Grid-Interactive Solar PV Systems: Component Breakdown, Design Considerations, and Case Study Review

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September 23, 2024

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Abstract— This paper presents a study on the various components of a grid-connected photovoltaic (PV) system and their functionality, along with key design considerations necessary for installation. A case study is provided on the '95 kWp on-grid photovoltaic system' implemented at Karunya Institute of Technology and Sciences in Coimbatore. The study focuses on a 95 kWp PV array consisting of 312 solar modules and four 25 kVA inverters. The results include data from the system's online monitoring, showcasing power generation in kWh/kWp, energy savings in MWh, and the amount of CO2 emissions avoided. Additionally, the simulated energy performance of the PV system is also analyzed. Promoting solar PV installations in educational institutions can reduce energy costs and provide a platform for research and development in renewable energy. Keywords—Solar energy, Photovoltaic system, Grid-connected solar PV system, PV system components, 95 kWp solar plant at Karunya, PV system design considerations

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I. INTRODUCTION

As the global demand for renewable energy grows, the on-grid solar photovoltaic (PV) system has emerged as one of the most efficient and sustainable methods for generating electricity. An ongrid PV system is directly connected to the utility power grid, allowing it to feed excess electricity back into the grid or draw power when the solar energy produced is insufficient. This system offers numerous advantages, including reduced electricity bills, fewer energy storage requirements, and the ability to contribute to the overall power supply【1】【2】. The integration of on-grid solar PV systems into both residential and commercial applications is becoming increasingly popular due to declining solar panel costs, improved efficiency, and government incentives in many countries【3】. Unlike off-grid systems, which require batteries for energy storage, on-grid systems eliminate the need for costly storage, making them more economically viable【4】. Additionally, the simplicity of installation, low maintenance, and long lifespan of these systems further contribute to their growing adoption【5 6】 Energy productions from photovoltaic system can be generated in simple manner when compared to other sources. The number individual components used in solar PV system are quite low were emerged. Literature review of related works is given in section-II. In section-III, working and various components of on-grid photovoltaic system is described. Section-IV highlights the design considerations to be followed during the installation. One of the on-grid photovoltaic system case study is discussed in section-V. Finally, the paper is concluded in section-VI. By generating electricity from sunlight, these systems offset a substantial amount of CO2 emissions, helping to meet international renewable energy targets【8】. In countries where feed-in tariffs or net metering policies are in place, homeowners and businesses can sell excess electricity back to the grid, further enhancing the economic benefits of on-grid systems【9】. The increasing emphasis on energy security, sustainability, and decarbonization makes on-grid solar PV systems an attractive option for both developed and developing economies【10】

II. LITERATURE REVIEW

(Arash Anzalchi & Arif Sarwat, 2017) discussed in detailed about the technical specifications and challenges related to the techniques, codes, and standards used for integrating photovoltaic systems to the electric grid. They highlighted various topologies, control strategies in photovoltaic system [8]. (Manasseh Obi & Robert Bass, 2016) presented a study on the need and increasing popularity of grid connected solar photovoltaic systems. The authors highlighted the various challenges and suggested few methods that improve the efficiency of grid connected PV systems [9]. (Sheeraz Kirmani et al. 2015) presented a study to overcome the intermittent behaviour of solar power plant resulting in power fluctuations. The study proposed the authors involves simulation modeling of a performance enhanced method providing a good solution in mitigating fluctuation in the power [10]. (C. Nemes & S. Costinas, 2015), presented a study on yield analysis and availability analysis of existing grid connected PV system to understand its performance indices. The study by the authors showed better performance of grid connected PV systems [11]. (A. E. Abdallah & A. Mordi, 2014) proposes the grid connected photovoltaic systems to the counter correct the voltage variations in the grid. This occurs due to the disturbances in grid voltage amplitudes at "point of common coupling". The proposed methodology will help in maintaining the grid voltages to the required during over and under grid voltages [12]. (V. Komoni et al. 2016) presented a study on the design and performance analysis of 3.9 kWp grid connected PV plant with rooftop installation. The system was monitored for two years and its performance variation with respect to few parameters were showed [13].

III. ON-GRID PHOTOVOLTAIC SYSTEM

when compared to other system. It does not involve any large size components also. Solar PV systems are classified into two: standalone or off-grid photovoltaic system, and grid connected or on-grid photovoltaic system. In earlier days photovoltaic installations are mostly based on offgrid type and works on isolated conditions. But due to advancements in PV technology, and power electronics these systems were started booming as on-

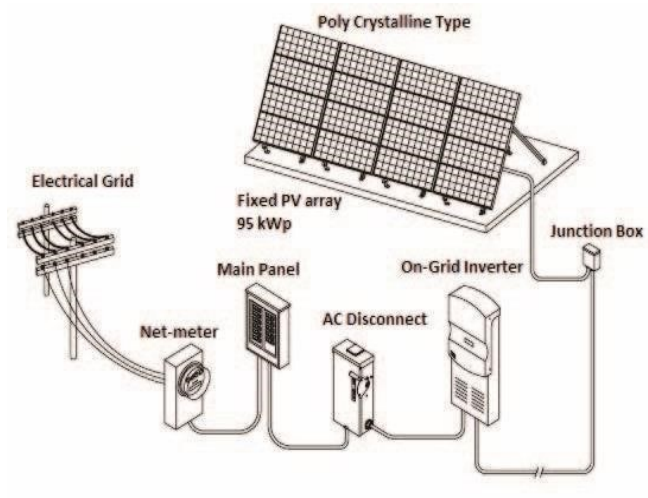

Fig. 1. Schematic view of on-grid photovoltaic system

grid PV system [7]. At present in most of the nations, the PV installations are working on grid connected mode and still contribute to electricity mix.

This article is structured in six different sections: section-I deals brief introduction about how clean energy technologies On-grid solar photovoltaic system is the one that generates electrical power with the help of solar photovoltaic harvesters and delivers the power to electric utility. The schematic view and working flow of the system is clearly shown in Fig. 1. Various components involved in the system is discussed in sub section-A, and the brief operation of the system is dealt in sub section-B.

A. Components

The various components involved in the grid connected photovoltaic system are as follows [14-17]:

1) *Photovolatic Modules:* Mono crystalline solar cells are simply referred as Si-mono. Si-mono photovoltaic modules or cells are made from a single cylindrical crystal ingot having high purity. From the single crystal, wafer can be sliced and cut in octagonal shapes. At Standard Test Conditions i.e. STC 1000 W/Sq. m, Si-mono cells shows the best performance but the same cell shows poor perfor-mance when temperature levels rise [18].

Poly crystalline solar cells are simply referred as Si-poly. Sipoly modules or cells consist of small crystals which make the cell or module to look as “crystal grain known as crystallites”. Si-poly cells are “produced by sawing a square cast block of silicon first into bars and then into wafers”. These cells performs better at STC and the performance reduces as the temperature rises. Si-poly modules are configured by series and paralle

combinations to form Si-poly PV generators as per the requirement [18].

Amorphous silicon solar cells are simply referred as Siamorph. Si-amorph PV generator is configured with the combinations of the Si-amorph PV modules. These modules are of thin film based and made by sandwiching the Si-amorph materials of 1 ɜm thickness between the two panes of glass. Siamorph PV generators perform better than those of Simono and Si-poly crystalline. Also perform better under elevated temperature conditions when compared with crystalline silicon cells [18].

2) *Junction Box:* The junction boxes were used majorly in two different places in PV systems i.e. one is at the conversion.

The AC energy can be used directly to electrical loads, or it can be supplied to utility grid by means net metering facility. If the generated is utilized for various load applications at the generation level itself, then it is said to be standalone PV system, if the generated energy continuously fed to the utility grid then it can be termed as on-grid photovoltaic system [1416].

IV. DESIGN CONSIDERATION TO BE FOLLOWED

While installing grid connected PV systems, one should follow few technical and non-technical design considerations.

These considerations will be different for each component

foremost and major design considerations when it comes to site

and they are inter depend on other components. For while, interconncetion to power converter. Here all the PV strings are joined together. Another place is at solar PV enclouse where this junction is used comprises the bypass diodes allowing the power flow only in one direction i.e. from soalr panel to the utility sytem.

3) On-Grid Inverter: On-grid inverter is the one which converts the DC power to AC power. This is one of the essential components of PV system to inter connect with the present day power sector. We have various type of inverter availble in the market whose rating is from small kVA to larger kVA. The present available inverter are coming with MPPT enabled and wider input Vdc range.

4) AC disconnect & Main Panel: In photovoltaic systems DC and AC disconnect are the two boxes where AC dissconnect role is to separate the on-grid power converter i.e. DC-AC inverter from the electrical utility grid. Output currents of the inverters have to be taken into consideration while sizing the AC dissconnect and it simply be circuit breaker. This is generally placed in Main panel.

Main panel comes into picture before the electrical system can be integrated to electrical power grid. This generally consists of electro mechanical devices that are used to dissconnect the photovoltaic system from the electric grid.

5) Net Meter: Net meter is a device that is used to monitor the inflow and outflow of electricity between the electrical power generating system to electric utility grid. In photovoltaic systems if excess energy is generated that can be sold to the utility by means of this.

6) Electrical Grid: It is an electrical power network interconnecting the load centers and energy providers. It is one of major parts of electrical power system network acting as interface between power generation plant, power transmission line, and distributin lines. It transmits electric power that is generated using any source (renewable or non-renewable) at a any place and distributes finally to the consumers as per the requirement (either in 1-ɮ or/and in 3-ɮ).

B. Operation

A photovoltaic system operates to generate electricity and the operation is similar for both the off-grid and on-grid photovoltaic systems. Whenever the incident light energy on the photovoltaic module is enough to produce electrons, then DC power is generated at the output terminals of the PV array and then is fed to the power converters which in turn helps in DC to AC selection would be the appropriate solar radiation data assessment, and other factors like shading, snow, wind, seasonal influences. When comes to the PV module or array mounting, this would be the optimal tilt angle, azimuth angle. Arranging the PV array as per the technical specification of the inverter input side one of the major design consideration. Identifying the suitable DC and AC cables and their rating as per the PV system parameters. Junction box sizing also plays vital role. Efficiency of each component must be considered during the design process to estimate the feasible energy yields. Make sure that, there should not be any stability and reliability issues during the operation of PV system [6, 16].

V. Case Study: 95 kWp On-Grid PV System

A case study on grid connected PV system is discussed in this section. A 95 kWp on-grid photovoltaic system is studied to demonstrate the functioning and performance of grid connected PV system. This system was installed on 1st August 2016 at an educational institute (Karunya Institute of Technology and Sciences) located in the foot hills of Western Ghats in Coimbatore. The PV system consists of 312 number of polycrystalline modules, four of 25 kVA inverters. The specifications of the discussed on-grid PV system is presented in Table I.

The PV modules were interconnected to form a PV array with possible strings. These were mounted on the vacant roof area with the extra support system called as open rack systems. The modules or the PV plant is installed as per the site geographical condition.

TABLE I. Specifications of On-Grid PV System

PV system component	**Value/Name**
System capacity	95 kWp
System type	On-grid
Module type	Poly crystalline
Module make	EMMVEE
Module power rating	310 Wp
Inverter rating	25 kVA
No. of inverters	4
Inverter make	SMA
Inverter type	Online monitoring

Fig. 2. Mounting structure used for PV instllation

Performance data is presented in the Table II. This data includes the specific energy generation i.e. 1890 kWh/kWp, and total power generation i.e. 192 MWh till 20th November 2017. The capacity factor for the operating duration from the date of installation to data presented in this paper is estimated. The operating days were identified to be around 446 days, in hours it is 10704. The estimated capacity factor for this operating duration is around 17.65%. Along with the experimental data the simulated energy performance using PVGIS and PV Watts [19, 20] is also evaluated and it shown in Fig. 5. Two software tools show the energy generation for typical year considering the average of past solar radiation of the location. For Coimbatore location the PV Watts shows the superior performance than PVGIS. The specific energy generation possible with PVGIS is 1406.632 kWh/kWp. Year, and for PV Watt is 1612.968 kWh/kWp. Year. The capacity factor evaluated in PVGIS and PV Watts are 16.05%, and 18.41% respectively. There is a slight variation observed in the performance metric parameter between PVGIS, PV Watt, and experimental data.

Fig. 3. On-grid solar power plant at Karunya Institute of Technology and Sciences -Part A

Fig. 4. On-grid solar power plant at Karunya Institute of Technology and Sciences-Part B.

In Fig. 2, the mounting position and tilt angle is clearly seen. Similarly, Fig. 3 and Fig. 4 shows the commercially working solar PV plant at Karunya Institute of Technology and Sciences.

TABLE II. PERFORMANCE DATA

PV system parameter	**Value with Units**
Date of installation	1 August 2016
Specific energy generation (till 20th November, 2017)	1890 kWh/kWp
Total power generation (till 20th Navermber, 2017)	192 MWh
CO_2 avoided (till 20th November, 2017)	134 tonne
Capacity factor (date of installation to monitored data)	17.65 %

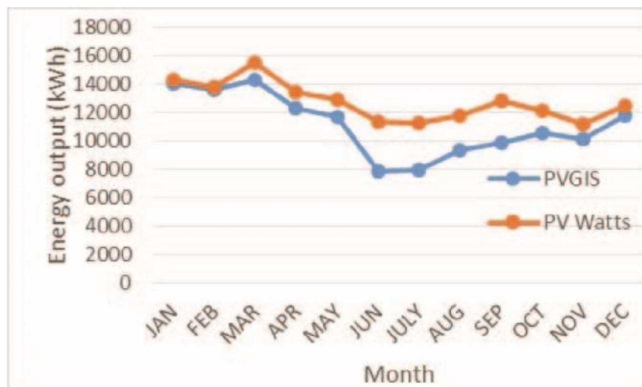

Fig. 5. Energy performance using PVGIS and PV Watts

VI. CONCLUSION

In this paper, the authors provide a comprehensive analysis of the technical sizing for on-grid photovoltaic systems. They offer a thorough explanation of the system components and design considerations that should be employed. Additionally, the paper includes a case study that demonstrates the performance evaluation of an on-grid PV system. To validate these experimental findings, the authors use PVGIS and PV Watt tools for verification. The results from these software tools closely align with the practical data. The insights presented in this paper are expected to benefit various stakeholders, including society, industry, and academia.

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