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Technological Assessment of Grid Connected Solar Photovoltaic System; Review

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***Abstract*—Rapidly and continuously increasing population and materialistic life styles, the power requirement is increasing at even faster pace. This increased power demand means further burning of fossil fuels for power generation and adding more and more greenhouse gases in to the local and global environment. Due to awareness and the adverse consequences of such environmental changes on the life of life cycle, the researchers, scientists, engineers, and environmentalists have started developing and using new, clean, and renewable sources of energy to minimize the greenhouse gases emissions. Some of the major resources of clean energy includes solar, wind, biomass, hydro, and geothermal. This paper presents a technological analysis of grid connected photovoltaic system presented by various researchers around the world. The grid connected PV systems are being used for electricity supply to residential, governmental buildings, schools, hospitals, remotely located health centers, street lighting, and so on. Such systems, specifically in residential sector, can generate revenue for house or building owners through sales of the extra energy during peak hours to the grid using the net metering systems. Some of the aspects presented in this paper are the PV properties which includes power capacity and output generated energy, cost of energy (COE), module efficiency, system efficiency, performance, and capacity factor.**

Keywords—Greenhouse gases; Renewable energy; Fossil fuel; Solar; Wind; Biomass; Hydro; Geothermal; Performance ratio; Capacity factor

I. INTRODUCTION

Renewable energy generation is one the promising technology and environmental friendly means of power production with less or no release of environmental pollution such as carbon dioxide (CO_2), Sulphur dioxide (SO_2), nitrogen oxide (NO_X). Moreover, renewable resources have no greenhouse effect which results in global warming and leads to series of catastrophes like melting of glaciers, extinction of various plants and animals around the globe. Among the various source of clean energy that are used for generating power now a days are solar Photovoltaic (PV), wind, biogas, biomass, hydro, geothermal etc.

Solar energy has started drawing attention of world around 1970s and it continues developing rapidly for the past decade compared with other renewable resources [1]. The objectives of mitigating greenhouse effect and carbon emission around the world makes solar energy technology to spread in both developing and developed countries.

The global estimated installed solar PV capacity as of now 2020 was 583.5 GW compared to 227 GW in 2015. Meanwhile, at the end of December 2018, International Renewable Energy Agency (IRENA) reported 480.3 GW as world's cumulative installed PV capacity with China as the top country with 175 GW in Asia, followed by Germany with 45.9 GW in Europe, and United State of America with 49.6 GW in North America, etc. Fig. 1 shows the world's cumulative installed PV capacity in different continent at the end of December 2018 while Fig. 2 shows national cumulative PV installed capacity of top seven countries. Government and Non-government organizations, in different countries, are making efforts in promoting the integration of solar PV projects in both urban and rural communities. This is achieved by providing financial supports to the individual citizens and industries to fulfil their basic energy needs.

Solar PV system configurations can be of different types for different applications. Some of the configurations are stand-alone PV systems with or without battery storage, grid connected PV system, hybrid power system, and building integrated PV (BIPV) system [2]. To provide basic requirements for the implementation of solar PV systems and utilizing the abundant solar radiation around the world, researchers have performed extensive studies in this field. This includes performance evaluation, feasibility studies, computer simulation, and experimental evaluation. Some of the most important parameters used for evaluating PV system are system capacity, generated energy, module efficiency, system efficiency, Performance ratio (PR), and capacity factor (CF).

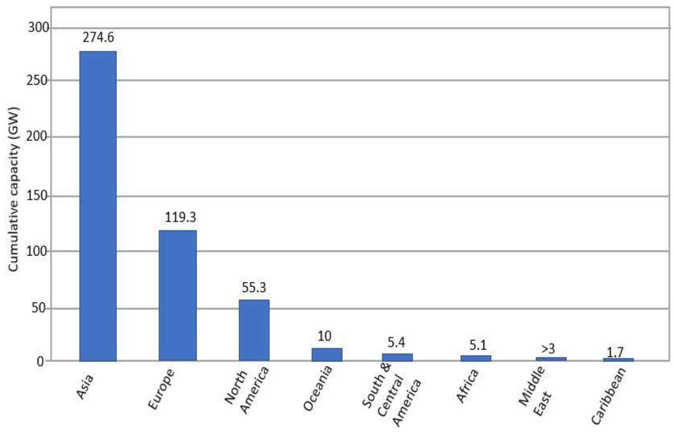

Fig. 1 World's cumulative installed PV capacity in different continent at the end of December 2018. [3]

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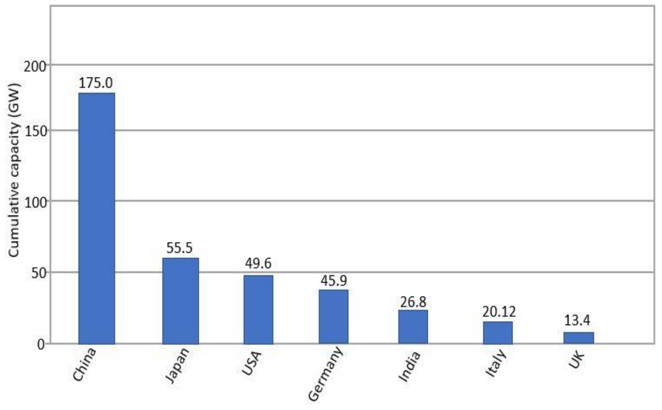

Fig. 2 National cumulative PV installed capacity of top seven countries at end of 2018. [3]

Goel and Sharma [2] presented a review on the performance evaluation of three configurations of PV systems and their application. Their study concluded that stand-alone PV systems are mainly used to provide electricity to small habitats/hamlets or single residences while hybrid PV systems comprise of two or more power sources and are used for rural electrification with ability to store excess energy. Grid connected systems can supply excess power to the utility grid when it is generating excess power. Goel and Sharma [2] reported that the PR of grid-connected systems varies from 25% to 90% with an value of average of 66%. Tian et al. [4] presented an evaluation of energy serving potential of semi-transparent PV (STPV) window in two identical buildings; one was made of amorphous silicon (a-silicon) while the other was conventional window. They observed that on typical sunny day, STPV windows might supply 0.26 kWh/day with 29% load saving on building load. Also, Wang Meng et al., [5] compared the energy performance of CdTe PV window and a-Si PV window in Hong Kong with annual generated energy of 52.3 kWh/m2 and 41.8 kWh/m2 having the module efficiency of 7.1% and 5.9%, respectively. Rehman et al. [6] performed an extensive feasibility evaluation of 44 site for implementing 10 MW power plants in Saudi Arabia using a Meteorological data and RETScreen software. They reported that Bisha is the best location to be used for power generation due to its high solar radiation intensity and longer sunny days.

II. GRID CONNECTED PV SYSTEM

A grid-connected PV system is an energy generating option connected to the utility grid. The main components of a grid-connected PV system are solar PV panel, DC to AC inverter, solar charge controller, bi-directional meter, and grid connection equipment. At normal condition a grid-connected PV system has an advantage of supplying excess energy to the utility grid. A typical schematic configuration of a grid connected PV system shown in Fig. 3.

Many grid-connected PV systems have been evaluated by different researchers to understand and ease the commissioning process and reduce the cost of operation. Berwal et al. [7] analyzed the technical and economic feasibility of 50 kW installed capacity gird-tied PV system at the rooftop of Saraswati library of Deenbandhu Chhotu Ram University of science and technology, India. The system used polycrystalline modules with efficiency of 14.66% and was able to generate 5,200 kWh of energy per month. This system resulted a

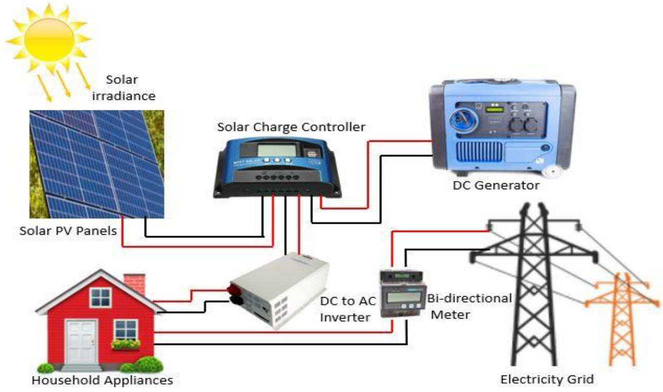

Fig. 3 Typical Grid-connected System

decrease of 4,070 kg of greenhouse gas emission per month to the environment. Similarly, Satsangi et al. [8] presented a performance evaluation of 40 kWp capacity grid connected system using standard IEC 61724 and reported annual energy generation of 32,374.8 kWh, with system efficiency, PR, and CF of 8.5%, 63% ,and 9.0%, respectively. In the same way, Sharma and Goel, [9] analyzed the performance of a 11.2 kWp installed capacity grid connected solar system installed on the roof top of the institute of Siksha 'O'Anusandhan University, Bhubaneswar, India and presented a total annual energy production of 14.960 MWh while the PR, PV module efficiency, and system efficiency were 78.0, 13.42% and 12.05% respectively. Furthermore, Dondariya et al. [10] presented a case study conducted in Ujjain, India. They evaluated the performance of 6.4 kW grid-connected rooftop solar PV using various software such as PV*SOL, PVGIS, SolarGISand SISIFO. The performance parameters were presented in the TABLE I. below.

The difference in the estimated values of the annual generated energy and PR are due to the difference in the model of the software used. However, the estimated PR by all software used are within reasonable range. Yadav and Bajpai [11] evaluated the performance of 5 kWp roof-top PV installed in Northern India with annual average energy production of 7175.4 kWh. The module efficiency, system efficiency, CF, and PR; for the reported system; were 11.34%, 10.02% 16.39% and 76.97% respectively.

Malvoni et al. [12] performed a long-term evaluation (over 43 months) of a 960 kWp PV system in Mediterranean climate located in southern Italy using measured data. It was found that the PR and CF were 84.4% and 15.6% while the annual module and system efficiencies were 15.3% and 14.9% respectively. Roumpakias et al. [13] conducted performance evaluation of a 9,984 kW grid-connected system installed in central Greece after 6 years of operation between 01-01-2013 and 08-31-2018. The system was comprised of 8 inverters, 416 PV panel with 14.7% module efficiency. The range of the PR of the system was 87% – 90% with decreasing trend and the average annual energy over the 6 years was 19,481.66 kWh.

TABLE I. PARFORMANCE PARAMETER OF VARIOUS SOFTWARE

Parameter	PVSOL	SolarGIS	PVGIS	SISIFO
Energy/Annum	9,780	9,901	9,970	11,238
PR (%)	75.01	73.50	76.40	73.80

Likewise, Banda et al. [14] carried-out performance evaluation of a 830 kWp grid-connected PV systems installed at Kamuzu international airport. They used both simulation and measured data for the period of 4 years from 2013 to 2017. The average annual module and system efficiencies, over 4 years' time, were 15.3% and 14.6% while average annual CF and PR were 17.7% and 79.5%. Peishi et al. [15] presented the life cycle assessment (LCA) of 1 MWp on-grid ground-mounted multi-si PV module solar station installed in china. The system was consisted of 4,568 modules and produced 2,313.33 MWh ($8.328x\,10^6 MJ$) of energy annually. of (2,313,333.333 kWh).

However, de Lima et al. [16] presented the performance of a 2.2 kWp grid-connected PV system installed at state University of Ceará, Fortaleza, Brazil. The system was analyzed using measured data from June 2013 to May 2014 and reported the annual average array and system efficiencies as 13.3% and 12.6%, respectively. The PR, CF and, annual generated energy values were 82.9%, 12.6% and 3,708.1 kWh; respectively. In an effort to promote the use of PV system in Jordan, Behiri et al. [17] performed an experimental evaluation of a 10 MW Oryx PV plant installed in Ma'an, Jordan. The evaluation was carried-out under real meteorological conditions and the annual energy generated was found to be 24.157 GWh. The system has annual energy efficiency, average PR and CF of 12.1%, 78.14% and 26.34%. Laib et al. [18] performed energy evaluation of a 1.2 kWp grid connected PV system using Matlab simulation tool for the residential house in Northern Algeria and reported the annual energy production of 2,253 kWh. Similarly, Moien and Mahmoud [19] analyzed the economic performance of 3 systems with capacity of 5 kWp each installed in Palastine. The annual energy generated was reported to be 8,780 kWh and the results encouraged the use of PV systems for electrifying homes in Palestinian residents.

TABLE II. GRID-CONNECTED PV SYSTEM STUDIED IN DIFFERENT LOCATION

Location	Size (kWp)	Energy (kWh)/yrs	Efficiency (%)		PR (%)	CF (%)	Reference
			Module	System			
India	50.0	5,200/month	14.66	---	52.3 – 87.4	---	[7]
India	40.8	32,374.8	9.36	8.5	63	9.0	[8]
India	11.2	14.960	13.42	12.05	78	---	[9]
India/Ujjain	6.4	9,780-11,238	---	---	73.5 - 76.5	---	[10]
India	5.0	7,175.4	11.34	10.02	76.97	16.39	[11]
Italy	960.0	1,321,920	15.3	14.9	84.4	15.6	[12]
Greece	9,984	19,481.66/6yrs	14.7	12.5 – 15.3	87 - 90	---	[13]
Malawi	830.0	---	15.3	14.9	79.9	17.7	[14]
Brazil	2.2	3,708.1	13.3	12.6	82.9	12.6	[16]
Jordan	10,000	24,157,000	---	12.1	78.14	26.34	[17]
Algeria	1.2	2,253	---	---	---	---	[18]
Palestine	5.0	8,780	---	---	---	---	[19]
New Zealand	10.0	910.13	---	---	78	---	[20]

In New Zealand, Emmanuel et al., [20] presented the techno-economic assessment of 10 kWp rooftop PV system installed at Maungaraki school, Wellington in 2014. They observed 78% annual PR with annually produced energy of 910.13 kWh. Also, Albadi [21] evaluated a 1.4 kWp PV system comprised of 6 polycrystalline modules installed in Oman 2012. The annual produced energy was found to be 2,217.6 kWh and system efficiency was 15%.TABLE I. Show grid-connected PV system studied in different location.

III. DISCUSSION AND CONCLUSION

This work reviewed the research work conducted in different parts of the globe by researchers on grid-connected PV systems. The main objective behind is to consolidate relevant performance information related to grid-tied PV systems of different capacities in varied meteorological conditions. Furthermore, this review will also provide useful information to help the attentive scholars in designing, selecting, and analyzing the performance of grid-connected PV systems. The study found that such systems are efficient and economical to use in apartment buildings and individual houses with net metering systems. In this way, these grids tied PV systems can generate revenues for the owners and at the same time can address the problem of greenhouse gases emissions. The study showed that the performance of the system and annual energy generated depends on the region where it is installed. The produced energy varies from one region to another region as shown in Table 2. However, based on the analysis most of the system under study have good performance ratio ranging from of 52% to 90%. This indicates the ability of such systems to supply energy to the owner of the system and also to the grid in any excess energy is available grid. Considering the capacity factor, the average annual capacity factor is found in the range of 10-21% for the PV systems.

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