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TRIPLE-JUNCTION SOLAR CELL AND MPPT BASED ON PERTURB AND OBSERVE METHOD FOR PV ENERGY SYSTEMS

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Abstract: *This paper presents a new Matlab/Simulink model of a PV module and a maximum power point tracking (MPPT) system for high efficiency triple-junction solar cell. The proposed technique is based on Perturb and Observe method. This model of the triple-junction solar cell includes the parameters of each sub-cell. It is also including the effect of the temperature variations on the energy gap of each sub-cell as well as the diode reverse saturation currents. The implementation of a PV model is based on the triple-junction solar cell in the form of masked block in Matlab/Simulink software package that has a user-friendly icon and dialog. It is fast and accurate technique to follow the maximum power point. The simulation results of the proposed MPPT technique are compared with Perturb and Observe MPPT technique. The output power and energy of the proposed technique are higher than that of the Perturb and Observe MPPT technique*

Keywords: **MPPT, PV model, Perturb and Observe method**

1. INTRODUCTION

Global warming and energy policies have become a hot topic on the international agenda in the last years. Developed countries are trying to reduce their greenhouse gas emissions. For example, the EU has committed to reduce the emissions of greenhouse gas to at least 20% below 1990 levels and to produce no less than 20% of its energy consumption from renewable sources by 2020. In this context, photovoltaic (PV) power generation has an important role to play due to the fact that it is a green source. The only emissions associated with PV power generation are those from the production of its components. After their installation they generate electricity from the solar irradiation without emitting greenhouse gases. In their lifetime, which is around 25 years, PV panels produce more energy than that for their manufacturing. Also, they can be installed in places with no other use, such as roofs and deserts, or they can produce electricity for remote locations, where there is no electricity network [1]. The latter type of installations is known as off-grid facilities and sometimes they are the most economical alternative to provide electricity in isolated areas. The efficiency of a PV plant is affected mainly by three factors: the efficiency of the PV panel (in commercial PV panels it is between 8-15%), the efficiency of the inverter (95-98 %) and the efficiency of the maximum power point tracking (MPPT) algorithm (which is over 98%) [2]. Improving the efficiency of the PV panel and the inverter is not easy as it depends on the technology available, it may require better components, which can increase drastically the cost of the installation. Instead, improving the tracking of the maximum power point (MPP) with new control algorithms is easier, not expensive and can be done even in plants which are already in use by updating their control algorithms, which would lead to an immediate increase in PV power generation and consequently a reduction in its price. MPPT algorithms are necessary because PV arrays have a nonlinear voltage-current characteristic with a unique point where the power produced is maximum [3-5]

1.1 Types of Solar Cells

1.1.1Mono crystalline silicon

Mono crystalline silicon solar cells are the most efficient ones. They are made from wafers (very thin slices) of single crystals obtained from pure molten silicon. These single crystal wafers have uniform and predictable properties as the structure of the crystal is highly ordered. However, the manufacturing process must be really careful and occurs at high temperatures, which is expensive. The efficiency of these cells is around 15-18% and the surface needed to get 1 kW in STC is about 7 m2.

1.1.2Amorphous and thin-film silicon

Amorphous silicon is the non-crystalline form of the silicon and it can be deposited as thin-films onto different substrates. The deposition can be made at low temperatures. The manufacturing process is simpler, easier and cheaper than in the crystalline cells. The weak point of these cells is their lower efficiency, around 6-8%. This efficiency is measured under STC.

1.1.3 Other Cells and Materials

There are other materials apart from silicon that can be used for manufacturing solar cells. These compounds are also thin-film deposited, so they have the same advantages as the silicon thin film solar cells but with a better efficiency. Among these compounds, two are already used in commercial solar cells. Gallium Arsenide (GaAs) has been used for space applications mainly for two reasons: firstly, it is less susceptible to suffer damage from the space radiation than silicon, and secondly, due to its direct band gap of 1.42 eV, it can take advantage of a greater part of the solar spectrum. Despite being a more expensive material, space projects can afford it as cost is not the most important factor to decide the components

2. Photo Voltaic Systems

PV system is design to give the electric supply to load and load can be ac type or dc type. Supply can be needed in day time or evening time or both times. PV system can give supply only in day time for night hours we needed supply for that we have batteries, where power can store and utilize

2.1 Types of PV system

Stand-alone PV system

Depending on the type of load, cost, resources availability and requirements of the load stand-alone system divided into several categories, which are describe below

a) Unregulated standalone system with DC load

Usually, this type of system is for low power applications. A PV system is directly connected to the load without any MPPT controller, night hours it will not provide any supply because of the absence of the battery.

b) Regulated standalone system with DC load

It is similar to unregulated standalone system with DC load but basic difference between this and previous one that this system requires a MPPT technique. Usually, system with MPPT should have one battery otherwise extra power will be waste.

C) Regulated standalone system with battery and DC load

Most common configuration PV array, battery, MPPT and DC load. Battery use to store the extra power of PV system, this will increase the cost of PV system. A charge controller is must for this type of system because battery life is less compared to PV module, extra charging deep discharging can reduce the life of battery.

d) Regulated standalone system with battery, AC and DC loads

This system is similar to previous one but here AC load can also draw the power from PV system and inverter (DC to AC converter) is require, it will increase the cost.

2.2 Grid interactive PV system

Grid connected PV system is a system when grid is connected to PV system. In this type of system consist PV array and inverter. Figure 2.5 shows grid connected PV system. Grid connected system deals with AC. Grid connected system deals with very high-power applications, so is tough to store this much of power in battery [6-7].

2.3 Operating Principle

Solar cells are the basic components of photovoltaic panels. Most are made from silicon even though other materials are also used. Solar cells take advantage of the photoelectric effect: the ability of some semiconductors to convert electromagnetic radiation directly into electrical current. The charged particles generated by the incident radiation are separated conveniently to create an electrical current by an appropriate design of the structure of the solar cell, as will be explained in brief below. For further details, the reader can consult references.

2.4. Modelling of Solar Cell

A solar cell is the building block of a solar panel. A photovoltaic module is formed by connecting many solar cells in series and parallel. Considering only a single solar cell; it can be modelled by utilizing a current source, a diode and two resistors. This model is known as a single diode model of solar cell. Two diode models are also available but only single diode model is considered. The single diode model of solar cell as shown in Figure-1.

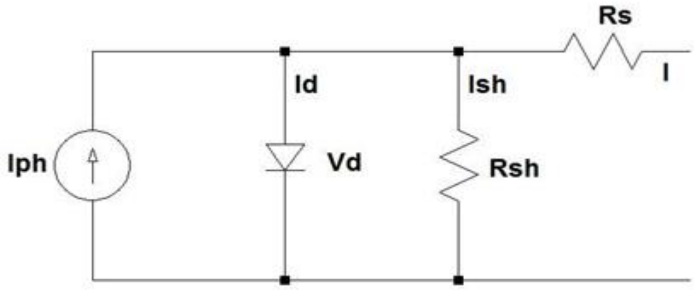

Figure 1. Single diode model of solar cell

$$I = Ilg - Ios * \left[\exp\left\{q * \frac{V+I*Rs}{A*k*T}\right\} - 1\right] - \frac{V+I*Rs}{Rsh}$$

Where,

$$Ios = Ior * \left(\frac{T}{Tr}\right)^3 * \left[\exp\left\{q * Ego * \frac{\frac{1}{Tr} - \frac{1}{T}}{A*k}\right\}\right]$$

$$Ilg = \{Iscr + Ki * (T - 25)\} * lambda$$

I&V: Cell output current and voltage;
Ios: Cell saturation current
T: Cell temperature in Celsius: Boltzmann's constant,$1.38*10^{-19}$C;
Q: Electron charge,$1.68*10^{-23}$C;Ki: Short circuit current temperature coefficient at Iscr;
Lambda: Solar irradiation in W/m^2;Iscr: Short circuit current at 25°C;
Ilg: Light-generated current; Ego: Band gap for silicon; A: Idealist factor;Tr: Reference temperature;
Ior: Cell saturation current at Tr;Rsh: Shunt resistance; Rs: Series resistance;
The characteristic equation of a solar module is dependent on the number of cells in parallel and number of cells in series. It is observed from experimental results that the current variation is less dependent on the shunt resistance and is more dependent on the series resistance.

$$I = Np * Ilg - Np * Ios * \left[\exp\left\{q * \frac{\frac{V}{Ns} + I * \frac{Rs}{Np}}{A*k*T}\right\} - 1\right] - \frac{V * \left(\frac{Np}{Ns}\right) + I*Rs}{Rsh}$$

The I-V and P-V curves for a solar cell are given in the following figure-2. It can be seen that the cell operates as a constant current source at low values of operating voltages and a constant voltage source at low values of operating current.

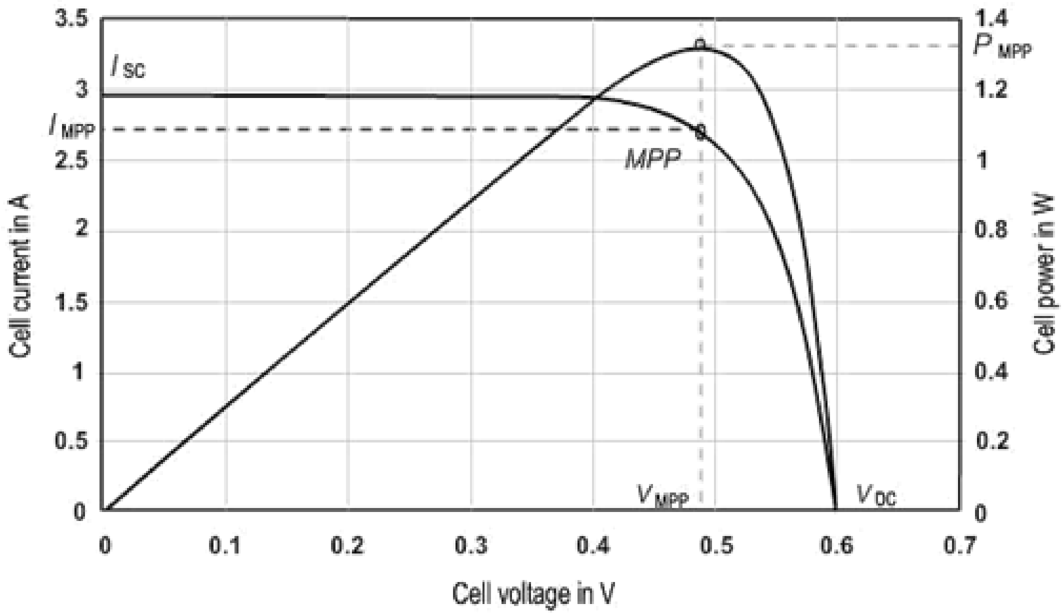

Figure 2. P-V & I-V Curve of solar cell at given temperature and Solar irradiation

2.5. Effect of variation of solar irradiation

The P-V and I-V curves of a solar cell are highly dependent on the solar irradiation values. The solar irradiation as a result of the environmental changes keeps on fluctuating, but control mechanisms are available that can track this change and can alter the working of the solar cell to meet the required load demands. The variation of P-V curve with solar irradiation and variation of I-V curve with solar irradiation shown in Figure-3 and Figure-4 respectively.

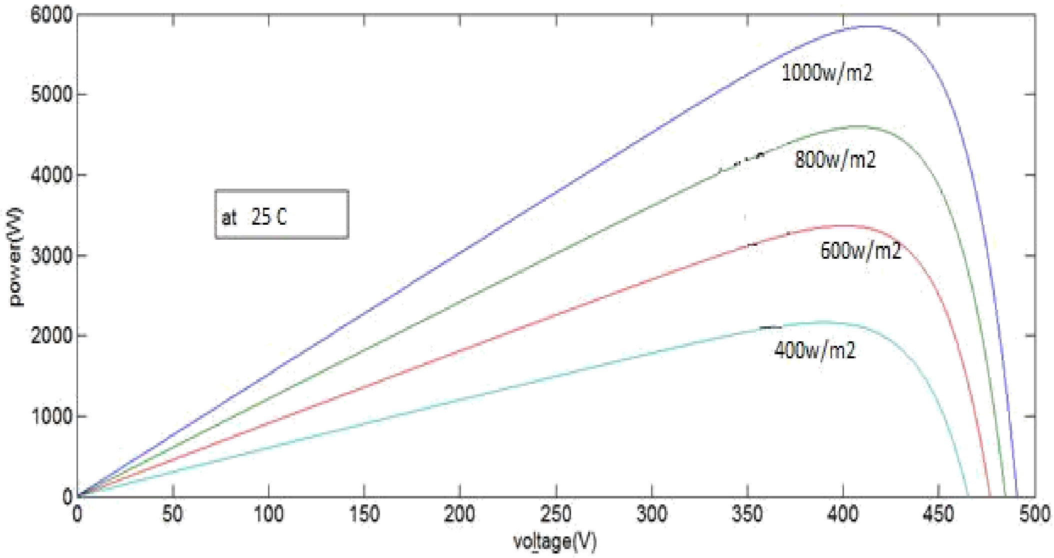

Figure 3. Variation of P-V Curve with solar irradiation

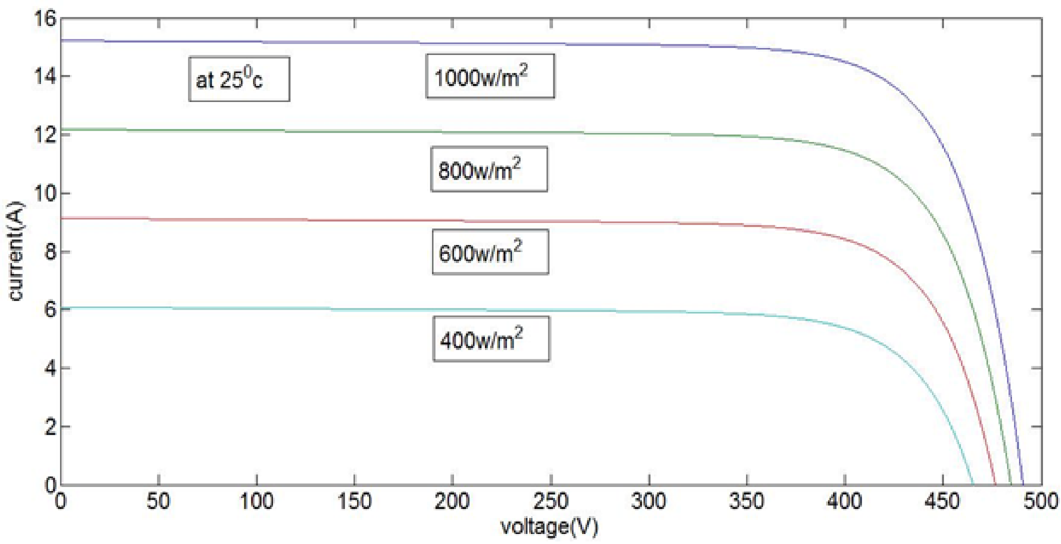

Figure 4. Variation of I-V curve with solar irradiation

2.6. Effect of variation of Temperature

On the contrary the temperature increase around the solar cell has a negative impact on the power generation capability. Increase in temperature is accompanied by a decrease in the open circuit voltage value. Increase in temperature causes increase in the band gap of the material and thus more energy is required to cross this barrier. Thus, the efficiency of the solar cell is reduced. The variation of P-V and I-V curve with temperature are shown in Figure-5 and Figure-6 respectively.

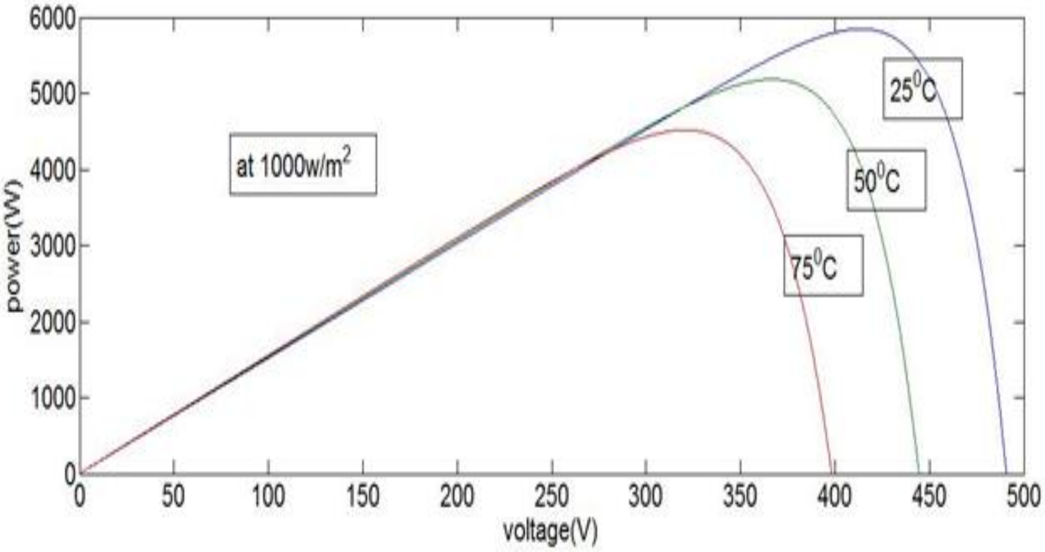

Figure 5. Variation of P-V Curve with temperature

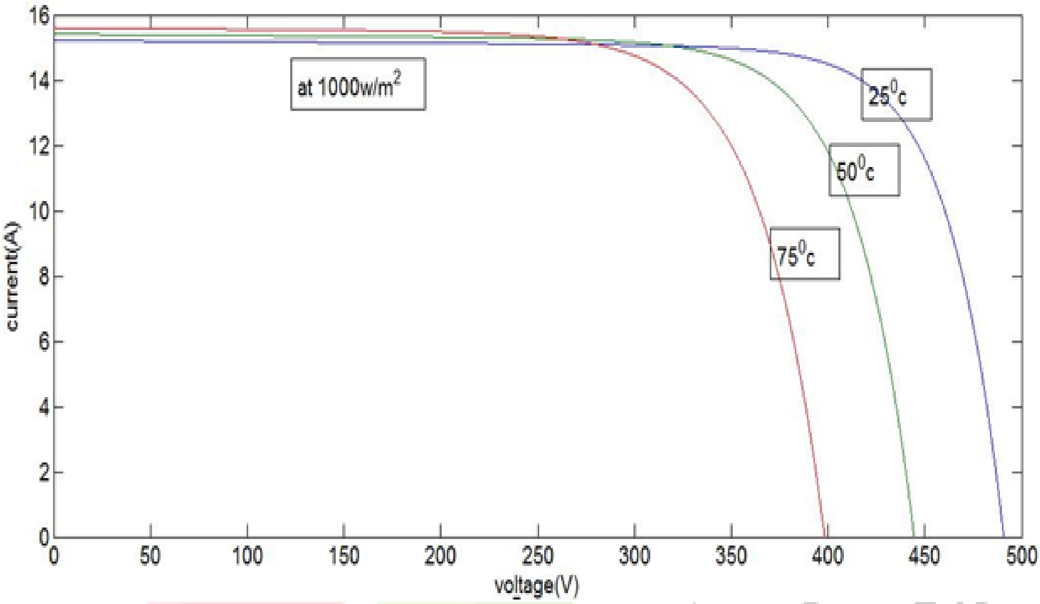

Figure 6. Variation of I-V with temperature

2.7. Photovoltaic Modul

PV modules are made from solar cells connected in series and parallel to obtain the desired current and voltage levels. Solar cells are encapsulated as they have to be weatherproofed and electric connections also have to be robust and corrosion free. As the cells are brittle, they are encapsulated in an airtight layer of ethylene viny lactate (EVA), Photo voltaic systems can be used in

1. Residential and Public Illumination. 2. Stroboscopic Signaling.
3. Electric Fence. 4. Telecommunications.
5. Water Supply and Micro-Irrigation Systems. 6. Control of Foods and Conservation of Food 7. Hydrogen and Oxygen Generation by Electrolysis.

8. Electric Power Supply. 9. Security and Alarm Systems

3. Maximum Power Point Tracking

Type your main text in 11-point Times New Roman, single-spaced. Do not use double-spacing. All paragraphs should be indented 1 pica (approximately 1/6- or 0.17-inch or 0.43 cm). Be sure your text is fully justified, flush left and flush right. Please do not place any additional blank lines between paragraphs. There are many methods used for maximum power point tracking a few are listed below:

1.Perturb and Observe (hill climbing method) 2. Incremental Conductance method

3.Fractional short circuit current 4. Fractional open circuit voltage

5.Neural networks 6. Fuzzy logic

3.1.1. Perturb and Observe method

This method is the most common. In this method very less number of sensors are utilized. The operating voltage is sampled and the algorithm changes the operating voltage in the required direction and samples dp/dv. If dp/dv is positive, then the algorithm increases the voltage value towards the MPP until dp/dv is negative. This iteration is continued until the algorithm finally reaches the MPP.

3.1.2. Incremental conductance method

This method uses the PV array's incremental conductance di/dv to compute the sign of dp/dv. When di/dv is equal and opposite to the value of I/V (where dp/dv=0) the algorithm knows that the maximum power point is reached and thus it terminates and returns the corresponding value of operating voltage for MPP. This method tracks rapidly changing irradiation conditions more accurately than P&O method.

P=V*I

Differentiating w.r.t voltage yields;

dP/dV=d(V*I)/dV

dP/dV=I*(dV/dV)+V*(di/dv)

dP/dV=I+V*(dI/dV)

When the maximum power point is reached the slope dP/dV=0. Thus, the condition would be;

dP/dV=0

I+V*(dI/dV)=0

dI/dV= -I/V

3.1.3. 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} method.

$$V_{mpp} = k_1 V_{oc}$$

where k_1 is a constant of proportionality. Since k_1 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_1 has been reported to be between 0.71 and 0.78. Once k_1 is known, V_{MPP} can be computed with V_{OC}

3.1.4. Fractional short circuit current

Fractional I_{SC} results from the fact that, under varying atmospheric conditions, I_{MPP} is approximately linearly related to the I_{SC} of the PV array.

$$I_{mpp} = k_2 I_{sc}$$

where k_2 is a proportionality constant. Just like in the fractional V_{OC} technique, k_2 has to be determined according to the PV array in use. The constant k_2 is generally found to be between 0.78 and 0.92. Measuring I_{SC} during operation is problematic. An additional switch usually has to be added to the power converter to periodically short the PV array so that ISC can be measured using a current sensor.

3.1.5. Fuzzy Logic Control

Microcontrollers have made using fuzzy logic control popular for MPPT over last decade. Fuzzy logic controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity.

3.1.6. Neural Network

Another technique of implementing MPPT which are also well adapted for microcontrollers is neural networks. Neural networks commonly have three layers: input, hidden, and output layers.The methods have certain advantages and certain disadvantages. Choice is to be made regarding which algorithm to be utilized looking at the need of the algorithm and the operating conditions. For example, if the required algorithm is to be simple and not much effort is given on the reduction of the voltage ripple then P&O is suitable. But if the algorithm is to give a definite operating point and the voltage fluctuation near the MPP is to be reduced then the IC method is suitable, but this would make the operation complex and more costly.

3.2. Flow chart for MPPT Algorithm

Two of the most widely used methods for maximum power point racking are studied here. The methods are,

- Perturb & Observe method
- Incremental conductance method

3.2.1. Perturb & Observe Algorithm

The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power P is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If P is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed. Below Fig. shows the plot of module output power versus module voltage for a solar panel at a given irradiation. The point marked as MPP is the Maximum Power Point, the theoretical maximum output obtainable from the PV panel. Consider A and B as two operating points.

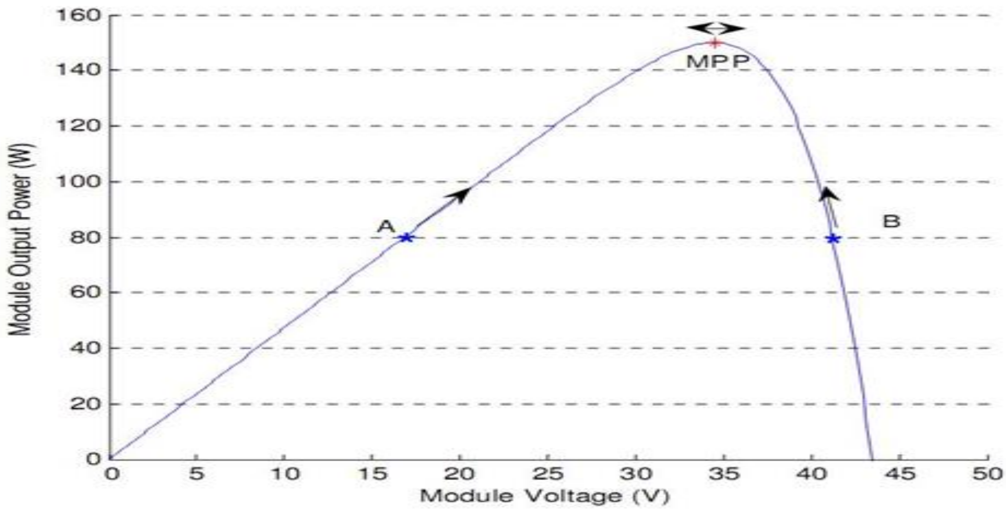

Figure 7. Solar panel characteristics showing MPP and operating points A and B

As shown in the figure-7 as above, the point A is on the left-hand side of the MPP. Therefore, we can move towards the MPP by providing a positive perturbation to the voltage. On the other hand, point B is on the right-hand side of the MPP. When we give a positive perturbation, the value of P becomes negative; thus, it is imperative to change the direction of perturbation to achieve MPP. The flowchart for the P&O algorithm is shown in Figure.8.

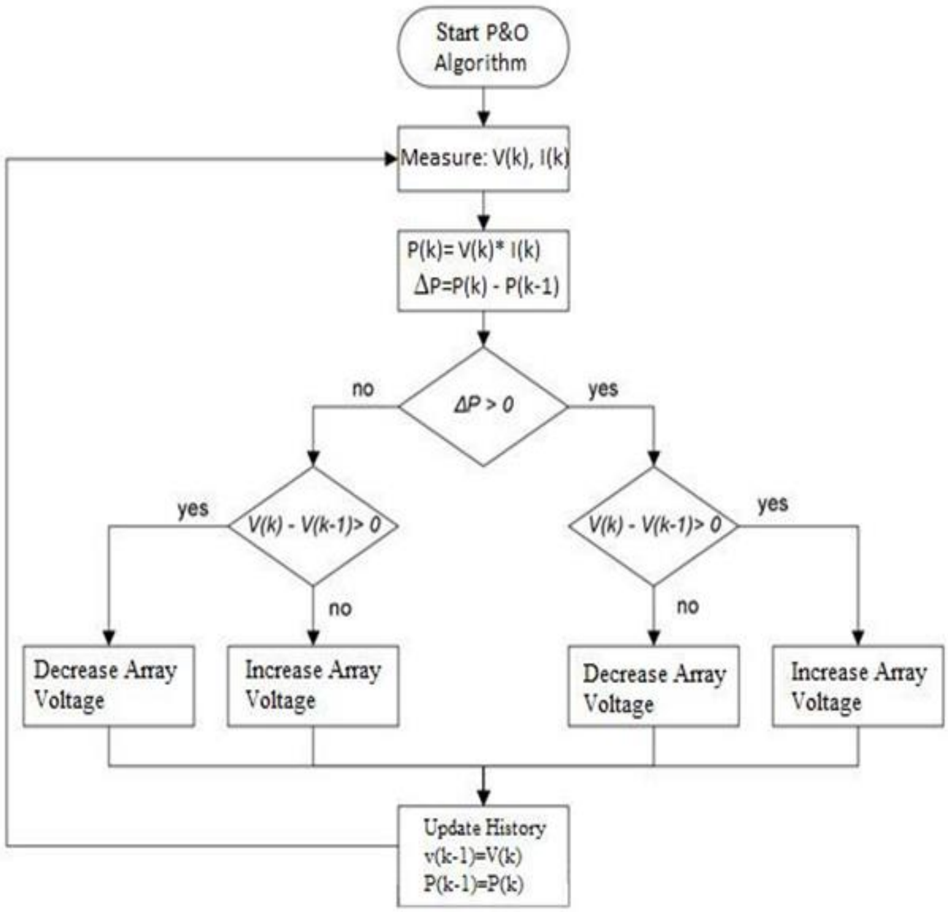

Figure 8. Flow chart for Perturb & Observe method

3.2.1.1. Limitations of Perturb& Observe Algorithm

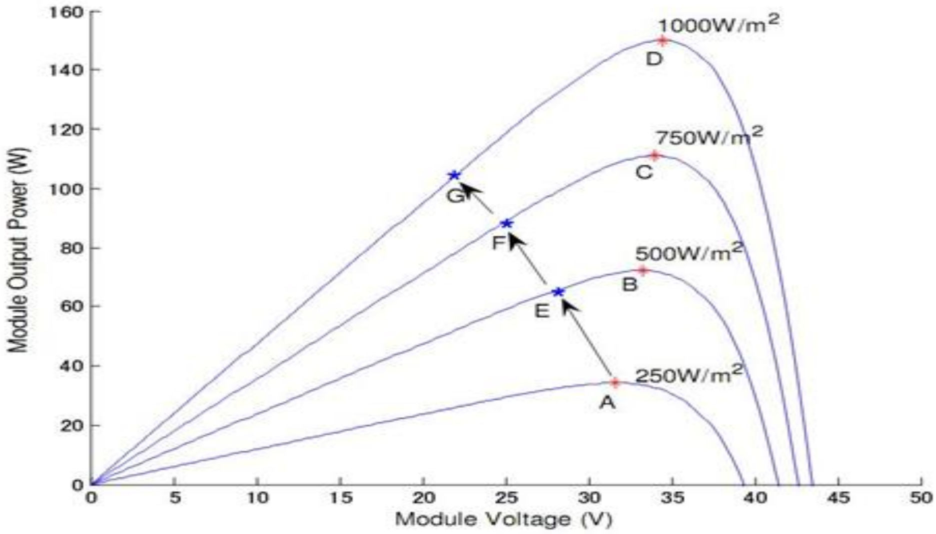

Figure 9. Characteristic showing wrong tracking of MPP by P&O algorithm under rapidly varying irradiance

In a situation where the irradiance changes rapidly, the MPP also moves on the right-hand side of the curve. The algorithm takes it as a change due to perturbation and in the next iteration it changes the direction of perturbation and hence goes away from the MPP as shown in the figure-9.

3.2.2. Flow Chart of Incremental Conductance Method

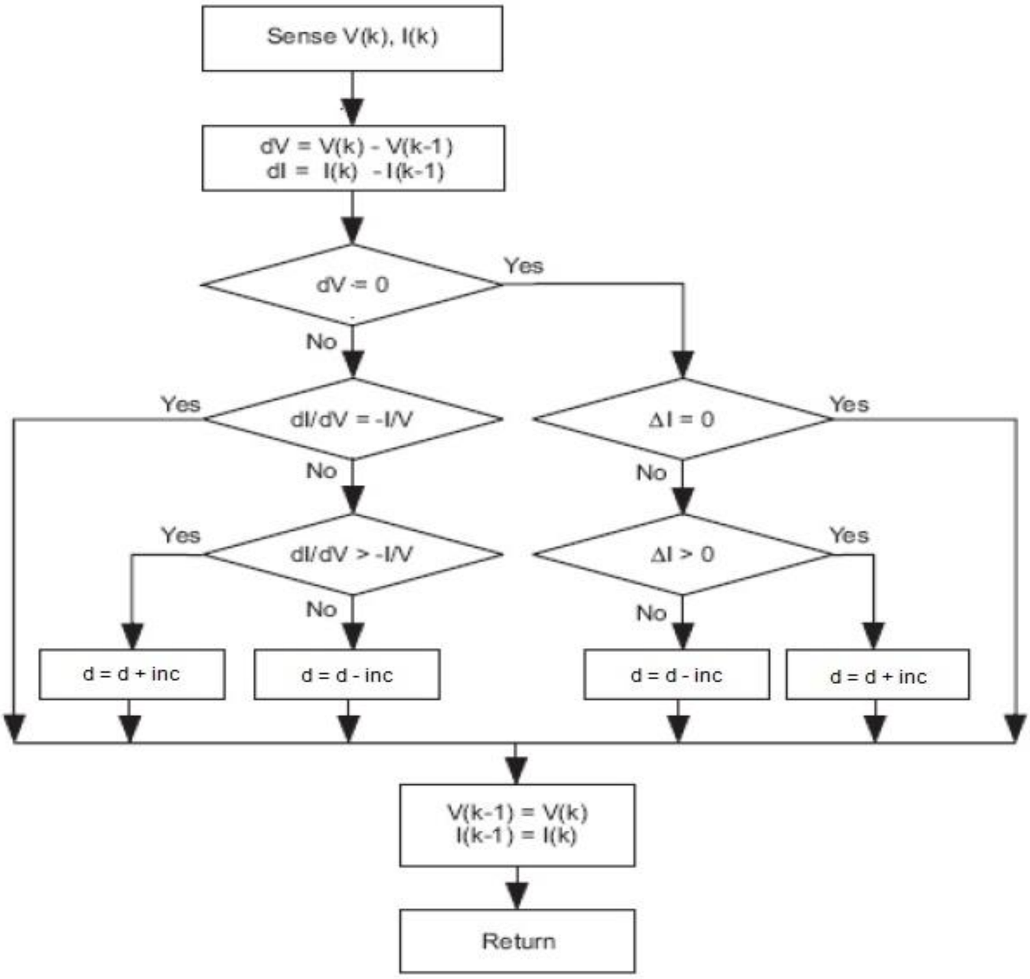

Figure 10. Flow chart for Incremental conductance method

3.3. Comparison of P&O and Incremental Conductance Method

- Concerning power efficiency, theoretically, INC method could provide a better tracking of MPP than P&O algorithm
- Due to the noise and error measurements, it is difficult to satisfy some of the equations
- When tracking step value is chosen correctly, P&O can have an energy efficiency equivalent to that obtained with INC
- Tracking step value has a significant effect on effectiveness of MPPT
- Complex to implement when compared to P&O

4.MODELING AND SIMULATION

4.1Modelling of PV System

4.1.1Modeling of PV Cell

For designing PV and battery, considered a basic domestic load requirement per day of 100W (i.e. light and fan load). The total energy required per day is 2.4kWh. Assuming PV will supply for 7hrs in a day, the PV power required can be calculated as

$$\text{PV power required} = \frac{\text{total energy required}}{\text{no of hrs PV present}} = \frac{2.4\text{kWh}}{7\text{hrs}} = 345\text{W}$$

As insolation of PV changes w.r.t time, so to meet the requirement in any condition the rating of PV is considered 1.5 times of required power.

$$\text{PV rating} = 1.5 \times 345\text{W} = 515\text{W}$$

Selecting battery nominal voltage of 48V, the A-H rating of battery is

$$\text{A} - \text{H rating of battery} = \frac{1.7\text{kWh}}{48\text{V}} = 35\ \text{A} - \text{H}$$

4.1.2. Design and Modelling of Boost converter

It involves the design of inductor L and capacitor C such that it always operates in CCM. Let ΔI be the allowed ripple in the inductor currents of 20% and ΔV_c & are the ripples in the capacitor voltages of 20%. The values of inductors and capacitors are given by

$$L_{min}= \{D(1-D)^2R\}/2f \quad (1)$$

$$\Delta i_L = \frac{VsDT}{L} \quad (2)$$

$$I_L=V_s/(1-D)^2R \quad (3)$$

$$=V_0*D/RCf \quad (4)$$

4.2. Simulation

4.2.1. Simulation of Solar Cell

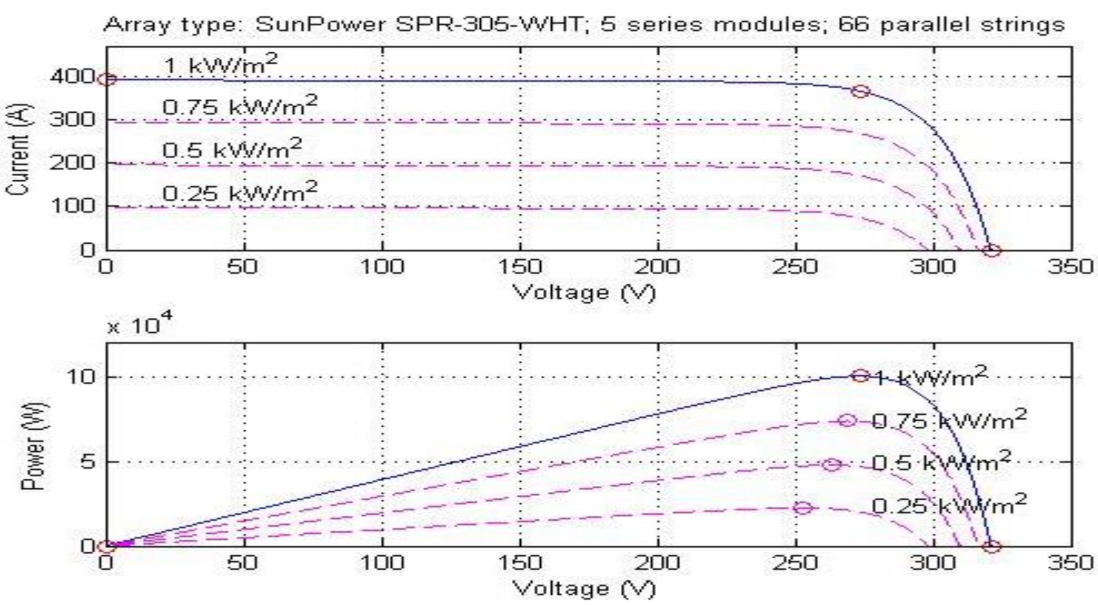

Figure 11. I-V & P-V Characteristics of PV Cell

6. Simulation Result

8.1 Simulation of DC-DC Boost Converter

The simulation of the proposed system has been implemented using MATLAB and the simulation of DC-DC boost converter the figure-12 is the inductor, capacitor and output current of the proposed converter and the figure-13 shows the Inductor, Capacitor and Output voltage of Boost Converter.

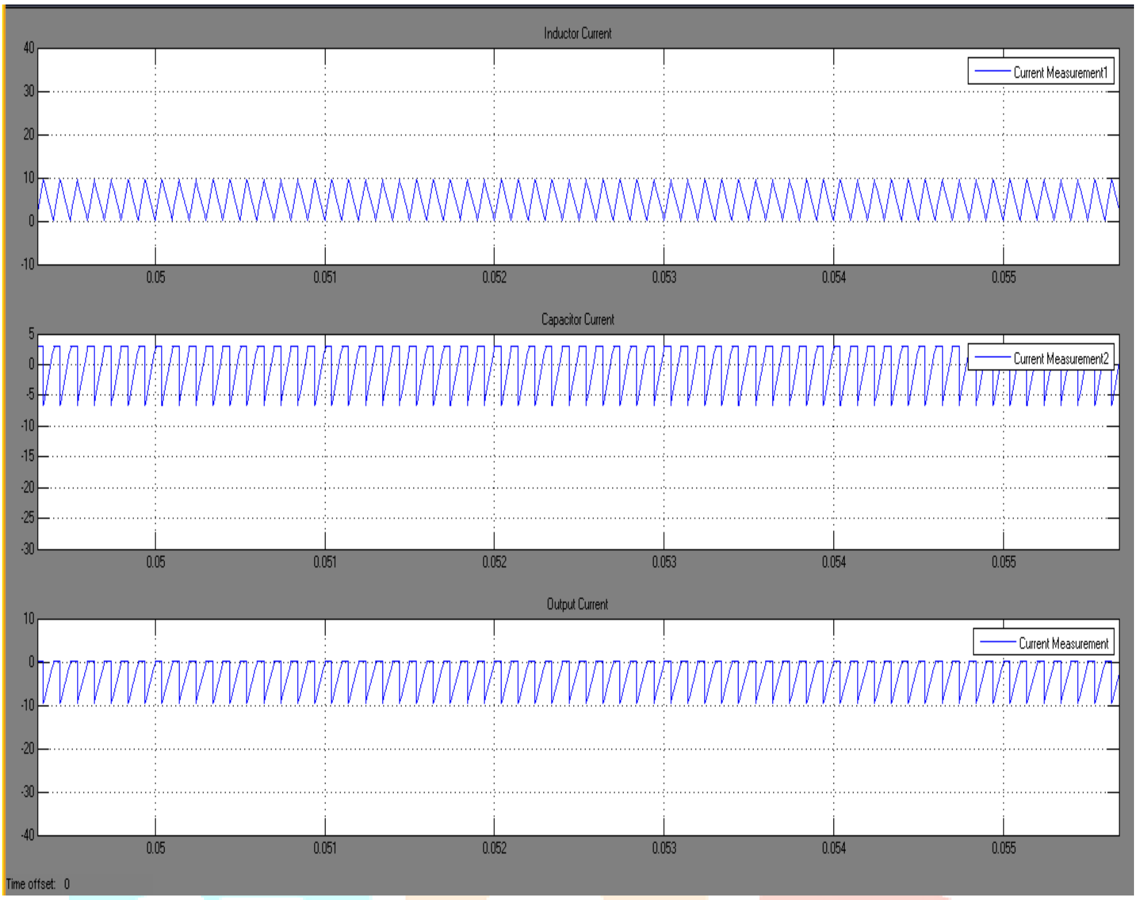

Figure 12. Inductor, Capacitor and Output Current of Boost Converter

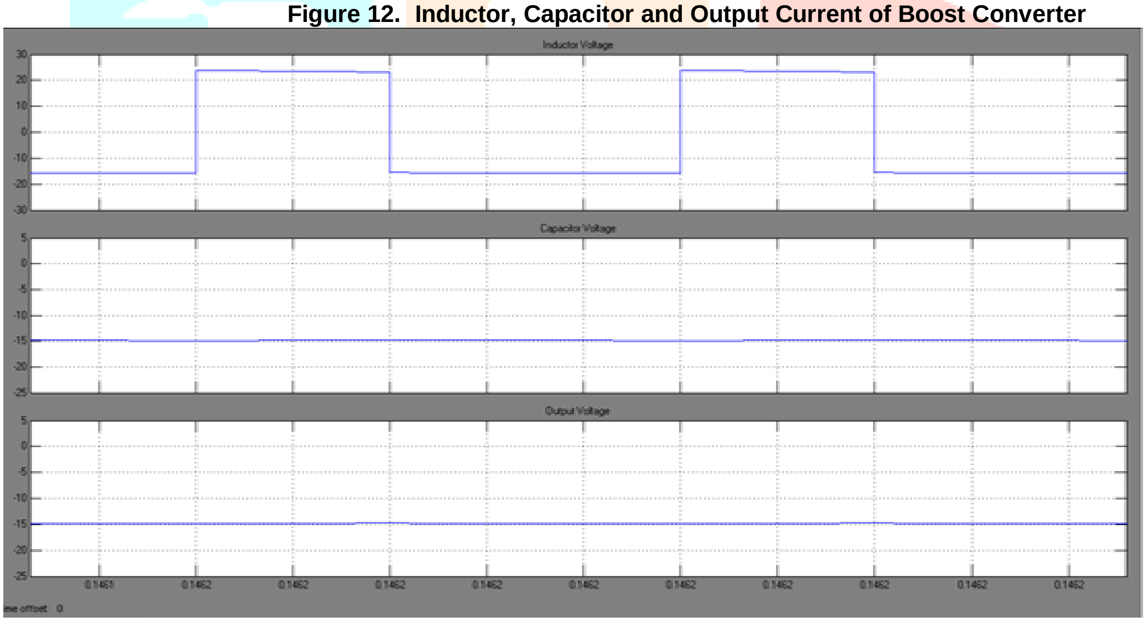

Figure 13. Inductor, Capacitor and Output voltage of Boost Converter

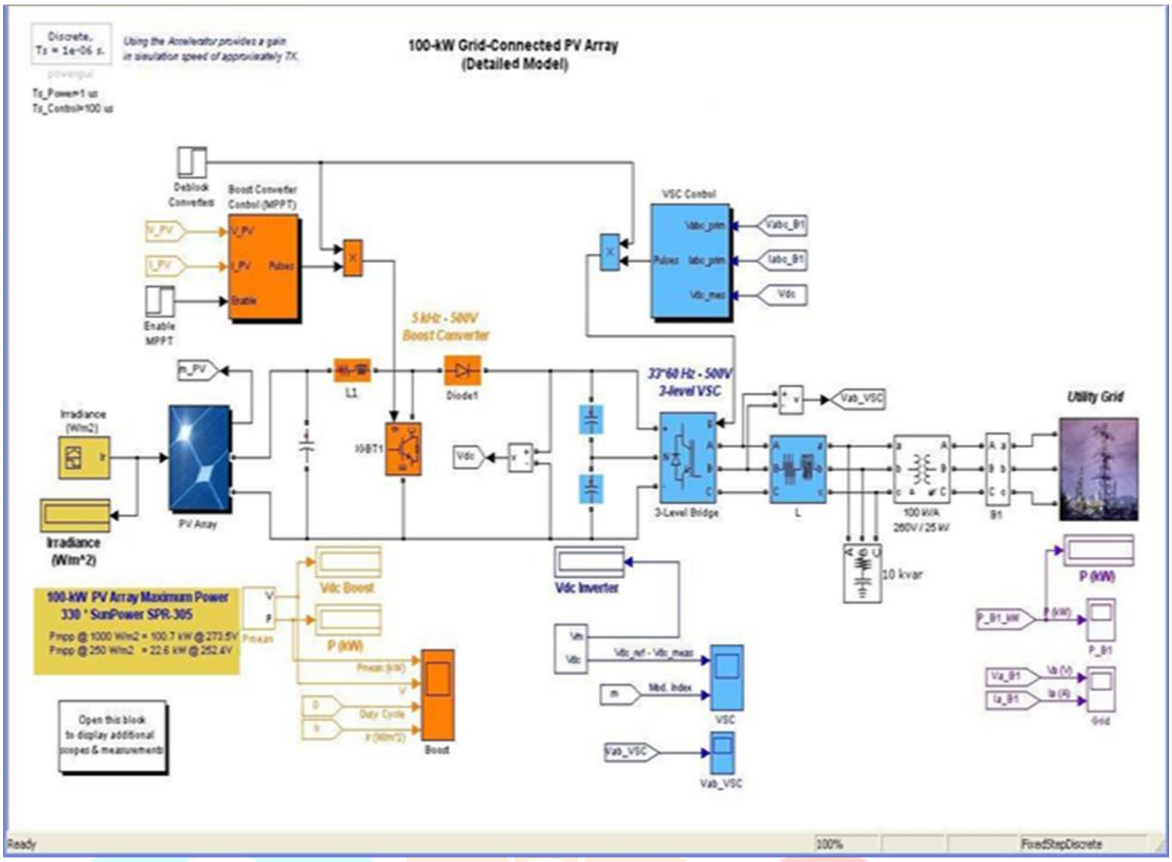

Figure 14. Simulation Layout Diagram

The model of triple-junction solar cell is implemented in the MATLAB/Simulink as shown 14. The simulation of waveform of V_PV, I_PV and I_diode_PV as shown in the figure-14. and input Irradiation, Pmean(KW), Vin and Duty Cycle of Boost Converter as shown in figure-15.The Modulation index and output Voltage of Boost and Power in KW are shown in figure-16-19.Simulation Waveform of Vab in VSC, Pu Id and Iq of VSC control, Grid voltage and current are shown in figure-19-21.

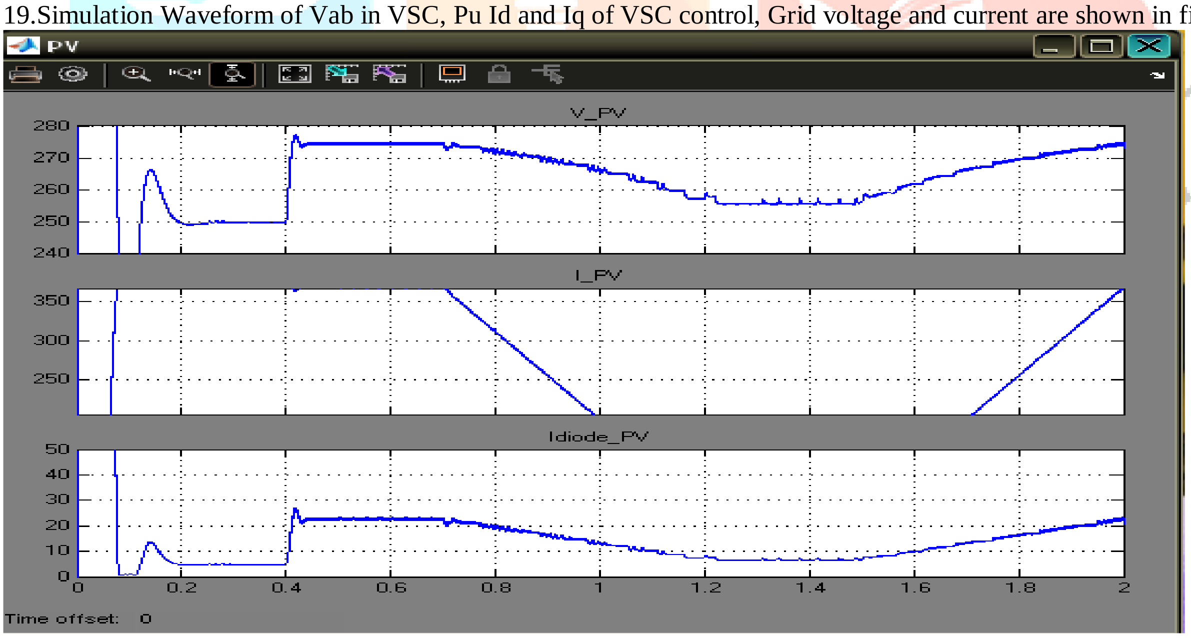

Figure 15. Simulation waveform of V_PV, I_PV and I_diode_PV

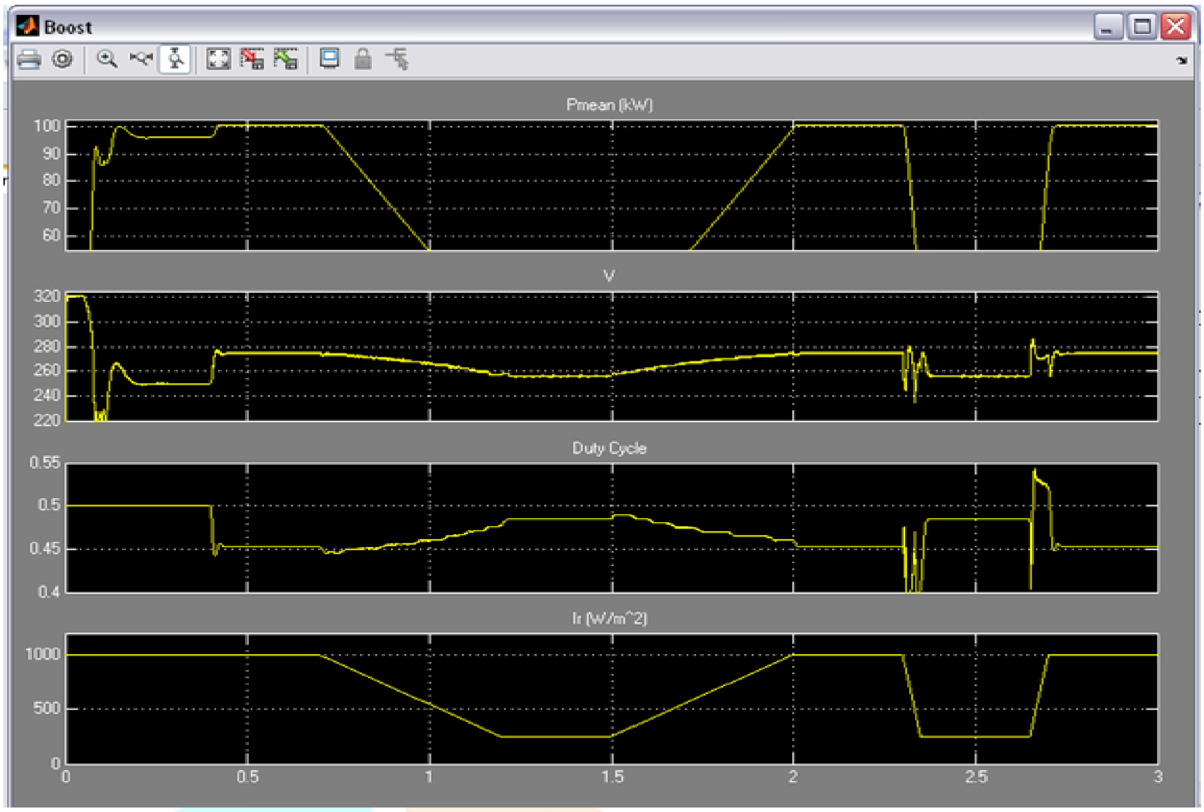

Figure 16. Input Irradiation, Pmean(KW), Vin and Duty Cycle of Boost Converter

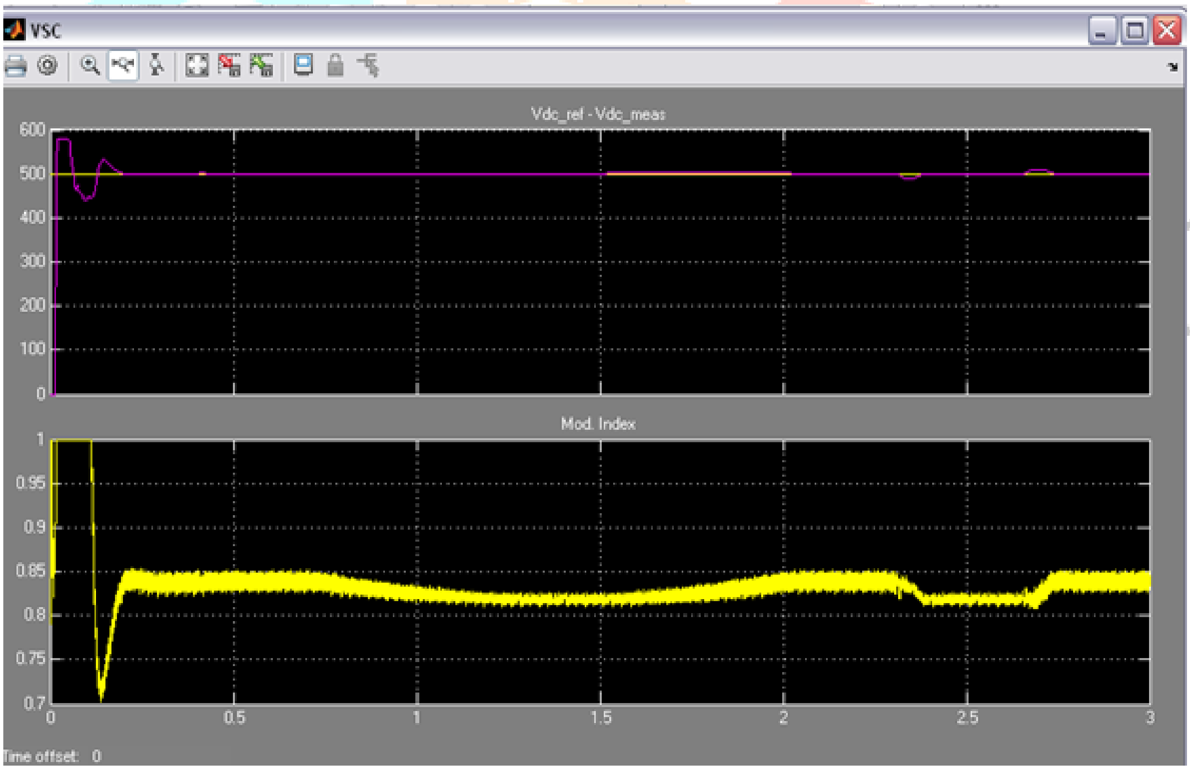

Figure 17. Modulation index and output Voltage of Boost

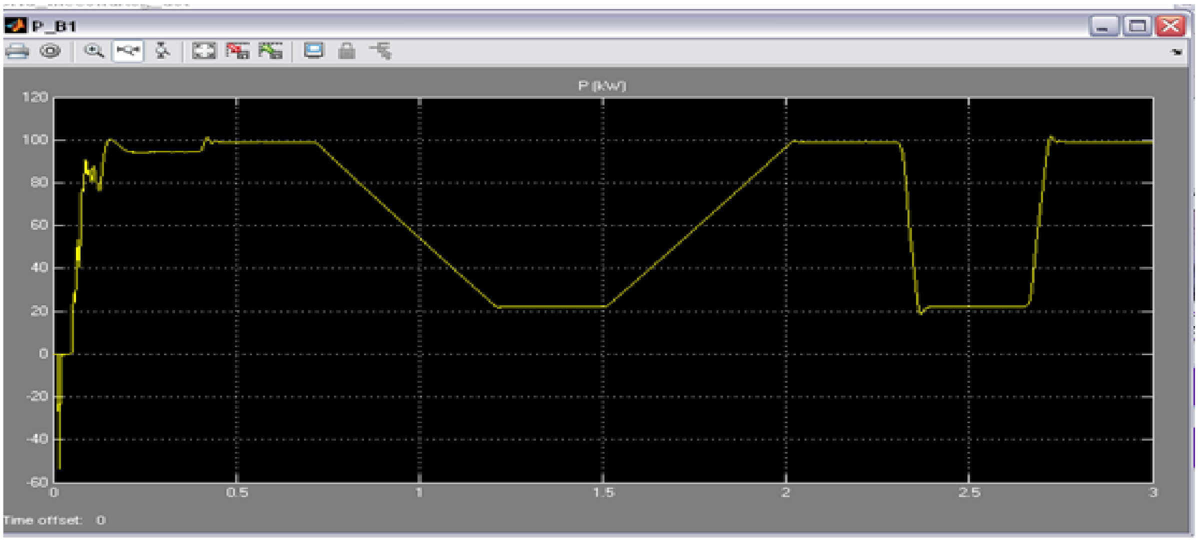

Figure 18. Power in KW

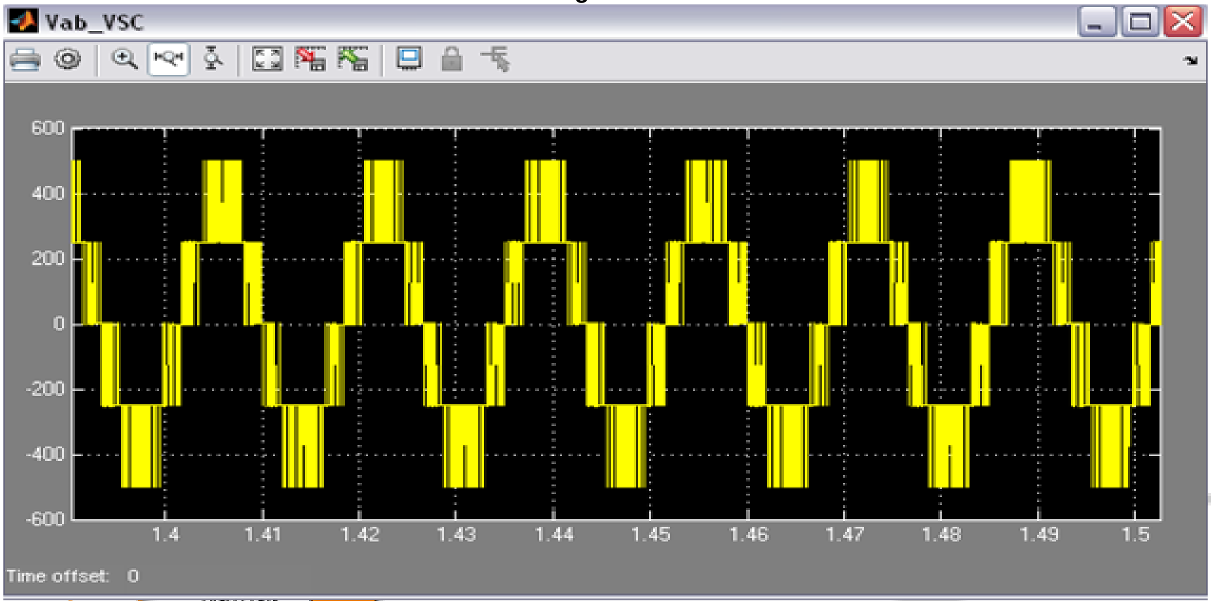

Figure 19. Simulation Waveform of Vab in VSC

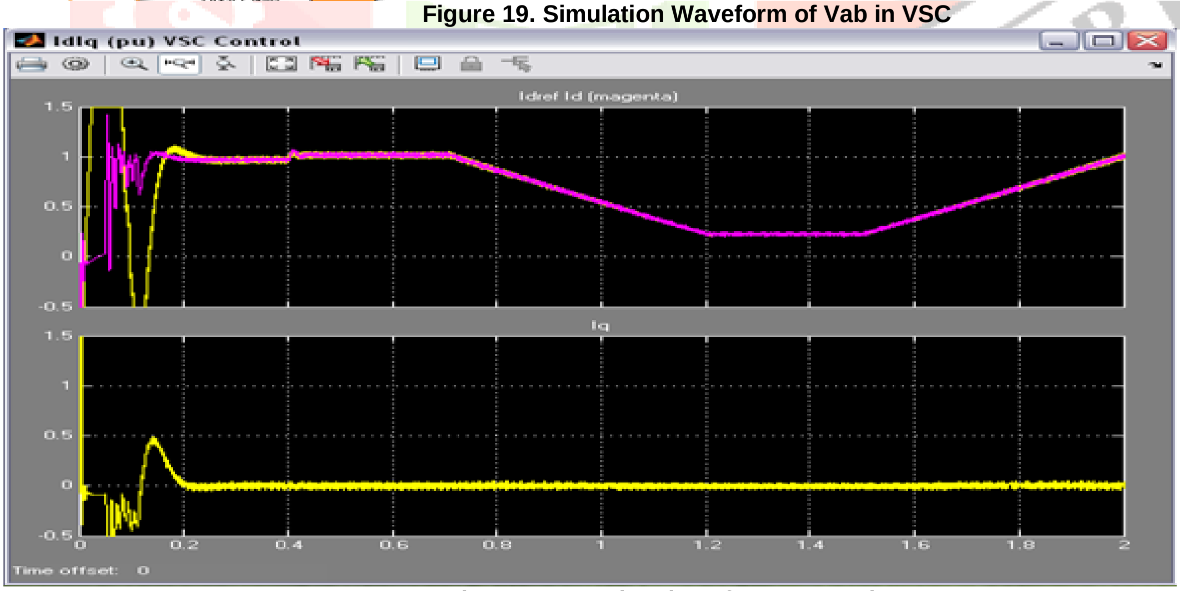

Figure 20. Pu Id and Iq of VSC control

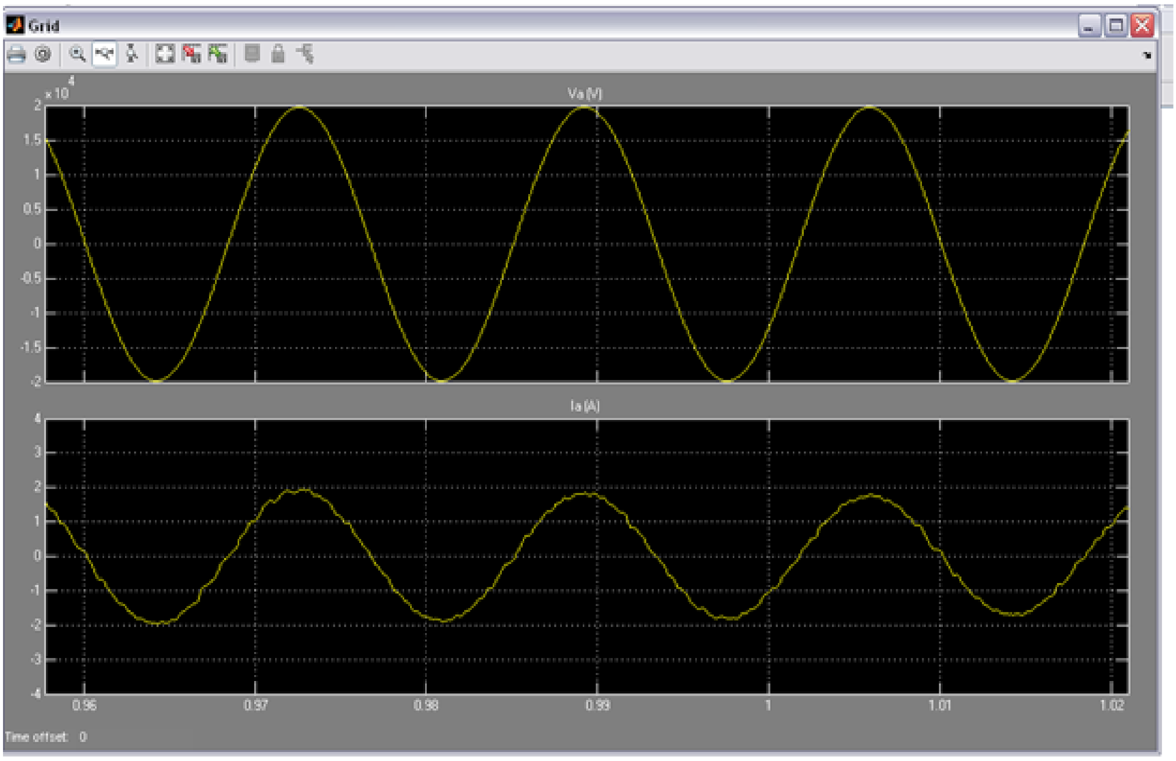

Figure 21. Grid voltage and current

7. Conclusion

In short, P&O MPPT Algorithm is the most efficient MPPT for photovoltaic system due to its characteristics of being simple and low-cost implementation. Still, the step size problem and partial shading issue affect the accuracy of the algorithm to achieve true MPP, as well as contribution for the power losses. Thus, some modifications must be made in order to improve the performance of P&O MPPT. This paper has reviewed and compared three modified methods for each issue and as a conclusion; the best method is the one that can provide good accuracy, simple and low cost.

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