International Journal of Scientific Research & Engineering Trends
Volume 11, Issue 5, Sep-Oct-2025, ISSN (Online): 2395-566X

# Power Electronic Interface for Grid-Connected Solar PV Systems with Maximum Power Point Tracking

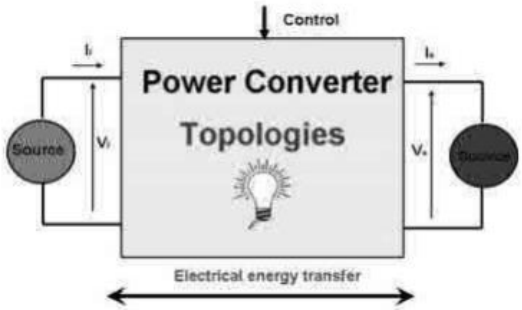
**Prof. Shraddha Tiwari, Prof. Mayanka Roy Mandal and Prof. Ankita Fouzdar**
Gyan Ganga Institute of Technology & Sciences (GGITS) Jabalpur

**Abstract- The integration of solar photovoltaic (PV) systems into the electrical grid requires efficient power electronic interfaces to ensure reliable operation and maximum energy extraction. This study focuses on the design and performance analysis of a power electronic interface for grid-connected solar PV systems incorporating Maximum Power Point Tracking (MPPT) techniques. A DC–DC converter controlled by MPPT algorithms such as Perturb and Observe (P&O) and Incremental Conductance (INC) is employed to optimize the PV output under varying irradiance and temperature conditions. The conditioned DC power is subsequently converted into synchronized AC power through a voltage source inverter (VSI) with appropriate grid synchronization and control strategies. The proposed system enhances the efficiency, stability, and power quality of PV-grid integration while minimizing harmonic distortion and ensuring compliance with grid codes. Simulation and experimental results validate that the implementation of an optimized MPPT-based power electronic interface significantly improves energy harvesting capability and supports sustainable and reliable integration of renewable energy into the power grid.**

**Keywords: PV Array, Single Phase Inverter, PID Controller, MATLAB.**

## I. INTRODUCTION

The task of a power converter is to process and control the flow of electric energy by supplying voltages and currents in a form that is optimally suited for the user loads. Energy was initially converted in electromechanical converters (mostly rotating machines). Today, with the development and the mass production of power semiconductors, static power converters find applications in numerous domains and especially in particle accelerators. They are smaller and lighter and their static and dynamic performances are better. A static converter is a meshed network of electrical components that acts as a linking, adapting or transforming stage between two sources, generally between a generator and a load.




**Power converter definition**

An ideal static converter controls the flow of power between the two sources with 100% efficiency. Power converter design aims at improving the efficiency. But in a first approach and to define basic topologies, it is interesting to assume that no loss occurs in the converter process of a power converter.

## II. RESEARCH MOTIVATION

The usage of non-renewable sources such as oil, gas and coal is growing at an alarming rate. Among the renewable energy options, solar photovoltaic (PV) energy has been drawing increasing attention in recent years as an important source of alternate energy both for isolated and grid connected applications. Since PV is a non-linear source there is a need for power electronic converters to be interfaced between the PV source and load/grid. The modest form of a grid tied PV system consists of a PV array and Voltage Source Inverter (VSI) [1-4]. The common constraint of such single-stage configurations is that the PV array voltage needs to be always higher than the peak value of the grid voltage. To overcome this limitation, the need for two stage conversion arises which consists of a dc-dc converter and an inverter [5]. Du et al. have proposed a two stage PV grid connected system with Hysteresis Current Controller (HCC) in which switching frequency of the inverter is not constant resulting in increased switching losses [6]. In [7 - 9], the authors have proposed a HCC with predictive and frequency limit control to limit variation in inverter switching frequency which lowers the switching losses. However, the autonomous control of active and reactive power is not feasible with the above mentioned controllers. Yao et al. have proposed an abc-dq controller along with SVPWM technique in which a stiff dc source was considered and hence the need for maximum power extraction did not arise [10].

## III. INTEGRATION ISSUES

In the last years, interest in photovoltaic (PV) solar power generation is increasing worldwide and the installation of large grid-connected PV systems is accelerating because of distinctive advantages such as simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts. In addition to these factors are the declining costs of solar modules, an increasing efficiency of solar cells, manufacturingtechnology improvements and economies of scale [1]. The grid integration of renewable energy sources (RES) based on PV systems is becoming today the most important application among PV solar systems, gaining interest over traditional stand-alone systems. This situation is mainly boosted by the numerous benefits of using RESs in distributed (aka dispersed) generation (DG) systems, including the strong support provided by governments of many countries, as investment subsidies and incentives [2,3].

The growing number of distributed PV systems brings new challenges to the operation and management of the power grid, especially when the variable and non-dispatchable energy source constitutes a significant part of the total system generation capacity. Under this scenario, the power electronics technology plays an important role in ensuring an effective grid connection of the PV system. Integration issues need to be addressed from both the distributed PV system side and from the utility side. In modern applications of grid-tied distributed PV generation, the power conditioning system (PCS) is the key component that enables to provide a more cost-effective harvest of energy from the sun and to meet specific electrical grid code requirements. This is especially significant for applications of DG in future smart grids. In the literature, numerous topologies of PCSs, varying in cost and complexity, have been widely discussed for integrating PV solar systems into the electric grid. In modern PV systems designs with control of both, active and reactive power, the PCS is typically built using a full-scale power converter made up of a two-stage power conversion hardware configuration [4], as depicted in Fig. 1. This PCS design is composed of a DC/DC/AC power converter that permits to simultaneously and independently control the active and reactive power flow exchanged with the electric utility grid. In this sense, multi-level converters are increasingly preferred for medium- and high-power applications due to their ability to meet the increasing demand of power ratings and power quality associated with reduced harmonic distortion, lower electromagnetic interference, and higher efficiencies when compared with the conventional two-level topologies [5].

Demand for clean, economical, and renewable energy has increased consistently over the past few decades. Among a variety of renewable energy resources available, solar energy appears to be a major contender due to its abundance and pollution-free conversion to electricity through photovoltaic (PV) process. Increasing interest in PV systems, demands growth in research and development activities in various aspects such as Maximum Power Point Tracking (MPPT), PV arrays, anti-islanding protection, stability and reliability, power quality and power electronic interface. With increase in penetration level of PV systems in the existing power systems, these issues are expected to become more critical in time since they can have noticeable impact on the overall system performance. More efficient and cost-effective PV modules are being developed and manufactured, in response to the concerns raised by the PV system developers, utilities and customers. Numerous standards have been designed to address power quality and grid-integration issues. Extensive research in the field of MPPT has resulted in fast and optimized method to track the maximum power point. Regarding power electronic converter to interface PV arrays to the grid, Voltage Source Inverter (VSI) is a widely used topology to date.

## IV. PHOTO VOLTAIC SYSTEM

One technology to generate electricity in a renewable way is to use solar cells to convert the energy delivered by the solar irradiance into electricity. PV energy generation is the current subject of much commercial and academic interest. Recent work indicates that in the medium to longer term PV generation may become commercially so attractive that there will be large-scale implementation in many parts of the developed world. The integration of a large number of embedded PV generators will have far reaching consequences not only on the distribution networks but also on the national transmission and generation system. If the PV generators are built on the roof and sides of buildings, most of them will be located in urban areas and will be electrically close to loads. On the other hand, these PV generating units may be liable to common mode failures that might cause the sudden or rapid disconnection of a large proportion of operating PV capacity.

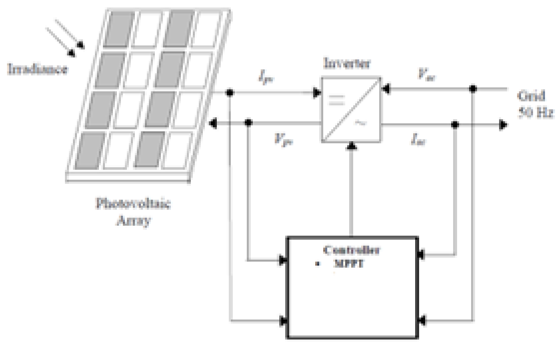



Fig. 1: Schematic diagram of Grid Connected PV Generation

**International Journal of Scientific Research & Engineering Trends**
**Volume 11, Issue 5, Sep-Oct-2025, ISSN (Online): 2395-566X**

Figure 1 shows a functional diagram of the basic configuration of a grid-connected PV system. The dc output current of the PV array Ipv is converted into ac and injected into the grid through an inverter. The controller of this inverter implements the entire main control: Maximum Power Point Tracking (MPPT). Solar irradiance is the radiant power incident per unit area upon a surface. It is usually expressed in w/m2. Radiant power is the rate of flow of electromagnetic energy. The most severe fluctuations in the output power of PV systems usually occur at maximum irradiance level around noon. This period usually coincides with the off-peak loading period of the electric network, and thus, the operating penetration level of the PV system is greatest.

Power electronics applications broadly include converters, inverters, choppers, etc. The AC to DC converter (rectifier) is one of the most popular power electronics device which is an efficient and convenient source of DC power. A large portion of the electrical and electronic devices currently in use are designed to operate using direct current (DC) power, while for reasons of distribution efficiency, most of the power is ultimately delivered to devices as alternating current (AC) power. Therefore, an AC-DC front-end converter is required to convert AC power to DC power in many electrical and electronic devices. The two-stage approach is widely used in AC-DC front-end converters for high power application.

Due to its constant input current and simplicity, the continuous conduction mode (CCM) boost topology is the most popular for the power factor correction (PFC) stage. The major concern of photo voltaic (PV) systems is to ensure the optimum performance of individual PV modules in a PV array while the modules are exposed to various environmental conditions arising due to differences in insolation level and/or operating temperature.

The presence of mismatch in the operating condition of the modules significantly reduces the power generation from the PV array. If the number of modules connected in series in a PV array is large, the problem with mismatched environmental conditions (MEC) becomes significant. To achieve the desired magnitude for the input DC link voltage of the inverter of a grid-connected transformerless PV system, the number of series-connected modules required becomes higher.

Therefore, power generation from grid-connected transformerless (GCT) PV systems such as single phase GCT (SPGCT) inverter-based systems obtained from H-bridge and neutral point clamp (NPC) inverter-based systems is significantly affected during MEC. A detailed investigation of such techniques is presented in. Power extraction during MEC can be enhanced by tracking the global maximum power point (MPP) of the PV array by choosing proper interconnections between PV modules or by employing complex MPP tracking (MPPT) algorithms. However, these techniques are not effective for low power SPGCT PV systems.

Similarly, reconfiguration of PV modules in a PV array by changing the electrical connections of PV modules is not effective for SPGCT PV systems due to considerable increase in component count and increased operational complexity. To extract maximum power from each PV module during MEC, attempts have been made to control each PV module in the PV array by either applying a power electronic equalizer or interfacing a DC to DC converter. The presented scheme uses a generation control circuit (GCC) to operate each PV module at their respective MPP, in which the power differences between each module are processed only through the GCC. The presented scheme uses shunt current compensation of each module as well as series voltage compensation of each PV string in the PV array to enhance the power yield during MEC. Schemes based on module integrated converter use a dedicated DC to DC converter integrated with each PV module.

## V. RESULT AND SIMULATION

The plot shows the frequency spectrum of the injected grid current during a steady operating window. The large peak at very low frequency corresponds to the 50 Hz fundamental component of the sinusoidal injected current.  The wide spread of smaller components at higher frequencies indicates harmonics and numerical noise from switching and averaging approximations.Ideally, the dominant component should be only at 50 Hz; extra ripples suggest that filtering or more refined inverter modeling is required for cleaner current injection

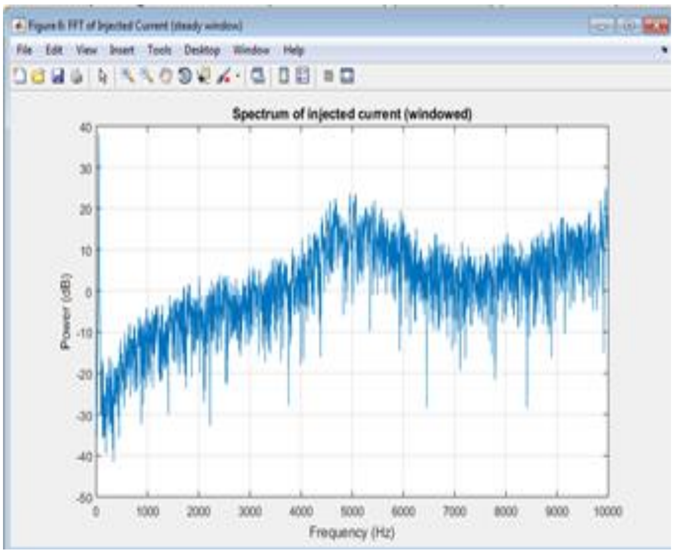



Fig.2. Power and Frequency curves.

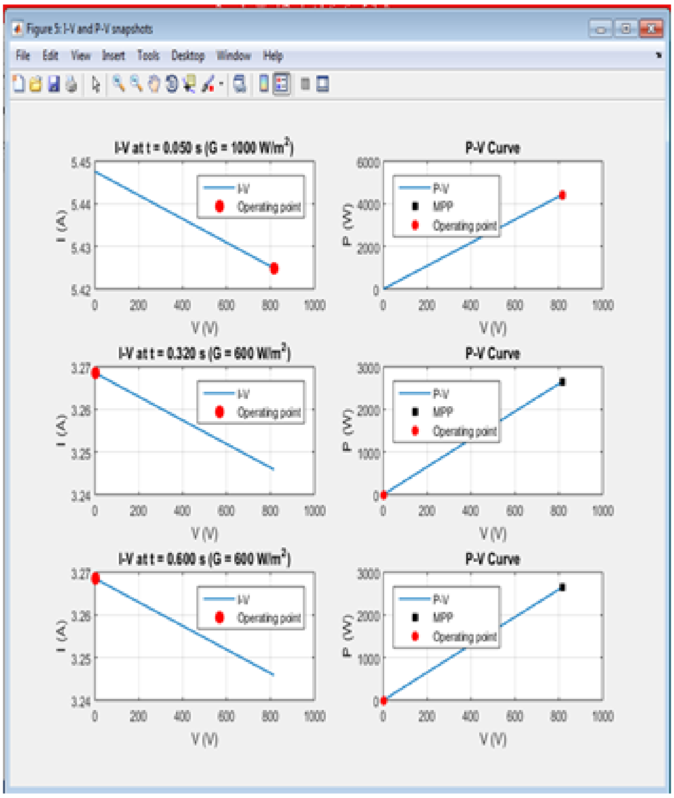



Fig.3. V-I and PV curves.

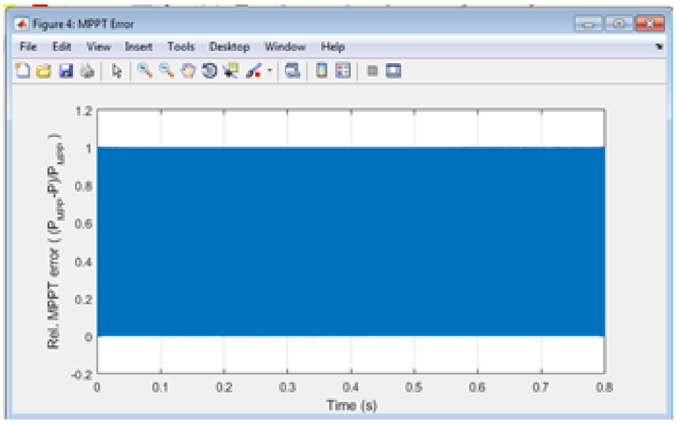



Fig.4. MPPT error Curve.

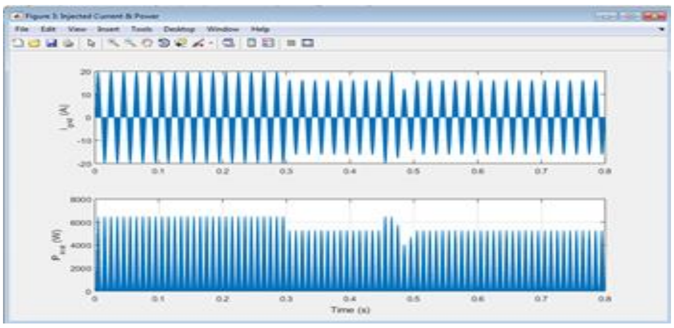


Fig.5. Power and Current curve.

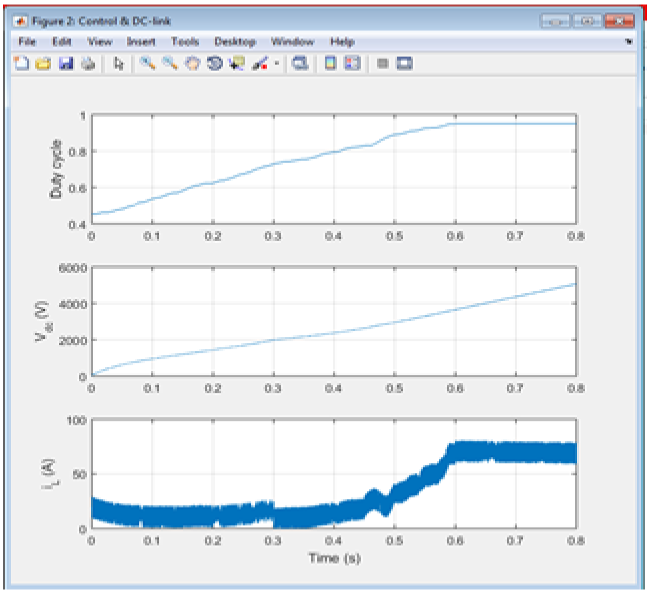



Fig.6. V-I curved.

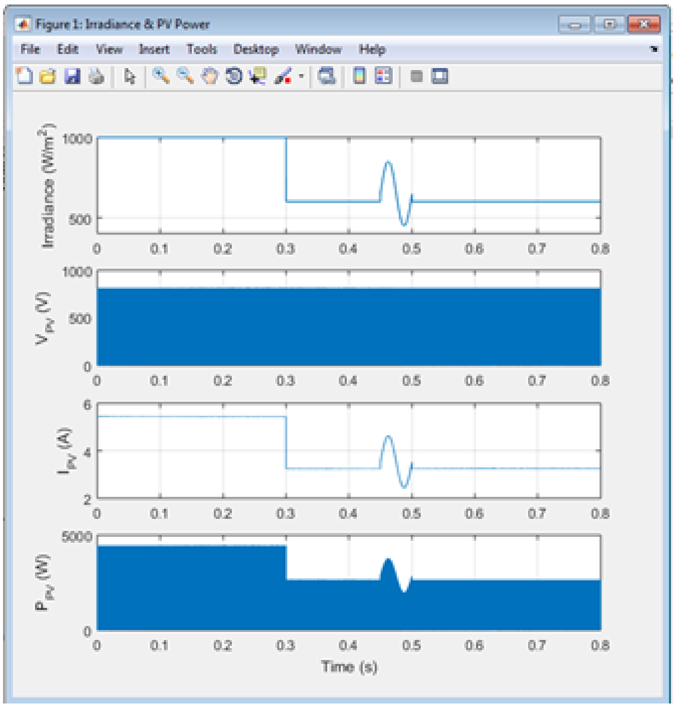



Fig.7. Solar parameters.

## VI. CONCLUSION AND FUTURE SCOPE

### Conclusion

The study demonstrates that the use of a power electronic interface with MPPT control significantly improves the performance of grid-connected solar PV systems. By employing a DC–DC converter with MPPT and a voltage source inverter for grid synchronization, maximum power can be extracted from the PV array under dynamic weather conditions while ensuring stable and high-quality power delivery to the grid. The results confirm that such systems enhance overall efficiency, reduce power losses, and meet grid code requirements effectively.

**Future Scope**

Future research can focus on developing more advanced MPPT algorithms using artificial intelligence and machine learning to further improve tracking speed and accuracy under rapidly changing conditions. Integration of energy storage systems can also be explored to ensure better grid stability and reliability during peak demand or low solar generation. Additionally, future work may include the implementation of multi-level inverter topologies, real-time hardware validation, and the study of cyber-secure smart grid communication to enable large-scale adoption of solar PV with improved efficiency and resilience.

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