Design and Analysis of P&O and IP&O MPPT Techniques for Photovoltaic System

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Abstract: *Photovoltaic (PV) energy is the most important energy resource since it is clean, pollution free, and inexhaustible. Due to rapid growth in the semiconductor and power electronics techniques, it is important to operate PV energy conversion systems near the maximum power point to increase the output efficiency of PV arrays. The output power of PV arrays is always changing with weather conditions, which mean solar irradiation and atmospheric temperature. Some MPPT techniques are available in that perturbation and observation (P&O) and improved perturbation and observation (IP&O). A P&O method is the most simple, which moves the operating point toward the maximum power point periodically increasing or decreasing the PV array voltage. It was proved that the P&O method control system sometimes deviates from the maximum operating point. When the MPP is reached, the P&O method will oscillate around it in case of constant or slowly varying atmospheric conditions. This problem can be solved to decrease the perturbation step; however, the tracking response will be slower. In case of rapidly changing atmospheric conditions, the P&O method can occasionally make the system operation point far from the MPP. Perturbation and observation (P&O) is that the operating point oscillates around the maximum power point (MPP).The improved P&O method is introduced, based on hysteresis band and auto-tuning perturbation step. There is trade-off between dynamic response and steady state due to the selection of "dv". The Improved perturbation and observation (IP&O) has the tracking response will be higher. IP&O method has rapidly changing atmospheric conditions then the unpredictable performance with oscillations around maximum power point (MPP). In IP&O has high reliability and it is very complexity. A Mat lab-Simulink based simulation study of PV cell/PV module/PV array is carried out and presented.*

Keywords: *Photovoltaic system, Modeling of PV arrays, Boost converter, perturbation and observation, improved perturbation and observation and Simulation Results.*

I. Introduction:

A photovoltaic system converts sunlight into electricity. The basic device of a photovoltaic system is the photovoltaic cell. Cells may be grouped to form panels or modules. Panels can be grouped to form large photovoltaic arrays. The term array is usually employed to describe a photovoltaic panel (with several cells connected in series and/or parallel) or a group of panels. The term array used henceforth means any photovoltaic device composed of several basic cells. The use of new efficient photovoltaic solar cells (PVSCs) has emerged as an alternative measure of renewable green power, energy conservation and demand-side management. The performance of a PV array system depends on the operating conditions as well as the solar cell and array design quality. The output voltage, current and power of PV array vary as functions of solar irradiation level, temperature and load current. Therefore the effects of these three quantities must be considered in the design of PV arrays so that any change in temperature and solar irradiation levels should not adversely affect the PV array output to the load/utility, which is either a power company utility grid or any stand alone electrical type load.

Perturbation and Observation (P&O) can track the Maximum Power Point (MPP) all the time, irrespective of the atmospheric conditions, type of PV panel, and even aging, by processing actual values of PV voltage and current. Since the cost of the required circuitry for implementing on-line MPPTs is higher, they are usually employed for larger PV arrays. P&O method is widely used in PV systems because of its simplicity and easy of implementation. However, it presents drawbacks such as slow response speed, oscillation around the MPP in steady state, and even tracking in wrong way under rapidly changing atmospheric conditions. To overcome the above drawbacks of P&O method, provided that the computation is carried out at very fast rates. They are usually based on the comparison of average values of 'i_{pv}' and 'v_{pv}' obtained from low-pass filters, which introduce delays, and on the control of the average value of either 'i_{pv}' or' v_{pv}' resulting in slow speeds of response. The proposes a new implementation of a P&O algorithm that mitigates the main drawbacks commonly related to the P&O Method.

An improved perturbation and observation method (IP&O) based on fixed algorithm is proposed, which is automatically adjusts the reference step size and hysteresis bandwidth for power comparison. The IP&0 increases the total PV output power by 0.5% at an unsettled weather condition compare to traditional perturbation and observation method (P&O). The Improved perturbation and observation (IP&O) has the tracking response will be higher. When IP&O method has rapidly changing atmospheric conditions then the unpredictable performance with oscillations around maximum power point (MPP). In IP&O has high reliability and it is very complexity The improved P&O method is introduced, based on hysteresis band and auto-tuning perturbation step. There is trade-off between dynamic response and steady state due to the selection of 'dv".

Organization of the paper is photovoltaic modelling, Equivalent electric circuit of Photovoltaic cell, Boost converter and Maximum power point tracking (MPPT) Techniques are Perturbation and Observation (P&O) in that

P&O with fixed Perturb, Improved Perturbation and Observation (IP&O) in that Improved P&O with fixed perturb, Simulation results, Comparison of P&O and IP&O curves and analytical comparison of P&O and IP&O curves.

II. Photovoltaic modeling

Equivalent Electric Circuit of Photovoltaic Cell:

A mathematical description of current voltage terminal characteristics for PV cells. The single exponential equation which models a PV cell is derived from the physics of the PN junction and is generally accepted as reflecting the characteristic behavior of the cell. A double exponential equation may be used for the polycrystalline silicon cells.

$$I = I_{ph} - I_s\left(\frac{\exp(q.(V+IR_S))}{N.K.T} - I\right) - \frac{(V+IR_S)}{R_{sh}} \quad (1)$$

A solar cell, which is basically a *p-n* semiconductor junction directly, converts light energy into electricity. PV cells are grouped in larger units called PV modules, which are further interconnected in a parallel-series configuration to form PV arrays or generators. The photovoltaic cell considered can be modeled mathematically using the following procedure:

Voltage output of a PV cell:

$$V_{pv} = \left[\frac{N_S AKT}{q}\right]\ln\left[\frac{N_P \times I_{ph} - I_{pv} + N_P \times I_O}{I_O}\right] - I_{PV} R_S \quad (2)$$

Current output of a PV cell:

$$I_{pv} = N_p \times I_{ph} - N_P \times I_o\left[\exp\left\{\frac{q \times (V_{pv} + I_{pv} R_s)}{N_s AKT}\right\} - 1\right] \quad (3)$$

$$I_{ph} = [I_{scr} + K_t(T - 298)] \times \frac{\lambda}{100}$$

(4)

$$I_o = I_{or}\left[\frac{T}{T_r}\right]^3 \exp\left[\frac{q \times E_{go}}{BK}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}\right] \quad (5)$$

The PV array power P can be calculated using the following equation:

$$P_{pv} = I_{PV} \times V_{PV}$$

$$P_{pv} = V_{pv} \times N_P \times I_{ph} - V_{pv} \times N_P \times I_o\left[\exp\left\{\frac{q \times (V_{pv} + I_{pv} R_s)}{N_S AKT}\right\} - 1\right] \quad (6)$$

Where,

V_{pv} Is output voltage of a PV cell (V)

I_{pv} Is output current of a PV cell (A)

N_s Is the number of modules connected in series

N_p Is the number of modules connected in parallel

I_{ph} is the light generated current in a PV cell (A)

I_o is the PV cell saturation current (A)
R_s is the series resistance of a PV cell
A=B is an ideality factor=1.6
K is Boltzmann constant=1.3805e-23Nm/K
T is the cell temperature in Kelvin=298K
Q is electron charge=1.6e-19Coulombs
T_r= The reference temperature=301.18k
I_{scr}= PV cell short-circuit current at 25°c and 100Mw/cm^2=3.27A
N= number of cells
K_i =The short-circuit current temperature co-efficient at I_{scr} =0.0017A/°C
R_{sh} = shunt resistance of a PV cell
I_s = saturation current
λ=is the PV cell illumination (MW/cm^2)=100Mw/cm^2
I_{or} =Saturation current at T_r=2.0793e^{-6}A
E_{go} = is the band gap for silicon=1.1eV

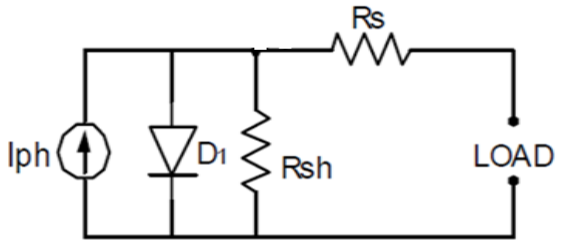

Figure1: PV Cell Circuit Model

The complete behavior of PV cells are described by five model parameters (I_{ph}, N, I_s, Rs, R_{sh}) which is representative of the physical behavior of PV cell/module. These five parameters of PV cell/module are in fact related to two environmental conditions of solar isolation & temperature. The determination of these model parameters is not straightforward owing to non-linear nature of equation.

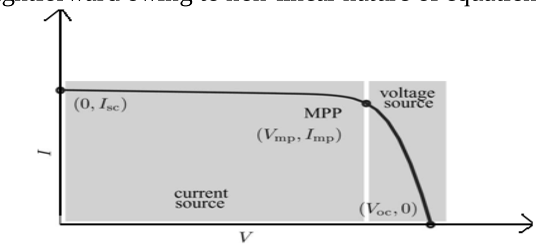

Figure 2: Maximum Power Point (V_{mp}, I_{mp})

Characteristic *I*–*V* curve of a practical PV device and the three remarkable points: short circuit (0, I_{sc}), MPP (V_{mp}, I_{mp}), and open circuit (V_{oc}, 0).

III. MPPT Techniques

A. Perturbation and Observation:

P&O algorithms are widely used in MPPT because of their simple structure and the few measured parameters which are required. They operate by periodically perturbing (i.e. incrementing or decrementing) the array termed voltage and comparing the PV output power with that of the previous perturbation cycle. If the power is increasing, the perturbation will continue in the same direction in the next cycle, otherwise the perturbation direction will be reversed. This means the array terminal voltage is perturbed every

MPPT cycle, therefore when the P&O is reached, the P&O algorithm will oscillate around it resulting in a loss of PV power, especially in cases of constant or slowly varying atmospheric conditions. This problem can be solved by improving the logic of the P&O algorithm to compare the parameters of two preceding cycles in order to check when the P&O is reached, and bypass the perturbation stage**.** Another way to reduce the power loss around the P&O is to decrease the perturbation step, however, the algorithm will be slow in following the P&O when the atmospheric conditions start to vary and more power will be lost.

The implementation of P&O type MPPTs with increased refresh rates of current (I)-requires two things. First, the P&O algorithm should operate with high sampling rates and the sample values of voltage and current should reflect the tendency of the output power when increasing or decreasing the reference signal for the MPPT power converter. Second, the response time of the MPPT power converter should be very fast while keeping the switching losses (frequency) low. This can be done by comparing instantaneous, instead of average, values of and V_{pv} and peak current control that presents one-cycle speed of response for small variations in the reference current, to further improve the performance of the system. The proposed MPPT system employs peak current control. The switch is turned on by a clock signal and turned off when the actual current reaches the reference current. Therefore, the reference current can be perturbed (increased or decreased) in every switching cycle, meaning that the perturbation cycle or refresh rate is equal to the switching cycle.

A.1 P&O With Fixed Perturb:

In this method, a fixed perturb value is utilized to generate a reference signal for the outer control loop. The Perturb signal is either the array reference voltage or current. The fixed perturb step is determined according to the system designer as a result of previous experience. Therefore, the solution provided by this method is not generic and system dependent. For small perturb steps, the tracking is slow but the power/voltage oscillations are minimal. In the case of large perturb step, faster tracking is achieved with increased oscillations. Hence, P&O techniques with fixed perturb suffer an inherent tracking–oscillations trade off problem. A PI/hysteresis Controller following the MPPT is utilized to control the power converter.

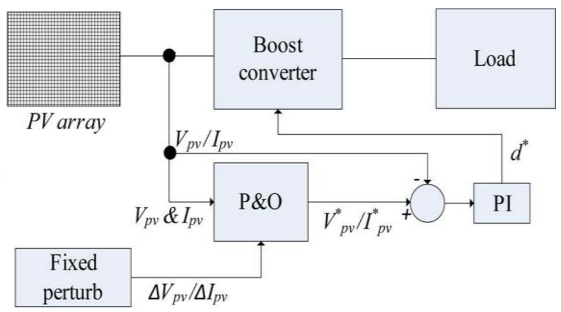

Fig.4 Fixed perturb with Perturbation and Observation

The size of the perturbation has to be chosen according to the inductor size and the switching (clock) frequency so that the switch always turns off before the next turn on signal. The perturbation and observation method (P&O), which moves the operation point of array toward the maximum power point (MPP) by periodically of any output voltage, is often used in many PV systems. It works well when the Irradiance changed very slowly, but the P&O method fails to track the MPP when irradiance changed suddenly by having slow dynamic response**.**

B. Improved Perturbation and Observation:

The improved perturbation and observation method (IP&O) is proposed. The IP&O method is implemented in a software program with fixed algorithm, which automatically adjusts the reference voltage step size and hysteresis band to achieve dynamic response and search exactly MPP under rapidly changing condition. The improved P&O method is introduced, based on hysteresis band and auto-tuning perturbation step. There is trade-off between dynamic response and steady state due to the selection of 'dv" the perturbation step. The system response of the IP&O method has faster dynamic response and higher induced-power than the Perturbation and Observation (P&O) method has. The overall Maximum Power Point (MPP) tracking efficiencies of Improved Perturbation and Observation (IP&O) method are also higher as around 0.5% in the unsettled weather condition than those of P&O method.

The number of samples per switching cycle, type (synchronized/ unsynchronized) and ideal instant for sampling (maximum and minimum current) are investigated in order to obtain fast calculation of the direction of the next perturbation. The Improved perturbation and observation was used to implement the proposed MPPT control system, which controls the dc/dc boost converter in the 3kW grid-connected PV power systems. The IP&O results shows that the increases total PV output power by 0.5% at an unsettled weather condition compare to traditional perturbation and observation.

The limitation of P&O methods is that they tend to mistrack the MPP under rapidly changing atmospheric conditions. During a transient it moves the operating point away from the MPP instead of towards it. This phenomenon shows how a faster IP&O implementation can reduce this problem. IP&O MPPT algorithms are based on the assumption of constant atmospheric conditions and that the variations in the output power are due to the injected perturbations. It compares values of p_{pv} and i_{pv} at are supposed to lie on the same curve. Problems arise when the two points are not on the same curve due to a sudden variation on the solar irradiation. Let's assume that the solar irradiation level is initially and then increases. Depending on the sampling frequency, the present values for P and I will be obtained from curves (high sampling rate)**.** The IP&O algorithm would be decrease *I*, driving the operating point towards the new MPP. However, for low sampling rates, would then be increased by the IP&O algorithm driving the operating point away from the new MPP. Therefore, operation with high sampling rates (small perturbation

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cycles) reduces the odds of wrong tracking the MPP during sudden solar irradiation variations.

B.1 Improved P&O With Fixed Perturb:

In this technique, instead of utilizing the array voltage or current as the perturbed signal, the converter duty ratio is used. This eases the control process as it eliminates the PI/hysteresis controller after the MPPT block, enabling direct control of the converter's duty cycle. The perturb step is fixed and designer dependent. Hence, the previously mentioned trade off problem still persists. In order to improve the performance of P&O techniques, the modified calculation of the perturb value is utilized instead of the fixed values. The Improved P&O techniques review are discussed in the following sections.

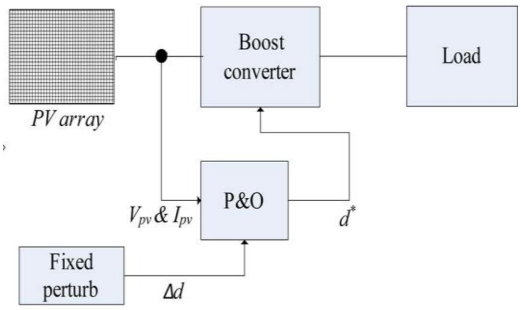

Fig5. Improved with fixed Perturbation and Observation

IV. Simulation Results

PV array Curves

The PV cell temperature is maintained constant at 25^{0}C and the solar intensity is varied in steps up to the rated value of 100mWcm^{-2}. It is seen from the figure .6 that for a constant solar intensity the current remains constant with increasing voltage up to 100Volts after which it decreases. It is further observed that the current increase with increasing intensity thereby increasing the power output of the solar cell.

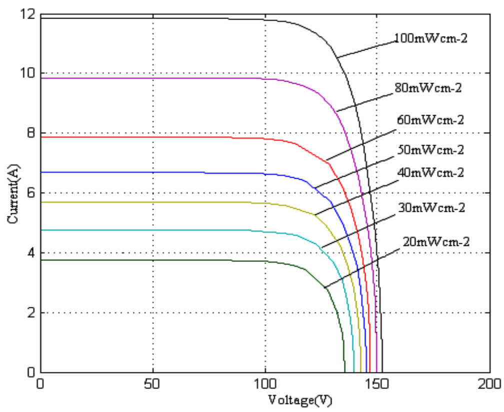

Figure6: V-I Curve with different irradiation

The PV cell temperature is maintained constant at 25^{0}C and the solar intensity is varied in steps up to the rated value of 100mWcm^{-2}. It is seen from the figure .7 that for a constant solar intensity the power remains constant with increasing voltage up to 100Volts after which it decreases.

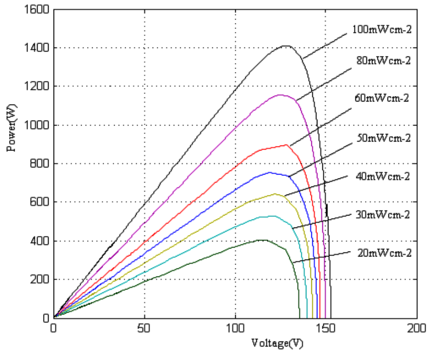

Figure7: P-V Curve with different irradiations

The effect of temperature variations on the V-I characteristics of the PV cell is shown in figure.8. A marginal variation in current is observed for a temperature variation from 25°C to 65°C for a voltage up to 65Volts. Above this value the current decreases in a sharp manner for small variation in voltage. It is further seen that the voltage of which the cell current becomes zero increases with decreasing temperature.

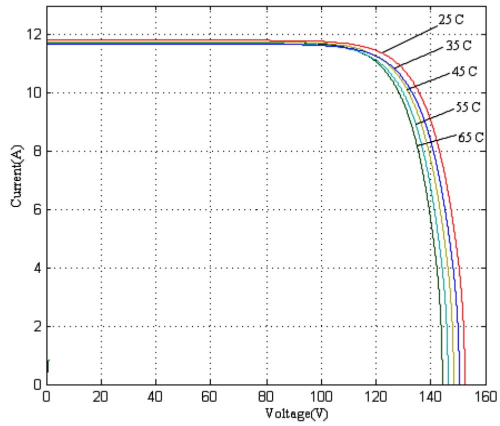

Figure8: V-I Curve with different temperature

The effect of temperature variations on the P-V characteristics of the PV cell is shown in figure 9.power variation is observed for a temperature variation from 25°C to 65°C for a voltage up to 65volts.the power decreases in a sharp manner for small variation in voltage.

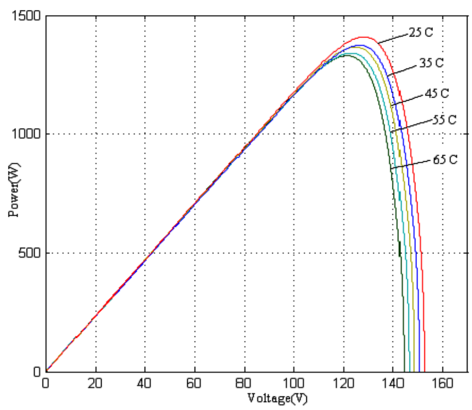

Figure9: P-V Curve with different Temperatures

Perurbation and Observation curves:

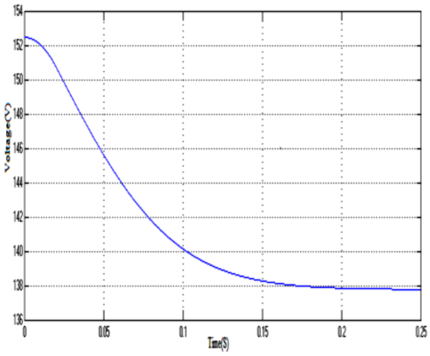

Fig 10(a): PV array output Voltage for P&O MPPT Technique

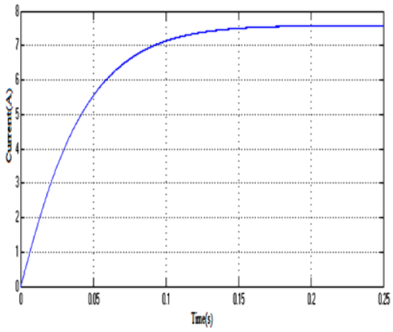

Fig 10(b): PV array output current for P&O MPPT Technique

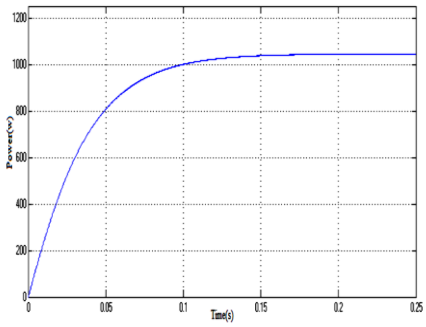

Fig 10(c): PV array output power for P&O MPPT Technique

From Fig10. The response with perturbation and observation (P&O) MPPT Technique waveforms are (a) PV array output voltage (b) PV array output current (c) PV array output power at temperature=25°c and solar irradiation =100mWcm-2.

Improved Perturbation and Observation curves:

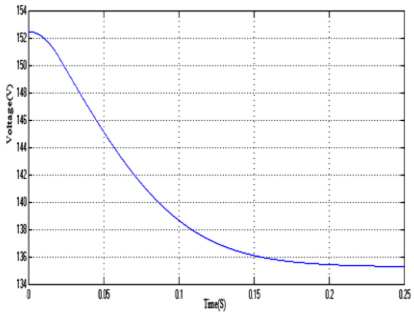

Fig 11(a): PV array output voltage for Improved P&O MPPT Technique

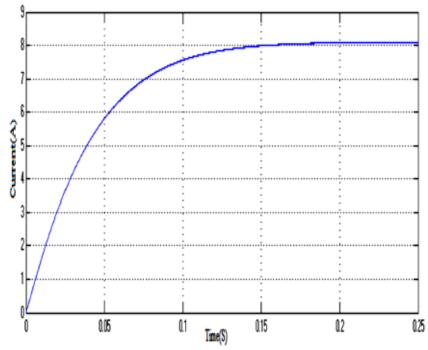

Fig 11(b): PV array output current for Improved P&O MPPT Technique

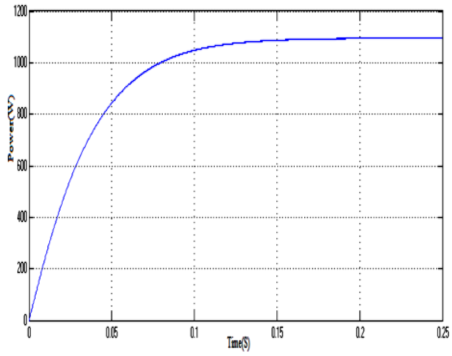

Fig 11(c): PV array output power for Improved P&O MPPT Technique

From Fig11. The response with Improved perturbation and observation (P&O) MPPT Technique waveforms are (a) PV array output voltage (b) PV array output current (c) PV array output power at temperature=25°c and solar irradiation =100mWcm-2.

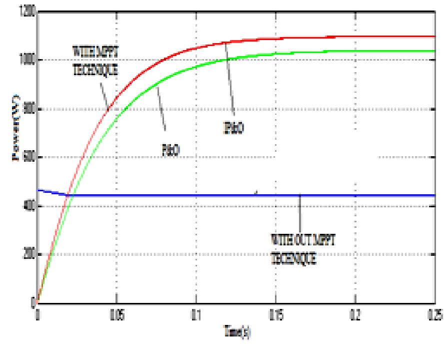

Fig12: Comparison of P&O and Improved P&O MPPT Technique power

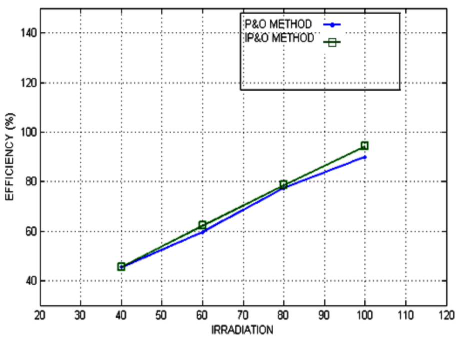

Fig13: Temperature constant and Irradiation vs. efficiency

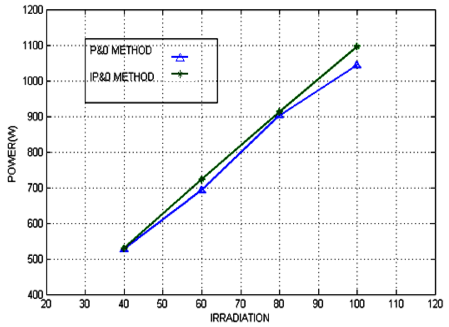

Fig14: Temperature constant and Irradiation vs. Power

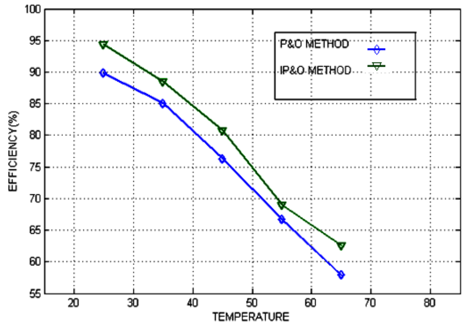

Fig15: Irradiation constant and Temperature vs. efficiency

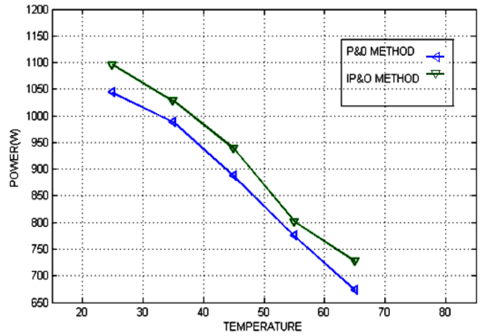

Fig16: Irradiation constant and Temperature vs. power

Table 1.Comparison of P&O and Improved P&O MPPT Techniques:

S.NO	MPPT TECHNIQUES	VOLTAGE (V)	CURRENT (A)	POWER (W)	EFFICIENCY (%)
1	PERTURBATION AND OBSERVATION	137.8	7.577	1044	90%
2	IMPROVED PERTURBATION AND OBSERVATION	135.2	8.104	1096	94.38%

Table2. Comparison of two MPPT methods:

Specifications	Perturbation and Observation	Improved Perturbation and Observation
Cost	Relatively lower	Moderately lower
Reliability	Accurate but oscillates around the MPP	Precise but oscillates around the MPP
Complexity	Easy but complex when site conditions vary	High
Realization	Easy to implement as few measured parameters	Difficult to implement as few measured parameters
Efficiency	High about 90%	High about 98%
Rapidly Changing Atmospheric conditions	Unpredictable performance with oscillations around MPP. slower response	Efficient performance with oscillations around MPP. Higher response

V. Conclusion

This paper proposes design of photo voltaic system, simple boost converter, perturbation and observation (P&O), improved perturbation and observation (IP&O). The PV cell output voltage varies with atmospheric parameters such as temperature and irradiation. By increasing series and parallel cells, voltage will be drop. The PV Array output voltage gradually decrease and then steady state conditions. PV array Cascaded with Boost converter is used to step up output voltage. Perturbation and observation (P&O) method is widely used in photovoltaic (PV) systems because of its simplicity and easily of implementation. A P&O method is the most simple, which moves the operating point towards the maximum power point. P&O method control system sometimes deviates from the maximum operating point. This paper proposes design of photo voltaic system, simple boost converter IP&O based on modified fixed algorithm is automatically adjusts the reference step size and hysteresis bandwidth for power conversion. The improved P&O method is based on auto-tuning perturbation. The Improved perturbation and observation (IP&O) has the tracking response will be higher. When IP&O method has rapidly changing atmospheric conditions then the unpredictable performance with oscillations around maximum power point (MPP). In IP&O has high reliability and it is very complexity. The advantage of improved perturbation and observation (IP&O). It finds the real MPP under any working conditions. No oscillation during tracking and steady state operations. Low computational burden required. Hence, fast tracking using low cost controller is achievable. Applications of Improved perturbation and observation (IP&O) are Impedance matching and Micro grid technology. In future, Advanced MPPT techniques are used like adaptive perturbation (AP&O), fuzzy logic controller and neural networks.

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