STUDY OF MODERN SOLAR TECHNOLOGIES: PERC and HJT

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Abstract - *For the purpose of reducing carbon emissions, clean energy technologies are crucial. The electricity generation sector in today's trend has started the deployment of solar photovoltaic (PV) as an alternative green source of energy on a large scale. The efficiency of the PV cell plays an important role in the manufacturing of PV modules and material selection as it affects the cost reduction for the processing of cells.*

This study compares important characteristics that have a substantial impact on the performance of solar cells after analyzing different emerging technologies in the field of solar PV. The article also tries to discuss, solar panel types; their working and emphasize the various applications and methods to promote the benefits of solar energy. By implementing technical solutions, photovoltaic applications and structures will continue to advance, improving their effectiveness and efficiency and enabling them to handle a range of problems and deficiencies.

***Key Words*: Green energy, Modern solar, Photovoltaics, Electricity, Efficiency.**

1. INTRODUCTION

Sun is an unlimited source of energy which is available at no cost. The primary advantage of solar energy over other traditional power sources is that it be produced directly using solar photovoltaic cells (PV), which allows sunlight to be directly transformed into solar energy. Through the development of solar cells, panels, and modules, there has been a significant amount of study done to integrate the solar energy for daily usage. In comparison to the cost of various fossil fuels and oils during the past ten years, the most advantageous aspect of solar energy is that it is readily available and free to the general public. Additionally, compared to traditional energy production technologies, solar energy requires significantly less manpower costs.

Thus, high power conversion efficiency of solar cells is essential for producing more electrical power while occupying a smaller space, which lowers the overall cost of producing solar energy.

2. PHOTOVOLTAICS

Photovoltaic (PV) cells generate electricity directly from sunlight via an electronic process. The PV cell is composed of semiconductor material; the "semi" means that it can conduct electricity better than an insulator but not as well as a good conductor like a metal. There are several different semiconductor materials used in PV cells. By using solar radiation to liberate electrons from these semiconductor materials, electrical circuits may be created that can power electrical appliances or feed electricity into the grid.

2.1 Photovoltaics Hierarchy

Photovoltaic Cell:

The photovoltaic cells converts solar radiation directly into electricity. It consists various kinds of semiconductor materials depending upon the advancements in technology. It has two types: positive charge (P-type) and negative charge (N-type).

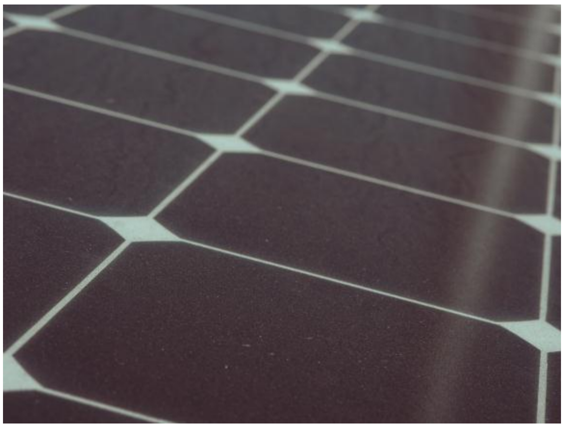

Fig -1: Photovoltaic cell (zoomed)

Photovoltaic Module:

A PV module is the fundamental component of a PV system and is made up of solar cell circuits sealed in an ecologically friendly laminate. To accommodate the energy demand, several PV modules are often stacked in series and parallel.

Fig -2: Photovoltaic module

Photovoltaic Panel:

An arrangement of photovoltaic cells installed in a frame work for installation is referred to as a solar panel.

Photovoltaic Array:

It contains several amount of PV cells in series and parallel connections. Series connections are responsible for increasing the voltage of the module whereas the parallel connection is responsible for increasing the current in the array. The total surface area of the array is directly proportional to the solar electricity produced by it.

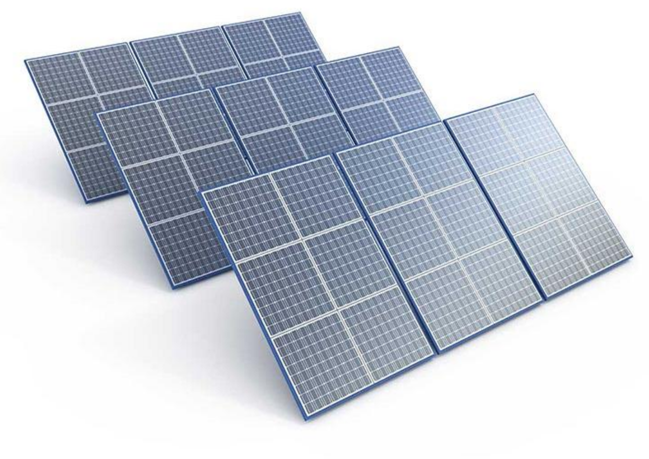

Fig -3: Photovoltaic array

A PV cell's efficiency may be calculated as the ratio of the electrical power it produces to the energy from the light coming on it. This ratio shows how well the cell converts energy from one form to another.

The properties of the light such as its intensity, wavelengths and other cell performance factors determine how much power will be generated by PV cells. One of the important factors of PV semiconductors is the bandgap, which describes what wavelengths of light the semiconductor can absorb and convert to electrical energy. The PV cell can effectively utilize all of the available energy if the semiconductor's bandgap matches the wavelengths of light falling on it.

Over the years, numerous technologies that increase the efficiency of photovoltaic (PV) have been developed by researchers.

Let us see different types of photovoltaics developed and are in most common use.

2.2 Types of Photovoltaics

Crystalline PV Cells:

a) Monocrystalline PV Cell:

Monocrystalline solar cells are made from single crystalline silicon. As they are frequently colored and have cylindrical cells, they have a highly unique look. Manufacturers remove the four sides of the monocrystalline cells to maintain low prices and maximum performance. They get their recognizable look as a result.

Fig -4: Monocrystalline cells

b) Polycrystalline PV Cell:

Polycrystalline silicon cells (multi-crystalline silicon) are created from cast square ingots, which are large chunks of molten silicon that have been properly cooled and solidified. They are made up of tiny crystals, which give the substance its classic metal-flake appearance. The most typical kind of solar cell is polysilicon, which is less costly than monocrystalline silicon but also less efficient.

Fig -5: Polycrystalline cells

Thin Film PV Cells:

The process of creating a thin-film solar cell involves depositing one or more thin layers of PV material onto a support material like glass, plastic, or metal. There are two main types of thin-film PV semiconductors are:

- Cadmium telluride (CdTe)
- Copper indium gallium diselenide (CIGS)

The efficiency rates for thin film solar cells typically range from 7% to 13%, depending on the technology employed.

a) Perovskite PV Cell:

Perovskite solar cells are a type of thin-film cell and are referred by their distinctive crystal structure. The layers of materials used to construct perovskite cells are printed, coated, or vacuum-deposited onto an underlying support layer called the substrate.

Perovskite solar cells' efficiency have increased in the lab more quickly than those of any other PV material, from 3% in 2009 to over 25% in 2020 [report by energy.gov]. Scaling-up costs for perovskite solar cells are also anticipated to be exceedingly low, making them a highly alluring alternative for commercialization.

Fig -6: Perovskite cells

Multi-Junction PV Cells:

Multi-junction cells are made up of several thin films each of which is basically a solar cell built on top of another. Each layer has a distinct band gap energy that enables it to absorb electromagnetic radiation across a particular region of the spectrum, making greater use of sunlight than single-junction cells.

The light that is not absorbed by the first semiconductor layer is collected by a layer below it, allowing multijunction solar cells to achieve record efficiency levels. Multijunction solar cells have shown efficiency of over 45%, but they are expensive and difficult to produce, thus they are only used in space exploration.

Fig -7: Multi-junction panel of Dawn spacecraft

Concentration PV Cells:

Concentration PV, sometimes referred to as CPV, concentrates sunlight onto a solar cell by utilizing a mirror or lens. Less PV material is needed since sunlight is concentrated onto a smaller area. The highest overall efficiencies are attained using CPV cells and modules because PV materials become more effective when light falls becomes more concentrated.

CPV systems are categorized according to the amount of their solar concentration. They are as follows:

- Low Concentration PV (LPV)
- Medium Concentration PV (MPV)
- High Concentration PV (HPV)

Solar trackers and cooling systems are frequently used with CPV systems to further boost efficiency. CPV requires more expensive materials, manufacturing techniques, and ability to track the movement of the sun, so cost advantage over today's high-volume silicon modules is becoming a challenge.

Fig -7: Concentration PV module

Organic PV Cells:

Organic PV, or OPV, cells are made of organic compounds rich in carbon. They can be designed to improve a particular PV cell property, such as bandgap, transparency, or color.

In comparison to inorganic materials, the energy conversion efficiencies obtained to date utilizing conductive polymers are quite low. However, Konarka Power Plastic reached efficiency of 8.3% [1]. Although OPV cells are currently only about half as efficient and have shorter working lives as crystalline silicon cells, they are less expensive to produce in large quantities.

An organic cell's active area is made up of two components: an electron acceptor and an electron donor. In contrast to most other solar cell types, when a photon is transformed into an electron hole pair, which normally occurs in the donor material, the charges tend to remain coupled in the form of an exciton, separating when the exciton diffuses to the donor-acceptor interface. The effectiveness of such devices is often constrained by the short exciton diffusion lengths of most polymer materials.

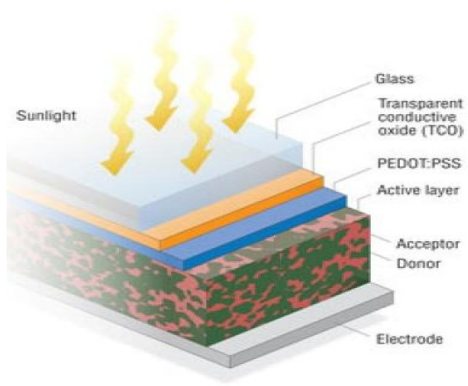

Fig -8: Organic PV cell structure

Quantum Dots PV Cells:

Quantum dot solar cells conduct electricity through tiny particles of different semiconductor materials just a few nanometers wide, called quantum dots. Quantum dots provide a new technique of processing semiconductor materials, they are currently not particularly effective due to the difficulty of establishing an electrical connection between them. They can be applied to a surface using a spin-coat technique, a spray, or roll-to-roll printers like those used to print newspapers.

Quantum dots are available in a range of sizes, and their bandgap can be varied, allowing them to absorb light that is challenging to absorb. They can be combined with other semiconductors cells, such as perovskites, to enhance the performance of a multijunction solar cell.

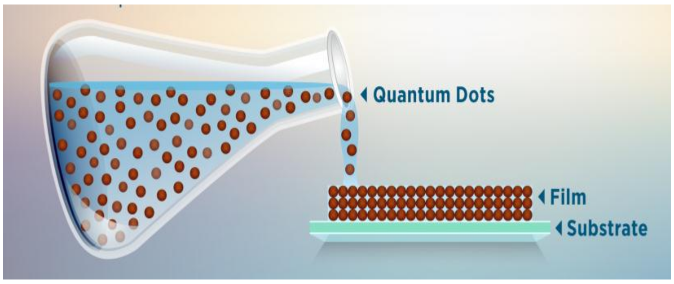

Fig -9: Quantum dots PV cell

2.3 Photovoltaics Material

In 95% of the modules currently supplied, silicon is by far the most common semiconductor material used in solar cells. The building blocks of crystalline silicon cells are silicon atoms interconnected to create a crystal lattice. This lattice offers a well-organized structure that improves the efficiency of turning light into energy.

P-type and N-type silicon are combined in every solar cell to create the fundamental p-n junction, which is essential to the solar cell's operation. The difference is that P-type cells use an n-type silicon base with an ultra-thin layer of P-type silicon, whereas N-type cells use an n-type silicon base with an ultra-thin layer of P-type silicon.

Currently, silicon-based solar cells provide a combination of high efficiency, low cost, and extensive lifespan. Modules can survive for at least 25 years and continue to generate more than 80% of their initial power after that.

3. MODERN SOLAR TECHNOLOGIES

In the modern electronic age, when industrialization is expanding quickly, we can see ongoing advancements in photovoltaic cell technology. The third-generation technologies, which are the most recent trend, have increased overall efficiency, weight reduction, decreased manufacturing cost, and capacity to entrap maximum light under various climatic circumstances. After thorough investigation into many technologies that are now accessible and the various metrics that indicate their performance, the two most recent developing solar technologies have been taken into consideration for this study.

3.1 Passivated Emitter Rear Cell (PERC)

3.1.1 Introduction

Power conversion efficiency (PCE) development is essential for the expansion of the photovoltaic (PV) technology. Standard solar cells with an aluminum back surface field (Al-BSF) have been deployed for decades using this characteristic feature. Al-BSF has recombination losses, which lowers PCE and present a significant issue for the PV sector. Passivated emitter rear cell (PERC), a modern fundamental technology, is employed to address the drawbacks of the conventional solar cell. Due to its ability to minimize optical and recombination losses in comparison to a regular solar cell, it has emerged as a prominent PV technology. However, compared to all other PV technologies, PERC is more compatible and capable of capturing more light.

Additionally, advancements in the structural methods used in PERC solar cells will increase their demand by the 2030s. Various passivating substances, including SiO_2, Al_2O_3, and SiNx, are employed as the passivation layers in PERC solar cells. Such passivating materials improve the PCE of PERC solar cells, lower light reflectance while increasing light trapping, and decreasing rear side recombination losses.

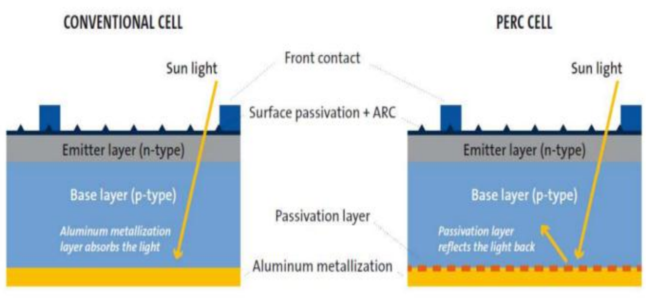

Fig -10: Differentiation of PERC solar cell from conventional solar cell

The primary benefit of the PERC type, from the perspective of production, is that it does not need significant changes to the way that manufacturing procedures are performed, i.e., only few modifications can be needed if the manufacturing processes are altered [2]. As a result, it encourages producers to create PERC cells with a significantly lower cost of production. It is constructed similarly to a standard solar PV cell and employs silicon wafers to produce energy using solar radiations. In comparison to mono-crystalline PV cells, the main distinction is that PERC cells have one additional rear surface passivation layer to enhance cell efficiency [3].

3.1.2 Construction and Working

In comparison to a typical Al-BSF solar cell, the PERC solar cell's PCE was improved by structural and technical advancements. By incorporating a rear passivation layer onto a conventional solar cell, PERC technology increases efficiency. The Si-wafer (p or n-type), antireflection coating (ARC), passivation layer on the front and rear side contact, and doped emitter make up the structural architecture of the PERC solar cell as illustrated in Fig. 11. Furthermore, in the PERC solar cell, several approaches including surface texturing and passivation are used to enhance light trapping and light absorption [4].

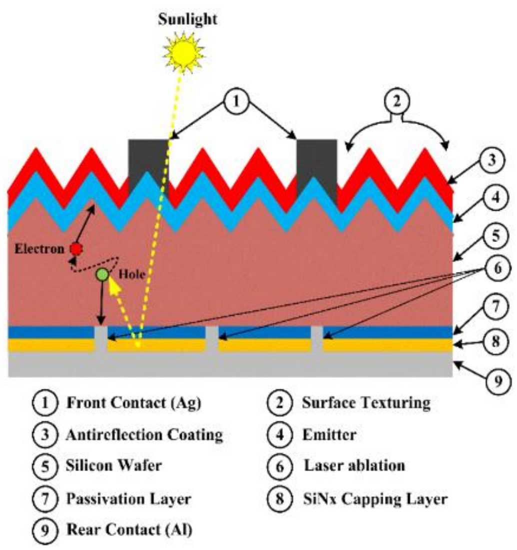

Fig -11: Structure design of PERC solar cell with passivated layer, texturing and rear contact

From the perspective of the working process, there are three possible outcomes for photons that impact the device's surface: i) absorption, ii) reflection, iii) transmission. Simply creating electron-hole pairs from the photons that are being absorbed produces the current. As they do not contribute to the production of current, photons that are reflected backward from the front surface are regarded as lost in conventional solar cells. As they pass through the apparatus and are not used to generate current, transmitted photons with photon energies below the bandgap are also counted as losses [4].

3.1.3 Advantages of PERC

Recombination of charge carriers also reduces conversion efficiency in the common solar cell. The Al-BSF's primary flaw is that Si-wafer typically absorbs light up to a wavelength range of 1180 nm; however, light with a wavelength greater than 1180 nm is transmitted through the wafer and absorbed by the back-metal sheet, producing heat as illustrated in

Fig. 12. Therefore, this heat loss lowers the device's efficiency. The PERC solar cell has various advantages and can solve these issues. The idea that incoming light with photon energies below the bandgap is regarded as unabsorbed light in a conventional solar cell is seen in Fig. 12.

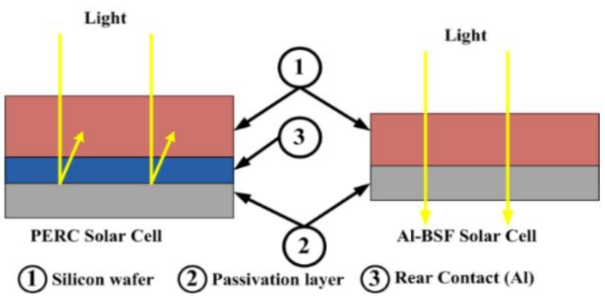

Fig -12: Concept of light absorption with passivation layer in PERC solar cell and without passivation layer in Al-BSF solar cell

The passivation layer provides this unabsorbed light a second chance to be absorbed in the PERC solar cell's active area. This procedure enhances the likelihood that an electron-hole pair will form, which in turn improves the device's total conversion efficiency [5]. Additionally, the effectiveness of passivation schemes is crucial to the performance of PERC solar cells, and an efficient passivation scheme must be used to lower carrier recombination on the rear side.

3.2 Heterojunction Technology (HJT)

3.2.1 Introduction

The recent market study states that the average consumer demands and favors the M2 size of solar cells, which has been remained same since past 10 years. However, the need for more power production and a decline in the levelized cost of electricity (LCOE) of solar PV made change inevitable. The industry started to adopt inspiration from the semiconductor industry in order to improve wafer size (see figure 13), which would directly boost power output. Within a period of around five years, the wafer's size development started increasing rapidly and changed from 156.75 mm/157 mm to an intermediate size of 161.75 mm/166 mm, and then on to 182 mm/210 mm. The PV module may have hit its size limits with the current conventional cell sizes, which range from 2.2 to 2.4 meters in length to 1.1 to 1.3 meters in width [6]. Due to the fact that end customers continue to demand higher power output, any additional increases in wafer size will be accompanied by an equal increase in module size. The economic benefit from such an improvement would be negated by limits associated with the increase in module size, such as the cost of manufacturing, one's own weight, handling restrictions, etc. Additionally, it is essential to pay attention to alternative technologies as PERC cells are approaching their maximum levels of efficiency.

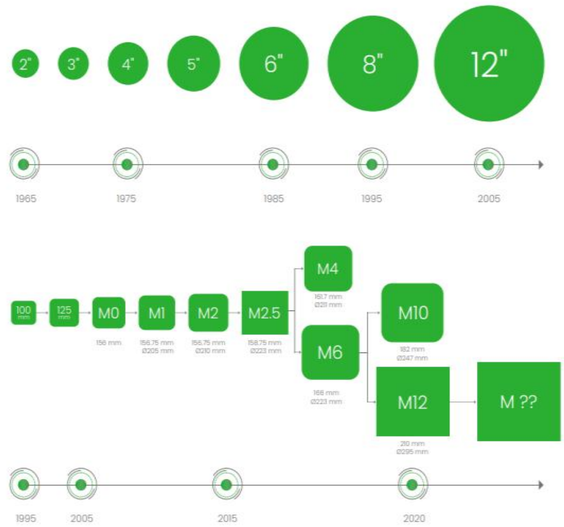

Fig -13: Improvement in wafer size of solar cell

3.2.2 Construction and Working

The HJT solar cell is composed of many layers that are fused together, as suggested by its name. Crystalline silicon forms the core of the cell, which is surrounded on both sides by thin films of amorphous silicon. This indicates that a better cell is produced as a result of combining the advantages of improved light absorption (from the crystalline layer) and better passivation capabilities (from the amorphous layer). The next generation of modules may finally be unlocked with the help of HJT cells, whose light conversion efficiency record now stands at more than 26.5 percent. But efficiency enhancement is only one of its many benefits. Before going through all of its benefits, let's take a moment to grasp how the HJT cell is made. Only after that all of its benefits can be discussed.

A silicon absorber made of n-type crystalline silicon is located in the center of the HJT cells (see Figure 15). It forms a p/i/n/i/n+ stacking because it contains both intrinsic (neutral) and doped amorphous silicon layers on either side. Crystalline silicon has the virtue of higher light absorption, which means it can absorb nearly all of the light that strikes it, producing more free carriers. There is inherent hydrogenated amorphous silicon (a-si:H(i)) immediately around the n-type crystalline silicon. There will be a loss of carriers due to the high resistance of bare amorphous silicon, despite the fact that it is simple to deposit on crystalline silicon and has many surface flaws. Amorphous silicon's bandgap is increased while the defect density is significantly reduced when it is hydrogenated in comparison to the crystalline silicon.

Better surface passivation is made possible by the intrinsic (or undoped) layer of a-si(H)(I), which implies that the departed electrons and holes does not tend to recombine before being collected. The hydrogenated amorphous silicon layers, which form the P-N junction in solar cells, are located after the intrinsic layers. Part of the light that strikes the top p-type layer is collected through inter-layer reflection as well as direct illumination. Similar to the top layer, the bottom layer likewise provides surface passivation while capturing any leftover light that may have gone through the top two levels. The a-Si:H layer's weak conductivity is typical and could not be enough to allow for a satisfactory carrier (charge) collection through the metal contacts. This deficiency is supported using transparent conductive oxide (TCO).

On both sides of the a-Si:H layer, the TCO layer is deposited. They function by encouraging a good ohmic contact, allowing the transfer of lateral carriers, and acting as an anti-reflective coating (ARC). Indium tin oxide (ITO) is the most widely used of the industry standard TCOs. It is possible for the top and bottom TCOs to have differing thicknesses. A reasonable sheet resistance for carrier movement, adequate transparency to prevent anomalous light absorption, and increased light trapping are all achieved by optimizing the top layer of the TCO's thickness and oxygen content.

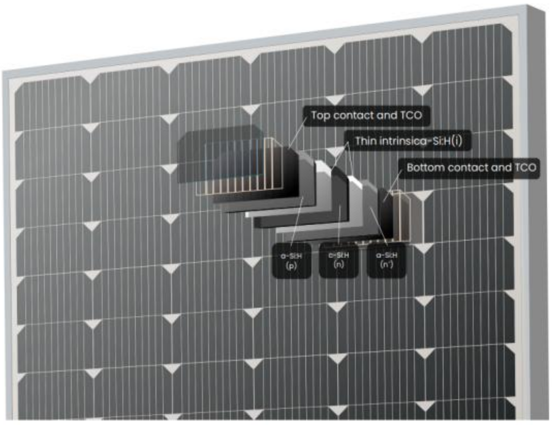

Fig -14: Structure design of HJT solar cell

3.2.3 Advantages

Now that the structure is evident, it's time to comprehend the benefits that HJT provides:

- The main benefit of HJT is that it uses less energy than traditional methods because of the thin film depositions on each side of the device. A lot of energy is saved while making HJT cells since they are manufactured at a temperature of under 250 °C. Comparing these cells to the industry standard PERC, the number of processes needed to make them is cut in half. In addition, when stringing the HJT cells onto a module, they are once again treated at roughly the same temperature.
- One of the most important solar module parameters is temperature coefficient. It establishes the degree of power loss that the cell or module would experience if the temperature increased. Numerous variables, including series and shunt resistance, the degree of surface passivation, the quantity of interstitial flaws, etc., affect temperature coefficient. The HJT cell offers the lowest thermal coefficients of any known solar PV technology because each interlayer works to improve light absorption, surface passivation at low series, and larger shunt resistances.
- The HJT modules are recognized to have the lowest power degradation rates since there are essentially no known mechanisms that may effectively damage them. Additionally, they are regarded to be more reliable than similar technology.

4. COMPARATIVE STUDY BETWEEN PERC AND HJT

4.1 Technical Comparison Between PERC and HJT

Several different factors play a vital role in the efficiency of the overall PV module. Even a slight change in any one of these factors may drastically affect the performance and the output generated. Some of these important factors considered in this study are explained in brief along with their comparative study to give a clear idea about PERC and HJT technologies.

1. **Bifaciality:** When subjected to the same irradiance, the bifaciality factor (percent) is defined as the ratio of rear efficiency to front efficiency.
2. **Micro Crack Resistance:** Micro-fractures, often referred to as micro-cracks, are a kind of solar cell deterioration that can have an impact on a solar photovoltaic (PV) system's lifetime and energy production. The ability to resist such crack generation over a period of time is called Micro crack resistance.
3. **Long Term Power Degradation Rate:** Degradation is the term used to describe the gradual decrease in solar panel output. According to NREL studies, solar panels degrade at a median rate of around 0.5% per year; however, in hotter areas and for rooftop systems, the rate may be greater.
4. **LID:** PV modules have a performance decline known as light-induced degradation (LID) during their first few hours of exposure to the sun.
5. **Low Light Performance:** The ability of the PV cell to function when the intensity of light changes can have a major impact on the total efficiency of the module. This terminology is termed as low light performance factor.

The following table represents these parameters which gives an idea about the overall efficiency of the PV technologies considered in this study.

Table no. - 1: Comparative Tabulation of PV Technologies

Sl. No	Module Properties	p-PERC	n-PERC	n-HJT
1	Bifaciality	70%	80%	>90%
2	Micro crack resistance	No	No	Yes
3	Long term power degradation rate	High	High	Low
4	LID/LeTID/PID	Yes	Yes	No
5	Low light performance	Good	Good	Better

4.2 Commercial Comparison Between PERC and HJT

As the above theoretical data shows that HJT is superior in many terms than PERC, it is still important to compare both the technologies commercially. The following comparison is based on the case study by Waaree technologies [6].

The study was done on 1 MW power plant in Gujarat. All the factors like module arrangement, tilt angle, loading ratio, etc. were kept constant for- better comparative results. The result gives graph shown in Fig:15. The temperature losses in a mono PERC module-based plant are around 50% more in terms of power plant output. This energy loss will be more when considered for larger capacity power plants [6].

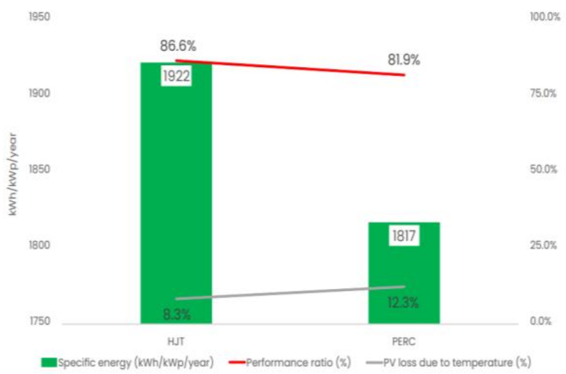

Fig -15: Comparison between PERC and HJT

With HJT's improved surface passivation & low light performance coupled with lowest initial degradation, HJT-based power plants produce 1922 kWh/kWp/year of specific energy, which is about 6% more than PERC-based power plants.

Finally, talking about performance ratio (PR) which indicates how good or bad a plant is performing. The PR of HJT based plant is 4.7% greater than the PERC based plant which clearly shows the advantages of utilizing HJT technology. With such advantages, HJT stands out tall when compared to its competitors in almost all the fields.

5. CONCLUSIONS

The comparison of PERC and HJT, the two advanced solar technologies, is given the utmost attention during this study. The following conclusion can be deduced by the same.

- The growth of solar cell absorption, conversion efficiency, heat transfer, performance of parameters under varied situations, and production costs are only a few of the difficulties that needs to be overcomed to increase PV efficiency in both the technologies.
- These new PV models (HJT and PERC) have the ability to work independently or in combination with other cell models to improve competency.
- While solar energy has enormous promise as a clean, abundant, economical energy source, it presents formidable basic research challenges in designing materials and in understanding the electronic and molecular basis of capture, conversion, and storage before its promise can be realized.

REFERENCES

[1] Konarka Power Plastic PV-tech.org. Retrieved 7 May 2011.

[2] A. Blakers, Development of the PERC Solar Cell, IEEE J. Photovoltaics PP (2019) 1–7.

[3] A.T. Sankara Subramanian, et al. "Performance analysis of various photovoltaic configurations under uniform shading and rapid partial shading formations", Biosci. Biotech. Res. Comm. Special Issue Vol 13 No (3) 2020 Pp-185-192

[4] S. Kashyap et, al, Comprehensive Study on Development of PERC Solar Cells -IEEE 2020

[5] H. Tang, Y. Liu, Q. Chen, et al., "Optical design of inverted pyramid textured PERC solar cells," ACS Applied Electronic Materials, 2019

[6] Heterojunction PV Module white paper by Waaree Technologies

[7] Shaikh, Mohd Rizwan & et al (2017). A Review Paper on Electricity Generation from Solar Energy. IJRASET

[8] Ashok Upadhyay, Arnab Chowdhury - Solar Energy Fundamentals and Challenges in Indian IJSRP, Volume 4, Issue 10, October 2014 1 ISSN 2250-3153

[9] M. A. Green, “The passivated emitter and rear cell (PERC): From conception to mass production,” Sol. Energy Mater. Sol. Cells, vol. 143,pp. 190–197, 2015.

[10] G.K. Singh, “Solar power generation by PV technology”