output of inverter **103**. The output of inverter **103** connects to AC load **105**.

Still referring to Figure 2, using the same numerical example as in system **10** (Fig. 1), three modules **207** may be used with inverter **103**. Two strings **109** may be equally irradiated such that each string of the two strings operates with a string voltage of 600 volts and string current of 10 amperes. Each of the two strings generates (10 amperes · 600 volts) or 6 kilowatts. If the one remaining string **109** is under performing, there may be maximum power point for the under performing string **109** of 550 volts and current of 10 amperes. Each DC-to-DC converter **205** may be configured to maximize power on each respective output to give 600 volts on DC bus **211**. The two equally irradiated modules **207** each produce 6 kW (10 amperes· 600 volts) and the under performing unit **207** produces 5.5 kW (10 amperes · 550 volts). Giving an overall power harvested from system **20** of 17.5 kW. It can be seen that system **20** offers an improvement of 1.9kW over system **10** in terms of minimized losses and increased power harvested. The improvement has been achieved through multiple DC-DC converters **205** which operate at wattage levels of around 6 kW. The high power DC-DC converters **205** in a power harvesting system may add to the cost of installation and maintenance of the power harvesting system and may present an overall decreased level of reliability for the power harvesting system because DC-DC converters **205** operate at high wattage levels.

The terms “monitoring”, “sensing” and “measuring” are used herein interchangeably.

The terms “power grid” and “mains grid” are used herein interchangeably and refer to a source of alternating current (AC) power provided by a power supply company.

The term "converter" as used herein applies to DC-to-DC converters, AC-to-DC converters, DC-to-AC inverters, buck converters, boost converters, buck-boost converters, full-bridge converters and half-bridge converters or any other circuit for electrical power conversion/inversion known in the art.

The term “DC load” as used herein applies to the DC inputs of converters, batteries, DC motors or DC generators.

The term “AC load” as used herein applies to the AC inputs of converters, transformers, AC motors or AC generators.

BRIEF SUMMARY

Various power harvesting systems may be provided including multiple parallel-connected photovoltaic strings, each photovoltaic string includes a series-connection of photovoltaic panels. Multiple voltage-compensation circuits may be connected in series respectively with the photovoltaic strings. The voltage-compensation circuits may be configured to provide respective compensation voltages to the photovoltaic strings to maximize power harvested from the photovoltaic strings. The voltage-compensation circuits may include respective inputs which may be connected to a source of power and respective outputs which may be connected in series with the photovoltaic strings. The voltage-compensation circuits may be an alternating current (AC) to direct current (DC) converter where the source of power is a source of AC power, or a DC-of-DC converter where the source of power is a source of DC power. The source of power may be provided by the power grid.

The power harvesting system may include further, a direct current power output attached to the parallel-connected photovoltaic strings. The voltage-compensation circuits may include source power inputs connected to the direct current power output.

The power harvesting system may also include a direct current power output attached to the parallel-connected photovoltaic strings and an inverter including a DC power input attached to the direct current power output. The inverter preferably includes an AC power output. The inverter may be configured to invert direct current power generated by the parallel-connected photovoltaic strings to alternating current power at the AC power output. The voltage-compensation circuits may include source power inputs from the AC power output.

The power harvesting system may include a central controller operatively attached to the voltage-compensation circuits. The central controller may be adapted to control the compensation voltages by tracking maximum power produced from all the parallel-connected photovoltaic strings. A power sensor may be connected to the direct current power output and the central controller. The power sensor may be adapted to sense power in the direct current power output and report a sensed power to the central controller. The central controller may control the compensation voltages to maximize power from all the parallel-connected photovoltaic strings based on the sensed power.

The voltage-compensation circuits may be optionally configured to provide the compensation voltages in the photovoltaic strings additional to the voltages provided by the series connected photovoltaic panels.

The power harvesting system may also include, multiple sensors operatively connected respectively to the voltage-compensation circuits. The sensors may be adapted to measure a circuit parameter of the photovoltaic strings. The voltage-compensation circuits may be adapted to provide the compensation voltages based on the at least one circuit parameter to maximize power in the photovoltaic strings. The circuit parameter may include respective currents flowing in the photovoltaic strings. The at least one circuit parameter may include respective voltages of the photovoltaic strings.

According to features presented there is provided a power harvesting system which includes a photovoltaic string including a series connection of photovoltaic panels and a voltage-compensation circuit connected in series with the photovoltaic string. The voltage-compensation circuit may be configured to provide a compensation voltage to the string to maximize power harvested from the photovoltaic string. The voltage-compensation circuit may include an input connectible to a source of power and an output connectible in series with the photovoltaic string.

The power harvesting system may further include a direct current power output attached to the photovoltaic string. The voltage-compensation circuit includes a DC-to-DC converter having a source power input connected to the direct current power output. The voltage-compensation circuit may have an AC-to-DC converter with an alternating current (AC) source input provided from an AC power source. The AC-to-DC converter also includes a DC output which connects in series with the photovoltaic string. A direct current power output attached to the photovoltaic string and an inverter having a DC inverter input connected to the direct current power output. The AC-to-DC converter may be connectible at the AC source input to either a power grid, or an AC output of the inverter.

According to features presented there is provided a method in a power harvesting system which includes a photovoltaic string. The photovoltaic string may include a series-connection of photovoltaic panels. The method connects in series a voltage-compensation circuit within the photovoltaic string. A circuit parameter may be monitored within the photovoltaic string. A compensation voltage of the voltage-compensation circuit may be configured based on the monitoring. The compensation voltage may be added serially within the photovoltaic string, thereby maximizing the power harvested from the photovoltaic string. A DC load may be attached to the photovoltaic string. An input of the voltage-compensation circuit may be connected to either a source of AC power or a source of DC power. The circuit parameter may include a current produced by the photovoltaic string, a voltage across the photovoltaic string or the power produced by the photovoltaic string.

BRIEF DESCRIPTION OF THE DRAWINGS

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

Figure 1 shows a photovoltaic power harvesting system according to conventional art.

Figure 2 shows another photovoltaic power harvesting system according to conventional art.

Figure 3a shows a power harvesting system according to a feature of the present invention.

Figure 3b shows a power harvesting system according to another feature of the present invention.

Figure 3c shows more details of a voltage-compensation circuit shown in Figures 3a and 3b, according to a feature of the present invention.

Figure 3d shows an implementation of a voltage-compensation circuit shown in Figures 3a and 3b, according to another feature of the present invention.

Figure 4 shows a method applied to the power harvesting systems shown in Figures 3a and 3b, according to a feature of the present invention.

DETAILED DESCRIPTION

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

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

It should be noted, that although the discussion herein relates primarily to photovoltaic systems, the present invention may, by non-limiting example, alternatively be configured using other distributed power systems including (but not limited to) wind turbines, hydro turbines, fuel cells, storage systems such as battery, super-conducting flywheel, and capacitors, and mechanical devices including conventional and variable speed diesel engines, Stirling engines, gas turbines, and micro-turbines.

By way of introduction, features of the present invention are directed towards maximizing output power from under-performing or partially shaded photovoltaic strings in a power harvesting system of parallel connected photovoltaic strings. The features may provide maximal overall power output of the system and reduced installation and maintenance cost of the system. The features may also provide increased reliability of the system, owing to lower power operating levels of switching converters added to each of the photovoltaic string compared with DC-DC converters **205** used in conventional system **20**.

Reference is now made to Figure 3a which shows a power harvesting system **30a** according to a feature of the present invention. A number of photovoltaic panels **101** are connected in series to form a photovoltaic string **109**. String **109** is connected in series with a voltage-compensation circuit **307** to provide a compensated string **315**. A source voltage (V_S) may be input to voltage-compensation circuit **307**. A number of compensated strings **315** may be connected together in parallel to give direct current (DC) power output **211**. A power sensor **370** operatively connected to central controller **313** measures the power on DC output **211**. DC power output **211** is connected to an input of a DC to alternating current (AC) inverter **103**. Inverter **103** converts the combined DC power output **211** of strings **315** to an alternating current power at an output of inverter **103**. The output of inverter **103** connects to AC load **105**. A central controller **313** may be operatively attached to each voltage-compensation circuit **307** by bi-directional control and communication lines as shown, by wireless communication or by power line communications in DC bus **211**. Central controller **313** may include a microprocessor with on-board memory and an interface which may include analogue to digital converters (ADCs) and digital to analogue converters (DACs).

Reference is now made to Figure 3b which shows a power harvesting system **30b** according to another feature of the present invention. String **109** is connected in series with voltage-compensation circuit **307** to provide a compensated string **315**. A source voltage (V_S) may be input to voltage-compensation circuit **307**. A number of compensated strings **315** may be connected together in parallel to give direct current (DC) power output **211**. DC power output **211** is connected to an input of a DC to alternating current (AC) inverter **103**. Inverter **103** converts the combined DC power output **211** of strings

315 to an alternating current power at an output of inverter **103**. The output of inverter **103** connects to AC load **105**. System **30a** is the same as system **30b** except that system **30b** does not have central controller **313**. Instead, monitoring and control in system **30b** is performed by each circuit **307**, which may include a microprocessor with on-board memory and an interface which may include analogue to digital converters (ADCs) and digital to analogue converters (DACs). Each circuit **307** is operatively attached to sensors **320**, **322** and **324**. Sensors **320** and **322** may be adapted to sense the voltage across photovoltaic string **109** as well as current in string **109**. Alternatively, sensors **320** and **324** may be adapted to sense the voltage across a compensated string **315** and current in string **315**. Alternatively, sensors **324** and **322** may be adapted to sense the voltage ($\mathbf{V_C}$) across a circuit **307** as well as current through the circuit **307**.

Reference is now made to Figure 3c which shows more details of voltage-compensation circuit **307** shown in Figures 3a and 3b, according to a feature of the present invention. Voltage-compensation circuit **307** may be implemented using a direct current (DC) to DC converter **307a**. DC-to-DC converter **307a** may be a buck circuit, a boost circuit, a buck + boost circuit or switched-mode power supply (SMPS). The output of DC-to-DC converter **307** is connected in series within string **315** to add compensation voltage ($\mathbf{V_C}$) to string **315**. The DC source voltage input ($\mathbf{V_s}$) to DC-to DC converter **307** may be provided from the combined DC output of strings **315**, or strings **109.** Alternatively, DC source voltage input ($\mathbf{V_s}$) may be provided by a micro-inverter converting AC from the mains grid or another independent source of DC power such as a battery or DC generator**.** Circuit **307** as shown in Figure 3c, is a conventional buck-boost DC- to-DC converter circuit which has an input voltage $\mathbf{V_S}$ with an input capacitor $\mathbf{C_1}$ connected in parallel across $\mathbf{V_S}$. Two switches may be implemented as field effect transistors (FET) with integral diodes: a high side buck switch $\mathbf{Q_1}$ and a low side buck switch $\mathbf{Q_2}$ connected in series by connecting the source of $\mathbf{Q_1}$ to the drain of $\mathbf{Q_2}$. The drain of $\mathbf{Q_1}$ and the source of $\mathbf{Q_2}$ may be connected parallel across the input capacitor $\mathbf{C_1}$. A node **A** is formed between switches $\mathbf{Q_1}$ and $\mathbf{Q_2}$ to which one end of an inductor **L** is connected. The other end of inductor **L** is connected to the boost circuit of buck-boost DC-to-DC converter **307** at a node **B**. Node **B** connects two switches implemented as field effect transistors (FET): a high side boost switch $\mathbf{Q_4}$ and a low side boost switch $\mathbf{Q_3}$ together in series where the source of $\mathbf{Q_4}$ connects to the drain of **Q_3** to form node **B**. The drain of **Q_4** and the source of **Q_3** connect across an output capacitor **C_2** to produce the output voltage **V_C** of buck-boost DC-to-DC converter **307**.

Reference is now made to Figure 3d which shows an implementation of circuit **307** shown in Figures 3a and 3b, according to another feature of the present invention. Voltage compensation circuit **307** may be implemented using an alternating current (AC) to DC inverter. The AC to DC inverter **307b** may be a type of switched mode power supply (SMPS). When voltage-compensation circuit **307** is an AC to DC converter **307b**, the DC output of the AC to DC converter is connected in series within a string **315**. The AC input (**V_s**) to the AC to DC converter may be provided from the mains grid, from the AC output of inverter **103** or by another independent source of AC power.

Reference is now made to Figure 4 which shows a method **400** which may be applied to power harvesting system **30b** shown in Figure 3b, according to a feature of the present invention. In step **402**, an output voltage (**V_C**) of circuit **307** is wired in series with a series-connection of panels **101** to form compensated string **315**. The input voltage (**V_S**) to circuit **307** may be from direct current (DC) output **211,** the alternating current (AC) output of inverter **103** or a separate independent AC or DC electric supply. Several compensated strings **315** outputs may then be connected in parallel and further connected to the input of an inverter **103** as shown in Figure 3b.

In step **404**, a circuit parameter of each parallel connected string **315** is monitored in the case of system **30b.** The circuit parameter may be the current flowing in a string **315,** the voltage across a string **315,** the voltage of a photovoltaic string **109** and/or the voltage (**V_C**) across a circuit **307**. The current and voltages in a string **315** may be used to determine the power (P) in a string **315** or a photovoltaic string **109** by virtue of power being equal to voltage (V) multiplied by current (I).

In decision block **406,** a control algorithm stored in a circuit **307** adjusts compensation voltage **V_C** to maximize output power of string **315.** In step **408**, a compensation voltage V_c for strings **315** is configured based on the result of the control algorithm performed in steps **404** and **406**. The compensation voltage V_c for strings **315** in step **408** may be a positive or a negative voltage polarity with respect to the voltage polarity of a string **109**. In step **410,** the compensation voltage V_c is added to string **315**. In the case of the positive voltage for V_c, the voltage of a string **315** may be increased in step **408**. In the case of the negative voltage for V_c, the voltage of string **315** may be decreased in step **408**.

Reference is still being made to Figure 4. Method **400** may also be applied to system **30a** (Figure 3a) which uses central controller **313.** In the case of system **30a**, in step **404** central controller monitors or calculates a net total power from system **30a**. The net total power from system **30a** is equal to the power produced by strings **109** subtracted from the power added by compensation circuits **307**.

When the voltage (**V_S**) and hence power to the input of circuit **307** is derived from DC bus **211** or the output of inverter **103** to give compensated voltage (**V_C**). The net total power from system **30a** may be derived directly by monitoring (step **404**) power on DC bus **211**.

When the voltage (**V_S**) and hence power to the input of circuit **307** is derived from an independent DC source or AC source such as a mains supply to give compensated voltage (**V_C**). The net total power from system **30a** may be derived by subtracting power monitored on DC Bus **211** (step **404**) from the power added by compensation circuits **307**.

In decision block **406**, compensation voltages V_c of all strings **315** may be adjusted to maximize the net total power from system **30a**. In step **408**, a compensation voltage V_c for a string **315** is configured based on the result of the control algorithm performed in steps **404** and **406**. In step **410,** the compensation voltage V_c is added to a string **315.**

During a sustained use of systems **30a** or **30b** over a period of time, the number and type of serial connected panels **101** in a string **315** may change, some panels may become faulty and/or operate in a current bypass mode or panels may be replaced with ones that have different electrical characteristics. Under these circumstances, the control algorithm maintains strings **315** at their maximum power point (MPP) by adding compensation voltage to each string **315** to maintain maximum power from each string **315**. When all strings **109** are found to be operating at maximum power output level and maximum power point, no voltage compensation V_c may be required and voltage compensation **V_c** added to string **315** is at or near zero volts.

With respect to both systems **30a** and **30b**. In each iteration of the control algorithm performed in steps **404** and **406**, it may be possible to subtract from all the compensation voltages (V_c) in each string **315**, the minimum compensation voltage V_c. Subtracting the minimum compensation voltage V_c, may prevent a drift in the compensation voltages (V_c) going too high for no reason. Alternatively, it may be possible to tie the compensation voltages (V_c) to a level that will optimize the overall voltage of strings **315** to be optimal for the input of inverter **103**, thereby increasing the conversion efficiency of inverter **103**.

The present features with respect to method **400** and systems **30a** or **30b**, may be compared to conventional system **20** (Figure 2) by way of the same numerical example, where three compensated strings **315** are used. It may be assumed just for the purpose of the numerical example that the three compensated strings **315** are compensated by circuit **307** which may be an AC to DC converter powered from the grid. Therefore, circuit **307** receives and converts voltage (**V_S**) and hence power from the electrical grid. If two strings **109** are equally irradiated such that each string operates with a string **109** voltage of 600 volts and string current of 10 amperes, each of the two strings generates (10 amperes · 600 volts) 6 kilowatts. If one under-performing string **109** is partially shaded or if a panel **101** is removed or bypassed, there may be a string voltage of 550 Volts and current of 10 amperes, which means (10 amperes · 550 volts) 5.5 kilowatts may be generated by the under-performing string **109**. The maximum power 5.5 kilowatts may be generated by the under-performing string **109** only if the under-performing string **109** can be operated at maximum power point (MPP).

Voltage-compensation circuit **307** of the under-performing string **109** may be configured (step **408**) by controller **313** to add 50 volts (**V_C**) in series with under-performing string **109** while maintaining the current of 10 amperes (step **410**). Adding 50 volts by use of voltage-compensation circuit **307**, maintains string **315** voltage at 600 volts also for under-performing string **109**. Increasing the voltage of the string **315**, allows the one under-performing string **109** to operate at MPP and also requires an extra (10 amperes · 50 volts) 500 Watts when compared to the 6 kilowatts in each of the other two strings **315**. The overall power output of system **30a** or **30b** is 18 kilowatts, from two strings **109** providing 12 kilowatts (2 · 6 kilowatts), the under-performing compensated string **109** providing 5.5 kilowatts and the grid providing 500 watts (50 volts · 10 amperes) via circuit **307**. The power provided from the 3 strings **315** may be therefore, the same as system **20** at 17.5 kilowatts (2 · 6 kilowatts + 5.5 kilowatts).

The benefit of systems **30** compared with system **20** is that 500W-1 kW switching converters **307** may be required compared with 6-10kW switching converters used in system **20.** The difference in power rating may represent a huge improvement in cost and reliability of systems **30** compared with system **20.**

The indefinite articles "a", "an" is used herein, such as "a string", "a voltage-compensation circuit" have the meaning of "one or more" that is "one or more strings" or "one or more voltage-compensation circuits".

Although selected features of the present invention have been shown and described, it is to be understood the present invention is not limited to the described features. Instead, it is to be appreciated that changes may be made to these features without departing from the principles and spirit of the invention, the scope of which is defined by the claims and the equivalents thereof.

CLAIMS

1. A power harvesting system comprising:

a plurality of parallel-connected photovoltaic strings, each photovoltaic string including a series-connection of photovoltaic panels; and

a plurality of voltage-compensation circuits connected in series respectively with said photovoltaic strings, wherein said voltage-compensation circuits are configured to provide respective compensation voltages to said photovoltaic strings to maximize power harvested from said photovoltaic strings.

2. The power harvesting system of claim 1, wherein said voltage-compensation circuits include respective inputs connectible to a source of power and respective outputs connectible in series with said photovoltaic strings.

3. The power harvesting system of claim 2, wherein said voltage-compensation circuits are selectively either:

an alternating current (AC) to direct current (DC) converter wherein said source of power is a source of AC power, or a DC-of-DC converter wherein said source of power is a source of DC power.

4. The power harvesting system of claim 2, wherein said source of power is provided by the power grid.

5. The power harvesting system of claim 1, further comprising:

a direct current power output attached to the parallel-connected photovoltaic strings; wherein said voltage-compensation circuits include source power inputs connected to said direct current power output.

6. The power harvesting system of claim 1, further comprising:

a direct current power output attached to the parallel-connected photovoltaic strings;

an inverter including a DC power input attached to said direct current power output, wherein said inverter includes an AC power output, wherein said inverter is configured to invert direct current power generated by said parallel-connected photovoltaic strings to alternating current power at said AC power output, wherein said voltage-compensation circuits include source power inputs from said AC power output.

7. The power harvesting system of claim 1, further comprising:

a central controller operatively attached to said voltage-compensation circuits wherein said central controller is adapted to control said compensation voltages by tracking maximum power produced from all said parallel-connected photovoltaic strings.

8. The power harvesting system of claim 7, further comprising:

a power sensor operatively connected to said direct current power output and said central controller, wherein said power sensor is adapted to sense power in said direct current power output and report a sensed power to said central controller, wherein said central controller controls said compensation voltages to maximize power from all said parallel-connected photovoltaic strings based on said sensed power.

9. The power harvesting system of claim 1, wherein said voltage-compensation circuits are configured to provide said compensation voltages in said photovoltaic strings additional to the voltages provided by the series connected photovoltaic panels.

10. The power harvesting system of claim 1, further comprising:

a plurality of sensors operatively connected respectively to said voltage-compensation circuits, wherein said sensors are adapted to measure at least one circuit parameter of said photovoltaic strings;

wherein said voltage-compensation circuits are adapted to provide said compensation voltages based on said at least one circuit parameter to maximize power in said photovoltaic strings.

11. The power harvesting system of claim 10, wherein said at least one circuit parameter includes respective currents flowing in said photovoltaic strings.

12. The power harvesting system of claim 10, wherein said at least one circuit parameter includes respective voltages of said photovoltaic strings.

13. A power harvesting system comprising:

a photovoltaic string including a series connection of photovoltaic panels; and

a voltage-compensation circuit connected in series with said photovoltaic string, wherein said voltage-compensation circuit is configured to provide a compensation voltage to the string to maximize power harvested from said photovoltaic string.

14. The power harvesting system of claim 13, wherein said voltage-compensation circuit includes an input connectible to a source of power and an output connectible in series with said photovoltaic string.

15. The power harvesting system of claim 13, further comprising:

a direct current power output attached to the photovoltaic string; wherein said voltage-compensation circuit includes a DC-to-DC converter having a source power input connected to said direct current power output.

16. The power harvesting system of claim 13, wherein said voltage-compensation circuit includes:

an AC-to-DC converter with an alternating current (AC) source input provided from an AC power source; wherein said AC-to-DC converter includes a DC output which connects in series with the photovoltaic string.

17. The power harvesting system of claim 16, further comprising:

a direct current power output attached to the photovoltaic string;

an inverter having a DC inverter input connected to said direct current power output; wherein said AC-to-DC converter is connectible at said AC source input to selectively either a power grid, or an AC output of said inverter.

18. A method in a power harvesting system including a photovoltaic string including a series-connection of photovoltaic panels, the method comprising:

connecting in series a voltage-compensation circuit within said photovoltaic string;

monitoring a circuit parameter within said photovoltaic string;

configuring a compensation voltage of said voltage-compensation circuit based on said monitoring; and

adding serially said compensation voltage within said photovoltaic string, thereby maximizing the power harvested from said photovoltaic string.

19. The method of claim 18, further comprising:

attaching a DC load to said photovoltaic string.

20. The method of claim 18, further comprising:

connecting an input of said voltage-compensation circuit to selectively either a source of AC power or a source of DC power.

21. The power harvesting method of claim 18, wherein said circuit parameter includes a current produced by said photovoltaic string.

22. The power harvesting method of claim 18, wherein said at least one circuit parameter is a voltage across said photovoltaic string.

23. The power harvesting method of claim 18, wherein said at least one circuit parameter is the power produced by said photovoltaic string.

Application No:	GB1201499.9	**Examiner:**	Mr Tony Oldershaw
Claims searched:	1 to 23	**Date of search:**	26 May 2012

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1 to 23	GB2476508 A (HARGIS) - see e.g. figure 1; page 6 line 10 to page 11 line 8
X	"	US5530335 A (DECKER) - see e.g. abstract; figure 1; column 3 line 55 to column 4 line 42
X	"	JP2004194500 A (EGUCHI) - see e.g. figure 1
X	"	JP11318042 A (EGUCHI) - see e.g. figure 1

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

G05F; H01L; H02J

The following online and other databases have been used in the preparation of this search report

Online: WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
H02J	0003/38	01/01/2006
G05F	0001/67	01/01/2006
H02J	0001/12	01/01/2006