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Solar Electrification Scenario in India: Technological Development and Challenges

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Abstract: Solar power is a clean way to generate renewable energy. Because of high onetime cost large scale utilization of solar energy did not take place. In recent years solar power sector has experienced phenomenal growth and solar energy systems are now easily available for industrial and domestic use. These solar energy systems could be installed with financial supports like tax incentives and rebates from the government. Most of the developed countries are switching over to solar energy. This article provides an overview of status of solar energy in India in terms of existing capacity and utilization of technologies in solar power plants. This paper also focuses on key challenges in technological development for future growth of solar energy.

Keywords: Solar power, Solar technology, Solar photovoltaic, Solar thermal, Solar cell, Solar module

I. INTRODUCTION

Power is one of the most important components for urbanization, industrialization, economic growth and improvement of living standard of society. India is holding third position in the world in terms of power generation as well as power consumption as of august 2019.[1,2] Power sectors of India consists of three sectors: state sector (28.5%), central sector (25.0%) and private sector (46.5%).[3,4] The utility electricity sector in India has one National Grid, i.e. a high voltage electric power transmission network, with an installed power generation capacity of 360.788 GW, out of which 63.15% is from thermal (54.4% from coal, 1.7% from lignite, 6.9% from Gas and 0.15% from Diesel), 1.9% from nuclear, 12.6% from hydro (renewable), and about 22.35 % from other renewable energy sources (as on 31.08.2019).[4] It is evident that renewable power has secured 2nd position after thermal. The thermal power stations are dependent on vast indigenous reserves of coal and emit a high amount of toxic and greenhouse gases such as NOx, COx and SOx gases which is ingenious to health and environment. Due to limited fossil fuels and environmental problems (such as global warming) associated with it, Government of India has taken several steps to reduce the use of fossil fuels-based energy while promoting Renewable Energy Source (RES). The Ministry of Power has reported that overall electricity production (including generation from grid connected renewable sources) by utilities in India has been reached 1371.5 Billion Units (BU) or Terawatt Hour (TWh) in 2018-2019 from 1303.5 BU in 2017-2018, 1236.4 BU (2016-17), 1168.4 BU (2015-16) and 1105.4 BU (2014-15).[5] The total electricity generation (utilities and non utilities) in the country in the 2018-19 fiscal year was 1,547 TWh.[6] The annual growth rate (2018-19) in renewable energy generation has been increased by 24.47 % [126.8 BU (2018-19) and 101.839 BU (2017-18)] and 3.6 % for conventional energy.[5,7] So, it is clear that our country is focusing more and more on energy efficiency, conservation and renewable energy. The wind and solar energy are important renewable energy resources and they are environment friendly and can lower worldwide carbon emissions. The wind energy systems are not possible at all sites because of low wind speeds and it is more unpredictable than solar energy. Therefore to meet the surging demand, solar energy is the best form of energy to fulfil the energy needs of India and bridge the energy demand-supply gap. This paper highlights current status of solar power in India. An attempt has been made to present an overview on the solar technologies and its development and barriers on the solar technology.

II. PRESENT STATUS OF SOLAR POWER IN INDIA

India is a tropical country and therefore it receives solar radiation[8] almost throughout the year, which amounts to 3,000 hours of sunshine. This is equal to more than 5,000 trillion kWh.[9] Because of geographical location of the country India has tremendous scope of generating solar energy. States like Andhra Pradesh, Karnataka, Tamil nadu, Telengana, Bihar, Gujarat, Haryana, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan and West Bengal have great potential for tapping solar energy due to their location. National Solar Mission (NSM) was launched on 11th January, 2010 and had set a target to achieve 20 GW solar power by the year 2022.[9, 10] Over the years, solar energy sector in India has emerged as a significant player in the grid interactive power generation capacity.[11] The Cabinet in its meeting held on 17/6/2015 had approved revision of target under NSM from 20 GW to 100 GW.[10] The target of 100 GW capacity set under the National Solar Mission (NSM) is principally consist of 40 GW Grid connected Rooftop projects

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and 60 GW large and medium size land based Grid Connected Solar Power Projects. The gross installed capacity of grid connected ground mounted solar power in the country has reached a capacity of 28,536.38 MW as on 31.08.2019.[12,13] In addition, the cumulative installed capacity of grid interactive rooftop solar power in the country has reached a capacity of 2172.44 MW as on 31.08.2019 from 823.64 MW (31.10.2017). Country witnessed significant growth in solar power generation capacity in last five years, i. e. from 2647 MW on 31.03.2014 to 26,384.30 MW on 31.03.2019 and an average annual growth rate of about 60 per cent was recorded.[14] India's solar energy capacity has expanded by a record 9362.65 MW in 2017-18, 6530 MW in 2018-19 and 5,525.98 MW in 2016-17.[15,16] In comparison, India had added 3,018 MW of solar capacity in 2015-16, which shows that growth nearly doubled over the year 2014-15. This year 2019-20 (up to 31.08.19) 2152.08 MW solar capacity have already been installed.[4,13,15] The cumulative installed capacity of Off-grid solar power systems (SPV) in India has been reached to 935.17 MW as on 31.08.2019 from 671.41 MW (31.03.18).[13] Off-grid solar projects includes installation of solar street lights, solar water pumps, solar home lighting systems, solar lamps, solar powered water purifiers, etc.,

Therefore, India occupies the 5th position in the world in installed solar capacity (as on 31.12.2018) and the 3rd global position in 2018 in capacity addition, i.e. 3rd biggest solar market in the world [1st: China (~44.3 GW), 2nd: US (~10.6 GW)].[17,18] As of February 2017, the world largest solar power plant was 850 MW Longyangxia Dam Solar Park in China. But now Kurnool solar park of 1000 MW in Andhra Pradesh, India is fully operational.[14] However, world largest solar park 2000 MW Shakti Sthala at Pavagada, Tumakuru district, Karnataka, India and Bhadla Solar Park of capacity of 2255 MW at Bhadla, Jodhpur district, Rajasthan, India are currently under installation as of 31st August 2019. Among state-wise installed solar power capacity, Karnataka has crossed 6.4 GW solar installed capacity as on 31. 08. 2019 and become India's top solar state.[12, 19-21] Rajasthan has second highest installed solar capacity of 3925.67 MW, whereas Telangana occupies third position with 3620.75 MW installed solar capacity as on 31st August 2019.[12] Andhra Pradesh stands at fourth position with 3310.67 MW installed solar capacity. Tamil Nadu holds fifth-highest installed solar power generation capacity (3097.97 MW) in the country.[12] Nearly 55% of the total new capacity addition has come from four southern states and therefore Telangana, Karnataka, Andhra Pradesh and Tamil Nadu have emerged as the fastest growing states. The installed capacity of grid connected solar power in West Bengal is about 96.82 MW as on 31.08.2019.[12, 22-23] West Bengal is holding 18th position in installed solar capacity in India.[12]

In 2009 country's first grid connected 1.1 MW capacity solar power plant[24] was installed in Jamuria, Asansol, West Bengal based on which the National Solar Mission was conceived. Once a pioneer in the renewable energy sector, West Bengal is lagging behind in solar power promotion. It is unfortunate that other states pursued the model that was first introduced in Bengal and went ahead to promote solar power. Due to lack of a policy and proper initiative, West Bengal gradually fell behind. In June 2012 the Government of West Bengal declared its renewal energy policy and sets out a target of creation of capacity of 500 MW to be achieved by 2022. But initiatives taken by state government and implementation of solar programmes are not sufficient for commitment to the policy.[25] However, 10 MW Teesta Canal Bank Solar PV Power plant has been commissioned on 18.08.2016 and now is running in full capacity. Its total Cumulative Generation as on 31.10.2018 is about 29.74 MU. In addition, recently 10 MW Mejia Solar PV Power Plant, Bankura, and 9 MW out of 10 MW Chharrah Solar PV Power Plant, Purulia have also been commissioned and total cumulative generation as on 31.10.2018 are 6.39 and 5.82 MU, respectively.[26, 27] The installation works are under progress at 10 MW Khemasuli Solar PV Power Plant, Paschim Medinipur, 10 MW Salboni Solar PV Power Plant, Paschim Medinipur,and 10 MW Santaldih Solar PV Power Plant, Purulia.[26, 27]

Large segment of ground mounted solar power in India is coming from solar photovoltaic power plants and rest small segment is from concentrated solar power (CSP) plants. Total installed CSP capacity in India is around 228.5 MW. [28, 17] Global CSP capacity hit 5.5 GW at the end of 2018 and Spain accounted for almost half of the world's capacity at 2,300 MW, making this country the world leader in CSP. United States holds 2nd position with 1,740 MW.[17] In contrast to ground mounted solar photovoltaics, floating solar photovoltaics (FPV) installations open new opportunities for the deployment of solar PV in many places with high population density. It may be mentioned here that installation cost and transportation cost for FPV are high in comparison to ground mounted solar photovoltaics. The country's first floating solar power plant (10 KW) was installed in 2014 on a waterbody at Rajarhat New Town, West Bengal.[29] At present India's largest floating solar power plant of 500 kWp have been installed at Banasura Sagar reservoir in Wayanad, Kerala, India.

In terms of grid connected rooftop solar programme, Gujarat has emerged as the state with the most rooftop solar panels installed and has an installed rooftop solar power capacity of 397.31 MW against total 2172.45 MW capacity of India.[12] Gujarat is followed by Maharashtra (210.57 MW) and Karnataka (205.41 MW) in terms of installed rooftop solar power capacity.

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III. TECHNOLOGY FOR SOLAR POWER PLANTS

Solar energy is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaics, solar thermal energy, solar architecture and artificial photosynthesis. It is an important source of renewable energy and its technologies are broadly characterized as either passive solar or active solar depending on how they capture and distribute solar energy or convert it into solar power. There are two main types of solar energy technologies-Photovoltaic (PV) and Concentrating Solar Power (CSP).

3.1 Solar Photovoltaic (PV) technologies

The basic component for this technology is Solar Photovoltaic (PV) cells which convert solar radiation directly into electricity. The process of converting light (photons) to electricity (voltage) is called the PV effect. The first solar PV cell was made in 1954 at Bell Telephone.

A solar cell is a sandwich of two different layers of silicon that have been specially treated or doped. The lower thick layer is doped with boron or gallium such that electron vacancy or “holes” are created. It’s called p-type or positively charged hole type silicon.[30] The upper thin layer is doped the opposite way to give it slightly too many electrons. It’s called n-type or negative type silicon. When a layer of n-type silicon is placed on a layer of p-type silicon, some of the electrons in the n-type portion will flow into the p-type to "fill in" the “holes”. Eventually enough will flow across the boundary to equalize the Fermi levels of the two materials and depletion zone is formed. The p-type side of the depletion zone now contains negatively charged ions and n-type side of the depletion zone now contains positively charged ions. Because of the presence of these oppositely charged ions at the interface, a potential barrier is created at the junction of the two materials (0.3 V to 0.7 V) and no electrons can cross the barrier even if this silicon sandwich is connected to a load. But when sunlight shines on the cell, photons (light particles) bombard the upper surface of thin layer. The photons carry their energy down through the cell and give up their energy at the depletion zone of p-n junction. As a result electrons are dislodged, creating free electrons and holes. Electrons so generated are attracted by positive field of n type layer and escaped out into the circuit through metal fingers. When a load is placed across the cell, these electrons will flow from the n-type side to the p-type side through the external circuit and they re-combine with the generated holes. In this way, sunlight creates an electric current.[30] A typical, single-junction silicon solar cell has a theoretical maximum efficiency of about 30 percent, known as the Shockley-Queisser limit.[31, 32] This is essentially because sunlight contains a broad mixture of photons of different wavelengths and energies and any single-junction solar cell will be optimized to catch photons only within a certain frequency band, wasting the rest. The electricity so generated is multiplied by the number of cells in each solar module or panel and the number of panels in each solar array. Combined, a solar array can make a lot of electricity. These systems can be used as both grid-connected and off-grid.

3.1.1 Solar Cell

The PV solar cells are manufactured by hundreds of manufacturers worldwide and solar cell technologies are traditionally divided into three generations. First generation (1G) solar cells are mainly based on silicon wafers and use simple p-n junction technology.[33] There are two main type of commercially available first generation silicon based PV cells viz.

1. Mono crystalline silicon PV cells – They are made from a single silicon crystal where atoms are arranged in particular order.
2. Polycrystalline silicon PV cells – They are made from a multi-crystals block of silicon.

Mono-crystalline solar cells produce electricity with about 24% conversion efficiency whereas power conversion efficiency of polycrystalline solar cells is about 19 %. At present these two categories dominate world markets constituting 90% of it.[17] The benefits of this first generation solar cell technology lie in their good performance, as well as their high stability. However, they are rigid and require a lot of energy in production. The cost of 1G solar cell is very high.

The Second generation (2G) solar cells are called thin-film solar cells because they are made from amorphous silicon or non-silicon materials, e.g. Cadmium telluride (CdTe), Copper indium gallium selenide (CIGS) using thin film technology. The bandgaps of CdTe (1.45 eV) and copper indium gallium selenide (CIGS, 1.04–1.68 eV) semiconductors can well meet the spectrum of sunlight and as a result CdTe and CIGS thin-film solar cells exhibit power-to-electricity conversion efficiency (PCE) of over 22%. It may be mentioned here that it is desirable to have bandgap of crystalline silicon (around 1.1 eV) which is capable of absorbing 77% of the solar irradiation. Thin film flexible solar cells use layers of semiconductor materials only a few micrometers thick. Many different photovoltaic materials are deposited with various deposition methods on a variety of flexible substrates. The performance of this second generation solar cell is 10-15 %. Since the second generation solar cells avoid use of silicon wafers and have a

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lower material consumption it has been possible to reduce production costs of these types of solar cells compared to the first generation, but there is still high energy consumption during deposition, and toxicity and availability of the materials are other concerns.

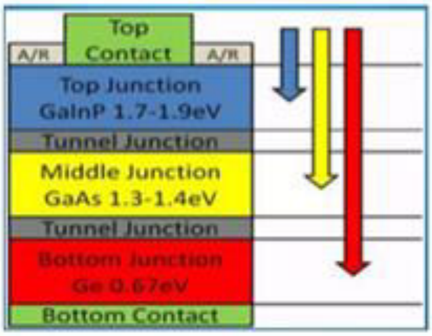

Fig.1 Multi-junction concept to solar cells

The two most important power-loss mechanisms in these single-bandgap cells are the inability to absorb photons with energy less than the bandgap and thermalization of photon energies exceeding the bandgap.[34] To achieve the highest efficiencies of the solar cells one can introduce multiple energy levels because multiple energy levels absorb different sections of the solar spectrum and this strategy gives third generation PV solar cells (Figure 1).

Third generation PV solar cells are cells that are able to overcome the Shockley-Queisser limit of 31 - 41 % power efficiency for single bandgap solar cells.[34] Common third generation systems include multijunction or tandem junction solar cells made of amorphous silicon or gallium arsenide. In these solar cells *p-n* junctions in different semiconductor materials of increasing bandgap are placed on top of each other, such that the highest bandgap intercepts the sunlight first (Figure 1). In addition to this 3G PV technology, organic materials such as conductive conjugated polymers or dendrimers or pigments are used in Organic photovoltaics (OPV) to convert solar energy to electrical energy.[35-38] Single layer Organic Solar cells wherein an organic semiconductor photoactive material sandwiched between two electrodes exhibit low efficiency due to poor electric field (as low dielectric constant of organic materials) to break up excitons (bound electron-hole pairs)
(Figure 2).

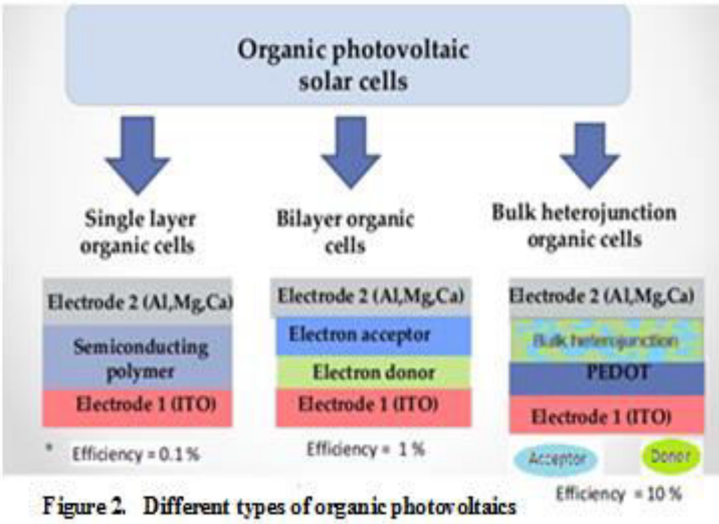

Figure 2. Different types of organic photovoltaics

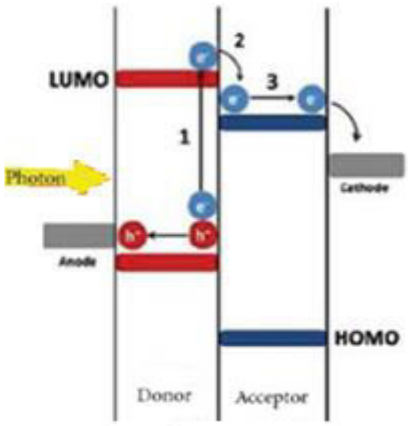

Figure 3. Operating mechanism of OPV

Whereas multiple layers hetero-junction organic solar cells use donor (*p*-typed materials) - acceptor (*n*-typed materials) molecules and involve photo-induced electron transfer from excited state (LUMO) of donor to LUMO of acceptor (Figure 3). Subsequent to charge separation at the donor-acceptor interface both the electron and the hole will reach the opposite electrodes, the cathode and the anode, respectively. Thus a direct current can be delivered to an outer circuit (Figure 4). In organic solar cell low bandgap materials such as conjugated polymers are used as donor and materials with high electron affinity and charge carrier mobility such as fullerene derivatives are used as acceptor. Organic solar cells have several features such as lightweight, flexibility, low cost, customized shape, and transparency, but these cells have certain disadvantages including their low efficiency (~ 15%)[37] and short lifetime, i.e. cell stability.

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Like organic solar cells, dye-sensitized solar cell (DSSC), e.g. Grätzel cell also emerged as a new class of low cost third generation solar cells. DSSC is an assembly of nanoporous titanium dioxide coated electrode soaked with a dye sensitizer, redox electrolyte and counter electrode.[39] So it has a sandwich-like structure that consists of a semiconductor formed between a photo-sensitized anode and an electrolyte (I^-/I_3^-) (Figure 5). When light shines on the anode of the dye-sensitized solar cell, dye molecules get excited and an electron of the dye molecule moves from a low-energy state HOMO to a high energy state LUMO. The excited electron from the dye molecule is injected into the mesosporous TiO_2 layer, leaving dye molecule is in oxidised state. The electrons flow toward the transparent electrode and escape into the external circuit and are re-introduced into the cell on cathode. The oxidized dye molecules are regenerated by receiving electrons from the iodide ion of the redox couple of the liquid electrolyte, which oxidizes into a triiodide ion and iodide ions are regenerated by reduction of triiodide on cathode. The use of sensitizers having a broad absorption band in conjunction with oxide films of nanocrystalline morphology permits to harvest a large fraction of sunlight. The certified highest power conversion efficiency (PCE) of DSSC has reached 11.9% till now.[40] Liquid electrolytes containing the iodide/tri-iodide redox couple causes electrode corrosion and electrolyte leakage and therefore DSSC suffers from long-term stability. To address these limitations, development of novel iodine-free electrolyte compositions and solid state DSSC are active area of research.[40-42] Apart from this degradation of the dye itself is considered another important parameter affecting the cell stability.

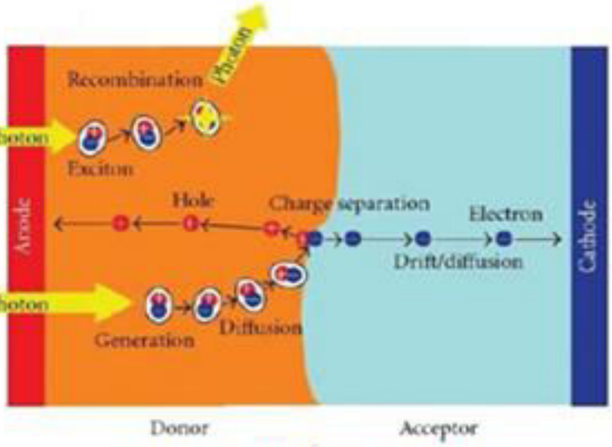

Figure 4. OPV working principle

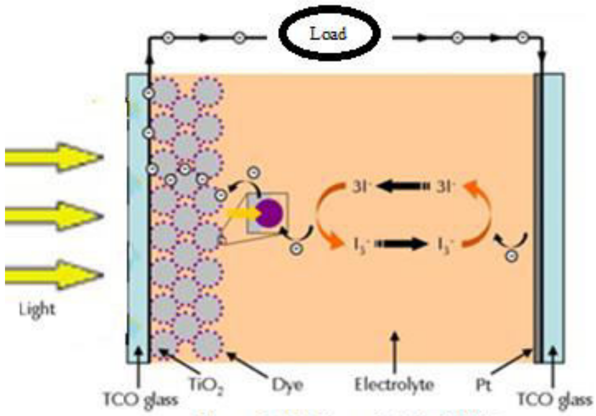

Figure 5. Working principle of DSSC

In the last few years, perovskite solar cell (PSC), which includes a perovskite structured (ABX_3 crystal structure where A and B are two cations of different sizes and X is an anion that attaches to both) compound, have become a very promising PV material with rapid increase in power conversion efficiency from about 3.8% in 2009 to about 24% in 2019.[43-45] The most common perovskite material is methyl ammonium lead trihalide $CH_3NH_3PbX_3$, a hybrid organic-inorganic lead halide based material. In the most efficient devices, the perovskite semiconductor is present as a solid absorber layer sandwiched between electron-transporting layer (ETL) and hole-transporting layer (HTL). Electron-transporting layer (ETL) is present on a transparent conducting oxide, i.e. front electrode and hole-transporting layer (HTL) is present on back electrode (Au or Ag). In this case, usually additives doped 2,2',7,7'-Tetrakis[N,N-di(4-methoxyphenyl)amino]-9,9'-spirobifluorene (spiro-MeOTAD) and poly[bis(4-phenyl)(2,4,6-trimethylphenyl)amine] (PTAA)-based solid state hole transport material (HTM) have also been used as electrolyte because it can provide a pure ionic conductivity between electrodes.[42] Working principle of PSC is almost similar to that of DSSC.[44] Perovskite layer absorbs light and generates excitons. Photogenerated electrons from the LUMO of perovskite are then migrated through the ETL to the electrode and holes from the HOMO of perovskite are migrated through HTL to the counter electrode. One key advantage of perovskites over silicon is that the band gap can be tuned broadly from around 1.2 eV to 2.4 eV. This enables the possibility of realising multi-junction solar cells, which could deliver much higher efficiency than single junction silicon, by either combining perovskites with silicon, or on their own. Beside this, fast charge separation, long transport distance of electrons and holes, long carrier separation lifetime make them very promising materials for solid-state solar cells. However, perovskite cell also deteriorate rapidly in the presence of moisture and the decay products attack metal electrodes. Heavy encapsulation to protect perovskite can add to the cell cost and weight. Therefore, perovskite solar cells commercialization is still challenging because of (i) stability issue,[45] (ii) toxicity issue and (iii) scaling up issue.

In addition to the above-mentioned third-generation technologies, there are a number of novel solar cell technologies under development that rely on using quantum dots or nanostructured materials.[46] If dye in DSSC is replaced by semiconductor quantum dots, i.e. tiny nanocrystals having a diameter that ranges from 2 to 10 nanometers, then these devices are called quantum dot (QD) sensitized solar cells (QDSSC). Working principle of QDSSC is almost similar to that of DSSC or PSC. Sulfide/polysulfide ($S^{2-}/S_n^{\ 2-}$) electrolytes have been used in this cell.[42] The energy levels of

Quantum dots, considered also as artificial atoms, are adjustable by altering their size, which in turn defines the bandgap. The quantum dots can be grown over a range of sizes which express a variety of bandgaps without changing materials or construction techniques. Besides this QD absorbers have been found to yield up to three electrons from one high energy photon of sunlight, i.e. multiple exciton generation (MEG) which could generate higher current and improve PCE. The major challenge in QDSSCs is the presence of defects in QDs, which lead to recombination reactions and thereby limit the overall performance of the device.

3.1.2 PV Solar System

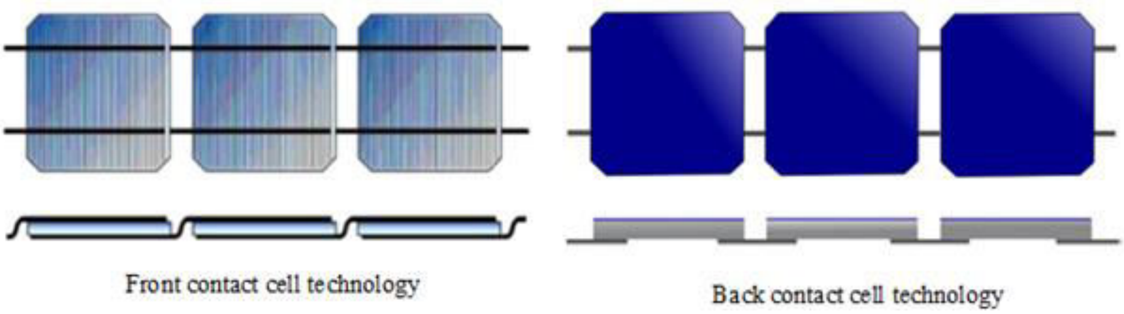

Fig.6 Interconnection of solar cells

One of the most important steps in photovoltaic industry is interconnection of solar cells by soldering and encapsulating them into two ethylene vinyl acetate (EVA) sheets covered with weatherproof glass and back sheet in vacuum. The available technologies for manufacturing solar PV module from solar cells are “front contact cell” method (conventional method) and “back contact cell” method (monolithic method) (Figure 6).[47, 48]
In conventional approach solar cells require out-of-plane interconnection between the front of one solar cell and back of the neighboring cell. The surface of conventional solar cell has several super-thin grid fingers which are formed by either screen printing or jetting of metallization paste (Ag paste) onto the front side laser cut grooves. Another metallization paste (Ag or Cu paste) was screen-printed perpendicular to grid fingers on solar cells as busbar. To connect the individual solar cells in series a copper ribbon strip i.e. tab wire is soldered to the busbar in tabbing process. After tabbing, ribbon on front metal contact is connected to back side metal contact of another cell in stringing operation. Several strings of series-connected solar cells are then electrically connected with wide copper ribbons (bussing) to complete the circuit. After lamination with EVA followed by framing develop a solar PV module. The major challenges in this technique are – (i) assembled solar circuit is very fragile before lamination step and (ii) cracks may be formed in the cell during soldering.[47]

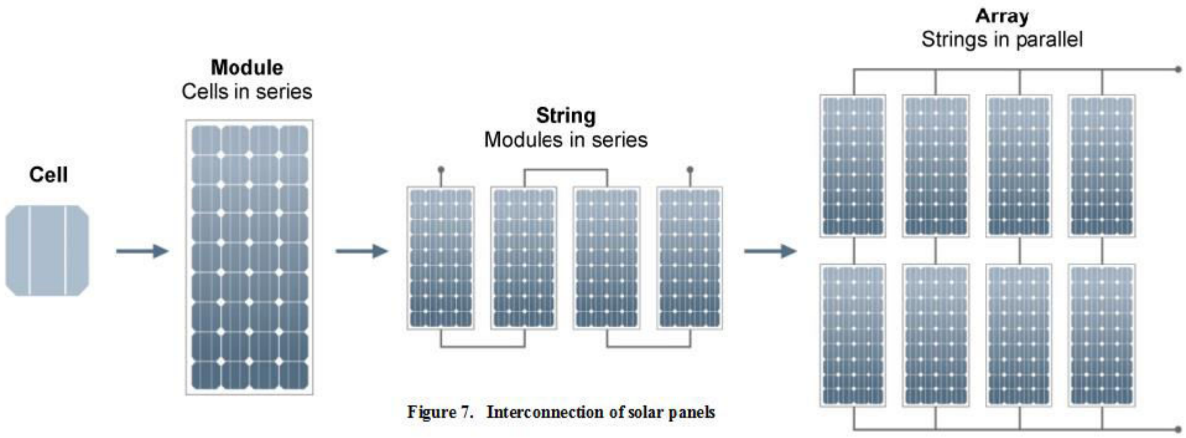

Fig.7 Interconnection of solar panels

Monolithic method requires back contact solar cells that have both positive and negative contacts on the back surface of the solar cell.[48] These back contact solar cells are placed on the flexible backsheet with a patterned electrical conductor layer. A polymer layer is provided between backsheet and the solar cells for encapsulation. Open channels are provided in this encapsulation layer where solar cells are electrically connected to the patterned electrical conductor on backsheet. The electrical circuit on the backsheet is brought to a single point so that a single junction box could be used. Several solar modules are coupled in series into a bigger unit known as a string of solar panels. Several strings of solar panels are connected in parallel to form solar array (Figure 7). One PV solar system has a number of solar arrays.

It may be mentioned here that mono-crystalline solar panel has missing corners and this distinctive pattern gives them their recognizable appearance, whereas polycrystalline solar panel has no missing corner because it is made by pouring molten silicon into a cast.

3.1.3 PV Solar System Installation

Based on the position of installation PV Solar System installations are of five different types: (i) Ground-mounted Solar PV installation (ii) Canal-top Solar PV installation (iii) Canal-bank Solar PV installation and (iv) Rooftop Solar PV installation (v) Floating solar PV installation.

3.1.3.1 Ground-mounted Solar PV installation

In this traditional approach, the panels are attached to the ground and slightly elevated. The power output of ground-mounted solar panels decreases at a rate of 1% every year for the first 10 years. Standard ground mounted system uses metal framework that is driven into the ground to firmly hold solar panel at a fixed angle. Some of these systems can be manually adjusted a few times a year to follow the seasonal shifting of the sun. Pole mounted solar system uses a single pole to support multiple solar panels and is constructed to hold the panels higher off the ground than the standard system. Pole mounted solar system can be either fixed mount, which means it holds the panel stationary, or it can move, or track, with the sun. A tracking system can automatically tip and lean the panels to maximize the amount of sunshine that is being captured.

3.1.3.2 Canal-top Solar PV installation

In this approach the panels are mounted on the canal. It may be mentioned here that panels mounted on Chandrasan's canal showed no degradation and power generated stayed stable over the past three years, according to research conducted by the Gujarat Energy Research and Management Institute (GERMI).[49] Canal-top solar system perform more efficiently because the generated electricity is utilised in nearby areas, the transmission losses of (normally) 4% and distribution losses of 3% are avoided. Apart from this, since the panels are placed on top of water, they are cooled from below, which also increases their efficiency and enhances output by 2.5-5%. This means the panels will last longer than 25 years, which is the average lifespan of a ground-mounted solar panel, while producing more power due to increased efficiency. Therefore, Canal-top solar power is most efficient, has longer life and saves water. The canal-top installations outperform both traditional ground-mounted solar installations, rooftop installations and systems on canal banks.

3.1.3.3 Canal-bank Solar PV installation

With this approach the panels are mounted on the bank of the canal and technologies are similar to the ground mounted solar PV installation. This installation utilizes the unutilized area on top of Canals.

3.1.3.4 Roof top Solar PV installation

The panels are built into new rooftops or retrofitted to existing ones. The solar panels are held together using any of the following three techniques – (i) Ballasted mount method, (ii) Mechanical attachment method and (iii) Hybrid mount method. Installation cost of this solar system is low compared to other kind of installations. Rooftop system will be much less productive if roof is not facing south, if there are obstructions such as shade from the surrounding trees, chimneys or skylights, and if the roof is not at the right angle.

3.1.3.5 Floating Solar PV installation

Floating solar installation required a structure that floats on a body of water, typically an artificial basin or a lake. Floating platforms are made of HDPE (high density polyethylene) and are anchored tightly so that they do not move too much. Mooring device is also needed to adapt the change of water level. Like canal top installations, floating solar system produce more energy due to cooling effect of water, last longer and help prevent evaporation in hot summers. There are a lot of challenges which includes system problems due to high moisture content, complications related to the anchoring and mooring of installations and safe transportation of power from floating objects.[50] The cost for installation of floating solar PV (FPV) is higher in comparison to that of ground mounted solar PV system because of need of floats, moorings and more resilient electrical components.

3.2. Solar thermal power technologies

Solar Thermal Power systems, also known as Concentrating Solar Power (CSP) systems, have solar energy collectors with two main components: reflectors and receiver. Reflectors (mirrors or lenses) capture and focus solar radiation onto a receiver (tubes).[28,51] A heat-transfer fluid (oil or molten salt or nanofluid) having low viscosity and high thermal capacity flowing through the tubes is heated. The heated fluid carry heat to a thermal storage tank through a heat exchanger and cold fluid is then circulated into the receiver. The heated fluid from thermal storage tank can be drawn for use and runs through another heat exchanger to generate high pressure steam. The steam is converted into mechanical energy in a turbine, which powers a generator to produce electricity. High temperature solar energy collectors are basically of four types (Figure 8):

Parabolic trough system (line focusing system): A parabolic trough collector uses line focusing technology and has a long parabolic-shaped reflector that focuses the sun's rays on a receiver pipe located at the focus of the parabola. At the receiver 400° C can reach and can produce steam for generating electricity.

Power tower system (point focusing system): A solar power tower system uses a large field of flat, sun-tracking mirrors called heliostats to reflect and concentrate sunlight onto a receiver on the top of a tower. The reflected rays of the sun are always aimed at the receiver, where temperatures well above 1000° C can be reached.

Parabolic dish systems (point focusing system): Solar Parabolic dish systems use a mirrored dish similar to a very large satellite dish. To reduce costs, the mirrored dish is usually composed of many smaller flat mirrors formed into a dish shape. Parabolic dish systems can reach 1000° C at the receiver, and achieve the highest efficiencies for converting solar energy to electricity.

Linear Fresnel Reflector (LFR) (line focusing system): It is similar to parabolic trough technology. Parabolic trough is sliced into individually tracking strips of mirrors and installed near the ground. Here receiver is stationary and does not move with the mirrors as in trough systems. It has lower production cost and require least amount of land per MW capacity.

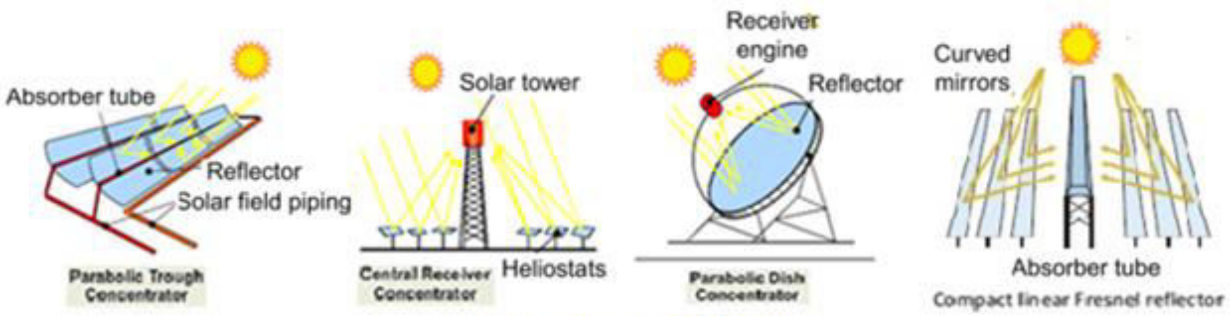

Figure 8. Different CSP technologies

Today two CSP technologies, parabolic troughs and solar towers, dominate the global market of solar thermal power plant projects. Parabolic trough systems are accounted for 90% of CSP plants.[17, 52] Parabolic trough concentrators are more efficient in comparison with linear Fresnel reflectors, but its investment cost is higher. The challenges related to CSP includes limitations in large scale manufacture of sharp edged mirrors/lenses, use of appropriate heat transfer fluids (HTF), achieving higher operating temperatures in CSP heat exchangers to get higher efficiency and lower running costs, many of which are subjects of active research activities.[17.52]

Solar thermal can be up to 70% more efficient in collecting heat from sun rays than solar PV system. CSP is capable of generating electricity in absence of solar radiation. It is less effective in winter months whereas solar PV systems are more versatile than solar thermal system. This system has shorter lifespan than solar panel.

IV. CONCLUSION

Energy demand in the country has increased rapidly and is expected to rise further in the years to come. In order to meet the increasing demand for electricity in the country, massive addition to the installed generating capacity is required. The cost of electricity generated from solar systems is still expensive and the central and state governments in India have been taking all necessary steps for solar energy utilization. This article gives an overview of the solar electrification scenario in India and development in solar technologies. It is seen that the development of low cost, stable, efficient and environment benign photovoltaic technologies such as advanced DSSCs, OPV, PSCs, QDSSCs and tandem or multijunction junction solar cells should be emphasized as promising alternative to conventional photovoltaic devices. A brief explanation has been given to better understand the working of solar cells. Each solar cell technology has its own advantages and limitations. The current stage of third generation solar PV technology requires lots of optimization and research before its commercialization. In terms of module efficiency and cost, back-contact silicon solar cells photovoltaic technology is expected to dominate the market in the near future. In addition, all CSP technologies which use mirrors of different architectures have considerable technical potential. Although cost of CSP systems is still high today in comparison to solar PV system, these systems can be a competitive option of electricity supply because of some inherent advantages such as poly-generation.

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