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Photovoltaic Cell in the Nutshell of Manufacturing Process

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Abstract: Photovoltaic cell (PV) 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. Day by day research work is going on for improvement in efficiency on these core component by the implementation of enhanced semiconductor materials and technology. 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 between a front glass plate and a rear polymer plastic back-sheet supported within an aluminium frame. The main objective of this article is to study of manufacturing of various types of PV cell.
Keywords: Semiconductor, sand, ingots, wafers, photovoltaic cell types, manufacturing process, grid

I. INTRODUCTION

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. 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. The need for a cleaner environment and the continuous increase in energy demands makes decentralized renewable energy production more and more important [22]. 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. 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 between a front glass plate and a rear polymer plastic back-sheet supported within an aluminium frame. The main objective of this article is to study of manufacturing of various types of PV cell [3] – [5].

A. *Insolation Map of India*

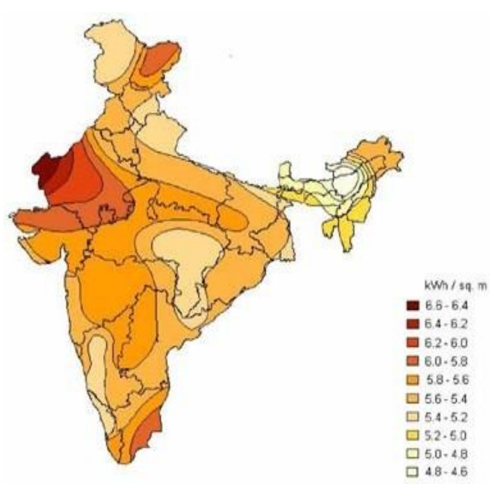


Fig. 1. Solar Map of India

Local location determines the amount of solar insolation (sunlight falling on the panel per day).

1) We generally receive 4-7 KWh of solar insolation per square meter in India as shown in Fig. 1.
2) The approximate solar insolation at your location can be ascertained by entering the latitude and longitude of your location at the NASA website.
3) To be absolutely certain of solar insolation at a particular site we would have to place sensors on-site that measure the actual insolation received over a period of time. These are an expensive and time-consuming process.

B. Solar Energy as Resources

1) Architecture and Urban Planning.
2) Agriculture and Horticulture.
3) Heating, Cooling and Ventilation.
4) Cooking.
5) Fuel Production.
6) Electricity Generation: Solar Energy can be used to generate electricity in two ways:

a) *Thermal Solar Energy:* Using solar energy for heating fluids which can be used as a heat source or to run turbines to generate electricity.
b) *Photovoltaic Solar Energy:* Using solar energy for the direct generation of electricity using photovoltaic phenomenon.

II. PHOTOVOLTAIC CELL

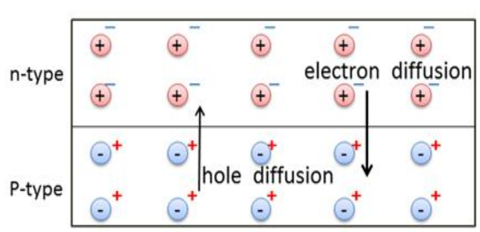
A photovoltaic cell (PV cell) is a specialized semiconductor diode that converts visible light into direct current (DC). Some PV cells can also convert infrared (IR) or ultraviolet (UV) radiation into DC electricity. Photovoltaic cells are an integral part of solar-electric energy systems, which are becoming increasingly important as alternative sources of utility power.

In most of solar cells, the absorption of photons takes place in semiconductor materials, resulting in the generation of the charge carriers and the subsequent separation of the photo-generated charge carries. Therefore, semiconductor layers are the most important parts of a solar cell [2].

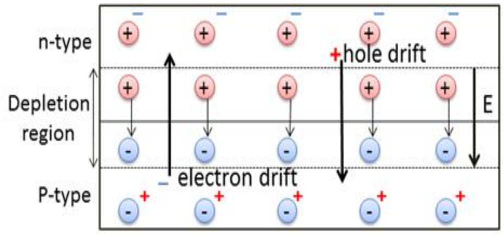
A solar cell is a device that converts the energy of sunlight directly into electricity by the photovoltaic effect [1]. Although there are many kinds of solar cells developed by using different semiconductor materials, the operating principle is identical. The most commonly known solar cell is configured as a large-area p-n junction made from silicon. When a piece of p-type silicon is placed in intimate contact with a piece of n-type silicon, a diffusion of electrons occurs from the region of high electron concentration (the n-type side) into the region of low electron concentration (p-type side). Similarly, holes flow in the opposite direction by diffusion [8], [10], [12].

This forms a diffusion current I_D from the p side to the n side Fig. 2 (a). When the electrons diffuse across the p-n junction, they recombine with holes on the p-type side. The diffusion of carriers does not happen indefinitely because of an electric field which is created by the imbalance of charge immediately on either side of the junction which this diffusion creates. The electric field established across the p-n junction generates a diode that promotes charge flow, known as drift current I_S, that opposes and eventually balances out the diffusion current I_D. The region where electrons and holes have diffused across the junction is called the depletion zone Fig. 2 (b).

The first PV cells were made of silicon combined, or doped, with other elements to affect the behaviour of electrons or hole (electron absences within atoms). Other materials, such as Copper Indium Di selenide (CIS), cadmium telluride (CdTe), and gallium arsenide (GaAs), have been developed for use in PV cells. The device is constructed in such a way that the junction can be exposed to visible light, IR, or UV [6].



(a) Diffusion current I_D from the p side to the n side



(b) Drift current I_S from n side to the p side and the depletion zone

Fig. 2 I_D, I_S, and depletion zone of a p-n junction

When a visible light photon with energy above the band-gap energy strikes a solar cell and is absorbed by the solar cell, it excites an electron from the valence band. With this newfound energy transferred from the photon, the electron escapes from its normal position associated with its atom, leaving a localized "hole" behind.

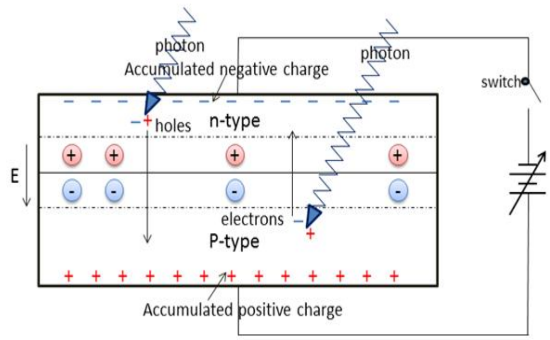


Fig. 3 Illustration of drift current as well as photo-generated current and voltage

When those mobile charge carriers reach the vicinity of the depletion zone, the electric field sweeps the holes into the p-side and pushes the electrons into the n-side, creating a photo-generated drift current. Thus, the p-side accumulates holes and the n-side accumulates electrons which creates a voltage that can be used to deliver the photo-generated current to a load as shown in Fig.2. At the same time, the voltage built up through the photovoltaic effect shrinks the size of the depletion region of the p-n junction diode resulting in an increased diffusion current through the depletion zone [13] – [16].

Hence, if the solar cell is not connected to an external circuit (switch in the open position in Fig. 3), the rise of the photo-generated voltage eventually causes the diffusion current I_D balancing out the drift current I_S until a new equilibrium state is reached inside a solar cell [1].

Electrodes connected to the semiconductor layers allow current to be drawn from the device. Large sets of PV cells can be connected together to form solar modules, arrays, or panels. The use of PV cells and batteries for the generation of usable electrical energy is known as photovoltaic. One of the major advantages of photovoltaic is the fact that it is non-polluting, requiring only real estate (and a reasonably sunny climate) in order to function. Another advantage is the fact that solar energy is unlimited. Once a photovoltaic system has been installed, it can provide energy at essentially no cost for years, and with minimal maintenance [7].

C. Types of Photovoltaic Cell (Based on Material)

1) Silicon
2) Thin-Film Photovoltaic
3) Perovskite Photovoltaic
4) Organic Photovoltaic
5) Quantum Dots
6) Multi junction Photovoltaic
7) Concentration Photovoltaic

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III.MANUFACTURING OF SILICON PHOTOVOLTAIC CELL

There are different types of material for manufacturing, such as mono silicon, poly silicon or amorphous silicon (AnSi). The first 2 kinds of cells have a somewhat similar manufacturing process [17]-[21].

A. Sand

It all starts with the raw material, which in our case is beach sand Fig. 4. Most photovoltaic cell are made of silicon, which is the main component in natural beach sand. Silicon is abundantly available, making it the second most available element on Earth. However, converting sand into high grade silicon comes at a high cost and is an energy intensive process. High-purity silicon is produced from quartz sand in an arc furnace at very high temperatures.

Fig. 4 beach sand

B. Ingots

The silicon is collected, usually in the form of solid rocks. Hundreds of these rocks are being melted together at very high temperatures in order to form ingots in the shape of a cylinder as shown in Fig. 5. To reach the desired shape, a steel, cylindrical furnace is used. In the process of melting, attention is given so that all atoms are perfectly aligned in the desired structure and orientation. Boron is added to the process, which will give the silicone positive electrical polarity.

Fig. 5 forming ingots in the shape of cylinder

C. Wafers

Wafers represent the next step in the manufacturing process. The silicon ingot is sliced into thin disks, also called wafers shown in Fig. 6. A wire saw is used for precision cutting. The thinness of the wafer is similar to that of a piece of paper. Because pure silicon is shiny, it can reflect the sunlight. To reduce the amount of sunlight lost, an anti-reflective coating is put on the silicon wafer.

Fig. 6 Wafers

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D. Solar Cell

The following processes will convert a wafer into a solar cell capable of converting solar power into electricity. Each of the wafers is being treated and metal conductors are added on each surface. The conductors give the wafer a grid-like matrix on the surface as shown in Fig. 7. This will ensure the conversion of solar energy into electricity. The coating will facilitate the absorption of sunlight, rather than reflecting it. In an oven-like chamber, phosphorous is being diffused in a thin layer over the surface of the wafers. This will charge the surface with a negative electrical orientation. The combination of boron and phosphorous will give the positive - negative junction, which is critical for the proper function of the PV cell.

Fig. 7 Solar Cell

IV. SILICON PHOTOVOLTAIC CELL

A. Principle p-n Junction Diode

From Fig. 8 the operation of a photovoltaic cell requires 3 basic attributes:

1) The absorption of light, generating either electron-hole pairs or excisions.
2) The separation of charge carriers of opposite types.
3) The separate extraction of those carriers to an external circuit.

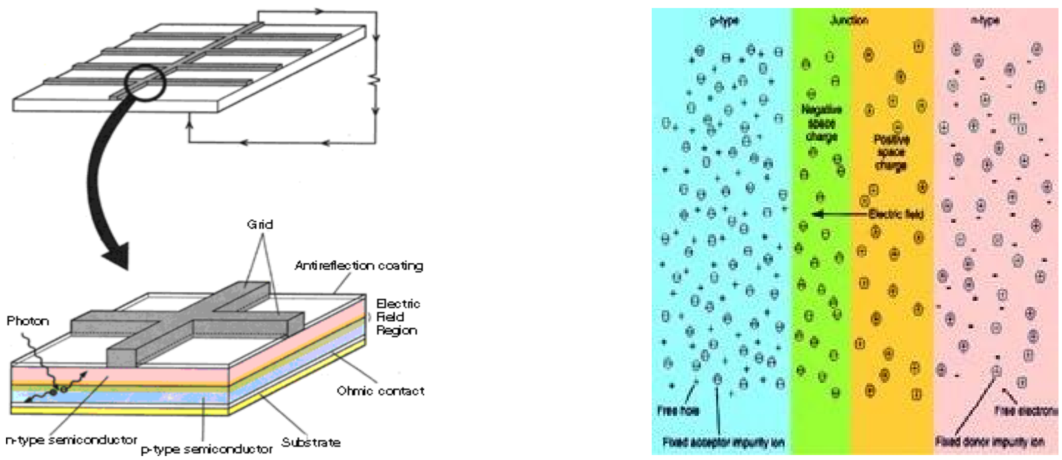

Fig. 8 Photovoltaic Cell operation

B. Types of PV Cell

1) *Mono Crystalline Silicon Cells:* The first commercially available solar cells were made from mono crystalline silicon, which is an extremely pure form of silicon Fig. 9. To produce these, a seed crystal is pulled out of a mass of molten silicon creating a cylindrical ingot with a single, continuous, crystal lattice structure.

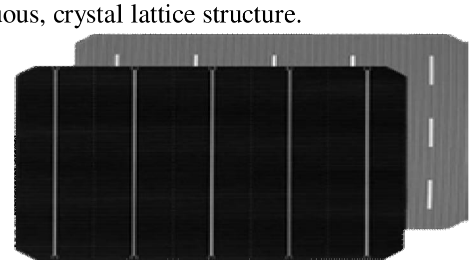

Fig. 9 Mono Crystalline Photovoltaic Cell

This crystal is then mechanically sawn into thin wafers, polished and doped to create the required p-n junction. After an anti-reflective coating and the front and rear metal contacts are added, the cell is finally wired and packaged alongside many other cells into a full solar panel. Mono crystalline silicon cells are highly efficient, but their manufacturing process is slow and labour intensive, making them more expensive than their poly crystalline or thin film counterparts. Various types of mono crystalline cells available in market are as under:

a) 2 Bus Bar Mono crystalline
b) 3 Bus Bar Mono crystalline
c) 4 Bus Bar Mono crystalline
d) 5 Bus Bar Mono crystalline (PERC) Multi-BB

2) *Poly Crystalline Silicon Cells:* Instead of a single uniform crystal structure, polycrystalline (or multi crystalline) cells contain many small grains of crystals as shown in Fig. 10. They can be made by simply casting a cube-shaped ingot from molten silicon, then sawn and packaged similar to Mono crystalline cells. Another method known as edge-defined film –fed growth (EFG) involves drawing a thin ribbon of polycrystalline silicon from a mass of molten silicon. A cheaper but less efficient alternative, polycrystalline silicon PV cells dominate the world market, representing about 70% of global PV productionin.

Fig. 10 Poly Crystalline Photovoltaic Cell

Different types of poly crystalline cells available in market are as under:

a) 2 Bus Bar Polycrystalline
b) 3 Bus Bar Polycrystalline
c) 4 Bus Bar Polycrystalline
d) 5 Bus Bar Polycrystalline

3) *Thin Film Cells:* Although crystalline PV cells dominate the market, cells can also be made from thin films—making them much more flexible and durable as shown in Fig. 11. One type of thin film PV cell is amorphous silicon (a-Si) which is produced by depositing thin layers of silicon on to a glass substrate. The result is a very thin and flexible cell which uses less than 1% of the silicon needed for a crystalline cell. Due to this reduction in raw material and a less energy intensive manufacturing process amorphous silicon cells are much cheaper to produce. Their efficiency, however, is greatly reduced because the silicon atoms are much less ordered than in their crystalline forms leaving 'dangling bonds' that combine with other elements making them electrically inactive. These cells also suffer from a 20% drop in efficiency within the first few months of operation beforestabilizing, and are therefore sold with power ratings based on theirdegraded output.

Fig. 11 Poly Crystalline Photovoltaic Cell

Various types of mono crystalline cells available in market are as under:

a) Cadmium Telluride (CdTe)
b) Amorphous Silicon (a-Si)
c) Copper Indium Diselenide (CIS)
d) Gallium Arsenide (GaAs)

V. CONCLUSIONS

A photovoltaic cell is a device that converts the energy of sunlight directly into electricity. Although there are many kinds of PV cells developed by using different semiconductor materials, the operating principle is identical. We have focused on theoretical concept of PV cell and manufacturing aspects as well. Indeed, global study of renewable energy sources is necessary so that one can analyse the fragile section of the system design and hub on that segment to achieve the target. If we focus on the off-grid solar power at the same time we are gaining on-grid power and able to provide that power to the needy one in remote areas. Only the drawback is it requires huge area for installation and initial cost is high. There is neither fuel nor labour charges have to be born to harness the Power. Therefore, for huge expansion of this engineering field from manufacturing unit to utilization sector, Central Government and State Government should offer incentive programs to make "green" energy a more economically viable option.

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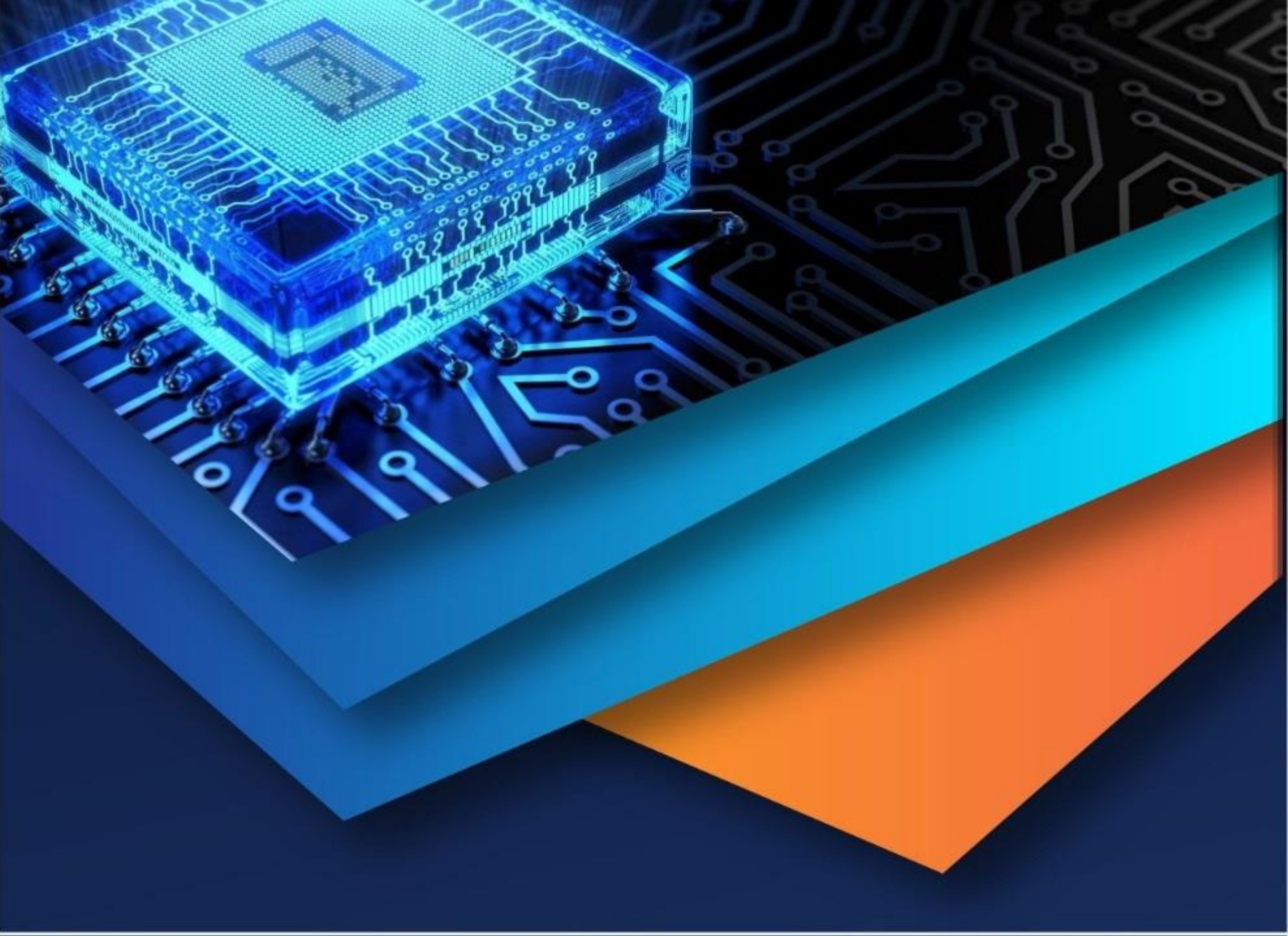
REFERENCES

[1] S P Sukhatme, J K Nayak "Solar Energy: Principles of thermal collection and storage"- Third Edition, published by Tata Mc-Graw Hill, 2010.
[2] M. H. Rashid. "Power Electronics Circuit, Device and Application" Third Edition, Published by pearson Education Pte. Ltd. 2004.
[3] SOTERIS A. KALOGIROU, Solar Energy Engineering:Processes and Systems.2nd edition (25 October 2013). Academics Press 2nd edition (25 October 2013).
[4] DR. SUBHASH L. GADHAVE, Renewable Energy Engineering, 3rd edition (January 2019) Technical publication.
[5] MICHAEL BOXWELL, Solar Electricity: A simple, practical guide to solar energydesign and installation solar photovoltaic systems. Greenstream Publishing; Revised edition (7 January 2019).
[6] Marcelo Gradella Villalva, Jonas Rafael Gazoli, and Ernesto Ruppert Filho, "Comprehensive Approach to Modeling and Simulation of Photovoltaic Arrays", IEEE Transactions on Power Electronics, Vol. 24, No. 5, pp. 1198-1208, May 2009.
[7] Omar Abdel-Rahim, Mohamed Orabi, Mahrous E. Ahmed. "High Gain Single - Stage Inverter for PV AC Modules", IEEE Transactions, 2011.
[8] Anwarul M. Haque, M. V. Makwana, Dr. Rahul R Dubey, "Solar Power: An Ever-lasting Non-Conventional Energy Resource" published in the proceedings of National Conference on Innovative & Emerging Technologies 'NCIET-2014' organized by Smt. S. R. Patel Engineering College- Dabhi, Mehsana (Gujarat) ISBN: 978-81-925650-0-2, pp. 296-300, January-2014.
[9] Huiying Zheng, "Solar Photovoltaic Energy Generation and Conversion —From Devices to Grid Integration" Dissertation for Doctor of Philosophy, Department Of Electrical & Computer Engineering, University Of Alabama, Tuscaloosa, Alabama, pp 6-8, 2013.
[10] Anwarul M Haque, Devendra Nagal, Dr. Swati Sharma "Photovoltaic system: A source to Harness Solar Energy" proceedings of 'International Conference on Emerging Trends in Scientific Research (ICETSR-2015)', published by Institute of Research and Development (IRD-India) ISBN 978-2-642-24819-9, pp. 73-78, 17-18 December 2015.
[11] B. Ankaiah et.al. "Grid Interconnection at the Distribution level with Power Quality Improvement for Renewable Energy Sources", National Conference on Emerging Trends in Power System" (NCETPS-2013), pp.90 – 95, March 2013.
[12] Anwarul M Haque, Devendra Nagal, Swati Sharma, "Power Electronics Interface for PV Systems", published in the proceeding of 2nd International Conference on Multidisciplinary Research & Practice (2ICMRP-2015) & International Journal of Research and Scientific Innovation (IJRSI), Volume III, Issue 1, ISSN 2321-2705, pp. 268-274, 24th December 2015.
[13] Anwarul M Haque, Dr. Rahul Dubey "Power Electronics – A Revolutionary Technology for Engineers and Researchers" published in *PEPCCI-2013* (ISBN-978-81-923462-1-2), January-2013.
[14] Anwarul Omar Abdel_Rahim et.al. "High Performance Power Conditioning for Grid Connected PV Module" MEPCON'10 Cairo University, Egypt, Paper ID 274, pp. 728– 733, December 2010.
[15] Anwarul M Haque, Dr. Swati Sharma, Devendra Nagal, "Power Electronics: A Serving Tool to Improve the Efficiency of Solar Power System", Proceedings of International Conference on Emerging Technologies in Engineering, Biomedical, Medical and Science (ETEBMS - 16) & International Journal for Technological Research in Engineering (IJTRE), Volume 16, Issue 6 (special issue), ISSN (Online): 2347-4718, pp 19-26, March 2016.

[16] Anwarul M Haque, Devendra Nagal, Dr. Swati Sharma "Photovoltaic system: A source to Harness Solar Energy" proceedings of 'International Conference on Emerging Trends in Scientific Research (ICETSR-2015)', published by Institute of Research and Development (IRD-India) ISBN 978-2-642-24819-9, pp. 73-78, 17-18 December 2015 & IRD-India:: International Journal of Electrical, Electronics and Computer Systems (IJEECS), Volume 4, Issue-1, ISSN (Online): 2347-2820, pp. 56-61, 2016.
[17] SINO VOLTAICS, Manufacturing of photovoltaic cells https://sinovoltaics.com/solar-basics/solar-cell-production-from-silicon-wafer-to-cell/
[18] ENERGY EFFICIENCY AND RENEWABLE ENERGY: Solar Photovoltaic manufacturing basics, https://www.energy.gov/eere/solar/solar-photovoltaic-manufacuring-basics
[19] LOOM SOLAR: How are Solar Panels made, https://www.loomsolar.com/blogs/collections/how-are-solar-panels-made-in-india
[20] GOLDI SOLAR: manufacturing of solar panels,https://goldisolar.com/
[21] GREENMATCH: All about photovoltaic cell, https://www.greenmatch.co.uk/blog/2014/12/how-are-solar-panels-made
[22] E Manual by Topsun "SOLAR GRID POWER PLANT" 2010.



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