A PHOTOVOLTAIC MODULE

FIELD OF INVENTION

[0001] The present invention relates broadly, but not exclusively, to a photovoltaic module, to a photovoltaic energy production system and to a method of manufacturing a photovoltaic module.

BACKGROUND

[0002] Photovoltaic (PV) electricity production is a major goal for the world as it is one of the most direct ways to access renewable energy. Recent developments in photovoltaic conversion techniques have made the production of electricity economically viable on a commercial scale.

[0003] Typically, the production of electricity from the photovoltaic effect can be through direct irradiance and/or using diffused sunlight. In a simplified way, photovoltaic panels are of two types, i.e. polycrystalline (or monocrystalline) modules which produce electricity in large part through direct irradiance and the so-called thin-film panels that produce electricity both by direct irradiance and diffused sunlight. For $1m^2$ of ground surface, the maximum surface covered by a flat PV panel is $1m^2$ when the panel is set parallel to the ground. Usually, the effective active area per unit area of ground is less as the PV panel is commonly installed at an angle to the ground, depending on the latitude of the location, to directly face the sun. In some existing systems, actuators are used to change the angle in order to track the sun's movement.

[0004] As a result, one concern that remains with PV electricity production is that a PV farm typically needs a large area to operate, and as we face a scarcity of land and all subsequent conflicts of use, this becomes a major issue for developing photovoltaic electricity production. There have been efforts to install PV panels on rooftops of buildings or on the buildings' façade to maximise use of space; however, the active area achieved by these conventional methods is still low.

[0005] A need therefore exists to provide a photovoltaic module that addresses at least one of the above problems.

SUMMARY

[0006] According to a first aspect of the present invention, there is provided a photovoltaic module comprising:

a support structure having a mounting surface, the mounting surface being at least partially cylindrical; and

a convex thin-film photovoltaic panel attached to the mounting surface, the photovoltaic panel occupying a selected portion of the mounting surface.

[0007] The selected portion may comprise an area of the mounting surface having an arc subtending an angle of at least 100°.

[0008] The angle may be approximately 180°.

[0009] The support structure may comprise a cylindrical tube having an axle and a plurality of spokes connecting the axle and the mounting surface.

[0010] The plurality of spokes may be disposed at predetermined intervals along the axle.

[0011] The axle may comprise a through hole extending along a longitudinal direction.

[0012] According to a second aspect of the present invention, there is provided a photovoltaic energy production system comprising a plurality of photovoltaic modules as defined in the first aspect.

[0013] The plurality of photovoltaic modules may be disposed in an end-to-end arrangement.

[0014] The plurality of photovoltaic modules may be suspended by a raised cable.

[0015] The system may comprise a plurality of cables arranged in parallel to each other.

[0016] According to a third aspect of the present invention, there is provided a method of manufacturing a photovoltaic module, the method comprising the steps of:

providing a support structure having a mounting surface, the mounting surface being at least partially cylindrical; and

attaching a convex thin-film photovoltaic panel to the mounting surface such that the photovoltaic panel occupies a selected portion of the mounting surface.

[0017] The step of attaching the convex thin-film photovoltaic panel to the mounting surface may comprise bending a flexible thin-film photovoltaic panel and affixing the bent photovoltaic panel onto the mounting surface.

[0018] The step of attaching the convex thin-film photovoltaic panel to the mounting surface may comprise forming a substantially rigid thin-film photovoltaic panel dimensioned to a curvature of the mounting surface and affixing said photovoltaic panel onto the mounting surface.

[0019] The step of attaching the convex thin-film photovoltaic panel to the mounting surface may comprise printing a photovoltaic panel onto the mounting surface.

[0020] The step of providing the support structure having the at least partially cylindrical mounting surface may comprise forming a cylindrical tube having an axle and a plurality of spokes connecting the axle and the mounting surface.

[0021] According to a fourth aspect of the present invention, there is provided a photovoltaic module comprising a generally convex photovoltaic panel.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

[0023] Figure 1a shows a perspective view of a photovoltaic module according to an example embodiment.

[0024] Figure 1b shows a front view of the photovoltaic module of Figure 1a.

[0025] Figure 1c shows a side view of the photovoltaic module of Figure 1a.

[0026] Figure 1d shows a top view of the photovoltaic module of Figure 1a.

[0027] Figure 1e shows a bottom view of the photovoltaic module of Figure 1a.

[0028] Figure 2a shows a perspective view of a photovoltaic energy production system according to an example embodiment.

[0029] Figure 2b shows a side view of the photovoltaic energy production system of Figure 2a.

[0030] Figure 2c shows a top view of the photovoltaic energy production system of Figure 2a.

[0031] Figure 3 shows a flow chart illustrating a method for manufacturing a photovoltaic module according to an example embodiment.

DETAILED DESCRIPTION

[0032] The example embodiments provide devices, systems and methods for increasing the active area of a photovoltaic (PV) energy production unit, hereinafter interchangeably referred to as a PV module, per unit area of ground. In particular, thanks to PV electricity production with diffused sunlight of PV panels like thin film panels, it will be efficient to curve the panel to offer a bigger active surface to the sun compared to flat panels. For example, for a half cylindrical shaped panel, the active surface may be multiplied by 1.57 (3.14/2) compared to a flat panel. In some embodiments, the ground is freed up for other uses. In some embodiments, PV energy production is made possible at locations where it is impossible or expensive to install conventional PV panels.

[0033] Figure 1a shows a perspective view of a photovoltaic (PV) module 100 according to an example embodiment. Figure 1b shows a front view of the photovoltaic module of Figure 1a. Figure 1c shows a side view of the photovoltaic module of Figure 1a. Figure 1d shows a top view of the photovoltaic module of Figure 1a. Figure 1e shows a bottom view of the photovoltaic module of Figure 1a.

[0034] The PV module 100 includes a support structure 102 having a mounting surface 104, and a convex PV panel 106 attached to the mounting surface 104. The mounting surface 104 is at least partially cylindrical, for example, half of a full cylindrical surface. As shown in Figures 1a-1e, the support structure 102 is a cylindrical tube and the PV panel 106 occupies a selected portion of the cylindrical mounting surface 104, typically the portion facing upward. For example, the length of the PV panel 106 substantially matches the longitudinal length of the mounting surface 104 while the width of the PV panel 106 covers an arc subtending an angle of at least 100°. In some example implementations, the angle is between about 100° and about 120°. In another example implementation, the angle is about 180°, i.e. the PV panel 106 covers half of a cylindrical surface.

[0035] In the example where the PV panel 106 covers half of a cylindrical surface, the active area of the PV panel 106 is about $\pi/2$ (≈ 1.57) times the active area of a rectangular flat PV panel that occupies the same ground area, assuming that such flat PV panel is disposed parallel to the ground. The ratio is higher if the flat PV panel is disposed at an angle to the ground. Put in a different way, in this example, the semi-cylindrical PV panel 106 requires approximately 63% of the ground surface that is occupied by a flat PV panel having the same active area.

[0036] As discussed above, in a preferred embodiment, the support structure 102 is a cylindrical tube. This geometry can provide several benefits. For example, such cylindrical support structure 102 is relatively aerodynamically stable and not affected by cross-winds. As a result, the support structure 102 is less likely to swing or rotate during windy conditions, thus allowing the PV module 100 to have stable operation in different weather conditions, or at locations with strong winds. Also, the PV module can be suspended above the ground, as described in further detail below, thereby freeing up the land/space below for other uses. Moreover, a cylindrical structure is relatively easy to manufacture and assemble, thus lowering the production cost.

[0037] Referring to Figure 1b, the cylindrical support structure 102 further includes an axle 108 and a plurality of radial spokes 110 connecting the axle 108 and the mounting

surface 104. The axle 108 includes a through hole 112 extending along a longitudinal direction of the axle 108. This hole 112 may allow a cable to cross the cylindrical support structure and then to hang up the structure 102 between 2 poles. The mounting surface 104 is typically made of a layer of a light-weight and rigid material, such as metal or plastic, capable of withstanding the maximum cross-winds at the location where the PV module 100 is to be installed. The spokes 110 are disposed at regular intervals along the axle, e.g. every few meters, to provide structural support for the cylindrical mounting surface 104 by preventing flexing or collapsing of the mounting surface 104. This arrangement can reduce the weight of the support structure 102, as most of the internal space is hollow, while maintaining the structural rigidity of the mounting surface 104. Items such as electrical wires, regulator circuits, electric connection box, etc. can be disposed in the hollow space inside the support structure 102.

[0038] It would be appreciated that in alternate embodiments, the mounting surface 104 of the support structure 102 may have different shapes. For example, an undulating or wavelike shape may provide a larger surface area for attaching the PV panel 106, hence further increasing the ratio of the active area of the PV panel 106 over a flat PV panel that occupies the same ground area. However, it would be appreciated by a person skilled in the art that an unsymmetrical shape may have the increased risk of the panel flipping over or at least uncontrolled movement as the shape does not offer symmetry against lateral winds.

[0039] The convex PV panel 106 used in the example embodiments is a thin-film type PV panel. Such a thin-film PV panel is capable of producing electricity not only by direct sunlight but also by diffused irradiation, e.g. sunlight striking at an angle, or reflected light. Furthermore, such a thin-film PV panel typically generates a relatively stable voltage, which does not change significant when there is a partial shade on the panel, compared to a polycrystalline PV panel.

[0040] The PV panel 106 can be fabricated and attached to the mounting surface 104 in a number of ways. In one embodiment, the PV panel 106 is formed as a flexible thin-film panel which is then bent and affixed to the mounting surface 104. In another embodiment, the PV panel 106 is formed as a substantially rigid thin-film panel dimensioned to a curvature of the mounting surface 104 and is then affixed onto the mounting surface 104. In yet another embodiment, the PV panel 106 may be directly printed onto the mounting surface 104 as a thin-film panel.

[0041] The PV module 100 of Figures 1a-1e can be installed in different ways. For example, if the support structure 102 is semi-cylindrical or partially cylindrical, the PV module 100 can be placed on a base or on the ground with the PV panel 106 facing generally upward. In a preferred embodiment, if the support structure 102 is wholly cylindrical, the PV module 100 can be mounted above ground, thereby freeing the ground and space below. This arrangement allows the PV module 100 to be used in a variety of locations where it would be otherwise impossible or uneconomical to install conventional PV panels.

[0042] Figure 2a shows a perspective view of a photovoltaic (PV) energy production system 200 according to an example embodiment. Figure 2b shows a side view of the PV energy production system of Figure 2a. Figure 2c shows a top view of the PV energy production system of Figure 2a.

[0043] The PV energy production system 200, also known as a PV farm, includes a plurality of PV modules 100 as described above with respect to Figures 1a-1e. As illustrated in Figures 2a-2c, the plurality of PV modules 100 are disposed in an end-to-end arrangement. For example, the plurality of PV modules 100 are suspended above ground by a raised cable 202, similar to how beads are stringed together. In one embodiment, the cable 202 is inserted in the through hole 112 (Figure 1b) of the axle 108 (Figure 1b). The cable 202 may be in frictional fit with the through hole 112 or is otherwise secured to the axle such that the support structure 102 (Figures 1a-1e) cannot freely rotate relative to the cable 202, thereby ensuring that the active surface of the PV panel 106 (Figures 1a-1d) is oriented generally upward. Alternatively, the support structure 102 may have two through holes (not shown) spaced from each other (e.g. diagonally opposite each other) and two separate cables are inserted in the respective holes. Such arrangement may provide greater stability against any rotational or twisting movement by the PV module, e.g. in windy conditions. Also, the use of two cables may increase the safety factor in case one cable fails and breaks.

[0044] The number of PV modules 100 that are suspended by the cable 202 depends on factors such as the strength of the cable 202, the size and weight of each PV module 100, the space available, etc. Typically, in a PV farm, a plurality of cables 202, each carrying a predetermined number of PV modules 100, are arranged in parallel to each other to maximise space use. In Figures 2a-2c, the cables are spaced apart for illustration, but in practical applications it would be appreciated that the cables maybe arranged much closer to each other. Fixed structures 204a, 204b may be used in some

embodiments to provide clearance between the PV modules 100 and the ground, and to support the weight of the PV modules 100 and cables 202. The maximum generating capacity can be determined based on the number of PV modules 100 used, as illustrated in the following example. In the example shown in Figures 2a-2c, the fixed structures 204a, 204b include rigid vertical and horizontal members, but it would be appreciated that the horizontal members may include support cables in alternate embodiments.

[0045] In this example, a PV farm can be installed over a river. Using a typical thin-film PV panel with a length of 5.5m and a width of 0.4m, weighting 7.7kg and rated 140W to attach to a cylindrical support structure such that the panel covers about 60% to 80% of the upper half of the cylindrical mounting surface, the cylinder diameter can be calculated to be approximately 0.4m. Assuming the material of the cylindrical tube is PVC and the mounting surface has a thickness of 3mm, the weight of a 5.5m long tube is approximately 31kg. Together, the weight of the PV module is about 39kg for a 140W generating capacity (or 0.28kg/W). If the river width is 240m, each cable can support 43 PV modules arranged end-to-end for a total weight of around 1677kg for an installed capacity of about 6kW. Further, if an average of 2 cables, each suspending 43 PV modules, is installed per meter of river flank, a length of about 800m alongside the river is required to have a 10 MW photovoltaic farm.

[0046] The PV energy production system as described in the example embodiments provide several advantages compared to conventional PV farms. The handling of the PV modules making up the system is relatively easy due to their low weight. It is estimated that the weight of the PV energy production system as described above with reference to Figures 2a-2c can be as low as 40% of existing flat a PV panels installation having similar generating capacity. The installation of the system is also much less time-consuming, as it is sufficient to cross the cylindrical support structure with a simple cable, e.g. through a hole in the axle.

[0047] The cylindrical shape of the PV modules can also prevent any water from staying on the panel in case of rain and can help cleaning the surface from dust. In case of a snowfall, the snow typically cannot stay long on the cylindrical surface, thereby allowing more time of production.

[0048] Moreover, while a conventional PV installation on ground needs costly civil work to prepare the erection of poles for the PV frame, the system of the example embodiments can be installed in areas such as rocky, inclined or non-consolidated

pieces of land, mountainous areas, quarries, lakes, ponds, or flooded areas, swamps, canals, or polluted zones. The installation of the system does not even need a man access to the land below. Such areas were conventionally considered unsuitable for PV energy production. Also, the partly shaded land below the installed system may still enable adapted agriculture activities which need shade. Importantly, the ground below can be freed for other use, thereby avoiding the "land-use conflict" issues. Put in a different way, the system of the example embodiments allows multiple-use of the same ground area.

[0049] In an urban context, the benefits can be (i) financial, as using the same ground for several purposes is an obvious major economic advantage, (ii) aesthetic with the possibility to create new beautiful and highly creative complex, and (iii) functional, as the shade provided by the system can reduce car sunlight exposure. The system of the example embodiments can also be installed above rooftops of buildings, e.g. by installing poles around the buildings, to cover the roof surface without adding and weight on the roof.

[0050] Figure 3 shows a flow chart 300 illustrating a method for manufacturing a photovoltaic (PV) module according to an example embodiment. At step 302, a support structure having a mounting surface, the mounting surface being at least partially cylindrical, is provided. At step 304, a convex thin-film photovoltaic panel is attached to the mounting surface such that the photovoltaic panel occupies a selected portion of the mounting surface.

[0051] It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

CLAIMS

1. A photovoltaic module comprising:

a support structure having a mounting surface, the mounting surface being at least partially cylindrical; and

a convex thin-film photovoltaic panel attached to the mounting surface, the photovoltaic panel occupying a selected portion of the mounting surface.

2. The photovoltaic module as claimed in claim 1, wherein the selected portion comprises an area of the mounting surface having an arc subtending an angle of at least 100°.

3. The photovoltaic module as claimed in claim 2, wherein the angle is approximately 180°.

4. The photovoltaic module as claimed in any one of the preceding claims, wherein the support structure comprises a cylindrical tube having an axle and a plurality of spokes connecting the axle and the mounting surface.

5. The photovoltaic module as claimed in claim 4, wherein the plurality of spokes are disposed at predetermined intervals along the axle.

6. The photovoltaic module as claimed in claim 4 or 5, wherein the axle comprises a through hole extending along a longitudinal direction.

7. A photovoltaic energy production system comprising a plurality of photovoltaic modules as claimed in any one of the preceding claims.

8. The photovoltaic energy production system as claimed in claim 7, wherein the plurality of photovoltaic modules are disposed in an end-to-end arrangement

9. The photovoltaic energy production system as claimed in claim 8, wherein the plurality of photovoltaic modules are suspended by a raised cable.

10. The photovoltaic energy production system as claimed in claim 9, wherein the system comprises a plurality of cables arranged in parallel to each other.

11. A method of manufacturing a photovoltaic module, the method comprising the steps of:

providing a support structure having a mounting surface, the mounting surface being at least partially cylindrical; and

attaching a convex thin-film photovoltaic panel to the mounting surface such that the photovoltaic panel occupies a selected portion of the mounting surface.

12. The method as claimed in claim 11, wherein the step of attaching the convex thin-film photovoltaic panel to the mounting surface comprises bending a flexible thin-film photovoltaic panel and affixing the bent photovoltaic panel onto the mounting surface.

13. The method as claimed in claim 11, wherein the step of attaching the convex thin-film photovoltaic panel to the mounting surface comprises forming a substantially rigid thin-film photovoltaic panel dimensioned to a curvature of the mounting surface and affixing said photovoltaic panel onto the mounting surface.

14. The method as claimed in claim 11, wherein the step of attaching the convex thin-film photovoltaic panel to the mounting surface comprises printing a photovoltaic panel onto the mounting surface.

15. The method as claimed in any one of claims 11 to 14, wherein the step of providing the support structure having the at least partially cylindrical mounting surface comprises forming a cylindrical tube having an axle and a plurality of spokes connecting the axle and the mounting surface.

16. A photovoltaic module comprising a generally convex photovoltaic panel.