An Efficient MPPT Strategy to Mitigate the Effects of Varying Irradiance on Solar Photovoltaic System

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Abstract

Solar irradiation and ambient temperature are two environmental factors that significantly impact the production of Photovoltaic (PV) power. The initial step response of the converter duty cycle of the conventional Maximum Power Point Tracking (MPPT) Incremental Conductance (IC) method is not precise, leading to misjudgement because of the single control condition and any change in the external environment. A modified IC algorithm is designed to track the Maximum Power Point (MPP) for Solar Photovoltaic (SPV) systems under varying solar irradiance levels. The proposed method outperforms in terms of complexity, stability, and efficiency. It tracks the MPP with an efficiency of more than 98% with a response time of less than 0.1 ms.

Keywords. Incremental Conductance, MPPT, Solar Energy, Solar Photovoltaic.

1. INTRODUCTION

The exponential growth of the global population and humans' use of electronic devices and electrical appliances to raise their living standards are the primary drivers of the day-to-day increase in energy consumption. In this scenario, fossil fuels are playing a significant role. However, the threats of carbon emission, air pollution, residual waste, and global warming will also increase simultaneously generated from power plants employing non-renewable energy sources [1]. The primary source of all energies can be thought of as the sun. The most abundant, limitless, and cleanest source of renewable energy available today is solar energy. It can be used in a variety of ways, including utilizing all of the sunlight to produce electricity directly or harnessing the heat from the sun as thermal energy. A very recent and exciting technological advancement that opens up a wide range of new prospects for producing" green" electricity is the capacity to produce electricity from sunlight [2] Global investment in SPV energy is rising quickly. A SPV modules generates electricity from sunlight and power converters for energy extraction and grid interface control help compensate a grid-connected SPV system [3]. A single SPV unit is referred to as a cell. It is typically tiny and produces around 1 or 2 watts of electricity [4]. It's a zero carbon emission source of energy, unlimited nature, and indigenous origin. However, during the last several decades, the high cost of photovoltaic (PV) energy has limited economically feasible utilisation to a small range of off-grid, low-energy consumption applications. A SPV module's output power and its lifespan depend on a variety of factors, some of which includes: The type of material used by SPV module manufacturing, solar radiation received intensity, temperature of the cell, parasitic resistance, cloud and other weather conditions, shading effects, efficiency of the inverter, orientations of modules, thickness of cable, geographical locations, etc [5, 6]. The non-linear relation between the Current and Voltage or Power and Voltage of the SPV cell, generated output power fluctuates with solar irradiation (G) and ambient temperature (T) [7]. Therefore, the Maximum Power Point (MPP) changes as the fluctuation in G and T [8]. An in-depth understanding of the *I-V* and *P-V* characteristics curves of SPV modules is necessary for the efficient analysis of SPV systems. The atmospheric factors affect the PV cell's output characteristics [9]. To modify the peak power output and raise the producing effectiveness of the PV system, several MPPT control strategies have been put forth. According to their control theoretic and optimization principles, the three primary MPPT approaches for PV systems are reviewed, summarised, and grouped into three groups in this work. In particular, the benefits and drawbacks of MPPT approaches for PV systems with PSCs are contrasted and examined.

2. LITERATURE REVIEW

The MPP from SPV energy systems under varying climatic circumstances has been tracked using several different ways. The most difficult problem for researchers in this domain is to extract electrical power from SPV systems in non-uniform irradiation, such as Partial Shade Condition (PSC) or Fast Transient Circumstances (FTC). To remove the losses and maximize the power from SPV systems, a power electronic architecture with a MPPT algorithm is required. MPP may be tracked using traditional MPPT methods with constant solar irradiation [10]. A Multiple Perturbation and Observation (MP&O) based MPPT method is suggested to quickly attain the global MPP using a reversed boost-buck converter architecture with a parallel power processing idea [11]. The effectiveness of algorithms for MPPT is impacted by inaccurate PSC or FTC detection. As there are several peaks in the *P-V* curve, an MPPT algorithm's typical role during PSC or FTC is to search among the local peaks for the global peak and stabilize the output voltage. The output system voltage stability is more of a concern during PSC for small isolated SPV systems than power efficiency [12]. Along with current publications on diverse hardware design processes, MPPT techniques are used for PV systems as documented in the literature. Depends on the tracking method used to track the MPP under PSCs, they are divided into four classes i.e.- Classical, Intelligent, Optimization, and last is Hybrid. Since there is just one peak in the *P-V* curve under uniform insolation, classical approaches are heavily favoured [13]. The oscillation, random fluctuation, and sluggish power tracking of PV systems might reduce their power. A unique optimization of grasshopper (GHO) approach is added to the MPPT controller under rapidly changing irradiates and PS circumstances to address these problems. Under 5 different weather scenarios, a difference between is done with known approaches i.e. - P&O, PSOGS, DFO, ABC, CS, and PSO optimization strategies. Complex partial shading reveals flaws in current methods (CPS) [14]. Based on research examining the output characteristics of SPV systems under partial shadowing situations, a unique MPPT is developed. Multiple peaks appear on PV curves when circumstances are partially shaded, which reduces the effectiveness of traditional methods. As a result, the suggested approach, which is based on the Modified Particle-Swarm Optimization (MPSO) methodology, boosts the output power of SPV systems under such abnormal situations and performs better than existing techniques [15]. For quick, precise, and effective tracking, a hybrid MPPT approach based on T-S Fuzzy-integral back-stepping is presented. The suggested method allows for dependable and steady functioning in the face of quick dynamic environmental changes. Additionally, it is easy because it doesn't need additional atmospheric sensors. Through simulations using Matlab/Simulink and practical outside testing, the theoretical model addressed confirmed. The effectiveness of the created MPPT approach is highlighted through a comparison with several alternative MPPT strategies [16]. In this regard, a novel framework for the MPPT

algorithm built on a sliding mode controller (SMC) is created in this research and applied to PV panels under partial shade circumstances (PSC) and uniform conditions [17].
According to published research, bio-inspired MPPT control systems have certain significant flaws, including long tracking and settling times, oscillations at global maxima (GM), and local maxima (LM) trapping under PS circumstances [18]. Based on a recent meta heuristic method for Manta Ray Foraging Optimization (MRFO), author have suggested a novel GMMPT algorithm. In the literature, a multi-port DC converter-based PV sub-module Distributed MPPT technique is proposed. The SPV model and its unmatched properties, the module Voltage Equalisation (VE) strategy, and its implementation with the multiple port buck-boost converter are all investigated and researched thoroughly. The trade-off between the real Distributed MPPT and VE in terms of to control the complexity and tracking precision, and a thorough derivation is made to show how they vary from one another. Experiments were used to confirm the suggested scheme's viability and development [19].

3. PROPOSED MPPT METHOD FOR SPV SYSTEM

To mitigate the effects of partial shading on a SPV system is employed with MPPT as shown in Figure 3.1a. The Pulse Width Modulated (PWM) signal is generated by MPPT under variation in Vpv and Ipv. PWM signal drives the DC–DC converter's gate driver circuit and maintains the output at MPP. This type of implementation required addition gate driver circuitry to adjust the duty cycle of DC-DC converter output. Using an inverter circuit, output AC powered load appliances are connected to the SPV system. Incremental Conductance (IC) is one of the popular techniques to track the MPP accurately. The algorithm searches the *P-V* curve's peak value by detecting the *P-V* curve's slope. It compares the instantaneous Conductance (I/V) and the PV array's incremental conductance (dI/dV) to track the MPP. Slope Detection for IC algorithm is shown in Figure 3.1b.
The operating point on the P–V curve is located by checking the relationship between these two values as expressed in Equations 3.1, 3.2, and 3.3. Equation 3.1 indicates the operation at MPP, and Equations 3.2 and 3.3 represent the PV system operation on the MPP's left and right sides.

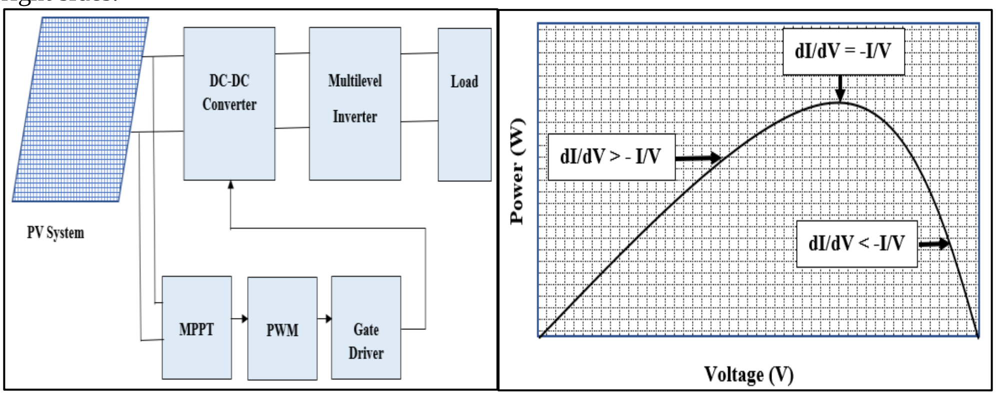


Figure 3.1 a) SPV System Block diagram with implementation of MPPT b) Slope Detection for IC algorithm

$$\frac{dI}{dV} > -\frac{I}{V} \qquad (3.1)$$

$$\frac{dI}{dV} = -\frac{I}{V} \qquad (3.2)$$

$$\frac{dI}{dV} < -\frac{I}{V} \qquad (3.3)$$

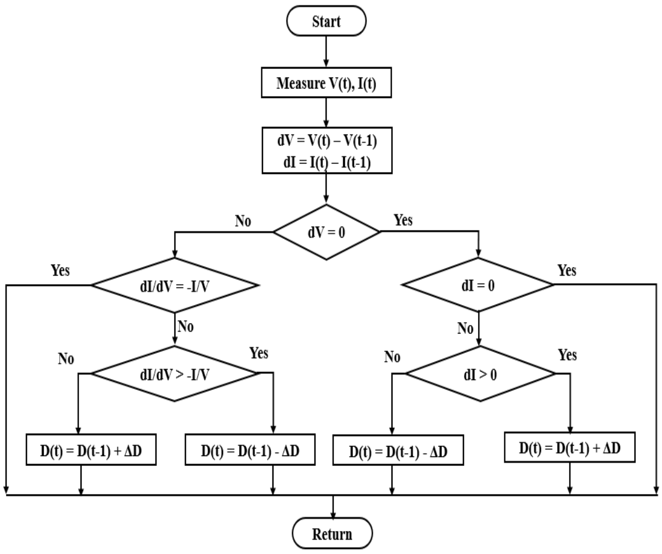
The slope of the *P-V* curve at MPP is 0.

$$\frac{dP}{dV} = 0 \qquad (3.4)$$

Re^{w}riting equation 4,

$$I + V\frac{dI}{dV} = 0 \qquad (3.5)$$

PV voltage and current are measured, and Equation 3.5 is used to detect MPP. If equation 1 is satisfied, the duty cycle of the DC-DC converter is decreased. If Equation 3.3 is satisfied, the duty cycle of the DC-DC converter is increased. According to these modifications in the



duty cycle, the required MPP is tracked by the algorithm, as shown in Figure 3.2.

Figure 3.2 Flowchart for IC-based MPPT Algorithm

4. RESULTS AND DISCUSSION

In a proposed methodology using the MPPT approach, four-panel were considered to experiment with four different cases (C1, C2, C3, and C4). In each instance, a separate irradiation was set, and the instantaneous voltage, current and power were recorded concurrently. These logged data are utilised to generate *I-V* and *P-V* graphs. Consequently, the output value of M_p and FF is noticed and recorded. Table 4.1 summarizes the influence of Variations in Solar Intensity on the Performance of SPV Systems.

Table 4.1 Impact of Variations in Solar Intensity on PV Systems

Case No.	**Panel 1 (W/m^2)**	**Panel 2 (W/m^2)**	**Panel 3 (W/m^2)**	**Panel 4 (W/m^2)**	**M_p (W_p)**	**FF (%)**
C1	1000	1000	1000	1000	30.562	0.8546
C2	1000	1000	1000	804	24.338	0.6852
C3	1000	1000	804	701	21.064	0.5956
C4	1000	809	701	609	18.067	0.5159

The combined graphs for the *I-V* plot and *P-V* plots for various situations are illustrated in Figures 4.1, and 4.2.

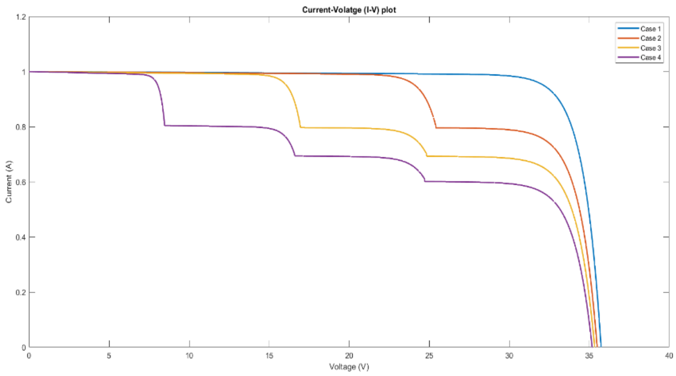


Figure 4.1. *I-V* Plot of data captured from emulator for four different cases

The IC algorithm-based MPPT is implemented in MATLAB-Simulink. The system is tested for five different levels of solar irradiance i.e., 350 W/m^2, 500 W/m^2, 650 W/m^2, 800 W/m^2, and 950 W/m^2. According to the changes in the duty cycle (D), the DC bus voltage is varied, and MPP is tracked. The available SPV power and load power are noted in all the cases. Table 4.2, summarizes the results logged for different cases using MATLAB-Simulink.

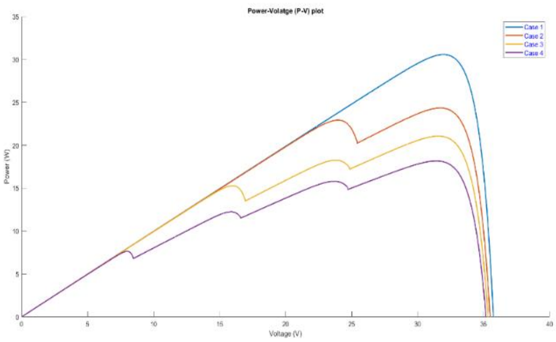


Figure 4.2. *P-V* Plot of data captured from emulator for four different cases

Table 4.2. Load Power for IC-based MPPT

Case	Irradiance (W/m^2)	DC Bus Voltage (V)	Solar PV Power (kW)	Load Power (kW)
1	350	265.8823	0.7709	0.7541
2	500	302.0581	0.9940	0.9732
3	650	345.0433	1.2735	1.2699
4	800	380.6385	1.5786	1.5455
5	950	419.6706	1.9009	1.8787

The results show that the DC bus voltage varies in response to solar irradiation variations to maintain the operating point at MPP. The findings indicate the variances in solar panel voltage and solar power. The IC-based MPPT reliably tracks the MPP as shown in Figure 4.3.

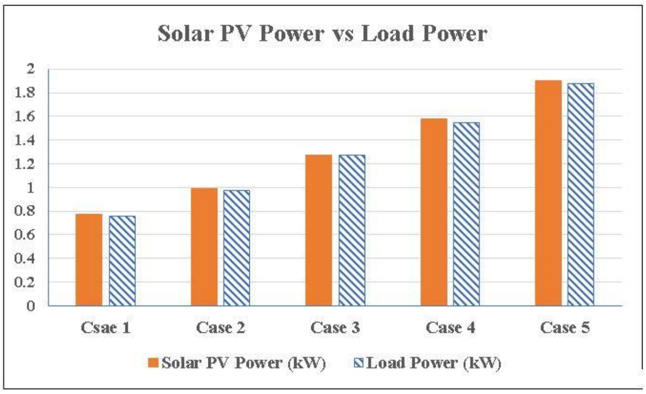


Figure 4.3 Solar PV Power vs. Load Power

5. CONCLUSION

This paper proposes an Incremental Conductance (IC) algorithm-based MPPT for PSV systems under varying solar irradiance levels. Compared to other MPPT methods, the proposed method is more straightforward and stable. The said technique can accurately track the MPP with an efficiency of more than 98 %. The MATLAB simulation results validate the stability and accuracy of the proposed algorithm. The algorithm also outperforms the convergence speed to track the MPP with a response time of less than 0.1 ms. Due to the more straightforward structure of the algorithm, it can be implemented with less complex hardware, which increases the possibility of utilising the proposed method in actual SPV power generation.

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