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Simulation of the Particle Swarm Optimization MPPT Algorithm for Photovoltaic Systems Using a SEPIC Converter

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Abstract: ***In this paper, Particle Swarm Optimization (PSO) algorithm for photovoltaic (PV) solar energy harvesting using MATLAB/ Simulink was developed. PV models of 50W cells are used to simulate the PSO under partial shading and varying irradiance levels. Results demonstrate that PSO successfully determines the global MPP under partial shading conditions, achieving ~95% tracking efficiency.***

Keywords: Particle Swarm Optimization, Partial Shading Conditions

1. Introduction

The increasing demand for clean, sustainable, and environmentally friendly energy has accelerated the adoption of solar photovoltaic (PV) systems as one of the most promising renewable energy technologies. However, the nonlinear current–voltage (I–V) and power–voltage (P–V) characteristics of PV modules cause the operating point corresponding to the Maximum Power Point (MPP) to vary continuously with changes in solar irradiance and cell temperature. Consequently, efficient Maximum Power Point Tracking (MPPT) techniques are essential to ensure maximum energy extraction and improve the overall efficiency of PV systems under dynamic environmental conditions.

Conventional MPPT methods, including the Perturb and Observe (P&O) and Incremental Conductance (INC) algorithms, provide satisfactory performance under uniform irradiance conditions because they can effectively track a single maximum power point. However, under partial shading conditions caused by clouds, trees, buildings, or other obstacles, the P–V characteristic exhibits multiple local maxima in addition to a single Global Maximum Power Point (GMPP). In such scenarios, conventional algorithms are prone to becoming trapped at a local maximum, resulting in reduced energy harvesting and significant power losses, which may range from **20% to 70%** depending on the shading pattern and system configuration [1], [2].

To address these challenges, metaheuristic optimization techniques have gained considerable attention owing to their superior global search capability and robustness in complex optimization problems. Among these methods, **Particle Swarm Optimization (PSO)** has emerged as an effective MPPT technique due to its fast convergence, simple implementation, and ability to locate the Global Maximum Power Point while avoiding local optima under partial shading conditions [3], [4]. This paper investigates the performance of the PSO-based MPPT algorithm under both uniform irradiance and partial shading conditions, demonstrating its effectiveness in enhancing power extraction and improving the overall performance of photovoltaic energy conversion systems.

2. Simulink Model

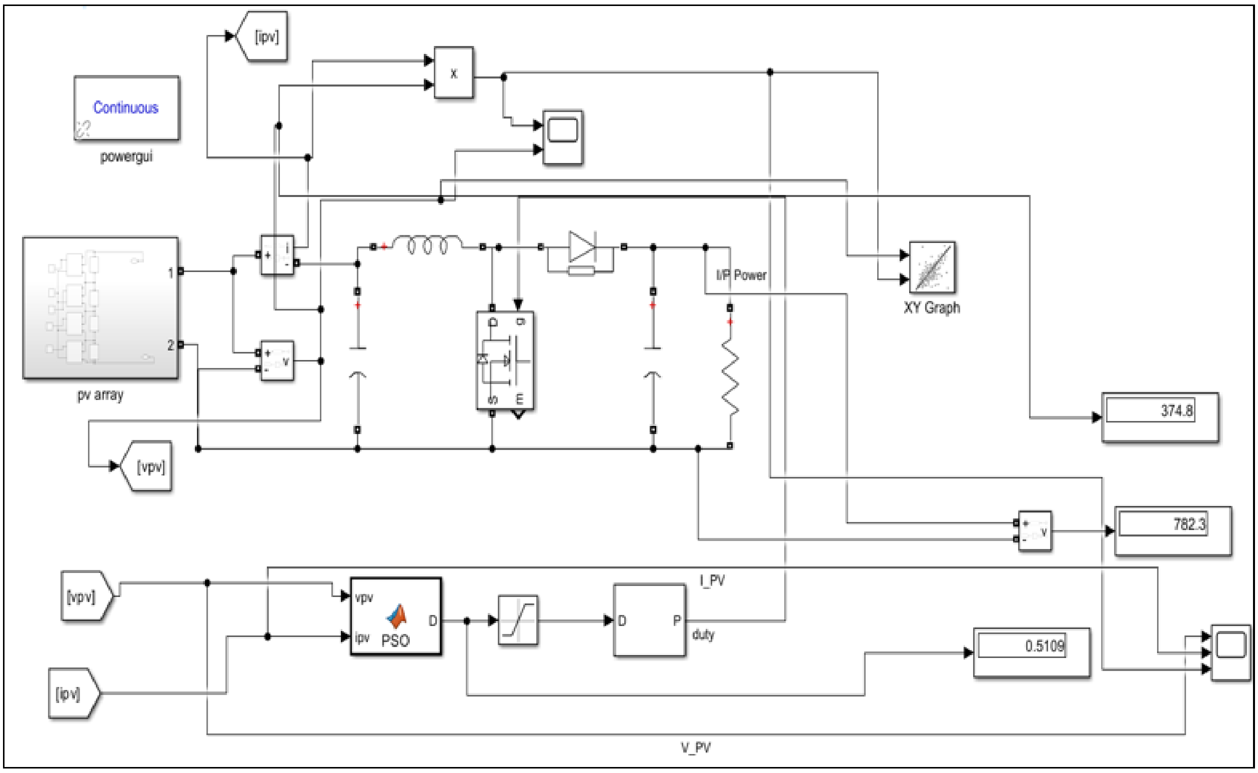

Figure 1: Simulink Model of MPPT using PSO Algorithm

Figure 6.8 illustrates the complete MATLAB/Simulink model of a photovoltaic (PV) system integrated with a Particle Swarm Optimization (PSO)-based Maximum Power Point Tracking (MPPT) controller employing a DC–DC Boost Converter. The simulation model incorporates a Continuous Powergui block, which configures the solver in continuous mode to ensure accurate representation of the power electronic switching dynamics and system behavior.

The PV array block, located on the left side of the model, represents the solar photovoltaic source and generates the PV terminal voltage V_{PV} and current I_{PV}. These measured signals are simultaneously supplied to the boost converter and the PSO-MPPT controller, thereby establishing a closed-loop control system for real-time maximum power point tracking. The boost converter, positioned in the upper section of the model, consists of an input inductor, a power MOSFET switch, a freewheeling diode, an output filter capacitor, and a resistive load. This converter regulates the operating point of the PV array and steps up the PV output voltage to the desired level while maintaining efficient power transfer to the load.

The PSO-based MPPT controller, shown in the lower section of the simulation model, serves as the intelligent control unit of the system. It continuously receives the measured V_{PV} and I_{PV} signals, calculates the corresponding PV output power, and executes the Particle Swarm Optimization algorithm to determine the optimal duty cycle that enables operation at the maximum power point. The computed duty cycle is applied to a PWM generator, which produces the gate pulses required to control the switching operation of the MOSFET. Through continuous optimization of the duty cycle, the controller ensures efficient maximum power extraction from the PV array under varying operating conditions, thereby improving the overall performance and energy conversion efficiency of the photovoltaic system.

3. Simulation Results

All simulations were performed in the MATLAB/Simulink environment using the single-diode photovoltaic (PV) model under Standard Test Conditions (STC), with an irradiance of 1000 W/m² and a cell temperature of 25°C. The performance of Maximum Power Point Tracking (MPPT) technique, namely Particle Swarm Optimization (PSO), was investigated using SEPIC DC–DC converter topology.

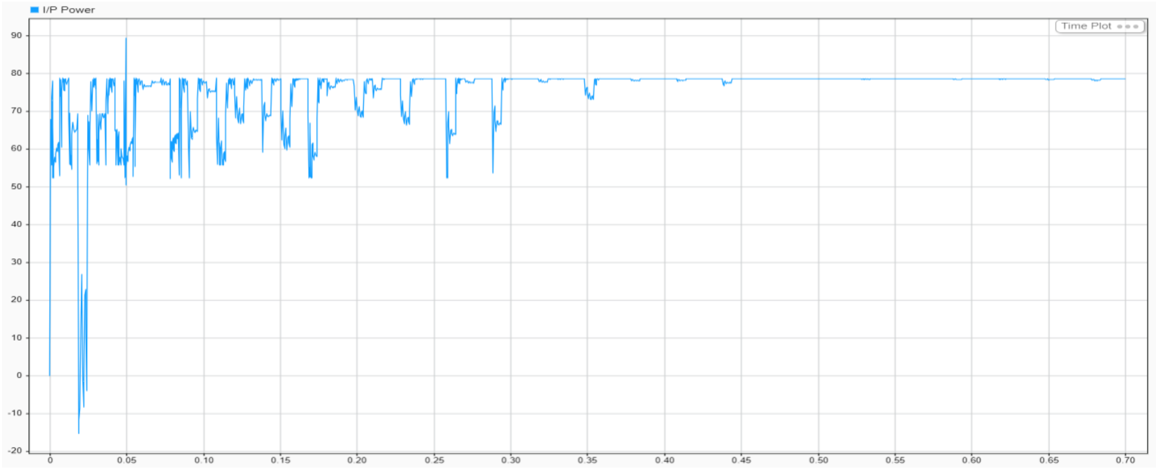

Figure 2: Pmax Vs Time Using PSO algorithm

Figure 2 presents the output power response of the photovoltaic (PV) system controlled by the Particle Swarm Optimization (PSO)-based Maximum Power Point Tracking (MPPT) algorithm. During the initial interval from 0 to 0.30 s, the PSO algorithm undergoes a search phase in which the swarm particles explore the solution space to identify the optimal operating point. As the particles iteratively update their positions and velocities based on their personal best (pbest) and global best (gbest) solutions, the output power exhibits transient fluctuations in the range of approximately 55–80 W. This behavior represents the normal convergence process of the optimization algorithm toward the global maximum power point (GMPP).

After approximately 0.30 s, the PSO algorithm successfully converges to the global maximum power point, and the output power stabilizes within the range of 78–80 W with negligible oscillations. The stable steady-state response confirms the effectiveness of the PSO algorithm in accurately tracking the maximum available power from the PV array. Compared with the conventional Perturb and Observe (P&O) algorithm, which generally exhibits persistent steady-state oscillations around the maximum power point, the PSO algorithm provides a smoother output with improved tracking accuracy and reduced power loss. The observed settling time of approximately 0.30 s indicates rapid convergence and stable operation at the optimum operating point.

The corresponding P–V characteristic of the four series-connected PV modules operating under partial shading conditions with irradiance levels of 1000, 750, 500, and 350 W/m² exhibits multiple local maxima and a global maximum power point (GMPP) of approximately 80 W. The simulation results demonstrate that the PSO-based MPPT controller successfully identifies and converges to this global optimum, as evidenced by the output power stabilizing at 78–80 W after 0.30 s. These results validate the capability of the PSO algorithm to avoid local maxima and reliably extract the maximum available power under non-uniform irradiance conditions.

4. Conclusion

Particle Swarm Optimization (PSO) MPPT algorithm was carried out using a 50 W photovoltaic system modeled in MATLAB/Simulink. PSO algorithm effectively tracks the Global Maximum Power Point (GMPP), exhibits faster convergence with minimal oscillations, and maintains higher tracking efficiency under non-uniform irradiance. The results indicate that the PSO-based MPPT achieves an efficiency of approximately **95%** under uniform conditions. Therefore, PSO is a more reliable and efficient MPPT technique for photovoltaic energy harvesting, particularly in practical applications where irradiance conditions vary dynamically.

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