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(54) **METHOD AND APPARATUS FOR CONVERTING A DIRECT CURRENT TO ALTERNATING CURRENT UTILIZING A PLURALITY OF INVERTERS**

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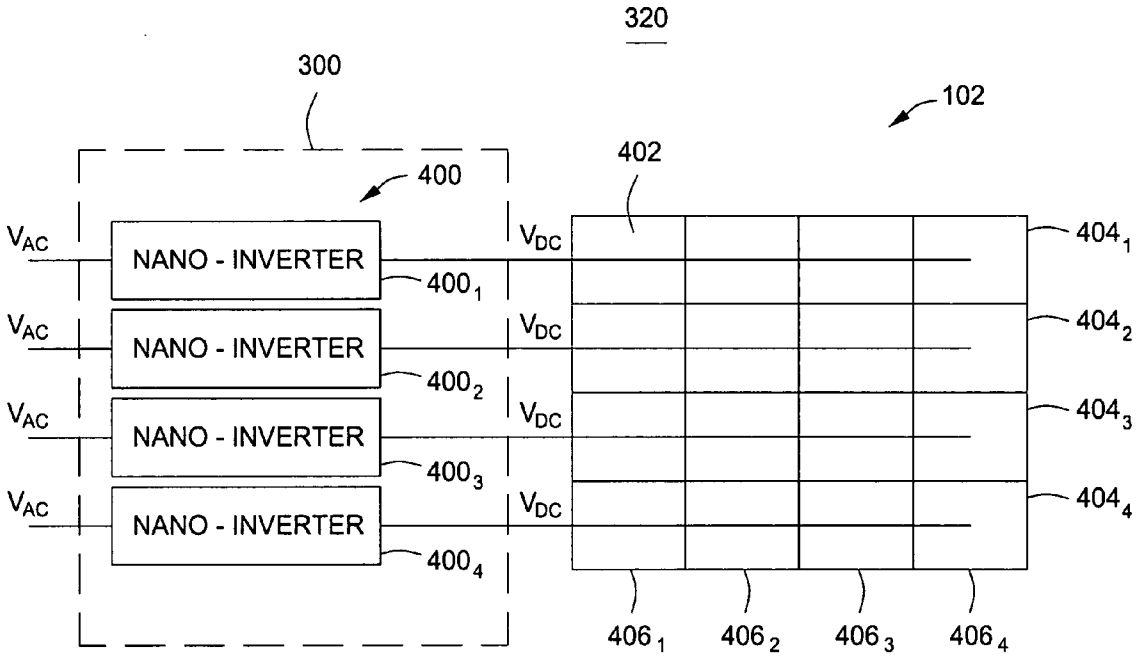
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(57) **ABSTRACT**

An apparatus for converting Direct Current (DC) to Alternating Current (AC), comprising a plurality of inverters, each inverter having a separate DC input adapted to be coupled to at least one solar cell defining an area of a solar panel.



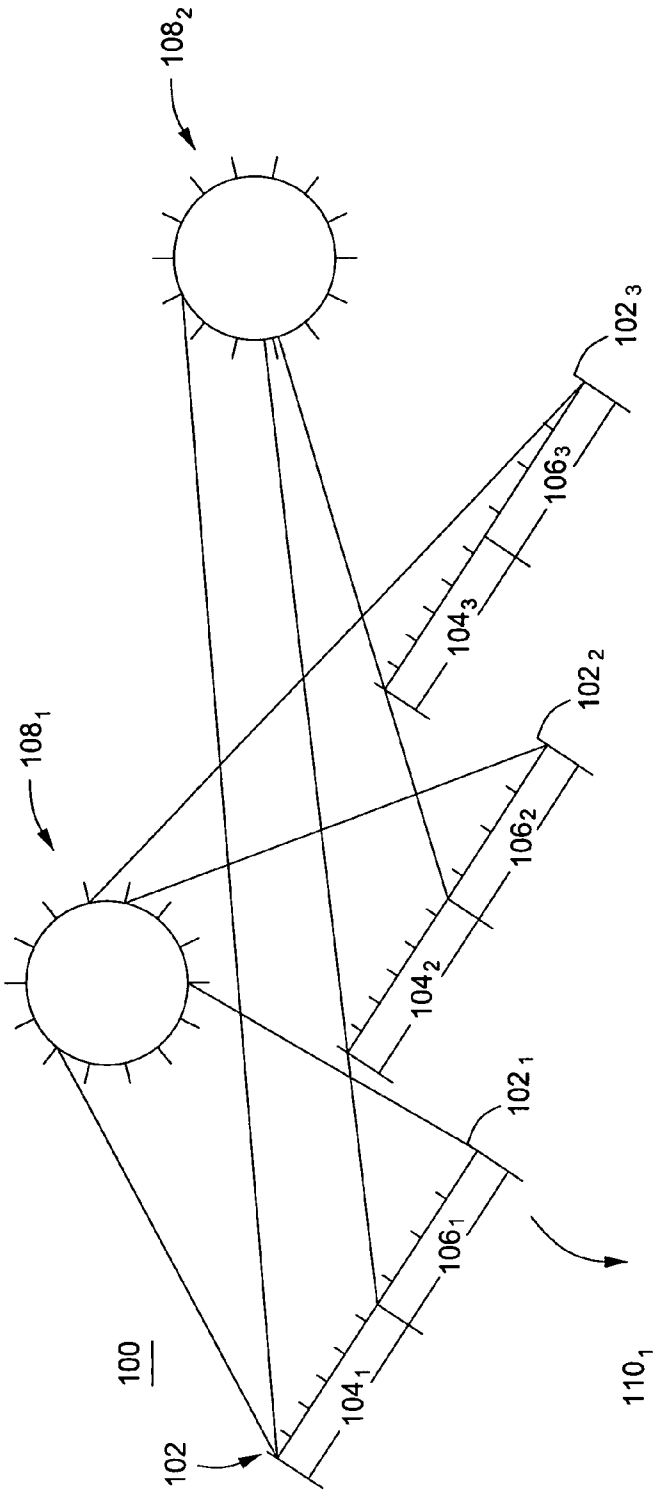

108_2
108_1
102_3
102_2
102_1
106_3
106_2
106_1
104_3
104_2
104_1
100
102

FIG. 1

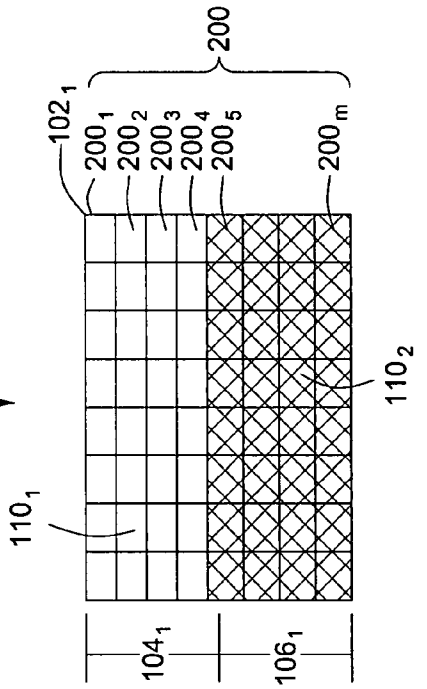
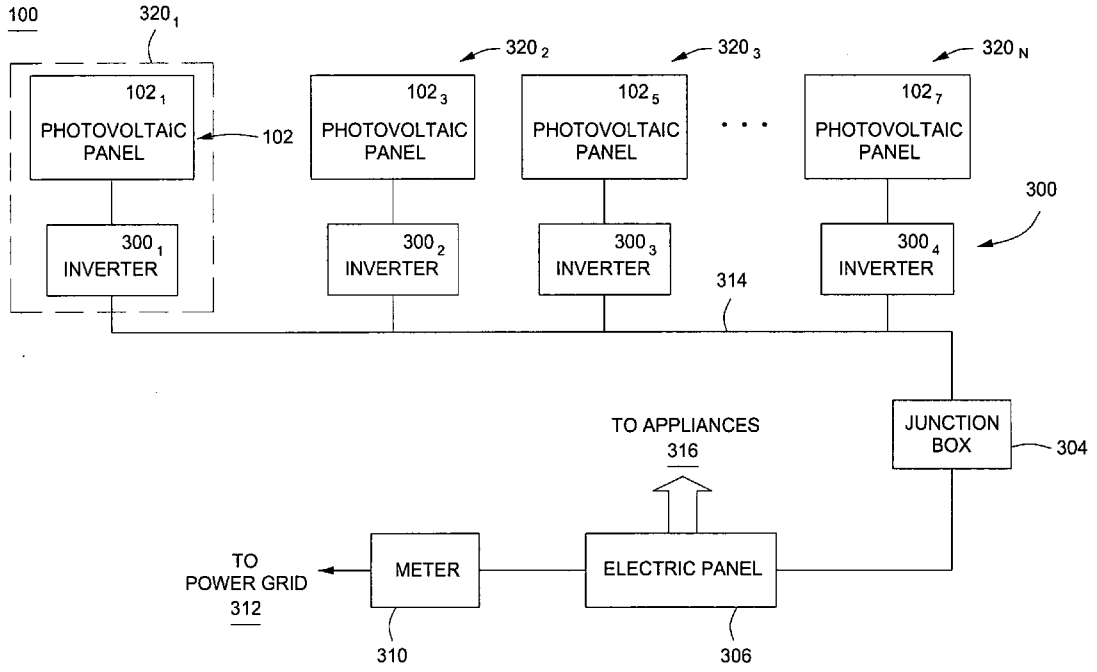

200
102_1
200_1
200_2
200_3
200_4
200_5
200_m
110_1
110_2
104_1
106_1

FIG. 2


100
320 1
320 2
320 3
320 N
102 1
PHOTOVOLTAIC PANEL
102
102 3
PHOTOVOLTAIC PANEL
102 5
PHOTOVOLTAIC PANEL
102 7
PHOTOVOLTAIC PANEL
300
300 1
INVERTER
300 2
INVERTER
300 3
INVERTER
300 4
INVERTER
314
JUNCTION BOX
304
TO APPLIANCES
316
TO POWER GRID
312
METER
ELECTRIC PANEL
310
306

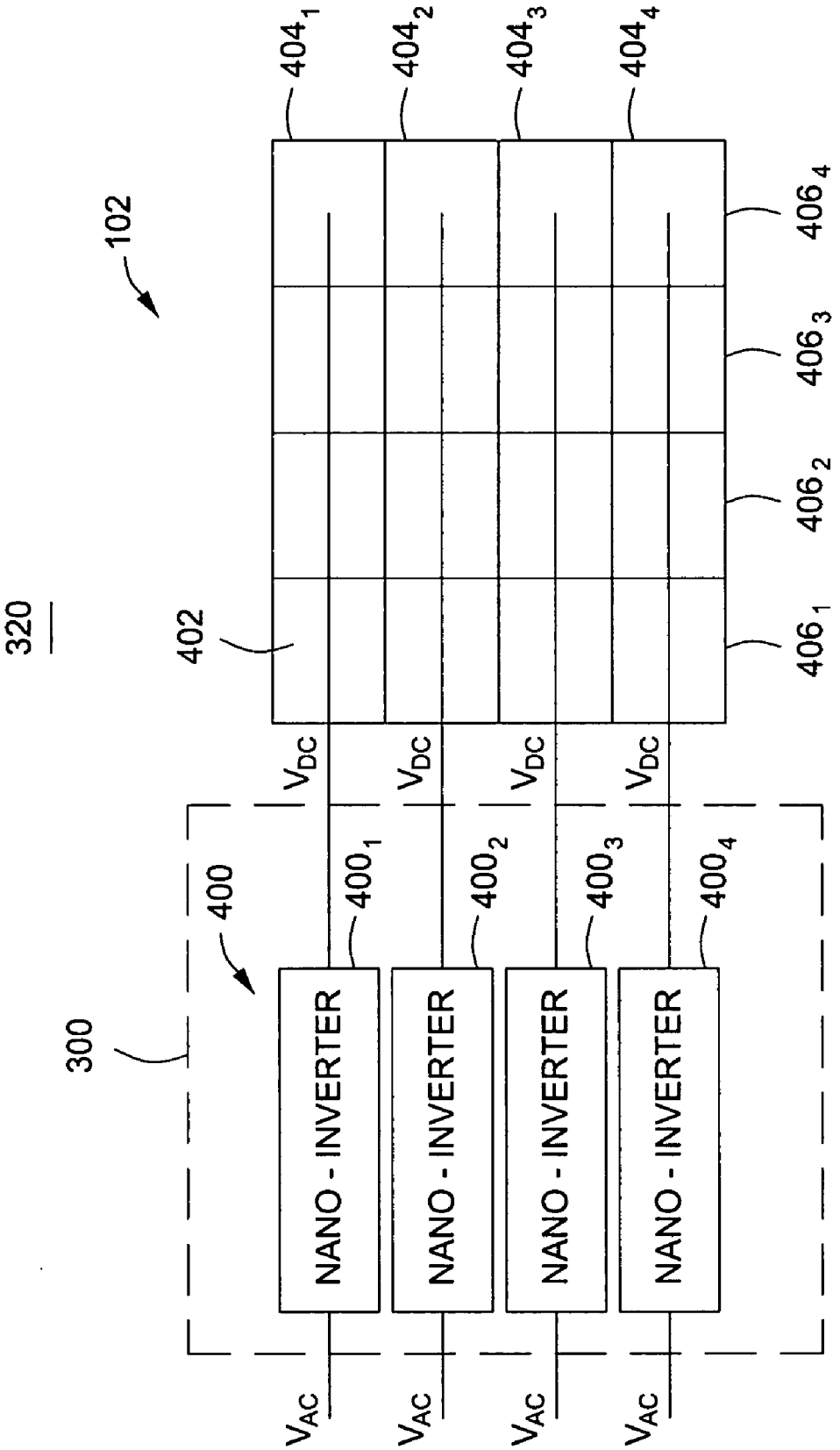

320
102
402
404 1
404 2
404 3
404 4
406 4
406 3
406 2
406 1
V DC
V DC
V DC
V DC
300
400
400 1
400 2
400 3
400 4
NANO - INVERTER
NANO - INVERTER
NANO - INVERTER
NANO - INVERTER
V AC
V AC
V AC
V AC

FIG. 4

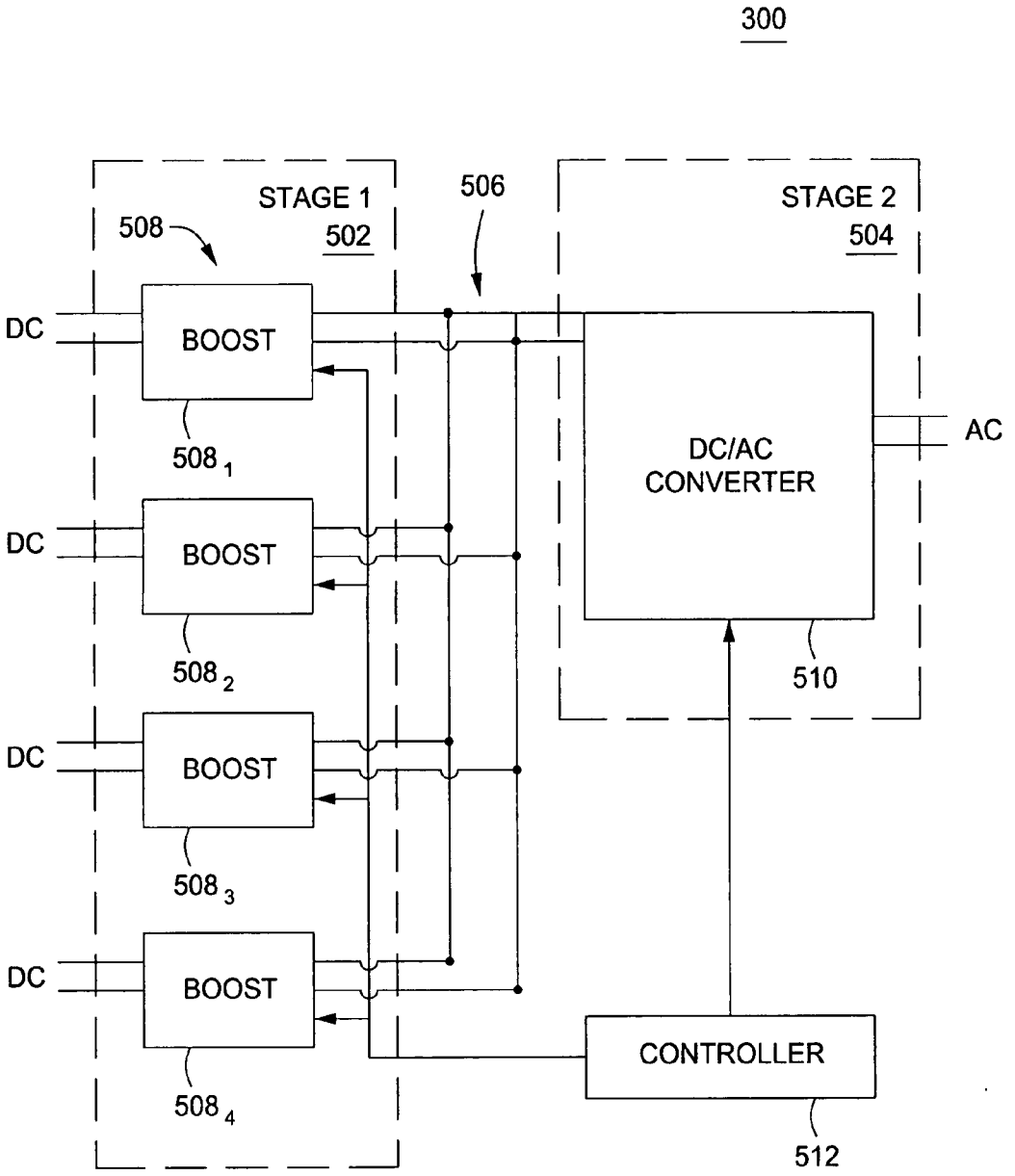

300
STAGE 1
502
506
STAGE 2
504
508
DC
BOOST
508_1
DC
BOOST
508_2
DC
BOOST
508_3
DC
BOOST
508_4
DC/AC
CONVERTER
AC
510
CONTROLLER
512

FIG. 5

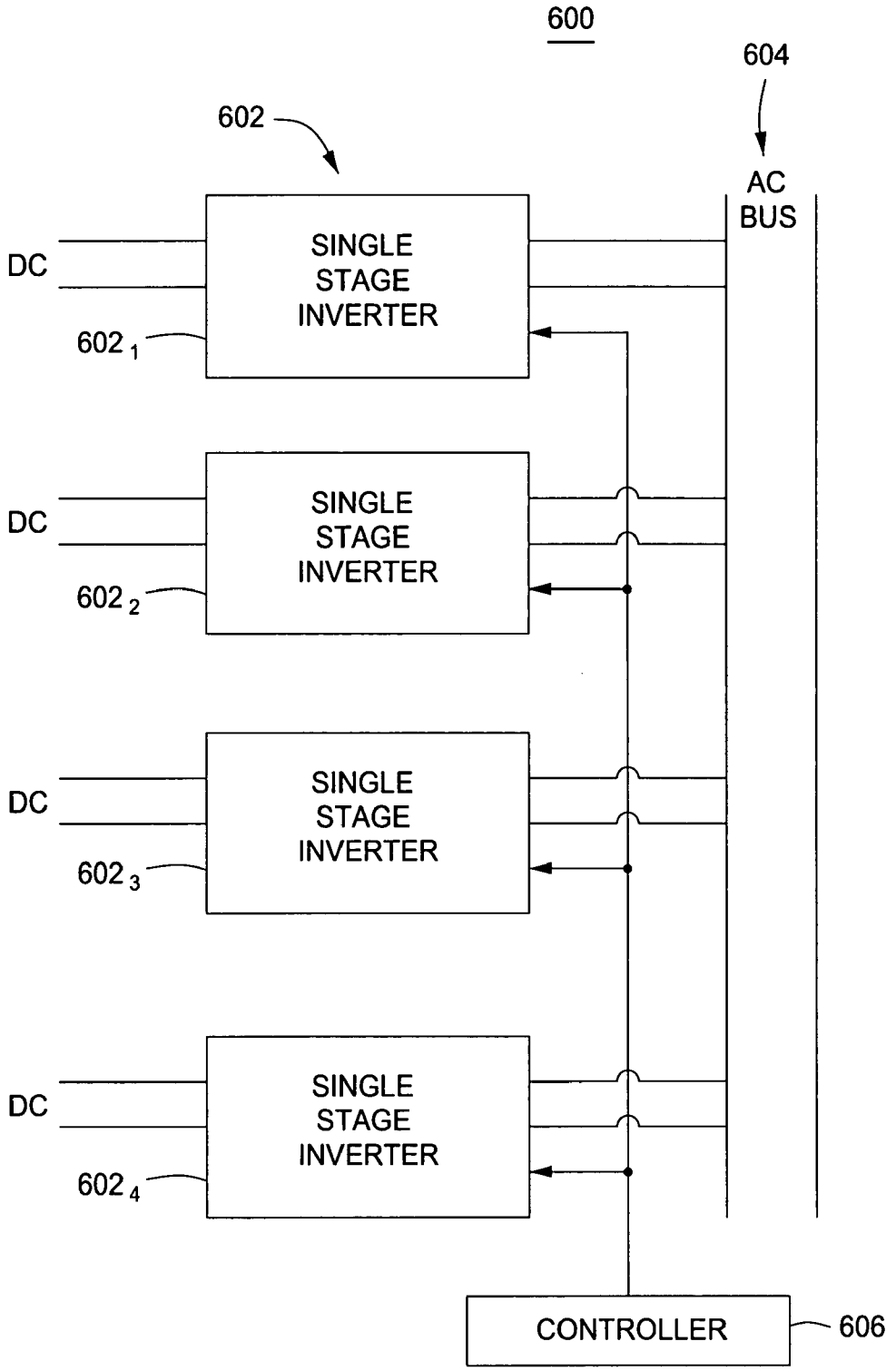

600
604
602
AC
BUS
DC
SINGLE
STAGE
INVERTER
602 1
DC
SINGLE
STAGE
INVERTER
602 2
DC
SINGLE
STAGE
INVERTER
602 3
DC
SINGLE
STAGE
INVERTER
602 4
CONTROLLER
606

FIG. 6

METHOD AND APPARATUS FOR CONVERTING A DIRECT CURRENT TO ALTERNATING CURRENT UTILIZING A PLURALITY OF INVERTERS

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates generally to a method and apparatus for converting a direct current (DC) to alternating current (AC). More particularly, the present invention relates to a method and apparatus for converting DC to AC utilizing a plurality of inverters.

[0003] 2. Description of the Related Art

[0004] Historically, photovoltaic panels have been used mostly in remote applications where commercial power was not available. This was due to the high cost of an installation making photovoltaic panels an economical choice only when nothing else was available. However, photovoltaic panels are now well established that the fossil energy reserves, which are currently used to generate electricity, are being rapidly depleted. The worldwide growth of power demand is leading to a durable increase in energy cost.

[0005] Photovoltaic generation systems require an inverter that converts Direct Current (DC) from solar cells to Alternating Current (AC) for use by household appliances, for example. It is important for any power generation system to produce and deliver electricity to electric appliances in the most efficient manner. A typical photovoltaic array comprises a plurality of sub-arrays, where each sub-array comprises a plurality of individual photovoltaic panels. A junction box combines the output of the various sub-arrays to form a DC signal that is supplied to an inverter. The inverter converts the DC to AC and supplies the AC to the power grid. The user uses power from the grid in a typical fashion; however, their cost of electricity from the grid is offset by the amount of electricity the photovoltaic generation system supplies to the grid.

[0006] In such a system, the amount of power that is efficiently coupled to the grid is important for the cost recovery of the system. As such, the inverter must be as efficient as possible. In a typical large-scale installation, rows of panels are installed on a flat surface with the panels tilted at an angle depending on local conditions such as latitude. Typically, for a location in the Northern Hemisphere, the more tilt, the more efficient will be the collection in winter, while a smaller tilt will harvest more power in summer, when the sun is higher in the sky. Some installations have variable tilts, thus, panels are always perpendicular to the sun's rays in order to harvest the maximum amount of energy. To enable the sun to fully illuminate all the panels, the panels are widely spaced from one another to avoid one panel shadowing another when the sun is low on the horizon. Although spacing the panels in such a manner maximizes the panel illumination for a given area, such spacing causes the solar array to occupy an excessive amount of space to produce a required amount of power. Consequently, solar energy systems are impractical in densely populated areas or in areas of high real estate prices.

[0007] More specifically, the current produced by the solar cell array is proportional to the incident solar energy. The cell should be biased at the Maximum Power Point (MPP) in order to extract the maximum power. This MPP changes based on temperature, incident light level and aging and cannot be predicted, but inferred. Due to manufacturing tolerances, all solar cells have slightly different characteristics that vary the MPP from cell to cell. As such, when the solar cells of an array are connected in series, the average MPP will be used for biasing the entire array, i.e., a "global" bias point. The "global" bias point is typically demonstrably less than the MPP of all the individual cells of the array. Additionally, if a row of cells is shaded, it cannot generate the current level that the other cells may generate in full sun. Any panel shading entails a very significant power production loss. In many cases, half a shaded panel produces no power at all. Thus, for an array that is partially shaded, the global MPP is substantially different than the MPP for either the shaded portion or full sun portion. Consequently, the individual cells are not biased optimally for peak power generation. In order to avoid shading of the panels on one another, as mentioned above, the panel rows are positioned a sufficient distance apart to minimize shadowing.

[0008] Therefore, there is a need for a method and apparatus for efficiently converting DC to AC for a solar array.

SUMMARY OF THE INVENTION

[0009] In one embodiment, the present invention discloses an apparatus for converting Direct Current (DC) to Alternating Current (AC), comprising a plurality of inverters, each inverter having a separate DC input adapted to be coupled to at least one solar cell defining an area of a solar panel

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0011] FIG. **1** is a side view of an exemplary embodiment of the photovoltaic panel system;

[0012] FIG. **2** is a front view of an exemplary embodiment of a photovoltaic panel of the photovoltaic panel system of FIG. **1**;

[0013] FIG. **3** is a block diagram of an exemplary embodiment of a photovoltaic panel system in accordance with the present invention;

[0014] FIG. **4** is a detailed block diagram of an exemplary embodiment of an inverter system of FIG. **3** in accordance with the present invention;

[0015] FIG. **5** is a block diagram of an exemplary embodiment of a dual stage inverter in accordance with the present invention; and

[0016] FIG. **6** is a block diagram of an exemplary embodiment of a single stage inverter in accordance with the present invention.

DETAILED DESCRIPTION

[0017] FIG. **1** is a side view of an exemplary embodiment of the photovoltaic panel system **100** that utilizes embodiments of the present invention. The photovoltaic panel system **100** includes a plurality of photovoltaic panels **102** (also referred to as solar cell arrays) and a sun $\mathbf{108}_1$ and $\mathbf{108}_2$. In this embodiment, the photovoltaic panels **102** include three panels $\mathbf{102}_1$, $\mathbf{102}_2$ and $\mathbf{102}_3$ that are densely arranged, i.e., the

panels shadow one another. Although three panels are shown, the photovoltaic panel system **100** may include any number of panels **102**.

[0018] In this dense arrangement of panels, the sun **108** illuminates the photovoltaic panels $\mathbf{102}_1$, $\mathbf{102}_2$ and $\mathbf{102}_3$ such that, when the sun $\mathbf{108}_1$ has a high elevation above the horizon, each panel $\mathbf{102}_1$, $\mathbf{102}_2$ and $\mathbf{102}_3$ is fully illuminated. However, with a lower elevation of the sun $\mathbf{108}_2$ with respect to the panels **102**, each panel **102** comprises lit-areas $\mathbf{104}_1$, $\mathbf{104}_2$ and $\mathbf{104}_3$ and shaded-areas $\mathbf{106}_1$ and $\mathbf{106}_2$. The lit-areas $\mathbf{104}_1$, $\mathbf{104}_2$ and $\mathbf{104}_3$ are areas that are illuminated with more light (direct sun) and thus optimally produce DC. Therefore, in the depicted arrangement, photovoltaic panel $\mathbf{102}_3$ is operating most efficiently of all the panels. The shaded-areas $\mathbf{106}_1$ and $\mathbf{106}_2$ are subjected to a shadow from a neighboring panel and are exposed to less light; thus, the shaded areas $\mathbf{106}_1$ and $\mathbf{106}_2$ may produce less DC than the areas exposed to direct sun. However, utilizing one embodiment of the invention as described below, a maximum amount of power can be extracted from the panel when fully illuminated or when shaded.

[0019] FIG. **2** is a front view of an exemplary embodiment of a photovoltaic panel $\mathbf{102}_1$ of the photovoltaic panel system of FIG. **1**. The panel $\mathbf{102}_1$ comprises rows **200** (rows $\mathbf{200}_1$ through $\mathbf{200}_M$, where M is an integer). The photovoltaic panel $\mathbf{102}_1$ has solar cells $\mathbf{110}_1$ in rows $\mathbf{200}_{1\text{-}4}$ that constitute the lit-area $\mathbf{104}_1$ and solar cells $\mathbf{110}_2$ in rows $\mathbf{200}_{S\text{-}M}$ that constitute the shaded-area $\mathbf{106}_1$. Therefore, the cells in the lit-area $\mathbf{104}_1$ have a different MPP as compared to the MPP of the cells in the shaded-area $\mathbf{106}_1$.

[0020] To further maximize power from a given panel, the solar cells within a panel (or rows thereof) may be tested for efficiency. The cells (or rows thereof) having the highest efficiency are positioned in a location on the panel that receives full illumination for the greatest amount of time, while the cells (or rows thereof) having comparatively lower efficiency at full illumination are positioned lower on a panel when substantially more shade it produced. In thins manner, the panel is designed to maximize the amount of power generated by the cells that are most efficient.

[0021] FIG. **3** is a block diagram of an exemplary embodiment of a photovoltaic panel system **100** in accordance with the present invention. This diagram only portrays one variation of the myriad of possible system configurations. The present invention can function in a variety of environments and systems.

[0022] The power generation system **100** comprises a plurality of power generators $\mathbf{320}_1$, $\mathbf{320}_2 \ldots \mathbf{320}_N$ (where N is an integer), a junction box **304**, an electric panel **306** and an electric meter **310**. Each power generator (for example generator $\mathbf{320}_1$) comprises a plurality of inverters $\mathbf{300}_1$ (see FIG. **4**) and a photovoltaic panel $\mathbf{102}_1$. As such, inverters $\mathbf{300}_1$ through $\mathbf{300}_n$ are respectively coupled to panels $\mathbf{102}_1$ through $\mathbf{102}_n$.

[0023] The system **100** supplies power to a power grid **312**, appliances **316**, or both. The photovoltaic panels $\mathbf{102}_1$, $\mathbf{102}_2 \ldots \mathbf{102}_n$ are well known in the art and are used for generating DC power from solar energy. The plurality of photovoltaic panels $\mathbf{102}_1$, $\mathbf{102}_2 \ldots \mathbf{102}_n$ (also referred to herein as solar panels or solar arrays) may be of any size or shape. Even though the system **100** shows four (4) photovoltaic panels $\mathbf{102}_1$, $\mathbf{102}_2 \ldots \mathbf{102}_n$, the system **100** may include any number of the photovoltaic panels **102**.

[0024] The inverter $\mathbf{300}_1$, $\mathbf{300}_2 \ldots \mathbf{300}_n$ converts DC power generated by the plurality of photovoltaic panels $\mathbf{102}_1$, $\mathbf{102}_2 \ldots \mathbf{102}_n$ into AC power. The inverters **300** of the present invention may produce current that is in-phase with the AC grid current and generate such current with low distortion.

[0025] The inverters $\mathbf{300}_1$, $\mathbf{300}_2 \ldots \mathbf{300}_n$ couple the output AC to an AC bus **314**. The AC bus **314** is terminated into a junction box **304**. Using such an AC bus **314** and discrete power generators $\mathbf{320}_N$, the system **100** is scalable and flexible to fit any user's needs. The structures of the inverters $\mathbf{300}_1$, $\mathbf{300}_2 \ldots \mathbf{300}_n$ are discussed below (See FIG. **5** and FIG. **6**).

[0026] The junction box **304** generally connects together the outputs from all the inverters $\mathbf{300}_1$, $\mathbf{300}_2 \ldots \mathbf{300}_n$ to form a single AC feed to the electric panel **106**.

[0027] The electric panel **306** connects the power from the junction box **304** to the power grid **312** and, in some applications, to appliances **316** within a user's facility. For example, in a home, the electric panel **306** is a well-known AC distribution hub comprising various circuit breakers and/or fuses to distribute electricity to various circuits within the home. The electric panel **306** is coupled through the electric meter **310** to the power grid **312**. The meter **310** determines the amount of power supplied to the grid **312**, such that the owner of the system **100** can be compensated for supplying electricity to the grid **312**.

[0028] FIG. **4** is a detailed block diagram of an exemplary embodiment of an power generator $\mathbf{320}_N$ in accordance with the present invention. This diagram only portrays one variation of the myriad of possible configurations for a power generator.

[0029] The power generator **320** includes a photovoltaic panel **102** and a plurality of inverters **300**. The photovoltaic panel **102** includes solar cells **402**. The solar cells **402** are generally arranged in rows **404** and columns **406**, which may include any number of solar cells **402**. By way of example, the rows **404** include rows $\mathbf{404}_1$, $\mathbf{404}_2$, $\mathbf{404}_3$ and $\mathbf{404}_4$ and the columns **406** include columns $\mathbf{406}_1$, $\mathbf{406}_2$, $\mathbf{406}_3$ and $\mathbf{406}_4$. For simplicity, a four by four cell array is depicted. Those skilled in the art will understand that any number of rows and columns may be used.

[0030] The inverters **300** are adapted to couple the rows **404** and/or the solar columns **406**. Each inverter **300** comprises a plurality of inverters $\mathbf{400}_1$, $\mathbf{400}_2$, $\mathbf{400}_3$ and $\mathbf{400}_4$ (referred to herein as nano-inverters). Although four nano-inverters are shown, the system **100** may include any number of inverters **300** and/or nano-inverters **400**.

[0031] In this embodiment, the nano-inverters $\mathbf{400}_1$, $\mathbf{400}_2$, $\mathbf{400}_3$ and $\mathbf{400}_4$ are coupled to the rows $\mathbf{404}_1$, $\mathbf{404}_2$, $\mathbf{404}_3$ and $\mathbf{404}_4$ of solar cells, respectively. Each of the nano-inverters $\mathbf{400}_1$, $\mathbf{400}_2$, $\mathbf{400}_3$ and $\mathbf{400}_4$ receive DC from a respective row $\mathbf{404}_1$, $\mathbf{404}_2$, $\mathbf{404}_3$ and/or $\mathbf{404}_4$. The cells within a row are connected on series. The nano-inverters $\mathbf{400}_1$, $\mathbf{400}_2$, $\mathbf{400}_3$ and $\mathbf{400}_4$ convert the DC to AC from, for example, each of rows $\mathbf{404}_1$, $\mathbf{404}_2$, $\mathbf{404}_3$ and $\mathbf{404}_4$, respectively. Thus, each of the row $\mathbf{404}_1$, $\mathbf{404}_2$, $\mathbf{404}_3$ and $\mathbf{404}_4$, may be treated as a separate entity, i.e. independently analyzed, controlled and/or configured for optimizing the efficiency and DC production of the row **404**. For example, each inverter is controlled to bias the inverter's associated row of cells at the Maximum Power Point (MPP) for the row. In this manner, as the MPP varies for rows that are shadowed, the optimal bias may be applied to rows in full sun

and rows in shade. Consequently, by operating each row at the row's MPP, the output of the entire panel is optimized. As such, in this embodiment, the panels may be installed much closer to each other, thereby, maximizing total power output for a given area of installation for the system.

[0032] FIG. **5** is a block diagram of an exemplary embodiment of a dual stage inverter **500** that may be used as an inverter **300** within a power generator **320** in accordance with the present invention.

[0033] The dual stage inverter **500** includes a first stage **502** and a second stage **504**. The first stage **502** comprises a plurality of boost circuits **508**, which include $\mathbf{508}_1$, $\mathbf{508}_2$ . . . $\mathbf{508}_n$. The second stage **504** comprises a DC/AC converter **510**. The nature and design of the boost circuits **508** and the DC/AC converter **510** are well known in the art, wherein the boost circuit performs DC to DC conversion and the DC/AC converter performs DC to AC conversion, such as, a pulse width modulator (PWM). A controller **512** provides an individual control signal to each boost circuit **508** to ensure that the rows of cells coupled thereto operates at the row's MPP. The boost circuits **508** are coupled by a DC bus **506**, which may be a high voltage bus. The bus **506** couples the combined DC outputs of the boost circuits, **508** to the DC/AC converter **510**. The controllers **512** controls DC/AC converter switching to convert DC to AC.

[0034] In this embodiment, the boost circuits $\mathbf{508}_1$, $\mathbf{508}_2$ . . . $\mathbf{508}_n$ share a single DC/AC converter **510**. Specifically, the nano-inverter $\mathbf{400}_1$ includes boost circuit $\mathbf{508}_1$ and the DC/AC converter **510**, the nano-inverter $\mathbf{400}_2$ includes boost circuit $\mathbf{508}_2$ and the DC/AC converter **510**, and the nano-inverter $\mathbf{400}_3$ includes boost circuit $\mathbf{508}_3$ and the DC/AC converter **510**, and so on. In other embodiments, a shared DC/AC converter may not be used and each inverter may have a separate boost and DC/AC converter circuit. The boost circuit **508** receives DC from a DC source, such as, rows **404**, columns **406**, solar cell **402**, portions thereof and the like. The boost circuits **508** input DC into the DC/AC converter **510** via the bus **512**. The DC/AC converter converts the DC to AC.

[0035] FIG. **6** is a block diagram of an exemplary embodiment of a single stage inverter **600** that may be used as an inverter **300** within a power generator **320** in accordance with the present invention.

[0036] The single stage inverter **600** includes a plurality of single stage nano-inverters **602** and a bus **604**. The DC may be generated by a DC source, such as rows **404**, columns **406**, solar cell **402**, portions thereof and the like. The DC from each area, e.g., a row of cells, is coupled to an individual single stage nano-inverter **602**. The plurality of single stage nano-inverters **602** comprises single stage nano-inverter $\mathbf{602}_1$, $\mathbf{602}_2$, $\mathbf{602}_3$ and $\mathbf{602}_4$. Each nano-inverter **602** converts DC to AC and couples the AC to an AC bus **604**, where the AC is combined to produce the output of the power generator. The bus **512** is shared by the plurality of single stage nano-inverters **602**. The structure of the nano-inverter is substantially the same as a conventional single stage inverter. A controller **606** provides signals to maintain the areas coupled to the inverter operating at the MPP for the area, e.g., row.

[0037] While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

1. An apparatus for converting direct current (DC) to alternating current (AC), comprising:

a plurality of inverters, each inverter having a separate DC input adapted to be coupled to at least one solar cell defining an area of a solar panel.

2. The apparatus of claim **1**, wherein each inverter of the plurality of inverters comprises a plurality of boost circuits, where each boost circuit is adapted to optimize the maximum power point of an area of the solar panel.

3. The apparatus of claim **2**, wherein a DC bus couples to an output DC of the plurality of boost circuits.

4. The apparatus of claim **3**, wherein each inverter of the plurality of inverters comprises a DC/AC converter coupled to the plurality of boost circuits, wherein the DC/AC converter is shared by the plurality of boost circuits.

5. The apparatus of claim **1**, wherein each inverter of the plurality of inverters comprises at least two boost circuits coupled to a DC/AC converter.

6. The apparatus of claim **1**, wherein the area is a row of serially coupled solar cells.

7. An apparatus for generating solar power comprising:

at least one photovoltaic panel, wherein the photovoltaic panel comprises a plurality of areas comprising at least one solar cell; and

an inverter coupled to each area in the plurality of areas of the photovoltaic panel.

8. The apparatus of claim **7**, wherein the plurality of areas comprising a row of at least one solar cell.

9. The apparatus of claim **7**, wherein the inverter comprises a plurality of boost circuits, where each boost circuit is adapted to optimize the maximum power point of an area of the solar panel.

10. The apparatus of claim **9**, wherein a DC bus couples to an output DC of the plurality of boost circuits.

11. The apparatus of claim **9**, wherein the inverter comprises a DC/AC converter coupled to the plurality of boost circuits, wherein the DC/AC converter is shared by the plurality of boost circuits.

12. The apparatus of claim **9**, wherein the inverter comprises at least two boost circuits coupled to a DC/AC converter.

13. The apparatus of claim **7**, wherein the area is a row of serially coupled solar cells.

14. The apparatus of claim **7** wherein the at least one photovoltaic panel comprises a plurality of photovoltaic panels, where each panel is positioned such that a first panel shades a second panel and each inverter that is coupled to an area that is shaded is adapted to optimally couple power from the shaded area of at least one solar cell.

15. A method for converting DC to AC, comprising:

receiving DC from at least one solar cell defining each of a plurality of areas of a photovoltaic panel; and

converting the DC from each of the plurality of areas to a single AC output.

15. The method of claim **14**, wherein the converting step comprises:

converting DC from each of the plurality of areas to support DC outputs;

combining the separate DC outputs to form a single DC output; and

converting the single DC output into the single AC output.

16. The method of claim **14**, wherein the converting step comprises:

converting DC from each of the plurality of areas to separate AC outputs; and

combining the separate AC outputs to form a single AC output.

* * * * *