



## An Improvement in Performance of Grid Connected PV System with High Step-up DC-DC Converters

Ravindra Janga<sup>1</sup> and Nagalakshminarayana Alluru<sup>2</sup>

<sup>1</sup>Asst.Professor, Department of Electrical & Electronics Engineering, Bapatla Engineering College, INDIA-522101

<sup>2</sup>Student, Department of Electrical & Electronics Engineering, Bapatla Engineering College, INDIA- 522101

ravindra.janga@becbapatla.ac.in & nlnarayanaalluru@gmail.com

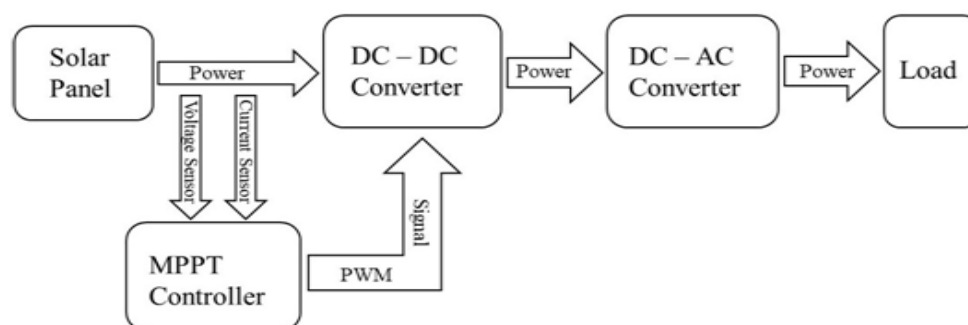
### ABSTRACT

With the rapid change and the continuous evolution towards renewable energy sources, solar energy becoming feasible one as compared to other renewable resources. To overcome the inconvenience in the conventional array and obtaining the maximum power from the solar PV array, a maximum power point tracking (MPPT) technique is adopted. This paper presents the step by step design procedure to design a grid connected solar PV system using high step-up DC-DC Converters. A PV array is first designed, for obtaining the maximum power from the PV array with the Perturb and Observe (P&O) MPPT controller and different DC-DC converter topologies are used to improve the performance of the system, which is then integrated with the a three phase multilevel inverter to connect with the commercial electrical grid and reliable usage of local household networks.

**Key words:** DC-DC converters, MPPT technique, Multi-level Inverters, P&O method, Solar PV cell

### INTRODUCTION

Due to the continuous evolution of renewable energy sources, the solar energy considered as one of the reliable energy source. The main draw back in solar energy conversion is its efficiency, for increasing the conversion rate and efficiency different tracking techniques are used [1]. Based on the load requirements, the solar array output can be stepped up by the high step DC converters. Some of the researchers are used Buck-Boost converter to get better performance from system but there is a remarkable topological advancements in the DC-DC Converters. In the present paper different DC-DC converter topologies are used including KY Converter and Sheppard Taylor DC-DC converter to improve the conversion efficiency and performance of the system. The step ratio or the duty cycle of the DC-DC converters are controlled by the Maximum Power Point Tracking (MPPT) controller. The Perturb and Observe (P&O) MPPT controller is designed here. The complete block diagram of the proposed grid connect solar PV system is shown in Fig.1.



**Fig. 1** Complete block diagram of the grid connected PV system

The MPPT controller senses the voltage and current from the output of the solar PV array which is then converted to PWM signal which is fed to the DC-DC converter. For grid interfacing and other local networking usage, the obtained dc power can be converted to ac power using an inverter. Multilevel inverters are considered for reducing the harmonics

in the output ac power. The grid connected solar PV system is proposed by connecting the above all modules i.e. the PV array is connected with the KY Converter and Sheppard Taylor DC-DC converter through a Perturb and Observe (P&O) MPPT controller, the dc output is given to three phase five level inverter and the ac power is obtained at the output of the inverter which is reliable to connect with grid and local household networks.

The main objective of this paper is to present step by step design procedure to implement the MPPT controller for PV System and to observe the improvement in performance of the system using KY Converter and Sheppard Taylor DC-DC converter which has better performance as compared to simple Buck-Boost Converter. And this paper also demonstrates the procedure to integrate a renewable energy system with Grid or isolated house hold system. Theoretical analysis of the various DC-DC converters are presented in detail and step by step design procedure for MPPT controller using P&O method described in detail., an improvement in efficiency of the system using MPPT controller is confirmed by the results of MATLAB, the performance of the controller are observed by applying disturbance and results are presented. Finally, conclusions are made based on the obtained results.

### MATHEMATICAL MODELING OF THE PV SYSTEM

It is possible to connect solar energy directly into electrical energy by means of silicon wafer photovoltaic cells, also called the solar cells, without any intermediate thermodynamic cycle. The solar cell operates on the principle of a photovoltaic effect, which is process of generating an emf as a result of the absorption of ionizing radiation. Thus a solar cell is a transducer, which converts the sun's radiant energy directly into electrical energy and is basically a semiconductor diode capable of developing a voltage of 0.5-1 volt and a current density of 20-40 mA/cm<sup>2</sup> depending on the material used and the conditions of sunlight. The efficiency of the solar cells is as low as 15%, but that does not matter as the solar energy is basically free of cost. Typically, one cell produces about 105 watts of power. Individual cells are connected together to form a solar panel or module, capable of developing 3 to 110 W power. Panels are connected together in series and parallel to make a solar array which can produce any amount of wattage as space will permit. Single crystal silicon is most highly developed material for photovoltaic conversion. When it is exposed to light, due to the electron migration, the electrical charges are generated [2-3]. The single diode model equivalent circuit of a PV cell can be shown in Fig.2.

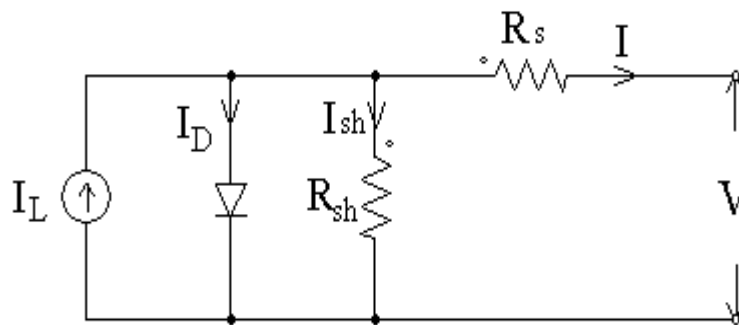


Fig. 2 Solar PV cell Equivalent Circuit

From the above equivalent circuit

$$I_D = I_0 \left[ e^{q(V+IR_s)/KT} - 1 \right] \quad (1)$$

$$I = I_L - I_0 \left[ e^{q(V+IR_s)/KT} - 1 \right] - (V+IR_s) / R_{sh} \quad (2)$$

Where

I: the cell current A, K: the Boltzmann's constant in j/k, I<sub>L</sub>: photo current in A, q: charge of electron in coulomb

I<sub>0</sub>: diode saturation current in A, T: cell temperature in Kelvin, V: output cell voltage in V

R<sub>s</sub>, R<sub>sh</sub>: series and shunt resistances of the cell in ohms

The I-V and P-V characteristics of a PV solar cell at different irradiance and temperatures can be shown in Fig.3 and Fig.4.

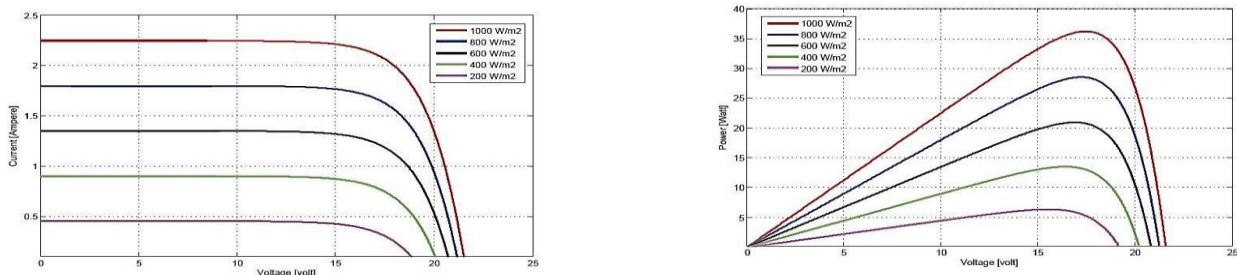
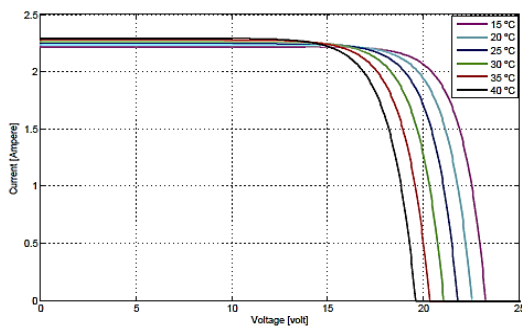
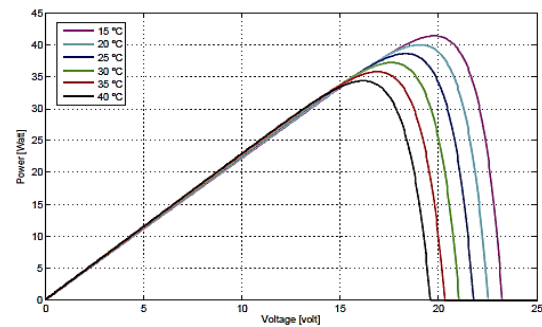


Fig. 3 Effect of irradiance on (a) I-V and (b) P-V characteristics



(a) I-V characteristics



(b) P-V characteristics

Fig. 4 Effect of temperature

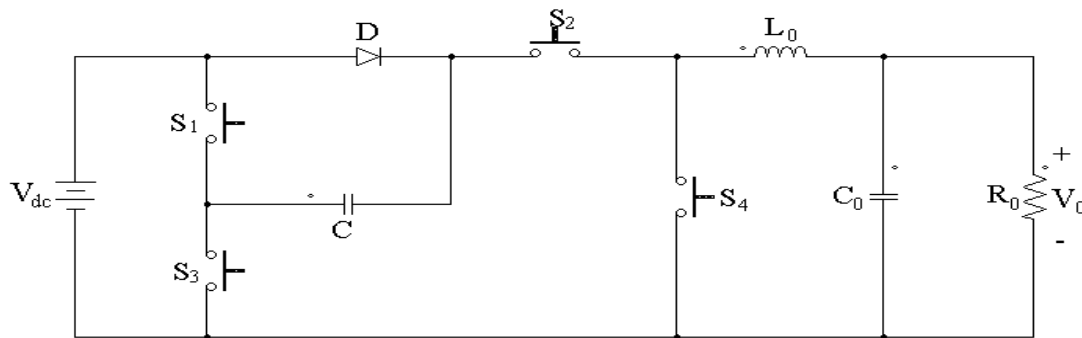
By increasing the solar irradiance, the solar input to the solar cell increases and hence power magnitude would be increases for the same voltage. By increasing the temperature, the energy gap in the cell increases and hence more energy is required for electron migration. Therefore, the efficiency of the cell is reduced.

### WORKING PRINCIPLE AND MATHEMATICAL MODELING OF THE DC-DC CONVERTERS

A DC-DC converter is a high speed ON/OFF semiconductor switch which connects and disconnects the source and load at a faster speed. These converts fixed dc input voltage to a variable dc (step-up or step-down) output voltage directly. They may be thought as dc equivalent of an ac transformer since they behave in an identical manner. Now a days, these are being used all over the world for rapid transit systems. Used in marine hosts, mine haulers, trolley cars etc. In future, these can be used for many applications in electrical automobiles like braking and speed control. The switches (or) power semiconductors used for DC-DC converters be power BJT, power MOSFETs, IGBT, GTO (or) force commutated thyristors. For obtaining high step voltages, different converter topologies are analyzed in this paper [4-10].

#### KY Converter

The circuit diagram of the KY converter [11] is shown in below Fig.5, which step up or step downs the magnitude of the

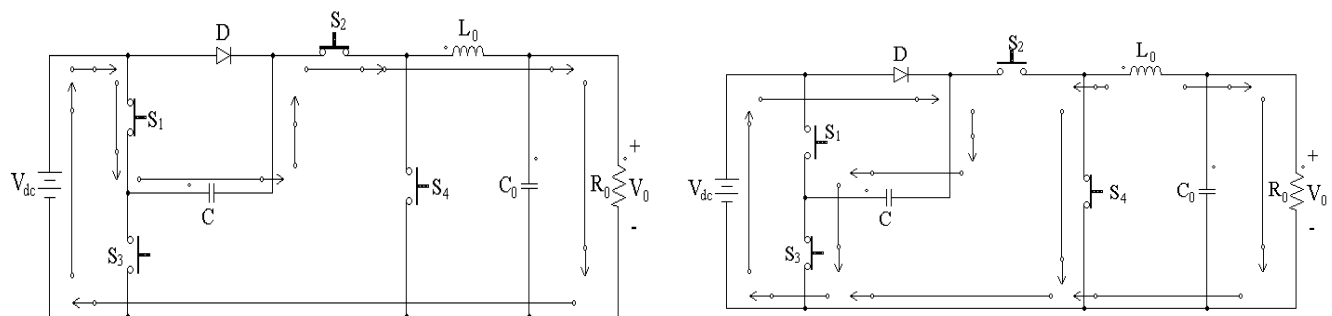


output voltage for a fixed input voltage.

Fig. 5 Basic Circuit Diagram for KY Converter

Based on the switching frequency, it can be operated in two modes of operation:

- Mode-I:** In this mode, the switches  $s_1$  and  $s_2$  are conducted and the switches  $s_3$  and  $s_4$  are in OFF state which is shown in the Fig.6 (a).
- Mode-II:** As shown in Fig.6 (b), the switches  $s_3$  and  $s_4$  are conducted and the switches  $s_1$  and  $s_2$  are OFF in this mode of operation.



(a) ON state of S1 and S2 (b) ON state of S3 and S4

Fig. 6 Modes of operation of K-Y Converter

In **mode-I**,

In this mode inductor  $L_0$  is magnetized and the voltage across it is given by

$$V_L = V_{Cb1} - V_0 \quad (3)$$

The current the capacitor  $C_0$ , inductor  $L_0$  and load resistance  $R$  is given by

$$L \frac{di}{dt} = 2Vi - V_0 \quad \text{and} \quad C \frac{dV_0}{dt} = i - (V_0/R) \quad (4)$$

In **mode-II**,

The inductor  $L$  is demagnetized, the current through the capacitor  $C_0$ , inductor  $L_0$  and the load resistance  $R_0$  is given by

$$L \frac{di}{dt} = Vi - V_0 \quad \text{and} \quad C \frac{dV_0}{dt} = i - (V_0/R) \quad (5)$$

From the above input and output differential equations, the relation between the input voltage  $V_{dc}$ , output voltage  $V_0$  and the duty cycle  $D$  is given as

$$\frac{V_o}{V_i} = 1 + 2D \quad (6)$$

### Sheppard-Taylor Converter:

For high step conversion, the Sheppard Taylor [12-14] converter topology is considered as shown in the Fig.7.

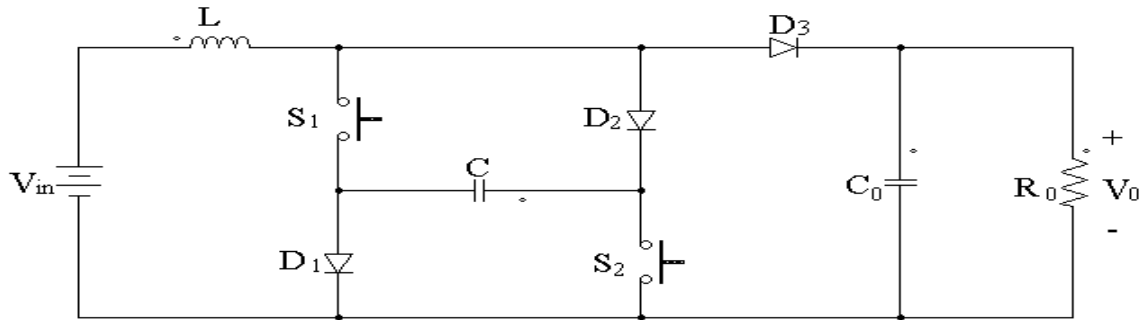


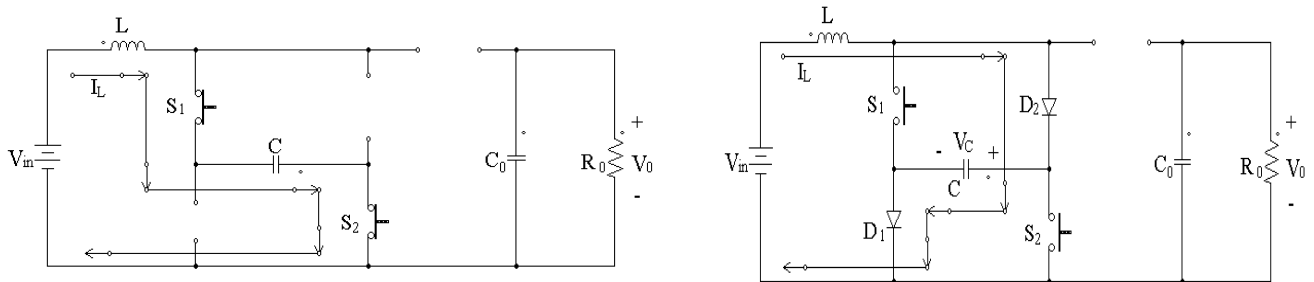
Fig. 7 Sheppard Taylor Converter

The Sheppard Taylor converter can be operated in three possible modes of operation:

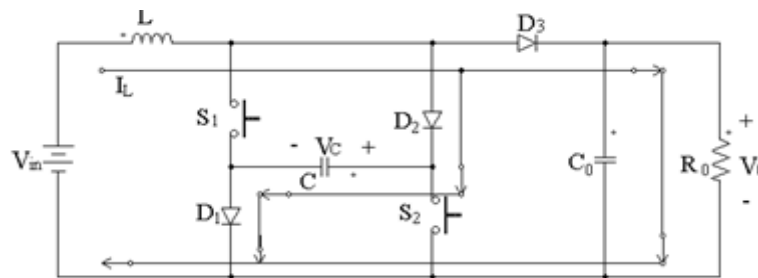
- i) **Mode-I:** In this, two switches  $S_1$  and  $S_2$  are turned ON and the diodes  $D_1$ ,  $D_2$  and  $D_3$  are turned OFF. The current flow path can be shown in Fig.8 (a).
- ii) **Mode-II:** As shown in Fig.8 (b), the switches  $S_1$ ,  $S_2$  and diode  $D_3$  are turned OFF and the diodes  $D_1$  and  $D_2$  are turned ON.
- iii) **Mode-III:** By turning off the switches  $S_1$ ,  $S_2$  and the diodes  $D_1$ ,  $D_2$  and  $D_3$  are turned ON. The current flow path can be shown in Fig.8(c).

In **mode-I**, the inductor  $L$  is magnetized and the capacitors  $C$  and  $C_0$  are discharged. Hence the corresponding equations can be written as

$$\frac{di_L}{dt} = \frac{V_{in} + V_C}{L}; \quad \frac{dV_0}{dt} = -\frac{V_0}{R_0 C_0}; \quad \frac{dV_C}{dt} = -\frac{i_L}{C} \quad (7)$$



(a) ON state of  $S_1$  and  $S_2$  (b) ON state of  $D_1$  and  $D_2$



(c) ON State of  $D_1$ ,  $D_2$  and  $D_3$

Fig. 8 Modes of operation of Sheppard Taylor Converter

In **mode-II**, the inductor  $L$  and the capacitor  $C$  are charged, the capacitor  $C_0$  remains discharged

$$\frac{di_L}{dt} = \frac{V_{in} - V_C}{L}; \frac{dV_0}{dt} = -\frac{V_0}{R_0 C_0}; \frac{dV_C}{dt} = \frac{i_L}{C} \quad (8)$$

In **mode-III**, both capacitors  $C$ ,  $C_0$  and the inductor  $L$  are charged and the corresponding equations are

$$\frac{di_L}{dt} = \frac{V_{in} - V_0}{L}; \frac{dV_0}{dt} = \frac{i_L}{C_0} - \frac{i_1}{C_0} - \frac{V_0}{R_0 C_0}; V_C = V_0 \quad (9)$$

### Multilevel Inverters

The obtained stepped DC voltage from the DC-DC converter can be converted to AC to fed into a commercial electrical grid and used for local, off-line electrical network. A device which converts dc power to ac power at desired output voltage and frequency is called an inverter. The multilevel inverter is to synthesize a near sinusoidal voltage from several levels of dc voltages. The need of multilevel inverter is to give a high output power from medium voltage source and to reduce harmonic content in output wave form [15-16]. The single phase five level and three phase five level inverters can be shown in the Fig.9 (a) and 9(b).

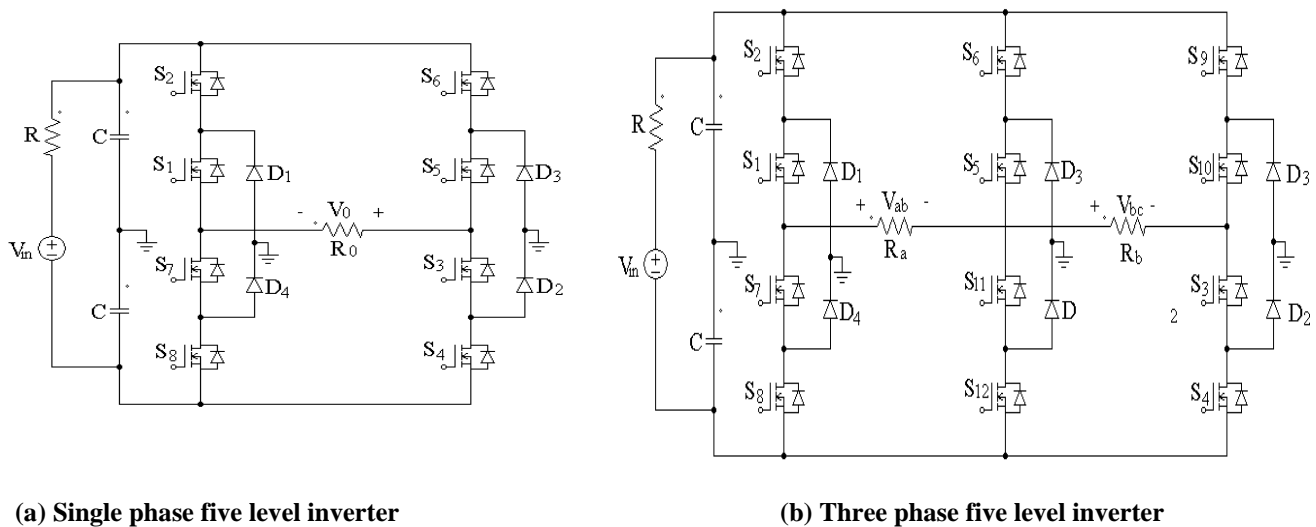


Fig. 9 Multilevel inverters

Now by considering the design parameters of DC-DC Converter as shown in Table-1 and by using the mathematical model of the converter a complete system is simulated in MATLAB software and is observed that a controller is required to get better performance from the converter.

Table-1 Design parameters of DC-DC Converter

Parameter	Symbol	Typical	Units
Input Voltage	$V_{in}$	12	V
Output Voltage	$V_0$	120	
Output Load Current	$I_0$	2.399	A
Switching Frequency	$F_s$	20	KHz
Duty cycle	$D$	60%	
Load Resistance	$R_L$	50Ω	
Inductance	$L$	1mH	
Capacitance	$C_1 \& C_2$	5&22μF	

### CONTROLLER DESIGN

Now with the A typical solar PV panel converts only (20-22) % (approx.) of the incident solar radiation to electrical energy equivalent, For absorbing more solar radiation and obtaining more electrical energy, different methods are considered like by installing concentrated mirrors, sun tracking, maximum power point tracking etc., Among the above, the MPPT technique is more reliable because of less losses due to the absence of rotating parts, more accurate due to the programmable interface. There are different MPPT techniques, listed as Perturb and observe (P&O) method, Incremental conductance method, Current sweep method, Constant voltage method etc.

In the presented paper a basic Perturb and observe (P&O) method is used for tracking the maximum power point on the solar panel. The flow chart for the Perturb and Observe method can be shown in Fig.10.

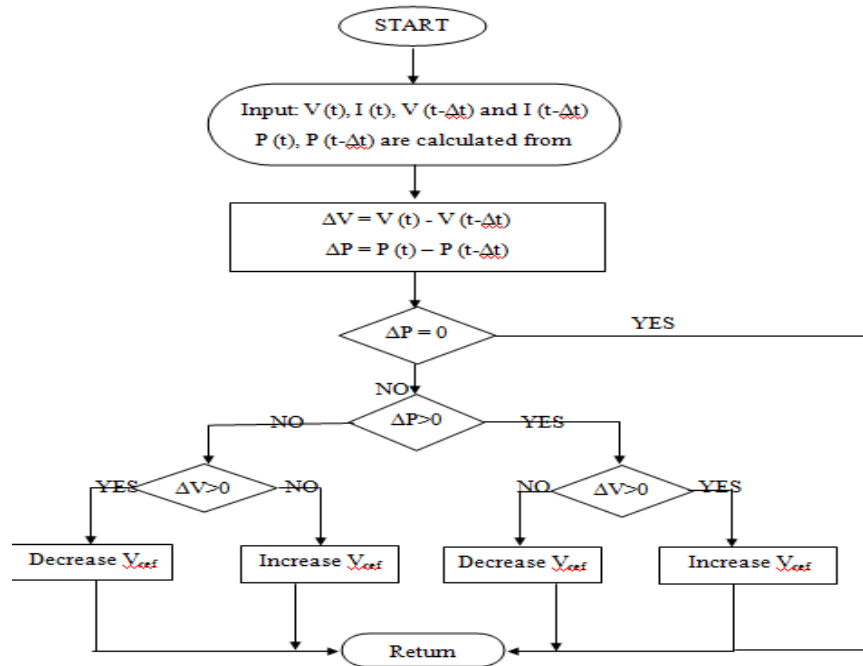


Fig. 10 Flow chart for P&amp;O Method

## RESULTS AND DISCUSSION

The detailed simulation, i.e., each element in the block diagram can be observed separately and the complete system was obtained by combining all the modules. In this paper, different DC-DC converter topologies are used and the simulation diagrams of the KY and Sheppard Taylor converters can be given in Fig.11 and Fig.12.

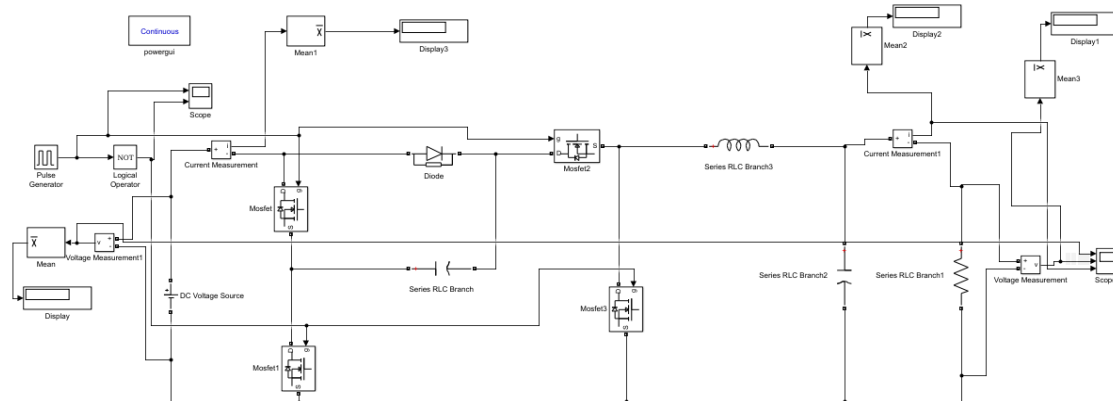


Fig. 11 Simulink model of KY Converter

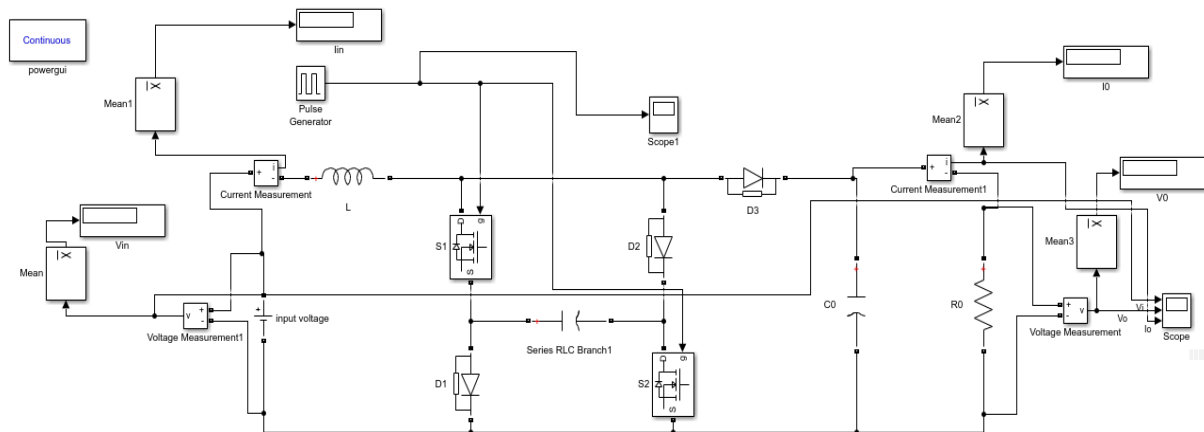
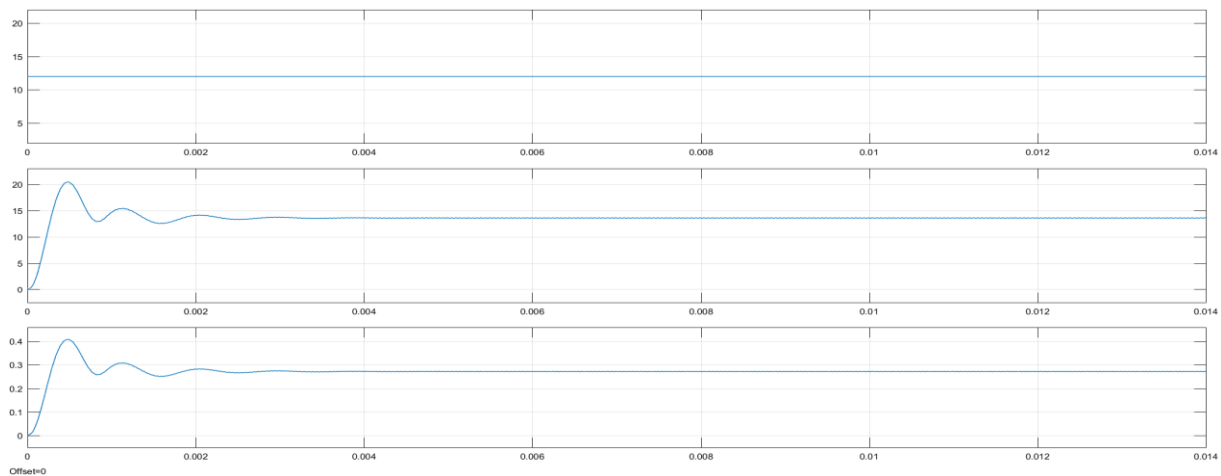
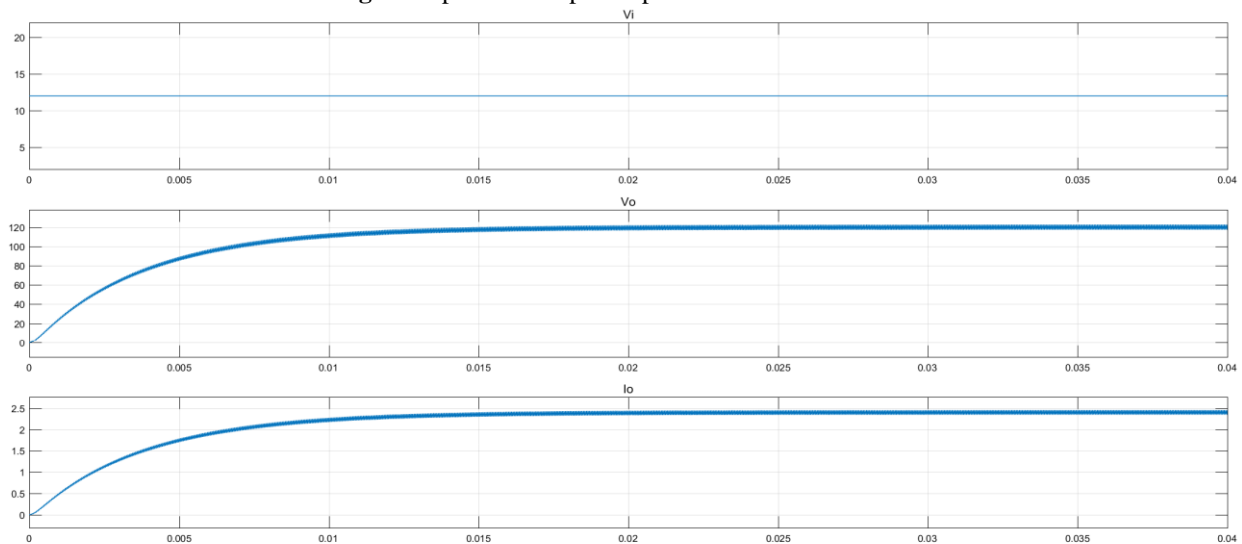


Fig. 12 Simulation model of Sheppard Taylor Converter

By taking input voltage as 12V and the duty cycle as 60%, the obtained results for both the converters are shown in Fig.13 and Fig.14.

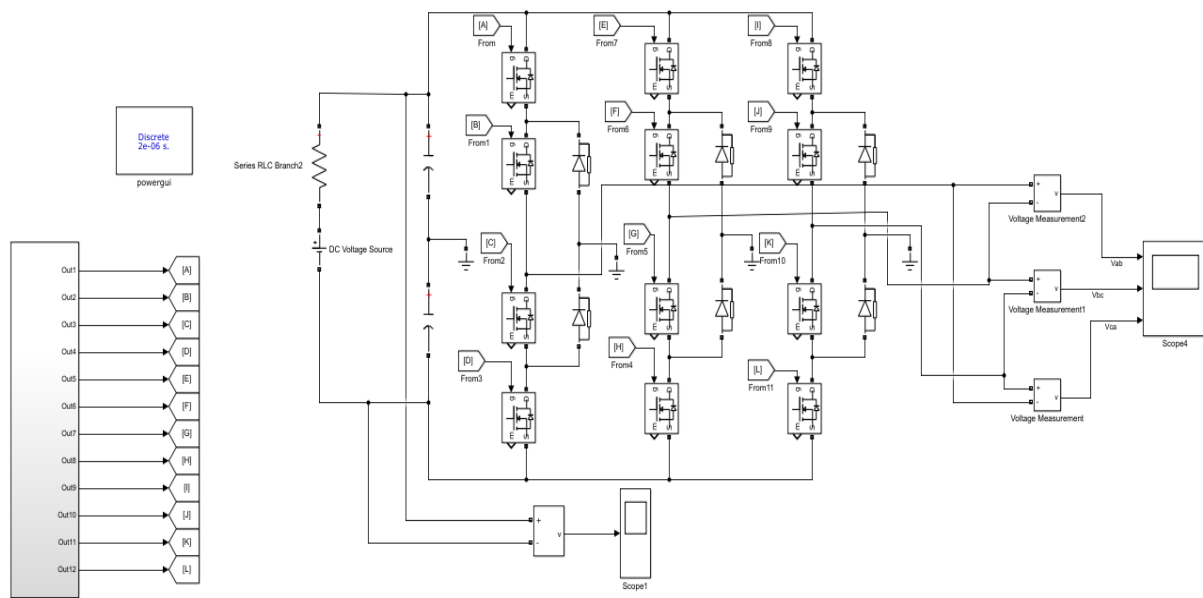


**Fig. 13** Input and Output responses for KY Converter

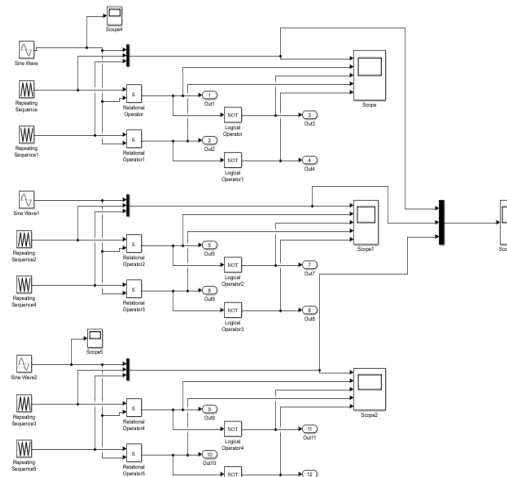


**Fig. 14** Input and Output responses for Sheppard Taylor Converter

Among the different inverter models, the three phase five level inverter simulation diagram is shown in Fig.15.

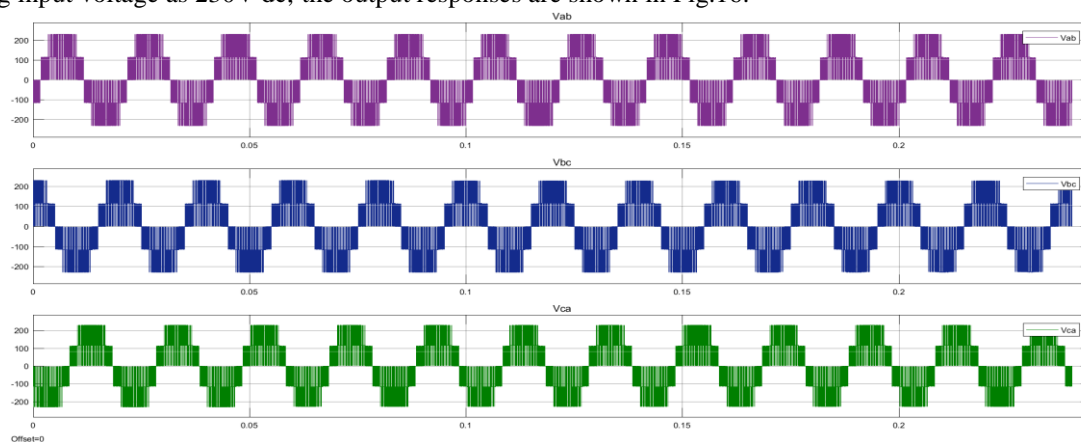


**Fig. 15 (a)** Simulink model of three phase five level inverter



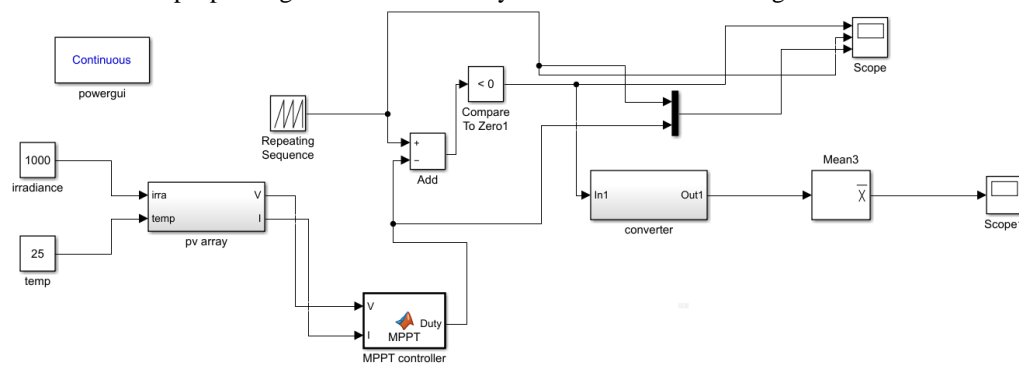
**Fig. 15 (b)** Sub system for sinusoidal PWM generation

By giving input voltage as 230V dc, the output responses are shown in Fig.16.

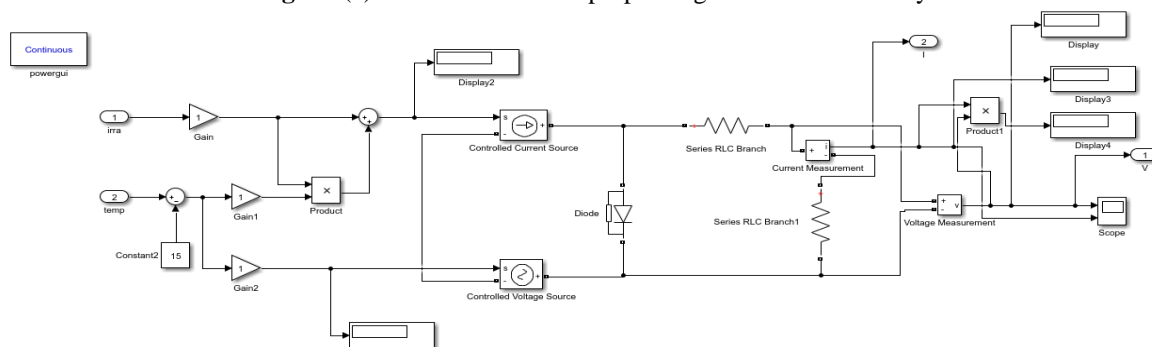


**Fig. 16** Output voltages of three phase five level inverter

The simulation model of the proposed grid connected PV system can be shown in Fig.17.



**Fig. 17 (a)** Simulink model of proposed grid connected PV System

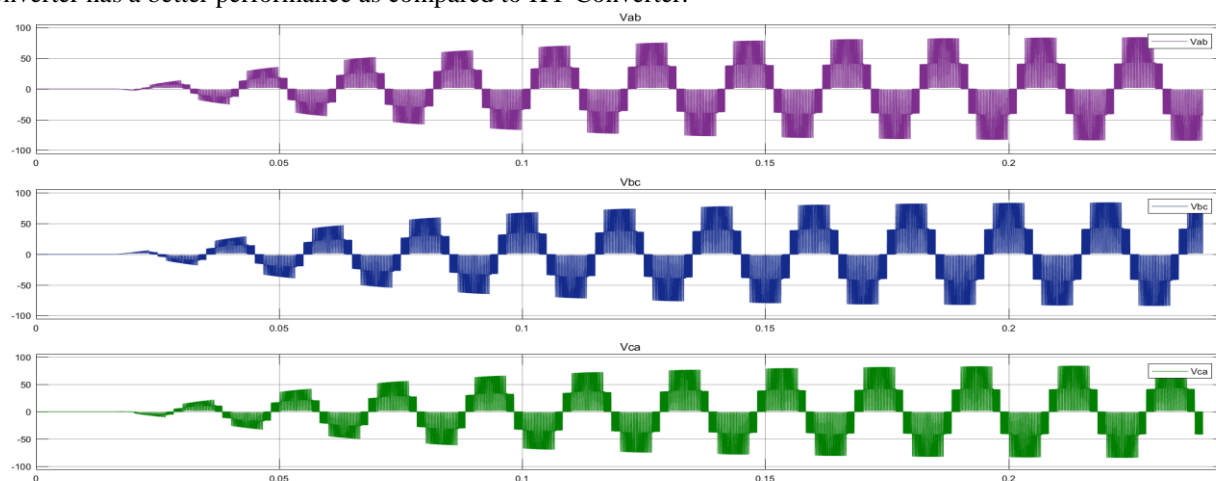


**Fig. 17 (b)** PV array sub system

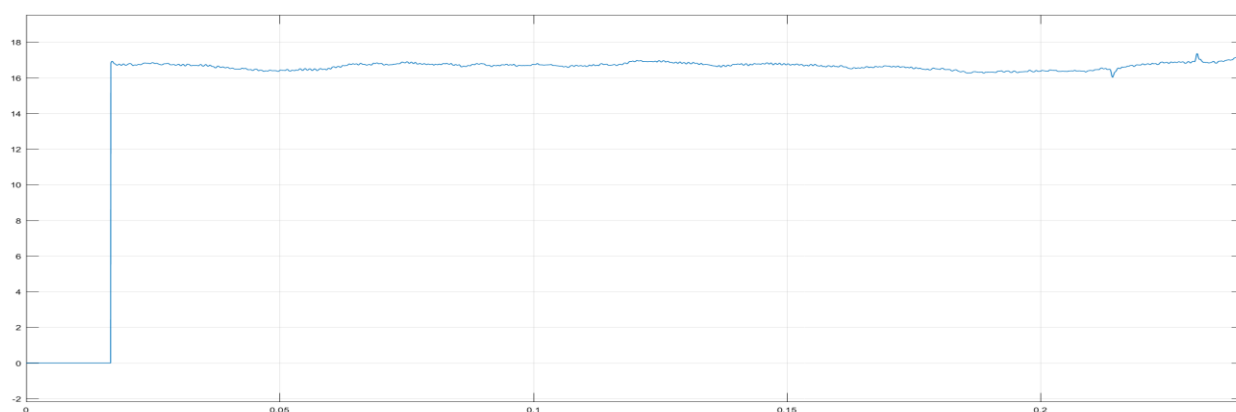


With the irradiance of  $1000 \text{ W/m}^2$  and temperature of  $25^\circ\text{C}$ , the PV array is connected to the DC-DC Sheppard Taylor converter through the MPPT controller which is a programmable interface. The output responses from inverter and the difference between KY and Sheppard Taylor are shown in Fig.18.

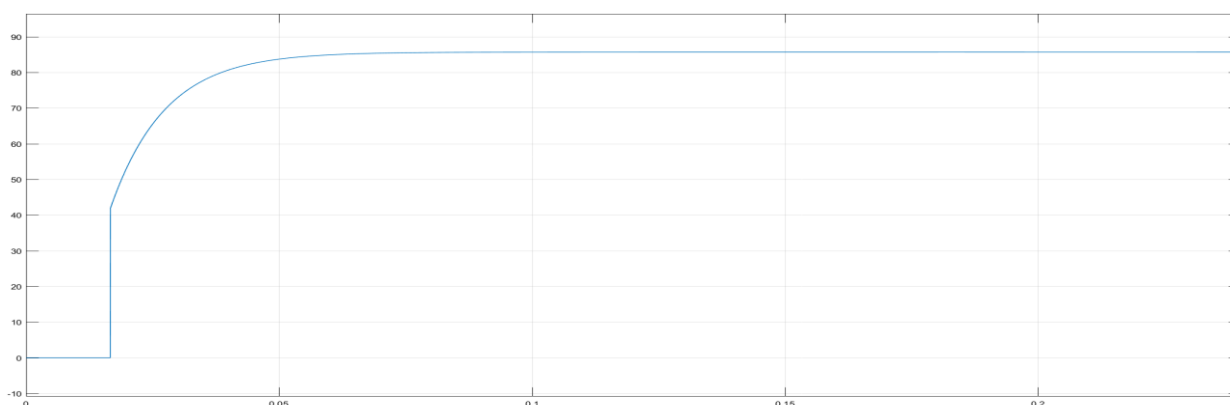
From the above results shown in Fig.18 (b) and in Fig.18 (c), we can conclude that a PV System with Sheppard Taylor Converter has a better performance as compared to KY Converter.



**Fig. 18 (a)** Voltages of the three phase five level inverter



**Fig. 18 (b)** Output voltage of the KY converter with MPPT controller



**Fig. 18 (c)** Output voltage of the Sheppard Taylor converter with MPPT controller

### CONCLUSION

A step by step design procedure for designing a grid connected PV system by analyzing with different DC-DC converters and with different inverters are presented. Among all the discussed DC-DC converters, the Sheppard Taylor gives the high step conversion. By comparing the output of the DC-DC converter with and without MPPT controller, the time required for reaching the maximum power is less with the MPPT controller. The final output from the three phase five

level inverter can be initially linearly increased up to maximum power is reached, after a constant voltage with 120° phase difference is obtained.

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