Design and Implementation of P&O MPPT algorithm for Solar PV System

Puja Kumari [1], Arbind Dang [1], Umesh Mahto [1], Ramesh Kumar [2]

[1] UG. Student, Department of Electrical and Electronics Engineering, RTC Institute of Technology, Ranchi, Jharkhand

[2] Assistant Professor, Electrical and Electronics Department, RTC Institute of Technology, Ranchi, Jharkhand

Abstract

The aim of this project explores the design and implementation of perturb and observe (P&O) Maximum Power Point Tracking (MPPT) method to optimize energy harvesting from solar photovoltaic (PV) systems. Our main aim was to design a system which can extract maximum power point (MPP) and maximum power point tracker (MPPT). By dynamically adjusting the operating point of the PV system, the P&O algorithm ensures maximum power output despite changes in environmental conditions such as sunlight intensity and temperature. The project involves developing and implementing the MPPT P&O algorithm, by the help of DC/DC Boost Converter using a MATLAB/SIMULINK. The results demonstrate the effectiveness of the P&O method in improving the efficiency and reliability of solar PV systems. Solar panels can lower utility bills and produce clean, environmentally friendly energy. The efficiency of photovoltaic solar panels is related to the quality of their photovoltaic (PV) cells. The conversion efficiency of a PV cell is the percentage of solar energy shining on a solar panel that is converted into usable electricity. The efficiency of solar panels has improved dramatically in recent years, from an average of around 15% conversion of sunlight to usable energy to around 20%. High-efficiency solar panels can reach nearly 23%. The power rating of a standard-sized panel has likewise increased from 250W to 370W.

Keywords

Solar Photovoltaic (PV) System, Maximum Power Point Tracking (MPPT), Perturb and Observe (P&O) Algorithm, DC/DC Converter (Boost Converter).

1. Introduction

As the world shifts towards renewable energy sources, solar photovoltaic (PV) systems have emerged as a promising solution for clean and sustainable power generation. However, the output power of solar PV systems varies significantly with changes in environmental conditions, such as sunlight intensity and temperature. Maximum Power Point Tracking (MPPT) algorithms are employed to optimize the energy output of solar PV systems. Among various MPPT techniques are used, we choose the Perturb and Observe (P&O) method stands out for its simplicity, effectiveness, and ease of implementation. This project aims to design and implement the P&O MPPT method for a solar PV system, ensuring maximum energy extraction under varying environmental conditions.

The increasing demand for renewable energy sources has led to a significant growth in the solar photovoltaic (PV) industry. Solar PV systems offer a clean and sustainable way to generate electricity, reducing our reliance on fossil fuels and mitigating climate change. However, solar PV systems face a significant challenge in terms of optimizing their energy output due to varying environmental conditions such as temperature and irradiance. PV system consist of PV panels and DC-DC converters such as boost converter. MPPT algorithms get voltage and current from solar PV panel and regulate the duty cycle of PWM which is applied to switch MOSFET of DC-DC converters to regulate voltage and current of converter.

Maximum Power Point Tracking (MPPT) algorithms play a crucial role in addressing this challenge by optimizing the energy output of solar PV systems. MPPT algorithms are designed to track the maximum power point (MPP) of the solar panel, which is the point at which the panel produces the maximum power output. By tracking the MPP, MPPT algorithms can increase the energy output of solar PV systems, improve their efficiency, and reduce energy losses [1][2].

2. Objective

The main objective of this paper is to design and implementation of a system, which can track the maximum power point at a point with the help of perturb and observe algorithm in solar PV system with different temp. and irradiance.

- Design a solar PV system with a DC-DC converter and MPPT controller.
- Implement the P&O MPPT algorithm using a MATLAB/SIMULINK.

- Evaluate the performance of the P&O algorithm under different environmental conditions.
- Optimize the system for maximum energy output and reliability.

By achieving these objectives, this project aims to contribute to the development of efficient and reliable solar PV systems that can maximize energy output and reduce costs.

3. System Description

3.1 Mathematical Model of a Photovoltaic Module

A photovoltaic (PV) cell, commonly called a solar cell, is a non-mechanical device that converts sunlight directly into electricity. Few PV cells can convert artificial light into electricity.

There are several PV Cell model: the single-cell model, dual-cell model, three-diode model, double-diode model, and single-diode model. Among these circuit models, the single-diode model has become the most widely used due to its effective balance between simplicity and accuracy.

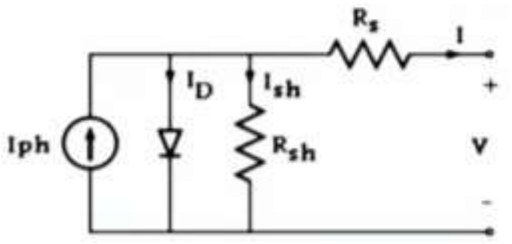

Figure 1: PV cell modelled as diode circuit.

The single-diode model of the PV cell is represented by Photocurrent (Iph), Diode, Series Resistance (Rs) and Shunt Resistance (Rsh) as in the above fig. The current source, Iph, represents the cell photocurrent, Rsh represents the cell's intrinsic shunt resistances, while Rs represents the cell's series resistances. Typically, the Rsh value is significant, whereas the Rs value is slight, so they can be left out in order to simplify the analysis. PV cells in groupings are called PV modules, and these groupings can be further interconnected in a parallel-series configuration to form PV arrays. As illustrated in Equations (1) to (2), the photovoltaic panel can be mathematically modelled.

Module photo current

$$\mathrm{Iph} = [\mathrm{Iscr} + \mathrm{Ki}(T - 298)] * \frac{\lambda}{1000} \qquad (1)$$

Module Reverse Saturation current

$$\mathrm{Irs} = \frac{\mathrm{Iscr}}{e\left[\frac{q.\mathrm{Voc}}{\mathrm{Ns.k.A.T}}\right]} \qquad (2)$$

Here, we can see that the module's saturation current Is varies according to cell temperature, given as:

$$\mathrm{Is} = \mathrm{Irs}\left[\frac{T}{\mathrm{Tr}}\right]^3 e\left[\frac{q.\mathrm{Ego}(\frac{1}{\mathrm{Tr}}-\frac{1}{T})}{\mathrm{rK}}\right] \qquad (3)$$

The PV module current is thus

$$\mathrm{Ipv} = \mathrm{Np} * \mathrm{Iph} - \mathrm{Np} * \mathrm{Is}\left[e\left(\frac{q.Vpv+Ipv.Rs}{Ns.A.k.T}\right)\right] \quad (4)$$

Where, Vpv =Voc

Np=1, Ns=36.

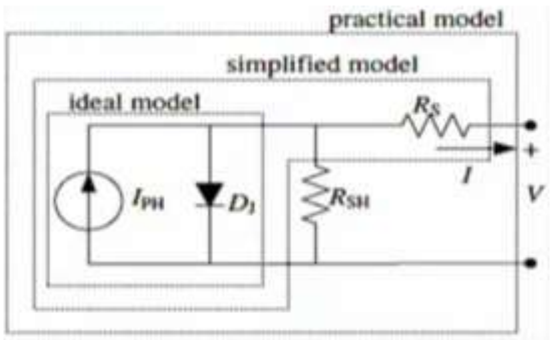

Figure 2: Different Models of Solar Cell

Table 1: Specification of PV Panel

Array data	
Parallel strings	64
Series – connected modules per string	5
Module data	
Module	1Soltech 1STH-215-P
Maximum Power	213.15 Watt
Voltage at maximum power point (Vmp)	29 V
Current at maximum power point (Imp)	7.35 A
Open Circuit Voltage (Voc)	36.3 V

Short Circuit Current (Iscr)	7.84 A
Cells Per Modules (Ncell)	60
Total Number of Cells in Parallel (Np)	1
Temp. coefficient of Voc (%/deg.C)	-0.36099
Temp. coefficient of Isc (%/deg.C)	0.102

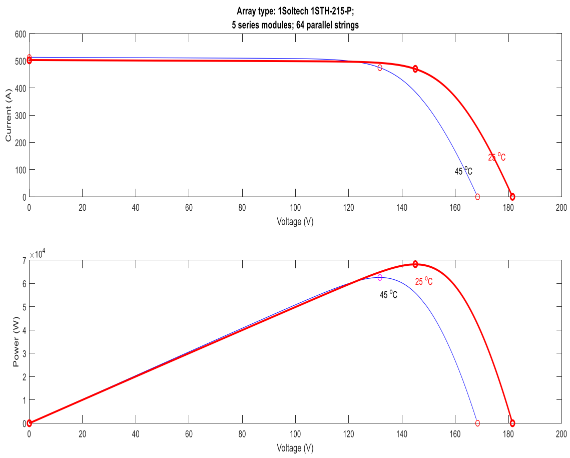

Figure 3: I-V & P-V Characteristics of PV panel with 1000 W/m^2 at temp. 25°C

3.2 MPPT (Maximum Power Point Tracking)

Maximum Power Point (MPP): The MPP is the point at which the solar panel produces the maximum power output. The MPP varies with changes in environmental conditions such as temperature and irradiance [3].

MPPT algorithms work by adjusting the operating point of the solar panel to match the MPP [4]. The algorithm continuously monitors the power output of the solar panel and adjusts the operating point to maximize energy production.

MPPT algorithms are essential for solar PV systems because they can:

1. Increase Energy Output: MPPT algorithms can increase the energy output of solar PV systems by up to 30%.

2. Improve Efficiency: MPPT algorithms can improve the efficiency of solar PV systems by reducing energy losses.

3. Reduce Stress on System Components: MPPT algorithms can reduce the stress on system components, such as inverters and batteries, by optimizing the energy output [5].

3.2.1 Perturb & Observe Algorithm

The P&O algorithm works by perturbing the duty cycle of the DC-DC converter and observing the change in power output [6]. If the power output increases, the algorithm continues to perturb the duty cycle in the same direction. If the power output decreases, the algorithm reverses the direction of perturbation [7][8].

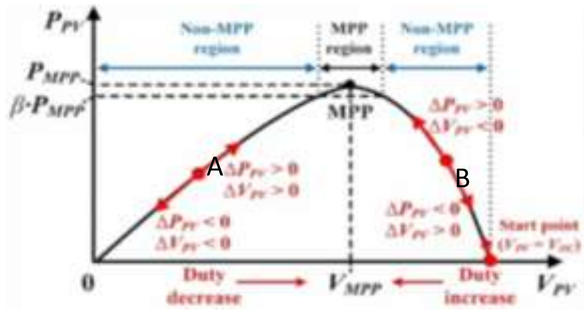

Figure 4: Perturb & Observe method showing MPP and operating points A & B.

Figure 4 shows the plot of module output power versus module voltage for a solar panel at a given irradiation in Perturb & Observe MPPT. The point marked as MPP is the Maximum Power Point, the theoretical maximum output obtainable from the PV panel. Consider A and B as two operating points. As shown in the figure above, the left hand side of the MPP. Therefore, we can move towards the MPP by providing a positive perturbation to the voltage. On the other hand, point B is on the right hand side of the MPP. When we give a positive perturbation, the value of P becomes negative, thus it is imperative to change the direction of perturbation to achieve MPP [9][10]. The flowchart for the P&O algorithm is shown in Figure.

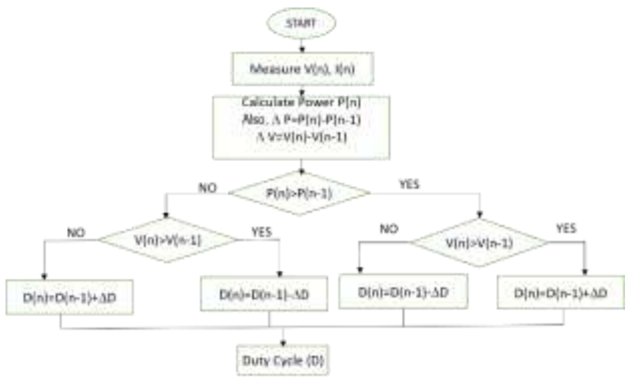

Figure 5: Flow chart of P&O MPPT Algorithm

3.3 DC/DC Converter

A DC-DC Converter converts the fixed dc input voltage to variable dc output voltage. A dc-dc converter is also known as dc chopper. In dc-dc converter circuit power MOSFET, power BJT, and IGBT is used as a switch [11]. In this system boost converter is used as MPPT circuit to operate at maximum power point. Perturb & Observe MPPT control method is applied to switch (MOSFET) of boost converter to adjust the duty cycle of PWM [12].

Table 2: Specification of boost converter.

S. NO.	Component	Value
1.	Input Voltage	181.5V
2.	Inductor	$5*10^{-3}$ H
3.	IGBT (Int. Resistance)	$1*10^{-3}$
4.	Diode	
5.	Input Capacitor	$100*10^{-6}$ F
6.	Output Capacitor	$12000*10^{-6}$
7.	Resistive Load	10Ω
8.	Switching Freq.	10kHz
9.	Duty Cycle	0.28

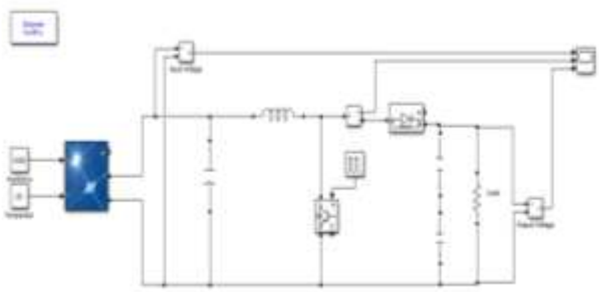

Figure 6: PV Panel with Boost Converter

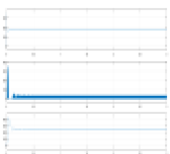

Figure 7: Waveform of Boost Converter

3.3.1 Operation of Boost Converter

Mosfet/Igbt is used as a switch and it is in on or off state. When D is defined as duty ratio, during $0 < t < DT$, the mosfet is on state and the diode is reverse biased. The voltage across inductor is VL =Vin. During $DT < t < T$, the mosfet is in off state and the diode becomes forward bias [13] [14].

The voltage across inductor

V_L = Vin-Vout

Operation at the steady state condition the total change of current on inductor must be zero in a period of switching.

$$Vin = Vout * (1 - D) \quad (5)$$

$$\frac{Vout}{Vin} = \frac{1}{1-D} \quad (6)$$

To find inductor and capacitor of boost converter the following equation

$$\Delta I_L = \frac{Vin\_min\, D}{fs.L} \quad (7)$$

Where, Vin(min) = minimum input voltage

fs = switch frequency

D = duty cycle

L = inductor

$$L = \frac{Vin.(Vout-Vin)}{\Delta IL\ fs\ .\ Vout} \quad (8)$$

Where, Vout = output voltage

Vin = input voltage

ΔIL = estimated inductor ripple current

$$C = \frac{Iout\ .\ D}{fs\ .\ \Delta Vout} \quad (9)$$

Where, C = capacitor

Iout = output current

D = duty cycle

fs = switching frequency

ΔVout = estimated output ripple voltage

4. Working Methodology

A PV system is implemented and evaluated using P&O Algorithm for MPPT using DC/DC Converter and the load. The proposed system consists of Solar PV system, MPPT P&O method, Boost Converter and the load.

The voltage of solar panel depends on:

Sunlight intensity (irradiance), temperature of solar panel and angle.

In the source side we are using a capacitor to which maintains the voltage of the PV panel to almost constant value and the output capacitor is used to obtain fixed DC output or maintain the output voltage at constant which is eliminating the ripples and the ripples are filtered out with the help of this capacitor.

MPPT algorithms get voltage and current from solar PV panel and regulate the duty cycle of PWM which is applied to switch MOSFET of DC-DC converters to regulate voltage and current of converter.

In the source side we are using a boost converter which is connected to a solar panel in order to enhance the output voltage so that it can be used for different applications like motor load. By changing the duty cycle of the boost converter appropriately we can match the source impedance with that of the load impedance.

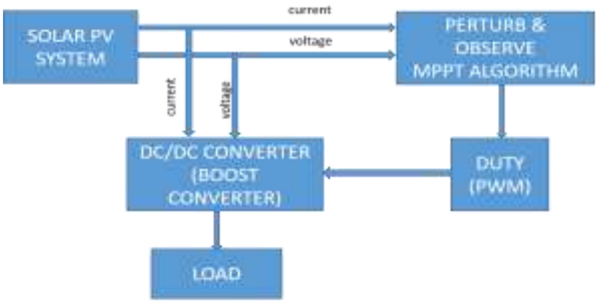

Figure 8: Block diagram of proposed system

The inputs for the solar panel are 3 irradiance and temperature i.e.; 1000 w/m^2, 750 w/m^2, 500 w/m^2 at 25ºC a boost converter is used for conversion and change in voltage level to match the load. The output of P&O MPPT Algorithm is Duty cycle (D) and input is vpv and ipv (voltage and current of pv panel).

Set initial duty cycle which is 0.4, maximum and minimum duty cycle limit which is 0.9 and 0.01 and

5. (A) Simulation Results

The simulation results are presented in this section. The system was operated for two states and three states:

For load resistor 10ohm

State 1: 1000 W/m^2 and 25ºC

State 2 : 500 W/m^2 and 25ºC

For load resistor 5ohm

State 1: 1000 W/m^2 and 25ºC

State 2 : 500 W/m^2 and 25ºC

State 3: 1000 W/m^2 and 25ºC

change in duty cycle which is 20e-6 and is set using the output and input voltage relation of boost converter.

Accordingly, the P&O Algorithm from the initially set duty cycle, voltage and current of the solar panel and there by measuring the instantaneous power which is termed as P(n), and measure the change in power ΔP. And then this P(n) values is compared with previous power P(n-1) which is zero.

If not equal to zero, then there are four possibilities:

I. ΔP<0, ΔV<0 the decrease D, Then {D=D(n-1) + ΔD else D=D(n-1)- ΔD for ΔV<0}
II. ΔP<0, ΔV>0 the increase D
III. ΔP>0, ΔV<0 the decrease D
IV. ΔP>0, ΔV>0 the decrease D

If P(n) is greater than Duty cycle is increased and perturb is continued in same direction, and if less then Duty cycle is decreased and perturb is continued in opposite direction. Hence MPPT is maintained corresponding to the set duty cycle. System continually checks the PV panel voltage, current and load voltage and current. Then it gives the output to the gate driver to which finally give the firing pulses to the power semiconductor switch i.e. MOSFET. Then it is actuated and step-up the load power accordingly.

Hence the main aim of the P&O Algorithm is to maintain the maximum output power, such that the load remains constant by varying the duty ratio.

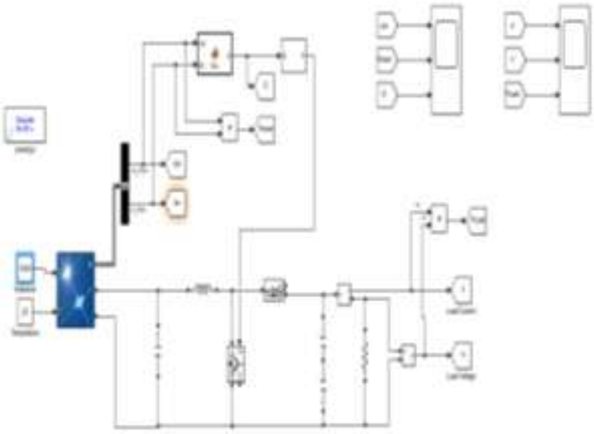

Figure 9: Simulation model of P&O MPPT Algorithm for Solar PV System with irradiance 1000 W/m^2 and temp. 25ºC

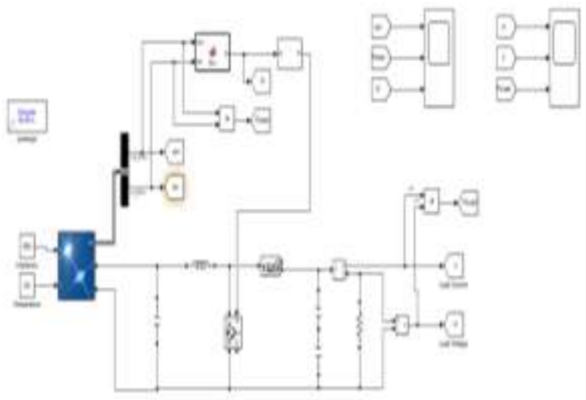

Figure 10: Simulation model of P&O MPPT Algorithm for Solar PV System with irradiance 500 W/m^2 and temp. 25ºC

5. (B) Waveforms

Figure 11: Waveform of Vpv, Power and duty cycle (D) with irradiance 1000 W/m^2 , 500 W/m^2 at temp. 25ºC with load resistor 10Ω.

Figure 12: Waveform of Load Voltage (vl), Load Current (il) and Load Power (PLoad) with irradiance 1000 W/m^2 , 500 W/m^2 at temp. 25ºC with load resistor 10Ω.

Figure 13: Waveform of Vpv, Power and duty cycle (D) with irradiance 1000 W/m^2 , 500 W/m^2 and 1000 W/m^2 at temp. 25ºC with load resistor 5Ω.

Figure 14: Waveform of Load Voltage (vl), Load Current (il) and Load Power (PLoad) with irradiance 1000 W/m^2, 500 W/m^2 and 1000 W/m^2 at temp. 25ºC with load resistor 5Ω.

6. Conclusion

In this paper, Design and Implementation of P&O MPPT for solar PV system has been done successfully. This system is design and modelled in MATLAB/SIMULINK and waveform shown in the above Figure. Our main aim was to design a system which can extract maximum power point (MPP) and maximum power point tracker (MPPT). The MPPT techniques considered in proposed work are Perturb & Observe method. The simulation was first run with the P&O MPPT algorithm, with the load resistor 10ohm with irradiance 1000 & 500 W/cm^2 at temp. 25ºC, the power obtained at the load side was more fluctuating for a solar irradiation value of 1000 and 500 W/cm^2. At 1000W/m the output for the existing system is 85KW and for the proposed system is 65KW. The proposed system improves the system power quality and gives the power supply to the load.

Therefore, it on that using the Perturb & Observe MPPT technique increased the efficiency of the photovoltaic system. And the obtained output power is 17.8watt.

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