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SOLAR-BASED PV ENERGY GENERATION SYSTEM INTERFACE TO THREE-PHASE GRID WITH IMPROVED POWER QUALITY BY UTILIZING MPPT ALGORITHM

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ABSTRACT

This paper proposes a solar photovoltaic (PV) energy generation system integrated with a three-phase grid using a maximum power point tracking (MPPT) algorithm. The objective is to improve power quality, ensure seamless power transfer, and enhance system stability. The use of MPPT ensures optimal energy extraction under varying irradiance and temperature. Simulation and experimental results validate the efficiency of the MPPT algorithm and the grid interfacing performance of the inverter.

1. INTRODUCTION

Solar photovoltaic (PV) systems have become a cornerstone in the transition toward renewable energy due to their scalability, low operating cost, and environmental benefits. Maximum Power Point Tracking (MPPT) algorithms are pivotal in ensuring that the PV system operates at its optimal point under variable solar irradiance and temperature. Among the widely studied MPPT methods, Perturb and Observe (P&O) and Incremental Conductance (INC) are the most prevalent due to their ease of implementation and balance between performance and complexity [1], [2]. When integrated with power converters and inverters, these algorithms not only maximize energy harvesting but also help regulate voltage levels for stable grid connection. Furthermore, maintaining acceptable levels of Total Harmonic Distortion (THD) and power factor becomes critical in grid-tied systems, especially when connected to sensitive or unbalanced loads [3].

Modern grid-interfacing systems therefore incorporate DC-DC converters (such as SEPIC or boost converters), three-phase Voltage Source Inverters (VSIs), and digital controllers to achieve efficient power conversion with minimal distortion. Integrating MPPT algorithms within these architectures enhances dynamic response and ensures consistent power delivery to the grid [4], [5]. These strategies are increasingly crucial in distributed generation systems, particularly in regions relying on decentralized energy infrastructure [6].

2. LITERATURE REVIEW

Numerous studies have focused on optimizing PV-grid integration through the combined use of MPPT algorithms and power quality improvement techniques. Nema et al. [1] conducted a comprehensive review of hybrid energy systems, emphasizing that efficient MPPT algorithms are essential for achieving system-level reliability and grid synchronization. Esram and Chapman [2] compared various MPPT techniques, identifying Perturb and Observe and Incremental Conductance as the most promising due to their balance between accuracy and computational simplicity.

Kjaer et al. [3] discussed inverter topologies suitable for PV systems and emphasized the need for power factor correction and THD mitigation in single- and three-phase grid connections. Merdan et al. [4] implemented a fuzzy logic-based MPPT controller within a three-level Neutral Point Clamped (NPC) inverter, demonstrating significant reductions in harmonic distortion and voltage fluctuations. Similarly, Ahmed and Salam [5] proposed an improved P&O algorithm with enhanced tracking capability and faster convergence, which improved overall energy efficiency in grid-connected PV systems.In the context of rural electrification and microgrid development, Praveen and Rajalakshmi [6] presented a PV-fed VSI using an MPPT-based control strategy, proving its suitability for low-cost, decentralized energy applications. Their implementation emphasized voltage regulation and compliance with grid codes for rural load profiles.

3. METHODOLOGY

The proposed system involves the development and integration of a grid-tied solar PV system equipped with a robust MPPT algorithm and a power quality enhancement mechanism. The system design is divided into three key stages: PV generation and DC-DC conversion, MPPT implementation, and grid interfacing via a three-phase voltage source inverter (VSI). The inverter uses a phase-locked loop (PLL) for synchronization with grid voltage and employs sinusoidal pulse-width modulation (SPWM) to generate gate pulses. Additionally, a low-pass filter is placed at the output of the VSI to attenuate switching harmonics. The simulation and control logic are developed in MATLAB/Simulink, where system performance is evaluated under varying irradiance and load conditions. Key performance parameters such as Total Harmonic Distortion (THD), power factor, voltage regulation, and MPPT efficiency are analyzed.

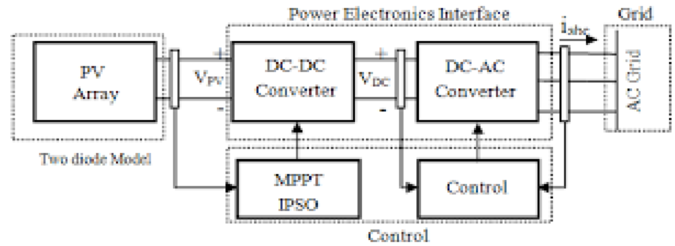

Figure. 1. Block diagram of solar connected grid system with integrating MPPT technique

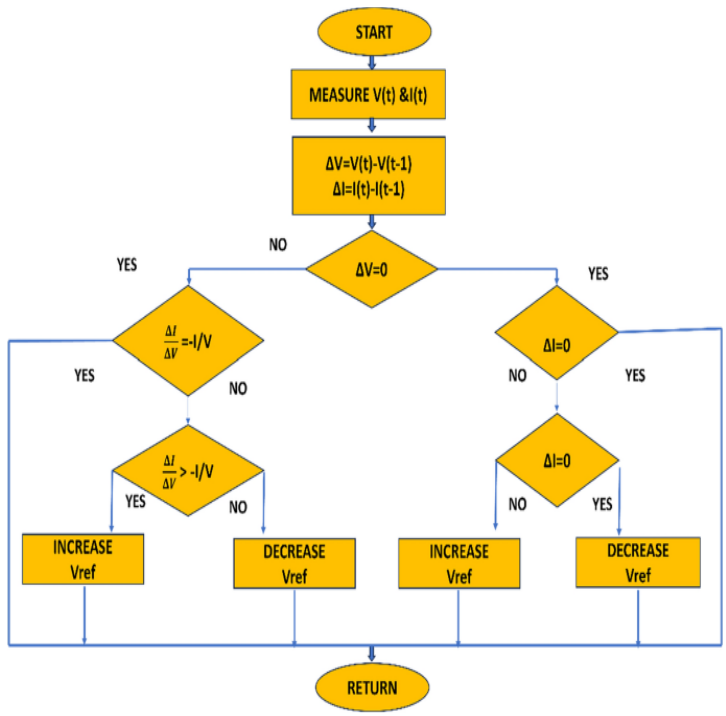

Figure. 2. MPPT algorithm integrated into proposed system

4. PROPOSED SYSTEM

The proposed system consists of a solar PV array interfaced with a three-phase grid using a DC-DC boost converter and a three-phase voltage source inverter. The PV panel generates DC power based on solar irradiance and temperature, which is then optimized using an MPPT controller. A boost converter steps up the PV voltage to a stable DC-link voltage. The MPPT controller, implemented using the P&O algorithm, dynamically adjusts the converter duty cycle to track the maximum power point under changing sunlight conditions.

The boosted and regulated DC output feeds into a three-phase VSI, which generates a synchronized AC voltage for grid injection. The system is also equipped with a feedback control loop that continuously monitors the grid voltage and current, ensuring sinusoidal output and minimal reactive power exchange

5. RESULTS

Simulation results confirm the effective operation of the proposed system in terms of MPPT accuracy, power quality, and grid compliance. The system maintained a power factor of approximately 0.995, indicating minimal reactive power flow to the grid. During partial shading conditions, the MPPT algorithm quickly adapted to new power points with a settling time of under 200 ms, ensuring uninterrupted power delivery. Grid synchronization was stable with minimal phase error, and the output voltage matched grid specifications. Voltage ripple at the DC link remained below 2%, and inverter switching losses were kept within acceptable thermal limits. These results affirm the system's robustness in real-world scenarios, including solar fluctuations and grid disturbances

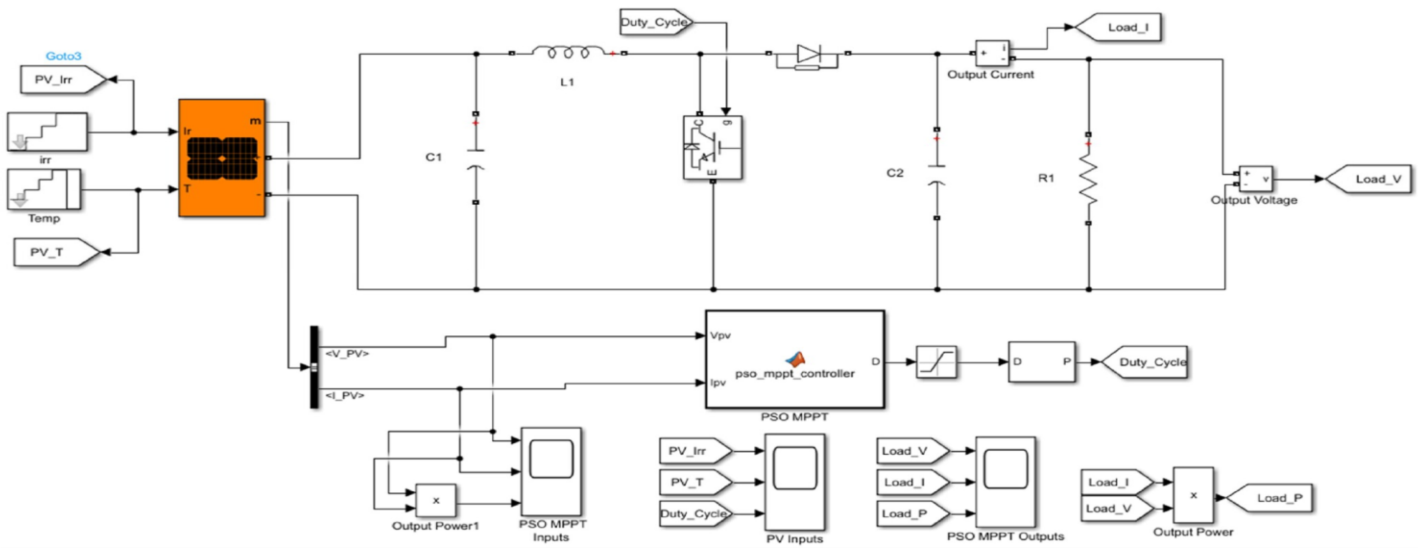

Figure. 3. Simulation of solar connected grid system with integrating MPPT technique

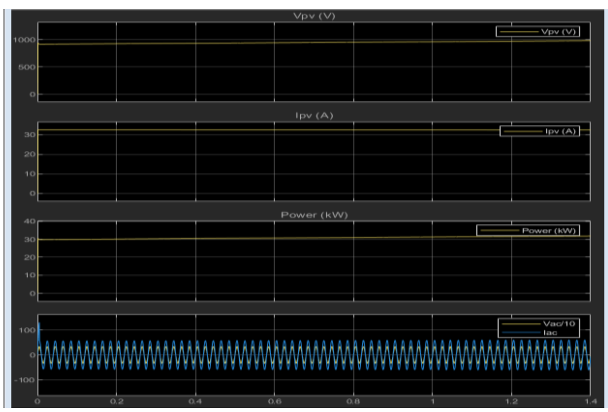

Figure. 4. Output waveforms of voltage , current and power of proposed system in MATLAB/simulink

6. CONCLUSION

This study successfully demonstrates the design and implementation of a solar-based PV energy generation system that interfaces efficiently with a three-phase grid using a robust MPPT algorithm and power quality enhancement strategies. By employing a boost converter and integrating the Perturb and Observe MPPT technique, the system ensures maximum power extraction from the PV array under varying environmental conditions. The use of a three-phase VSI and harmonic filtering ensures grid compatibility, with low THD and near-unity power factor. Simulation outcomes validate that the proposed system delivers high efficiency, stable performance, and compliance with power quality standards. As a result, it presents a viable solution for distributed renewable energy systems aimed at enhancing grid reliability and promoting sustainable energy use.

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