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Advanced Techniques and Emerging Trends in Solar Photovoltaic Technologies

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ABSTRACT: This article gives a comprehensive review of the solar photovoltaic systems in the trend of development of the technology, in particular the advancements in recent years, and the future work required. Solar photovoltaic technology is a one of the renewable technologies, which has a potential to create a clean, reliable, expandable and cost effective electricity system for the future. The rapidly reducing unit cost of silicon-based photovoltaic (PV) cells over past four decades has facilitated the arrival of PV as a commercially sustainable energy source. Though, emerging PV technologies currently in development show the potential to disturb and replace the superior market required crystalline silicon technology in the future. In addition, the building integrated PV systems reduces the area requirement as well the material and infrastructure costs of the building, and therefore, fulfills the technical thrust for smart building requirements. On the other hand, as the PV systems produce both the electricity, and the heat energy which are found to be more helpful, acceptable, and auspicious for most of real life applications particularly, where both forms of energy are required simultaneously.

KEYWORDS: Solar cell, Solar PV, thin film, silicon

I.INTRODUCTION

For the last several decades, the demand for energy has been increase, due to the improvedmechanization, growing population and evaluation in the standardof living of the people, worldwide. The International Energy Agency (IEA) analysed that the developing countries are increasing their energy consumption at the abruptly than that of developed ones and will necessary to about the double of their present installed generation capacity by theforthcoming to meet their energyneeds [1,2].It is also observed that more than 1.4 billion people in the developing countries are living in the short supply or without any access to electricity due to shortage of grid in these areas and other requirements [3,4].

In the developing countries, more than 80% people lives in the rural areas and continuously harnessing the conventional source of energy to meet their daily requirements of energy. For example, kerosene for home lighting,wood fuel for cooking, home heating, fueling steam engines and steam turbines to generate electricity, animals for agricultural activities, solar and wind energy for crop drying,heating, harvesting purposes, while diesel engine, rivers, canal, ponds etc. for irrigation purposes . Therefore, the use of wood for cooking, home heating, food processing, etc. consumes large amount of energy and creates the deforestation and pollution in the environment.

In the current scenario, the composed energy sources or fossil fuels such as coal, oil and gas are the major driver of economy for the whole world andalso the main contributor of environmental pollution [5]. There fore, with increase in computerization with the increasing population, there is an urgent need of more and more energy for healthy and competitive economic growth, while keeping the environmental fact in the mind. It means the time has come when there is annecessaryneed toanalyzethe renewable energy resources which meet the increased energy requirements and which are environmental friendly. Therefore, the time has come when the world community requires the energysources which are technologically, economically, environmentally, and socially compatible is the need of time, for the sustainable development [6,7]. Also the renewable energy sources such as, solar, wind, small hydro, Bioenergy, geothermal and tidal, etc. are the auspicious energy sources with all the qualities required to meet the present and future energy need. The renewable energy sources are free and generously available in the environment, however, facing some serious challenges regarding the low efficiency, highcapital cost and uneven availability over the time and location around the world. The capital amount of these systems ishigher than that of the fossil fuel based systems while, the efficiencyis quite low and hence, are not much economical at this point of time. The scientists and engineers around the globe are continuously making numerous efforts to overcome these issues and make this world a livable place for the common population [8].

The prompt increase in overall photovoltaic (PV) electricity production has been promoted by one key factor – the declining unit cost of silicon-based solar cells. Photovoltaic electricity generation is here and commercially viable today. Representing over 90% of worldwide installed PV capacity, c-Si PV cellshave been the vanguard to date. The affordability of such c-Si cells is managed by the economies of scale of its main ingredient, silicon, generated in the booming semi-conductor industry. Although the cost reduction of c-Si was excellent news for manufacturers in terms of competitiveness with conventional energy sources, the tough competitive position of c-Si in the free market drove other assuring PV technologies out to the margins.

II. CLASSIFICATION OF SOLAR PV

There has been a continuous growth in the utilization of renewable energy in general and solar energy in particular for useful applications, especially, after the oil crisis during the late 1970s. This has compelled the scientists and policy makers around the globe to emphasize on different ways to harness solar energy more effectively and efficiently, especially, in the area of thrust. In the terrestrial regions, solar energy can be utilized in two different ways; one through solar thermal route using solar collectors, heaters, dryers, etc. and the other is solar electricity using solar photovoltaic (SPV). The photovoltaic is the direct conversion of sunlight into electricity without using any interface. Solar PV systems are rugged and simple in design, modular in the nature, requires a little maintenance and stand alone can generate the power from microwatts to megawatts. The standalone PV system has played a very important and critical role in the electrification of the rural areas, especially, in the developing world [9]. A solar PV module along with the charge controller and battery as per the requirement is sufficient for electrifying the rural home and known as the solar home lighting system. This increasesthe demand for solar PV for a variety of applications.

Many solar energy systems, including but not limited to solar water heaters, solar air heater/dryer, solar desalination, solar home lighting, concentrated PV, Building integrated PV (BIPV) has been implemented and studied using energetic and energetic approaches for different purposes [10–12]. The different types of PV materials for solar cells are available in the market nowadays, but due to high efficiency and matured technology, Silicon based solar cells are leading the market from the beginning. However, researchers around the world are exploring the other options to produce electricity more efficiently by means of solar cells and hence, R&D for developing new material is going on. Many authors have reviewed the recent studies and developments on solar PV systems and their possible applications in different areas. However, low cost and flexibility in nature makes the thin film technology to be the potential technology for the solar cells. First Solar reduced itsprice down to $0.75 per watt, 50% less than crystalline solar cells. But its conversion efficiency is still a cause of concern among the scientific community. Therefore, the experimental work on different materials such as, amorphous silicon, CdS/CdTe and CIS is going on for efficiency enhancement of the thin film solar PV technology. Also options in selection of materials such as, material polymer or organic material as a solar cell are the other competent options in the thin film technology which not only enhanced the conversionefficiency but also suitable to meet the concern over the environmental problems . Advancement in the research and development related to different types of solar cell materials is going on. The classification of solar PV is given in figure 1.

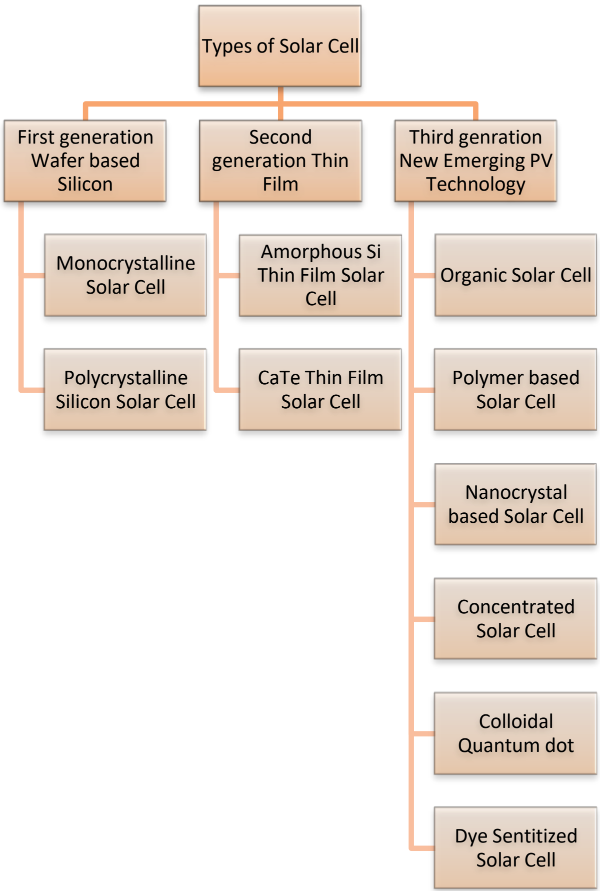

Figure 1: Types of Solar Cell

There are various types of PV materials of solar cells are available in the market. However, due to high efficiency and matured technology, the Silicon based solar cells are leading the market.World's overall PV cell/module production is increasing day by day. Crystalline semiconductors viz. Si and GaAs have the highest performance as compared the other options available in the market. While, the solar cells based on the less pure materials viz. polycrystalline or amorphous inorganic or organic materials, or combination of these having less performance but cost is low. Therefore, researchers all over the world are exploring other options with higher performance to produce electricity by the means of solar cells. Also due to low cost and light weight as compared to the mono and poly crystalline solar cells, the thin film technology

2.1Wafer based silicon solar cell

The crystalline silicon solar cells have many advantages such as, highefficiency than that of other solar cells and easy availability which forced the manufacturers to use them as a potential material for solar cells. In most of the cases, the monocrystalline type solar cells are used as they have high efficiency but due to higher cost of the material, it is still a cause of concern for both the manufacturers and the end users. Therefore, the industries are looking for alternatives and polycrystalline type of solar cell may be another option which has lower cost as compared to the mono crystalline cell . The scientific community also looking for GaAs based solar cell as an alternative, which is a compound semiconductor, form by gallium (Ga) and arsenic (As) having the similar structure as silicon. The GaAs material is having high efficiency and low weight, but higher cost as compared to the mono- and polycrystalline silicon solar cells. However, the GaAs based solar cell exhibits to have high heat resistance and found to be suitable for concentrated PV module for power generation, hybrid use and space applications.

2.2 Thin film solar cells

The thin film technology based solar cells are cheaper as compared to silicon based solar cells due to the fact that the requirement of material is lesser in the manufacturing process of the former. The amorphous silicon being non-crystalline and disordered structure form of silicon is having 40 times higher absorptivity rate of light as compared to

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the monocrystalline silicon. Thus the amorphous silicon based solar cells are very famous as compared to other materials such as, CIS/CIGS and CdS/cdTe due to the higher efficiency of the former. Williams et al. presented the challenges and prospects in developing the CdS/CdTesubstrate solar cells on Mo foil. By combining the close-space sublimation and RF sputtering, ITO/ZnO/CdS/CdTe/Mo solar cells have been grown in the substrate configuration. CdCl2 annealing process was developed using the two stage process, CdTe doping was done in the first stage while second stage contributes to the CdTe/CdSinterdiffusion by secondary ion mass spectrometry analysis. The efficiency had been found to be increased from 6% to 8% by the inclusion of a ZnO layer between CdS and ITO layers and increasing the shunt resistance. However, for improving the CdTe solar cell characteristics, an experiment study has been conducted by Soliman et al.which revealed that the chemical heat treatment is needed to produce better cells. On the other hand, the copper indium gallium selenide (CIGS) based polycrystalline semiconductor is found to be one of the most popular choice for materials in the recent years due to its higher laboratory scale efficiency of about 20.3% . Jun-feng et al.investigated the selenization and annealing in CIGS films and found that after selenization at 450 °C, two separated phases as CIS and CGS at the top and bottom of the film as were formed. Kumar and Rao presented the review on fundamentals and critical aspect of CdTe/ CdS thin film heterojunction photovoltaic devices from the both physics and chemistry point of view. Efficiency enhancement, reliability and life time of this device were the prime target among the researchers around the globe, but the target achieved till date is far from the theoretical limits. They found that lack of understanding of some points such as junction activation treatment, the formation of stable back contacts, interfacial and grain boundary properties and impurities diffusion within the device are responsible for the slow progress towards the achievement.

2.3. Concentrated solar PV

When the solar energy concentrated and made fall onto the photovoltaic cells thereby, enhancing the irradiance for improving the conversion efficiency by replacing the highly expensive solar cell material by less expensive concentrating mirrors or lenses is termed as the concentrated solar photovoltaic (CPV) system. In this arrangement, the low cost solar concentrating collector with a concentration ratio of 3–5 along with a laboratory scale PV cell which is quite expensive may be used. Therefore, the cost of using higher number of low efficiency PV cells may be compensated by using smaller size and lesser number of PV modules with the availability of higher intensity radiation and hence, can make the system more efficient, economical and reliable. High efficiency is one of the key factor which is necessary to make CPV a cost effective technology. However, the durability and life cycle of such systems needs further R&D in this direction because high intensity radiation may cause deformation and damage to some parts of the PV panel. As a fact, only a fraction of the incident solar radiation striking the cell is being converted into electrical energy. While, the remaining gets absorbed and converted into thermal energy in the cell and may cause the junction temperature to rise unless the heat is efficiently dissipated to the environment. As the temperature of the solar cell increases, the photovoltaic cell efficiency decreases and also the cells exhibit longterm degradation with increment in the temperature. Thus the use of the extracted thermal energy from the CPV system through a suitable cooling medium can also lead to a significant increase in the overall conversion efficiency of the combined system. The major challenges and promise of concentrators is presented by Swanson.

2.4 Organic and polymer cells

In recent years, the organic solar cells are becoming favourable choice as the alternative material for solar cells because of their suitable prosperities such as, mechanical flexibility, low fabrication cost, semi transparency and light weight. However, the efficiency of these types of solar cells is still very low as compared other types of solar cells and has been reported around 8% in the literature.

2.5 Dye-sensitized solar cell

The dye-sensitized(DS) solar cells exhibit certain qualities including lower cost and simple manufacturing process as compared to silicon based which make them suitable and potential alternative for the future application as solar cells. Generally, this type of material comprises of five working principles such as ,a mechanical support coated with Transparent Conductive Oxides; the semiconductor film, usuallyTiO2; a sensitizer adsorbed onto the surface of the semiconductor; an electrolyte containing a redoxmediator; a counter electrode capable of regenerating the redox mediator like platine

2.6 Nanocrystal solar cells

Nanocrystal solar cells are solar cells based on a substrate with a coating of nanocrystals. The nanocrystals are typically based on silicon, CdTe or CIGS and the substrates are basically silicon or various organic conductors. Although research is still in its infancy, in the future nanocrystal photovoltaics may have superiority such as flexibility, cost efficient, clean power generation and an efficiency more compared to first-generation, crystalline silicon-based photovoltaics.

2.7 Quantum dot solar cell

A quantum dot solar cell (QDSC) is a solar cell design that uses quantum dots as the absorbing photovoltaic material. It attempts to replace bulk materials such as silicon, copper indium gallium selenide (CIGS) or cadmium telluride (CdTe). Quantum dots have bandgaps that are tunable across a wide range of energy levels by changing their size. In bulk materials, the bandgap is fixed by the choice of material(s). This property makes quantum dots attractive for multi-junction solar cells, where a variety of materials are used to improve efficiency by harvesting multiple portions of the solar spectrum.

Cell Type/ Characteristics	Wafer based silicon solar cell		Thin film Solar Cell2		Third Generation Solar cell					
	Monocrystalline	Polycrystalline	Amorphous	CaTe	Organic Solar cell	Nanocrystal based solar cell	Dye - sensitized	Polymer	Concentrated	Colloidal quantum dot
Efficiency	14%-18%	12%-14%	4%-8%	9%-11%	7%-10%	7%-8%	= 10%	3% - 10%	= 40%	17%
Size	Significantly less volume to produce the same amount of power	Significantly less volume to produce the same amount of power	Offering a wide range of product design from flexible, light durable	Offering a wide range of product design from flexible, light durable	Offering a wide range of product design from flexible, light durable	Offering a wide range of product design from flexible, light durable	Offering a wide range of product design from flexible, light durable	Offering a wide range of product design from flexible, light durable	Offering a specialized range of product design	Offering a wide range of product design from flexible, light durable
Cost	Two times more expensive than thin film	Two times more expensive than thin film	50 % less expensive than conventional silicon cell	50 % less expensive than conventional silicon cell	50 % less expensive than conventional silicon cell	50 % less expensive than conventional silicon cell	50 % less expensive than conventional silicon cell	50 % less expensive than conventional silicon cell	50 % less expensive than conventional silicon cell	50 % less expensive than conventional silicon cell
Space requirement	Small space is required	Small space is required	Small space is required	Large space is required	Large space is required	Large space is required	Large space is required	Large space is required	Large space is required	Large space is required

2.8. Environmental aspects

Tezuka et al. proposed a new method for estimating the amount of CO2-emission reduction in the case where the carbon-tax revenue is used as the subsidy to promote PV-system installations and concluded that the amount of CO2-emission reduction increases by advertising the PV system with subsidy policy even under the same tax-rate and the CO2-payback time of the PV system reduces by half if the GDP is assumed not to change after the introduction of carbon taxation [90]. Krauter et al. examined a CO2 comprehensive balance within the life-cycle of a photovoltaic energy system and found that the actual effect of the PV system in terms of net reduction of carbon dioxide is the contrast between the sum of electrical yield related to the local grid and the value for recycling and the sum of the production requirements and the transport emissions. Kannan et al. performed life cycle assessment (LCA) and life cycle cost analysis for a distributed 2.7 kWp grid-connected monocrystalline solar PV system operating in Singapore and provided various energy payback time (EPBT) analyses of the solar PV system with reference to a fuel oil-fired steam turbine and their greenhouse gas (GHG) emissions and costs are also compared revealing that GHG emission from electricity generation from the solar PV system is less than one-fourth that from an oil-fired steam turbine plant and one-half that from a gas-fired combined cycle plant . Tsoutsos et al. presented an overview of an Environmental Impact Assessment for central solar systems, to estimate the magnitude of potential environmental impacts and proposed appropriate mitigation measures, can play a significant role to proper project design and to a subsequent project public acceptance. Pacca et al. assessed the modeling parameters that affect the environmental performance of two state-of-the-art photovoltaic (PV) electricity generation technologies: the PVL136 thin film laminates and the KC120 multi-crystalline modules.

2.9. Sizing, distribution and control

Hernandez et al. presented a systematic algorithm to determine the optimal allocation and sizing of Photovoltaic Grid-connected Systems (PVGCSs) in feeders that reaches the best compromise for both technical and economical aspect by multi-objective optimization approach and is robust with moderate computer requirements. Yang et al. developed the Hybrid SolarWind System Optimization Sizing (HSWSO) model, to optimize the capacity sizes of different components of hybrid solar–wind power generation systems employing a battery bank. Koutroulis et al. proposed a methodology for optimal sizing of stand-alone photovoltaic wind generation (PV/WG) systems that suggests, among a list of commercially available system devices, the optimal number and type of units ensuring that the 20-year round total system cost is minimized subject to the constraint that the load energy requirements are completely covered, resulting in zero load rejection implementing the cost (objective) function minimization using genetic algorithms . Burger et al. discussed the influence of time resolution of solar radiation data on the correct sizing of PV plants .

Conti et al. studied the voltage profile of a LV feeder in order to assess the maximum value of the power that can be injected into multiple load points of the feeder by PV units without violating the voltage constraints and showed that with reference to a set of contiguous generation units, it is possible to derive analytical relationships between the position of the point of maximum/minimum voltage on the feeder and the characteristics of the distributed generation .Paatero et al. evaluated the effects of a high level of grid connected PV in the middle voltage distribution network and emphasized on static phenomena, including voltage drop, network losses and grid benefits using a multi-purpose modeling tool and demonstrated that high penetration levels of PV power generation may cause voltage problems in the electrical network .

Conti and Raiti dealt with the solution of the Load flow (LF) problem in distribution networks with photovoltaic (PV) distributed generation (DG) and used suitable models incorporated in a radial distribution probabilistic load flow (PLF) program that has been developed by using Monte Carlo techniques for prediction of the active power produced by PV DG units and the power absorbed by the loads are used to represent the uncertainty of solar energy availability and load variations and the developed program allows probabilistic predictions of power flows at the various sections of distribution feeders and voltage profiles at all nodes of a network .

III.CONCLUSION

A review of major solar photovoltaic technologies consisting of PV power generation, various lights absorbing materials, performance and accuracy of PV system, sizing, distribution and control is given. This article presents the recent advances in solar photovoltaic systems for advanced techniques and emerging trends and performance analysis of the solar photovoltaic systems. The recent developments in the research on different applications such as, water pumping, home lighting, space technology, building integrated PV systems, concentrated PV, desalination and photovoltaic thermal have been reviewed and presented. The space application of solar PV systems be very ancient, despite, needs further research in analyzing new solar cell materials for the efficiency enhancement, therefore a reduction in the area of the module. This paper would be useful for the solar system manufactures researchers as well as academicians.

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