# RECENT ADVANCES IN SOLAR PV TECHNOLOGY: RESEARCH AND FUTURE TRENDS

**Saad Ahmad**[1]

[1] Department of Electrical Engineering, Iqra National University, Peshawar 25000, Pakistan

**Abstract**

Industrial development and population growth have led to a surge in the global demand for energy. Moreover Global environmental concerns coupled with steady progress in renewable energy technologies, are opening up new opportunities for utilization of renewable energy resources. Solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources till date. The ability to generate electricity from sunlight is a relatively new and exciting technology that offers many new opportunities in generating green‘ electricity. Presently, extensive research work is going for efficiency improvement of solar cells for commercial use. The efficiency of mono crystalline silicon solar cell has showed very good improvement year by year. It starts with only 15% in 1950s and then increase to 17% in 1970s and continuously increases up to 28% nowadays. The growth in solar photovoltaic technologies including worldwide status, materials for solar cells, efficiency, factor affecting the performance of PV module, overview on cost analysis of PV and its environmental impact are reviewed in this paper.

**Keywords:** Solar cells; PV materials; Renewable energy; PV cell efficiency

---

## 1 Introduction

In order to secure the future for ourselves and generations to follow, it is widely accepted that we must act now to reduce energy consumption and substantially cut greenhouse gases, such as carbon dioxide. World leaders have resolved to tackle global warming by signing the Kyoto Protocol, an international treaty committing signatory countries to reduce their emissions of carbon dioxide and five other greenhouse gases from 1990 levels. The UK is a signatory of the Kyoto Protocol and is actively involved in measures to meet our commitment of a 12.5 per cent cut in greenhouse gas emissions by the period 2008-12. However, there is no single solution for the UK or the 155 other countries also aiming to reduce their emissions. Considering the scenario of favorable Government policies and reduction in prices of solar PV modules, there is a huge interest for the installation of solar PV systems. In order to enable the deployment of solar PV systems in India, there is a need for large number of trained people in the solar PV area. The trained manpower is required at various levels ranging from managers and researchers to engineers and technicians. The training is required in various disciplines ranging from design and engineering through to installation, testing, operation and maintenance. Solar power is the conversion of energy from sunlight into electricity, either directly using photovoltaic (PV), indirectly using concentrated solar power, or a combination. Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaic cells convert light into an electric current using the photovoltaic effect [1]. The International Energy Agency projected in 2014 that under its "high renewable" scenario, by 2050, solar photovoltaics and concentrated solar power would contribute about 16 and 11 percent, respectively, of the worldwide electricity consumption, and solar would be the world's largest source of electricity. Most solar installations would be in China [2] now-a-days building integrated photovoltaic (BIPV) system are in great demand which incorporate photovoltaic properties into building materials such as roofing, siding, and glass and thus offer advantages in cost and appearance as they are substituted for conventional materials in new construction. Moreover the BIPV installations are architecturally more appealing than roof-mounted PV structures. Yoo et al. [3] proposed a building design to have the PV modules shade the building in summer, so as to reduce cooling loads, while at the same time allowing solar energy to enter the building during the heating season to provide daylight and conducted an analysis of the system performance, evaluation of the system efficiency and the power output. Bakos et al. [4] described the installation, technical characteristics, operation and economic evaluation of a grid-connected building integrated photovoltaic system (BIPV) and the technical and economical factors were examined using a computerized renewable energy technologies (RETs) assessment tool. Ordenes et al. [5] analyzed the potential of seven BIPV technologies implemented in a residential prototype simulated in three different cities in Brazil and performed simulations using the software tool Energy Plus to integrate PV power supply with building energy demand. Xu et al. [6] developed and evaluated the performance of an Active Building Envelope (ABE) system. A new enclosure technology with the ability to regulate their temperature (cooling or heating) by interacting with the sun which integrates photovoltaic (PV) and thermoelectric (TE) technologies. Chow et al. [7] described effectiveness of cooling by means of a natural ventilating air stream numerically based on two cooling options with an air gap between the PV panels and the external facade: (i) An open-air gap with mixed convective heat transfer (ii) A solar chimney with buoyancy induced vertical flow and found that effective cooling of a PV panel can increase the electricity output of the solar cells.

## 2 Materials for solar cell

The brief overview on materials for solar cell production is given in Fig. 6. Silicon is a leading technology in making solar cell due to its high efficiency. However, due to its high cost, most researchers are trying to find new technology to reduce the material cost to produce solar cell and to till date, thin film technology can be seen as a suitable substitute [8]. The reasons behind the low cost of thin film technology are because it uses less material and the layers are much thinner compared to mono- and polycrystalline solar cell thus lowering the manufacturing cost. However, the efficiency of this technology based solar cells is still low. Three materials that have been given much attention under thin film technology are amorphous silicon, CdS/CdTe and CIS, but researchers are continuously putting in more effort to enhance the efficiency.

However, all of these materials have some bad impact on the environment [9]. Another solution for thin film technology has been carried out by researchers by using polymer or organic as a solar cell material. Polymer materials have many advantages like low cost, lightweight and environmental friendly [10]. The only problem is it has very low efficiency compared to other materials with just 4–5% [9].

### 2.1 Crystalline materials

From all other solar cell materials, crystalline silicon based solar cell has the highest efficiency compared to others. On top of that, silicon supply can be easily available since it is the second easiest raw material that can be found on earth [11]. The brief overview of crystalline materials is given below.

#### 2.1.1 Monocrystalline cells

This type of material has been widely used in developing PV cells due to its high efficiency compared to polycrystalline cells by 15%. Among other type of solar cell material, monocrystalline solar cell has highest efficiency with more than 20% but for commercialization, the efficiency claim from manufacturer are normally lies between 15% and 17%. Most of monocrystalline silicon has been developed using Czochralski process [12]. In this process, high-purity, semiconductor-grade silicon is melted in a crucible, usually made of quartz. Dopant impurity atoms such as boron or phosphorus are added to the molten silicon in precise amounts to dope the silicon, thus changing it into an n-type or p-type silicon. Fig. 3. Comparison of PV distribution in Europe and worldwide [13]. The results Simulation of hetero-structure (AFORS-HET) program demonstrated the effects of band offset determined by band bending at the interface of the CSFC layer/passivation layer. In addition, the nc-SiOx: H CSFC layer not only reduces parasitic absorption loss but also has a tunneling effect and field effect passivation [14].

This influences the electronic properties of the silicon. A precisely oriented rod-mounted seed crystal is dipped into the molten silicon. The seed crystal's rod is slowly pulled upwards and rotated simultaneously. By precisely controlling the temperature gradients, rate of pulling and speed of rotation, it is possible to extract a large, single-crystal, cylindrical ingot from the melt. Occurrence of unwanted instabilities in the melt can be avoided by investigating and visualizing the temperature and velocity fields during the crystal growth process. This process is normally performed in an inert atmosphere, such as argon, or in an inert chamber, such as quartz [15].

### 2.1.2 Polycrystalline cells

Polycrystalline cell is a suitable material to reduce cost for developing PV module; however, its efficiency is low compared to monocrystalline cells and other developing materials [16]. Even though, polycrystalline cell have low flaws in metal contamination and crystal structure compared to monocrystalline cell [17]. Polycrystalline is produced by melting silicon and solidifying it to orient crystals in a fixed direction producing rectangular ingot of polycrystalline silicon to be sliced into blocks and lastly into thin wafer. However, final step can be abolished by cultivating ribbons of wafer thin ribbons of polycrystalline silicon. Polycrystalline manufacturing technology was developed by evergreen solar [18].

### 2.4 Hybrid solar cell

Generally, the idea of hybrid is by combining crystalline silicon with non-crystalline silicon [19]. Higher ratio of performance to cost has been evaluated by Wu et al. [20] by adopting amorphous silicon with crystalline silicon. One of the biggest solar cell manufacturers from Japan, Sanyo has developed a hybrid solar cell with 21% efficiency. It is called as HIT (combination of Hetero junction and Intrinsic thin film layers solar cell). The base of this solar cell is n-type CZ silicon wafer that functions as a light absorber. Sanyo plans to commercialize this solar cell and plant production is on the way.

### 2.5 New technology for PV cell production

Other than searching for new material to improve solar cell output, new technology in processing PV solar cell has been ascertained. Nanotechnology or sometimes referred as “third generation PV” [21] is used in order to help increase conversion efficiency of solar cell since energy band-gap can be controlled by nanoscale components. Nanotubes (CNT), quantum dots (QDs) and “hot carrier” (HC) solar cell are three devices used in nanotechnology for PV cell production [22]. The advantages of using this technology are [23]: (i) Enhance material mechanical characteristic, (ii) Low cost, (iii) Lightweight and (iv) Good electrical performances.

## 3 Efficiency of solar cell

The efficiency of solar cell is one of the important parameter in order to establish this technology in the market. Presently, extensive research work is going for efficiency improvement of solar cells for commercial use. The efficiency of monocrystalline silicon solar cell has showed a very good improvement year by year. It starts with only 15% in 1950s and then increased to 17% in 1970s and continuously to increase up to 28% nowadays. According to Zhao et al. [24] research work, the role of light trapping in polycrystalline solar cell and improvement of contact and surface of solar cell help in increasing the efficiency. The polycrystalline solar cell also achieved 19.8% efficiency to this date but the commercial efficiency of polycrystalline is coming in between 12% and 15% [25]. The different materials’ efficiencies for solar cells are given in Fig. 13 from 1975 until 2010. The monocrystalline solar cell has 24.7% efficiency, polycrystalline cells with 20.3% and thin film technology with 19.9% in 2010, respectively. The work of Fraunhofer ISE in the field of high-efficiency silicon solar cells is strongly dedicated to the transfer of high efficiency cell structures into industrial production [26]. They are working on fabricated laser-fired contacts (LFC) cells on very thin substrates. In order to compare this new technology with a standard laboratory high-efficiency process scheme, laser-fired contacts (LFC) and PERC solar cells have been fabricated on monocrystalline p-type silicon in a resistivity range between 0.5 O cm and 10 O cm and on n-type silicon with a resistivity of 1 O cm in the same solar cell batch. The measured efficiencies for PERC and LFC cells on p-type material with different resistivities are given in Fig. 1. The highest silicon solar cell practicalsize (4100 $cm^2$) conversion efficiency of 22% was achieved by Tsunomura et al. [27]. They developed a cleaning process that achieves a clean c-Si surface and an improved textured structure, a lower-damage-deposition process, a lower-light-absorbing TCO, and a finer grid electrode with reduced spreading area. The progress in conversion efficiency of HIT solar cells with a practical-size of 100 cm2 in the last fifteen years is given in figure. Mishima et al. [28] described the development status of high efficiency hetero junction with intrinsic thin-layer (HIT) solar cells at SANYO Electric. After the year round test for HIT double and single-sided HIT modules (Fig. 2), the output power of the HIT Double solar cell is higher than that of the single-sided HIT module throughout the year. The HIT double produces 10.9% more output in comparison to a single-sided HIT module. They have also achieved a considerably high open circuit voltage (Voc) of 743 mV, and a high conversion efficiency of 22.8% using only a 98-mm-thick substrate. The result of the study showed that the HIT solar cell has the potential to further improve cost performance. Chen and Zhu [29] simulated of a-Si/c-Si hetero junction solar cell with high conversion efficiency by the help of computer. They designed a prospective a-Si:H/Nþ c-Si solar cell of high performance with high efficiency of 21.894%, high fill factor of 0.866 and high open voltage of 0.861 V. The simulation results of this study are valuable for further development of high conversion efficiency and low cost solar cells. Friedman [30] described the next-generation high-efficiency multi-junction solar cells with efficiencies above 40%, is far in excess to the performances of any conventional single-junction cell. They concluded that several new generations of multi-junction cells with efficiencies above 40%—are the most efficient cells ever developed. The approaches used to achieve these efficiencies provide paths to continued improvement in cell performance. It is likely that 45% efficiencies will be demonstrated within the next couple of years, while in the longer term, with sustained vigorous development efforts, efficiencies approaching 50% are a realistic goal.

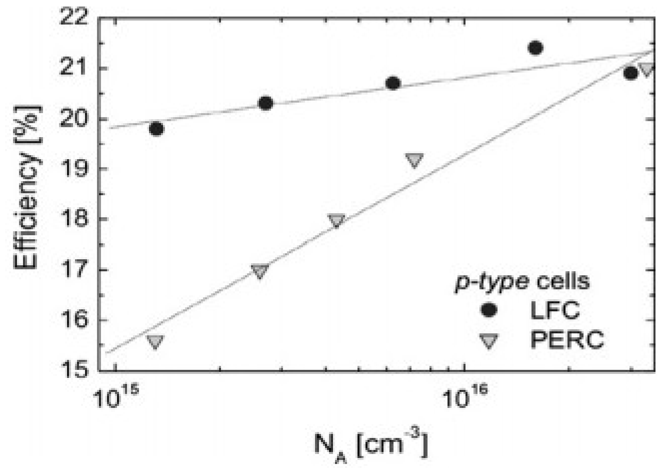


Fig. 1. LFC and PERC cells measured efficiency on p-type silicon

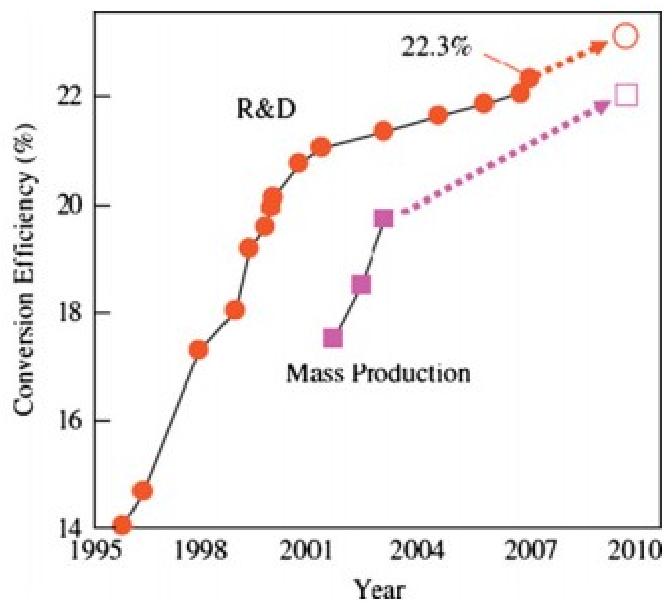


Fig. 2. Efficiency of HIT solar cells, progress in the conversion

**4 Factors affecting PV cell efficiency**

As mentioned in the previous section, it is known that efficiency is a main parameter for establishment of PV technology in the market but some factors are affecting the PV efficiency. The main factors are (1) temperature of solar cell, (2) effect of dust on solar cells.

**4.1 Temperature**

It is widely accepted that efficiency of photovoltaic solar cells decrease with an increase of temperature, and cooling is necessary at high illumination conditions such as concentrated sunlight, or cosmic or tropical conditions. The temperature plays critical factor that leads to a decrement of PV efficiency and its output power. This is due to the shrinkage of band gap as temperature increases, thus the open circuit voltage will drop [31]. During this time, energy charge carriers from valence band to conduction band increase since more incidents light have been absorbed [32]. Fig. 3 shows the effect of temperature on PV cell characteristic [33]. Temperature influence has high impacts on monocrystalline silicon compared to polycrystalline silicon and thin film solar cells. Efficiency decreases by 15% and 5%, respectively for monocrystalline silicon solar cell and thin film solar cell [34]. Singh and Ravindra [35] analyzed a detailed study for temperature dependence of solar cell performance in the temperature range of 273–523 K. They calculated the efficiency for three cases with temperature i.e., temperature creasing temperature, reverse saturation current increases, and therefore decreases which decreases the fill factor, hence the efficiency of the solar cell as well. Ting and Chao [36] studied experimentally on temperature influence of photoelectric conversion efficiency with dye-sensitized solar cells (DSSCs).

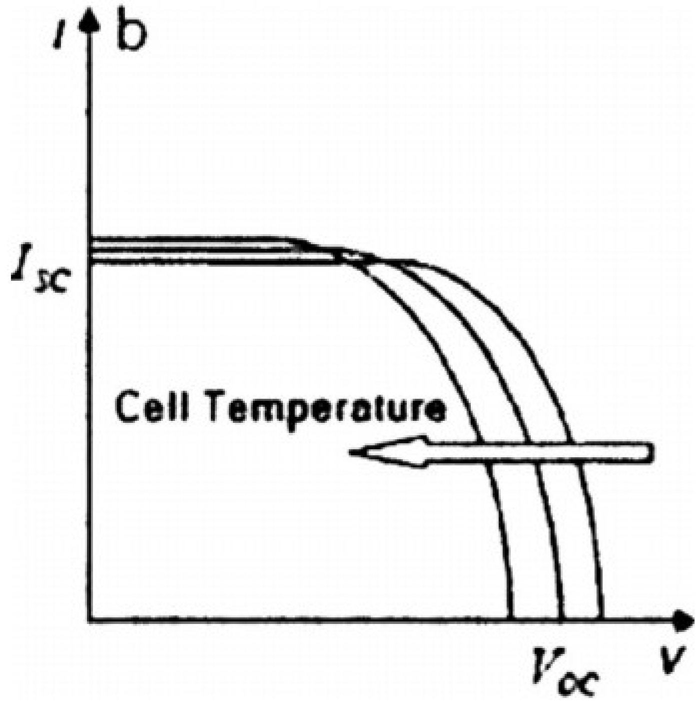


Fig. 3. Effect of temperature on PV cell characteristic

**4.2 Dust**

Dust is also affecting the PV efficiency because it may block the coming irradiance onto PV modules [37]. Goossens and Kerschaever [38] investigated the effect of wind velocity and airborne dust concentration on the PV cell performance caused by dust accumulation on such cells. They studied experimentally for power output of PV cell at every level. Fig. 4 shows the power output of PV cell for different dust density and different air velocity. From the graph, it can be seen that power output drop drastically as dust density increase. Jiang et al. [39] tested the effect of airborne dust on three types of PV modules which are (1) monocrystalline (2) polycrystalline and (3) amorphous silicon. The experiments were conducted in a lab, using a solar sun simulator and dust generator. They concluded that airborne dust will reduce the short circuit current and thus affect the efficiency of the PV module and the efficiency drop linearly with the dust deposition density. The results of this study also indicated that dust pollution has a significant impact on PV module output. With dust deposition density increasing from 0 to 22 g/$m^2$, the corresponding reduction of PV output efficiency grew from 0% to 26%. The reduction of efficiency has a linear relationship with the dust deposition density, and the difference caused by cell types was not obvious.

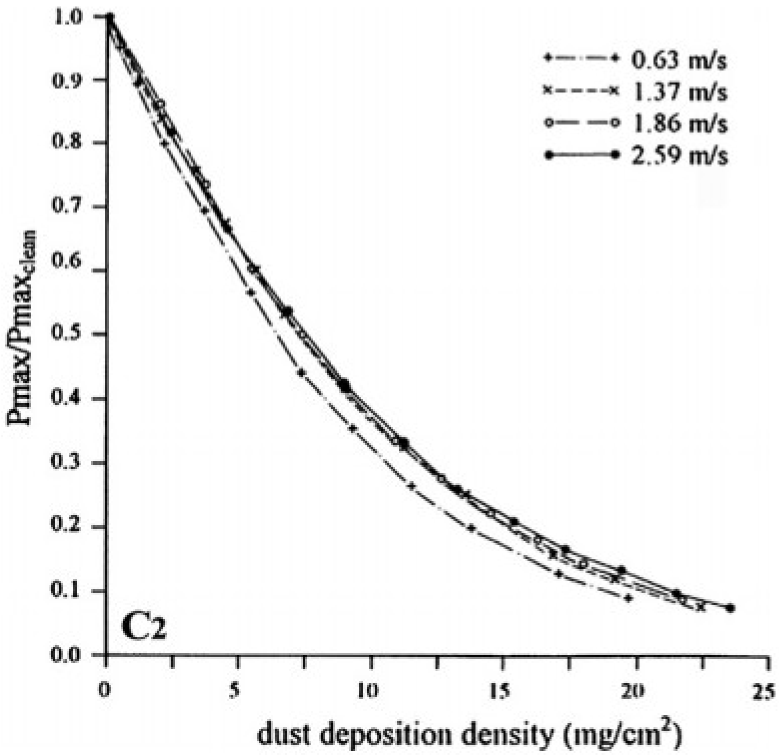


Fig. 4. Effect of dust on PV cell power output [38].

## 5 Solar photovoltaic technology

Solar energy has experienced phenomenal growth in recent years due to both technological improvements resulting in cost reductions and government policies supportive of renewable energy development and utilization. India is supposed to be one of the few countries, which is blessed with abundant solar energy. There is a tremendous scope for the growth for the Indian Solar Market. However, two factors which affect the same growth according to us are, lack of proper knowledge about the solar power technology amongst the consumers and penetration of not so good quality products in the market. Photovoltaic, also called solar cells, are electronic devices that convert sunlight directly into electricity. A French scientist Edmond Becquerel first discovered photovoltaic power in 1839. The first working solar cell was successfully made by Charles fritts in 1882. It was made of thin sheets of selenium and coated with gold. The use of solar panels for generating electricity and heat seems relatively like new development, it has actually been widely used to generate power since early 1900"s. In 1954 Bell laboratory mass produced the first crystal silicon solar cell. The bell PV converted 4% of the sun's energy into electricity a rate that was considered the cutting edge in energy technology. Daryl M. Chapin et al made a silicon-based solar cell with an efficiency of about 6% reported in [8]. Solar energy has experienced an impressive technological shift. While early solar technologies consisted of small-scale photovoltaic (PV) cells, recent technologies are represented by solar concentrated power (CSP) and also by large-scale PV systems that feed into electricity grids There are various types of solar photovoltaics panels.

5.1 Monocrystalline silicon PV panels

These are made using cells sliced from a single cylindrical crystal of silicon. This is the most efficient photovoltaic technology, typically converting around 15% of the sun's energy into electricity. The manufacturing process required to produce monocrystalline silicon is complicated, resulting in slightly higher costs than other technologies.

5.2 Polycrystalline silicon PV panels

Also sometimes known as multicrystalline cells, polycrystalline silicon cells are made from cells cut from an ingot of melted and recrystallized silicon. The ingots are then saw-cut into very thin wafers and assembled into complete cells. They are generally cheaper to produce than monocrystalline cells, due to the simpler manufacturing process, but they tend to be slightly less efficient, with average efficiencies of around 12%.

5.3 Thick-film silicon PV panels

This is a variant on multicrystalline technology where the silicon is deposited in a continuous process onto a base material giving a fine grained, sparkling appearance. Like all crystalline PV, it is normally encapsulated in a transparent insulating polymer with a tempered glass cover and then bound into a metal framed module.

5.4 Amorphous silicon PV panels

Amorphous silicon cells are made by depositing silicon in a thin homogenous layer onto a substrate rather than creating a rigid crystal structure. As amorphous silicon absorbs light more effectively than crystalline silicon, the cells can be thinner - hence its alternative name of 'thin film' PV. Amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible, which makes it ideal for curved surfaces or bonding directly onto roofing materials. This technology is, however, less efficient than crystalline silicon, with typical efficiencies of around 6%, but it tends to be easier and cheaper to produce. If roof space is not restricted, an amorphous product can be a good option. However, if the maximum output per square meter is required, specifies should choose a crystalline technology.

5.5 Other thin film PV panels

A number of other materials such as cadmium telluride (CdTe) and copper indium diselenide (CIS) are now being used for PV modules. The attraction of these technologies is that relatively inexpensive industrial processes, certainly in comparison to crystalline silicon technologies, can manufacture them yet they typically offer higher module efficiencies than amorphous silicon. Most offer a slightly lower efficiency: CIS is typically 10-13% efficient and CdTe around 8 or 9%. A disadvantage is the use of highly toxic metals such as Cadmium and the need for both carefully controlled manufacturing and end-of-life disposal; although a typical CdTe module contains only 0.1% Cadmium, which is reported to be lower than is found in a single AA sized NiCad battery. Table 1 presents a comparison between various types of solar photovoltaic panels.

Table 1. Comparison of Solar Photovoltaic Technologies.

| **S. No** | **Property** | **Mono Crystalline** | **Multi/Polycrystalline** | **Thin Film (CdTe, CIGS, Amorphous crystalline etc.)** |
|---|---|---|---|---|
| 1 | Efficiency | Highest | Moderate (13-15%) | Lowest |
| 2 | Cost | Highest | Moderate | Lowest |
| 3 | Area occupied per kW | Lowest | Moderate (approx. 100 sq. ft) | Highest |
| 4 | High Temperature Performance | Poor | Poor | Better |
| 5 | Generation in diffused light | Average | Average | Better |

The most commonly available panels are polycrystalline/ multi-crystalline. Table 2 discusses the factors that affect the performance of solar panels based on Indian conditions.

Table 2. Factors affecting Solar Panel Output.

| S. No | Factor | Remarks |
|---|---|---|
| 1 | Direction | For panels that have fixed position without any sun tracking mechanism they should face south direction for better output throughout the year. |
| 2 | Tilt/ Angle of Inclination | Preferably according to the latitude of the place. |
| 3 | Shading | Even a small part of shaded panel, affects the entire output of the panels largely. Ensure the panels are placed such that there is no shadow on them throughout the day. Even a single partially shaded panel affects the output of all other solar panels in the system. Also, ensure that there is no dust etc on the panel to avoid shading. |
| 4 | Temperature | Higher the temperature, lower will be the output from solar panels. Usually, panels are rated according to standard test conditions (i.e., temperature: 25 degree Celsius, insolation $1000W/m^2$, Air Mass: 1.5). Hence, if temperature is higher than this, your panels may give less than rated output. |

## 6 Future researches in solar technology

Research in photovoltaics is proceeding rapidly on many fronts. Some of these approaches are still in the early stages and far from being put into production, but they may become mainstream in the future. Making a solar cell with several layers is possible since the band gap can be tuned by adjusting the doping. Each layer would have a band gap tuned to a particular wavelength of light. These ―multi-junction‖ cells can attain 40 percent efficiency but remain expensive. As a result, they‘re more likely to be found on NASA spacecraft right now than on a terrestrial roof. The research behind solar energy is booming, too. Scientists are discovering new ways to decrease costs and increase efficiency of solar panels and coming up with creative, impressive ways to generate power. Following are the futuristic developments in solar technology:

### 6.1 Bionic leaf

Scientists at Harvard recently created a bionic leaf, which uses a catalyst to make sunlight split water into hydrogen and oxygen, then a bacteria engineered to convert carbon dioxide and hydrogen into a liquid fuel called isopropanol. They're almost at a 1% efficiency rate of turning the sunlight into the fuel — in other words; they've found a way to recreate the efficiency of photosynthesis.

### 6.2 3D printed solar powered trees

Researchers at the VTT Technical Research Centre of Finland created a solar powered electric forest with 3D printed trees. That's quite a bit of buzz worthy tech in one project. The trunks of the trees are made from 3D printed wood biomaterials, and the leaves are the solar "panels".

They are much less efficient than traditional PV panels, but the research they're doing for solar cells is promising as well.

### 6.3 Perovskites

Perovskites are materials with a specific crystalline structure. Stanford University researchers found that using lead, ammonia, and iodine, they could make a lot of it for cheap. Perovskites are more efficient than silicon in some ways, so the idea is using them to supplement rather than replace silicon may be a way to increase the efficiency of solar cells. At Stanford, a silicon solar cell with an efficiency of 11.4% increased to 17% with perovskite.

### 6.4 Thin film solar

New research from Cornell, published in Nature in January, showed that scientists are reporting better solar cells by changing the chemistry of the materials. Thin film solar, which is a photovoltaic material onto a substrate like silicon. The ones made by these researchers at Cornell are organic-inorganic metal halide perovskites, which the team has been studying for a while. The new solar cells use a liquid source and a simple coating, which can make it appealing for more commercial uses.

### 6.5 Carbon-Based Solar Cells

Another cheap alternative to silicon that has emerged is printed carbon-based, or organic, solar cells. The efficiency is still relatively low compared to other materials, and the research surrounding it peaked about a decade ago. But, as perovskites gain popularity in reducing the cost and increasing efficiency of cells, carbon-based options are looking like contenders, too.

### 6.6 Colored solar panels

Scientists have found a way to make solar panels a little more aesthetically pleasing. They layered silicon dioxide, often used to make glass optical fibers, and titanium dioxide, used to absorb UV rays, to make a photonic crystal structure that can absorb sunlight. Colors appear when light is reflected and absorbed, and the colors change depending on the thickness of the materials. The problem is, these panels are much less efficient than black solar panels, only reaching up to 9%. The blue, for instance, is only about 6%. The hope is that as the technology advances, the efficiency will increase — but for now, it is a way to possibly mainstream the idea of solar even more.

### 6.7 Polymer Solar Cells

Polymer solar cells, called P1D2, may increase solar cell efficiency. The research comes from the University of Chicago's chemistry department, the Institute for Molecular Engineering, and Argonne National Laboratory. The polymer breaks down easier and allows more electrons to travel faster. The researchers said in a test, it increased solar cell efficiency by 15%.

### 6.8 Solar Concentration Technology

Concentrating photovoltaic (CPV) systems are giant and have to be angled very accurately to get the right amount of sun during the day. They work great, but they are not ideal for roofs. Now, a team of researchers is working on using that high-efficiency technology for rooftop PV systems by building them with miniaturized, gallium arsenide photovoltaic cells and 3D printed plastic lens arrays. The systems weigh less, cost less, and are much smaller than CPV systems, though, and can be optimized for rooftops.

## 7 Discussion and Conclusions

A review of major solar photovoltaic technologies comprising of PV power generation is discussed. It is highlighted that there is tremendous renewable energy resources available and Solar PV is one of them for electricity generation. This demand deployment of PV cells on building facades or rooftops. This will lead to reduction in power cuts and emission of greenhouse gases. Increasing environmental concerns and the need to achieve emission reduction targets should help the technology to become further established as a marketable and economically viable product. Moreover government policies and research in development of new solar technology needs to be implanted. This paper would be useful for the solar PV system manufactures, academicians, researchers, generating members and decision makers.

The worldwide energy consumption is increasing every year and different technologies are using to produce electricity to compete the energy demand. The environmental pollution is also a serious problem nowadays due to the more use of fossil fuel for energy production. Solar PV technology is growing rapidly in past decades and can play an important role to achieve the high energy demand worldwide. Huge amount of PV systems installed yearly shows the seriousness and the responsibility of every country about the issue to save the earth by using renewable energy. This paper illustrated about the worldwide status of PV technology, research in materials for solar cell, factor affecting for PV efficiency, present cost of solar cell and environmental impact. The conclusions of this review are as:

Presently, mono- and polycrystalline PV technology have more than 40% market share with 15–17% efficiency. However, thin film, polymer based solar cell and third generation based solar cells are also in development stage and extensive research work is going for efficiency improvement for commercial use. The efficiency of solar cell is one of the important parameter in order to establish this technology in the market. The performance of solar cell are also depends on its surrounding such as temperature, irradiation and dust. Temperature can affect PV performance drastically and due to that fact, studies has focus on lowering the temperature by extracting heat and use it for other purpose such as water or air heating. For dust problem, it is advised that PV surface need to be clean often to maintain the performance. Every developed technology should have advantages and disadvantages to the environment. The solar cell production has some disadvantages on environment during manufacturing and process time but it gives much more advantages during use. The electricity production through PV system is clean and safe for environment with comparison to coal and fossil fuel. Electricity production through PV module reduces the carbon dioxide emission in environment and safe for global warming problem. At the end of PV module life, it can be recycled and safely disposal will give minimum effect on environment. So, research for recycled for PV materials are also a key issue for minimizing the environmental effect of PV technology during entire period of life.

## References

[1] Energy Sources: Solar". Department of Energy. Retrieved 1 June 2020.

[2] International Energy Agency (2014). "Technology Roadmap: Solar Photovoltaic Energy". IEA. 7 October 2014.

[3] Yoo S-H, Lee E-T. Efficiency characteristic of building integrated photovoltaics as a shading device. Building and Environment 2002; 37:615–23. W.-K. Chen, Linear Networks and Systems. Belmont, CA: Wadsworth, 1993, pp. 123–135.

[4] Bakos GC, Soursos M, Tsagas NF. ―Techno economic assessment of a building integrated PV system for electrical energy saving in residential sector. Energy and Buildings 2003; 35:757–62.

[5] Ordenes M, Marinoski DL, Braun P, Ruther R. The impact of building integrated photovoltaics on the energy demand of multi-family dwellings in Brazil. Energy and Buildings 2007; 39:629–42.

[6] Xu X, Van Dessel S. Evaluation of an active building envelope window-system. Energy and Buildings 2008; 40:168–74.

[7] Chow TT, Hand JW, Strachan PA. Buildingintegrated photovoltaic and thermal applications in a subtropical hotel building. Applied Thermal Engineering 2003; 23:2035–49.

[8] McCann MJ, Catchpole KR, Weber KJ, Blakers AW. A review of thin film crystalline silicon for solar cell applications. Part 1: Native substrates. Solar Energy Materials and Solar Cells 2001; 68: 135–71.

[9] El Chaar L, Lamont LA, El Zein N. Review of photovoltaic technologies. Renewable and Sustainable Energy Reviews 2011; 15: 2165–75.

[10] Gorter T, Reinders AHME. A comparison of 15 polymers for application in photovoltaic modules in PV-powered boats. Applied Energy 2012; 92: 286–97.

[11] Global market outlook for photovoltaics until 2012. http://www.epia.org/ index.php?id=18. Retrieved 1 June 2020.

[12] http://en.wikipedia.org/wiki/File:Silicon-unit-cell-labelled-3D-balls.png. Retrieved 1 June 2020.

[13] Global market outlook until 2014, European Photovoltaic Industry Association report, (2010).http://www.epia.org/fileadmin/EPIA_docs/public/Global_Market_Outlook_for_Photovoltaics_until_2014.pdfS. Retrieved 1 June 2020.

[14] Lee, S.; Pham, D.P.; Kim, Y.; Cho, E.-C.; Park, J.; Yi, J. Influence of the Carrier Selective Front Contact Layer and Defect State of a-Si:H/c-Si Interface on the Rear Emitter Silicon Heterojunction Solar Cells. Energies 2020, 13, 2948.

[15] http://en.wikipedia.org/wiki/Czochralski_process. Retrieved 1 June 2020.

[16] Becker C, Sontheimer T, Steffens S, Scherf S, Rech B. Polycrystalline silicon thin films by high-rate electronbeam evaporation for photovoltaic applications—influence of substrate texture and temperature. Energy Procedia 2011; 10: 61–5.

[17] Manna TK, Mahajan SM. Nanotechnology in the development of photovoltaic cells. IEEE 2007:379–86.

[18] http://www.evergreensolar.com. Retrieved 1 June 2020.

[19] Itoh M, Takahashi H, Fujii T, Takakura H, Hamakawa Y, Matsumoto Y. Evaluation of electric energy performance by democratic module PV system field test. Solar Energy Materials and Solar Cells 2001; 67: 435–40.

[20] Wu L, Tian W, Jiang X. Silicon based solar cell system with a hybrid PV module. Solar Energy Materials and Solar Cells 2005; 87: 637–45.

[21] Wu CY, Mathews JA. Knowledge flows in the solar photovoltaic industry: Insights from patenting by Taiwan, Korea, and China. Research Policy 2012; 41:524–40.

[22] Sethi VK, Pandey M, Shukla P. Use of nanotechnology in solar PV cell. International Journal of Chemical Engineering and Applications 2011; 2.

[23] http://www.nano.gov. Retrieved 1 June 2020.

[24] Zhao J, Wang A, Campbell P, Green. MA. A 19.8% efficient honeycomb multicrystalline silicon solar cell with improved light trapping. IEEE Transactions on Electron Devices 1999;46:1978–83.

[25] Azykov TM, Ferekides CS, Morel D, Stefanakos E, Ullal HS, Upadhyaya HM. Solar photovoltaic electricity: current status and future prospects. Solar Energy 2011; 85:1580–608.

[26] Glunz SW. New concepts for high-efficiency silicon solar cells. Solar Energy Materials and Solar Cells 2006; 90: 3276–84.

[27] Tsunomura Y, Yoshimine Y, Taguchi M, Baba T, Kinoshita T, Kanno H, et al. Twenty-two percent efficiency HIT solar cell. Solar Energy Materials and Solar Cells 2009; 93: 670–3.

[28] Mishima T, Taguchi M, Sakata H, Maruyama E. Development status of high efficiency HIT solar cells. Solar Energy Materials and Solar Cells 2011; 95: 18–21.

[29] Chen A, Zhu K. Computer simulation of a-Si/c-Si heterojunction solar cell with high conversion efficiency. Solar Energy 2012; 86: 393–7.

[30] Friedman DJ. Progress and challenges for next-generation high-efficiency multijunction solar cells. Current Opinion in Solid State and Materials Science 2010; 14:131–8.

[31] Shenck NS. Alternative energy systems. U.S. Naval Academy Lecture Readings; 2010.

[32] Dincer F, Meral ME. Critical factors that affecting efficiency of solar cells. Smart Grid and Renewable Energy 2010; 1: 47–50.

[33] Kalogirou S. Solar energy engineering: processes and systems: chapter 9. Academic Press; 2009 pp. 469–517.

[34] Kumar R, Rosen MA. A critical review of photovoltaic-thermal solar collectors for air heating. Applied Energy 2011; 88: 3603–14.

[35] Singh, P, Ravindra N. M. Temperature dependence of solar cell performancean analysis, Solar Energy Materials and Solar Cells, 101, (2012), 36–45.

[36] Ting CC, Chao WS. Measuring temperature dependence of photoelectric conversion efficiency with dye-sensitized solar cells. Measurement 2010; 43: 1623–1627.

[37] Evans D. L. Simplified method for predicting photovoltaic array output. Solar Energy 1981; 27: 555–60.

[38] Goossens D, Kerschaever EV. Aeolian dust deposition on photovoltaic solar cells: the effects of wind velocity and airborne dust concentration on cell performance. Solar Energy 1999; 66:277–89.

[39] Jiang H, Lu L, Sun K. Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules. Atmospheric Environment 2011; 45: 4299–304.

[40] http://www.darvill.clara.net. Retrieved 1 June 2020.

# Term Assignment

*By* Saad Ahmad

# RECENT ADVANCES IN SOLAR PV TECHNOLOGY: RESEARCH AND FUTURE TRENDS

**Saad Ahmad**[1]

[1] Department of Electrical Engineering, CECOS University of IT and Emerging Sciences, Peshawar 25000, Pakistan

**Abstract**

Industrial development and population growth have led to a surge in the global demand for energy. Moreover Global environmental concerns coupled with steady progress in renewable energy technologies, are opening up new opportunities for utilization of renewable energy resources. Solar energy is the most abundant, inexhaustible and clean of all the renewable energy resources till date. The ability to generate electricity from sunlight is a relatively new and exciting technology that offers many new opportunities in generating green‘ electricity. Presently, extensive research work is going for efficiency improvement of solar cells for commercial use. The efficiency of mono crystalline silicon solar cell has showed very good improvement year by year. It starts with only 15% in 1950s and then increase to 17% in 1970s and continuously increases up to 28% nowadays. The growth in solar photovoltaic technologies including worldwide status, materials for solar cells, efficiency, factor affecting the performance of PV module, overview on cost analysis of PV and its environmental impact are reviewed in this paper.

**Keywords:** Solar cells; PV materials; Renewable energy; PV cell efficiency

## 1 Introduction

In order to secure the future for ourselves and generations to follow, it is widely accepted that we must act now to reduce energy consumption and substantially cut greenhouse gases, such as carbon dioxide. World leaders have resolved to tackle global warming by signing the Kyoto Protocol, an international treaty committing signatory countries to reduce their emissions of carbon dioxide and five other greenhouse gases from 1990 levels. The UK is a signatory of the Kyoto Protocol and is actively involved in measures to meet our commitment of a 12.5 per cent cut in greenhouse gas emissions by the period 2008-12. However, there is no single solution for the UK or the 155 other countries also aiming to reduce their emissions. Considering the scenario of favorable Government policies and reduction in prices of solar PV modules, there is a huge interest for the installation of solar PV systems. In order to enable the deployment of solar PV systems in India, there is a need for large number of trained people in the solar PV area. The trained manpower is required at various levels ranging from managers and researchers to engineers and technicians. The training is required in various disciplines ranging from design and engineering through to installation, testing, operation and maintenance. Solar power is the conversion of energy from sunlight into electricity, either directly using photovoltaic (PV), indirectly using concentrated solar power, or a combination. Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. Photovoltaic cells convert light into an electric current using the photovoltaic effect [1]. The International Energy Agency projected in 2014 that under its "high renewable" scenario, by 2050, solar photovoltaics and concentrated solar power would contribute about 16 and 11 percent, respectively, of the worldwide electricity consumption, and solar would be the world's largest source of electricity. Most solar installations would be in China [2] now-a-days building integrated photovoltaic (BIPV) system are in great demand which incorporate photovoltaic properties into building materials such as roofing, siding, and glass and thus offer advantages in cost and appearance as they are substituted for conventional materials in new construction. Moreover the BIPV installations are architecturally more appealing than roof-mounted PV structures. Yoo et al. [3] proposed a building design to have the PV modules shade the building in summer, so as to reduce cooling loads, while at the same time allowing solar energy to enter the building during the heating season to provide daylight and conducted an analysis of the system performance, evaluation of the system efficiency and the power output. Bakos et al. [4] described the installation, technical characteristics, operation and economic evaluation of a grid-connected building integrated photovoltaic system (BIPV) and the technical and economical factors were examined using a computerized renewable energy technologies (RETs) assessment tool. Ordenes et al. [5] analyzed the potential of seven BIPV technologies implemented in a residential prototype simulated in three different cities in Brazil and performed simulations using the software tool Energy Plus to integrate PV power supply with building energy demand. Xu et al. [6] developed and evaluated the performance of an Active Building Envelope (ABE) system.

A new enclosure technology with the ability to regulate their temperature (cooling or heating) by interacting with the sun which integrates photovoltaic (PV) and thermoelectric (TE) technologies. Chow et al. [7] described effectiveness of cooling by means of a natural ventilating air stream numerically based on two cooling options with an air gap between the PV panels and the external facade: (i) An open-air gap with mixed convective heat transfer (ii) A solar chimney with buoyancy induced vertical flow and found that effective cooling of a PV panel can increase the electricity output of the solar cells.

## 2 Materials for solar cell

The brief overview on materials for solar cell production is given in Fig. 6. Silicon is a leading technology in making solar cell due to its high efficiency. However, due to its high cost, most researchers are trying to find new technology to reduce the material cost to produce solar cell and to till date, thin film technology can be seen as a suitable substitute [8]. The reasons behind the low cost of thin film technology are because it uses less material and the layers are much thinner compared to mono- and polycrystalline solar cell thus lowering the manufacturing cost. However, the efficiency of this technology based solar cells is still low. Three materials that have been given much attention under thin film technology are amorphous silicon, CdS/CdTe and CIS, but researchers are continuously putting in more effort to enhance the efficiency.

However, all of these materials have some bad impact on the environment [9]. Another solution for thin film technology has been carried out by researchers by using polymer or organic as a solar cell material. Polymer materials have many advantages like low cost, lightweight and environmental friendly [10]. The only problem is it has very low efficiency compared to other materials with just 4–5% [9].

### 2.1 Crystalline materials

From all other solar cell materials, crystalline silicon based solar cell has the highest efficiency compared to others. On top of that, silicon supply can be easily available since it is the second easiest raw material that can be found on earth [11]. The brief overview of crystalline materials is given below.

#### 2.1.1 Monocrystalline cells

This type of material has been widely used in developing PV cells due to its high efficiency compared to polycrystalline cells by 15%. Among other type of solar cell material, monocrystalline solar cell has highest efficiency with more than 20% but for commercialization, the efficiency claim from manufacturer are normally lies between 15% and 17%. Most of monocrystalline silicon has been developed using Czochralski process [12]. In this process, high-purity, semiconductor-grade silicon is melted in a crucible, usually made of quartz. Dopant impurity atoms such as boron or phosphorus are added to the molten silicon in precise amounts to dope the silicon, thus changing it into an n-type or p-type silicon. Fig. 3. Comparison of PV distribution in Europe and worldwide [13]. The results Simulation of hetero-structure (AFORS-HET) program demonstrated the effects of band offset determined by band bending at the interface of the CSFC layer/passivation layer. In addition, the nc-SiOx: H CSFC layer not only reduces parasitic absorption loss but also has a tunneling effect and field effect passivation [14]. This influences the electronic properties of the silicon. A precisely oriented rod-mounted seed crystal is dipped into the molten silicon. The seed crystal's rod is slowly pulled upwards and rotated simultaneously. By precisely controlling the temperature gradients, rate of pulling and speed of rotation, it is possible to extract a large, single-crystal, cylindrical ingot from the melt. Occurrence of unwanted instabilities in the melt can be avoided by investigating and visualizing the temperature and velocity fields during the crystal growth process. This process is normally performed in an inert atmosphere, such as argon, or in an inert chamber, such as quartz [15].

### 2.1.2 Polycrystalline cells

Polycrystalline cell is a suitable material to reduce cost for developing PV module; however, its efficiency is low compared to monocrystalline cells and other developing materials [16]. Even though, polycrystalline cell have low flaws in metal contamination and crystal structure compared to monocrystalline cell [17]. Polycrystalline is produced by melting silicon and solidifying it to orient crystals in a fixed direction producing rectangular ingot of polycrystalline silicon to be sliced into blocks and lastly into thin wafer. However, final step can be abolished by cultivating ribbons of wafer thin ribbons of polycrystalline silicon. Polycrystalline manufacturing technology was developed by evergreen solar [18].

### 2.4 Hybrid solar cell

Generally, the idea of hybrid is by combining crystalline silicon with non-crystalline silicon [19]. Higher ratio of performance to cost has been evaluated by Wu et al. [20] by adopting amorphous silicon with crystalline silicon. One of the biggest solar cell manufacturers from Japan, Sanyo has developed a hybrid solar cell with 21% efficiency. It is called as HIT (combination of Hetero junction and Intrinsic thin film layers solar cell). The base of this solar cell is n-type CZ silicon wafer that functions as a light absorber. Sanyo plans to commercialize this solar cell and plant production is on the way.

### 2.5 New technology for PV cell production

Other than searching for new material to improve solar cell output, new technology in processing PV solar cell has been ascertained. Nanotechnology or sometimes referred as ‘‘third generation PV’’ [21] is used in order to help increase conversion efficiency of solar cell since energy band-gap can be controlled by nanoscale components. Nanotubes (CNT), quantum dots (QDs) and ‘‘hot carrier’’ (HC) solar cell are three devices used in nanotechnology for PV cell production [22]. The advantages of using this technology are [23]: (i) Enhance material mechanical characteristic, (ii) Low cost, (iii) Lightweight and (iv) Good electrical performances.

## 3 Efficiency of solar cell

The efficiency of solar cell is one of the important parameter in order to establish this technology in the market. Presently, extensive research work is going for efficiency improvement of solar cells for commercial use. The efficiency of monocrystalline silicon solar cell has showed a very good improvement year by year. It starts with only 15% in 1950s and then increased to 17% in 1970s and continuously to increase up to 28% nowadays. According to Zhao et al. [24] research work, the role of light trapping in polycrystalline solar cell and improvement of contact and surface of solar cell help in increasing the efficiency. The polycrystalline solar cell also achieved 19.8% efficiency to this date but the commercial efficiency of polycrystalline is coming in between 12% and 15% [25]. The different materials’ efficiencies for solar cells are given in Fig. 13 from 1975 until 2010. The monocrystalline solar cell has 24.7% efficiency, polycrystalline cells with 20.3% and thin film technology with 19.9% in 2010, respectively. The work of Fraunhofer ISE in the field of high-efficiency silicon solar cells is strongly dedicated to the transfer of high efficiency cell structures into industrial production [26]. They are working on fabricated laser-fired contacts (LFC) cells on very thin substrates. In order to compare this new technology with a standard laboratory high-efficiency process scheme, laser-fired contacts (LFC) and PERC solar cells have been fabricated on monocrystalline p-type silicon in a resistivity range between 0.5 O cm and 10 O cm and on n-type silicon with a resistivity of 1 O cm in the same solar cell batch. The measured efficiencies for PERC and LFC cells on p-type material with different resistivities are given in Fig. 1. The highest silicon solar cell practicalsize (4100 $cm^2$) conversion efficiency of 22% was achieved by Tsunomura et al. [27]. They developed a cleaning process that achieves a clean c-Si surface and an improved textured structure, a lower-damage-deposition process, a lower-light-absorbing TCO, and a finer grid electrode with reduced spreading area. The progress in conversion efficiency of HIT solar cells with a practical-size of 100 cm2 in the last fifteen years is given in figure. Mishima et al. [28] described the development status of high efficiency hetero junction with intrinsic thin-layer (HIT) solar cells at SANYO Electric. After the year round test for HIT double and single-sided HIT modules (Fig. 2), the output power of the HIT Double solar cell is higher than that of the single-sided HIT module throughout the year. The HIT double produces 10.9% more output in comparison to a single-sided HIT module. They have also achieved a considerably high open circuit voltage (Voc) of 743 mV, and a high conversion efficiency of 22.8% using only a 98-mm-thick substrate. The result of the study showed that the HIT solar cell has the potential to further improve cost performance. Chen and Zhu [29] simulated of a-Si/c-Si hetero junction solar cell with high conversion efficiency by the help of computer. They designed a prospective a-Si:H/Nþ c-Si solar cell of high performance with high efficiency of 21.894%, high fill factor of 0.866 and high open voltage of 0.861 V. The simulation results of this study are valuable for further development of high conversion efficiency and low cost solar cells. Friedman [30] described the next-generation high-efficiency multi-junction solar cells with efficiencies above 40%, is far in excess to the performances of any conventional single-junction cell. They concluded that several new generations of multi-junction cells with efficiencies above 40%—are the most efficient cells ever developed. The approaches used to achieve these efficiencies provide paths to continued improvement in cell performance. It is likely that 45% efficiencies will be demonstrated within the next couple of years, while in the longer term, with sustained vigorous development efforts, efficiencies approaching 50% are a realistic goal.

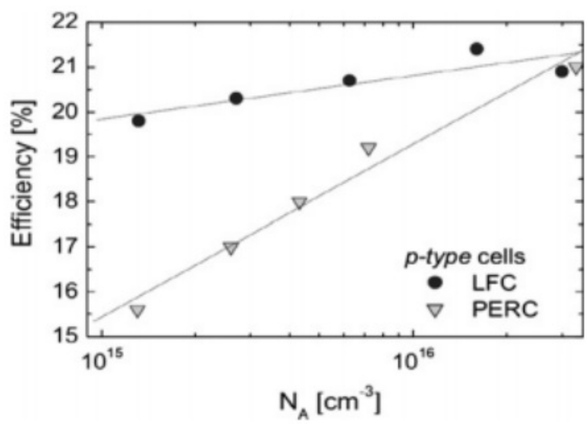


Fig. 1. LFC and PERC cells measured efficiency on p-type silicon

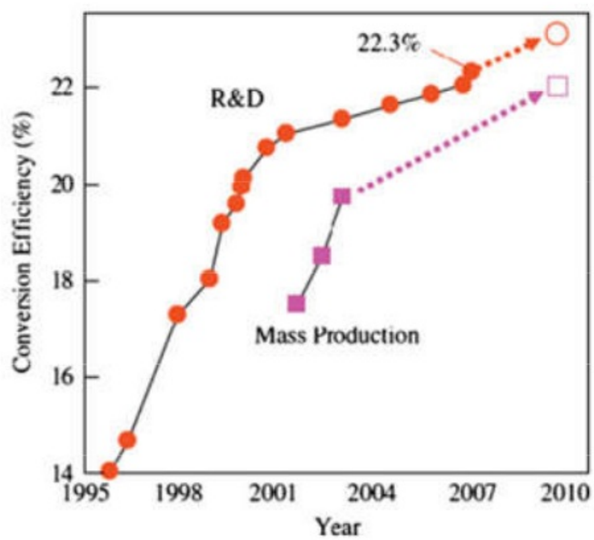


Fig. 2. Efficiency of HIT solar cells, progress in the conversion

## 4 Factors affecting PV cell efficiency

As mentioned in the previous section, it is known that efficiency is a main parameter for establishment of PV technology in the market but some factors are affecting the PV efficiency. The main factors are (1) temperature of solar cell, (2) effect of dust on solar cells.

### 4.1 Temperature

It is widely accepted that efficiency of photovoltaic solar cells decrease with an increase of temperature, and cooling is necessary at high illumination conditions such as concentrated sunlight, or cosmic or tropical conditions. The temperature plays critical factor that leads to a decrement of PV efficiency and its output power. This is due to the shrinkage of band gap as temperature increases, thus the open circuit voltage will drop [31]. During this time, energy charge carriers from valence band to conduction band increase since more incidents light have been absorbed [32]. Fig. 3 shows the effect of temperature on PV cell characteristic [33]. Temperature influence has high impacts on monocrystalline silicon compared to polycrystalline silicon and thin film solar cells. Efficiency decreases by 15% and 5%, respectively for monocrystalline silicon solar cell and thin film solar cell [34]. Singh and Ravindra [35] analyzed a detailed study for temperature dependence of solar cell performance in the temperature range of 273–523 K. They calculated the efficiency for three cases with temperature i.e., temperature creasing temperature, reverse saturation current increases, and therefore decreases which decreases the fill factor, hence the efficiency of the solar cell as well. Ting and Chao [36] studied experimentally on temperature influence of photoelectric conversion efficiency with dye-sensitized solar cells (DSSCs).

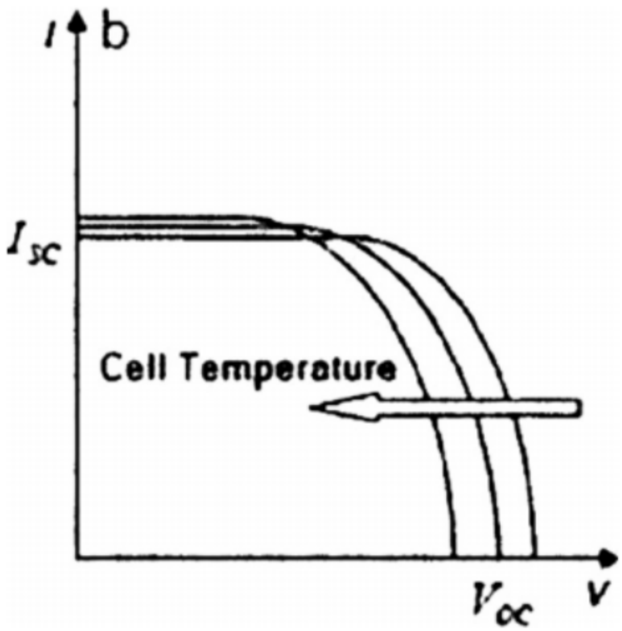

Fig. 3. Effect of temperature on PV cell characteristic

**4.2 Dust**

Dust is also affecting the PV efficiency because it may block the coming irradiance onto PV modules [37]. Goossens and Kerschaever [38] investigated the effect of wind velocity and airborne dust concentration on the PV cell performance caused by dust accumulation on such cells. They studied experimentally for power output of PV cell at every level. Fig. 4 shows the power output of PV cell for different dust density and different air velocity. From the graph, it can be seen that power output drop drastically as dust density increase. Jiang et al. [39] tested the effect of airborne dust on three types of PV modules which are (1) monocrystalline (2) polycrystalline and (3) amorphous silicon. The experiments were conducted in a lab, using a solar sun simulator and dust generator. They concluded that airborne dust will reduce the short circuit current and thus affect the efficiency of the PV module and the efficiency drop linearly with the dust deposition density. The results of this study also indicated that dust pollution has a significant impact on PV module output. With dust deposition density increasing from 0 to 22 g/m$^2$, the corresponding reduction of PV output efficiency grew from 0% to 26%. The reduction of efficiency has a linear relationship with the dust deposition density, and the difference caused by cell types was not obvious.

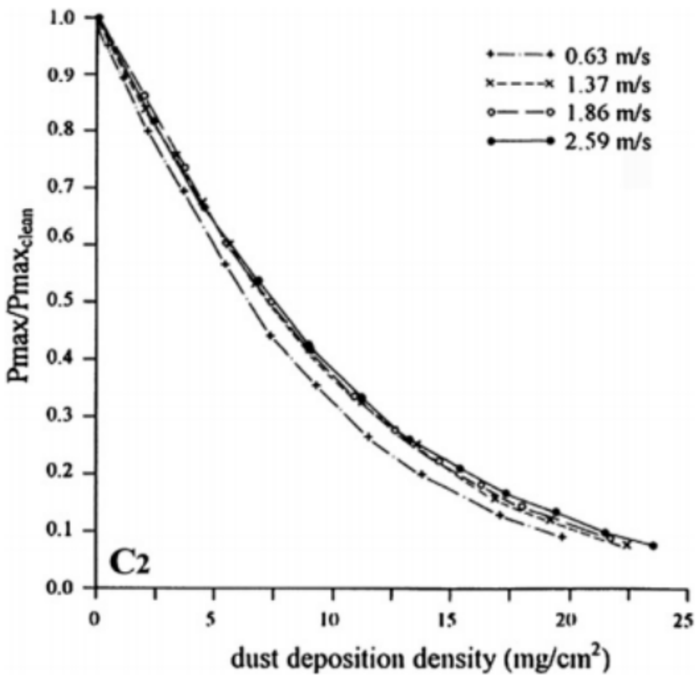


Fig. 4. Effect of dust on PV cell power output [38].

## 5 Solar photovoltaic technology

Solar energy has experienced phenomenal growth in recent years due to both technological improvements resulting in cost reductions and government policies supportive of renewable energy development and utilization. India is supposed to be one of the few countries, which is blessed with abundant solar energy. There is a tremendous scope for the growth for the Indian Solar Market. However, two factors which affect the same growth according to us are, lack of proper knowledge about the solar power technology amongst the consumers and penetration of not so good quality products in the market. Photovoltaic, also called solar cells, are electronic devices that convert sunlight directly into electricity. A French scientist Edmond Becquerel first discovered photovoltaic power in 1839. The first working solar cell was successfully made by Charles fritts in 1882. It was made of thin sheets of selenium and coated with gold. The use of solar panels for generating electricity and heat seems relatively like new development, it has actually been widely used to generate power since early 1900‟s. In 1954 Bell laboratory mass produced the first crystal silicon solar cell. The bell PV converted 4% of the sun‘s energy into electricity a rate that was considered the cutting edge in energy technology. Daryl M. Chapin et al made a silicon-based solar cell with an efficiency of about 6% reported in [8]. Solar energy has experienced an impressive technological shift. While early solar technologies consisted of small-scale photovoltaic (PV) cells, recent technologies are represented by solar concentrated power (CSP) and also by large-scale PV systems that feed into electricity grids There are various types of solar photovoltaics panels.

5.1 Monocrystalline silicon PV panels

These are made using cells sliced from a single cylindrical crystal of silicon. This is the most efficient photovoltaic technology, typically converting around 15% of the sun's energy into electricity. The manufacturing process required to produce monocrystalline silicon is complicated, resulting in slightly higher costs than other technologies.

5.2 Polycrystalline silicon PV panels

Also sometimes known as multicrystalline cells, polycrystalline silicon cells are made from cells cut from an ingot of melted and recrystallized silicon. The ingots are then saw-cut into very thin wafers and assembled into complete cells. They are generally cheaper to produce than monocrystalline cells, due to the simpler manufacturing process, but they tend to be slightly less efficient, with average efficiencies of around 12%.

5.3 Thick-film silicon PV panels

This is a variant on multicrystalline technology where the silicon is deposited in a continuous process onto a base material giving a fine grained, sparkling appearance. Like all crystalline PV, it is normally encapsulated in a transparent insulating polymer with a tempered glass cover and then bound into a metal framed module.

5.4 Amorphous silicon PV panels

Amorphous silicon cells are made by depositing silicon in a thin homogenous layer onto a substrate rather than creating a rigid crystal structure. As amorphous silicon absorbs light more effectively than crystalline silicon, the cells can be thinner - hence its alternative name of 'thin film' PV. Amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible, which makes it ideal for curved surfaces or bonding directly onto roofing materials. This technology is, however, less efficient than crystalline silicon, with typical efficiencies of around 6%, but it tends to be easier and cheaper to produce. If roof space is not restricted, an amorphous product can be a good option. However, if the maximum output per square meter is required, specifies should choose a crystalline technology.

5.5 Other thin film PV panels

A number of other materials such as cadmium telluride (CdTe) and copper indium diselenide (CIS) are now being used for PV modules. The attraction of these technologies is that relatively inexpensive industrial processes, certainly in comparison to crystalline silicon technologies, can manufacture them yet they typically offer higher module efficiencies than amorphous silicon. Most offer a slightly lower efficiency: CIS is typically 10-13% efficient and CdTe around 8 or 9%. A disadvantage is the use of highly toxic metals such as Cadmium and the need for both carefully controlled manufacturing and end-of-life disposal; although a typical CdTe module contains only 0.1% Cadmium, which is reported to be lower than is found in a single AA sized NiCad battery. Table 1 presents a comparison between various types of solar photovoltaic panels.

Table 1. Comparison of Solar Photovoltaic Technologies.

| S. No | Property | Mono Crystalline | Multi/Polycrystalline | Thin Film (CdTe, CIGS, Amorphous crystalline etc.) |
|---|---|---|---|---|
| 1 | Efficiency | Highest | Moderate (13-15%) | Lowest |
| 2 | Cost | Highest | Moderate | Lowest |
| 3 | Area occupied per kW | Lowest | Moderate (approx. 100 sq. ft) | Highest |
| 4 | High Temperature Performance | Poor | Poor | Better |
| 5 | Generation in diffused light | Average | Average | Better |

The most commonly available panels are polycrystalline/ multi-crystalline. Table 2 discusses the factors that affect the performance of solar panels based on Indian conditions.

Table 2. Factors affecting Solar Panel Output.

| S. No | Factor | Remarks |
|---|---|---|
| 1 | Direction | For panels that have fixed position without any sun tracking mechanism they should face south direction for better output throughout the year. |
| 2 | Tilt/ Angle of Inclination | Preferably according to the latitude of the place. |
| 3 | Shading | Even a small part of shaded panel, affects the entire output of the panels largely. Ensure the panels are placed such that there is no shadow on them throughout the day. Even a single partially shaded panel affects the output of all other solar panels in the system. Also, ensure that there is no dust etc on the panel to avoid shading. |
| 4 | Temperature | Higher the temperature, lower will be the output from solar panels. Usually, panels are rated according to standard test conditions (i.e., temperature: 25 degree Celsius, insolation 1000W/$m^2$, Air Mass: 1.5). Hence, if temperature is higher than this, your panels may give less than rated output. |

**6 Future researches in solar technology**

Research in photovoltaics is proceeding rapidly on many fronts. Some of these approaches are still in the early stages and far from being put into production, but they may become mainstream in the future. Making a solar cell with several layers is possible since the band gap can be tuned by adjusting the doping. Each layer would have a band gap tuned to a particular wavelength of light. These ―multi-junction‖ cells can attain 40 percent efficiency but remain expensive. As a result, they‘re more likely to be found on NASA spacecraft right now than on a terrestrial roof. The research behind solar energy is booming, too. Scientists are discovering new ways to decrease costs and increase efficiency of solar panels and coming up with creative, impressive ways to generate power. Following are the futuristic developments in solar technology:

6.1 Bionic leaf

Scientists at Harvard recently created a bionic leaf, which uses a catalyst to make sunlight split water into hydrogen and oxygen, then a bacteria engineered to convert carbon dioxide and hydrogen into a liquid fuel called isopropanol. They're almost at a 1% efficiency rate of turning the sunlight into the fuel — in other words; they've found a way to recreate the efficiency of photosynthesis.

6.2 3D printed solar powered trees

Researchers at the VTT Technical Research Centre of Finland created a solar powered electric forest with 3D printed trees. That's quite a bit of buzz worthy tech in one project. The trunks of the trees are made from 3D printed wood biomaterials, and the leaves are the solar "panels". They are much less efficient than traditional PV panels, but the research they're doing for solar cells is promising as well.

6.3 Perovskites

Perovskites are materials with a specific crystalline structure. Stanford University researchers found that using lead, ammonia, and iodine, they could make a lot of it for cheap. Perovskites are more efficient than silicon in some ways, so the idea is using them to supplement rather than replace silicon may be a way to increase the efficiency of solar cells. At Stanford, a silicon solar cell with an efficiency of 11.4% increased to 17% with perovskite.

6.4 Thin film solar

New research from Cornell, published in Nature in January, showed that scientists are reporting better solar cells by changing the chemistry of the materials. Thin film solar, which is a photovoltaic material onto a substrate like silicon. The ones made by these researchers at Cornell are organic-inorganic metal halide perovskites, which the team has been studying for a while. The new solar cells use a liquid source and a simple coating, which can make it appealing for more commercial uses.

6.5 Carbon-Based Solar Cells

Another cheap alternative to silicon that has emerged is printed carbon-based, or organic, solar cells. The efficiency is still relatively low compared to other materials, and the research surrounding it peaked about a decade ago. But, as perovskites gain popularity in reducing the cost and increasing efficiency of cells, carbon-based options are looking like contenders, too.

6.6 Colored solar panels

Scientists have found a way to make solar panels a little more aesthetically pleasing. They layered silicon dioxide, often used to make glass optical fibers, and titanium dioxide, used to absorb UV rays, to make a photonic crystal structure that can absorb sunlight. Colors appear when light is reflected and absorbed, and the colors change depending on the thickness of the materials. The problem is, these panels are much less efficient than black solar panels, only reaching up to 9%. The blue, for instance, is only about 6%. The hope is that as the technology advances, the efficiency will increase — but for now, it is a way to possibly mainstream the idea of solar even more.

6.7 Polymer Solar Cells

Polymer solar cells, called P1D2, may increase solar cell efficiency. The research comes from the University of Chicago's chemistry department, the Institute for Molecular Engineering, and Argonne National Laboratory. The polymer breaks down easier and allows more electrons to travel faster. The researchers said in a test, it increased solar cell efficiency by 15%.

6.8 Solar Concentration Technology

Concentrating photovoltaic (CPV) systems are giant and have to be angled very accurately to get the right amount of sun during the day. They work great, but they are not ideal for roofs. Now, a team of researchers is working on using that high-efficiency technology for rooftop PV systems by building them with miniaturized, gallium arsenide photovoltaic cells and 3D printed plastic lens arrays. The systems weigh less, cost less, and are much smaller than CPV systems, though, and can be optimized for rooftops.

## 7 Discussion and Conclusions

A review of major solar photovoltaic technologies comprising of PV power generation is discussed. It is highlighted that there is tremendous renewable energy resources available and Solar PV is one of them for electricity generation. This demand deployment of PV cells on building facades or rooftops. This will lead to reduction in power cuts and emission of greenhouse gases. Increasing environmental concerns and the need to achieve emission reduction targets should help the technology to become further established as a marketable and economically viable product. Moreover government policies and research in development of new solar technology needs to be implanted. This paper would be useful for the solar PV system manufactures, academicians, researchers, generating members and decision makers.

The worldwide energy consumption is increasing every year and different technologies are using to produce electricity to compete the energy demand. The environmental pollution is also a serious problem nowadays due to the more use of fossil fuel for energy production. Solar PV technology is growing rapidly in past decades and can play an important role to achieve the high energy demand worldwide. Huge amount of PV systems installed yearly shows the seriousness and the responsibility of every country about the issue to save the earth by using renewable energy. This paper illustrated about the worldwide status of PV technology, research in materials for solar cell, factor affecting for PV efficiency, present cost of solar cell and environmental impact. The conclusions of this review are as:

Presently, mono- and polycrystalline PV technology have more than 40% market share with 15–17% efficiency. However, thin film, polymer based solar cell and third generation based solar cells are also in development stage and extensive research work is going for efficiency improvement for commercial use. The efficiency of solar cell is one of the important parameter in order to establish this technology in the market. The performance of solar cell are also depends on its surrounding such as temperature, irradiation and dust. Temperature can affect PV performance drastically and due to that fact, studies has focus on lowering the temperature by extracting heat and use it for other purpose such as water or air heating. For dust problem, it is advised that PV surface need to be clean often to maintain the performance. Every developed technology should have advantages and disadvantages to the environment. The solar cell production has some disadvantages on environment during manufacturing and process time but it gives much more advantages during use. The electricity production through PV system is clean and safe for environment with comparison to coal and fossil fuel. Electricity production through PV module reduces the carbon dioxide emission in environment and safe for global warming problem. At the end of PV module life, it can be recycled and safely disposal will give minimum effect on environment. So, research for recycled for PV materials are also a key issue for minimizing the environmental effect of PV technology during entire period of life.

**References**


[1] Energy Sources: Solar". Department of Energy. Retrieved 1 June 2020.

[2] International Energy Agency (2014). "Technology Roadmap: Solar Photovoltaic Energy". IEA. 7 October 2014.

[3] Yoo S-H, Lee E-T. Efficiency characteristic of building integrated photovoltaics as a shading device. Building and Environment 2002; 37:615–23. W.-K. Chen, Linear Networks and Systems. Belmont, CA: Wadsworth, 1993, pp. 123–135.

[4] Bakos GC, Soursos M, Tsagas NF. ―Techno economic assessment of a building integrated PV system for electrical energy saving in residential sector. Energy and Buildings 2003; 35:757–62.

[5] Ordenes M, Marinoski DL, Braun P, Ruther R. The impact of building integrated photovoltaics on the energy demand of multi-family dwellings in Brazil. Energy and Buildings 2007; 39:629–42.

[6] Xu X, Van Dessel S. Evaluation of an active building envelope window-system. Energy and Buildings 2008; 40:168–74.

[7] Chow TT, Hand JW, Strachan PA. Buildingintegrated photovoltaic and thermal applications in a subtropical hotel building. Applied Thermal Engineering 2003; 23:2035–49.

[8] McCann MJ, Catchpole KR, Weber KJ, Blakers AW. A review of thin film crystalline silicon for solar cell applications. Part 1: Native substrates. Solar Energy Materials and Solar Cells 2001; 68: 135–71.

[9] El Chaar L, Lamont LA, El Zein N. Review of photovoltaic technologies. Renewable and Sustainable Energy Reviews 2011; 15: 2165–75.

[10] Gorter T, Reinders AHME. A comparison of 15 polymers for application in photovoltaic modules in PV-powered boats. Applied Energy 2012; 92: 286–97.

[11] Global market outlook for photovoltaics until 2012. http://www.epia.org/ index.php?id=18. Retrieved 1 June 2020.

[12] http://en.wikipedia.org/wiki/File:Silicon-unit-cell-labelled-3D-balls.png. Retrieved 1 June 2020.

[13] Global market outlook until 2014, European Photovoltaic Industry Association report, (2010).http://www.epia.org/fileadmin/EPIA_docs/public/Glo bal_Market_Outlook_for_Photovoltaics_until_2014.pdfS. Retrieved 1 June 2020.

[14] Lee, S.; Pham, D.P.; Kim, Y.; Cho, E.-C.; Park, J.; Yi, J. Influence of the Carrier Selective Front Contact Layer and Defect State of a-Si:H/c-Si Interface on the Rear Emitter Silicon Heterojunction Solar Cells. Energies 2020, 13, 2948.

[15] http://en.wikipedia.org/wiki/Czochralski_process. Retrieved 1 June 2020.

[16] Becker C, Sontheimer T, Steffens S, Scherf S, Rech B. Polycrystalline silicon thin films by high-rate electronbeam evaporation for photovoltaic applications—influence of substrate texture and temperature. Energy Procedia 2011; 10: 61–5.

[17] Manna TK, Mahajan SM. Nanotechnology in the development of photovoltaic cells. IEEE 2007:379–86.

[18] http://www.evergreensolar.com. Retrieved 1 June 2020.

[19] Itoh M, Takahashi H, Fujii T, Takakura H, Hamakawa Y, Matsumoto Y. Evaluation of electric energy performance by democratic module PV system field test. Solar Energy Materials and Solar Cells 2001; 67: 435–40.

[20] Wu L, Tian W, Jiang X. Silicon based solar cell system with a hybrid PV module. Solar Energy Materials and Solar Cells 2005; 87: 637–45.

[21] Wu CY, Mathews JA. Knowledge flows in the solar photovoltaic industry: Insights from patenting by Taiwan, Korea, and China. Research Policy 2012; 41:524–40.

[22] Sethi VK, Pandey M, Shukla P. Use of nanotechnology in solar PV cell. International Journal of Chemical Engineering and Applications 2011; 2.

[23] http://www.nano.gov. Retrieved 1 June 2020.

[24] Zhao J, Wang A, Campbell P, Green. MA. A 19.8% efficient honeycomb multicrystalline silicon solar cell with improved light trapping. IEEE Transactions on Electron Devices 1999;46:1978–83.

[25] Azykov TM, Ferekides CS, Morel D, Stefanakos E, Ullal HS, Upadhyaya HM. Solar photovoltaic electricity: current status and future prospects. Solar Energy 2011; 85:1580–608.

[26] Glunz SW. New concepts for high-efficiency silicon solar cells. Solar Energy Materials and Solar Cells 2006; 90: 3276–84.

[27] Tsunomura Y, Yoshimine Y, Taguchi M, Baba T, Kinoshita T, Kanno H, et al. Twenty-two percent efficiency HIT solar cell. Solar Energy Materials and Solar Cells 2009; 93: 670–3.

[28] Mishima T, Taguchi M, Sakata H, Maruyama E. Development status of high efficiency HIT solar cells. Solar Energy Materials and Solar Cells 2011; 95: 18–21.

[29] Chen A, Zhu K. Computer simulation of a-Si/c-Si heterojunction solar cell with high conversion efficiency. Solar Energy 2012; 86: 393–7.

[30] Friedman DJ. Progress and challenges for next-generation high-efficiency multijunction solar cells. Current Opinion in Solid State and Materials Science 2010; 14:131–8.

[31] Shenck NS. Alternative energy systems. U.S. Naval Academy Lecture Readings; 2010.

[32] Dincer F, Meral ME. Critical factors that affecting efficiency of solar cells. Smart Grid and Renewable Energy 2010; 1: 47–50.

[33] Kalogirou S. Solar energy engineering: processes and systems: chapter 9. Academic Press; 2009 pp. 469–517.

[34] Kumar R, Rosen MA. A critical review of photovoltaic-thermal solar collectors for air heating. Applied Energy 2011; 88: 3603–14.

[35] Singh, P, Ravindra N. M. Temperature dependence of solar cell performancean analysis, Solar Energy Materials and Solar Cells, 101, (2012), 36–45.

[36] Ting CC, Chao WS. Measuring temperature dependence of photoelectric conversion efficiency with dye-sensitized solar cells. Measurement 2010; 43: 1623–1627.

[37] Evans D. L. Simplified method for predicting photovoltaic array output. Solar Energy 1981; 27: 555–60.

[38] Goossens D, Kerschaever EV. Aeolian dust deposition on photovoltaic solar cells: the effects of wind velocity and airborne dust concentration on cell performance. Solar Energy 1999; 66:277–89.

[39] Jiang H, Lu L, Sun K. Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules. Atmospheric Environment 2011; 45: 4299–304.

[40] http://www.darvill.clara.net. Retrieved 1 June 2020.

# Term Assignment

ORIGINALITY REPORT

19%

SIMILARITY INDEX

PRIMARY SOURCES

| | | |
|---|---|---|
| 1 | V.V. Tyagi, Nurul A.A. Rahim, N.A. Rahim, Jeyraj A./L. Selvaraj. "Progress in solar PV technology: Research and achievement", Renewable and Sustainable Energy Reviews, 2013<br>Crossref | 430 words — 8% |
| 2 | ijsrcseit.com<br>Internet | 402 words — 8% |
| 3 | www.sciencedirect.com<br>Internet | 54 words — 1% |
| 4 | debojyotisen.blogspot.com<br>Internet | 40 words — 1% |
| 5 | www.print2webcorp.com<br>Internet | 23 words — < 1% |
| 6 | www.greengenuk.com<br>Internet | 23 words — < 1% |
| 7 | www.mdpi.com<br>Internet | 15 words — < 1% |
| 8 | studentsrepo.um.edu.my<br>Internet | 8 words — < 1% |
| 9 | Engineering Materials, 2012.<br>Crossref | 6 words — < 1% |
| 10 | Akinyele, D.O., R.K. Rayudu, and N.K.C. Nair. "Global progress in photovoltaic technologies and the | 6 words — < 1% |

scenario of development of solar panel plant and module performance estimation − Application in Nigeria", Renewable and Sustainable Energy Reviews, 2015.
Crossref

11 Tyagi, V.V., Nurul A.A. Rahim, N.A. Rahim, and Jeyraj A./L. Selvaraj. "Progress in solar PV technology: Research and achievement", Renewable and Sustainable Energy Reviews, 2013.
Crossref

5 words — < 1%

| | | | |
|---|---|---|---|
| EXCLUDE QUOTES | ON | EXCLUDE MATCHES | OFF |
| EXCLUDE BIBLIOGRAPHY | ON | | |