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Implementation Of Maximum Power Point Tracking With A Boost Converter And A Three Level 3-Phase Inverter Connected To The Grid

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***Abstract:** The power output of the solar array is dependent of the irradiance, temperature and internal properties of the materials used to make solar cells. These factors contribute in the position of the Maximum power point. Changes in atmospheric conditions affect directly the output of the solar panel. Therefore, there is a need to track the Maximum power point to ensure that the system delivers the maximum power and the losses are reduced at any given time despite the change in temperature and irradiation throughout a day. The maximum power point tracking(MPPT) of the PV output for all sunshine conditions is a key to keep the output power per unit cost low for successful PV applications. Several techniques have been proposed for maximum power point tracking. The most commonly used technique for MPPT is the perturb and observe technique. MATLAB was used to simulate the Perturb and observe. The main aim will be to track the maximum power point of the photovoltaic module so that the maximum possible power can be extracted from the photovoltaic. The algorithms utilized for MPPT are generalized algorithms and are easy to model or used as a code. The algorithms are written in m files of MATLAB and utilized in simulation where the values of the irradiance and temperature were chosen based on the average values in Benue State. The solar cell is modeled using SIM Power Systems blocks.*

***Keywords:** Maximum Power Point Tracking (MPPT), Perturb and Observe (P&O), VSC converter, Photovoltaic (PV), Pulse width Modulation (PWM).*

I. INTRODUCTION

In today’s world, renewable energy sources play important role in electricity generation. Several sources like wind, solar, biogas etc. are important energy sources. Energy from the sun is the best option for renewable energy as it is available almost everywhere and is free to harness [1]-[2]. Solar radiation from the sun is converted to electrical energy by using solar cells which exhibit photovoltaic (PV) effect. However, for PV systems, the amount of electric power generated changes continuously with weather conditions.

For solar to be a competitive energy source it is extremely important to extract the maximum power from each panel and lower the cost per kilowatt. It turns out that this is not as simple as just hooking a panel to a battery or grid; there are many variables that affect the performance of a panel, such as shade, shadows, and ambient temperature—thus the need for MPPT algorithms. Solar cells, like other silicon diodes, have an exponential transfer function from voltage to current. A small change in voltage results in a large change in current. Two important factors that have to be taken into account are the irradiation and the temperature. In general, I-V curve for a PV array is non – linear so a specific point on the curve namely maximum power point needs to be tracked so that the whole system operates at maximum efficiency and produces maximum output power. Hence, Maximum Power Point Tracking (MPPT) algorithm is used for extracting maximum power available from a PV module under different conditions. Out of numerous available techniques the one that is used most widely and commonly is Perturb & Observe (P&O) algorithm. P&O is also called as hill climbing method because it checks the rise of the curve till MPP and the fall after that point[3]-[8]. Using P&O algorithm the controller adjust voltage and measures power and if this measured power is greater than the previous value of power, adjustments are made in the same direction until there is no more increment in power.

Generally, the MPPT controller is embedded in the power electronic converter systems, so that the corresponding optimal duty cycle is updated to the photovoltaic power conversion system to generate the maximum power point output.

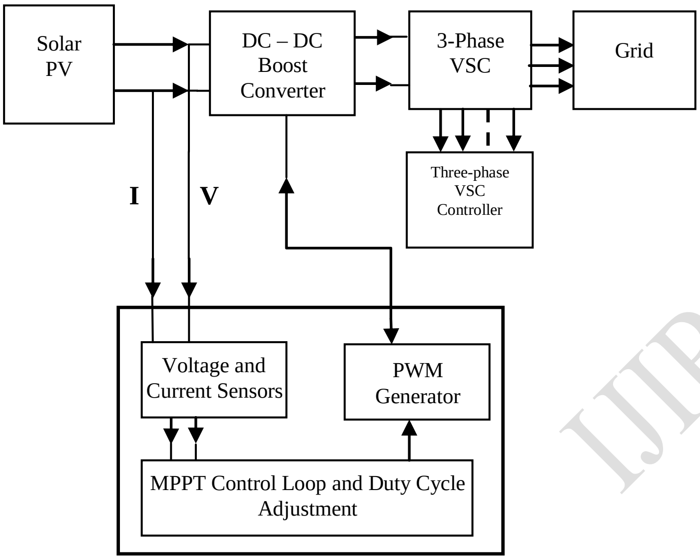

Figure 1: Block diagram of the proposed system

II. THE SOLAR CELL

The solar cell is the basic building block of solar photovoltaic. The cell can be considered as a two terminal device which conducts like a diode in the dark and generates a photo voltage when charged by Sun[9]. When charged by the Sun, this basic unit generates a dc photo voltage of 0.5 to 1volt and in short circuit, a photocurrent of some tens of miliamperes per cm^2.

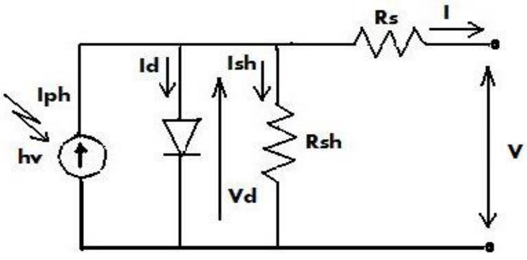

Figure 2: Equivalent circuit of PV solar cell

PV arrays are built up with combined series or parallel combinations of PV solar cells, which are usually represented by a simplified equivalent circuit model such as the one given in Figure2 and/or by an equation as in (1).

$$I = I_{ph} - I_0\left[\exp\left\{\frac{q(v+R_sI)}{nKT}\right\}-1\right]-\left[\frac{V+R_sI}{R_sh}\right] \qquad (1)$$

The output characteristic of a photovoltaic (PV) array is non-linear and is influenced by solar irradiance level, ambient temperature, wind speed, humidity, pressure, etc. The irradiation and ambient temperature are the two primary factors. To study the output characteristics of PV cell, some experiments based on simulation of PV cell have been done.

For constant temperature (25˚C) and different intensity (400-1000W/m2) The PV array current constant up to some voltage level and then it will be decreased. The PV array current always increases with intensity.

THE BOOST CONVERTER

The boost converter was chosen for its benefits in terms of cost saving, simplicity and efficiency. The values of some components such as inductor and capacitor were determined by using suitable equations in order to make sure continuous conduction mode is sustained.

Figure 3 depicts the basic circuit of an ideal boost converter with V_d and V_o as input and output voltages respectively and figure 4 shows the waveforms of the boost converter.

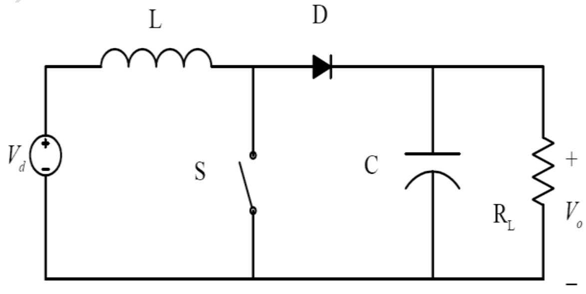

Figure 3: Ideal boost converter

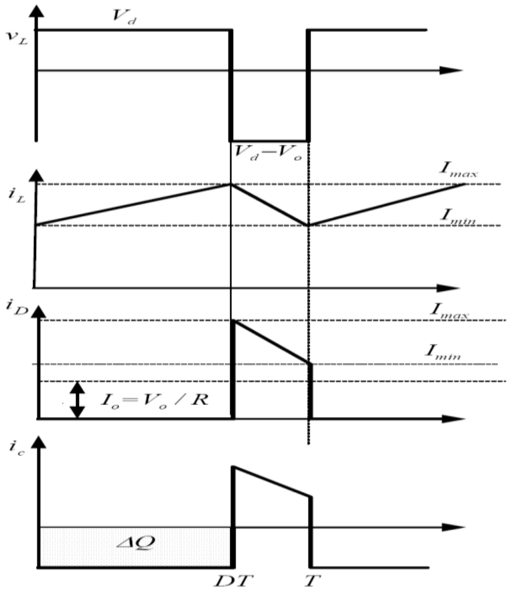

Figure 4: The waveforms of Boost Converter

There are two modes of operation of a boost converter. The operation mainly based on the ON and OFF mode of the switch. Firstly, when the switch is closed, this can be known as charging state. After that, second mode of operation will be initiated by opening the switch, and this state is known as discharging mode of operation.

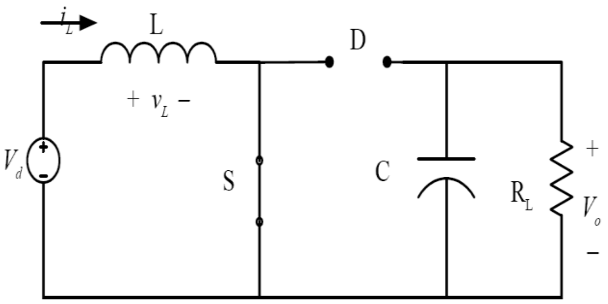

Figure 5: Equivalent Circuit during Switch Closed

$$V_d = L\frac{di}{dt} \tag{2}$$

$$V_d = L\frac{(\mathrm{I}_{\max} - \mathrm{I}_{\min})}{dt} \tag{3}$$

$$\frac{V_d}{L}dt = \mathrm{I}_{\max} - \mathrm{I}_{\min} \tag{4}$$

$$\mathrm{I}_{\max} = \mathrm{I}_{\min} + \frac{V_d}{L}dt \tag{5}$$

During discharging mode of operation, the switch is open and the diode is forward biased, as shown in Figure 6. At this time, the inductor is discharged to the capacitor and meets the load demand.

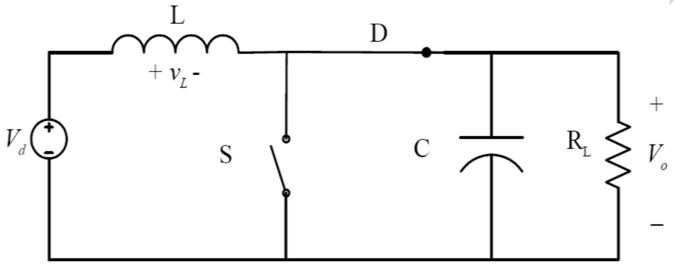

Figure 6: Equivalent Circuit during Switch Opened

$$\frac{V_0}{V_d} = \frac{I}{I-d} \tag{6}$$

$$\mathrm{L} = \frac{(I-d)^2\,Rd}{2f} \qquad (\text{Since } \mathrm{D} = 2f) \tag{7}$$

$$\frac{\Delta V_O}{V_0} = \frac{d}{Rcf} \tag{8}$$

$$C = \frac{V_0}{\Delta V_o R}\,\mathrm{dT} \tag{9}$$

VSC CONVERTER

The proposed inverter structure is designed to make use of a three-level topology called neutral point clamped. The IGBT semiconductor is used due to its lower switching losses and reduced size when compared to other power electronic devices. Indeed, the control of the output voltage is provided by the PWM technique. The three-level VSC regulates DC bus voltage at 500 V and keeps unity power factor. Id current reference is the output of the DC voltage external controller. Iq current reference is set to zero in order to maintain unity power factor. Vd and Vq voltage outputs of the current controller are converted to three modulating signals Uref_abc used by the PWM three-level pulse generator. The control system uses a sample time of 100 µs for voltage and current controllers. In the detailed model, pulse generators of Boost and VSC converters use a fast sample time of 1µs in order to get an appropriate resolution of PWM waveforms.

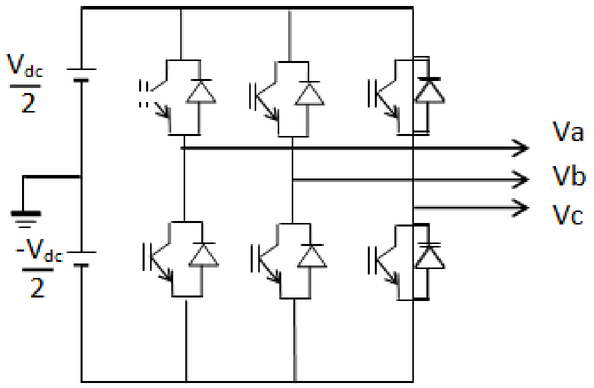

Figure 7: 3-Level Inverter

The inverter block implements a 3-level three-phase power converter that consists of up to six power switches connected in a bridge configuration. The type of power switch and converter configuration is selectable from the dialog box. The block allows simulation of converters using either naturally commutated (or line-commutated) power electronic devices (diodes or thyristors) and forced-commutated devices (GTO, IGBT, MOSFET).

SWITCHING TABLE

The switching table is formed using the sector, the corresponding voltage vector and the switch state. The summary of various states are given in table 1.

State No.	**SwitchingStates**								
	S1	S2	S3	S4	S5	S6	V_{ab}	V_{bc}	V_{ca}
1	ON	ON	OFF	OFF	OFF	ON	V_S	0	$-V_S$
2	ON	ON	ON	OFF	OFF	OFF	0	V_S	$-V_S$
3	OFF	ON	ON	ON	OFF	OFF	$-V_S$	V_S	0
4	OFF	OFF	ON	ON	ON	OFF	$-V_S$	0	V_S
5	OFF	OFF	OFF	ON	ON	ON	0	$-V_S$	V_S
6	ON	OFF	OFF	OFF	ON	ON	V_S	$-V_S$	0
7	ON	OFF	ON	OFF	ON	OFF	0	0	0
8	OFF	ON	OFF	ON	OFF	ON	0	0	0

Table 1: 3 Level Inverter Switching Table

III. MPPT ALGORITHM: PERTURB AND OBSERVE METHOD (P&O)

This method is one of the simplest online methods which, has been considered by a number of researchers [10–17]. P&O can be implemented by applying perturbations to the reference voltage or the reference current signal of the solar panel. A flowchart illustrating this method, which is also known as the ‘hill climbing method’ is depicted in Figure 7, where ‘‘V’’ is the reference signal. In this algorithm, if the reference signal, V is taken as the voltage, the goal will involve pushing the reference voltage signal towards V_{MPP} thereby causing the instantaneous voltage to track the V_{MPP}. As a result the output power will approach MPP. To this end, a small but constant perturbation is applied to the solar panel voltage. The solar panel voltage is changed by applying a series of small and constant perturbations denoted by (C=ΔV) on a step-by-step basis in order to change the system operating point. Following each perturbation, the output power variation (ΔP) is measured. If ΔP is positive, power will approach MPP, therefore a voltage perturbation of the same sign must be applied in the following stage. A negative ΔP, on the other hand, implies that power has moved away from MPP, and a perturbation of opposite sign will have to be applied. This process is repeated until the MPP is reached.

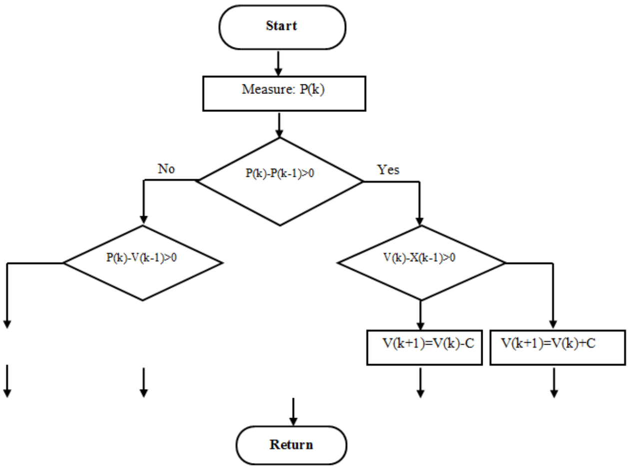

Figure 8: Conventional Perturb and Observe algorithm

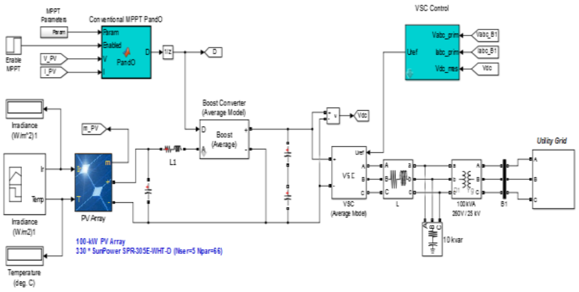

Figure 9: Proposed circuit diagram

IV. RESULTS

A. SIMULATION OF TEMPERATURE AND IRRADIATION

Figure 10 shows the irradiance and temperature variations generated as inputs on the solar array. Figure 10a shows irradiance generated at a constant value of 1000Kw/m^{2}for 0.5 second, decreases at 250Kw/m^2 for 0.5 second. The system increases steadily from 250Kw/m^2 at 0.5seconds to 1000Kw/m^2 at 2 seconds and is maintained constant.

Figure 10b shows a simulated behavioural pattern of temperature variation on the PV module. At a temperature of 25^{0}C (room temperature) for a period of 2 seconds, the PV module output varies as its temperature increases to an extreme value of 50^{0}C.

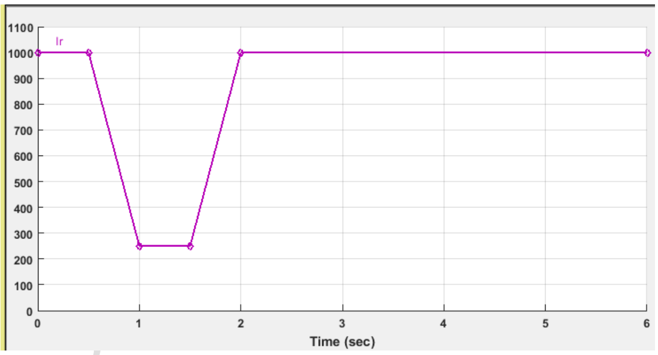

Figure 10a: Irradiance variations

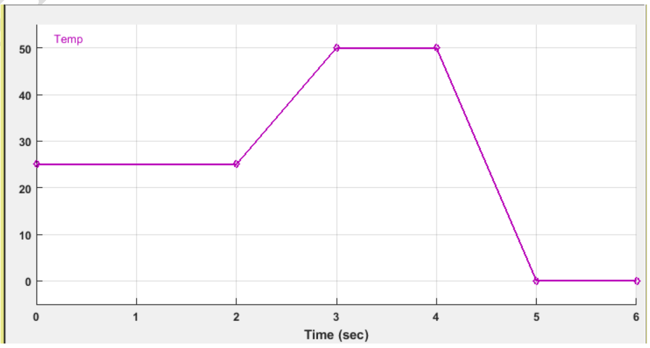

Figure 10b: Temperature variations

B. RESULT FROM THE SOLAR PANEL

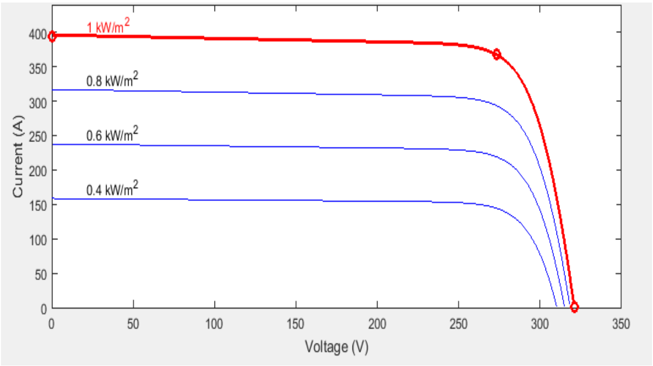

Figure 11 (a): I-V characteristics of Solar array for various irradiance at a constant temperature of 250C

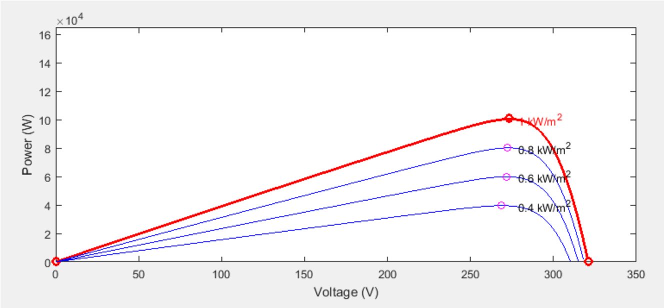

Figure 11 (b): P-V characteristics of Sola array for various irradiance at a constant temperature of 250C

For constant temperature (25˚C) and different intensity (400- 1000W/m2), the PV array power increases up to some voltage level and then it will be decreased. The PV array power always increases from low to high intensity.

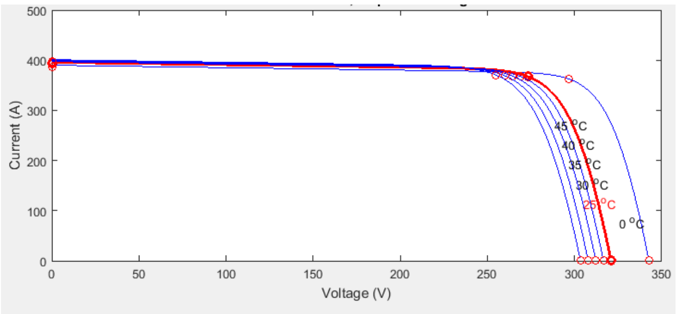

Figure 12 (a): I-V characteristics of Solar array for various temperature at constant irradiance of 1000W/m2

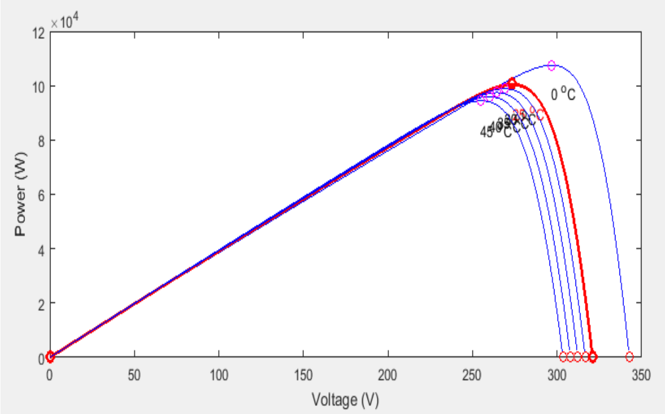

Figure 12 (b): P-V characteristics of Solar array for various temperature at a constant irradiance of 1000W/m2

C. RESULTS FROM THE BOOST CONVERTER OUTPUT

Figure 13 shows the duty cycle of the DC converter over a period of 5.5seconds which also varies a lot as the irradiance and temperature are varied.

Figure 14 displays the waveform of the current output of the DC converter over a period of 5.5seconds using the same variations in the irradiance and temperature. The current also varies with the duty cycle. The system has a dynamic performance as it can be noted as it has a quick rise time as the duty cycle also rises.

Figure 15 shows the voltage output of the DC converter over a period of 5.5seconds using the conventional technique with the same variations in the input parameters. The voltage curve also shows that the voltage decreases as the duty cycle changes.

Figure 16 shows the power output of the DC converter over a period of 5.5seconds using the conventional technique with the irradiance and temperature varied. By adjusting the voltage different output curves can be obtain with different steady state response and rise time.

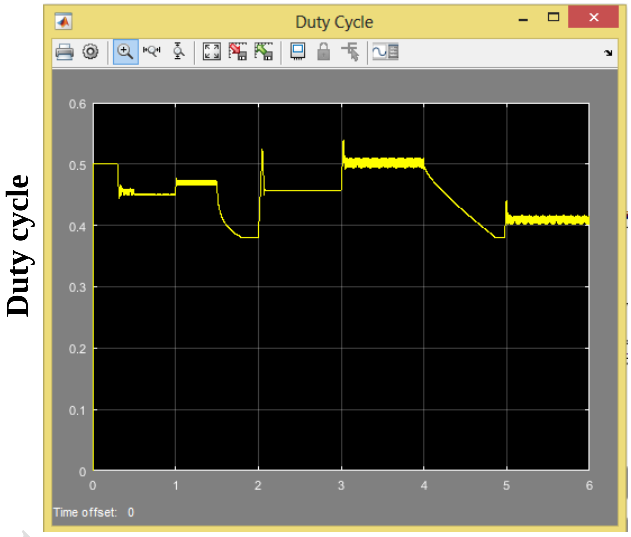

Figure 13: Duty cycle using the conventional MPPT

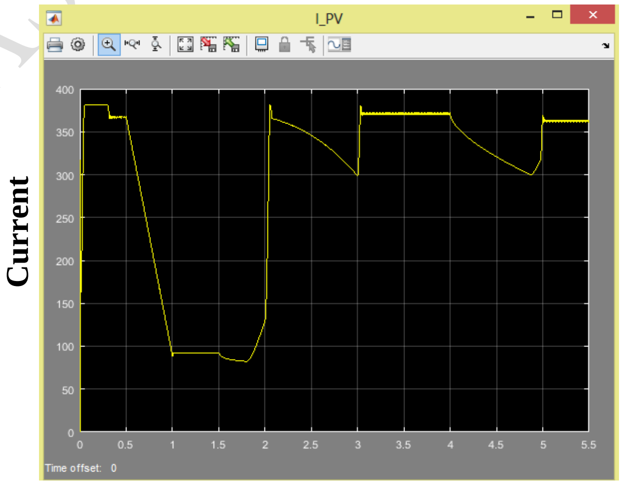

Figure 14: current output using the conventional MPPT

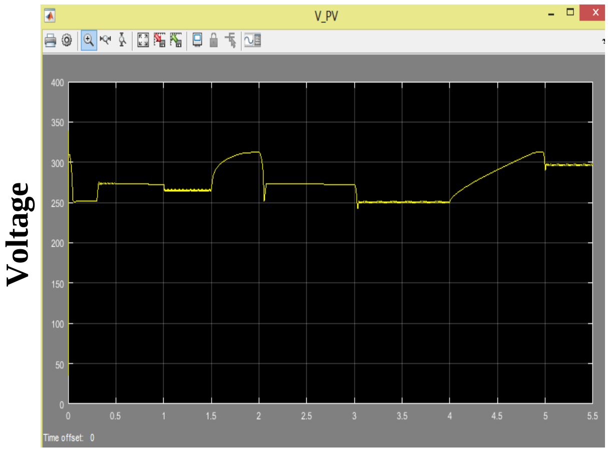

Figure 15: voltage output using the conventional MPPT

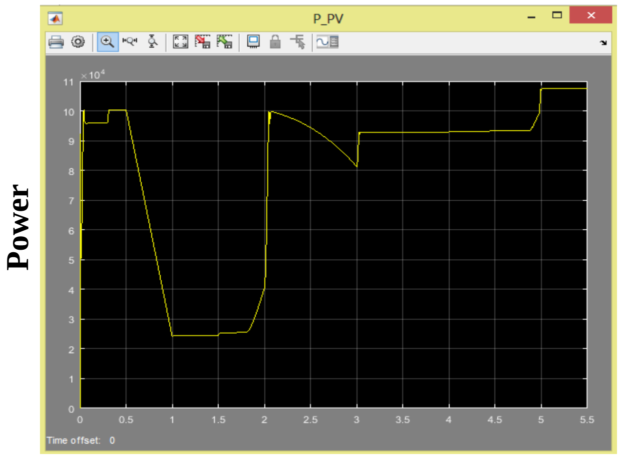

Figure 16: Power output using the conventional MPPT

D. RESULTS FROM THE VOLTAGE SOURCE CONVERTER

a. RESULTS FROM THE VOLTAGE SOURCE CONVERTER USING THE CONVENTIONAL PERTURB AND OBSERVE TECHNIQUE

Figure 17 shows the voltage of the VSC using the conventional perturb and observe technique as the irradiance and temperature are varied.

Figure 18 shows the current output of the VSC using the conventional perturb and observe technique; as the input parameters (irradiance and temperature) are varied, changes are also observed.

Figure 19 shows the power output of the VSC where many oscillations are observed and also the hill climbing problem is glaring. The curve also exhibits changes as the input parameters are varied.

Figure 20 shows the modulation index of the VSC as it varies with the input parameters.

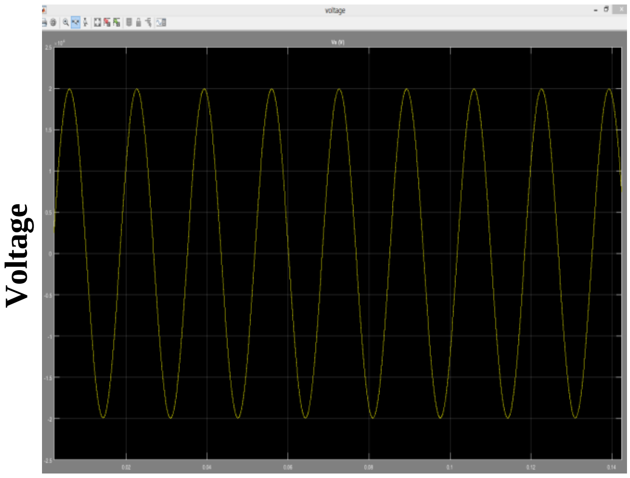

Figure 17: Voltage output of the VSC

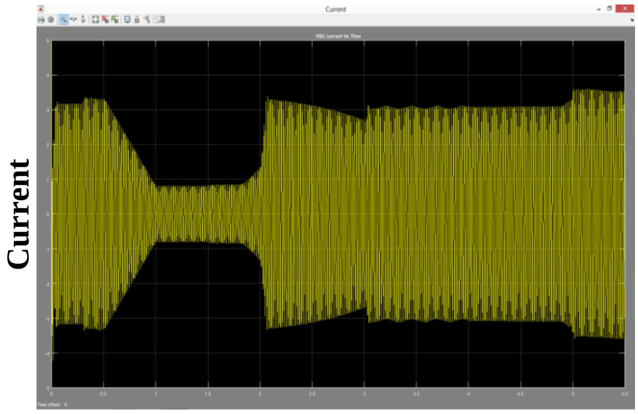

Figure 18: Current output of the VSC

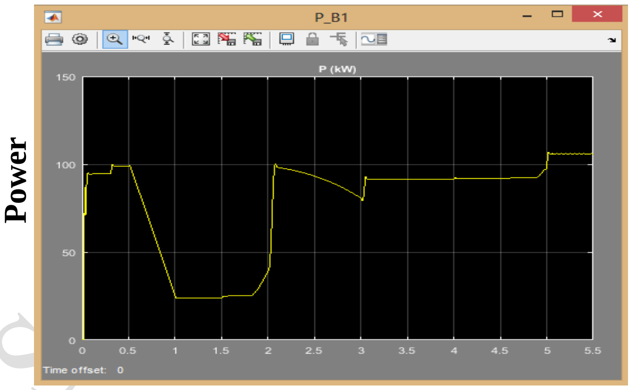

Figure 19: Power output of the VSC

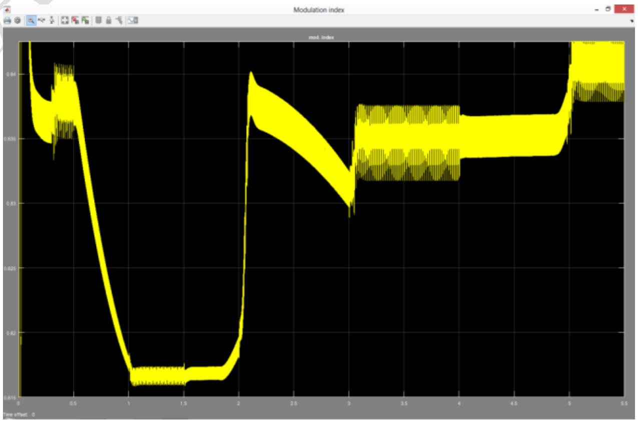

Figure 20: Modulation Index

V. CONCLUSIONS AND RECOMMENDATIONS

This work presented the implementation of the Perturb and Observe algorithm using a boost converter and a VSC converter connected to the utility grid. From the classification of available power distribution standalone and grid, a number of MPPT techniques are available. Selecting a particular MPPT for a system has to deal with its cost, reliability, speed, safety of the system. The power ratings of PV panel and climate conditions are also factors in certain areas and in some applications. MPPT techniques arement for mismatched conditions such as partial shedding, non-uniformity of PV panel temperatures, dust effects, damages of panel glass. Cases studied and discussed in the paper gives us a brief idea of PV panel working with a connected load. It also gives an advantage of pre evaluating overall system before going into real time. The whole PV panel – MPPT – Grid tied system is created in MATLAB/Simulink. PV panel Simulink block has under gone I-V, P-V characteristic check and results are obtained.

Further work is required to address some shortcomings of the algorithm. The original basis for the algorithm was the Perturbation and Observation technique which means that it may suffer from tracking in the wrong direction under rapidly changing conditions. Further work is also required into the methods used to select the best combination of parameters for the algorithm.

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