(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 January 2017 (12.01.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/006337 A2

(51) International Patent Classification: Not classified

(21) International Application Number:
PCT/IN2015/050153

(22) International Filing Date:
5 November 2015 (05.11.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
3404/CHE/2015 3 July 2015 (03.07.2015) IN

(71) Applicant: **TATA POWER SOLAR SYSTEMS LTD.** [IN/IN]; 78, Electronics City, Phase I, Hosur Road, Bangalore, Bangalore 560100 (IN).

(72) Inventors: **MOHAN, Suraj**; 78, Electronics City, Phase I, Hosur Road, Bangalore 560100 (IN). **KUMAR R, Senthil**; 78, Electronics City, Phase I, Hosur Road, Bangalore 560100 (IN). **K, Rajeshwari**; 78, Electronics City, Phase I, Hosur Road, Bangalore 560100 (IN). **DEVANADHAN, Seshadri**; 78, Electronics City, Phase I, Hosur Road, Bangalore 560100 (IN).

(74) Agent: **KEWALRAMANI, Nishant**; G2 (Ground floor), #7 Shah Complex, 9th Main Road, 5th Block Jayanagar, Bangalore 560041 (IN).

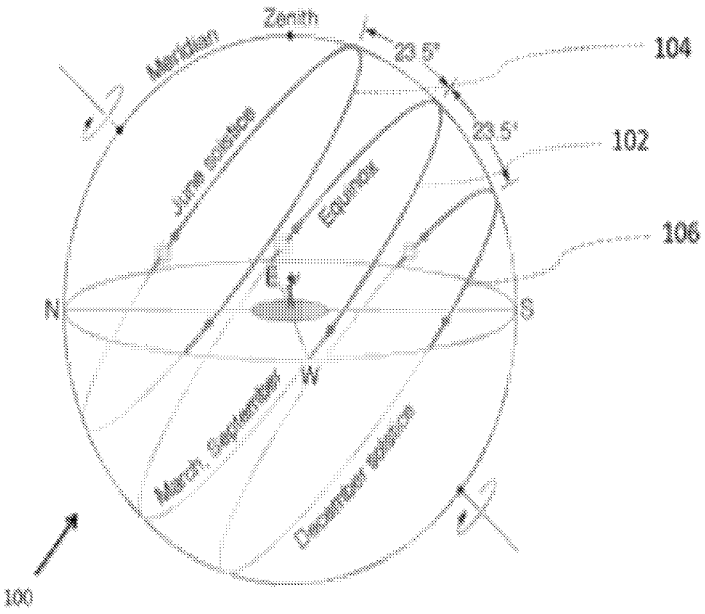
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: METHOD TO MAXIMIZE THE ENERGY YIELD OF PHOTOVOLTAIC MODULES AND SYSTEM THEREOF

[Fig. 1]



(57) Abstract: A method and a system for maximizing the energy yield of a photovoltaic module of a PV module unit are provided. The method includes the step of determining the tilt angle corresponding to optimized conversion of solar energy to electric energy. The PV module unit is then configured to the negative tilt angle. Also provided is a PV module unit configured to achieve such negative tilt angle.

WO 2017/006337 A2

Declarations under Rule 4.17:

— *as to the identity of the inventor (Rule 4.17(i))*

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

— *of inventorship (Rule 4.17(iv))*

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

Description

Title of Invention : Method to maximize the energy yield of photovoltaic modules and system thereof

Technical Field

[1] The invention generally relates to photovoltaic module containing power systems and more specifically to maximize the energy yield of a photovoltaic module by configuring a PV module unit to a negative tilt angle.

Background Art

[2] Fossil fuels have been and are the major source for the generation of electricity across the world and rising prices and environmental factors are paving the way for higher utilization of renewable sources of energy, including utilizing energy from the sun.

[3] Recent years have witnessed a huge growth in the utilization of solar modules in both commercial and personal setups. Over the years, reduction in the cost of manufacture of such solar modules and the increase in their efficiency in converting solar energy to electrical energy has lead the way in widespread use of the technology.

[4] However, maintaining high efficiency of a solar module is a challenging task as the power incident on a PV module depends not only on the power contained in the sunlight, but also on the angle between the module and the sun. When the absorbing surface and the sunlight are perpendicular to each other, the power density on the surface is equal to that of the sunlight.

[5] Orientation and the tilt of the solar module with respect to the position of the sun plays an important factor in determining the output of the solar module. The position of sun across the globe is shown in the Fig. 1 (prior art). At the equinox 102 (i,e., late march and late September) , the sun's path fallows the celestial equator. After the equinox 102, the sun's path gradually drifts towards north, by the June solstice 104 the sun rises considerably north of due east and sets considerably north of due west.

[6] After the June solstice 104, the sun's path gradually drifts southward. By the September equinox 102, its path is again along the celestial equator. The southward drift then continues until the December solstice 106 where the sun rises considerably south of due east and sets considerably south of due west. This illustration shows the sun's daily paths around the celestial sphere. (source: http://physics.weber.edu/schroeder/ua/SunAndSeasons.html)

[7] Fig.1 clearly shows that the angle between the sun and a fixed surface is continually changing, and hence the power density on a fixed PV module is less than that of the incident sunlight.

[8] To avoid this problem, different solar tracking mechanisms are used in PV systems that regularly change the orientation of the PV module based on the changing position of the sun. These tracking mechanisms can broadly be classified into manual and automated tracking systems. Manual tracking involves manually adjusting the solar module's orientation to get the maximum power based on the position of the sun. On the other hand we have automated tracking systems. As the sun moves across the sky during the day, it is advantageous to have the solar panels track the location of the sun, such that the panels are always perpendicular with the position of the sun. Panels in perpendicular (90 degree) with sun draw maximum solar radiation and provide high insolation

efficiency. These automatic tracking systems generally rely on some form of automatic tracking of the sun to change the orientation of the PV module.

[9] Automatic trackers though may provide higher efficiency due to their regular movements continuously across the day, they suffer from a few disadvantages like frequent need for lubrication and maintenance, high amount of auxiliary power required to facilitate their movements, higher deployment cost and larger land requirement for installation. Though manual tracking systems do not suffer from some of these problems, the efficiency of the manually tracked solar modules is generally lower than the automatic trackers as the solar modules have to be manually oriented and titled.

[10] Hence, there is a need to increase the energy yield of manual trackers without the higher operational costs associated with automatic trackers.

Summary of Invention

[11] The object of the invention is to maximize the energy yield of a manually adjustable photovoltaic module by configuring a Photovoltaic (PV) module unit to a negative tilt angle.

[12] Accordingly the invention provides a method of maximizing the energy yield of photovoltaic module by determining the negative tilt angle of the said PV module which corresponds to providing optimized conversion of solar energy to electrical energy. Once the negative tilt angle is determined, PV module unit is configured to said negative tilt angle.

[13] These and other aspects of the embodiments herein will be better appreciated and understood when considered in conjunction with the following description and the accompanying drawings.

Brief Description of Drawings

[14] This invention is illustrated in the accompanying drawings, throughout which, like reference letters indicate corresponding parts in the various figures.

[15] The embodiments herein will be better understood from the following description with reference to the drawings, in which:

[16] **Fig.1** (prior art) provides the position of the sun across globe.

[17] **Fig. 2** provides a flowchart illustrating the method to maximize the energy yield of a photovoltaic module.

[18] **Fig. 3** illustrates a PV module unit including a photovoltaic module, a manual tracking system and a mount system depicting various tilt angles.

[19] **Fig. 4** illustrates a PV module unit including a photovoltaic module, a manual tracking system and a mount system with positive tilt.

[20] **Fig. 5** illustrates a PV module unit including a photovoltaic module, a manual tracking system and a mount system with negative tilt.

[21] **Fig. 6** illustrates energy generation graph corresponding to negative and positive tilted PV modules.

[22] **Fig. 7a** illustrates sun's position in the northern hemisphere.

[23] **Fig. 7b** illustrates the sun window corresponding to the sun's position in the northern hemisphere

Description of Embodiments

[24] The embodiments herein and the various features and advantageous details thereof are explained more fully with reference to the non-limiting embodiments that are illustrated in the accompanying drawings and / or detailed in the following description. Descriptions of well-known components and processing techniques are omitted so as to not unnecessarily obscure the embodiments herein. The examples used herein are intended merely to facilitate an understanding of ways in which the embodiments herein may be practiced and to further enable those of skill in the art to practice the embodiments herein. Accordingly, the examples should not be construed as limiting the scope of the embodiments herein.

[25] The embodiments herein below provide a method and a system for maximizing the energy yield of a module of a Photovoltaic (PV) module unit. It

involves achievinga negativetilt angle providing optimized conversion of solar energy to electric energy, and configuring the PV module unit to the said negative tilt angle. Negative tilt of a PV module is nothing but tilting of the module in the direction opposite to traditional tilting (traditional tilting involves tilting PV modules towards the southern direction in the northern hemisphere and towards the northern direction in the southern hemisphere). This explains negative tilt as, tilting of panel towards north in northern hemisphere and towards south in southern hemisphere.

[26] Referring now to the drawings, where similar reference characters denote corresponding features consistently throughout the figures, there are shown preferred embodiments.

[27] The main objective of the invention is to utilize seasonal tilt for solar panels for maximum efficiency and to arrive at a suitable angle of inclination to capture maximum incident solar radiation. It is known in the prior art that the amount of solar radiation incident on a tilted PV module surface is the component of the incident solar radiation, which is perpendicular to the module surface.

[28] To calculate the radiation incident on a tilted surface (S_{module}), either the value of solar radiation measured on horizontal surface (S_{horiz}) or the value of solar radiation measured perpendicular to the sun ($S_{incident}$) should be known. The equation relating S_{module}, S_{horiz} and $S_{incident}$ is given by

[Math. 1]

$$S_{horizontal} = S_{incident} \sin \alpha$$

$$S_{module} = S_{incident} \sin(\alpha + \beta)$$

In the above equation α is the elevation angle and β is the tilt angle of the module measured from the horizontal. From these equations a relationship between S_{module} and $S_{horizontal}$ can be determined as:

[Math . 2]

$$S_{module} = \frac{S_{horizontal} \sin(\alpha + \beta)}{\sin \alpha}$$

Using the above formula the value of solar radiation incident on the tilted surface can be measure theoretically.

[29] Further, Fig. 2 provides a method to maximize the energy yield of a photovoltaic module 200 including the steps of measuring the tilt angle providing optimized conversion of solar energy to electric energy 202, inversing the positive tilt angle to retrieve negative tilt angle 204 and configuring a PV module unit to the negative tilt angle 206.

[30] In an alternative embodiment, GPS tracking system can be used to find the latitude of any particular place and further to pre-decide the possibility of negative tilt in that particular place. GPS tracking unit can be mounted on to said PV module unit (not shown in the Figure) and user can pre-decide the possibility of negative tilt of said PV module in that area.

[31] In an embodiment, measurement of tilt angles providing optimized conversion of solar energy to electric energy 202 can be achieved by taking systematic measurements at different tilt angles (with the help of pre disposed angle settings on the mount structure) and selecting the tilt angle corresponding to the highest

current flow through the photovoltaic module. In another embodiment, random tilt angles are tested and the measurement of the angle providing the highest current flow is selected. Various techniques know in the art can be used to measure the tilt angles which provide optimized conversion of solar energy to electric energy, and are incorporated herein by reference.

[32] In a preferred embodiment, the measured tilt angle providing optimized conversion to electric energy 202 is positive. Once, the positive tilt angle corresponding to the optimized conversion of solar energy to electric energy is measured 202, the measured positive tilt angle is inversed to retrieve the corresponding negative tilt angle. In a non limiting example, if the tilt angle corresponding to the highest current flow is measured to be 10 degrees, the corresponding negative tilt angle will be -10 degrees.

[33] Once, the negative tilt angle providing optimized conversion of solar energy to electric energy has been measured, the next step includes configuring the PV module unit to the retrieved negative tilt angle.

PV module unit and configuration of tilt angles

[34] Fig. 3, 4 and 5 depict a non limiting embodiment of a PV module unitshowing different tilt positions andinclude a photovoltaic module 302, a module frame 304, openings in the frame 303, a mount system 306, a manual tracking system 308 and a hinge joint 310.

[35] Fig. 3 depicts a PV module unit 300 having a photovoltaic module 302 set at a 40 degree angle along with sample representations for 0 to 30 degree tilts of the photovoltaic module 302. The photovoltaic module 302 is connected to a module

frame 304, which is in turn connected to a mount system 306. The mount system 306 acts as a base and provides support to the entire PV module unit 300, and connects to the module frame 304 through a hinge joint 310. To set the photovoltaic module 302 to a particular tilt angle, the manual tracking system 308 is adjusted. In order to provide for both positive and negative tilt angles, openings in the frame 303 are provided on both ends of the frame as shown in Fig. 3. In an embodiment, the adjustment required to achieve a desired tilt angle can be done by using a linear actuator as a manual tracking system 308; or by having a plurality of openings on the frame 303 and the manual tracking system 308, wherein such openings 303 are designed to achieve predetermined tilt angles. Other techniques for changing the tilt angle used in the art are also incorporated herein by reference.

[36] Fig. 4 depicts a PV module system 400 as an illustrative embodiment, which is located in the northern hemisphere and hasthe photovoltaic module 302 tilted towards the south. Since, the photovoltaic module 302 is illustratively located in the northern hemisphere,it should traditionally face true south to provide for a positive tilt angle. Similarly, fig. 5 depicts a PV module system 500 as an illustrative embodiment located in the northern hemisphere and having the photovoltaic module 302 tilted towards the north. Since, the photovoltaic module 302 is facing towards the north, the embodiment herein provides for a negative tilt angle.

[37] In an embodiment, the change in the tilt angle from positive to negative angle is obtained by changing the point of connection of the manual tracking system 308 with the openings in the frame 303 on the opposite sides. In another embodiment, the manual tracking system 308 may includeopenings and provide for both positive and negative tilt angles by connecting to opposite ends of the module frame 304. Other techniques well known in the art for connecting the manual tracking system 308 to the opposite ends of the module frame 304 are within the scope of this application and incorporated herein by reference.

ExperimentalResults:

[38] In order to support the invention, an experiment was conducted in Tamil Nadu, India to prove the efficiency of PV module with negative tilt. The experimental setup consists of two PV module apparatus, one with positive tilt and other with negative tilt. These two modules are placed at two different sites. Further, the string data was tabulated for both the sites throughout the year. Supporting the negative tilt, there was 6.9 – 7.2% of string current improvement was seen.

[39] Based on the positive results seen, there was another experiment conducted over a period of two months in Satara, India. Two different locations are selected, site 1 and site 2 where site 1 is having PV module with negative tilt and site 2 is having PV module with positive tilt. Below is the tabulated reading of energy generated between site 1 and site 2.

Date	Site 1 (kWh)	Site 2 (kWh)	Difference
6/24/2015	4802	4922	-2%
6/25/2015	5243	5422	-3%
6/26/2015	4521	4662	-3%
6/27/2015	5163	5322	-3%
6/28/2015	5302	5463	-3%
6/29/2015	4382	4602	-5%
6/30/2015	5262	5462	-4%
7/1/2015	5102	5303	-4%
7/2/2015	5423	5642	-4%
7/3/2015	6382	6623	-4%
7/4/2015	5983	6223	-4%
7/5/2015	6063	6262	-3%
7/6/2015	5722	5943	-4%
7/7/2015	5122	5282	-3%
7/8/2015	4783	4682	2%
7/9/2015	4501	4362	3%
7/10/2015	4462	4262	4%
7/11/2015	5323	5102	4%
7/12/2015	5542	5142	7%
7/13/2015	5482	5043	8%
7/14/2015	4863	4501	7%
7/15/2015	5642	5263	7%
7/16/2015	4802	4482	7%
7/17/2015	5062	4562	10%
7/18/2015	4742	4261	10%
7/19/2015	3862	3482	10%
7/20/2015	4762	4242	11%
7/21/2015	3361	3001	11%
7/22/2015	3922	3522	10%
7/23/2015	4042	3722	8%

[40] Though both the sites had modules with same capacity, generation of power was high at the module with negative tilt and the energy gain of almost 6% has been recorded. Thus the experiment can be concluded by saying 6% gain in energy generation for the period considered with a corresponding 3% increase in the incoming inclined insolation.

[41] In Fig.6, the graph 600 depicts the above illustrated energy generation in site 1 and site 2. In the graph energy generation is plotted against date of the year. First curve 602 represents the energy generation at site 1 having negative tilt and second curve 604 represents the energy generation at site 2 having positive tilt. The graph 600 clearly shows that from the date 24/06/15 to 07/07/15, the energy generation is higher at site 2 which is represented by second curve 604 (generation gap is about -4%) and from the date 08/07/15 to 23/07/15, the energy generation is higher at site1 which is represented by first curve 602 (generation gap is about 7%).

[42] It is also pertinent to note that the present invention may be applicable to various types of PV installations for various purposes including but not limited to Solar PV pumping, off grid solar PV tracking system, etc.

Advantages of negative tilt

[43] Due to earth's tilt around it own axis by 23.45 degrees and the revolution of the earth around the sun, the declination angle ranges from +23.45 degrees to -23.45 degrees. The declination angle is zero at the equinoxes 102 (March 22 and September 22) and positive during the summers of the respective hemispheres. ie. Between March 22 to September 22 in the northern hemisphere and September 22 to March 22 in the southern hemisphere.

[44] In an illustrative embodiment 700a, sun's position in the northern hemisphere is considered. Tilting of PV module 302 towards north in northern hemisphere for a specific period in a calendar year will help capturing higher insolation. Similarly, in southern hemisphere to get a maximum insolation, PV module should be tilted towards south.

[45] Further, Fig. 7b, is a graph that depicts direct sun radiation plotted against time of the day in northern hemisphere. The first curve 710 represents the sun window throughout the day when the PV module is having negative tilt and the second curve 712 represents sun window when the PV module is having positive tilt (i,e., tilted towards south). It is clearly seen that module tilted towards north in the northern hemisphere fetches more sun window.

[46] Further, in an embodiment, during the months with positive declination angle in the northern hemisphere, a negative tilt provides for a better wind flow, which helps to reduce the temperature of the module and reduce the accumulation of dust on the photovoltaic module and thereby reduce losses. Since, the photovoltaic module with a negative tilt is exposed to a larger sun window it results in higher electricity generation.

[47] In an embodiment, the measured tilt angle providing optimized conversion of solar energy to electric energy 202 may be predetermined to be negative during

certain months. In such an instance, the step of inversing the positive tilt angle to retrieve negative tilt angle 204 will be skipped. In a non limiting example, if the tilt angle corresponding to the highest current flow is measured to be -10 degrees, the inversing step is skipped and the PV module unit is configured to a tilt angle of -10 degrees.

[48] In an embodiment, the measured tilt angle providing optimized conversion of solar energy to electric energy 202 may be measured to be positive during certain months. In such an instance, the step of inversing the positive tilt angle to retrieve negative tilt angle 204 will be skipped. In a non limiting example, if the tilt angle corresponding to the highest current flow is measured to be +10 degrees, the inversing step is skipped and the PV module unit is configured to a tilt angle of +10 degrees.

[49] The foregoing description of the specific embodiments will so fully reveal the general nature of the embodiments herein that others can, by applying current knowledge, readily modify and/or adapt for various applications such specific embodiments without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be comprehended within the meaning and range of equivalents of the disclosed embodiments. It is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation. Therefore, while the embodiments herein have been described in terms of preferred embodiments, those skilled in the art will recognize that the embodiments herein can be practiced with modification within the spirit and scope of the embodiments as described herein.

Claims

[Claim 1] A method to maximize the energy yield of a photovoltaic module, the method comprising

determining a negative tilt angle of the photovoltaic module with suitable azimuth that corresponds to providing optimized conversion of solar energy to electric energy; and

configuring a PV module unit to the negative tilt angle.

[Claim 2] The method of claim 1 wherein determining the negative tilt angle further comprising,

measuring a positive tilt angle of the photovoltaic module that corresponds to providing optimized conversion of solar energy to electric energy; and

inversing the positive tilt angle to determine the negative tilt angle.

[Claim 3] The method of claim 1 wherein the PV module is configured to the negative tilt angle such that the PV module faces true north direction in the Northern Hemisphere.

[Claim 4] The method of claim 1 wherein the PV module is configured to the negative tilt angle such that the PV module faces true south direction in the Southern Hemisphere.

[Claim 5] The method of claim 3 wherein the PV module is configured to the negative tilt angle such that the PV module faces true north direction in the Northern Hemisphere for a specific period in a calendar year.

[Claim 6] The method of claim 4 wherein the PV module is configured to the negative tilt angle such that the PV module faces true south direction in the Southern Hemisphere for a specific period in a calendar year.

[Claim 7] A Photovoltaic module unit comprising:

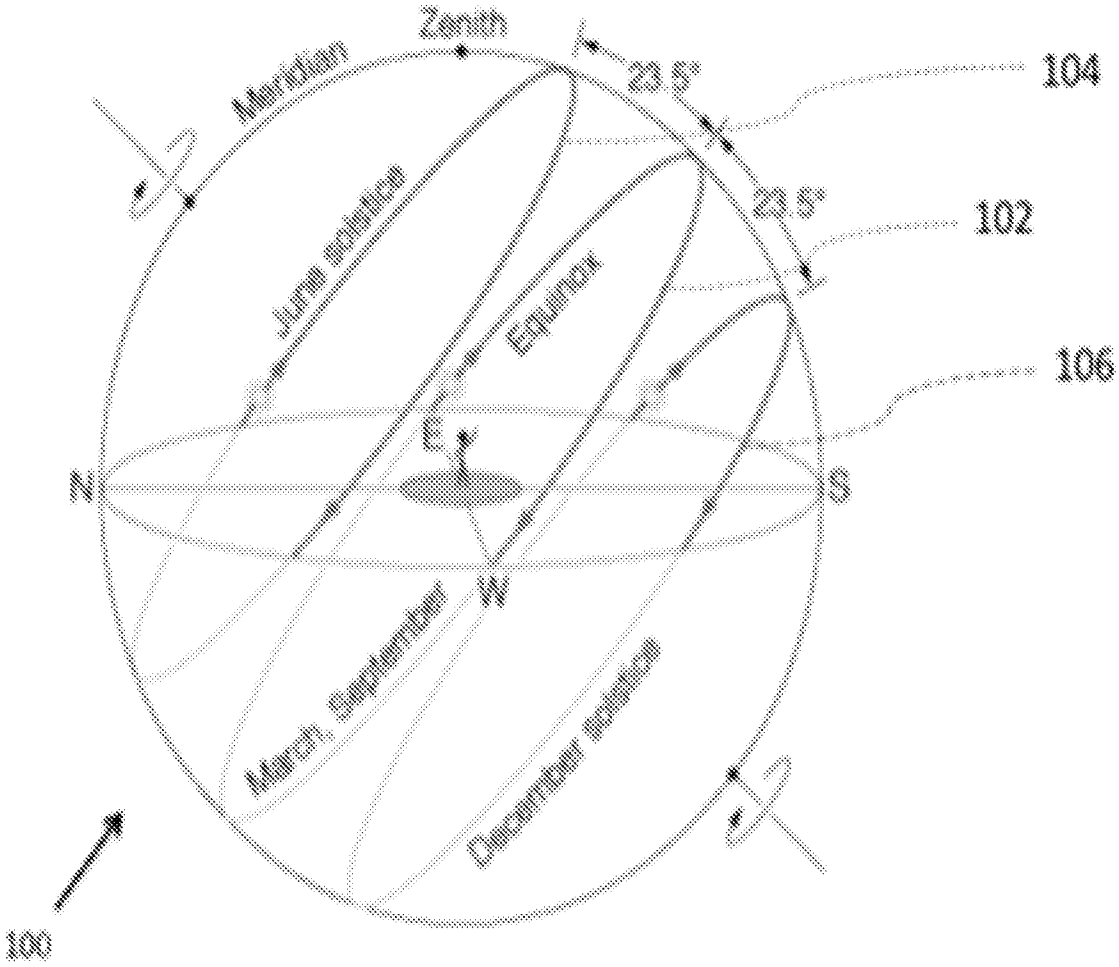
a photovoltaic module;

a mount system, wherein the photovoltaic module is movably disposed on the mount system;

a manual tracking system, wherein the manual tracking system is in connection with the mount system and the photovoltaic module and the manual tracking system is configured to provide for zero, positive and negative tilt angles of the photovoltaic module.

[Claim 8] The module unit of claim 7 further comprising a GPS tracking unit disposed on the module unit, wherein the GPS tracking unit is configured to identify the latitude of a geographic location where the PV module is to be affixed.

[Fig. 1]


Zenith
Meridian
23.5°
104
23.5°
102
June solstice
Equator
106
E
N
S
W
March, September
December solstice
100

[Fig. 2]

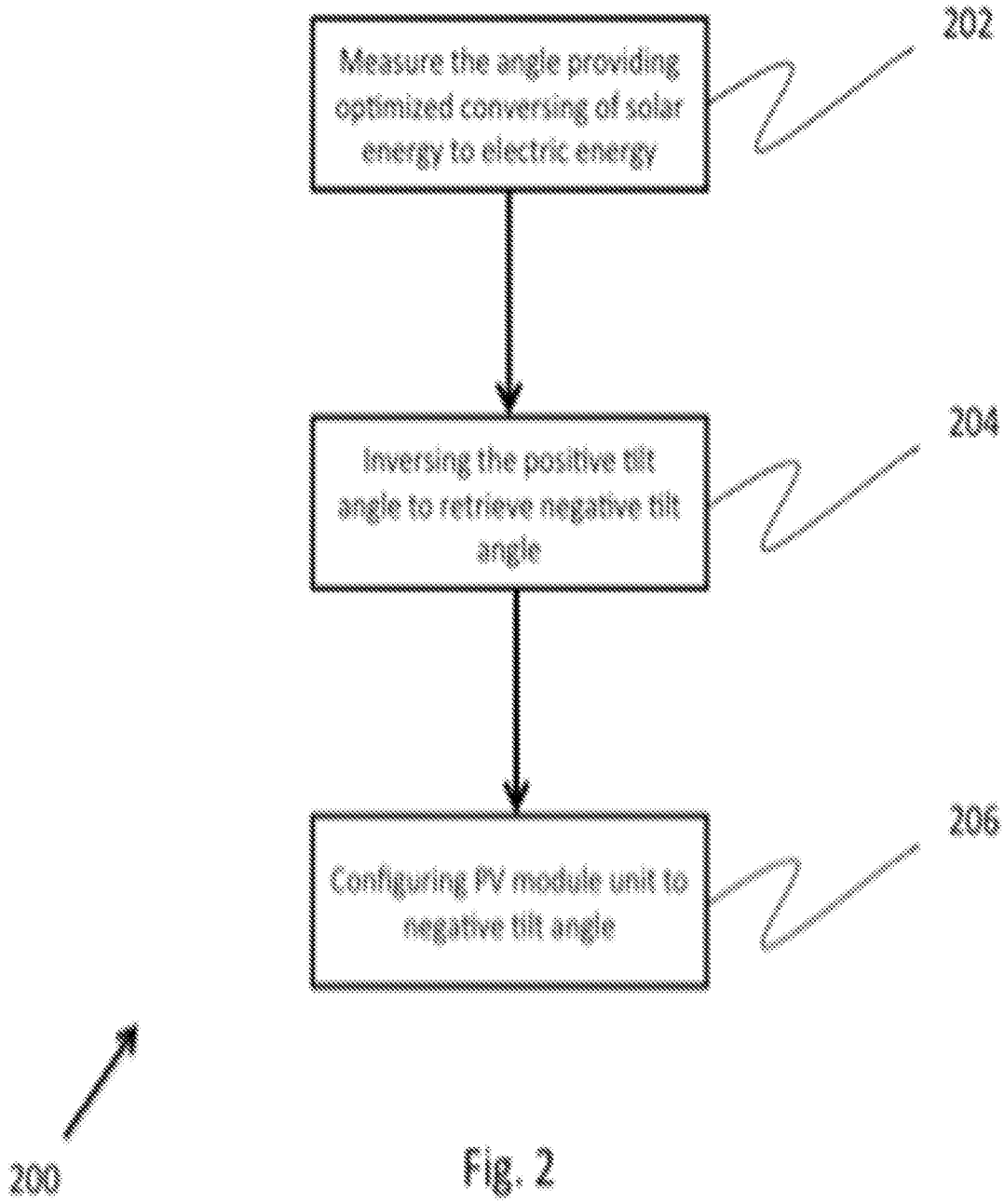

Measure the angle providing optimized conversing of solar energy to electric energy
202
Inversing the positive tilt angle to retrieve negative tilt angle
204
Configuring PV module unit to negative tilt angle
206
200

Fig. 2

[Fig. 3]

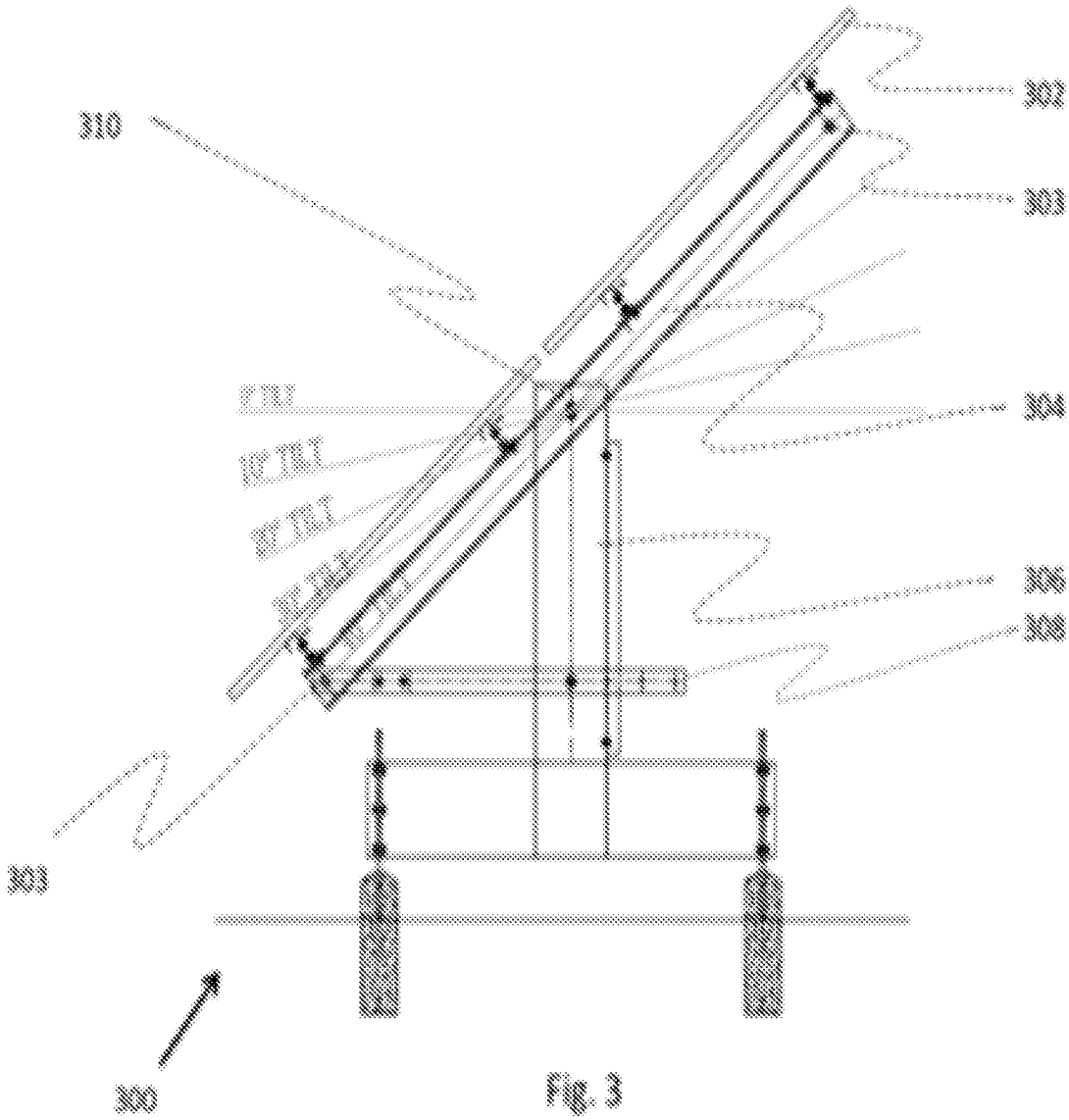


Fig. 3

[Fig. 4]

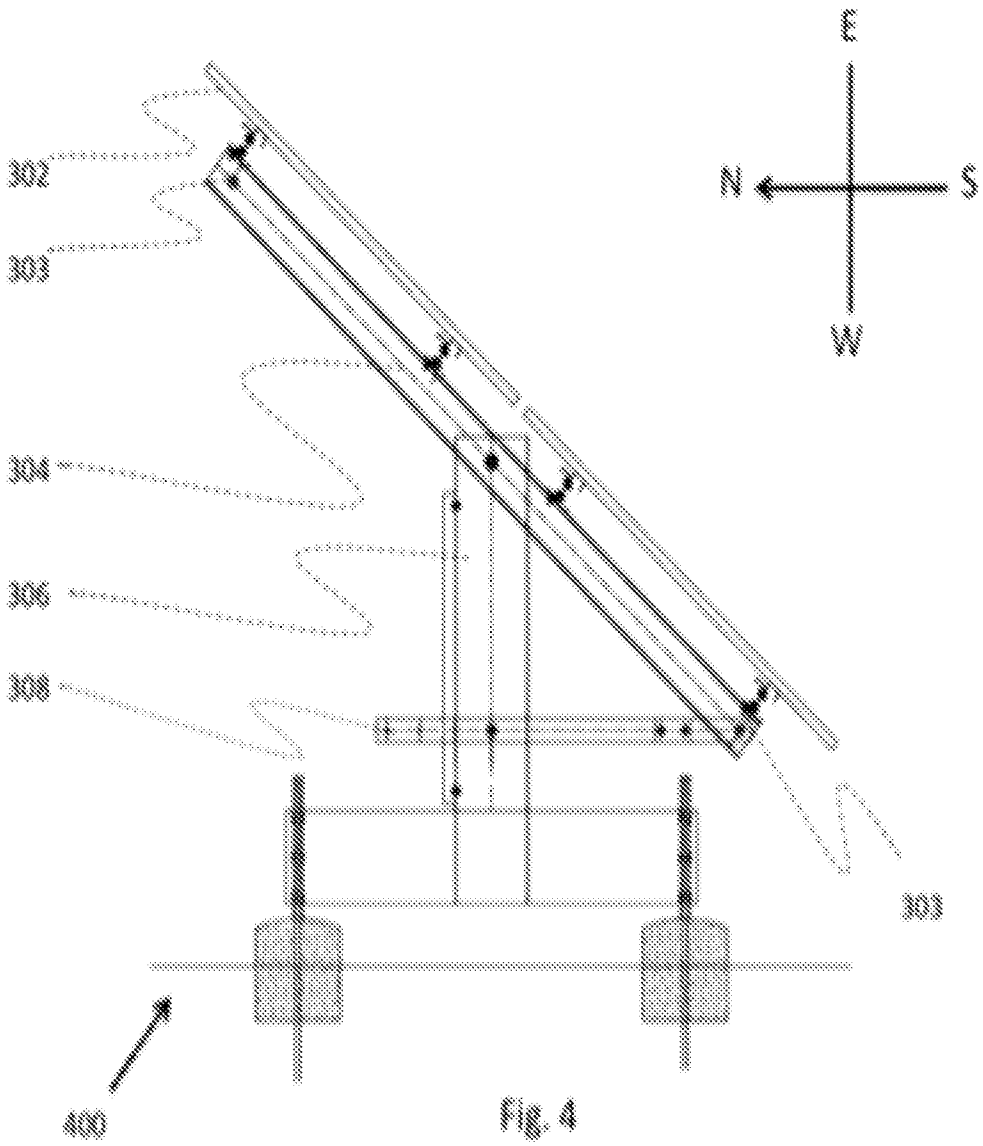


Fig. 4

[Fig. 5]

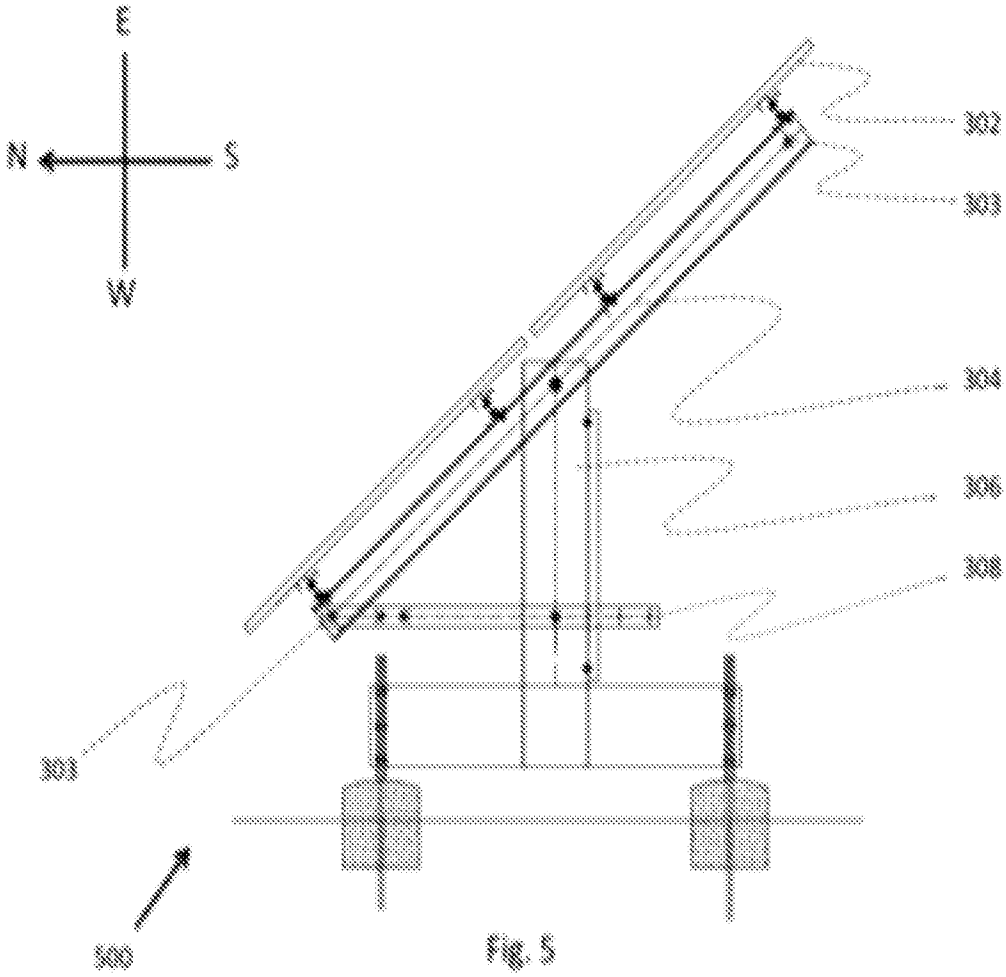


Fig. 5

[Fig. 6]

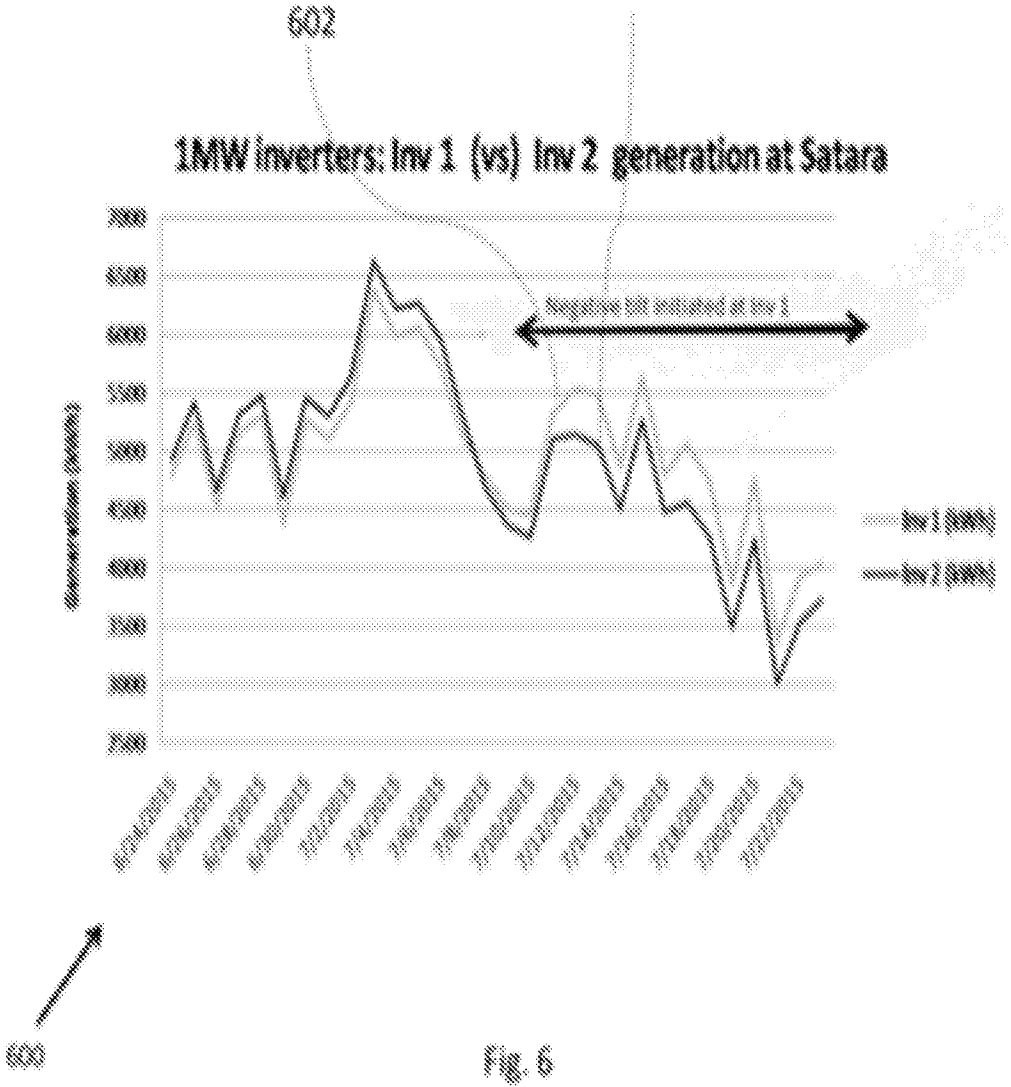


Fig. 6

[Fig. 7a]

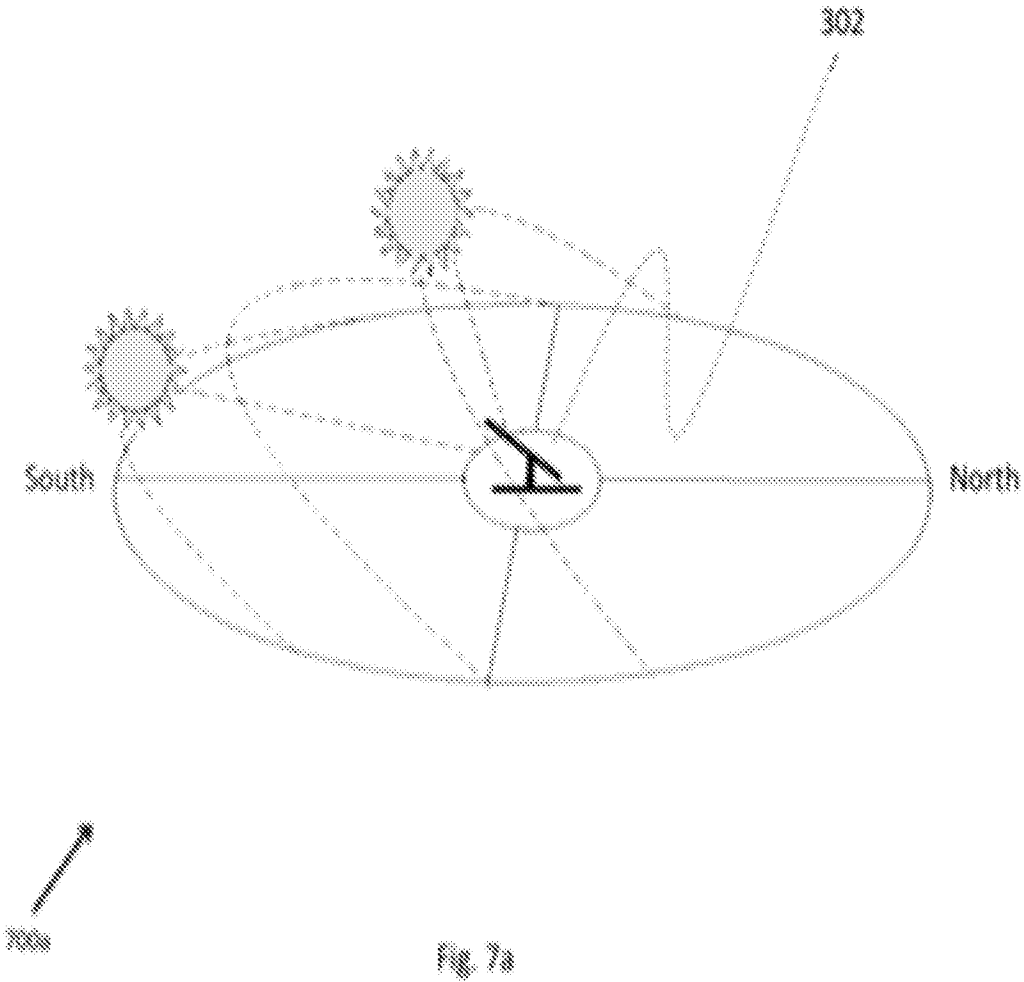


Fig. 7a

[Fig. 7b]

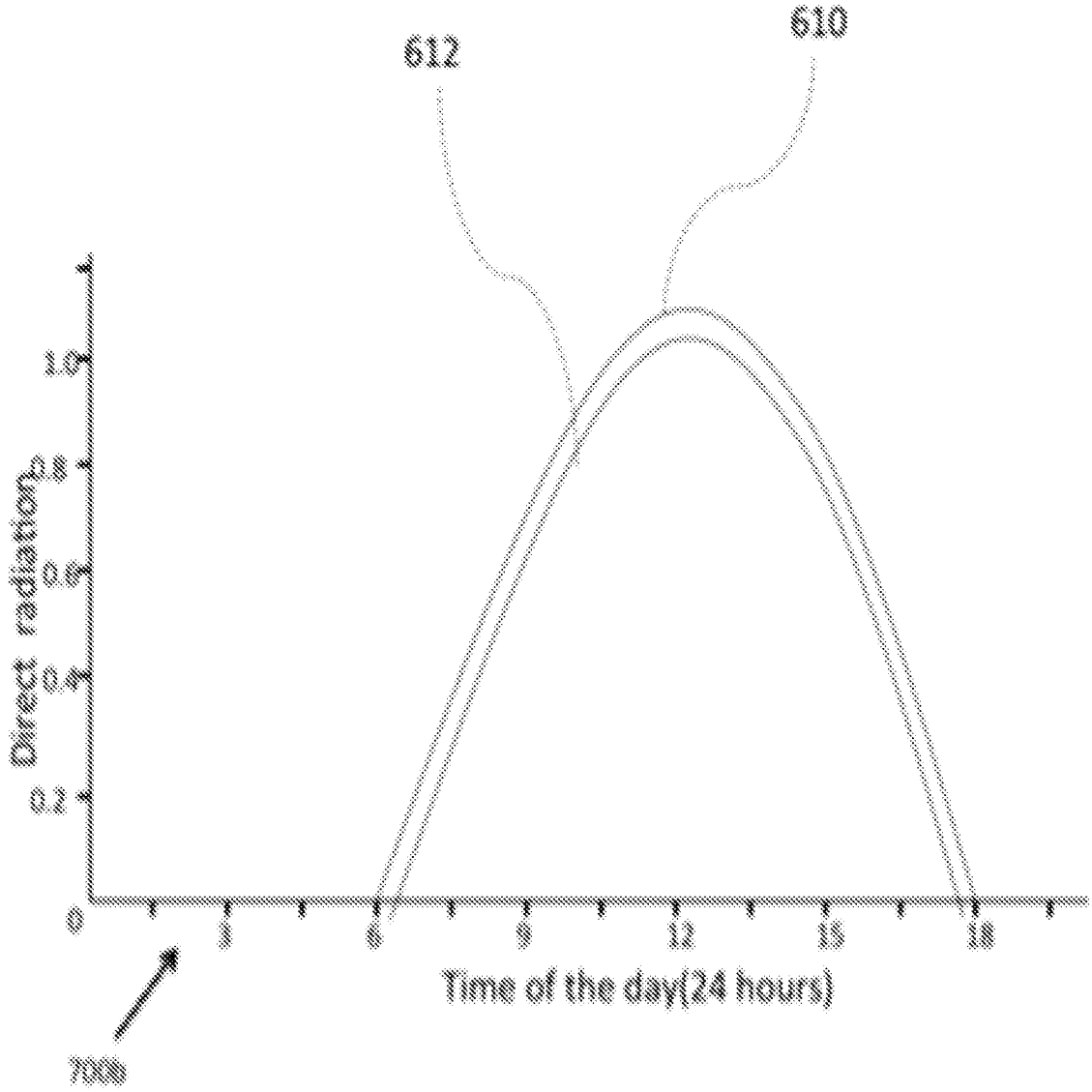

612
610
Direct radiation
1.0
0.8
0.6
0.4
0.2
0
3
6
9
12
15
18
Time of the day(24 hours)
700b

Fig. 7b