NEW PERTURB AND OBSERVE MPPT ALGORITHM AND ITS VALIDATION USING DATA FROM PV MODULE

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ABSTRACT

The perturbation and observation (P&O) technique for maximum power point tracking (MPPT) algorithm is very commonly used because of its ability to track maximum power point (MPP) under widely varying atmospheric condition. In this paper a new MPPT algorithm using bisection method for PV module is proposed. The algorithm detects the voltage of the PV module and then it calculates the power after which it follows steps of the algorithm to reach to the maximum power. For verification of the algorithm an equation of power has been formed by using the readings of voltage and current obtained from that solar PV module. With the same equation of power, new MPPT algorithm has been compared with the conventional P&O technique to verify that it reaches to the maximum power much faster than the conventional P&O. The complete system is modeled and simulated in the MATLAB 7.8 using SIMULINK.

KEYWORDS: *Photovoltaic, Maximum Power Point Tracking (MPPT), Algorithm, Bisection Method, Perturb and Observe (P&O)technique.*

I. INTRODUCTION

In today's climate of growing energy needs and increasing environmental concern, we must have to think for an alternative to the use of non-renewable and polluting fossil fuels. One such alternative is solar energy. Photovoltaic cells, by their very nature, convert radiation to electricity. This phenomenon has been known for well over half a century. Solar power has two big advantages over fossil fuels. The first is in the fact that it is renewable; it is never going to run out. The second is its effect on the environment. Solar energy is completely non-polluting.

Solar panel is the fundamental energy conversion component of photovoltaic (PV) systems. Its conversion efficiency depends on many extrinsic factors, such as insolation levels, temperature, and load condition. There are three major approaches for maximizing power extraction in medium- and large-scale systems. They are sun tracking, maximum power point (MPP) tracking or both. MPP tracking is popular for the small-scale systems based on economic reasons. The algorithms that are most commonly used are the perturbation and observation method, dynamic approach method and the incremental conductance algorithm [1].

Photovoltaic (PV) generation systems are actively being promoted. PV generation systems have two big problems, namely; (1) the efficiency of electric power generation is very low, especially under low radiation states and (2) the amount of electric power generated by solar arrays is always changing with weather conditions, i.e., irradiation [2]. Therefore, a maximum power point tracking (MPPT) control method to achieve maximum power output at real time becomes indispensable in PV generation systems. Till date several MPPT techniques have been proposed and some among those are also implemented on hardware platform.

The problems with the conventional perturb and observe algorithm and that of incremental conductance is their slow response in reaching to the maximum power point. And hence to overcome the problem of slow response a new algorithm has been developed.
In this paper, a new MPPT technique is proposed which suggests a modified perturb and observe algorithm to reach fast to the MPP compared to the conventional perturb and observe technique.
This paper explains the PV equivalent circuit, current-voltage, power-voltage characteristics of photovoltaic systems and the operation of the some commonly used MPPT techniques. A new perturbation and observation algorithm has been formed and has been validated with the help of practical data along with modelling and the results of simulations which compare its performance with that of algorithms of conventional P&O technique.

II. EQUIVALENT CIRCUIT OF A PV SOLAR CELL

The solar cell is the basic building block of solar photovoltaic. The cell can be considered as a two terminal device which conducts like a diode in the dark and generates a photo voltage when charged by Sun. When charged by the Sun, this basic unit generates a dc photo voltage of 0.5 to 1volt and in short circuit, a photocurrent of some tens of mili amperes per cm^2.

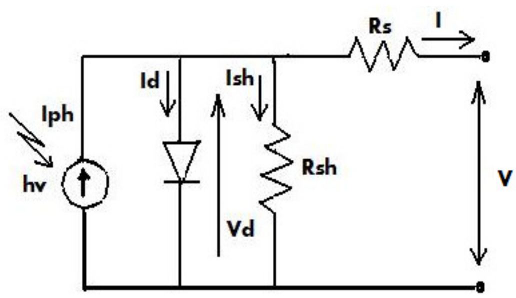

Figure 1. Equivalent circuit of PV solar cell

The output current I of solar arrays [2] is given by (1) using the symbols in figure 1.

$$I = I_{ph} - I_d - V_d / R_{sh} \quad (1)$$

$$V_d = V + R_s I \quad (2)$$

$$I_d = I_0\{\exp(qV_d / nKT) - 1\} \quad (3)$$

Where,

- I_{ph} is the photocurrent (in amperes)
- I_d is the diode current (in amperes)
- I_0 is the reverse saturation current (in amperes)
- R_s is the series resistance (in ohms)
- R_{sh} is the parallel resistance (in ohms)
- n is the diode factor
- q is the electron charge=$1.6\text{x}10^{-19}$ (in coulombs)
- k is Boltzmann's constant (in Joules/ Kelvin)
- T is the panel temperature (in Kelvin).
- V is the cell output voltage (Volts)
- V_d is the diode voltage (Volts)

The output current I after eliminating the diode components is expressed as

$$I = I_{ph} - I_0[\exp\{q(V + R_s I)/ nKT\} - 1] - [(V + R_s I)/ R_{sh}] \quad (4)$$

III. PV CHARACTERISTICS WITH PRACTICAL READINGS

Two sets of reading of voltage (V) and current (A) taken from the PV module along with the calculated values of power (W) are as shown in table I and table II below.

TABLE I Voltage and current readings

I(A)	V(V)	P(W)
0.67	0.00	0.00
0.67	2.00	1.34
0.67	3.00	2.01
0.66	4.00	2.64
0.66	5.00	3.30
0.65	6.00	3.90
0.65	7.00	4.55
0.63	8.00	5.04
0.61	9.00	5.49
0.59	10.00	5.90
0.53	**11.50**	**6.10**
0.45	13.00	5.85
0.42	13.50	5.67
0.38	14.00	5.32
0.33	14.50	4.79
0.27	15.00	4.05
0.20	15.50	3.10
0.12	16.00	1.92
0.02	16.50	0.33
0.01	**16.52**	0.10

TABLE II Voltage and current readings

I(A)	V(V)	P(W)
0.71	0.00	0.00
0.69	0.85	0.59
0.68	4.36	2.96
0.66	7.99	5.27
0.64	9.56	6.12
0.60	**11.28**	**6.77**
0.51	12.92	6.59
0.43	13.94	5.99
0.37	14.49	5.36
0.28	15.20	4.26
0.25	15.40	3.85
0.23	15.58	3.58
0.21	15.74	3.31
0.18	15.93	2.87
0.16	16.05	2.57
0.15	16.15	2.42
0.12	16.24	1.95
0.12	16.47	1.91
0.12	16.50	1.90
0.00	**17.94**	0.00

Fig.2 shows arrangement for taking readings of voltage and current from a PV module

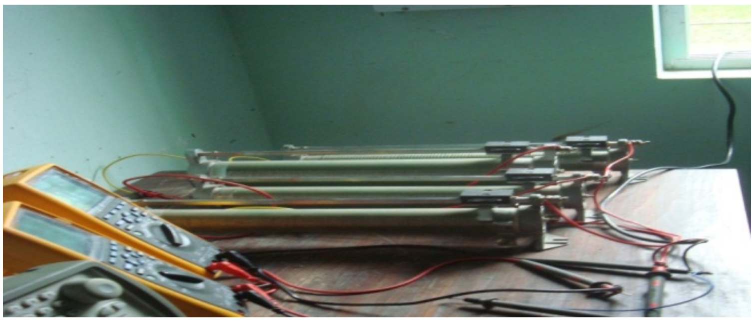

Figure 2. Arrangement for collecting data from the PV module

Fig. 3 & fig. 4 shows the I-V and P-V curve respectively, obtained with the help of MATLAB for the data collected from the PV module for table I and these data are used throughout the work.

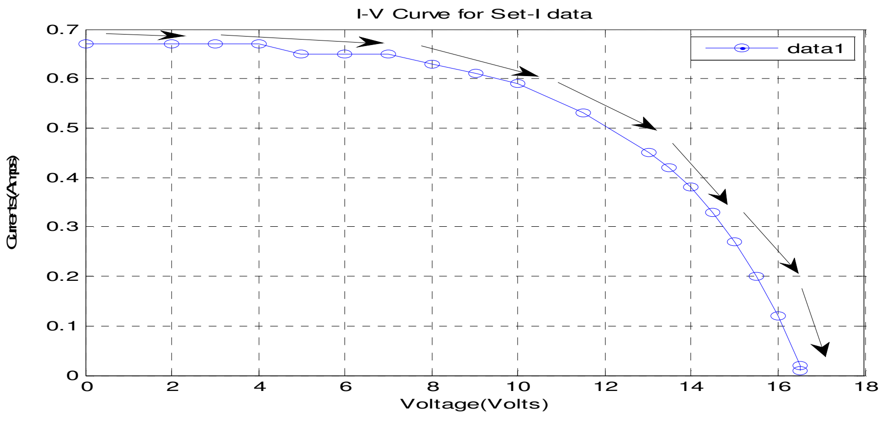

Figure 3. I-V curve of the PV module

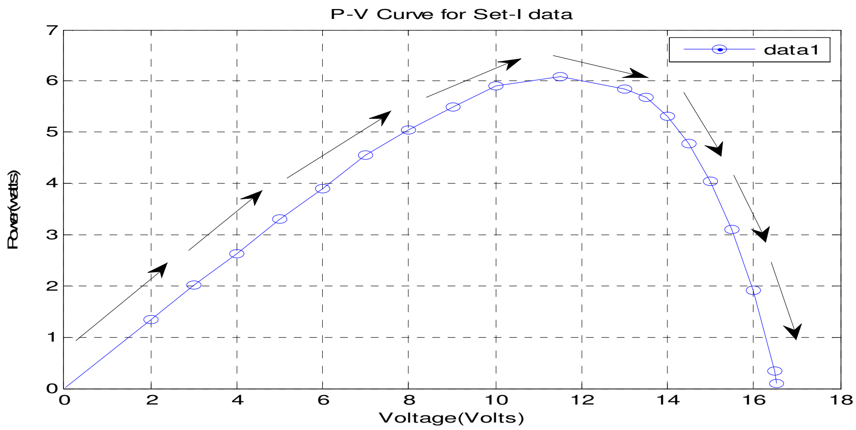

Figure 4. P-V curve of the PV module

IV. FREQUENTLY USED MPPT TECHNIQUES

Tracking the maximum power point (MPP) of a photovoltaic (PV) array is usually an essential part of a PV system. As such, many MPP tracking (MPPT) methods have been developed and implemented. The problem considered by MPPT techniques is to automatically find the voltage V_{MPP} or current I_{MPP} at which a PV array should operate to obtain the maximum power output P_{MPP} under a given temperature and irradiance. Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of [3]. MPPT is not a mechanical tracking system that "physically moves "the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. Additional power harvested from the modules is then made available as increased battery charge current. MPPT can be used in conjunction with mechanical tracking system, but the two systems are completely different. Some of the commonly used MPPT techniques are described here.

4.1. Fractional short-circuit current

Fractional I_{SC} results[4] from the fact that, under varying atmospheric conditions, I_{MPP} is approximately linearly related to the I_{SC} of the PV array as shown by the equation –

$$I_{MPP} \approx K_1 Isc \quad (5)$$

Where, K_1 is proportionality constant. The constant K_1 is generally found to be between 0.78 and 0.92. Power output is not only reduced when finding I_{SC} but also because the MPP is never perfectly matched as suggested by (5).The accuracy of the method and tracking efficiency depends on the accuracy of K_1 and periodic measurement of Short circuit current. Reference [5] suggests a way of compensating K_1 such that the MPP is better tracked while atmospheric conditions change.

4.2. Fractional open-circuit voltage

The near linear relationship between V_{MPP} and V_{OC} of the PV array, under varying irradiance and temperature levels, has given rise to the fractional V_{OC} voltage method [6].

$$V_{MPP} \approx K_2 Voc \quad (6)$$

Where, K_2 is a constant of proportionality. Since K_2 is dependent on the characteristics of the PV array being used, it usually has to be computed beforehand by empirically determining V_{MPP} and V_{OC} for the specific PV array at different irradiance and temperature levels. The factor K_2 has been reported to be between 0.71 and 0.78.Although the implementation of this method is simple and cheap, its tracking efficiency is relatively low due to the utilization of inaccurate values of the constant in the computation of V_{MPP}.

4.3. Incremental conductance

The incremental conductance method [7] is based on the fact that the slope of the PV array power curve is zero at the MPP, positive on the left of the MPP, and negative on the right, as given by

$$dP/dV = 0, \quad \text{at MPP} \tag{7}$$
$$dP/dV > 0, \quad \text{left of MPP} \tag{8}$$
$$dP/dV < 0, \quad \text{right of MPP} \tag{9}$$

Since, $dP/dV = d(IV)/Dv$

$$= I + V dI/dV = I + V \Delta I/\Delta V \tag{10}$$

Equation (10) can be rewritten as

$$\Delta I/\Delta V = -I/V, \quad \text{at MPP} \tag{11}$$
$$\Delta I/\Delta V > -I/V, \quad \text{left of MPP} \tag{12}$$
$$\Delta I/\Delta V < -V, \quad \text{right of MPP} \tag{13}$$

The MPP can thus be tracked by comparing the instantaneous conductance (I/V) to the incremental conductance (ΔI/ΔV). The increment size determines how fast the MPP is tracked. This method requires high sampling rates and fast calculations of power slope.

4.4. Perturb and observe technique

In Perturb and observe (P&O) [9] method, the MPPT algorithm is based on the calculation of the PV power and the power change by sampling both the PV current and voltage. The tracker operates by periodically incrementing or decrementing the solar array voltage. This algorithm is summarized in table III.

TABLE III Summary of hill-climbing and P&O algorithm

Perturbation	Change in Power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

The algorithm works when instantaneous PV array voltage and current are used, as long as sampling occurs only once in each switching cycle. The process is repeated periodically until the MPP is reached. The system then oscillates about the MPP. The oscillation can be minimized by reducing the perturbation step size. However, a smaller perturbation size slows down the MPPT.Fig.5 below shows the flow chart of conventional P&O technique [9]. To overcome the problem of this slow response in reaching to MPP, a new algorithm has been developed so that MPP can be reached faster compared to that of conventional P&O.

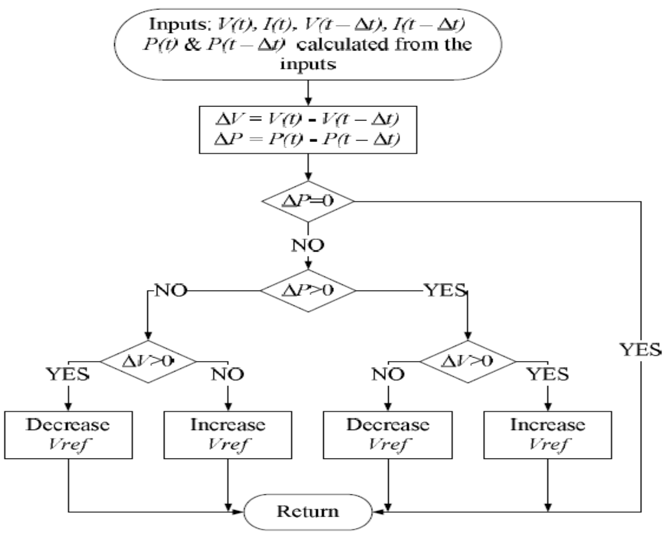

Figure 5. Flow chart of Conventional P&O technique

4.5. Learning-Based Algorithm

While Incremental Conductance addresses some of the shortcomings of basic Perturbation and observation algorithms, a particular situation in which it continues to offer reduced efficiency is in its tracking stage when the operating point is moving between two significantly different maximum power points. For example, during cloud cover the maximum power point can change rapidly by a large value. Perturbation and Observation based techniques, including the Incremental conductance algorithm, are limited in their tracking speed because they make fixed-size adjustments to the operating voltage on each iteration. The aim of this algorithm is to improve the tracking speed of Perturbation and Observation based algorithms by storing I-V curves and their maximum power points and using a classifier based system [10].Fig.6 below shows the activity diagram illustrating learning-based MPPT algorithm. This learning-based maximum power point tracking algorithm for photovoltaic systems is based on a K-Nearest-Neighbours classifier and this algorithm provides improved maximum power point tracking under rapidly changing atmospheric conditions, when compared to the Perturbation and Observation and Incremental Conductance Algorithms [10].

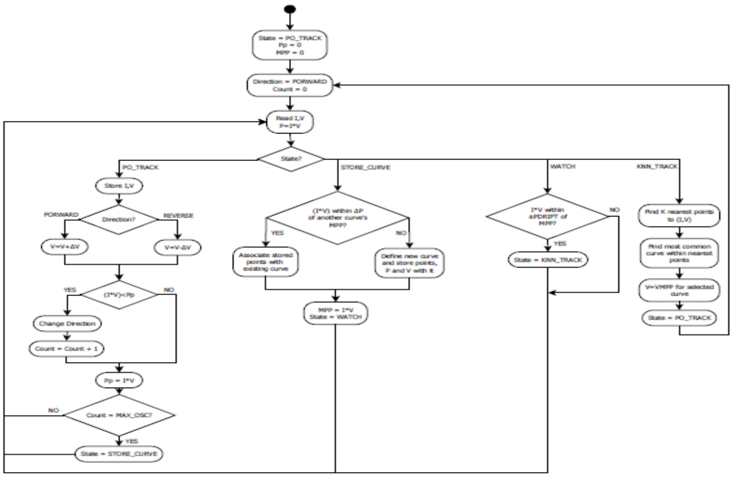

Fig. 6. Activity diagram illustrating learning-based maximum power point tracking algorithm.

V. PROPOSED MPPT TECHNIQUES (BISECTION METHOD)

Modification over the conventional P&O algorithm has been developed here. In this method, the maximum power operating point can be reached much earlier than the conventional P&O method. Here, first measurement of the voltage and calculation of the power is done at any instant. After that the slope (dP/dV) checking is done to see whether the operating point is lying in the left hand side of MPP or in the right hand side.

If the slope is positive then a specific increment, say 3volts, has been provided and corresponding power is calculated. Again the slope checking is done .If slope comes to be positive the increment is continued and if it comes to be negative, then that voltage and power is measured. The earlier voltage on the positive slope corresponding to the earlier power is updated as V_{pos} and the voltage corresponding to the power on the negative slope is updated as V_{neg}. The average of the two voltages is calculated and the slope checking is done. If the slope lies within a specific range than that power is read as maximum power point.

Else, if slope comes to be positive, then new average voltage will be updated as V_{pos} where as V_{neg} will remain as before and the average is taken and this process continues until it comes in very small range, say 0.1. On the other side i.e., if slope comes to be negative then voltage in the negative slope corresponding to last power on the negative side is updated as V_{neg} where as V_{pos} will remain same as before. Average of the two voltages is taken. If new average voltage lies in the specified small range then MPP is tracked else the process is continued until the MPP is reached

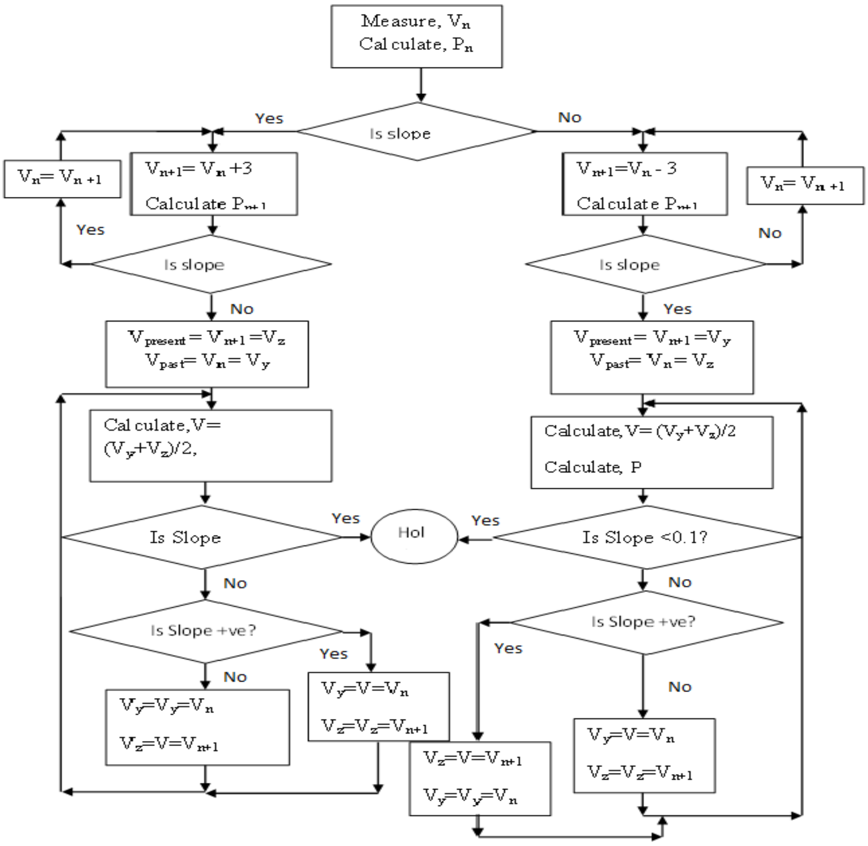

Figure7. Flowchart of Modified P&O algorithm (bisection method)

If initially the slope comes to be negative after measuring the voltage and power, then a specific decrement of voltage is done till the voltage obtained is lying at positive dP/dV. The recently obtained voltage at positive dP/dV and the last obtained voltage at negative dP/dV is specified as V_{pos} and V_{neg} respectively. The average voltage is calculated and at the average voltage slope checking has been done. If slope is positive V_{pos} and if slope is negative V_{neg} has been updated. The process continues till the average lies in the specified small range. Fig. 7 shows the total system in flowchart form. Fig. 8 shows the subroutine that is working in the decision box of the algorithm in fig.7.

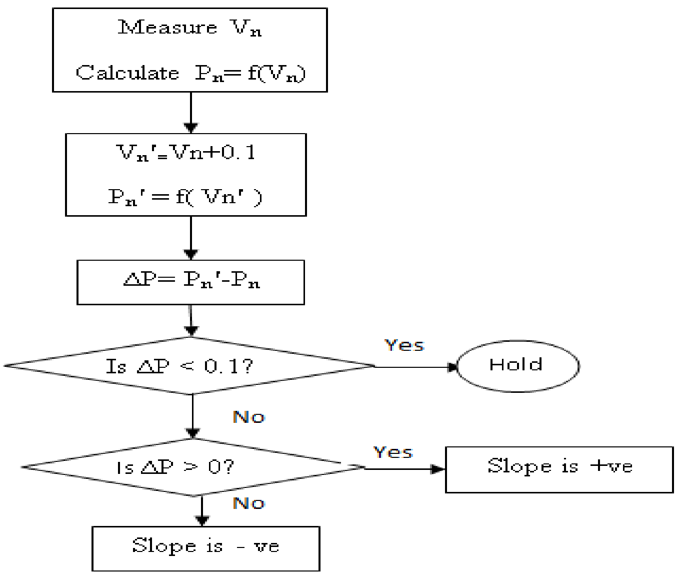

Figure 8. Slope checking flow chart

VI. SIMULINK MODEL OF THE CONVENTIONAL P&O AND NEW P&O BY USING BISECTION METHOD

Fig.9 shows the simulink model [11] of PV module by utilizing the user defined block after determining the equation with the help of excel function for the data of table I. The function used here is P= -0.0084x V^3+0.1365xV^2+0.0629 xV+0.4477.

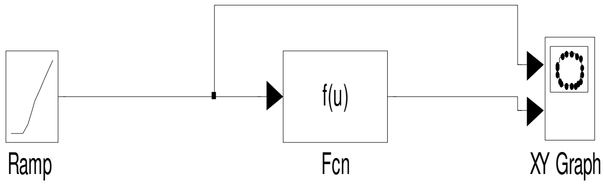

Figure 9. Simulink model for P-V Curve of the PV module

In conventional P&O method first a constant input of 3 volts is given. After that the corresponding power has been calculated. It is updated as old power .Then an increment of +0.1 is given and the corresponding power is calculated and updated as new power corresponding to the new voltage. Then the absolute value of the difference of two powers is taken. If the difference is greater than the specified value (here it is 0.0005) and old power is less than the new power, the process of increment is continued until it reaches the MPP. Else, a decrement of 0.1 is given and this process is continued until the absolute of the difference of two powers is greater than the specified value i.e, 0.0005 and new power less than the old power is satisfied so as to assume that the maximum power is reached. Fig. 10 shows the simulink model [11] of conventional perturb and observes technique. The simulink model for the modified P&O (bisection method) is shown in fig.11 and that of the combination of the two techniques is shown in fig.12.

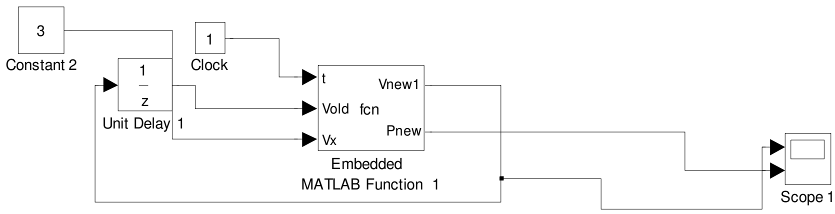

Figure 10. Simulink model of conventional P&O technique

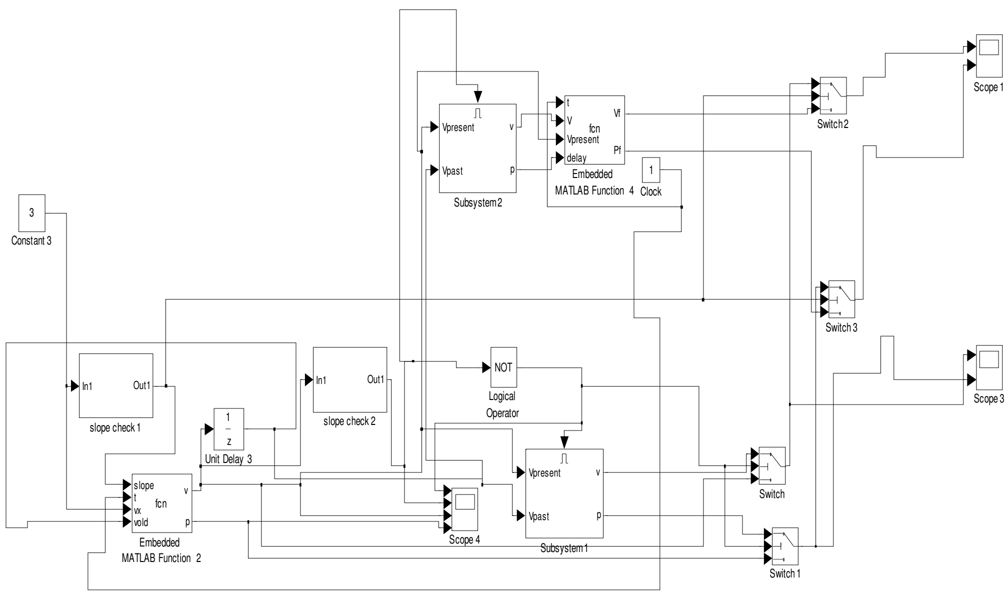

Figure 11. Simulink model of P&O (bisection method) technique

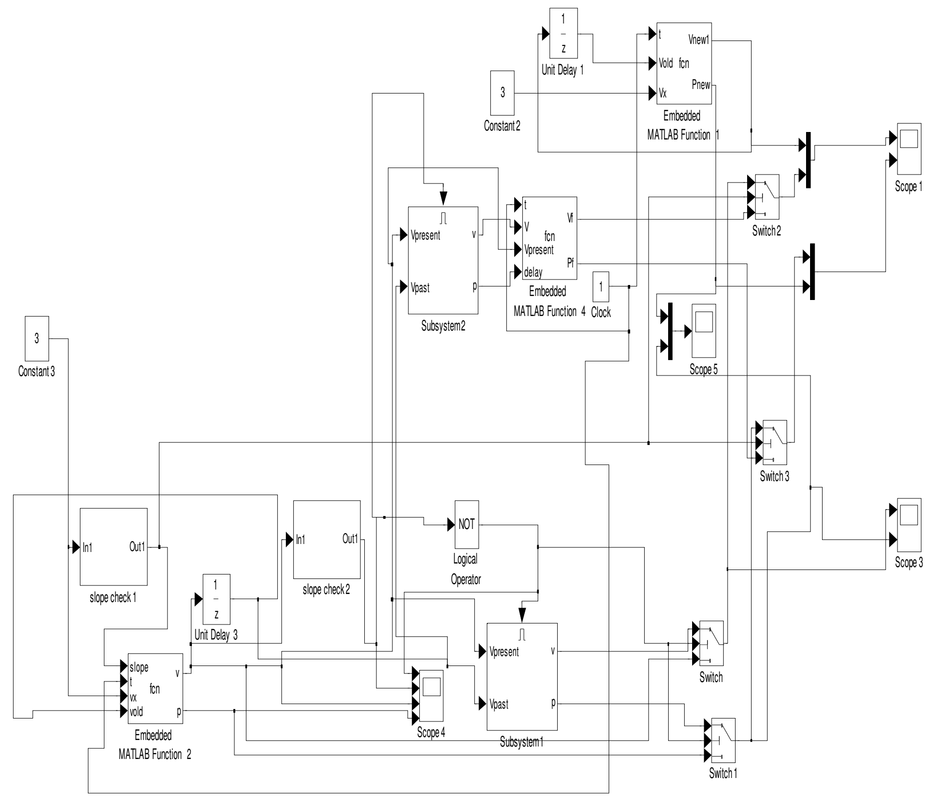

Figure 12. Simulink model of the combination of the two techniques.

Fig.13 below shows the simulink model [11] of the sub-system of modified P&O of the fig.11 and fig.14 show the simulink model of the slope check for modified P&O technique.

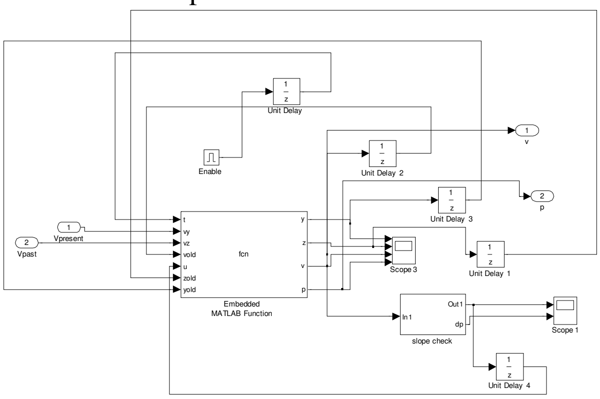

Figure 13. Simulink model of sub systems

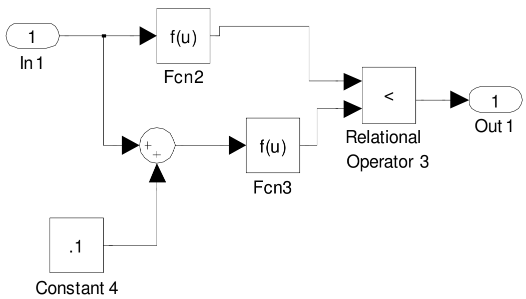

Figure 14. Slope checking model

VII. Simulation Results

Fig.15 shows the simulated P-V curve by utilizing the equation obtained from the data of table I as mentioned before.

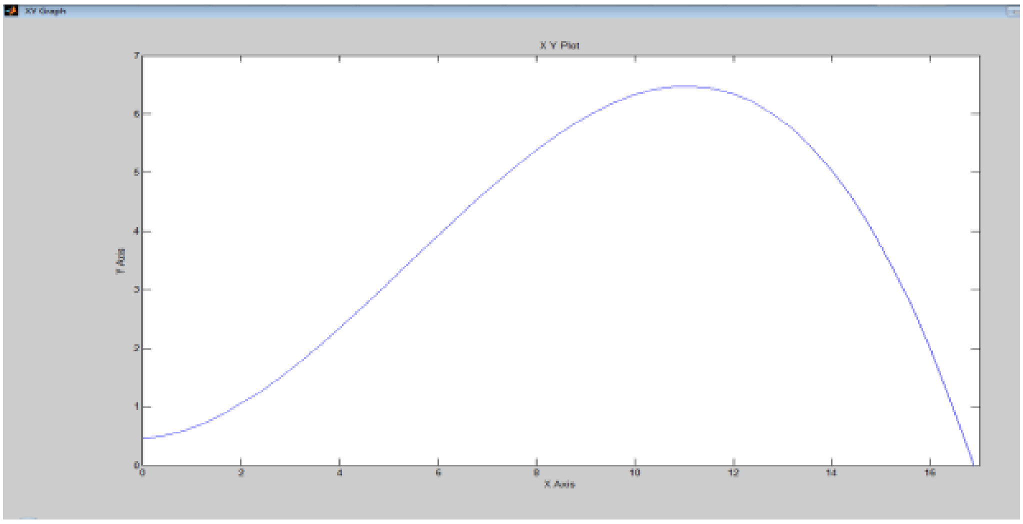

Figure 15. Simulated P-V curve

In that function it has a positive constant of 0.4477.That is why, the simulated P-V graph initially starts from the constant value as it seems in the curve. More accurate graph can be obtained by using the matfile. The graphs obtained for both I-V and P-V were already shown in figure 5 and fig.6 respectively [11].

Fig. 16 shows the simulated result of conventional P&O technique. From the upper curve of the fig.16 it is clear that the voltage starts rising from the initial 3 volts and then it reaches maximum voltage and also it shows the voltage at which the maximum power is reached in the lower curve.

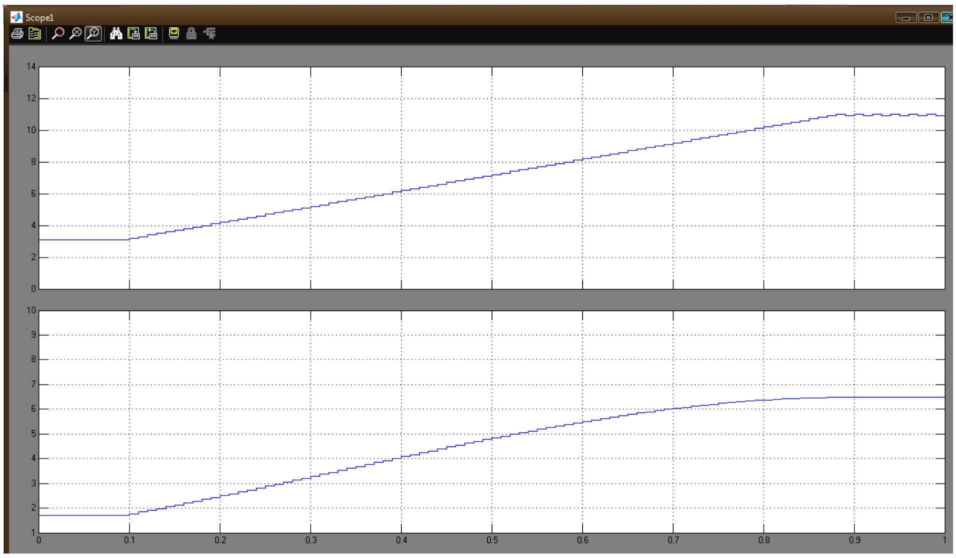

Figure 16. Simulated result of V_{mpp} and P_{mpp} by conventional P&O technique for starting 3 voltage.

Fig.17 shows the simulation result of V_{mpp} and P_{mpp} by Modified Perturb and Observe (using bisection method) technique.

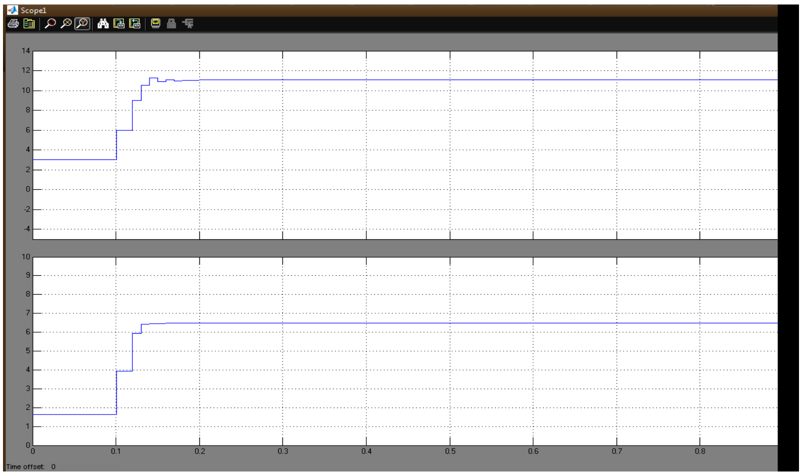

Figure 17. Simulated result of V_{mpp} and P_{mpp} by Modified P& O (using bisection method) technique for starting voltage of 3 volts

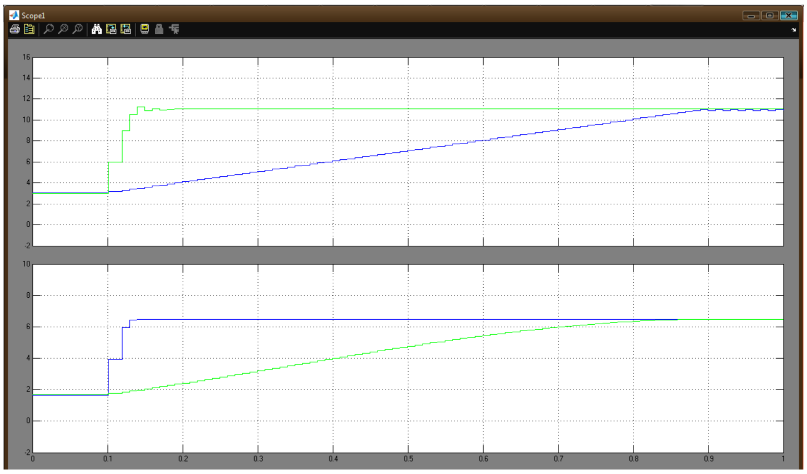

Figure 18. Simulation result of V_{mpp} & P_{mpp} of two methods for a starting voltage of 3 volts

Fig. 18 above shows the comparison of the two methods for reaching to V_{mpp} as well as to the P_{mpp}. In fig. 18 upper curve with blue color or the curve which is rising slowly is obtained for the conventional P&O method and graph with green color rising sharply to the voltage at which the power is maximum is obtained for the modified P&O technique. Comparison shows that the voltage at which the power is maximum reached by the modified P&O is faster than the convention P&O.
Also in the lower part of the graph, the curve with green color shows the maximum power reached by conventional P&O and the curve with blue color shows maximum power reached by the modified P&O technique. Comparison shows that modified P&O technique takes less time compared to the conventional P&O technique. In both the cases the graph is obtained for the starting voltage of 3 volts.

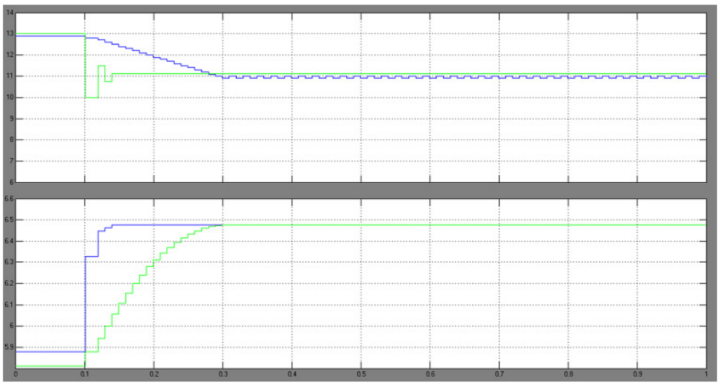

Figure 19. Simulation result of V_{mpp} & P_{mpp} of two methods for a starting voltage of 13 volts

The above fig. 19 shows the maximum voltage at which the power is maximum in the upper part of the figure as well as maximum power in the lower part for a starting voltage of 13 volts.

VIII. OBSERVATION OF THE WAVEFORMS

Here the result of the simulation has been studied for the conventional as well as for the developed P&O (by using bisection method) algorithm for different values of input voltages which has been considered as the variable in the system. From table I it is seen that the V_{mmp} is11.50volts and the maximum output voltage of the cell is 16.52Volts. So, for testing the algorithm for tracking MPP, simulation has been done for 3 volts as input variable to the function which is less than 11.50volts and another for 13 volts which is higher than 11.50 volts. In both the cases it is seen that the MPP is tracked much faster in the modified method compared to that of conventional P&O for 3volts and 13 volts as in fig.18 and fig.19 respectively.

IX. CONCLUSION

Different MPPT techniques has been studied for solar PV systems and then on the basis of conventional perturb and observe, a modified perturb and observe technique (by using bisection method) was developed which can track the maximum power much faster than the conventional perturb and observe method. Modeling & simulation of the complete system has been done using Matlab7.8 & simulation result shows the developed algorithm can track maximum power much faster than the conventional P&O algorithm.

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