

Design and Investigation of Improved Perturb & Observe MPPT algorithm for Photovoltaic Systems

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Abstract: *As the use of energy is increasing, the requirements for the quality of the supplied electrical energy are more tighten. The conventional sources of energy are rapidly depleting and the cost of energy is rising, photovoltaic energy becomes a promising alternative source. Photovoltaic (PV) generation is becoming increasingly important as a renewable source since it exhibits a great many merits such as cleanness, little maintenance and no noise. However, the output power of PV arrays is always changing with weather conditions, i.e., solar irradiation and atmospheric temperature. Therefore, a Maximum Power Point Tracking (MPPT) control to extract maximum power from the PV arrays at real time becomes necessary in PV generation system. In recent years, a large number of techniques have been proposed for tracking the maximum power point (MPP). The present Perturb & Observe (P&O) MPPT algorithm is used in photovoltaic (PV) systems to maximize the photovoltaic array output power, irrespective of the temperature and irradiation conditions. However, the resulting system has poor-efficiency with fixed perturb. In this paper proposes, Improved Perturb & Observe algorithm (IP&O), system for PV arrays is proposed and analyzed. Improved Perturb & Observe algorithm (IP&O) is a very promising technique that allows the increase of efficiency with self-tuning perturb. This paper present in details comparison of most popular MPPT algorithms techniques which are Perturb & Observe algorithm (P&O) and Improved Perturb & Observe algorithm (IP&O).*

Key words: *Photovoltaic system, modeling of PV arrays, MPPT algorithm, DC-DC Boost converter and Simulation Results.*

1. Introduction

THE continuous growth of the global energy demand associated with society's increasing awareness of environmental impacts from the widespread utilization of fossil fuels has led to the exploration of renewable energy sources with the quick development of society, the rapid trend of industrialization of nations and increased interest in

environmental issues have recently to consideration of the use of renewable forms such as solar energy, wind energy, tidal energy and Bio-energy. As the world's energy demands rise and resources become limited, the search for alternative energy resources has become an important issue for our time. Very much exploitation and research for new power has been done not only in the area of nuclear power generation but also in the area of unlimited energy sources such as solar energy generation and wind energy transformation.

As conventional sources of energy are rapidly depleting and the cost of energy is rising, photovoltaic energy becomes a promising alternative source. Also, solar energy is the most readily available source of energy and it is free. Moreover, solar energy is the best among all the renewable energy sources since, it is non-polluting. Photo voltaic arrays are used in many applications such as water pumping, street lighting in rural town, battery charging and grid connected PV systems.

The proposed photovoltaic array simulation model to be used in Matlab/Simulink environment is developed. The model is using basic circuit equation of the photovoltaic solar cells including the effects of solar irradiation and temperature changes. The DC-DC converters which are, commonly referred to as inverter, have experienced great evolution in the last decade due to there wide use in uninterruptible power supplies and industrial applications. Usually a DC-DC converter performs the maximum power point tracking (MPPT) and also the DC-DC converter may operates with constant duty cycle and frequency.

Perturb and observe (P&O) techniques, although thoroughly investigated in previous research, still suffer from several disadvantages, such as sustained oscillation around the MPP, fast tracking versus oscillation tradeoffs, and user predefined constants. In this paper, a modified P&O MPPT technique, applicable for PV systems, is presented. The proposed technique achieves: first, adaptive tracking; second, no steady-state oscillations around the MPP and lastly, no need for predefined system-dependent constants.

2. Mathematical Modeling of PV Array

The PV receives energy from sun and converts the sun light into electrical DC power. The simplified equivalent circuit model is as shown in Fig.1. The PV cell output voltage is a function of mathematical equation of the photocurrent that mainly determined by load current depending on the solar irradiation level during the operation.

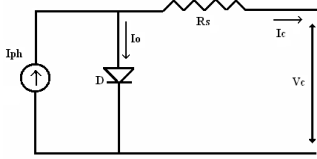


Fig.1 Simplified-equivalent circuit of photovoltaic cell

The equation (1) is,

$$V_{cx} = \frac{AKT_c}{q} \ln \left[\frac{I_{ph} + I_0 - I_c}{I_0} \right] - R_s I_c \quad (1)$$

Where the symbols are defined as follows:

- q: electron charge (1.602×10^{-19} C).
- k: Boltzmann constant (1.38×10^{-23} J/ $^{\circ}$ K).
- I_c : cell output current, A.
- I_{ph} : photocurrent, function of irradiation level and junction temperature (5 A).
- I_0 : reverse saturation current of diode (0.0002 A).
- R_s : series resistance of cell (0.001 Ω).
- T_c : reference cell operating temperature (25 $^{\circ}$ C).
- V_c : cell output voltage, V.

Both k and T_c should have the same temperature unit, either Kelvin or Celsius. A method to include these effects in the PV array modeling is given in [1]. These effects are represented in the model by the temperature coefficients C_{TV} and C_{TI} for cell output voltage and cell photocurrent, respectively, as in equation (2) and (3),

$$C_{TV} = 1 + \beta_T (\alpha_x - T_x) \quad (2)$$

$$C_{TI} = 1 + \frac{\gamma_t}{S_c} (\alpha_x - T_a) \quad (3)$$

Where, $\beta_T=0.004$ and $\gamma_T=0.06$ for the cell used and $T_a=20^{\circ}$ C is the ambient temperature during the cell testing. If the solar irradiation level increases from S_{X1} to S_{X2} , the cell operating temperature and the photocurrent will also increase from T_{X1} to T_{X2} and from I_{ph1} to I_{ph2} , respectively. C_{SV} and C_{SI} , which

are the correction factors for changes in cell output voltage V_c and photocurrent I_{ph} respectively in equation (4) and (5),

$$C_{SV} = 1 + \beta_T \alpha_s (\alpha_x - S_c) \quad (4)$$

$$C_{ST} = 1 + \frac{1}{S_c} (\alpha_x - S_c) \quad (5)$$

where S_c is the benchmark reference solar irradiation level during the cell testing to obtain the modified cell model. The temperature change, ΔT_c , occurs due to the change in the solar irradiation level and is obtained using in equation (6),

$$\Delta T_c = 1 + \alpha_s (\alpha_x - S_c) \quad (6)$$

The constant α_s represents the slope of the change in the cell operating temperature due to a change in the solar irradiation level [1] and is equal to 0.2 for the solar cells used. Using correction factors C_{TV} , C_{TI} , C_{SV} and C_{SI} , the new values of the cell output voltage V_{CX} and photocurrent I_{PHX} are obtained for the new temperature T_X and solar irradiation S_X as follows in equation (7) and (8),

$$V_{CX} = C_{TV} C_{SV} V_c \quad (7)$$

$$I_{ph} = C_{TI} C_{SI} I_{ph} \quad (8)$$

V_c and I_{PH} are the benchmark reference cell output voltage and reference cell photocurrent, respectively. The resulting I-V and P-V curves for various temperature and solar irradiation levels were discussed and shown in [3, 4, and 5]; therefore they are not going to be given here again. The output power from PV is the result from multiplying PV terminal voltage and PV output current are obtained from equation (9) and (10).

$$P_c = V_c \left(I_{ph} - I_a * \exp \left(\frac{q}{AKT} V_c - 1 \right) \right) \quad (9)$$

$$I_c = I_{ph} - I_0 * \exp \left(\frac{q}{AKT} V_c - 1 \right) \quad (10)$$

3. MPPT Algorithm for Photovoltaic System

The tracking algorithm works based on the fact that the derivative of the output power P with respect to the panel voltage V is equal to zero at the maximum power point as in Fig.2.

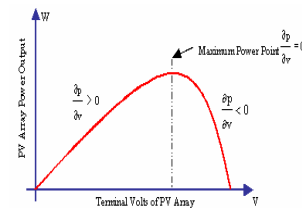


Fig. 2 P-V Characteristics of a module

The derivative is greater than zero to the left of the peak point and is less than zero to the right in (11), (12) & (13).

$$\frac{\partial P}{\partial V} = 0 \text{ for } V = V_{mp} \quad (11)$$

$$\frac{\partial P}{\partial V} > 0 \text{ for } V < V_{mp} \quad (12)$$

$$\frac{\partial P}{\partial V} < 0 \text{ for } V > V_{mp} \quad (13)$$

Various MPPT algorithms are available in order to improve the performance of PV system by effectively tracking the MPP. One of the most widely used MPPT algorithm is Perturb & Observe algorithm has been developed in this paper.

3.1 Perturb & Observe Algorithm

The most commonly used MPPT algorithm is P&O method and is also known as hill-climbing algorithm. The perturbation and observation method, which moves the operating point toward the maximum power point by periodically increasing or decreasing the array voltage, is often used in many photovoltaic systems. This technique employs simple feedback arrangement and few measured parameters. The P&O method is implemented in a software program with a self-tuning function, which automatically adjusts the array reference voltage and voltage step size to achieve the maximum power tracking under rapidly changing conditions. However, the resulting system have poor efficiency with fixed perturb. The block diagram of the P&O method is shown in Fig.3.

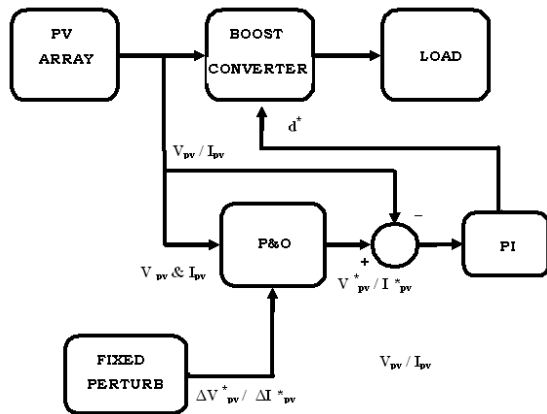


Fig.3 Block diagram of Photovoltaic system with P&O

Therefore, the perturbation and observation method was used in this paper to control the output current and voltage of the solar arrays.

3.2 Improved Perturb & Observe Algorithm

The conventional perturbation and observation (P&O) MPPT algorithm is impossible to quickly acquire the maximum power point (MPP), and the tracking course is very difficulty under changing weather conditions. To overcome the drawback, this paper has presents Improved Perturbation and Observation (IP&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'. As previously mentioned, 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. 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. For a given switching perturbation cycle, the larger the perturbation step the faster the PV current can be driven from an MPP (I_{MPP1}) to the next (I_{MPP2}) to a variation on the solar irradiation level. On the other hand, the magnitude of the intrinsic oscillations around the MPP in steady state would be larger, yielding a reduced average PV power conversion in steady state. Since low power converters can operate with frequencies of hundreds of kHz, a satisfactory trade-off between fast transient responses and steady state performance can be obtained with a small perturbation step size. The block diagram of IP&O method as shown in Fig.4.

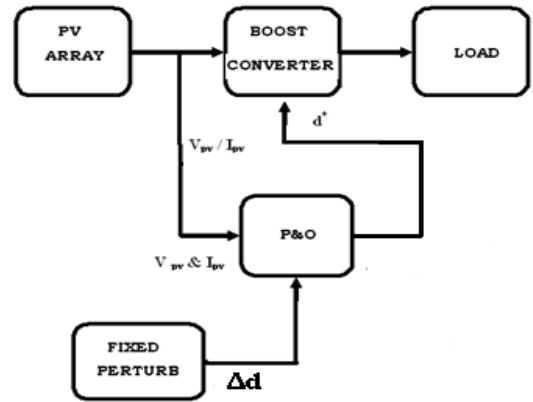


Fig.4 Block diagram of Improved Perturb & Observe MPPT

A calculate the correct direction of the next perturbation with only one instantaneous sample per switching cycle in the actual and previous cycles. Besides, the sampling instants can be arbitrary. This is valid when the instantaneous values of the current are always either below or above I_{MPP} , where ever, in steady state, when the operating point oscillates around the

MPP. The direction of the calculated perturbation can vary depending on the sampling instant used. The remainder of this section investigates the effect of the sampling instant on the power drawn from the PV array. The $p_x i$ curve of a PV array can be represented by three segments. In segment-I ($0 < i_{pv} < I_{mpp} - \Delta I$), the curve is approximated by a straight line with a small positive slope. In segment-II ($I_{mpp} - \Delta I < i_{pv} < I_{mpp} + \Delta I$), the curve is represented by a co-sinusoid centered at I_{mpp} . The curve is approximated by a straight line with a large negative slope. Operation in segment-III should be avoided since the output power decreases very fast with minor increases in the output current is discussed in Fig.5.

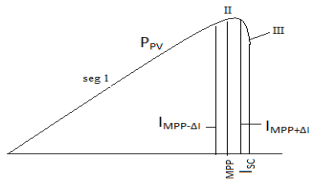


Fig.5 The I-P curve divided in three segments.

4. Result and Discussion

The mathematical model of an 1162W photovoltaic array is accurate implemented in the form of a current source controlled by voltage, sensible to two input variables, i.e., temperature and solar irradiation power. The solar array electrically equivalent circuit is based on the single-diode model of a photovoltaic cell. The PV array model simulates with parallel and series combinations. The characteristic I-V curves are shown in Fig 6(a) and 6(b). Likewise, the characteristic P-V curves are shown in Fig. 7(a) and 7(b).

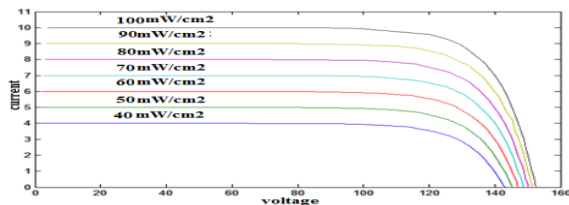


Fig.6 (a) I-V Characteristics of Solar Array for Various Irradiance at a constant Temperature of 25°C.

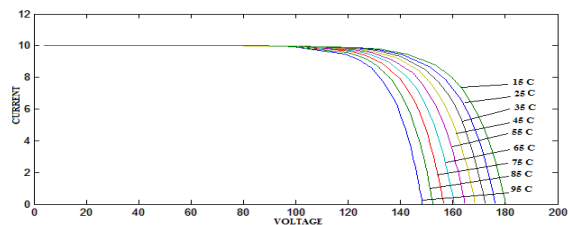


Fig. 6(b) I-V characteristics of PV array with various temperature at constant irradiation 100mW/cm²

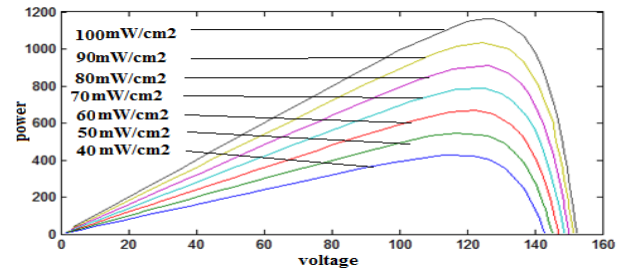


Fig. 7(a) P-V Characteristics of Solar Array with Various Irradiance at Temperature of 25°C.

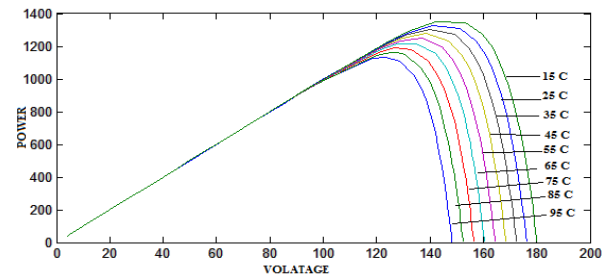
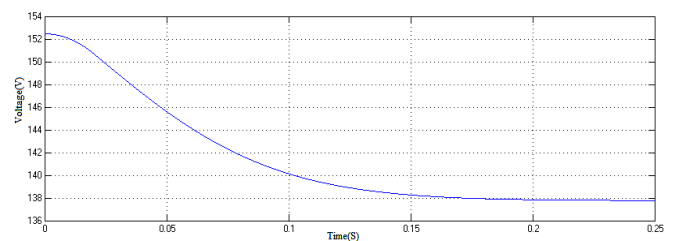
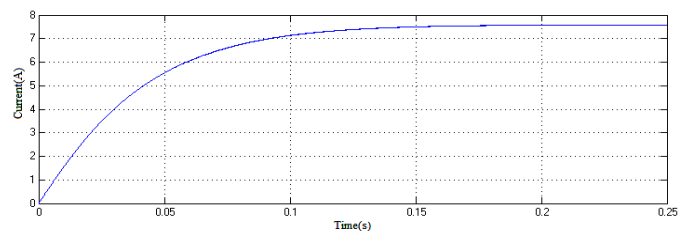


Fig. 7(b) P-V characteristics of PV array with various temperature at constant irradiation 100mW/cm².

The voltage, current and power of PV system without MPPT technique is 148.8V, 2.97A and 442.8W respectively. By using Perturb & Observe MPPT technique the power tracking can be improved from 37% to 90%, the output voltage, current and power of the PV array with Perturb & Observe maximum power point tracking (MPPT) technique is shown in Fig. 8. The voltage, current and power values are 137.8V, 7.577A and 1044W respectively.



(a)



(b)

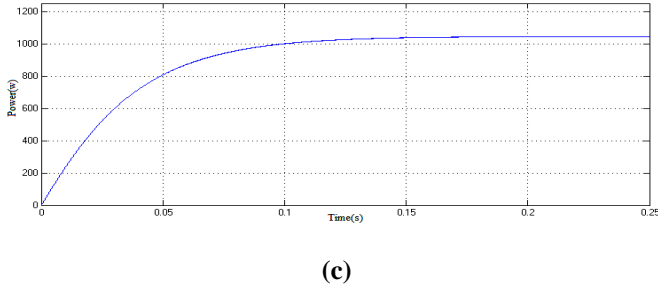
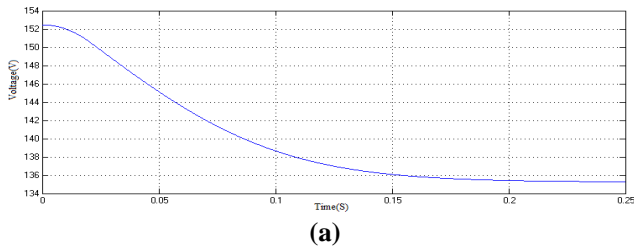
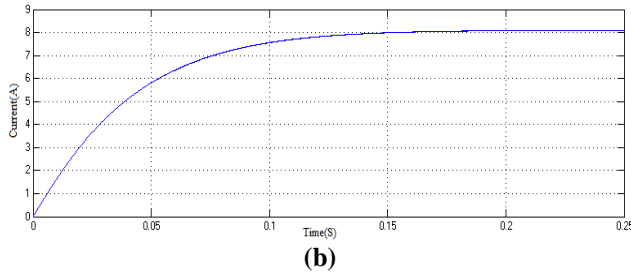


Fig. 8 (a) Output Current (b) Voltage and (c) Power with P&O MPPT technique.

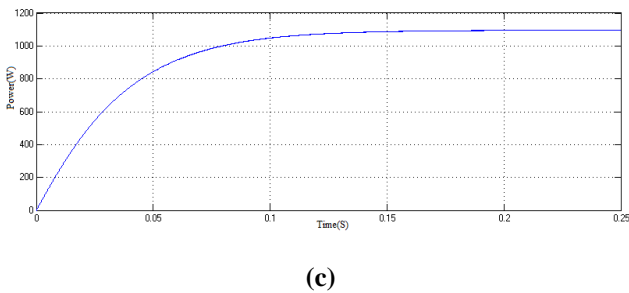
This Perturb & Observe method also has some disadvantages like Fail to track MPP when partially shaded or cells are damaged. These can be overcome by using a different MPPT technique that is improved perturb and observe (IP&O). By using this MPPT technique the output results are shown in Fig.9. The voltage, current and power values are 142.3V, 7.7A and 1096W respectively. From the Fig.10 shows that comparison of output power with and without MPPT techniques.



(a)



(b)



(c)

Fig. 9 (a) Output Current (b) Voltage and (c) Power with IP&O MPPT technique.

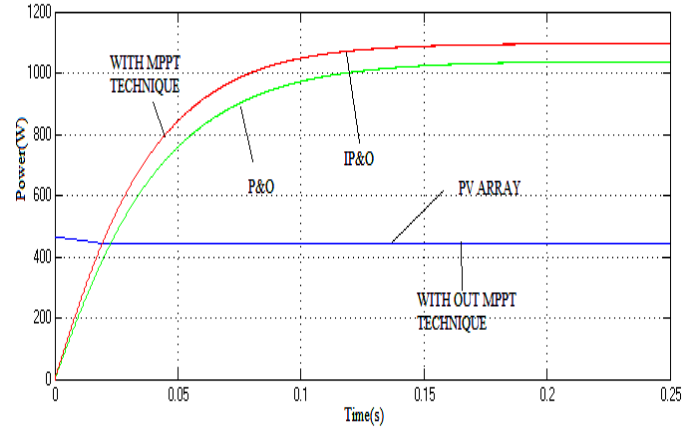


Fig. 10 Comparison of output power with and without MPPT techniques.

From the Table 1, it can be concluded that the power availability with various irradiance at constant temperature (25°C), it can be found that the IP&O method has gives higher power than P&O method. It is concluded that the proposed IP&O control strategy performed well than P&O control. The corresponding analytic waveform as shown in Fig.11.

Table.1

Analytic Evaluation of Output Power with Various Solar Irradiance at Constant Temperature.

Irradiance (W/Cm ²)	Power Availability (Watts)	
	P & O	IP & O
400	429.8	527
600	666.8	692.2
800	902.9	912.5
1000	1044	1096

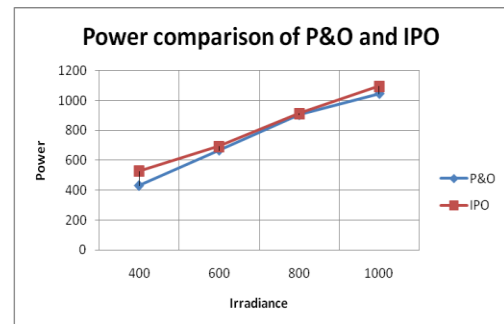


Fig.11 Power comparison of P&O and IP&O constant temperature 25°C at various irradiance.

From the Table 2, it can be concluded that the IP&O method has gives higher efficiency than P&O method. From

the analytic evaluation shows that the proposed IP&O control strategy gives well performance than P&O control. From the Fig. 12, it can be found that IP&O method has capability to tracked more power and efficiency than P&O at different temperature with constant irradiance (100mW/cm²).

Table.2

Analytic Evaluation of Output Efficiency with Various Solar Irradiance at Constant Temperature.

Irradiance (W/Cm ²)	Efficiency (%)	
	P & O	IP & O
400	36.98	45.35
600	57.38	59.56
800	77.72	79.52
1000	89.84	94.32

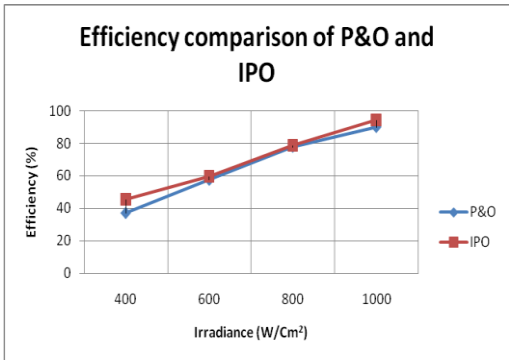


Fig.12 Efficiency comparison of P&O and IP&O constant temperature 25°C at various irradiance.

Similarly, from the Table 3, it can be concluded that the power is reduced by increasing of temperature. It can be observed that IP&O method has capability to tracked more power and efficiency than P&O at different temperature with constant irradiance.

Table.3

Analytic Evaluation of Output Power with Various Solar Temperatures at Constant Irradiance.

Temperature (°C)	Power Availability (Watts)	
	P&O	IP&O
25	1044	1096
35	982.4	988.1
45	827	886
55	721.3	775

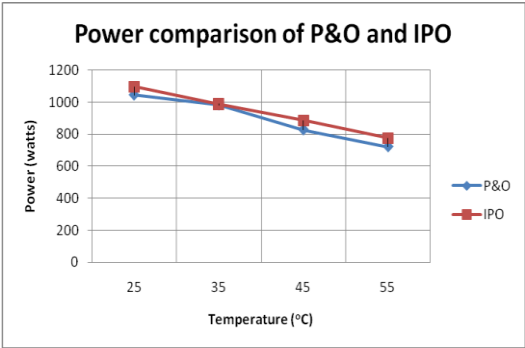


Fig.13 Power comparison of P&O and IP&O with various temperatures at constant irradiance.

Likewise, from the Table 4, it can be concluded that the efficiency is reduced by increasing of temperature. It can be observed that IP&O method has capability to tracked more power and efficiency than P&O at different temperature with constant irradiance. The corresponding waveform has discussed in Fig.13 and 14.

Table.4

Analytic Evaluation of Output Efficiency with Various Solar Temperatures at Constant Irradiance.

Temperature (°C)	Efficiency (%)	
	P&O	IP&O
25	89.84	94.32
35	84.54	85.03
45	71.70	76.24
55	62.64	66.69

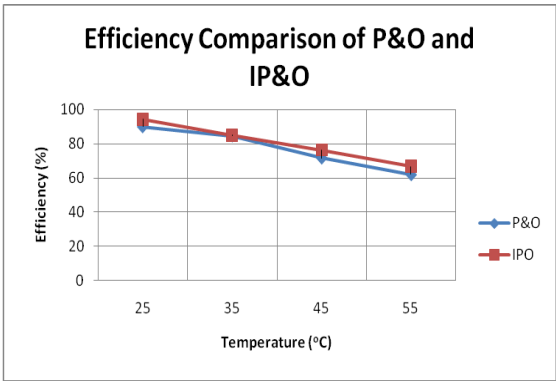


Fig.14 Efficiency comparison of P&O and IP&O with various temperatures at constant irradiance.

5. Conclusion

In order to obtain the maximum power point of PV generate systems it is important to choose an efficient MPPT algorithms. One of the prominent MPPT is Perturbation and Observation method is relatively simple and easily to realized with simulation as well as implementation. P&O method has dramatic fast tracking capability, however it perform poor efficiency due to the nonflexible of environmental conditions and fixed perturb step size. To overcome this drawback, in this paper has proposed improved perturbation and observation control algorithm based on power as a control variable in this method. The behavior of an IP&O MPPT has performed in the DC-DC boost converter stage. As a result, a better response for the system under rapid atmospheric variations can be obtained by increasing the execution speed and also its gives significant high efficiency about 94.32% than P&O is 89.84%. Moreover, the IP&O is automatically adjusts the reference step size with hysteresis bandwidth for power conversion. In addition, no oscillation during tracking and steady state operations. The correctness and validity of MPPT method is verified through simulation under various weather conditions.

REFERENCES

- [1] I.H. Altas; A.M. Sharaf, "A Photo voltaic Array Simulation Model for Matlab-simulink GUI Environment". IEEE- 2007.
- [2] Chihchiang Hua and Chihming Shen, "Study of Maximum Power Tracking Techniques and Control Dc/Ac Converters for Photovoltaic Power System", IEEE transactions 1998
- [3] S. Meenakshi, K. Rajambal, C.Chellamuthu, and S. Elangovan, "Intelligent Controller for a Stand-Alone Hybrid Generation System", IEEE proceedings 2006
- [4] J Surya Kumari, Ch Sai Babu et.al, "An Enhancement of Static Performance of Multilevel Inverter for Single Phase Grid Connected Photovoltaic modules", International journal of Recent Trends in Engineering, Academy Publishers, Finland, Vol. 3, No. 3, May 2010, pp.20-24.
- [5] J Surya Kumari, Ch Sai Babu et.al, " Design and Investigation of Short Circuit Current Based Maximum Power Point Tracking for Photovoltaic System" International Journal of Research and Reviews in Electrical and Computer Engineering (IJRRECE) Vol. 1, No. 2, June 2011 ISSN: 2046-5149
- [6] J Surya Kumari, Ch Sai Babu et.al, Mathematical Model of Photovoltaic System with Maximum Power Point Tracking (MPPT) International Conference on Advances in Engineering and Technology, (ICAET-2011), May 27-28, 2011.
- [7]Yen-Jung Mark Tung, Dr. Aiguo Patrick Hu and Dr. Nirmal- Kumar Nair, "Evaluation of Micro Controller Based Maximum Power Point Tracking Methods Using space Platform", Australian university power engineering conference 2006
- [8]Mohamed Azab, "A New Maximum Power Point Tracking for Photovoltaic Systems", proceedings of world academy of science, engineering and technology, October 2008.
- [9] A. Yafaoui, B.Wu and R.Cheung, "Implementation of Maximum Power Point Tracking Algorithm for Residential Photovoltaic Systems" 2nd Canadian solar buildings conference Calgary, June 10-14, 2007.
- [10] Roberto Faranda, Sonia Leva, "Energy Comparison of MPPT Techniques for PV Systems", Wseas transactions of power systems, June 2008
- [11] K.H. Hussein, I.Muta, T.Hoshino, M.Osakada, "Maximum Photovoltaic Power Tracking: And Algorithm for Rapidly Changing Atmospheric Conditions" IEEE Proc-Generation, Transmission, Distribution, vol.142, No.1, January 1995
- [12] Yeibg-Chau Kuo, Tsornf-Juu Liang, Jiann-Fuh chen, " Novel Maximum- Power-Point-Tracking Controller for Photovoltaic Energy Conversion System" IEEE Transactions on industrial electronics, vol.48, NO.3, June 2001
- [13]Weidong Xiao, Nathan ozog, William G.Dujford, "Topology Study of Photovoltaic Interface for Maximum Power Point Tracking" IEEE transactions on industrial electronics, vol.54, NO.3, June 2007
- [14] M.Salhi, R.El-Bachtiri, "Maximum Power Point Tracking Controller For PV Systems Using A Pi Regulator With Boost Dc/Dc Converter" ICGST-ACSE journal, vol.8, Issue III, January 2009
- [15] S.Jain and V.Agarwal, "Comparison of the Performance Of Maximum Power Point Tracking Schemes Applied To Single Stage Grid Connected Photovoltaic Systems", IET Electr. Power Appl, 2007, 753-762
- [16] Jawad Ahmad and Hee-Jun Kim, " A Voltage Based Maximum Power Point Tracker for Low Power and Low Cost Photovoltaic Applications" world academy of science, engineering and Technology 60 2009
- [17] Nicola Femia, Giovanni Petrone, Giovanni Spagnuolo and Massimo Vitelli, "A Technique for improving P&O MPPT Performances of double-stage grid connected photovoltaic systems",IEEE transactions on industrial electronics, vol.56,no.11, november2009.
- [18] Eduardo Román, Ricardo Alonso, Pedro Ibañez, Sabino Elorduizapatarietxe, and Damián Goitia, " Intelligent PV Module for Grid-Connected PV Systems", IEEE transactions on industrial electronics, vol. 53, no. 4, august 2006
- [19] Yang Haizhu, Liu Jie, "simulation study of MPPT strategy of photovoltaic grid connected generation system based on single parameter control",2010 International conference on computing , control and industrial engineering.
- [20]Mahrous E. Ahmed, Mostafa Mousa and Mohamed Orabi, "Development of High Gain and Efficiency Photovoltaic System Using Multilevel Boost Converter Topology" 2010

2nd IEEE International Symposium on Power Electronics
for Distributed Generation Systems.