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Solar Energy & Smart City: The Status in India

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***Abstract*- Solar energy is imperishable, easily available and clean source of energy. Depending upon solar irradiance, solar PV system produces variable output with requisite infrastructure. As modern civilization following industrial revolution shows an upward trend in consumption of electrical energy, power shortage is inevitable. So all developed and many developing nation like India have started working with green energy projects for production of not only energy-efficient appliances but with drastic reduction in greenhouse gas emission as well. The net result is revival of the environment but maintaining the pace of the economic growth and technological development of the country with smart cities. Implementation of Solar Energy projects with photovoltaic (PV) system is one such significant step considered globally along with India. In this work, different aspects of solar energy are highlighted considering India's present status.**

***Index Terms*--energy-efficient appliances, green energy projects, greenhouse gas, photovoltaic system, solar energy, smart city**

I. INTRODUCTION

Solar energy, being a renewable energy source is free of environment-threating carbon emissions. So solar produces cleaner power and protect the environment from climatic changes. Now as producer of solar energy, solar photovoltaic (PV) cells are mainly used irrespective of the source considered as sunlight or an artificial light [1,2]. These are used either as photo detector (infrared detectors, for example) or other electromagnetic radiation source near the visible range. In all cases, such cells are often heaped together to make larger units, called solar modules and when they are coupled into a bigger unit, a solar panel is formed. These solar panels when combined with inverter and other electrical and mechanical hardware, generate electricity using solar energy. Size of such PV systems can vary largely from very small portable or rooftop system to large utility-scale power-production plants.

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II. WORKING PRINCIPLE OF A PV SOLAR CELL

The operation of a Photovoltaic cell follows three basic steps [1,2] as given below.

i) The absorption of light in generating electron-holepairs.
ii) The separation of these charge carriers in oppositedirections
iii) The separate extraction of these carriers to anexternal circuit.

Actually, photon is the quantum of light energy. When a solar cell is illuminated by energy of a photon

$$E_P = hv = h\frac{C}{\lambda},$$

which is more than the energy band-gap of the semiconductor, electron-hole pairs are created. These electrons and holes are separated by the electric field of the depletion region. Electrons swept to the n-side and holes to the p-side of the junction. Once, the newly created free electrons and holes come to the n-side and the p-side respectively, they further cannot cross the junction as the barrier potential exists across the junction. As the accumulation of electrons becomes higher in one side, this p-n junction will serve as a small battery giving rise to photovoltage.

Quantum - Efficiency (Q_E) for a photo-voltaic cell is considered in the form of

$$Q_E = \frac{\text{Number of electron}-\text{hole pairs generated/area}}{\text{Number of photons striking on the cell}}$$

III. CLASSIFICATION OF SOLAR CELL

These cells are divided into the following three broad classes as:

i) Crystalline silicon-based cells
ii) Thin-film cells
iii) Hybrid cells

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A. Crystalline silicon-based solar cell

These are solar cells of 1st generation and are made up of Crystalline silicon [2,3] which is semiconducting in nature and exists either in monocrystalline silicon form as a continuous crystal or as polycrystalline silicon.

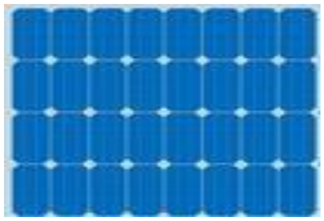

Fig 1. Crystalline silicon- based cells

They are used in photovoltaic technology to produce solar cells. These cells form solar panels to generate solar power from sunlight as part of a photovoltaic system

Such silicon based cells are very efficient and long lasting than the cells made-up of non-silicon based materials. But their efficiency decreases at higher temperatures.

B. Thin-film solar cells

Thin-film solar cell is a 2nd generation solar cell which is formed by thin-film technologies [2,4] depositing one/more thin layers (only a few µm thick) of photovoltaic material like glass, plastic or metal. Use of lesser material and cost-effective manufacturing processes allow the manufacturers to produce solar panels at a lower cost. Commercially available most common second generation cells are used in many technologies with materials of copper indium (CuIn), cadmium telluride (CdTe), gallium arsenide (GaAs), gallium di-selenide (CIGS) as well as amorphous thin-film silicon. The flexibility makes it an excellent choice for use in integrated PV in building rooftop.

Fig 2. Thin-film solar cell

C. Hybrid solar cells

These cells combine the best features of two generations' cells where it may be mentioned that in 1st generation cells, efficiencies are higher, around 25% , particularly for monocrystalline cells but they are costlier. Second generation cells are mainly made from materials like amorphous silicon, organic polymers, perovskite crystals which feature multiple junctions. Their efficiencies are less though they are less expensive.

Fig 3. Hybrid solar cells

In hybrid cell, amorphous silicon layer or an organic material layer is deposited on a single crystal wafer of high electron transit material like silicon to form heterojunction-type photoactive layer [4,5]. Such fabricated material increases cell's efficiency of power conversion largely compared to that of a single material and performs well at higher temperature and in indirect light and shows longer life with less production costs.

Additionally, third-generation cells are now under consideration which, though are not of significant commercially advanced innovative technologies, but are made now-a-days from some specific materials like silicon nanotubes and silicon wires. The aim is to improve the working efficiency of the cell over wider band of the solar spectrum including infrared radiation.

IV. COMPONENTS OF A SOLAR POWER PLANT

Following are the essential components of an ideal solar power plant.

i) Photovoltaic panel
ii) Photovoltaic Inverter
iii) Energy storage devices
iv) Charge controller
v) System balancing component

A. Photovoltaic panel

This panel is one of the major components of the power plant and is made up of small solar cells to covert solar photon energy to electrical energy. Here though the solar irradiation as primary energy is naturally available, the conversion efficiency of photo voltaic panels play the crucial role in their production and energy sharing. Various faults and failures may lead to the decrease in this value for these panels [6].

B. Photovoltaic Inverter

A photovoltaic inverter, being a very essential equipment in a solar energy system, basically converts the variable direct current output of a solar photovoltaic panel into an alternating current at utility frequency which can be fed into a commercial electrical grid or used by a off-grid, local electrical network [Fig.4]. The efficiency of such inverter depends on the data measured by it. So always there must be some provision for its performance analysis when there is conversion of input solar energy to the system power output, considering probable loss as well as the fault in the system [7, 8].

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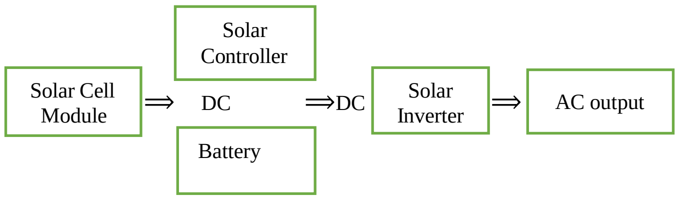

Fig. 4 Block Diagram of a PV inverter in a Network

General Photovoltaic inverters are of three types, namely, string inverters, microinverters, and power optimizers. They all transform the power generated by solar panels from direct current (DC) to alternating current (AC) to make the energy usable for practical purposes.

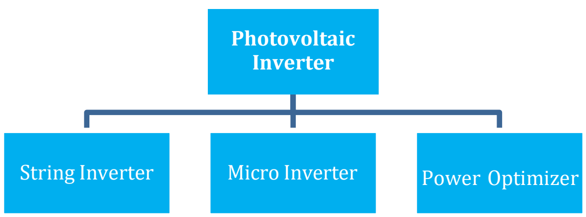

Fig. 5 Classification of PV Inverters

C. *Energy Storage Devices*

Solar panel's generated excess energy can be stored in different energy storage devices. Such solar photovoltaic energy and its storage technologies are combined for clean, renewable power production and its consumption throughout the days, particularly during the night and in bad weather condition when sunlight is not available. The storage technologies most commonly coupled with solar power plants are electrochemical type like batteries with PV plants and thermal storage with concentrating solar power (CSP) plants [9,10].

Two types of batteries which are used frequently in solar power plants are

a. Lead-Acid battery.
b. Nickel-Cadmium battery.

There may be differences in battery types, but any standard solar battery can store energy up to five days.

Again for storing thermal energy from CSP facilities, the fluids which are used normally :

i) Synthetic thermal fluids
ii) Molten metals
iii) Mineral oils
iv) Water
v) Molten inorganic salts
vi) Water-Glycol mixtures(at low temperature only)

D. *Charge Controller*

Solar Charge Controller is an electronic device controlling a voltage or current to charge the battery and keep the cells away from overcharging. It ensures the power not to run back to the solar panels to drain the batteries. Few charge controllers are available with additional features and capabilities of lighting and load control.

E. *System Balancing Component*

It is a set of components used to monitor, conserve and distribute power in the entire power plant system. It refers to the equipment and components including the wiring, switches, the mounting system, solar inverters, battery chargers with battery bank. So these components assist in flowing DC energy produced by solar panels through the conversion system to produce the AC output and basically refers to all the components of a PV system other than the solar modules. It ensures the other components to work in proper condition with maximum output maintaining the safety security of the plant.

V SOLAR ENERGY & SMART CITY

A Smart City is actually an advanced urban city or town with well- connected infrastructure and communication through data centers as well as automated networks [11]. It is mandated that solar energy will fulfil smart cities' energy requirement by providing a clean and green living environment with applications in the form of solar street lights, rooftop solar, solar water heaters, etc. A solar city runs on solar panels for electricity. Considering more population density, the villages of rural India along with its towns and cities in near future will encounter more power demands and expect innovative approaches to enhance existing electrical infrastructure. Policy-makers around the world including India are in search of some 'smart energy' solutions characterising energy resilience with low carbon emissions to support growing populations as well as their digital footprints. In India solar power contribution is the most significant so far as renewable source of energy [12] is concerned and is the necessity for running smart cities by reducing their dependence on non-renewable energy resources and shifting towards renewable and sustainable energy resources.

A. Requirements for a smart city from energy perspective

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Following are few of the basic requirements and corresponding planning.

i) Economic development demands for increasing supply of energy values continuously, both in urban and rural areas. Many towns and cities of India, particularly to mention, are experiencing a sharp rise in value of electricity requirement of around 16% [12,13]. So there is a need to develop concrete plans of action for generating more energy mainly through renewable solar sources, the efficient one and to preserve those energy for providing the urban services.
ii) The proposed action plans for solar cities development must support and encourage Urban Local Bodies (ULB) for guiding their cities/towns to become renewable-energy operated solar establishments and hence must help them for preparation of concerned Road Maps.
iii) The solar cities expect reduction of at least 10% values in their projected demand of energy from conventional sources and need to

a. empower the ULBs to address such challenges in energy values at city - level
b. build capacity in the ULBs to create awareness among various sections of the local civil society.

B. An estimation of solar panels for a sample solar energy supply unit

As example, if a 10kW system can produce 16kWh of electricity in a year, it shows a production ratio of 1.6 (16/10 = 1.6). Now considering this as a sample for average household in a small locality which has a total electricity demand of 1826 kWh per day [14] with

i) 52% for households
ii) 7% for enterprises
iii) 31% for agriculture,

Annual Electricity demand will be = 1826 x 365=666,490 kWh
Number of Solar Panels required will be = system size / production rate / panel watt. = 666490 kWh/1.6/390W=1068 (approx.)
(considering panel wattage 390.)

Using this sample calculation, no. of solar panels required for houses of various floor-spaces in the locality can be easily estimated in Table 1.
For commercial building, following consumptions/year are taken into considerations.

i) Refrigeration & equipment: Approximately 8 kWh/sq. ft
ii) Lighting: 7 kWh/sq. ft
iii) Other household electrical appliances: 7.5 kWh/sq .ft

So approximately 22.5 kWh/Square Ft/ year is used here.

Table I Solar Panel Estimation
(assuming 390 W Solar Panel & 1.6 production Ratio)

Home Size (commercial building)	Estimated Electricity Demand(Per Yr.)	No of Solar Panels
1000 sq. ft	**22,500 kWh**	**36**
2000 sq. ft	**45,000 kWh**	**73**
2500 sq. ft	**56,250 kWh**	**105**
3000 sq. ft	**67,500 kwh**	**109**

C. Solar Plant Setup Cost in India

Projected cost of land = Rs. 5 lakh/acre
Land required for a 1 MW plant = 5 acres
For 5 MW solar plant, total cost = Rs. 1.25 crore.

D. India's Solar Power Parks

The country has initiated some Mega Solar Projects (the Solar Parks) (listed in Table 2) including Rajasthan Renewable Energy Corporation's Bhadla Solar Park, world's largest solar park. Some of these parks are already operational and few others are going to be commissioned soon. Here emphasis is given obviously to the regions having favourable conditions for establishment of the proposed infrastructure, both from environmental point of view [15] and availability of lands.

Table II Solar Power Parks, India

Solar Park Name	**Location**	**Operational status**	**Capacity in MW**
Bhadla Solar Park	Jodhpur, Rajasthan	Operational (2020)	2245
Kadapa Ultra Mega Solar Park	Galiveedu, Andhra Pradesh	Operational (2018)	1000
Dholera Solar Park	Dholera SIR, Gujarat	To be commissioned in 2030	5000

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Agar- Shajapur Solar Park	Shajapur, Madhya Pradesh	To be commissioned	550
Rajnandgaon Solar Park	Rajnandgaon, Chhattisgarh	To be commissioned	500
NP Kunta Ultra Mega Solar Park	Anantapur, Andhra Pradesh	Operational partially (2016), with 978.5 MW	1500

For a example, Bhadla Solar Park is a 2245 MW solar complex being developed in Bhadla village in Jodhpur district of Rajasthan. Total cost of this park is around Rs 98.5bn. The Bhadla Solar- park plant cuts around 800,000 tons of Carbon. With 2245 MW capacity and over 10 million solar panels are there. The park has create more than 2,000 jobs in this field.

VI. CONCLUSION

Here basic methods of environment-friendly clean solar power production is highlighted along with its various components. Size-specific photovoltaic solar panels are estimated for smart-city houses. Accordingly, the tentative cost calculation is attempted. Finally India's solar power plant status is given which is considered to be an important concept of next generation green power transmission system .

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VI. BIOGRAPHIES

Arghya Mondal was born in Kolkata, in the state of West Bengal, India, on 9th March, 2003. He completed his secondary education at Barasat Ramkrishna Mission, where he demonstrated a strong academic foundation and a keen interest in learning. Continuing his educational journey, Arghya pursued his higher secondary education at Hatthuba Adarsha Bidyapith. During this time, he further honed his knowledge and skills, particularly in the field of electronics and communication engineering.

Currently, Arghya is studying at Gurunanak Institute of Technology, specializing in Electronics and Communication Engineering. This choice reflects his passion for understanding and working with the latest advancements in technology and communication systems. Beyond academics, Arghya is known for his determination and dedication. He possesses excellent problem-solving abilities and enjoys working in team environments, which allows him to collaborate effectively with his peers. Arghya has also demonstrated leadership qualities and takes initiatives to contribute positively to his academic and personal pursuits.

In addition to his studies, Arghya is an avid learner who keeps himself updated with the latest developments in his field. He actively participates in workshops, seminars, and technological competitions, allowing him to stay abreast of emerging trends and expand his knowledge.

Arghya Mondal's future aspirations revolve around making significant contributions to the field of electronics and communication engineering. With his solid educational background, determination, and passion for innovation, he aims to pursue a successful career that not only benefits him personally butalso has a positive impact on society.

Dr. Sucharita Bhattacharyya, was born in Kolkata in the state of West Bengal, India. She graduated in Physics from Burdwan Raj College and obtained her Masters Degree from Burdwan University in 1989. She did her Ph.D. from Visva-Bharati University.

She is currently working at Guru Nanak Institute of Technology, Kolkata as Professor of Physics. Her working area was low & medium energy Physics during her Ph.D. tenure. She received national scholarships and CSIR and DST Research Fellowship.

After Ph.D., Dr. Bhattacharyya worked as research assistant at Oak Ridge National Laboratory in their National Project on Nuclear Internal Conversion study and was awarded fellowship from University of Tennessee, USA (2001). Later she shifted to work in the area of Computational Electromagnetics and was awarded research grants from UGC, AICTE, and DST, Govt. of India. She supervised Ph.D. work as empaneled supervisor of MAKAUT successfully. She has authored more than 55 publications in peer- reviewed journals and conferences.