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MANUFACTURING OF SOLAR PANELS: FROM CELL TO MODULE

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Abstract: To harness the power from sunlight has become a common phenomenon to the places situated near equator globally. Photovoltaic cell is the core component of the solar system and generate electricity when sunlight bombard on it. Though efficiency of the photovoltaic cell has been claimed by the manufacturers 85% against virtual gain of 65-68%. Day after day research work is going on for improvement in efficiency on these core component by the implementation of enhanced semiconductor materials and technology. The main objective of this article is to study of manufacturing of solar panel and their work. Here we distinguishes the types of solar panels and discuss their features. In this article, we will study all processes of solar panel manufacturing from the Stringer machine to module packing. We will also calculate the power production of panels and analyze the efficiency of panels. This article will eventually be helpful for the enhancement of knowledge about solar panels and will realize its importance for selecting a particular panel.

Key Words **– Stringer Machine, Glass Feeder, Lay-Up & Bussing, Electroluminescence Testing, Assembling & Packaging**

I. INTRODUCTION

To harness the power from sunlight has become a common phenomenon to the places situated near equator globally. Photovoltaic cell is the core component of the solar system and generate electricity when sunlight bombard on it. It directly convert the sun's energy into electricity which can be easily transported and converted to other forms for the benefit of society. When sunlight shines on a PV cell, the absorbed light produces electricity. To raise the overall efficiency of the solar system with the advent of power electronics engineering is also continuously performing an important and novel role. Power Electronics Interface are incorporated with Photovoltaic (PV) System to intensify the efficiency of the PV system and undoubtedly we have reached to the goalmouth. The need for a cleaner environment and the continuous increase in energy demands makes decentralized renewable energy production more and more important. Though efficiency of the photovoltaic cell has been claimed by the manufacturers 85% against virtual gain of 65-68%. Day after day research work is going on for improvement in efficiency on these core component by the implementation of enhanced semiconductor materials and technology. Power Electronics Engineering has also gained their achievement in the improvement of overall efficiency from harnessed energy through photovoltaic cell to utility grid [4]-[11].

Solar panel technology is advancing rapidly with greater efficiency and lower prices resulting in a huge increase in demand. However, despite the massive advancements in technology, basic solar panel construction hasn’t changed much over the years. Most solar panels are still made up of a series of silicon crystalline cells sandwiched betweena front glass plate and a rear polymer plastic back-sheet supported within an aluminum frame. Here we have emphasized on complete panel manufacturing process viz. Manufacturing of PV Cell, different types of PV Cell, Solar Panels, Testingof Solar Panels, Packaging & Quality Control and Grading of Solar Panels. We also acquire the knowledge of measurement the specific panel's type and its cost that produce efficient energy [12]-[18].

II. Manufacturing of Panels

The process step by step mentioned below Fig.1.

- ✓ Stringer machine
- ✓ Glass feeder
- ✓ Lay-up
- ✓ Bussing
- ✓ Electroluminescence testing
- ✓ Rework
- ✓ Visual Inspection
- ✓ Laminator
- ✓ Frame Assembling
- ✓ Junction Box Fitting
- ✓ Module cleaning
- ✓ Module packing

Figure 1: Module Production Line

2.1 Stringer Machine

Stringer machine welder Fig.2 allows soldering without mechanical and thermal stress, which is indicated for very thin solar cells and for ribbon cells. The machine is available also with laser soldering system that is indicated also for lead free ribbon. Thanks to the high flexibility the machine is suitable for all types of standard photovoltaic modules but also for BIPV modules.

Figure 2: Stringer Machine

2.2 Glass Feeder

When selecting a solar panel brand, people usually take a close look at topics such as the efficiency and wattage of a solar PV panel. An often-overlooked issue is the type of solar panel glass used as shown in Fig.3. Solar panel glass is one of the important barriers which protect solar photovoltaic cells against damaging external factors, such as water, vapor and dirt. The solar panel glass also offers low reflection, high transmissivity and high strength. The size of glass and Ethylene Vinyl Acetate (EVA) is 1950*985*3.2mm.

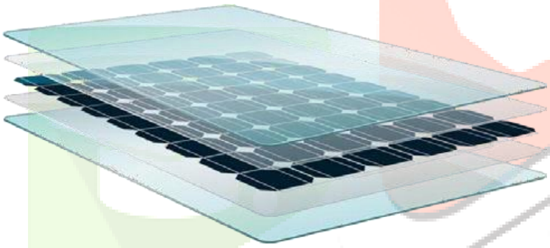


Figure 3: Solar Panel Glass

2.3 Lay-Up

- Observation of the Lay-up process until familiarity was felt with the process.
- The workers would load the Ethylene-Vinyl Acetate (EVA) covered glass onto the Lay-Up table Fig.4; the strings were already arranged on it during the Tabbing & Stringing process. This was the first step of the Lay-Up process.
- The workers would tear up small pieces of adhesive tape and apply them on the cells to hold them in place. The time recording for this step was divided into two sub-steps – tearing of tape, and its deposition on the cells.
- Placements of a second layer of EVA sheet, polymer back-sheet and soldering strips were recorded in a similar way.
- The soldering operation of bus-bars with the string ribbons was recorded by breaking the operation into pickingup the soldering iron, soldering, and placing their on back.
- Finally, allowances of 10 seconds and 5 seconds were given for the top-edge and bottom-edge operations respectively

Figure 4: Lay-Up Table

2.4 Bussing

In the bussing method of PV cells auto bussing machine adopts the method of separating the cell string from the glass and grab the

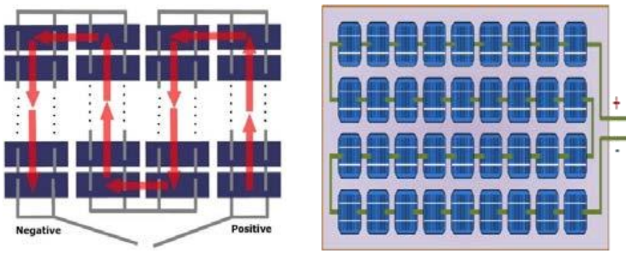


Figure 5: Separation of Cell and its interconnection

Cell string in the air, then it is to be interconnected solder to the head, middle and tail bus bar of the middle wire edition module at a certain height; it has the function of a roll feeding bus bar, bending U and L leads upwards Fig.5.

2.5 Electroluminescence Testing and Inspection

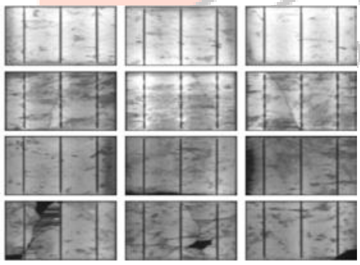
When current passes through PV cells, light emission occurs. This phenomenon is called Electroluminescence. Testing of modules using this phenomenon can detect hidden defects in the structure of PV cells. This method makes the current distribution visible in the PV module and helps detect defects. With the help of an EL test Fig.6, a PV manufacturer can evaluate the structural quality of the PV cells or any other defects generated while handling.

Figure 6: Electroluminescence Testing and Inspection Machine

2.6 Rework

Defects that can be found from EL testing machine and inspection machine are as given below.

- ✓ Micro cracks
- ✓ Cell cracks
- ✓ Soldering defects
- ✓ PID defects
- ✓ Diode failure
- ✓ Dead cell
- ✓ Back sheet scratches
- ✓ Wafer defects



2.7 Visual Inspection

Visual inspection of a PV module is performed before and after the module has been subjected to environmental, electrical or mechanical stress testing in the laboratory. Stress tests are usually used to evaluate module designs in the pre-phase of production, production quality and lifetime of the module.

2.8 Laminator

In order to laminate a solar panel, two layers of Ethylene-Vinyl Acetate (EVA) are used in the sequence: glass / EVA / solar cell strings / EVA / tedlar polyester tedlar (TPT). Now it is ready for lamination. During the lamination process, the prepared 5-layer module is placed in the lamination machine and heated to maximum 135°C for a period of approximately 22 minutes. The laminate that comes out is complete.

2.9 Junction Box Fitting

A junction box Fig.8 has bypass diodes that keep power flowing in one direction and prevent it from feeding back to the panels. Frank Rosenkranz, product manager of solar for EMEA, India and Americas for connector and junction box manufacturer TE Connectivity, described the junction box as the "most important part on a panel". "Every string is protected by a diode (in the junction box)." He said, "The diode is the gateway that allows an endless stream of power".

2.10 Frame Assembling

The auto-framing machine Fig.7 frames the post-laminate, assemblingfour aluminum rails around the glass.

2.10.1 Main Features

- Adjustable panel dimensions
- Automatic silicon dispensing system
- Manual frame loading
- Controlled frame insertion
- Frame loading buffer as an option
- Optional frame loading buffer

Figure 7: Auto Framing Machine

Figure 8: Connector

2.11 Module Cleaning and Packing

If you are able to safely climb up the roof for a closer wash, you can use isopropyl alcohol to clean oily smudges without leaving any marks. We don’t recommend detergent or soap to clean stubborn stains, as they tend to leave residue on panel glass that can attract more dirt in the future. Make sure you do not stand on the solar modules under any circumstance. Any pressure on the solar panel’s risk creating micro cracks that can reduce energy output. Packing of solar modules Solar panels are typically either horizontally or vertically stacked in a box. Usually, separators are placed between each module, and extra protections are added to the four corners of each module stack. In some cases, modules arealso packed in individual cartons boxes to be packed into a large master carton box. The box on the pallet is then sealed and strapped followed by being wrapped in plastic film. Solar panels are then usually shipped via ocean on pallets, holding on average 28-30 panels and – depending on order quantities, with extra few panels stacked on top in extra small cartons [1]-[3].

III. METHODOLOGY

The first process in solar panel manufacturing is purifying the silicon from quartz sand. Once silicon is purified, it is collected into solid rocks. These rocks are then molten together, forming cylindrical ingots. A steel and cylindrical furnace is utilized to achieve the desired shape. When manufacturing is underway, thereis a keen attention to have all atoms align in desired orientation and structure. Once the formed ingot cools, it is shinned and polished toleave flat sides. It is a fully automated process. Here we are using any cell of size greater than 39 mm. These cells are then assembled or soldered together. The upper Sun facing Side (Blue / Black side) isthe negative part while the bottom white side is positive.

Once the cells are stringed together, the machine transfers it to tempered glass, which already having ethylene vinyl acetate (EVA) encapsulation layer over it and then cells are examined by a technician for any fault or error in any string. After that a technician tapes the cells into a matrix alignment and forward the panels to the busing section and connections are then soldered together. Any excess material is cut out. The next step consists of insulating the connections by using a back sheet and EVA encapsulation. This process protects the module from any dust and moisture. The module is visually checked once again for any dust particle, color mismatch, etc.

After that, EI Testing or Electroluminescence test is the real testing of the module made so far. It is a testing process, where the module is kind of scanned in an EI machine. We can easily spot any dead or low power cell, short circuit cells, cracks, etc. If any such error is spotted, the module is sent back for fixing the error. And now the module is laminated at 140-degree Celsius. This process takesapproximately 20 minutes. After lamination, the modules are left for10-15 minutes to cool down till it reaches room temperature. This step involves cutting off the excess material of the back sheet to make perfectly shaped modules. After cutting of extramaterial the next step, frames of different sizes are cut out for bordering the panels. After assembling of aluminum frames, the silicon sealant is applied on the frame and pressed by a machine. A sealant protects the panels from air, dust, and moisture and helps the module to firmly attach on the frame. After the frame is attached to the module it is again sent to the framing machine, where it is punched to make sure it is permanently attached to the frame [22].

A junction box is attached to the module using the sealant to firmly attach it to the structure. Connections are then soldered and left for10-12 hours for curing, so that the structures are perfectly dry and attached properly. The module is then wiped outside to remove any traces or dust, foreign particles or extra sealant. After this process the module are connected to check its output current, voltage, power, etc. in a sun simulator. A report is generated for each module’s output data. A back label (with all details) is pasted behind the module for the benefit of the users. Finally, the module is sent to the QC lab where it is tested for insulation resistance. A 3000V DC is passed through it for a minute. If the panel can endure the current, it is passed else failed. Then it is sent to Mechanical Load Test.

After Final Quality Assurance (FQA), this is the last step in the module manufacturing process, where the modules are safely packed into large boxes for transportation and storage [19]-[24].

3.1 Sun Simulator VI Characteristics

The developed sun simulator has been prepared to test the characteristics of PV module Fig.9. The system was set in proper place where the accurate data can be measured. For measuring the data, the panel is placed in different position to get different illumination. Also, we take reading in open sunlight at various times for different radiation level. We want to get full sun in the sun simulator. From these data we can calculate the performance of a solar panel in open sun or in sun simulator [19]-[21].

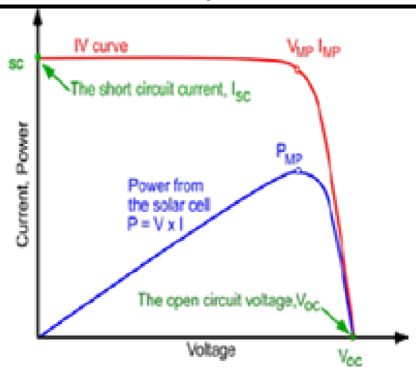


Figure 9: Photovoltaic VI Characteristics

3.2 Electrical Specification Use Isopropyl Alcohol to Clean Stubborn Stains

Table 1: Electrical Data

PARAMETERS	VALUE
Rated Power Supply	335W
Open Circuit Current	46.50A
Short Circuit Current	9.26A
Voltage at Maximum Power	37.7V
Current at Maximum Power	8.90A
Maximum System Voltage	1500V
Module Weight	21.5kg
Dimension	1955*990*35
Model Number	Goldi072F3359Y24

IV. Measurement, Grade and Selection Criteria of Solar Cells & Panels

4.1 PV Cell

PV cells come in a standard size of 156 mm * 156 mm, which is approximately 6 inches long and 6 inches wide Fig.10. An optimumsilicon solar cell with light trapping and very goodsurface passivation is about 100 µm thick. However, thicknessbetween 200 and 500µm are typically used, partly for practical issues such as making and handling thin wafers, and partly for surface passivation reasons [2].

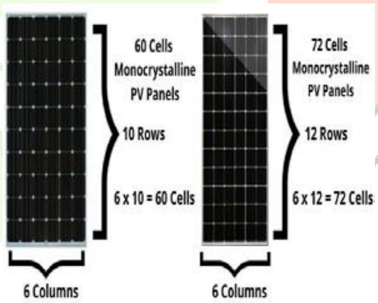


Figure 10: Cell and Panel Sizes

4.2 Solar Panels and Modules

Typical residential solar panel dimensions today are about 65 inches by 39 inches, or 5.4 feet by 3.25 feet, with some variation among manufacturers [3].

4.2.1 Standard Size of Solar Panels

- The size of a solar panel with 60 cell configuration is 39-inch X66 inch (3.25 ft. X 5.5 ft.).
- The size of a solar panel with 72 cell configuration is 39-inch X77 inch (3.25 ft. X 6.42 ft.).
- The thickness of a 60 cell or 72 cell solar panel is around 40mm

4.2.2 Standard Weight of Solar Panels

- The weight of a 60-cell solar panel is 19 kg.
- The weight of a 72-cell solar panel is 25 kg.

4.3 Grade of Cells

With solar cells accounting for 60%+ of the solar panelmanufacturing costs, solar cells are the number one component used to cut overall costs of a solar panel. There's a lot of confusion between different grade solar cells. Any deviation is often graded as B; however, a correct classification is complicated because there aredozens of different solar cell defects that can occur. This is a first attempt to design a classification (A, B, C, D) of solar cells.

4.3.1 Grade-A Solar Cell

As shown in Fig.11Grade-A cells are simply without any visible defects, and the electrical data tallies as per specification. The specifications of the cells can be measured with cell testing equipment. Theperfect grade-A cell may still have a slight bend of <= 2.0mm and a tiny color deviationis permitted. Below a grade-A solar cell, due to the light the color seems to deviate; but infact, this is a flawless solar cell.

Figure 11: Grade-A Solar Cell

4.3.2 Grade-B Solar Cell

Grade-B cells have visible but tiny defects as shown in Fig. 12, and the electrical data are as per specification. The following visible defects are common:

- ✓ **Slight bend** of 2.0mm – 2.5mm
- ✓ **Colour deviation**, Visible yellow area takes more than 1/4 areaof total on the Surface
- ✓ **Missing prints** < 0.5mm
- ✓ Part of front **Bus bar missing**, missing area ≤ W:0.5mm×L: 5mm
- ✓ **Paste leakag**e, for a single area: 0.3mm – ≤2.0mm2
- ✓ **Scratch**, length 15-50mm
- ✓ **Water marks**, L<15mm, W<2mm

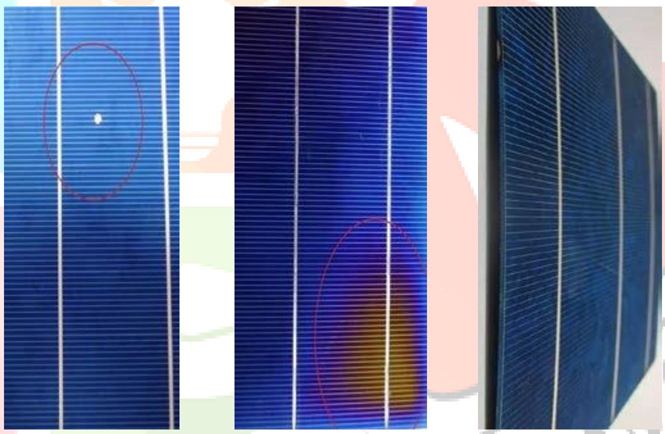


Figure 12: Grade-B Solar Cell

4.4 Selection Criteria for Solar Panels

Critical parameters to be considered for solar panel evaluation:

- Selecting the right technology: The selection of solarpanel technology generally depends on space availablefor installation and the overall cost of the system.
- Selecting the right manufacturer for better warranty.
- Check operating specifications beyond STC ratings
- Negative Tolerance can lead to a lower systemperformance and reduced capacity
- Solar Panel efficiency under different conditions andover time.

V. Design Concept for a PV Off Grid System

- Collect some data viz. Latitude of the location, and solar irradiance (one for every month).
- Calculation of total solar energy.
- Estimate the required electrical energy on a monthly / weekly basis (in kWh): Required Energy = Equipment Wattage X UsageTime.
- Calculate the system size using the data from 'worst month' which can be as follows:

✓The current requirement will decide the number of panels required.

✓The days of autonomy decides the storage capacity of the system i.e., the number of batteries required.

➢ For Example:

First of all, we have to calculate the total energy consume in a day atyour home.

Calculation: Equipment × Watts × Hours = Total Power

Table 2: Power Calculation Description

Equipment	Watts	Hours	Total Power
2 Fan	60W (1Fan)	15 hours	1800Wh
1Television	150W	5 hours	750Wh
3 LED	9W (1LED)	8 hours	216Wh
1 Electric Iron	1000W	1 hour	1000
Total Load	**1297**	-	**3766**

Now the addition of total power consumed is **3766Wh** from Table-2. Now convert Wh into **kWh** and we get **3.766kWh**. Thus we have to choose **1kWh** Solar panels which provides enough energy to our home. Here the selected Solar panel is provided 1KWh energy in one hour so the total sun light available in a day is 5-6 hours at peak time. So the Solar panels harness 5-6 kWh energy in a day.

VI. Comparison Between Mono-crystalline, Polycrystalline & Thin Film Solar Panels (5W)

Table 3: Comparison Chart

Parameters	Mono-crystalline	Poly-crystalline	Thin film
Optimum Operating Voltage(V_{mp})	17.82V	17V	18V
Optimum Operating Current (I_{mp})	0.285A	0.29A	0.278A
Open-Circuit Voltage(V_{oc})	21.396V	21V	26.7V
Short-Circuit Current (I_{sc})	0.315A	0.35A	0.401A
Maximum Power	5W	5W	5W
Module Efficiency	16.2%	14%	NA
Maximum System Voltage	1000VDC	600VDC	600VDC
Module Dimension	350*176*34 mm	359*197*26mm	385*322*18mm
Warranty: 90%Power Output 85% Power Output	10 Years 25 Years	10 Years 15 Years	10 Years 15 Years

VII. Conclusion

In this article we have come across the manufacturing process and various machines applied in the production of PV panels starting from stringer machine to module packaging. We extensively elaborated the various cell and panel sizes including its grades. Selection criteria for PV panel and design concept for PV off grid system extravagantly illustrated. Comparative statement between Mono-crystalline, Poly-crystalline and Thin-Film solar panel exposed phenomenal differences and opened up new research vistas for the new PV cell & panels.

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