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Improvement in Perturb and Observe Method Using State Flow Approach

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Abstract

This paper proposed a novel perturb and observe (P&O) method to track the maximum power point (MPP) of photovoltaic system without oscillating around it using stateflow as its control tool. The state flow approach was used to study the influence of variable and rapidly changing in irradiance and temperature conditions concerning the performance of the photovoltaic system. The simulation results were presented to validate that the improved (P&O) approach has better steady state performance than the traditional one under various conditions which improves the efficiency of the PV system. The algorithm structure was built using MATLAB Simulink software.

Keywords- Hybrid Photovoltaic (PV); Maximum Power Point (MPP); Maximum Power Point Tracking (MMPT); Perturb and Observe (P&O); Stateflow.

1. Introduction

Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and bio-fuels and hydrogen derived from renewable resources. Renewable energy resources and significant opportunities for energy efficiency exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. Rapid deployment of renewable energy and energy efficiency, and technological diversification of energy sources, would result in significant energy security and economic benefits [1].

Among those renewable energy resources, solar energy is most important and interesting source as it is inexhaustible, noiseless and non-polluting. The use of this source to produce electricity means the use of the photovoltaic (PV) arrays which is the device that converts the solar energy or light into electrical

energy or voltage and current. A good profitability of the PV can be carried out if it works with the maximum available power all the time. However, this maximum power point (MPP) changes according to several conditions such as variation in the irradiance of sunlight and atmospheric temperature, for that reason photovoltaic systems normally combined with maximum power point tracking (MMPT) techniques to continuously track the maximum possible power.

2. PV Modelling and MPPT Approaches

The modeling of PV (photovoltaic) systems is very crucial for embedded power system applications and maximum power point tracking. PV cell is considered the fundamental power conversion unit of a PV-based power system [2]. Solar irradiance, temperature, and output voltage of the PV are the essential factors that affect the output characteristics of a PV cell. The principle of operation of a PV cell is based on the photoelectric effect. Which defined as a phenomenon in which an electron gets ejected from the conduction band as a consequence of the absorption of sunlight of a certain wavelength by a material either metallic, non-metallic, solids, liquids or gases [3-6].

The simplest equivalent circuit of a PV cell is shown in Figure1 [7] and the characteristic equation describing the photovoltaic cell is in Equation 1 [8]. The series resistance R_s represents the internal losses due to the current flow. Shunt resistance $R_{sh,}$ in parallel with diode, this corresponds to the leakage current to the ground. Since the PV has a nonlinear current-voltage (*I-V*) and power-voltage (*P-V*) characteristics as it is clear in Figure 2 with different irradiance and temperatures, it is vital to model the PV unit with MPPT (maximum power point tracking) in PV-based power systems.
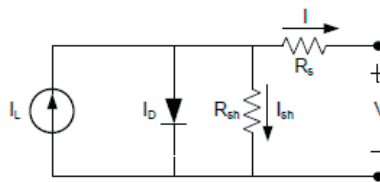

Figure 1: Equivalent Circuit of Solar Cell.

$$I = I_L - I_o \left[exp^{V/AV_t} \right] - \frac{V + IR_s}{R_{sh}} \qquad (1)$$

Where, I_L is photocurrent, I_o is the reverse saturation current, V is the diode voltage or the terminal voltage, V_t is the thermal voltage which is 27.5mV at 25℃ it is calculated as in Equation 2 and A is the diode ideality factor usually between 1 and 2.

$$V_t = \frac{kT}{q} \qquad (2)$$

As, k is the Boltzmann constant 1.38×10^{-23} J/K, q is an electron charge 1.6×10^{-19} C and T is the PV cell temperature in Kelvin and described as Eq. 3

$$T = 3.12 + \frac{0.25G}{G_{ref}} + 0.899T_a - 1.3W_s + 273 \qquad (3)$$

Where, G is the irradiance intensity, G_{ref} is the reference irradiance intensity at 1000W/m², T_a is the ambient temperature and W_s is local wind speed. While the I_L and I_{SC} in Equation 1 is a function of the

irradiance intensity and the cell temperature and the band-gab energy E_g of the cell as Equation 4 and Equation 5 describe respectively.

$$I_L = \frac{G}{G_{ref}}\left[I_{SC,ref} + \mu_{I_{SC}}\left(T - T_{ref}\right)\right] \qquad (4)$$

Where, $I_{SC,ref}$ is the cell short-circuit current at reference conditions G_{ref} and T_{ref} equal to 25 ℃ and $\mu_{I_{SC}}$ is the cell short-circuit temperature coefficient 0.95×10^{-3}

$$I_0 = I_{o,ref}\left(\frac{T}{T_{ref}}\right)^{\frac{3}{A}} \exp\left[{}^{qE_g\left(1/T_{ref} - 1/T\right)} /_{kA}\right] \qquad (5)$$

Where $I_{o,ref}$ is explained in Equation 6 as function of open-circuit voltage and short-circuit current at reference conditions $V_{oc,ref}$.

$$I_{o,ref} = {}^{I_{SC,ref}} /_{\left[\exp\left(\frac{V+IR_S}{AV_t}\right) - 1\right]} \qquad (6)$$

One of the more complete analyses of MPPT techniques is given in [9] in which a comparison between different techniques is explained. These techniques are Constant Voltage, Open Circuit Voltage, Short Circuit Current, Perturb and Observe (P&O), Incremental Conductance and Temperature methods but the Perturb and Observe and Incremental Conductance are widely used in practice due to its simplicity and in [10] there is a comparison between Perturb & Observe and Incremental Conductance algorithms.
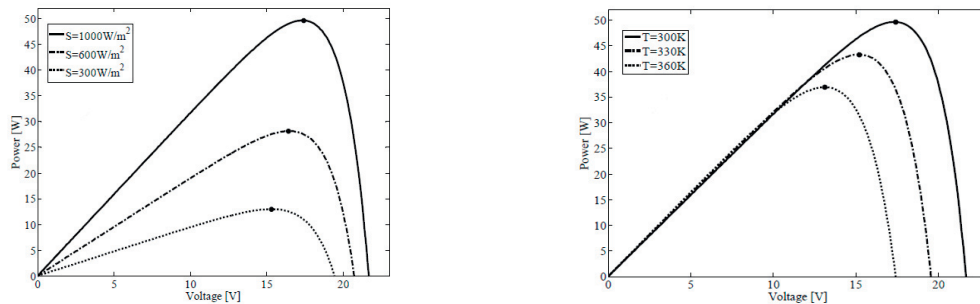

Figure 2: V-P curve for three different irradiance levels & temperatures with MPP of each.

The incremental conductance algorithm is derived by differentiating the PV array power with respect to voltage and setting the result equal to zero as shown in Equation 7.

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} = 0 \; at \; the \; MPP \qquad (7)$$

If the operating point is off of the MPP, it means that Equation 7 is not equal to zero that indicates whether the operating voltage is above or below the MPP voltage. And it began to either increase or decrease the voltage until the MPP is reached, once it continue to operate at this point until a change in

current is measured. This change in current will correlate with a change in irradiance on the array. As shown in Figure 3, as the irradiance on the array increases, the MPP moves to the right with respect to the array voltage. To compensate for this movement of the MPP, the MPPT must increase the array operating voltage. The opposite is true when a decrease in irradiance is detected (via a decrease in the measured current). This method is fully detailed in [11].
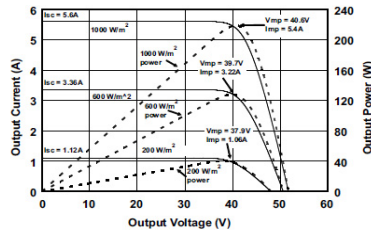

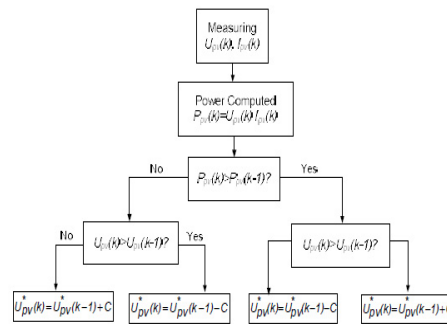Figure 3: Photovoltaic array current-voltage and power–voltage relationship

Figure 4: Flowchart of P&O method for MPPT

However, the P&O algorithms operate by incrementing or decrementing the array terminal voltage or current periodically and comparing the PV output power with that of the previous perturbation cycle as noticed in the flow chart in Figure 4. If the PV array operating voltage changes and power increases ($dP/dV>0$), the control system moves the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way. But the common problem in P&O algorithm is that, when the MPP is reached the output power oscillates around the maximum due to that the array terminal voltage is perturbed every MPPT cycle causing power loss in the PV system. This is especially true in constant or slowly-varying atmospheric conditions. In addition, this method can fail under rapidly changing atmospheric conditions as described in Figure 5 [12-13]. But The study in [14] shows even the mathematical modeling of large n-dimensional PV system in which the central controller tracks the MPP for all the PV arrays,
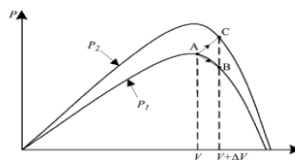

Figure 5: Divergence of P&O from MPP

Starting from an operating point A, if atmospheric conditions stay approximately constant, a perturbation ΔV the voltage V will bring the operating point to B and the perturbation will be reversed due to a decrease in power. However, if the irradiance increases and shifts the power curve from $P1$ to $P2$ within one sampling period, the operating point will move from A to C. This represents an increase in power and the perturbation is kept the same. Consequently, the operating point diverges from the MPP and will keep diverging if the irradiance steadily increases.

Herein, lays a primary advantage of incremental conductance over the perturb-and-observe algorithm: incremental conductance can actually calculate the direction in which to perturb the array's operating point to reach the MPP, and can determine when it has actually reached the MPP. Thus, under rapidly changing conditions, it should not track in the wrong direction, as P&O can, and it should not oscillate about the MPP once it reaches its [15]. While in [16] the main difference of the proposed system to existing MPPT systems includes elimination of the proportional-integral control loop and investigation of the effect of simplifying the control circuit.

As this paper represents a solution to all these problems of (P&O) algorithm using state flow for applying it in a simple and reliable way. State flow is a part of the Simulink/Matlab library as it can communicate also with m.files. it has a lot of powerful features that give it the ability to be a good controller.

3. State Flow

Stateflow is a graphical design and development tool that can be used in logic problems and complex control, it is easy to create and consider various scenarios, then iterate until it models the desired behaviour and above all these it brings system specifications and design closer together. State flow has different uses such as embedded systems, man machine interface and hybrid systems. Beside the different options of design as:

- Use Stateflow with Simulink for simulation.
- Use Stateflow, Stateflow Coder, Simulink, and Real-Time Workshop to generate target code for the complete model.
- Use Stateflow and Stateflow Coder to generate target code for a machine.

Stateflow uses a variant of the finite state (FSM) which is a representation of an event-driven (reactive) system. Where, the system transitions from one state (mode) to another prescribed state, provided that the condition defining the change is true. Traditionally, designers used truth tables to represent relationships between the inputs, outputs, and states of an FSM. The resulting table describes the logic necessary to control the behavior of the system. Another approach is to model the behavior of the system by describing it in terms of transitions among states under certain conditions [17].

Using Stateflow, means creating Stateflow diagrams, that is a graphical representation of a finite state machine where *states* and *transitions* form the basic building blocks of the system. Additionally, Stateflow enables the representation of hierarchy (able to organize complex systems by defining a parent/offspring object structure.), parallelism (can have two or more orthogonal states active at the same time), and history (provides an efficient means of basing future activity on past activity).

A state describes a model of a reactive system. Where its activity or inactivity dynamically changes based on events and conditions. Stateflow provides two types of states: parallel (AND) and exclusive (OR) states. AND (parallel) states represent the parallelism. Exclusive (OR) states are used to describe

modes that are mutually exclusive. All sub states of super states must be of the same type either AND or OR.

Every state has a parent. In a Stateflow diagram consisting of a single state, that state's parent is the Stateflow diagram itself (also called the Stateflow diagram root). But if states are placed within other higher-level state, these states are children in the hierarchy to the higher-level state (Super State). A state also has a history and labels that can specify actions executed in a sequence based upon action type. The action types are entry, during, exit, and on.

A state is characterized by its label in this general form as shown in Figure 6. An ***entry*** action is executed as a result of any transition into the state. The state is marked active before its entry action is executed and completed. A ***during*** action executes to completion when that state is active and an event occurs that does not result in an exit from that state. An ***on event_name*** action executes to completion when the event specified, (***event_name)***, occurs and that state is active. An active state executes its ***during*** and ***on event_name*** actions before processing any of its children's valid transitions. ***During*** and **on** ***event_name*** actions are processed based on their order of appearance in the state label. An ***exit*** action is executed as a result of any transition out of the state. The state is marked inactive after the exit action has executed and completed.

```
Power_on/
entry: ent_action();
during: dur_action();
exit: exit_action();
on Switch_off: on_action();
```
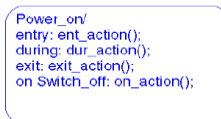
Figure 6: General State Characteristics

The transition is a graphical object that links one state to another, that has a source and destination thus any actions associated with the source or destination are related to the transition that joins them and it has a general form as;

event [condition]{condition action}/transition action

where, ***event*** causes the transition to be evaluated, ***condition*** defines what, if anything have to be true for the condition action and the transition to take place, ***condition action*** if the condition is true the action specified executes and completes and ***transition action*** it executes after the source state for the transition is excited but before the destination state is entered. As each part of the transition is an option depending on the desired scenario. The transition has different types such as; Self Loop transition, Inner State transition, To & From Exclusive States, To & From Exclusive Super States and To & From Junctions.

This paper uses the power of stateflow to implement the perturb and observe (P&O) algorithm applied to track the MPP for a photovoltaic cell under varying dynamic conditions.

4. Proposed Algorithm & Application Result

The objective of this paper is to use the power of state flow to implement perturb and observe (P&O) algorithm applied to track the MPP for a photovoltaic cell under varying dynamic conditions as shown in Figure 7.
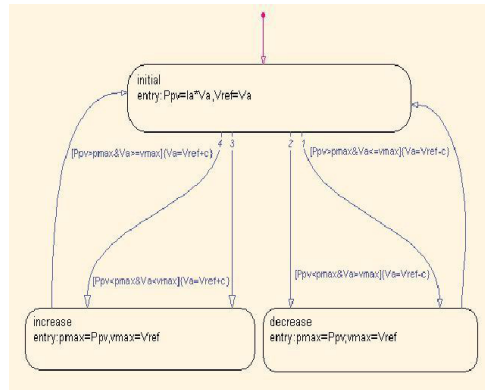
Figure 7: General State Characteristics

In addition to applying it for getting the same results of the P&O technique, it also succeeds in representing an improved approach for the P&O technique preventing its disadvantages in reaching the MPP without oscillating around it with the same simplicity but more reliable. Both approaches are applied to a photovoltaic cell and are implemented in MatLab/Simulink software as shown in Figure 8.
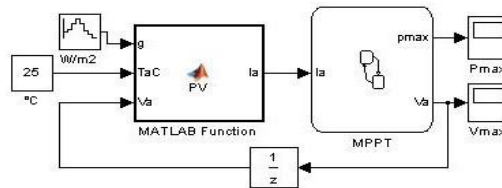

Figure 8: PV model with MPPT using State flow

The results show the comparison between the normal P&O technique and the improved one in four cases:

        a-   Constant Temperature and Irradiance

        b-   Constant Temperature , Variable Irradiance

        c-   Constant Irradiance , Variable Temperature

        d-   Variable Irradiance and Temperature

In the first case: Temperature is kept constant at 25 °C and irradiance of 1000 W/m^2 and the result for both approaches are shown in figures 9, 10. As Figure 9 show the maximum power and its maximum voltage for the traditional technique while Figure 10 presents the maximum power and voltage for the improved technique. In the second case: The temperature kept constant at 25 °C while the irradiance is variable. Figure 11 shows the MPP and voltage for normal P&O and Figure 12 shows the improved respectively. While in the third case the temperature varies and the irradiance considered being constant at 1000 W/m^2. The difference between the MPP and its voltage for both approaches appears in Figures 13, 14. Finally in the fourth case both temperatures and irradiance will be variable as shown in Figures 15, 16.
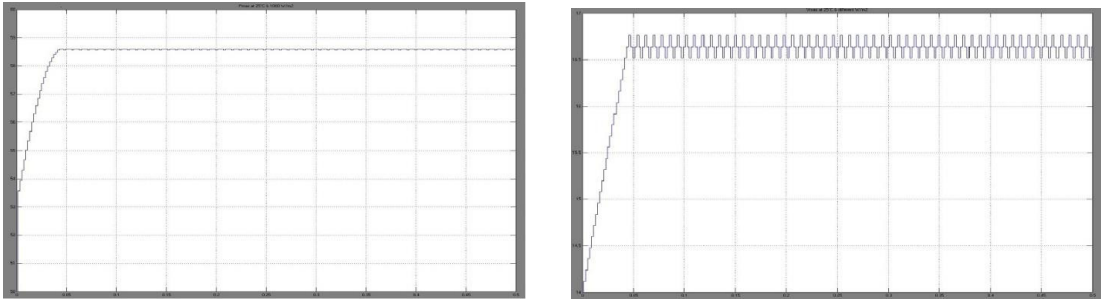
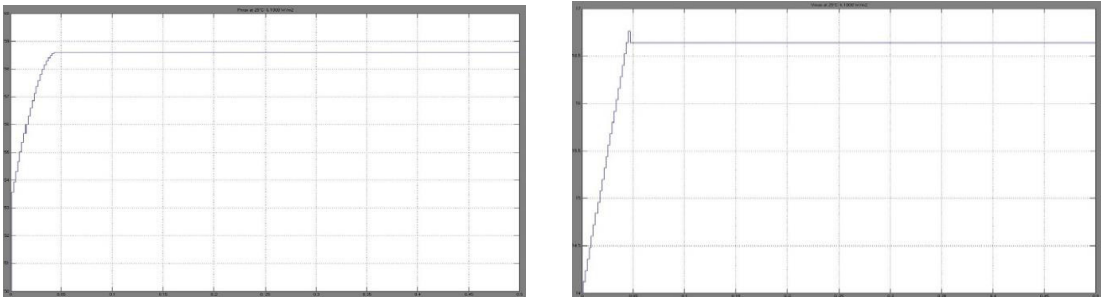Figure 9: MPP & Voltagefor normal P&O

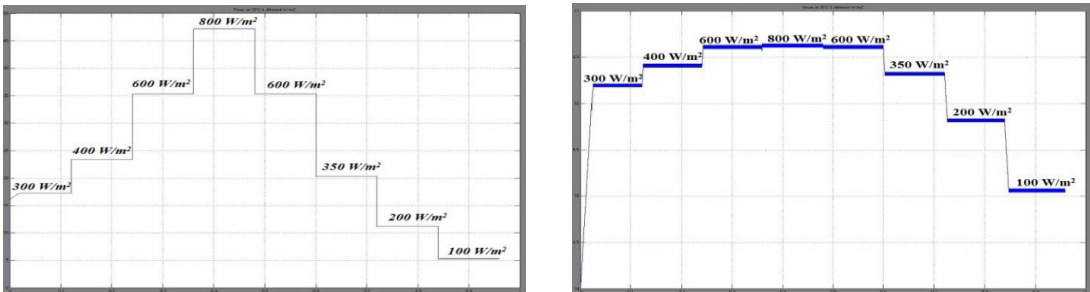

Figure 10: MPP & Voltage for improved P&O

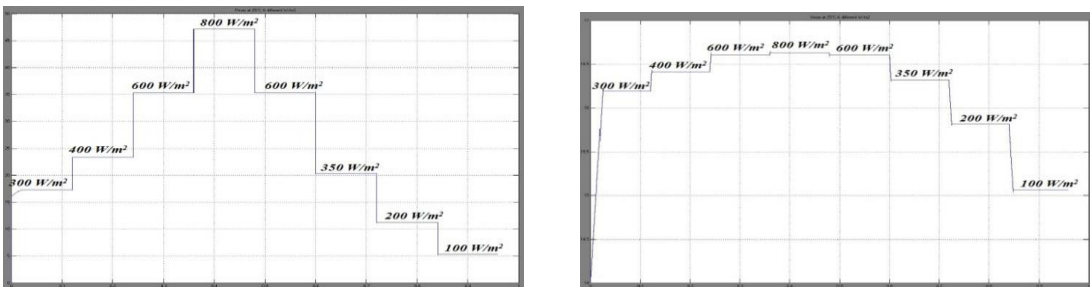Figure 11: MPP & Voltage for normal P&O at different irradiance

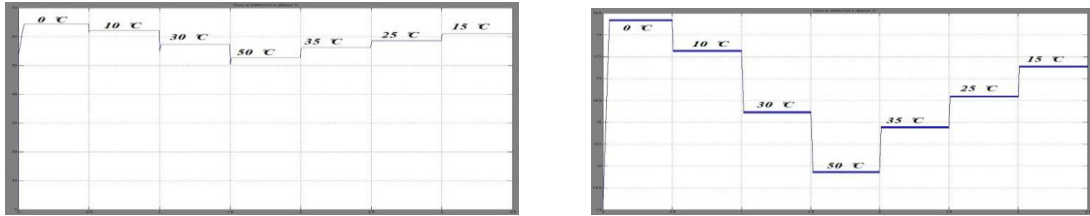Figure 12: MPP for improved P&O at different irradiance.

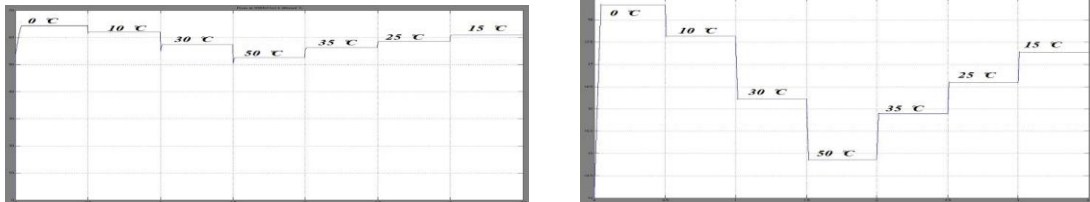Figure 13: MPP & Voltage for normal P&O at different temperatures

Figure 14: MPP & Voltage for improved P&O at different temperatures.
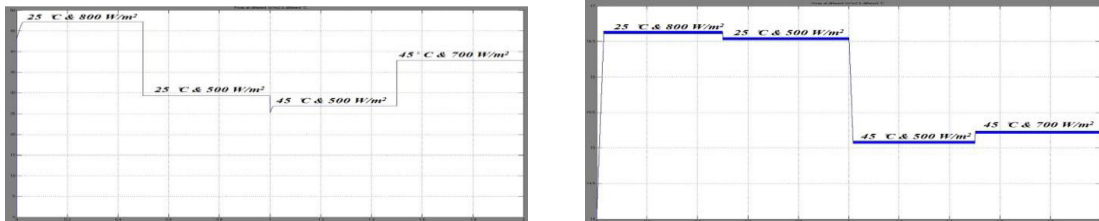

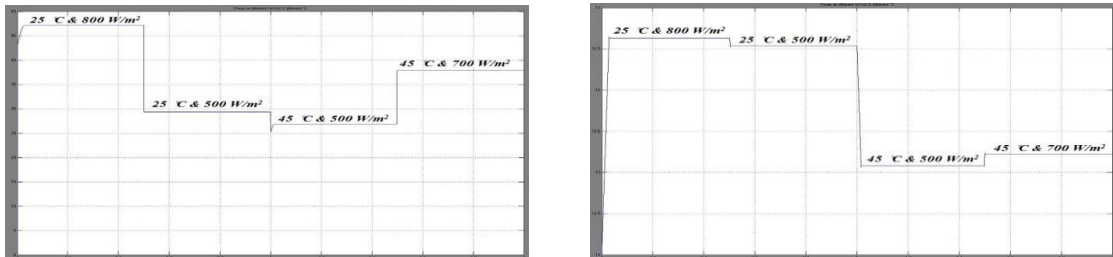Figure 15: MPP & Voltage for normal P&O at different temperatures & irradiance.

Figure 16: MPP & Voltage for improved P&O at different temperatures & irradiance.

5. Conclusion

This paper discusses the simple general Perturb and observes approach for the maximum power point tracking (MPPT) using the state flow and gives the same results but in more simplicity comparing to all the machine languages that applied to the normal approach. As, it also improved the approach to track the MPP with no oscillation around it in any irradiation level and for any temperature and moreover for any variation of either of them or both together which means that the approach is robust to any variable or rapid changes in atmospheric conditions. This gives more advantages for the P&O approach over other techniques by this improvement.

6. Prespectives

The future work is using the new extended approach of state flow to control the duty cycle of the boost converter in order to complete the control of a whole PV system. Then apply the approach to reach MPP for wind energy. Furthermore, the power of state flow will be used in controlling the switching of hybrid sources and varies loads to finally be implemented on the micro controller device to achieve real time acquisition.

References

[1]. International Energy Agency "Energy Technology Perspectives 2012" (2012).

[2]. H.L. Tsai, C.S. Tu, Y.J. Su, Development of generalized photovoltaic model using MATLAB/SIMULINK, in: Proceedings of the World Congress on Engineering and Computer Science, San Francisco, USA, 2008.

[3]. K. Ishaque, Z. Salam, H. Taheri, Accurate MATLAB simulink PV system simulator based on a two-diode model, Journal of Power Electronics 11 (2011) 179-187.

[4]. Samer Said, Ahmed Massoud, Mohidldine Benammar and Shehab Ahmed "A Matlab/Simulink-Based Photovoltaic Array Model Employing SimPowerSystems Toolbox" Journal of Energy and Power Engineering 6 (2012) 1965-1975.

[5]. H. Patel, V. Agarwal, MATLAB-based modeling to study the effects of partial shading on PV array characteristics, IEEE Transactions on Energy Conversion 23 (2008) 302-310.

[6]. A.A. Hassan, F.H. Fahmy, A.A. Nafeh, M.A. El-Sayed, Modeling and simulation of a single phase grid connected photovoltaic system, WSEAS Transactions on Systems and Control 5 (2010) 16-25.

[7]. A. Chouder, S. Silvestre and A. Malek. "Simulation of photovoltaic grid connected inverter in case of gridfailure". Revue des Energies Renouvelables, Vol. 9 N°4, 285 – 296. 2006

[8]. Chen Qi, Zhu Ming"Photovoltaic Module Simulink Model for Stand Alone PV system" International conference on Applied Physics and Industrial Engineering, 2012.

[9]. ROBERTO FARANDA, SONIA LEVA "Energy comparison of MPPT techniques for PV Systems" WSEAS TRANSACTIONS on POWER SYSTEMS, Issue 6, Volume 3, June 2008.

[10]. A. Zegaoui, P. Petit, J.P. Sawicki, J.P. Charles, M. Aillerie, M.DellaKrachai and A.O. Belarbi "Simulation of Photovoltaic Generators and Comparison of two common Maximum Power Point Trackers" International Conference on renewable Energies and Power Quality (ICREPQ'10)   Granada, Spain, 23-25 March 2010.

[11]. M.Lokanadham, K.Vijaya Bhaskar " Incremental Conductance Based Maximum Power Point Tracking (MPPT) for Photovoltaic System" International Journal of Engineering Research and Applications (IJERA) Vol. 2, Issue 2,Mar-Apr 2012, pp.1420-1424

[12]. J. Salazar, F. Tadeo, C. Prada, L. Palacin "Simulation and Control of a PV System connected to a Low Voltage Network" JORNADAS DE AUTOMÁTICA, SEPTEMBER 08-10, 2010, JAÉN, SPAIN.

[13]. Nicola Femia, Giovanni Petrone, Giovanni Spagnuolo, and Massimo Vitelli "Optimization of Perturb and Observe Maximum Power Point Tracking Method" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 20, NO. 4, JULY 2005.

[14]. Seyedmahmoudian Mohammadmehdi; et al., Analytical Modeling of Partially Shaded Photovoltaic Systems, Energies Volume: 6 Issue: 1 pp: 128-144, JAN 2013

[15]. D. P. Hohm and M. E. Ropp "Comparative Study of Maximum Power Point Tracking Algorithms" Prog. Photovolt: Res. Appl. 2003; 11:47–62.

[16]. Safari. A et al. Simulation and Hardware Implementation of Incremental Conductance MPPT with Direct Control Method Using Cuk Converter IEEE Transactions on Industrial Electronics, Vol. 58, Issue 4, 2011, 1154 -1161

[17]. Harel, David, "Statecharts: A Visual Formalism for Complex Systems," Science of Computer Programming 8, 1987, pages 231-274.