

# Performance Enhancement of Solar Array using MPPT through Simulation and Modelling

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**Abstract**—Globally, there is an increase in the demand for renewable energy due to depleting levels of fossil fuels and increasing carbon emission levels. Solar, Wind and Hydroelectric energy sources are 3 main sources of renewable energy. Solar is the most practical to implement within cities due to the space requirements and on-site generation. However, there are some limitations related to solar energy. The main limitations being, the availability of sun light only during daytime and the low efficiency of the solar cells (11% - 12%). There is a need to generate maximum energy whenever available. Maximum Power Point Tracking (MPPT) is one of the techniques that extracts maximum power from the Photovoltaic (PV) System. In this paper, methods for enhancement of performance of Solar Arrays through algorithms such as Perturb & Observe (P&O) and Incremental Conductance method of MPPT will be discussed. The system output has been recorded for the two methods and compared. Modelling and simulations have been carried out on Simulink.

**Index Terms**— MPPT, PV system, P&O, incremental conductance, PWM, micro grid, duty cycle.

## I. INTRODUCTION

A total of 4272.54 MW of renewable energy capacity has been added during the year 2019-20, taking cumulative installed renewable energy capacity to 82.58 GW as on Sept, 2019 with 36.93 GW coming from wind power, 31.10 GW from solar power, 9.94 GW from bio power and 4.61 GW from Small Hydro Power in India[1]. Solar energy takes up 31.10 GW of energy which is a vast inexhaustible resource that supplies significant portion of India's renewable energy. Due to the increasing demands, it is essential to improve the efficiency of the current systems. As mentioned above, MPPT technique is one such method. A PV System with MPPT comprises of mainly 4 parts. These are, PV Panel, DC-DC converter (Boost Converter is used in this paper), Load and a MPPT block. The terminals of the Panel are connected to the input of the Boost converter. Here the boosted voltage is provided across the load. The MPPT controller takes the voltage values and the current values from the PV panel and depending on the method of MPPT, a suitable duty cycle is provided to the boost converter. The boost converter provides a boosted output to the load as depicted in Figure 1. MPPT's help improve the efficiencies of systems like Standalone system, Hybrid, Micro Grid and more.

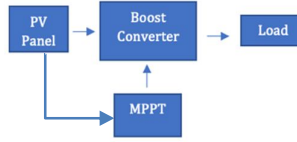


Figure 1. Simple PV system with MPPT

## II. PARTS OF THE PV SYSTEM

### A. PV Panel

A PV module comprises of many PV cells in series or parallel or both. When exposed to light, it produces power if connected to load. Figure 2. Single Diode Model of solar cell [2]

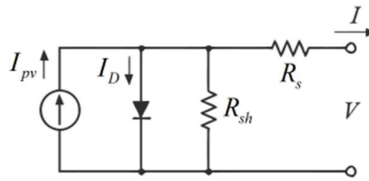


Figure 2 shows the model of a solar cell [2] from which the current  $I$  can be derived as follows,

$$I = I_{pv} - I_0 \left( e^{\frac{V+IR_s}{nV_t}} - 1 \right) - \frac{V+IR_s}{R_{sh}} \quad (1)$$

$$I_d = I_0 \left( e^{\frac{V+IR_s}{nV_t}} - 1 \right)$$

$I_d$  is the diode current (A)

$I_{pv}$  = Photogenerated current

$N$  is the ideality factor and it is between 1 and 2. Sometimes, it is observed to be greater than 2. [3]

$K$  is the Boltzmann's constant

$$V_t = n \frac{KT}{q} = 25.85 \text{ mV at } 300 \text{ K}$$

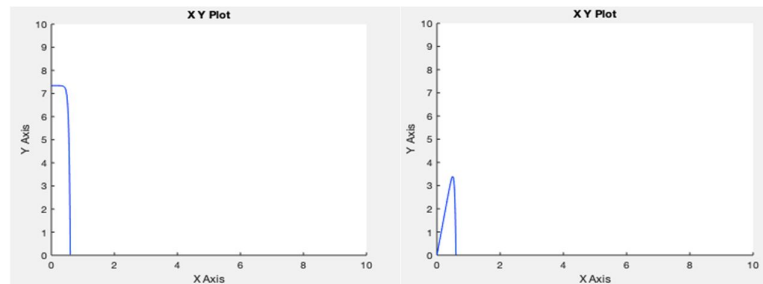


Figure 3. IV and PV Characteristics

**IV & PV Characteristics.** Provided in Figure 3 are the IV and PV characteristics of a solar cell simulated on Simulink. From the I-V Graph in Figure 3 we obtain short circuit current and the open circuit voltage. The short circuit Current is denoted as  $I_{sc}$ , the open circuit Voltage is denoted as  $V_{oc}$ , the Current and Voltage at maximum power are denoted as  $I_{mp}$ ,  $V_{mp}$ .

$$I_{sc} = I_{pv} - I_0 \left( e^{\frac{I_{sc}R_s}{nV_t}} - 1 \right) - \frac{I_{sc}R_s}{R_{sh}} \quad (2)$$

$$0 = I_{pv} - I_0 \left( e^{\frac{V_{oc}}{nV_t}} - 1 \right) - \frac{V_{oc}}{R_{sh}} \quad (3)$$

From the P-V Graph in Figure 3 shows the point at which the power is maximum. The corresponding equation for  $I_{mp}$  is equal to equation 3.

The atmospheric parameters such as irradiance level, ambient temperature, dirt/dust and the particular installing conditions also have effects the PV system [4].

### B. DC-DC Boost Converter

The PV panel produces an output that is not enough to supply the load. Therefore, boost converter is used between the load and the PV panel. The input voltage to the boost converter is denoted by  $V_i$  and the output voltage of the boost converter is denoted by  $V_o$ . DC-DC boost converter is controlled by an IGBT. The equation for the boost converter is the follows [5]

$$V_i = (1-D) V_o \quad (4)$$

$$V_o = V_L$$

where D is the duty cycle of the waveform driving the switch.  $V_L$  is the voltage across the load.

### C. Load

In this paper we have used a resistive load of 120 W active power connected to the boost converter. From equation (4) the output voltage across the resistive load is obtained.

$$V_L = V_o = \frac{V_{in}}{(1-D)} \quad (5)$$

## III. MPPT

Under all conditions, MPPT can be applied to PV solar systems and in Wind Turbines to maximize the extracted power.

MPPT algorithms can be classified into the following,

1. Incremental Conductance
2. P&O : Perturb and Observe
3. Current Sweep
4. Constant Voltage
5. Temperature Method

This paper will focus on the comparison between the first two methods. Irradiance ( $Wm^{-2}$ ) will be used as the variable for which the values of voltage and power obtained at the output will be compared for each method.

### A. Perturb & Observe

P&O algorithm is used due to its structural simplicity and requirements of few measured parameters. Voltage and Current values are the inputs to the P&O algorithm. Consider figure 4.

**Case 1:** The initial operating point is B of the P vs V graph at time t. The voltage and power initially are denoted by  $V_i$  and  $P_i$  and let the next point of operation be A, the voltage is denoted by  $V_f$  and power is denoted by  $P_f$ .  $\Delta V$  &  $\Delta P$  values are negative. The operation point is moved to the left of the maximum power point. To move it towards the point of maximum power, the reference voltage ( $V_i$ ) in equation 4 has to be increased. To do this, the duty cycle has to be decreased.

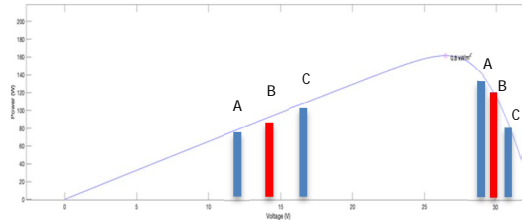


Figure 4. PV with operation points taken from Simulink

**Case 2:** Considering the initial operating point to be B, corresponding voltage and power are  $V_i$  and  $P_i$ . Considering C to be the next operating point, corresponding voltage and power are  $V_f$  and  $P_f$ .  $\Delta V$  is positive and  $\Delta P$  is positive. Despite the operation moving in the direction of the point of maximum power, it is not at

the point yet. Therefore, reference voltage has to be increased towards  $V_p$  (voltage at maximum power). Using equation 4,  $V_{ref}$  can be increased by decreasing the value of duty cycle.

**Case 3:** Consider the initial point as B', corresponding points of voltage and power as  $V_i$  and  $P_i$ . Consider point A' as the next point of operation, corresponding voltage and power points are  $V_f$  and  $P_f$ . Here  $\Delta V$  is negative and  $\Delta P$  is positive. This operation moves towards the point of maximum power, however the reference voltage must be further reduced to reach the  $V_p$ . Using equation 4, by increasing the value of delta, reference voltage can be reduced.

**Case 4:** Consider the initial point as B', corresponding points of voltage and power as  $V_i$  and  $P_i$ . Consider point C' as the next point of operation, corresponding voltage and power points are  $V_f$  and  $P_f$ . Here  $\Delta V$  is positive and  $\Delta P$  is negative. This operation moves away from the point of maximum power, the reference voltage must be reduced to reach the  $V_p$ . Using equation 4, by increasing the value of Delta reference voltage can be reduced.

TABLE I. SUMMARY OF THE 4 CASES IN P&O METHOD

| Case   | $\Delta V$ | $\Delta P$ | D         |
|--------|------------|------------|-----------|
| Case 1 | Negative   | Negative   | Decrease  |
| Case 2 | Positive   | Positive   | Decrease  |
| Case 3 | Positive   | Negative   | Increased |
| Case 4 | Negative   | Positive   | Increased |

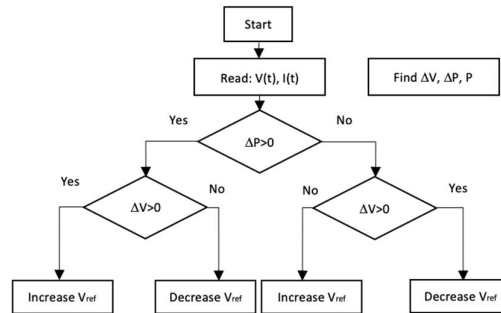


Figure 5. P&O Algorithm flowchart [6]

The algorithm for the flowchart in Figure 5- can be written by if and else statements for the decision shape blocks. In order to reduce the lines of code, we can analyse table 1 and come up with the following logic.

TABLE II. ANALYSIS FROM TABLE I

|                           |                   |
|---------------------------|-------------------|
| $\Delta V * \Delta P > 0$ | D should decrease |
| $\Delta V * \Delta P < 0$ | D should Increase |

Applying the above analysis from Table 2, two if statements and one else statement can do the same as the code technique discussed above. This method saves on lines of code. For both these cods, the value of  $\Delta D$  must be pre-selected and the values of  $V_{prev}$  and  $I_{prev}$  must be recorded at the end.

$$D = D \pm \Delta D \quad (6)$$

### B. Incremental Conductance

Through change in current the change in voltage in the panel is predicted in this method. Nature of the P vs V curve are found through the changes in Conductance. On the left and the right of MPP the values of ( $\Delta P / \Delta V$ ) are negative and positive respectively. Based on these parameters, the MPPT controller either decides to increase or decrease the reference voltage values, thus altering the values of D in equation 4 [7].

The algorithm for the above flowchart in Figure 6 can be obtained by simple if and else statements at every decision box. However, in order to reduce to lines of code, the following analysis can be used. The logic used in table 3 can be implemented by checking condition for  $\Delta V$ . Based on that the expression for sum is chosen.

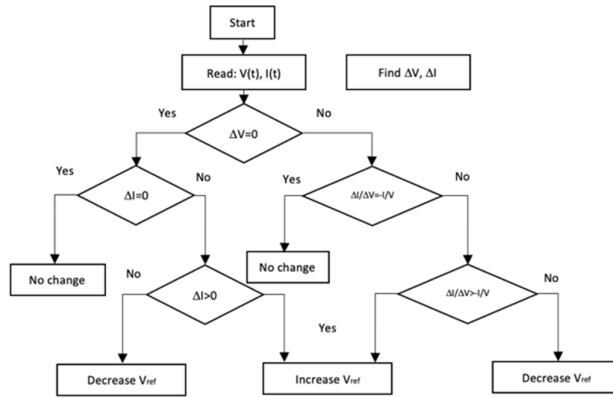


Figure 6. – Incremental Conductance Flow Chart [8]

Depending up to whether the value of sum is positive, negative or zero, value of is changed accordingly thereby changing  $V_{ref}$

$$D = D \pm \Delta D \quad \text{---(6)}$$

TABLE III. ANALYSIS FROM FIGURE 6

| $\Delta V$   | Sum | D         | Sum   |
|--------------|-----|-----------|---|
| 0            | +ve | Increase  | $\Delta V + \Delta I$ --(a)                     |
| 0            | -ve | Decrease  | $\Delta V + \Delta I$ --(a)                     |
| $\neq 0$     | +ve | Increase  | $\frac{\Delta I}{\Delta V} + \frac{I}{V}$ --(b) |
| $\neq 0$     | -ve | Decrease  | $\frac{\Delta I}{\Delta V} + \frac{I}{V}$ --(b) |
| 0 / $\neq 0$ | 0   | No change | (a) Or (b)                                      |

#### IV. CIRCUIT MODEL AND CONDITIONS

PV array used Kyocera Solar KC200GT

Total time of Simulation 2.5 seconds

Standard test conditions : 25 ° C

Duty cycle for No MPPT test case = 0.7

TABLE IV. IRRADIANCE PROVIDED FOR VARYING TIME

| Irradiance w.r.t Time    |     |     |     |     |     |     |
|--------------------------|-----|-----|-----|-----|-----|-----|
| Time(s)                  | 0   | 0.5 | 1   | 1.5 | 2   | 2.5 |
| Irradiance ( $Wm^{-2}$ ) | 500 | 700 | 800 | 900 | 100 | End |

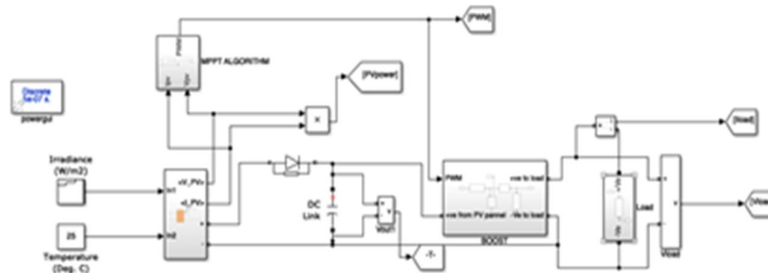


Figure 7. – PV System Test Bed

## V. SIMULATION RESULTS & ANALYSIS

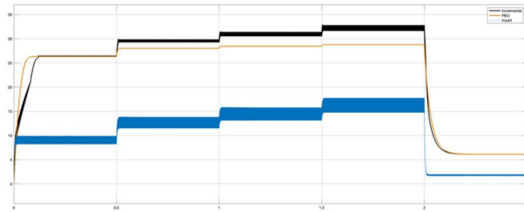


Figure 8. – V load vs Time

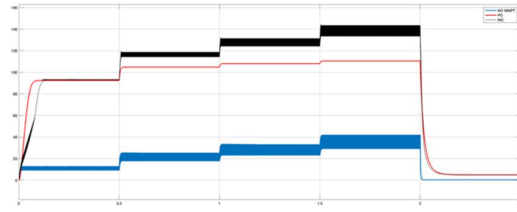


Fig. 9. – P load vs Time

TABLE V. SIMULATION RESULTS

| Time seconds | Irradiance Wm <sup>-2</sup> | Incremental Conductance |                   | P&O               |                   | No MPPT           |                   |
|--------------|-----------------------------|-------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|              |                             | V <sub>load</sub>       | P <sub>load</sub> | V <sub>load</sub> | P <sub>load</sub> | V <sub>load</sub> | P <sub>load</sub> |
| -            | -                           | 26.45                   | 93                | 26.3              | 92.5              | 9.8               | 13                |
| 0            | 500                         | 29.8                    | 118.9             | 28                | 104.8             | 13.5              | 25.5              |
| 0.5          | 700                         | 31.4                    | 131.8             | 28.4              | 108               | 15.75             | 33.3              |
| 1            | 800                         | 32.8                    | 143.8             | 28.8              | 110.5             | 17.75             | 42                |
| 1.5          | 900                         | 6.13                    | 5                 | 6.13              | 5                 | 2                 | 0.3               |
| 2            | 100                         |                         |                   |                   |                   |                   |                   |

In this paper, from Table 5, it is evident that the MPPT yields more output power and voltage at a given time for different irradiance levels. However, while comparing the results obtained for Perturb and Observe method and Incremental Conductance method we observe that, in Incremental Conductance method yields higher levels of Voltage and power. The voltage incremental analysis goes as high as 12.2 % than that of Perturb and Observe in this test case, average percentage increases are 11.08 %. The percentage output power increase in this test case goes as high as 30 %. The average percentage output increase in incremental conductance is 21.8 %.

It is also observed that for every change in irradiance. The output settles down slower in incremental conductance method as compared to P&O. This is a key differentiating factor between P&O and IC methods of MPPT.

## VI. CONCLUSION

This paper deals with the performance enhancement techniques of a Solar Array and its analysis. The techniques discussed are P&O method and Incremental conductance method. Various logics have been presented to implement these algorithms for extracting maximum power from the PV Array. Simulated characteristic graphs of solar cells are also present. Simulation results reveal that Incremental Conductance is better than P&O method by an average of 11.08 percent for Output Voltage and 21.8 percent for Output Power. Effect of variation of voltage and power for change in irradiance is also presented. For higher Output Voltages and Power incremental conductance is proposed. Incremental conductance is observed to have more spikes in the output which may pose challenges to the protection of the system.

Based on this understanding, the future enhancement may include the protection of the system.

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