

Utility Patent Application

Photovoltaic Module Construction Method

Hang Cek Liong, Singapore, SG

Jeevan Sivaraman, Singapore, SG

Bo Zhang, Singapore, SG

SPECIFICATION

BACKGROUND OF THE INVENTION

[0001] The electrical characteristics of a typical conventional PV module is determined by the electrical routing of the PV cells within the entire module. These PV cells can be electrically connected in a serial or in a parallel configuration to form a PV string array. The voltage and current values produced by a PV module determines the output power (or P_{max}) of a module. These values are further determined by the number of PV cells that makes up the entire PV module circuitry, along with the electrical and optical losses that are fundamentally present within the PV module.

[0002] System requirements for a PV module varies with regard to end user applications. For example, a PV system designed for a solar farm is configured differently compared to residential system. PV modules are sometimes designed specifically to cater for this differentiation. Requirements such as module dimension and mounting methods are customized to best suit any particular application. Dimensional and mounting requirements can be varied with ease during

module design stage, however, electrical characteristics, particularly the output current of a PV module have limited flexibility to be configured with a wide range of options.

[0003] On a conventional PV module, the short circuit current (I_{sc}) for the PV module is almost equals to the short circuit current of the PV cells, typically around 8~9 Amperes (A), and the primary factor which determines this is the total surface area of a single PV cell. The design of a PV module circuitry allows for higher current output by connecting multiple PV cells in parallel, however, it is not possible to reduce the overall output current to a significantly lower value below the cell's short circuit current. Due to this limitation, the PV module have limited options and cannot be directly integrated into a system or load which operates at a lower current, unless it is coupled with transformers and inverters. Moreover, a PV system or module which operates at higher current suffers from higher resistive losses and this lowers down the overall module or system efficiency.

SUMMARY OF THE INVENTION

[0004] Embodiments of the present disclosure generally relate to the design of a PV module which can be configured with pre-determined electrical characteristics, followed by the method of constructing these modules. More particularly, embodiments of the subject matter relate to techniques for constructing a PV module which enables a wider range of output current options.

[0005] According to a first aspect of the invention, a method of electrically connecting multiple PV cells to form a matrix circuit is provided, comprising: separating a full PV cell into multiple smaller pieces, electrically connecting multiple PV cells and interconnects to form into a PV string; and connecting multiple PV strings to form into a PV string matrix.

[0006] According to a second aspect of the invention, a method of encapsulating, laminating and completing the PV module construction is provided, comprising: placing the string matrix that was

constructed between a front and back cover; laminating the PV string matrix to form into a PV module; and attaching junction box on the PV module.

[0007] In another embodiment, the PV cell is produced from a wafer and divided into multiple smaller pieces.

[0008] In another embodiment, interconnects are placed between the PV cells to enable electrical connectivity between the PV cell and external circuitry.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. 1 shows a top plan view of an example of an electrical schematic diagram of a PV module constructed with multiple PV cells which is divided into four quadrants;

[0010] FIG. 2 shows a flowchart diagram of an example of a method of constructing the PV module in the present invention;

[0011] FIG. 3 shows a top plan view of an example of a circular PV cell;

[0012] FIG. 4 shows a bottom plan view of an example of a circular PV cell in FIG. 3;

[0013] FIG. 5 shows a top plan view of an example of a PV cell which is cut from a circular wafer into a pseudo-square shape;

[0014] FIG. 6 shows a bottom plan view of an example of a PV cell in FIG. 5 which is cut from a circular wafer into a pseudo-square shape;

[0015] FIG. 7 shows a top plan view of an example of a circular PV cell in FIG. 3 divided into three smaller pieces;

[0016] FIG. 8 shows a bottom plan view of an example of a divided PV cell in FIG. 7;

[0017] FIG. 9 shows a top plan view of an example of pseudo-square PV cell in FIG. 5 divided into five smaller pieces;

[0018] FIG. 10 shows a bottom plan view of an example of a divided PV cell in FIG. 9;

[0019] FIG. 11 shows a top plan view of multiple examples of an interconnect;

[0020] FIG. 12 shows a top plan view of an example of PV cell in FIG. 7 electrically connected to each other using ribbon interconnect;

[0021] FIG. 13 shows a top plan view of an example of PV cell in FIG. 7 electrically connected to each other in a partial overlapping manner;

[0022] FIG. 14 shows a top plan view of an example of PV cell in FIG. 9 electrically connected to each other using ribbon interconnect;

[0023] FIG. 15 shows a top plan view of an example of PV cell in FIG. 9 electrically connected to each other in a partial overlapping manner;

[0024] FIG. 16 shows a top plan view of multiple examples of an interconnect electrically connected to a cell;

[0025] FIG. 17 shows a top plan view of an example of a string constructed with reference to FIG. 13 and FIG. 16;

[0026] FIG. 18 shows a top plan view of an example of multiple strings from FIG. 17 connected to form a PV string matrix;

[0027] FIG. 19 shows a side view of an example of a PV string matrix which is encapsulated;

[0028] FIG. 20 shows a top plan view of an example of a PV module with four bypass quadrants which is encapsulated and attached with two junction boxes and two diode boxes;

[0029] FIG. 21 shows a top plan view of an example of two PV module from FIG. 20 connected electrically in series into a larger module.

DETAILED DESCRIPTION

[0030] Certain terminology may also be used in the following description for the purpose of reference only, and thus are not intended to be limiting. For example, terms such as "top", "bottom", "upper", "lower", "above", and "below" refer to internally consistent directions in the drawings to which reference is made. Terms such as "front", "back", "rear", "side" may describe the orientation and/or location of portions of the component within a consistent but arbitrary frame of reference which is made clear by reference to the text and the associated drawings describing the component under discussion. Such terminology may include the words specifically mentioned above, derivatives thereof, and words of similar import.

[0031] "Photovoltaic" – Photovoltaic, or PV in short, may refer to the conversion of light into electricity using semiconductor materials that exhibit photovoltaic effect. Photovoltaic cells and photovoltaic modules can also be regarded as solar cells and solar modules.

[0032] "Photovoltaic Cell" – Photovoltaic cell, or PV cell in short, may refer to the semiconductor material that exhibit photovoltaic effect that converts light into electricity. Photovoltaic cells can also be regarded as solar cells.

[0033] "Photovoltaic Module" – Photovoltaic module, or PV module in short, may constitute PV cells which are interconnected and are encapsulated into an assembly that generates solar electricity. Photovoltaic modules can also be regarded as solar modules or solar panels.

[0034] "Photovoltaic String" – Photovoltaic string, or PV string may refer to two or more Photovoltaic cells that are connected in series to form a chain or a string of PV cells.

[0035] "Photovoltaic String Matrix" – Photovoltaic string matrix, or PV string matrix may refer to two or more PV strings that are interconnected within a PV module.

[0036] "Interconnect" – Interconnect may refer to an element which is fully conductive or partially conductive which is used within a PV module circuitry to link and establish electrical connection. The term interconnect in the present invention refers to the element which is connected in the PV string, as referred to in FIG. 11.

[0037] "Busbar" – Busbar may refer to a conductive bar which is used in a PV module. Busbar which is used on a PV cell is regarded as PV cell busbar and busbar which is used to electrically link PV cells to PV strings to form PV matrices is regarded as inter-circuit busbar.

[0038] FIG. 1 illustrates an example of an electrical schematic diagram of a PV module 800, constructed with multiple PV cells 500, which are then electrically connected using inter-circuit busbar 600 and electrically divided into four quadrants 801,802,803,804 for bypass operation. The present invention details the method for constructing an actual PV module based on the schematic diagram example.

[0039] FIG. 2 depicts an example of the process flowchart of a method of constructing a PV module of the present invention. The various tasks performed in FIG. 2 may be performed by manual human intervention, standalone equipment, fully automatic equipment or any combination thereof. For illustrative purposes, the descriptions mentioned in FIG. 2 may refer to examples shown in FIGS. 3-21.

[0040] A brief description of FIG. 2 flowchart includes preparing and securing a PV cell firmly for separation process 300, dividing the PV cell into multiple small pieces by physical separation 301, constructing a PV string by electrically connecting multiple PV cells 302, electrically connecting multiple PV strings into a PV string matrix 303, encapsulating the PV string matrix 304, and attachment of junction box and diode box onto the encapsulated PV module 305.

[0041] FIG. 3 shows a top plan view of an example of a circular bi facial PV cell. The circular PV cell 100 is produced from a round wafer, which is sliced from a cylindrical Silicon ingot. The circular PV cell includes front cell busbars 101, along with fingers 103 disposed on the top surface of a silicon substrate and front contact pads 105.

[0042] FIG. 4 shows a bottom plan view of the same circular bi facial PV cell 100 shown in FIG. 3. It is shown a rear cell busbars 102, along with fingers 103 disposed on the rear surface of a silicon substrate and rear contact pads 106.

[0043] FIG. 5 shows a top plan view of an example of a pseudo square PV cell. The pseudo square PV cell 200 is sliced from a cylindrical Silicon ingot. The pseudo square PV cell includes a front cell busbars 201, along with fingers 203 disposed on the top surface of a silicon substrate.

[0044] FIG. 6 shows a bottom plan view of the same pseudo square PV cell 200 as shown in FIG. 5. It is shown a rear cell busbars 202, along with fingers 203 disposed on the rear surface of a silicon substrate.

[0045] FIG. 7 shows a top plan view of an example of a circular PV cell in FIG. 3 physically divided into three smaller pieces. It is shown a center cell 110 along with two semi-circle cells 111.

[0046] FIG. 8 shows a bottom plan view of an example of a divided PV cell in FIG. 7. It is shown a center cell 120 along with two semi-circle cells 121.

[0047] FIG. 9 shows a top plan view of an example of a pseudo square PV cell in FIG. 5 physically divided into five smaller pieces. It is shown three rectangular cells 210 along with two chamfered cells 211.

[0048] FIG. 10 shows a bottom plan view of an example of a divided PV cell in FIG. 9. It is shown three rectangular cells 220 along with two chamfered cells 221.

[0049] In FIGS. 7-10, multiple techniques can be used to physically separate a PV cell into multiple smaller pieces. Methods such as wire cut, diamond saw and laser cut are examples of separation techniques that can be used. With these examples of methods mentioned above, careful consideration must be made on the process selection to ensure separation accuracy, electrical and mechanical properties of the PV cell is not affected.

[0050] FIG. 11 shows a top plan view of multiple examples of an interconnect 400,401,402,403,404. The variety of multiple interconnect design is best suited for different application within the PV module. The interconnect design provides electrical connections which include, but not limited to: (1) between PV cells; (2) between PV strings; (3) between PV cells and PV strings; (4) to external circuitry, within a PV module. The interconnect can also be placed at any locations within the PV string to establish a by-pass route, which is beneficial when integrated with by-pass diode. The interconnect can be electrically coupled onto PV cells and/or PV strings through multiple methods, which includes, but not limited to: (1) either partial or complete overlapping method, whereby the interconnect makes physical contact with the PV cell busbar; (2) induction soldering, contact soldering, Infra-Red soldering or hot air soldering; (3) using solder adhesives or other conductive adhesives for bonding.

[0051] The interconnect in FIG. 11 can be constructed with a fully conductive material or a partially or non- conductive material with conductive surface. The dimension of the interconnect is optimized for the present disclosure and PV cell size, but generally, the length of this interconnect must be able to cover certain percentage of the PV cell length and the width of the interconnect must be sufficient to allow partial surface overlapping with the PV cells. The size of the interconnects are also designed to provide reliable electrical connections. The interconnect may have a rectangular shaped member and includes an interconnection point. The interconnection point, for example, is an extrusion point to provide additional surface contact area for soldering or other bonding techniques.

[0052] Considerations in determining the dimension and material selection for the interconnect may include: (1) the interconnect should not significantly attribute to performance loss to the PV module. In other words, the interconnect should be able to channel power in and out of a PV cell with minimal electrical loss and with minimal impact to overall PV module efficiency; (2) the introduction of the interconnect to the PV module should not jeopardize the reliability of the PV module from its existing state.

[0053] FIG. 12 shows a top plan view of an example of PV cell in FIG. 7 electrically connected to each other to form into a PV string using ribbon interconnect. It is shown five center cells 110 electrically connected to each other in series. These PV cells are electrically connected by physical contact between the ribbon interconnect 400 and the front cell busbar 101 of a PV cell and connecting the other end of the ribbons onto the rear cell busbar 102 of another PV cell.

[0054] FIG. 13 shows a top plan view of an example of PV cell in FIG. 7 electrically connected to each other in a partial overlapping manner to form into a PV string. It is shown three center cells 110 and two semi-circle cells 111 electrically connected to each other in series. These PV cells are electrically connected by partially overlapping two or more PV cells such that the rear busbar of a PV cell makes direct contact with the front busbar of another PV cell.

[0055] FIG. 14 shows a top plan view of an example of PV cell in FIG. 9 electrically connected to each other to form into a PV string using ribbon interconnect. It is shown five rectangular cells 210 electrically connected to each other in series. These PV cells are electrically connected by physical contact between the ribbon interconnect 400 and the front cell busbar 201 of a PV cell and connecting the other end of the ribbons onto the rear cell busbar 202 of another PV cell

[0056] FIG. 15 shows a top plan view of an example of PV cell in FIG. 9 electrically connected to each other in a partial overlapping manner to form into a PV string. It is shown five chamfered cells 211 connected to each other in series. These PV cells are electrically connected by partially overlapping two or more PV cells such that the rear busbar of a PV cell makes direct contact with the front cell busbar of another PV cell.

[0057] The number of PV cells that are connected to each other to construct a PV string are customizable based on system needs and requirements set by the PV module designer. The method of electrically connecting the PV cells is subjected to the technology availability and equipment capability.

[0058] FIG. 16 shows a top plan view of multiple examples of an interconnect electrically connected to a PV cell. It is shown an example of a type of interconnect 404 electrically connected to a semi-circle cell 111 by physical contact with the front contact pads 105. In another example, it is shown an interconnect 403 electrically connected to two adjacent center cell 110 by physical contact with the front cell busbar 101 of a cell and rear cell busbar 102 of another cell. It is also shown another example of an interconnect 402 electrically connected to a center cell 110. The same interconnect 402 is also electrically connected to a rectangular cell 210 and a chamfered cell 211 by physical contact with the front cell busbar 201.

[0059] The electrical connections in FIG. 16 can be achieved by multiple methods, which includes, but not limited to: (1) either partial or complete overlapping method, whereby the interconnect makes physical contact with the PV cell busbar; (2) induction soldering, contact

soldering, Infra-red soldering or hot air soldering; (3) using solder adhesives or other conductive adhesives for bonding

[0060] FIG. 17 shows a top plan view of an example of a PV string constructed with reference to FIG. 13 and FIG. 16. It is shown ten center cells 110 electrically connected in series, interconnect 401 electrically connected to the front busbar 101 of the first cell of the PV string, interconnect 402 electrically connected to the rear busbar 102 of the last cell of the PV string and interconnect 403 electrically connected to the fifth and sixth cell of the PV string. In another example, it is shown eight center cells 110 electrically connected in series along with two semi-circle cells 111 placed at both opposing ends of the PV string. It is also shown two interconnects 404 electrically connected to the front contact pads 105 of a semi-circle cell located at the end of the PV string and rear contact pads 106 of a semi-circle cell located at the opposite end of the same PV string and interconnect 403 electrically connected to the fifth and sixth cell of the PV string.

[0061] FIG. 18 shows a top plan view of an example of multiple PV strings from FIG. 17 connected to form a PV string matrix 902. It is shown two PV strings 910,911 electrically connected to each other in a parallel circuit configuration. It is also shown another two PV strings 912,913 electrically connected to each other in a parallel circuit configuration. PV strings 910,911 are then connected to PV strings 912,913 in a series circuit configuration with the use of an inter-circuit busbar 906. It is also shown interconnects 401,402,403,404 being used at end PV cells and mid PV cells location to establish external circuitry connection.

[0062] FIG. 19 shows a side view of an example of a PV string matrix which is encapsulated. It is shown a PV string matrix 902 encapsulated within an encapsulating material 901 and top and bottom covers 900. The top and bottom covers can be made of materials which include, but not limited to glass, polymer or resin based materials or any combination thereof.

[0063] FIG. 20 shows a top plan view of an example of a PV module with four bypass quadrants which is encapsulated and attached with two junction box and two diode box. It is shown a PV module 800, encapsulated with encapsulating material 901 between two sheets of glass 900. It is also shown a negative terminal junction box 903, a positive terminal junction box 904 and two

diode box 905. The PV module circuit consist of a PV string matrix 902 constructed with four PV strings which are constructed with multiple PV cells 110, 111 which are electrically connected to each other using interconnects 403,404 and inter-circuit busbar 906.

[0064] The PV module in FIG. 20 is designed to be electrically divided into four quadrants 801,802,803,804 for bypass operation, as per the schematic example in FIG. 1. These quadrants acts as independent circuit in the event of shading. With the introduction of interconnect 403 at the mid string location, it not only allows for serial connection between the quadrants during normal operation, but it also provides an accessible point to channel out power from the string for bypass operation, in the event of shading.

[0065] In a PV module design, by-pass diodes are commonly used to protect PV cells from junction break-down and local hotspot failure, caused by reverse bias that builds up from partial shading or PV cell failure. In the example in FIG. 20, each quadrant 801,802,803,804 is designed with a bypass route which is connected to four bypass diodes. These bypass diodes are integrated into the negative terminal junction box 903, positive terminal junction box 904 and two diode box 905.

[0066] In the PV module design of the present invention, the number of PV cells which are connected in series to form a string, the number of PV strings that are connected in parallel to form a PV string matrix and the number of interconnects, junction box, diode box and bypass routes used are not limited to the example shown in FIG. 20. These components which makes up the entire PV module circuitry can be customized and optimized further, according to the design requirements.

[0067] On the example shown in FIG. 20, a bypass route is constructed by placing an interconnect for every five PV cells which are connected in series. This configuration can be altered and optimized further for improved reliability and hotspot tolerance. The designer also have an option to trade-off reliability with improved module performance. As an example, if the designer designs the circuit so as to have the bypass route for every one hundred PV cells in series, this would provide an advantage to process, cost and module efficiency. But the drawback is that the PV

module is now more susceptible to failures arising from local hotspot and/or junction breakdown. On the other hand, when a bypass route is established for every single PV cell within the PV module, this setup will provide an excellent condition for reliability but it impacts the module efficiency significantly and adds cost and process complexity.

[0068] To ensure proper balance is achieved between module performance and reliability, the bypass circuitry must be established and channeled out approximately every twenty PV cells which are connected in series. However, for customization options, the designer have an option to reduce this number to just one PV cell or increase the maximum number of series connected PV cell to any value.

[0069] FIG. 21 shows a top plan view of an example of two PV module from FIG. 20 connected electrically in series into a larger module. It is shown two PV string matrices 902 connected in series into a single large module. A larger top and bottom covers 900 is used for this module. It is also shown a negative terminal junction box 903, positive terminal junction box 904 and six diode box 905.

[0070] During normal operation, the larger module operates at its peak performance, similar to any conventional module, but in the event of shading, the in-built network of bypass circuitries works at its optimal point to ensure energy generation is not severely impacted. This is because the larger PV module in FIG. 21 has been configured into eight standalone segments and each segment has its own bypass circuit. For example, in the event of minor shading, caused by a leaf shading one PV cell of one segment, the affected segment is bypassed and the module generates about eighty five percent of its rated power. In the event of larger shading, caused by a street lamp post for example, the affected area will be bypassed and the module will still be able to generate power.

[0071] Besides having improved power generation, the standalone segments with its own bypass circuit will also improve the reliability tolerance of the module in the event of shading. Since each segment operates independently, the probability of hotspot failure and PV cell junction breakdown failure could be mitigated tremendously.

[0072] With these customization options available in the design of the present invention, it paves way for the designer to determine the electrical attributes of the PV module based on the application design requirements. The designer will also have an option to trade-off between reliability and performance.

[0073] While the foregoing written description of the invention enables one of ordinary skill to make and use what is considered presently to be the best mode thereof, those of ordinary skill will understand and appreciate the existence of variations, combinations, and equivalents of the specific embodiments, method, and examples herein. The invention should therefore not be limited by the above described embodiments, method, and examples, but by all embodiments and methods within the scope and spirit of the invention.

WHAT IS CLAIMED IS:

1. A PV module design comprising a plurality of PV cells which are physically separated into smaller pieces and re-connected again, whereby the PV cell electrical characteristics are first measured and this information is used to pre-determine the desired surface area. The PV cell is then measured, analyzed and compensated for any defects and the boundary for the region of interest which consists of the desired surface area is then identified and the PV cell is then physically separated into at least one smaller piece.
2. A method to pre-determine the desired surface area for the separated PV cell in claim 1 whereby the target current output requirement for the PV module is first identified. The electrical characteristics of the PV cell is then measured and this information is used to calculate the proportionate surface area of the PV cell which is desired for the target current output requirement for the PV module.
3. A method to measure and analyze the PV cell for the region of interest of the pre-determined desired PV cell surface area in claim 1, whereby the PV cell's dimensional attributes, PV cell's quality and PV cell's electrical characteristics are measured and analyzed using the following methods;
 - a. Two-dimensional surface area measurement;
 - b. Film thickness analysis for front and/or rear surface;
 - c. Electro-luminescence, Photo-luminescence, X-Ray and hotspot analysis;
 - d. Current-voltage tester.

And the resulting outcome from any/all of these methods is used to compensate for any PV cell related defects and further define the boundary for the region of interest.

4. A method of separating the PV cell in claim 1, wherein the boundary for the region of interest identified in claim 3 is physically separated by;
 - a. Diamond saw cutting and separation process;
 - b. Wire cutting and separation process;
 - c. Laser scribing and separation process.

5. The separated PV cell in claim 4, whereby the PV cell is physically separated into at least one smaller part, wherein;
 - a. The PV cell is separated with exactly the same surface area;
 - b. The PV cell is separated with unequal surface areas;
 - c. The PV cell is separated according to the desired shape.
6. The PV module design in claim 1, whereby the PV module is integrated with bypass circuit, and at least one electrically conductive interconnect is electrically connected to a separated PV cell in claim 5 in a PV string wherein;
 - a. The attributes of the interconnect is pre-formed and shaped with reference to the attributes of the separated PV cell in claim 5 such that the length, width and thickness of the interconnect is designed to provide a reliable electrical connection with the separated PV cell;
 - b. The attribute of the interconnect has at least one protrusion which is used to electrically inter-connect with another interconnect and/or an external node outside of the PV cell and/or PV string.
7. A PV module design made up of two or more smaller PV module from claim 1 to form a larger PV module. These smaller PV modules are connected electrically in a serial and/or parallel manner and connected to a bypass circuit which consists of at least one bypass diode..

