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A Review on Solar Photovoltaic Technology and Future Trends

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ABSTRACT

Industrial development and population growth have led to a surge in the global energy 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. Energy from sun can be considered the main source of all types of energies. It can be used by various techniques such as making full use of sunlight to directly generate electricity or by using heat from the sun as a thermal energy. The ability to generate electricity from sunlight is a relatively new and exciting technology that offers many new opportunities in generating 'green' electricity. This technology is called solar photovoltaics or more simply, PV. Also referred to as solar electric, PV offers the ability to generate electricity in a clean, quiet and renewable way. It makes use if the abundant energy from the sun, to generate electricity without the production of harmful carbon dioxide (CO2) emissions, one of the main gases affecting climate change.The major objective of this review study is to help anyone working in solar PV technology by introducing them to the new developments in this fields. This paper helps them to review the technology of solar PV as on date along with various incentives schemes introduced by the governments to attract, the utilities to go green In this paper various applications and future development of Solar technology is also discussed.

Keywords: Renewable energy, Solar, Panel, Grid

I. 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.

Many countries are joining this league and India is one of them. In this connection, India has launched the Jawaharlal Nehru National Solar Mission (JNNSM) in 2009-10 with the ambitious target of installing 100 GW of solar power, solar Photovoltaic (PV) as well as solar thermal, in the country by year

2022. The JNNSM provides incentives that promote solar PV system installations both at grid-connected PV system and off-grid PV system levels. There is several state Governments in India that are also making and implementing their own plans for promoting solar PV systems by providing incentives. 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. As per the MNRE, Govt. Of India, the requirement is of 100,000 people. 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 renewables" 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 and India [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. 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 [3].

Bakos et al. 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 [4].

Ordenes et al. 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 [5].

Xu et al. 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 [6].

Chow et al. 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 [7].

II. 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. heir scientists 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.

- 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.

- 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%.

- 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.

- 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 metre is required, specifiers should choose a crystalline technology.

- 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. The table No. 1 will give you a comparison between various types of solar photovoltaic panels.

Table No.1 Comparison of Solar Photovoltaic technologies

Sr. 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 (apprx 100 sq.ft)	Highest
4	High Temperature Performance	Poor	Poor	Better
5	Generation in diffused light	Average	Average	Better

In India, the most commonly available panels are polycrystalline/ multi-crystalline. Table No.2 discusses the factors that affect the performance of solar panels based on Indian conditions.

Table No.2 Factors affecting Solar Panel Output

Sr. 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/m2, Air Mass: 1.5). Hence, if temperature is higher than this, your panels may give less than rated output.

III. GOVERNMENT POLICIES FOR SOLAR PV TECHNOLOGY

The political purpose of incentive policies for PV is to facilitate an initial small-scale deployment to begin to grow the industry, even where the cost of PV is significantly above grid parity, to allow the industry to achieve the economies of scale necessary to reach grid parity. The policies are implemented to promote national energy independence, high tech job creation and reduction of CO2 emissions. Three incentive mechanisms are often used in combination as investment subsidies: the authorities refund part of the cost of installation of the system, the electricity utility buys PV electricity from the producer under a multiyear contract at a guaranteed rate, and Solar Renewable Energy Certificates (SRECs)

- Rebates

With investment subsidies, the financial burden falls upon the taxpayer, while with feed-in tariffs the extra cost is distributed across the utilities' customer bases. While the investment subsidy may be simpler to administer, the main argument in favour of feed-in tariffs is the encouragement of quality. Investment subsidies are paid out as a function of the nameplate capacity of the installed system and are independent of its actual power yield over time, thus rewarding the overstatement of power and tolerating poor durability and maintenance. Some electric companies offer rebates to their customers, such as Austin Energy in Texas, which offers $2.50/watt installed up to $15,000.

- Net metering

Net metering, unlike a feed-in tariff, requires only one meter, but it must be bi-directional. In net metering the price of the electricity produced is the same as the price supplied to the consumer, and the consumer is billed on the difference between production and consumption. Net metering can usually be done with no changes to standard electricity meters, which accurately measure power in both directions and automatically report the difference, and because it allows homeowners and businesses to generate electricity at a different time from consumption, effectively using the grid as a giant storage battery. With net metering, deficits are billed each month while surpluses are rolled over to the following month. Best practices call for perpetual roll over of kWh credits. Excess credits upon termination of service are either lost, or paid for at a rate ranging from wholesale to retail rate or above, as can be excess annual credits. In New Jersey, annual excess credits are paid at the wholesale rate, as are left over credits when a customer terminates service.

- Feed-in tariffs (FIT)

With feed-in tariffs, the financial burden falls upon the consumer. They reward the number of kilowatt-hours produced over a long period, but because the authorities set the rate, it may result in perceived overpayment. The price paid per kilowatt-hour under a feed-in tariff exceeds the price of grid electricity. Net metering refers to the case where the price paid by the utility is the same as the price charged. The complexity of approvals in California, Spain and Italy has prevented comparable growth to Germany even though the return on investment is better. In some countries, additional incentives are offered for BIPV compared to stand-alone PV.

IV. APPLICATION OF SOLAR PV TECHNOLOGY

When we think of solar panels, chances are we think of roofs or giant arrays of glimmering panels in the desert. However, advances in photovoltaic (PV) technologies over the last decade have made possible many more smaller-scale applications for everyday living, on a more personal level. Improvements in design and configuration, energy storage, efficiency, and battery size have created opportunities for solar energy in a variety of situations, some of which you have probably not considered—including off-grid scenarios that can help you survive emergency situations. Below are nine examples of innovative, low-cost ways solar energy is being used to enhance our daily lives.

- Streetlights

More cities across the world are powering streetlights with solar energy. The sun charges the batteries during the day, which then powers light-emitting diodes (LEDs) at night to illuminate the streets. San Diego is incorporating smart sensors into streetlights that can even direct drivers to open parking spaces and help first responders during emergencies. Combining internet-linked sensors with solar powered streetlights saves both time and money.

- Vaccine Refrigerators

In developing countries, 24-hour electricity isn't guaranteed, and in many cases, there is no electrical grid. "Private companies have been manufacturing solar-powered vaccine refrigerators so healthcare workers in remote areas can administer critical medication to those who need it," states Charlie Gay, director of the Solar Energy Technologies Office for the Office of Energy Efficiency and Renewable Energy (EERE). "This technology solution has been saving lives for more than four decades."

- Ovens

Solar ovens—also called solar cookers—reflects the sun's energy to cook food. Solar cookers can be parabolic or square structures lined with a reflective material that directs the rays into the box, where it heats the food evenly. The lid on top is typically made out of glass to better focus the sun's rays. They are ideal for living and often used in developing countries, which reduces air pollution that results from burning fuel.

- Cell-Phone Charger

USB cell phone chargers can charge a phone to almost full after only a few hours exposure to UV sunlight. These portable solar panels are about the size of a tablet and can also charge GPS trackers, tablets, or even laptops. They can be hooked on backpacks to collect solar energy as you walk, making them ideal for outdoor excursions.

- Paint

Instead of constructing typical solar cells of silicon, "polymers dissolved in a solvent create a 'paint' or coating that can be applied to any surface – from homes to offices to cars," writes technology writer Stephanie Hicks on Hub Pages. "It's inexpensive and versatile. Unlike bulky photovoltaic solar panels, solar paint uses thin-film nanoparticles instead of silicon as solar conductors. When applied to the sides of structures that face the sun, the thin solar cells invisibly generate clean, green power."

- Tents

Solar-powered tents are essentially larger versions of solar-powered backpacks. The tents have imbedded photovoltaic cells that store solar energy by day, which is then used to illuminate the tent at night and charge or power devices and small appliances, including heaters. The U.S. Army has a version that can generate up to 2 kilowatts of power a day.

- Bike Locks

The Ellipse Skylock is the world's first solar-powered bike lock. It powered by a built-in solar panel that provides enough power for a week after just one hour of charging. The Skylock connects wirelessly to the rider's phone to provide keyless entry, theft detection, bike sharing, and crash alerts. It also sends an alert if the bike is disturbed, using its long-range Bluetooth.

- Backpacks

Thin-film solar panels attached to the outside of backpacks provide up to about four watts of power—enough to charge phones, cameras, and other devices while simply walking. These exterior solar cells can also be attached to briefcases and handbags. These backpacks are ideal for students, hikers, and campers, who will always have a charged device during their travels, or when they reach their destination.

- Solar Fabric

Solar fabric is an application of solar technology with a wide range of applications. Solar cells are woven into textile fibers and generate convenient solar electricity. "One version, created by FTL Solar, can literally be pitched like a tent to provide both shelter and electricity," writes Hicks. "Consider the endless possibilities: military, rescue operations, disaster relief, recreational options, medical units, and even temporary housing. Any place you need flexible convenient solar power, solar fabric is your answer. "Rooftops are just one of thousands of places where solar panels are generating power," says Gay. "As costs drop and energy production rises, we expect to see many more places where solar technologies are put to work—providing unleashed, inexpensive electricity."

V. FUTURE RESEARCH 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

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.

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 trunk 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.

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.

4. Thin film solar

- 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.

- 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.

- 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.

- 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%.

- 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.

VI.CONCLUSION

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.

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