Performance Evaluation of MPPT Algorithms for Enhanced Efficiency in Photovoltaic Systems

Mr. Sreenivasan R*

Assistant Professor, C.K.College of Engineering &Technology, Cuddalore, Tamilnadu, India.

Corresponding Author*
DoI: https://doi.org/10.5281/zenodo.15768268

Abstract

Algorithms of maximum power point tracking are widely used in most of photovoltaic systems to optimize the output power which depends on ambient conditions such as solar irradiance and PV arrays' temperature. In general, these techniques can be classified into two categories: conventional algorithms such as Perturb and Observe (P&O) and Incremental Conductance (INC).In this investigation, a comparison of these algorithms is conducted to analyse, compare, and assess their performances when they are integrated in a PV power system under dynamic changed conditions. The simulation results obtained from MATLAB/Simulink environment show that the dynamic performances of intelligent MPPT controller are much better than those of traditional algorithms such as P&O and INC.

Keywords: Photovoltaic, Conventional Algorithms, MPPT.

1. Introduction

Photovoltaic (PV) panels, commonly known as solar panels, are devices designed to convert sunlight directly into electrical energy through the photovoltaic effect. They are a cornerstone of renewable energy technology, offering a sustainable and environmentally friendly solution to meet the growing global demand for clean energy.

PV panels are composed of multiple interconnected solar cells, typically made from semiconductor materials like silicon. When sunlight strikes the surface of these cells, photons excite electrons within the material, creating an electric current. This direct conversion of solar energy into electricity makes PV panels a reliable and efficient option for various applications, from residential and commercial power generation to large-scale solar farms.

The efficiency and performance of PV panels depend on several factors, including solar irradiance, temperature, and shading. Advanced technologies and innovative algorithms, such as maximum power point tracking (MPPT), are employed to optimize their energy output under varying environmental conditions. With continuous advancements in materials and designs, PV panels are becoming more affordable and efficient, playing a pivotal role in reducing reliance on fossil fuels and promoting a sustainable energy future.

2. PV Characteristics

Photovoltaic (PV) panels exhibit specific electrical characteristics that define their performance under varying environmental conditions, such as solar irradiance and temperature. These characteristics are primarily represented by two key curves: the **Current-Voltage (I-V)** curve and the **Power-Voltage (P-V)** curve. Understanding these characteristics is essential for optimizing the performance of PV systems and designing efficient Maximum Power Point Tracking (MPPT) algorithms.

2.1 Current-Voltage (I-V) Curve

The I-V curve shows the relationship between the output current (I) and voltage (V) of a PV module under specific operating conditions.

- **Open Circuit Voltage (Voc)**: The maximum voltage the PV module can produce when there is no load (current = 0).
- **Short Circuit Current (Isc)**: The maximum current generated when the output terminals are shorted (voltage = 0).

2.2 Power-Voltage (P-V) Curve

The P-V curve illustrates the relationship between the output power (P) and voltage (V) of a PV module.

- **Maximum Power Point (MPP)**: The point on the curve where the power output is maximized, corresponding to an optimal combination of voltage and current.

Understanding PV characteristics is critical for:

- Designing efficient MPPT algorithms to extract maximum power under dynamic conditions.
- Selecting and sizing PV modules for specific applications.
- Evaluating the performance of PV systems under varying environmental factors.

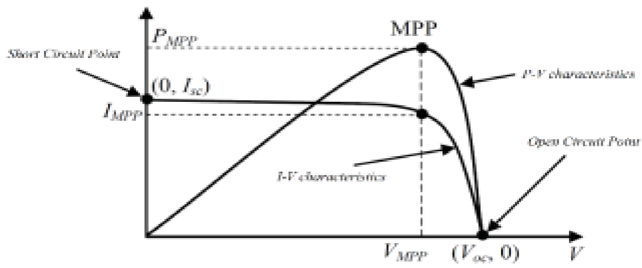

Figure.1. I-V and P-V characteristics of a PV panel

3. Maximum Power Point Tracking Method

3.1 Perturb and Observe (P&O) Technique

The Perturb and Observe (P&O) technique is one of the most widely used methods for Maximum Power Point Tracking (MPPT) in photovoltaic (PV) systems due to its simplicity, ease of implementation, and cost-effectiveness. This method operates by periodically perturbing the operating voltage (or current) of the PV system and observing the corresponding change in output power.

The technique introduces a small incremental change to the operating voltage or current of the PV panel.

The resulting output power is measured and compared to the power before the perturbation.

- If the output power increases, the perturbation direction is retained.
- If the output power decreases, the direction of perturbation is reversed.

This process is repeated continuously to ensure the system operates near the maximum power point (MPP).

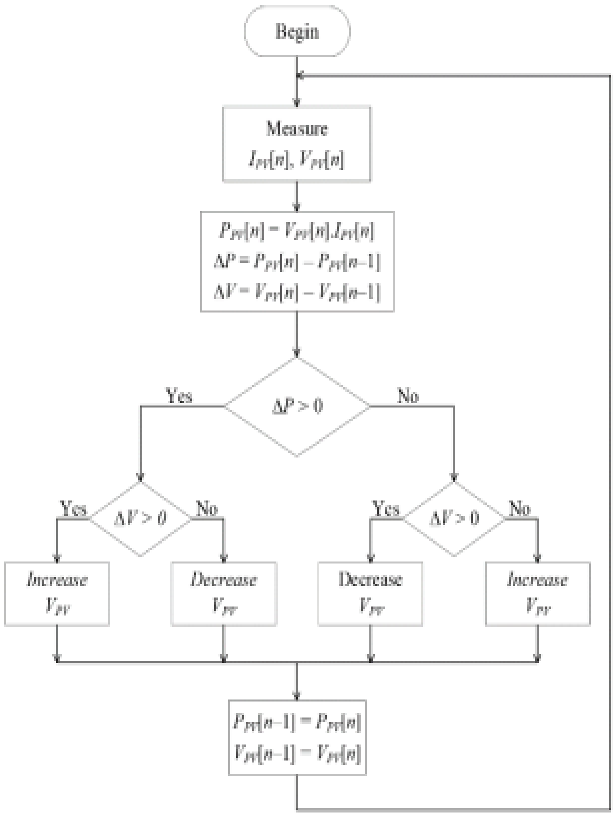

Figure.2. Flow Chart of P&O Algorithm

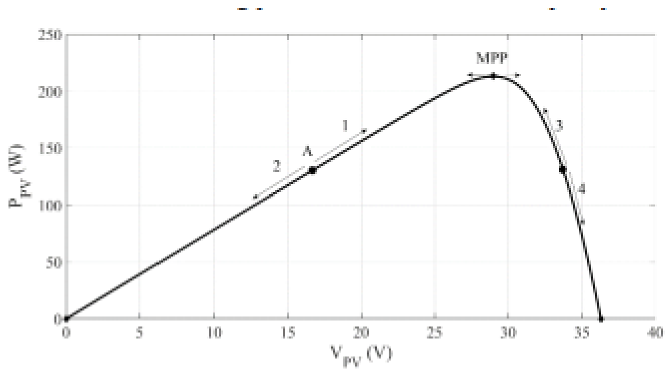

Figure.3. P-V Characteristics of P&O Algorithm

3.2. INC Technique

The Incremental Conductance (INC) technique is an advanced and widely used Maximum Power Point Tracking (MPPT) algorithm in photovoltaic (PV) systems. It is designed to address some of the limitations of simpler algorithms, such as Perturb and Observe (P&O), particularly under rapidly changing environmental conditions.

The INC technique is based on the fact that at the Maximum Power Point (MPP), the derivative of power with respect to voltage is zero:

$$\frac{dP}{dV} = 0$$

Since power P is the product of voltage V and current I, the derivative can be expressed as:

$$\frac{dP}{dV} = I + V\frac{dI}{dV}$$

Using this relationship, the following conditions are evaluated:

At the MPP: $\frac{dP}{dV} = 0 \implies I + V\frac{dI}{dV} = 0$

Left of the MPP: $\frac{dP}{dV} > 0 \implies I + V\frac{dI}{dV} > 0$

Right of the MPP: $\frac{dP}{dV} < 0 \implies I + V\frac{dI}{dV} < 0$

The INC algorithm uses these conditions to adjust the operating voltage or current of the PV system to track the MPP accurately.

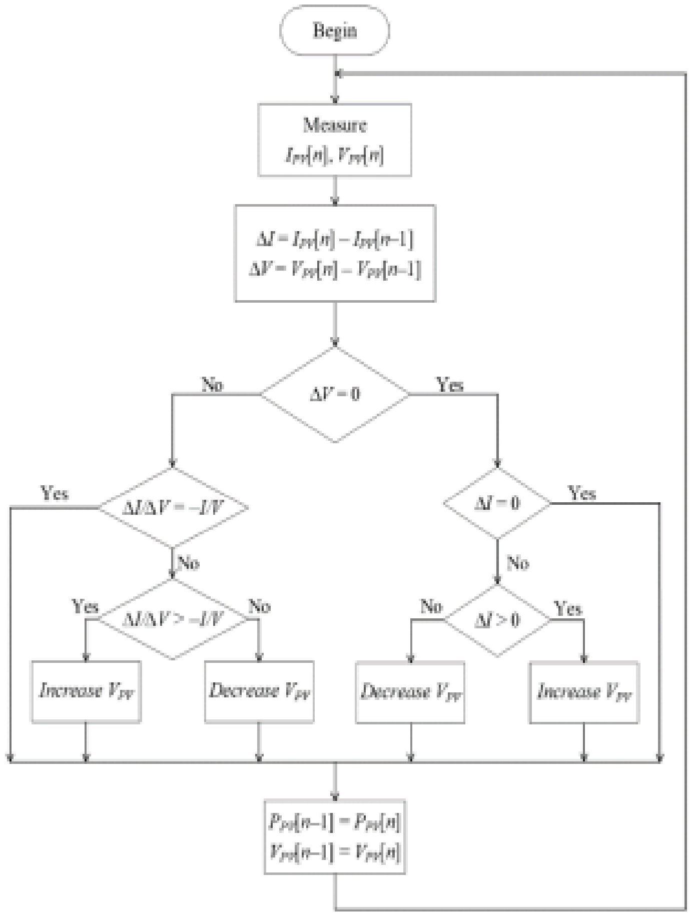

Figure.4. Flow chart of INC Algorithm

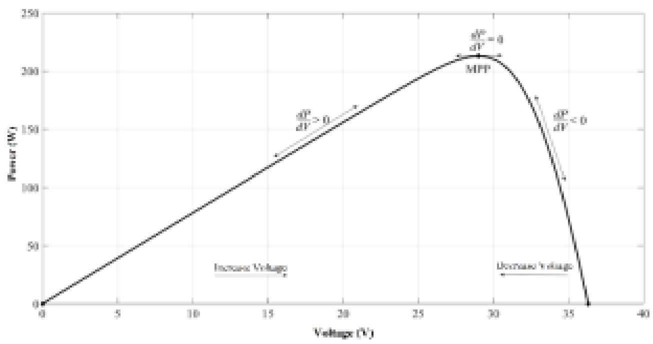

Figure.5. P-V Characteristics of INC Algorithm

Table.1. Efficiency of MPPT Algorithms

Algorithm	MPP Tracking Efficiency (%)	
	Slowly Changed Irradiation	Rapidly Changed Irradiation
P&O	99.52	34.42
INC	99.55	34.46

4. Conclusion

Integrating MPPT peak power scoring algorithms into DC - DC power converters will make it possible to get more energy from the same amount of solar radiation. The obtained research results confirm that the most effective algorithm is the proposed INC control algorithm with the efficiency MPPT always reaching over 99% under various changing radiation conditions.

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