

# MODELING AND SIMULATION OF THREE-PHASE TWO-STAGE GRID-CONNECTED PV SOLAR BASED ON BOOST CONVERTER AND INVERTER WITH P&O ALGORITHM

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**Abstract**—In this paper, an effective way of feeding solar power to the grid is discussed. Voltage is kept constant at grid voltage when the irradiance is varying and the current fed to the grid is varied accordingly. Maximum Power Point Tracking (MPPT) is used to obtain the maximum power point and the boost converter works according to the output given by the MPPT. The perturb and observe algorithm is used for the MPPT. There are six Insulated-Gate Bipolar Transistors (IGBTs) in the inverter and one PWM signal input for each IGBT to switch those. The PWM signals are generated by the control circuit to obtain a sinusoidal output. The inverter output is fed to a LCL filter to deplete the harmonics. To synchronize the frequency and the phase of the system with the grid, the voltage and current are measured from the grid side and they are fed to a phase locked loop. For the control purpose, the d-q frame and  $\alpha\beta$  frame are used. Signals of d and q axis currents and voltages are fed to the current control blocks from where the PWM signals required for the inverter are produced.

**Keywords**— Photovoltaic; Maximum power point tracking; Perturb and Observe, Two-stage; Grid-connected.

## I. INTRODUCTION

The continuous rise in the global energy demand has overloaded the distribution grids causing problems such as a decline in power quality, power outages, power insecurity and grid instability. Renewable energy sources such as solar, wind and biomass are seen as promising solutions to stabilize the generation and energy demand.

Among the above-mentioned renewable energy sources, solar energy is widely accepted as the most effective resource due to its abundance and its cost-free nature. The maintenance cost for solar energy is zero and pollution is minimal [1]. Direct solar insolation density up to 1000 W/m<sup>2</sup> is received by some tropical countries. There are some advantages such as a simple control scheme and system configuration compared to conventional standalone photovoltaic systems. However, battery banks are needed to store excess energy and to draw maximum power from photovoltaic arrays in these systems [1,2]. Solar cell arrays are connected into arrays through modules to generate large load demands because individual solar cell arrays can generate only a small amount of power. The output voltage of the photovoltaic array varies with solar radiation and ambient temperature.

The generation of photovoltaics has taken the attention of academia and industry in inspiring the severe need to depart from the generation of electricity using fossil fuels. Grid connected and standalone systems are the two main forms of photovoltaic systems. In low-power applications and several battery stores for power generation, standalone systems can be used.

To provide the utility grid with renewable energy in high and low power applications, grid connected applications can be used. Grid connected systems can be divided into single stage or two stage systems. In two stage systems, the first stage comprises the dc-dc boost converter which boosts the photovoltaic voltage and achieves MPPT, and the second stage consists of the DC-AC inverter which synchronizes the power provided with the utility grid power and relocates the collected power from the photovoltaic array to the main grid [3,4]. But when the single-stage systems are considered, there are some disadvantages such as switching losses, higher harmonic contents in high voltage applications, lower DC voltage stability, and higher AC side voltage total harmonic distortion (THD).

Since the characteristic curve of a PV panel is non-linear, it is essential to operate it at the maximum power point (MPP) in order to obtain the highest output power and maximize efficiency. MPP's current and voltage depend on the factors of the environment such as module surface temperature and sun insolation [4]. The PLL (phase locked loop) is used to synchronize the photovoltaic inverter with the main grid [5]. The major role of the PLL is to supply a unity power factor operation that contains synchronization of the inverter output current with the grid voltage, and it can be used in controlling grid current using p-q theory and d-q theory. Harmonic currents which are generated by the grid connected inverter are removed using the LCL filter. Removing harmonic currents results in a smooth sinusoidal current and as a result of that, the power quality is improved [2,5].

## II. LITERATURE REVIEW

The literature review done regarding the previous researches on the same topic revealed the following research gaps. It was identified that single stage solar inverters were more widely proposed in researches [2,5]. Consequently, the switching losses and harmonic contents will be higher in high voltage applications. The proposed two stage design will alleviate this drawback. Most researches have not incorporated maximum power point tracking capability in the design [1,2]. The inclusion of MPPT in this design is a major advantage as it improves the efficiency of the system. The absence of a filter to attenuate the current harmonics produced by the switching activities of the inverter is another limitation identified during the literature review [3]. The LCL filter included in the proposed design is used to overcome this limitation. The phase and frequency synchronization of the inverter output and the grid were not discussed in the previous researches done on the same topic. This research intends to overcome the afore mentioned short comings identified during the literature review.

### III. SYSTEM DESCRIPTION

According to the basic schematic of a two stage three phase grid connected solar inverter, a boost converter at the input can be used in the implementation of the MPPT and to increase the input solar voltage to a higher value. The output of the boost converter should be connected to a three-phase inverter followed by an LCL filter. The specifications of the systems are mentioned in TABLE I.

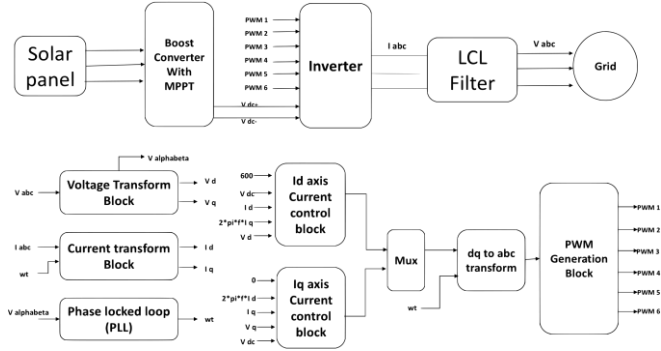


Fig. 1. The proposed block diagram of three-phase two-stage grid connected PV solar inverter

Fig. 1 Shows the proposed blocked diagram for the three-phase two-stage grid connected PV solar inverter. According to the above figure, the output of the PV array is given to a boost converter with MPPT. Then the inverter is fed with the output of the boost converter and six PWM signals. These PWM signals are generated using a separated circuit which consists of current and voltage transform blocks, PLL,  $I_d$  and  $I_q$  axis current control blocks and a PWM generation block. The output of the inverter is given to the grid through a LCL filter.

TABLE I. ELECTRICAL SPECIFICATIONS OF THE SYSTEM DESCRIBED IN THE

Parameter	PAPER	Symbol	Value
Open circuit voltage of solar panel		$V_{OC}$	363 V
MPPT operating range		$V_{MPPT}$	270 V – 300 V
Switching frequency of the boost converter		$F_{SW1}$	5 kHz
Inductance of the boost converter		$L_{BC}$	1.45 mH
Capacitance of the boost converter		$C_{BC}$	3227 $\mu$ F
Output voltage of the boost converter		$V_{BC}$	600 V
Switching frequency of the inverter		$F_{SW2}$	10 kHz
Inductance of the LCL filter		$L_{LCL}$	500 $\mu$ H
Capacitance of the LCL filter		$C_{LCL}$	100 $\mu$ F
Total rated power of the system		$P_{rated}$	100 kW

### IV. PV GENERATOR MODEL

Under current generators with dependent sources, photovoltaic generators can be considered as an approximated component. But it cannot be categorized as a fixed current source or a voltage source. When it is dark, the solar cell is an inactive device. It does not produce either a current or a voltage. A p-n semiconductor junction is an essential part of a solar panel cell. When it is exposed to light, a current is generated (DC). The current generated is changed linearly with solar irradiance.

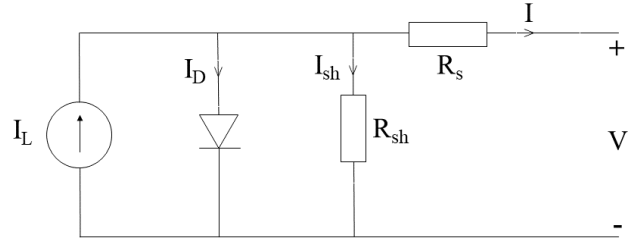


Fig. 2. Equivalent electrical circuit of an ideal solar cell

The following equations describe the V-I characteristics of the circuit of the solar cell shown in the Fig. 2. The current through the diode is given by:

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

While the solar cell output current:

$$I = I_L - I_D - I_{Sh} \quad (2)$$

$$I = I_L - I_0 \left[ \exp \left( \frac{q(V + IR_s)}{KT} \right) - 1 \right] - \frac{V + IR_s}{R_{sh}} \quad (3)$$

Where:

- $I_L$ : Light generated current (A)
- $I$ : Solar cell current (A)
- $q$ : Electron charge ( $1.6 \times 10^{-19}$  C)
- $I_0$ : Diode saturation current (A)
- $K$ : Boltzmann constant ( $1.38 \times 10^{-23}$  J/K)
- $V$ : solar cell output voltage (V)
- $T$ : Cell temperature in Kelvin (K)
- $R_{sh}$ : Solar cell shunt resistance ( $\Omega$ )
- $R_s$ : Solar cell series resistance ( $\Omega$ )

Using MATLAB software, V-I and P-V curves of the PV array are obtained assuming a constant solar irradiance and a constant temperature. If there is a variation in the irradiance or cell temperature, the current-voltage and power-voltage characteristics also vary. When the temperature increases, the efficiency decreases. This is an indication of the necessity of voltage, or current regulation power electronic circuits (MPPT), and this can act as a system to maximize the generated power. Fig. 3 represents the V-I and P-V curves of a PV array when the solar irradiance is  $1000 \text{ W/m}^2$ .

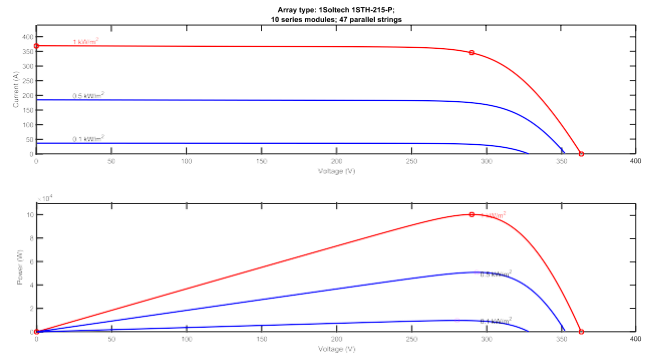


Fig. 3. V-I curve and P-V curve of the PV array

V. MODEL OF MPPT WITH BOOST DC-DC CONVERTER

There are two hardware topologies for MPPT in photovoltaic applications. They are single stage and two stage photovoltaic systems. The two-stage photovoltaic energy conversion system has been used since it facilitates easy operation of the system when compared to the single stage configuration. As the output voltage of a PV cell is low, low voltage photovoltaic arrays are enabled by the boost circuit to use in this system. As a result of that, the total cost will be lesser. A capacitor is normally fixed between the photovoltaic array and the boost circuit, which reduces high frequency harmonics. DC-DC boost converters increase the photovoltaic voltage to the level of the accepted maximum line voltage and the constant required dc level without storage elements.

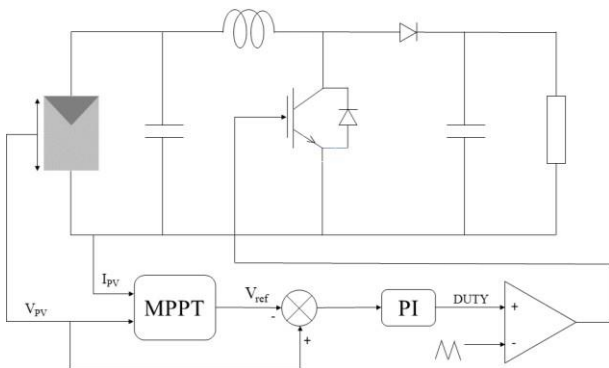


Fig. 4. Block diagram of the boost converter with MPPT

In addition, a variable input and constant output are possible with PWM in a boost converter. The control circuit regulates the output by adjusting the duty cycle of the gating system.

The energy stored in the inductor of the boost converter is proportional to the square of the inductor current. As a result, the inductor stores more energy when it is connected to electricity for a longer time. In addition, the capacitors of the boost converter filter the ripples of the output voltage. This indicates that as the capacitance is increased, the ripples are reduced.

$$L_{BC} = \frac{V_{in}(V_{op}-V_{in})}{f_{sw} * \Delta V * V_{op}} = 1.45 \text{ mH} \quad (4)$$

$$C_{BC} = \frac{I_{op}(V_{op}-V_{in})}{f_{sw} * \Delta V * V_{op}} = 3227 \text{ } \mu\text{F} \quad (5)$$

Where,

- Solar operating voltage range ( $V_{in}$ )= 250 – 350 V
- Output voltage ( $V_{out}$ ) = 600 V
- Rated power = 600 W
- Switching frequency ( $f_{sw}$ ) = 5 kHz
- Input current =  $\frac{100 \text{ kW}}{250 \text{ V}} = 400 \text{ A}$
- Current ripple ( $\Delta I$ ) = 5% \* 400 = 20 A
- Voltage ripple ( $\Delta V$ ) = 1% \* 600 = 6 V
- Output current =  $\frac{100 \text{ kW}}{600 \text{ A}} = 166 \text{ A}$

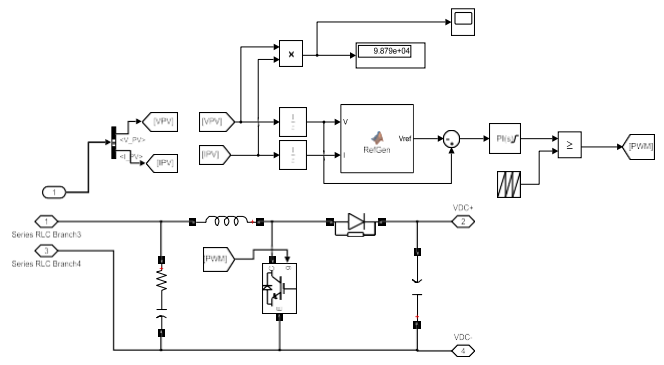


Fig. 5. MPPT with boost converter circuit diagram

An IGBT (Insulated Gate Bipolar Transistor) is a device which consists of three terminals made of semiconducting materials. IGBT is a rapid switching device that is used to maintain high efficiency in the system. When the diode of the boost converter is placed in reverse bias, it slows the voltage drop across the output capacitor by supplying stored energy to the load.

The maximum power that a photovoltaic panel can deliver highly depends on the operating temperature. Due to this, it is essential to monitor the maximum power point. Usually, the operation of a photovoltaic system varies due to changes in load and weather. A dynamic tracking technique is needed in ensuring that the PV arrays produce the maximum amount of power. Here, the perturb and observe method is used. The flowchart of the P&O algorithm is shown in Fig. 6. According to that, a few parameters are measured and those are fed as inputs to this algorithm which employs a simple feedback arrangement.

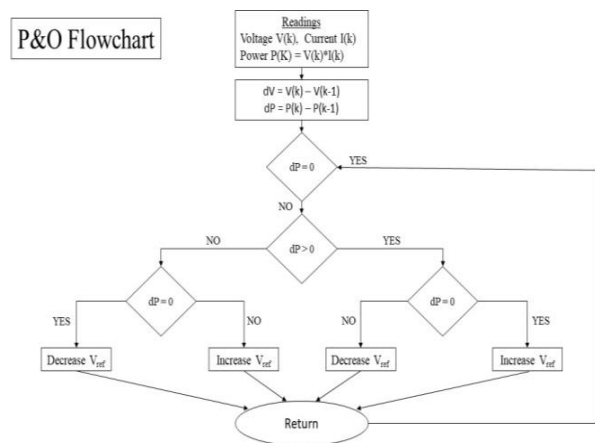


Fig. 6. Perturb and Observe method flow chart

According to this method, the module voltage is perturbed regularly. Then the available output power is compared to that of the previous perturbing cycle. The system is subjected to a minor perturbation according to this algorithm. A Solar module will result in varying power because of this perturbation process. If the power goes up because of this perturbation process, the perturbation will happen repeatedly in the same direction. After reaching the maximum power, the difference between previously calculated power and present power output at the maximum power point is zero and

the next instant present power output decreases, causing the perturbation to reverse. When the algorithm reaches a stable state, it oscillates around the maximum power point. To keep the variations in power as trivial as possible, the size of the perturbation is kept at a smaller value. This method is continued in a way that it establishes a reference voltage for the module that corresponds with the maximum voltage of the module. Then the PI controller is used to transfer the operating point of the module to that specific voltage level.

This means that  $V_{in}$  and  $I_{in}$  are the inputs to the MPPT MATLAB function, and  $V_{Ref}$  is the output.  $V_{Ref}$  is the voltage that corresponds to maximum power at a given irradiance. The difference between  $V_{Ref}$  and  $V_{PV}$  is then fed to the PI controller as an input, and it generates a corresponding output signal. The output is then compared to the sawtooth waveform, and a corresponding pulse stream is produced.

MATLAB code occasionally shows an error in evaluating PV array values. To avoid this error, unit delay blocks are connected

### VI. INVERTER MODELING

Inverters are used to convert DC sources into AC sources.

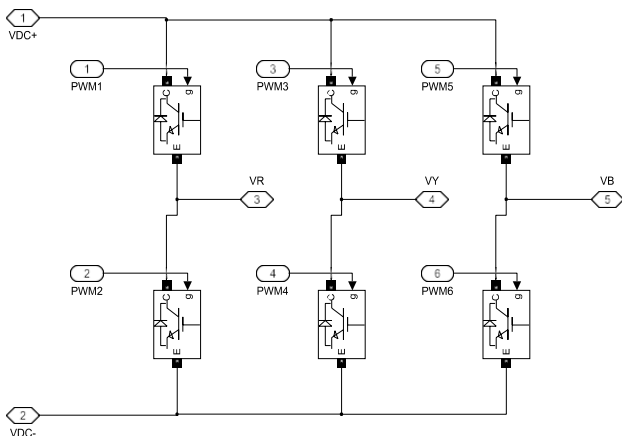


Fig. 7. Inverter circuit diagram

PWM signals determine the on/off state of IGBT switches as well as the time period of retention in each state. As in Fig. 7, six inputs for six PWM signals must be provided separately. It employs a different circuit. The inverter converts the input dc signal to the relevant three phase ac signals  $V_r$ ,  $V_y$ , and  $V_b$ .

In addition, in this case, an IGBT combines an isolated gate FET for the control input and a bipolar power transistor as a switch in a single device. Capacitors in the inverter are connected in parallel with the input to reduce the effects of voltage fluctuations.

#### A. PWM Signals Generation Block

The inverter control strategy has two control loops. They are a rapid inner control loop and external voltage loop. The rapid inner control loop regulates the grid current, and the external voltage loop regulates the dc link voltage. Power quality issues such as a low power factor and high total harmonic distortion are controlled by the current control loop while the voltage control loop is responsible for balancing the power flow of this system. To convert these currents and

voltages into dq frame, an abc to dq transformation block is utilized. Fig. 8 shows the main components of the PWM signal generation block.

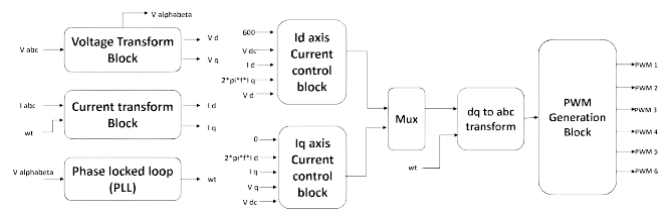


Fig. 8. PWM signals generation block

#### B. Phase Locked Loop (PLL)

PLL techniques cause one signal to follow another. It maintains the frequency and the phase synchronization between an output signal and a reference input signal. PLL can be implemented in a three-phase grid-connected system by employing a d-q transformation block and a properly designed loop filter.

Voltages and currents must be in-phase in order to feed the grid. In the dq-frame, the angle between the d-axis and  $V$  should be zero, or the reactive part of  $V_q$  and  $I_q$  should be zero in the dq-frame. PLL is used to find  $\omega t$  based on these requirements.

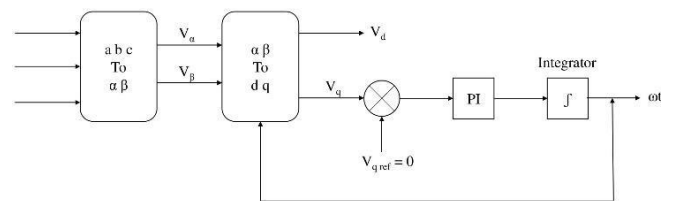


Fig. 9. Block diagram of the PLL

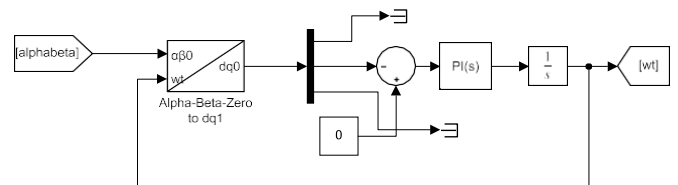


Fig. 10. Circuit diagram of the PLL

As in Fig. 9 and Fig. 10, initially  $V_a$ ,  $V_b$ , and  $V_c$  signals are converted in to  $V_\alpha$  and  $V_\beta$  signals. Then they are converted in to  $V_d$  and  $V_q$  signals. By using a control mechanism, the value of  $V_q$  is made zero.

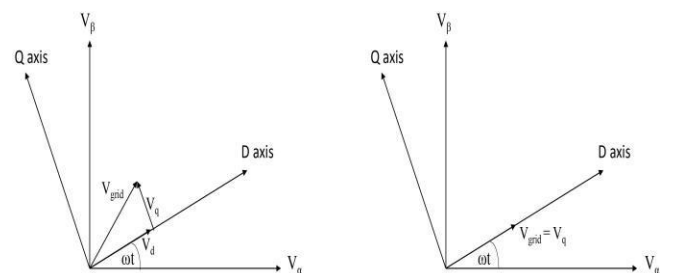


Fig. 11. Graphical representation

Fig. 11 shows the graphical representation before and after the control mechanism is used to make  $V_q = 0$ .

Now  $V_d$  and  $V_{grid}$  graphs coincide with each other and the angle between  $V_\alpha$  and  $V_d$  is  $\omega t$ .

$V_{abc}$  is the sensed grid voltage that is converted to DC components using the coordinate transformation abc-dq, and the PLL is locked by setting  $V_{qRef}$  to zero. PI is a low pass filter in the loop filter which functions as an integrator. It is used to suppress high frequency components and to supply a signal which is DC-controlled to an oscillator that is voltage-controlled. To get the phase angle required for the inverter, a PI controller is introduced which gives the inverter frequency as the output. When the difference between the inverter phase angle and the grid phase angle is reduced to zero, the PLL activates, resulting in synchronously rotating voltages  $V_q = 0$  and  $V_d$  giving the magnitude of the grid voltage.

$V_{abc}$  is the input to the Voltage transform block and  $V_{\alpha\beta}$ ,  $V_d$ , and  $V_q$  are given as an output from it. Also,  $I_{abc}$  and  $\omega t$  are the inputs to the current control block and  $I_d$  &  $I_q$  are the outputs of it.

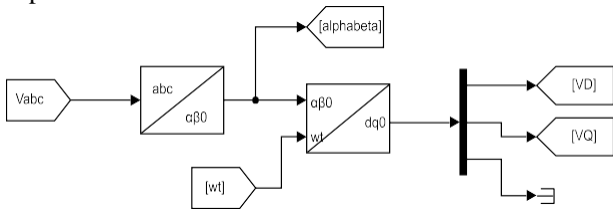


Fig. 12. Voltage control block

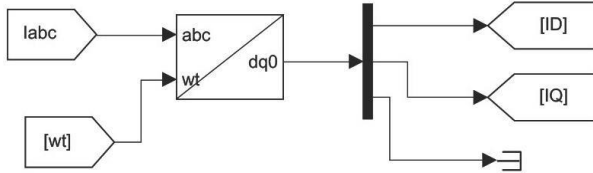


Fig. 13. Current control block

C.  $I_d$  and  $I_q$  Axis Current Control Blocks

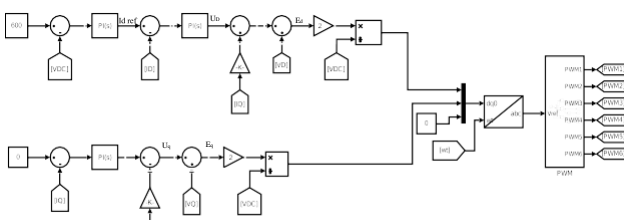


Fig. 14.  $I_d$  and  $I_q$  axis current control blocks

In the  $I_d$  axis current control block shown in Fig. 14, difference between  $V_{DC}$  and  $V_{DC Ref}$  (600) is fed to the PI controller as input and according to that difference,  $I_{d Ref}$  current is generated. Then the difference between  $I_d$  and  $I_{d Ref}$  is again fed to another PI controller. Next, the output of that controller ( $U_D$ ) is added to  $(2 \cdot \pi \cdot f \cdot L) I_q$  and  $V_D$  to obtain  $E_d$ . Then  $m_d$  is obtained by the equation given below.

$$m_d = \frac{2E_d}{V_{DC}} \quad (6)$$

According to equation (6),  $I_d$  axis current control block gives the value  $m_d$  to the multiplexer as an input.

In the  $I_q$  axis current control block, the difference between  $I_q$  and  $I_{q Ref}$  (0) is fed to the PI controller as an input. Then,  $(2 \cdot \pi \cdot f \cdot L) I_q$  is subtracted from the output of the PI controller to obtain the  $U_q$ . Next,  $V_q$  is added to  $U_q$  to obtain  $E_q$ . Then  $m_q$  is obtained by using the equation given below.

$$m_q = \frac{2E_q}{V_{DC}} \quad (7)$$

According to equation (7),  $I_q$  axis current control block gives the value  $m_q$  to the multiplexer as an input.

Next, these  $m_d$  and  $m_q$  values (modulation indexes) are sent through a multiplexer and the output of the multiplexer is fed in to a dq0 to abc transform block. Finally, that output is sent to the PWM signal generator sub-circuit.

D. PWM Signals Generator

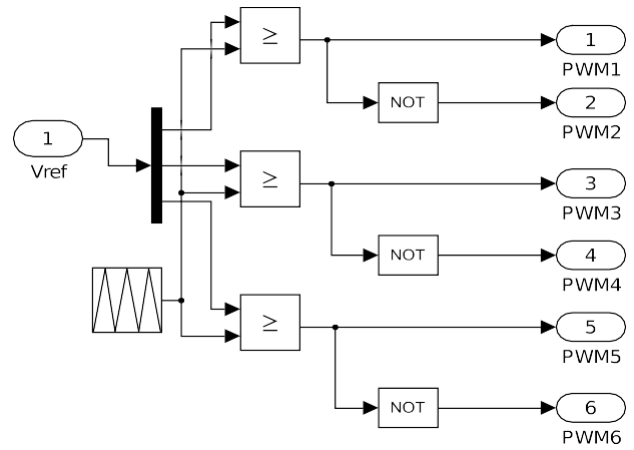


Fig. 15. PWM signal generator

By using a demultiplexer, three-phase voltage signal  $V_{abc}$  is divided into  $V_a$ ,  $V_b$  and  $V_c$ . Then those signals are compared with a ramp signal to generate PWM signals.

VII. LCL FILTER

The function of the LCL filter is to attenuate the harmonics created by the switching activity of the three-phase inverter. The filtering of the harmonics is important when sensitive equipment is connected to the grid and for applications where total harmonic distortion is a major consideration. Compared to the conventionally used L filters, the LCL filter has better attenuation capacity of high-order harmonics, better dynamic characteristics, and minimized size and cost. The LCL filter was incorporated into the inverter design due to the aforementioned reasons. The circuit diagrams of the LCL filter are shown in Fig. 16.

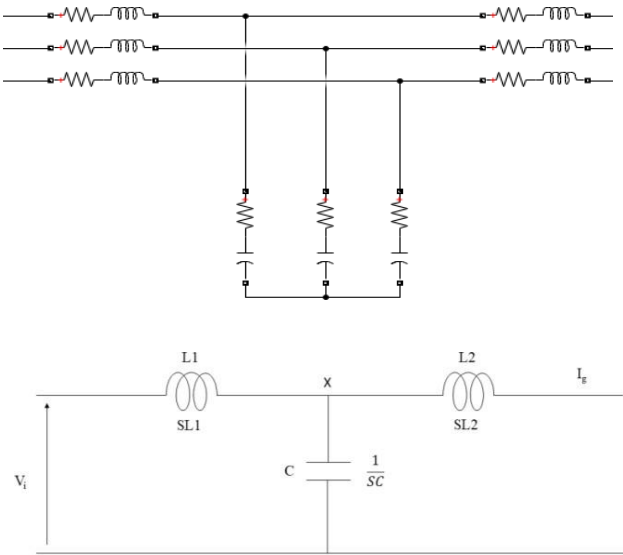


Fig. 16. Circuit diagrams of the LCL filter

The calculations are done to obtain the L and C values of the LCL filter as follows.

$$\frac{V_i - V_x}{SL1} = I_g + \frac{V_x}{1/SC} \quad (8)$$

$$V_x = I_g SL2 \quad (9)$$

$$I_g = \frac{1}{\frac{V}{\omega} \left[ S^3 * L1 * L2 * 2 * C + S(L1 + L2) \right]} \quad (10)$$

Let,  $L = L_1 + L_2$  and  $L_p = \frac{L1 * L2}{L1 + L2}$

$$\frac{I_g}{V_i} = \frac{1}{s * L(1 + s^2 CL_p)} \quad (11)$$

resonance angular velocity,

$$\omega_{res} = \frac{1}{\sqrt{C * L_p}} \quad (12)$$

switching frequency,  $f_{sw} = 10$  kHz

resonance frequency,  $f_{res} = \frac{f_{sw}}{10} = 1000$  Hz

reactive power (Q) = 5% of rated power (S)

$$Q = \frac{V^2}{1/(2\pi f c)} = 5\% \text{ of } S \quad (13)$$

$$C = \frac{0.05 * S}{V^2 * 2\pi * f} \quad (14)$$

By substituting  $S = 100$  kVAr,  $V = 230$  V and  $f = 50$  Hz,

$$C = 300.84 \mu F$$

So, the capacitance of one capacitor = 100.28  $\mu F$

From (1), (2), and  $s = j * \omega_{sw}$

$$L = \left| \frac{1}{\omega_{sw} * V_{i(s\omega)} * \left(1 - \frac{s\omega}{\omega_{res}^2}\right)} \right| \quad (15)$$

$$I_g = \frac{S/3}{V} = \frac{100 * 10^3 / 3}{230} = 144.92 \text{ A} \quad (16)$$

According to standards,

$$I_{g(s\omega)} = 0.3\% * I_g = 0.434 \text{ A} \quad (17)$$

$$V_{i(s\omega)} = 0.9 * V_i = 207 \text{ V} \quad (18)$$

By substituting (17) and (18) in (15),  
 $L = 76.68 \mu H$

Minimum Inductance value,

$$L_1 = L_2 = \frac{L}{2} = \frac{76.68 \mu H}{2} = 38.34 \mu H \quad (19)$$

voltage drop,

$$V_1 = 20\% * V_g \quad (20)$$

$$L = \frac{0.2 * V_g}{2\pi * 50 * I_g} = \frac{0.2 * 230}{2\pi * 50 * 144.92} = 1 \text{ mH} \quad (21)$$

Maximum Inductance value,

$$L_1 = L_2 = \frac{L}{2} = \frac{1 \text{ mH}}{2} = 500 \mu H \quad (22)$$

### VIII. SIMULATION RESULTS

A. When the Solar Irradiance is 1000 W/m<sup>2</sup>

Simulink software is used to simulate the whole system shown in Fig.17. Simulation time was set for 1 second

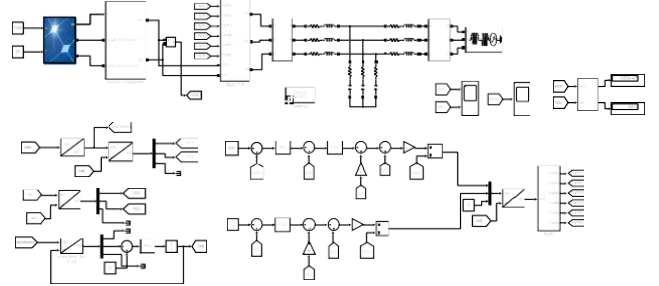


Fig. 17. Entire MATLAB Simulink model

The first simulation case is a steady state operation, with a solar irradiance is  $1000 \text{ W/m}^2$  and a temperature of  $25^\circ\text{C}$ , assuming that atmospheric conditions were not varied during the simulation process.

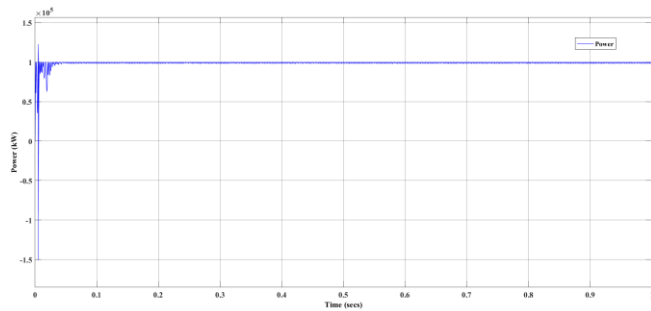


Fig. 18. Graphical representation of the power generated by the solar panel within one second

According to the graph shown in Fig 18, the power generated by the solar panel for  $1000 \text{ W/m}^2$  irradiance is approximately equal to 100 kW indicating that the MPPT is functioning properly. Also, it reaches a steady state very quickly.

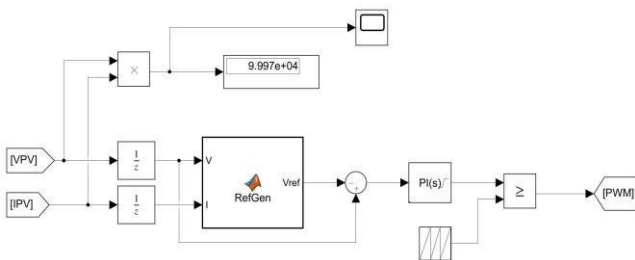


Fig. 19. Power generated by the solar panel after one second

The function of harnessing the maximum power from the PV array was done successfully using the MPPT algorithm. From the output shown in Fig. 19, it is clear that the process of maximum power point tracking continued successfully despite the initial fluctuations.

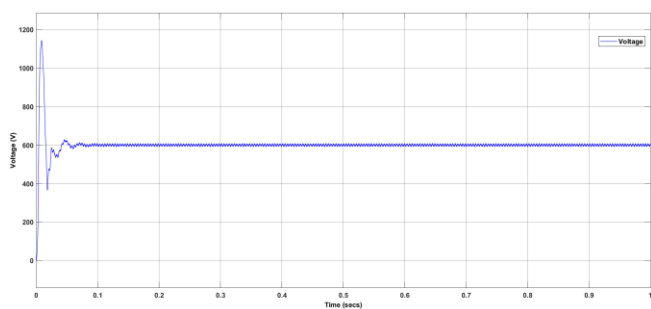


Fig. 20. The output voltage of the boost converter

$V_{DC}$  voltage is almost 600 V. The graph shown in Fig. 20 confirms that expected output voltage value given in the specifications of the boost converter is obtained and that the boost converter functions properly.

Fig. 21 represents the grid voltage variation of three phases at constant irradiance of  $1000 \text{ W/m}^2$ . The peak value of the voltage of a phase is around 325 V which ensures a 230 V root mean square voltage

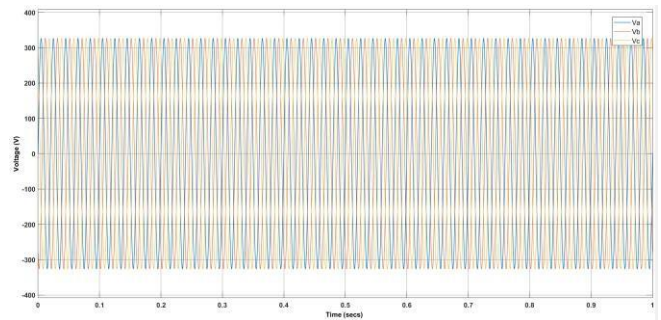


Fig. 21. Grid voltage during the simulation time

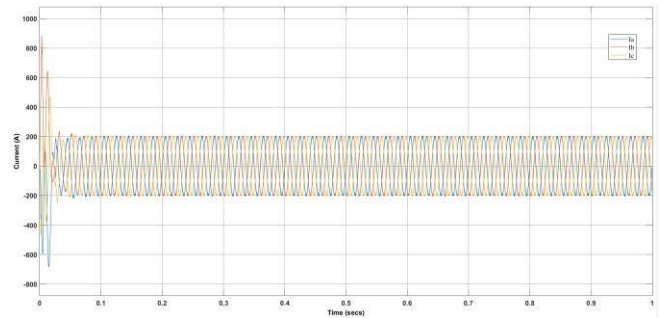


Fig. 22. Grid current during the simulation time

Fig. 22 represents the grid current variation of the three phases which is around 200 A.

Also, the output power is nearly 100 kW and that is the MPP value for  $1000 \text{ W/m}^2$  irradiance

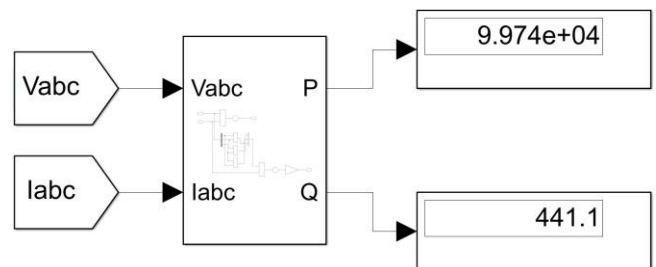


Fig. 23. Output power

**B. When the Solar Irradiance is  $500 \text{ W/m}^2$**

The next simulation case is when the solar irradiance is  $500 \text{ W/m}^2$  with a temperature of  $25^\circ\text{C}$ , assuming that atmospheric conditions remained constant throughout the simulation process.

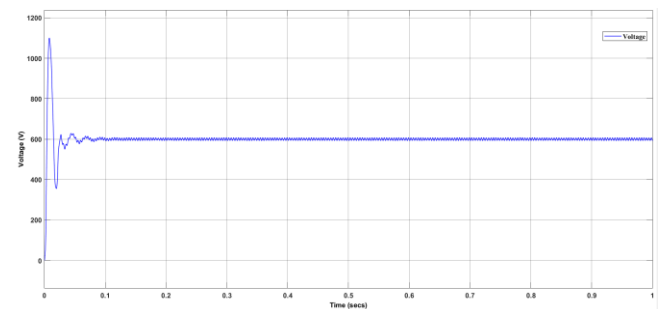


Fig. 24. Output voltage of the boost converter

In this case, Fig. 24 clearly shows that the output voltage of the boost converter ( $V_{DC}$ ) is 600 V. This means the output voltage is independent of the variation of irradiance.

Similarly, according to Fig. 25, the grid voltage is independent of the irradiance but the grid current changes with the irradiance. Fig. 26 clearly indicates that point. Therefore, when the irradiance decreases, the grid current also decreases.

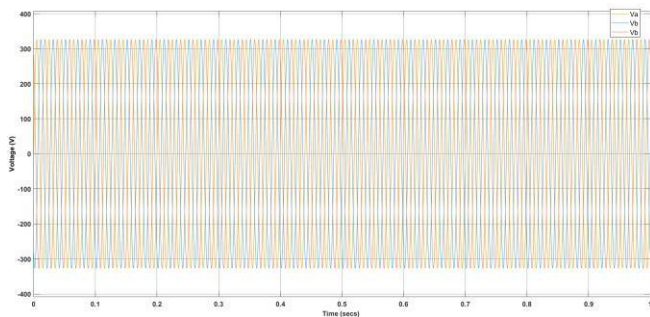


Fig. 25. Grid voltage during the simulation time

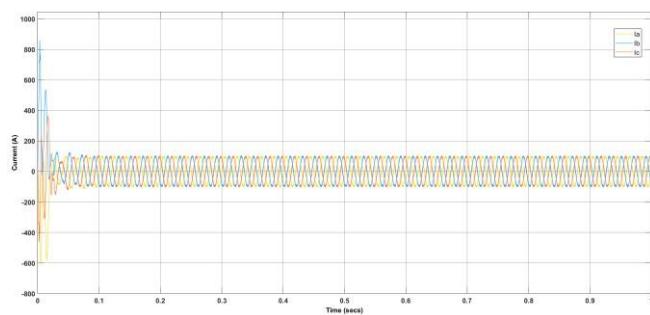


Fig. 26. Grid current during the simulation time

**C. With a Varying Solar Irradiance Between 1000 W/m<sup>2</sup> And 100 W/m<sup>2</sup>**

Finally, the irradiance is varied between 1000 W/m<sup>2</sup> and 100 W/m<sup>2</sup> while maintaining the ambient temperature at 25 °C. The entire system model (when the irradiation is not a constant) is shown in the below figure.

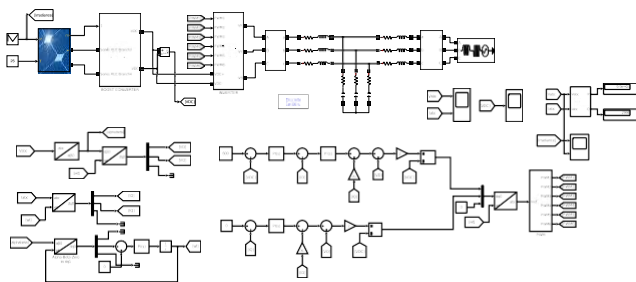


Fig. 27. Entire MATLAB Simulink model

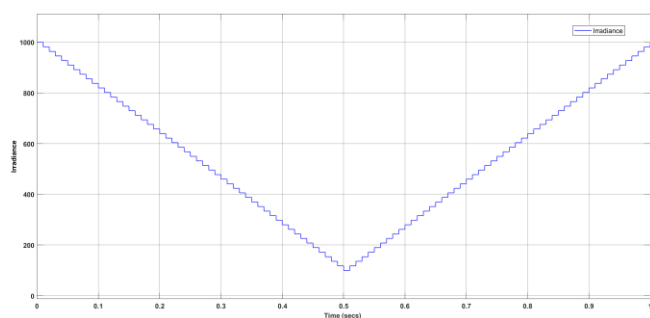


Fig. 28. Variation of irradiance during the simulation time

The variations of power generated by the solar panel, V<sub>DC</sub>, grid voltage, and grid current during the simulation time are shown in the figures given below.

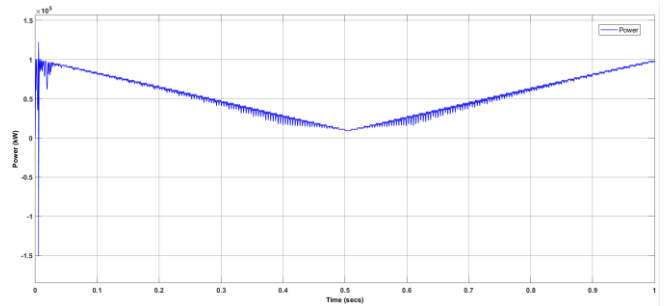


Fig. 29. Variation of power generated by the solar panel

The graph in the Fig. 29 shows that the power fluctuates around the MPPT and is not smooth. That is due to the maximum power point tracking algorithm. When the variation of solar irradiance is rapid, perturb and observe method may take a longer time to track the maximum power point. That is a drawback of the P&O algorithm.

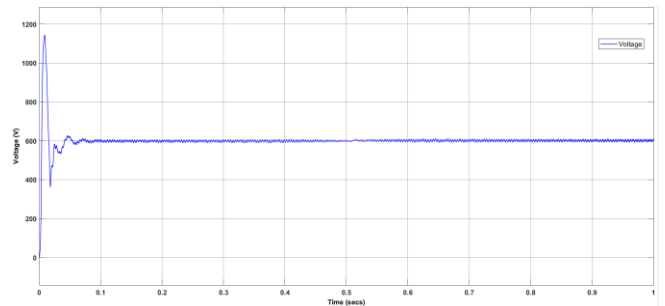


Fig. 30. Output voltage of the boost converter

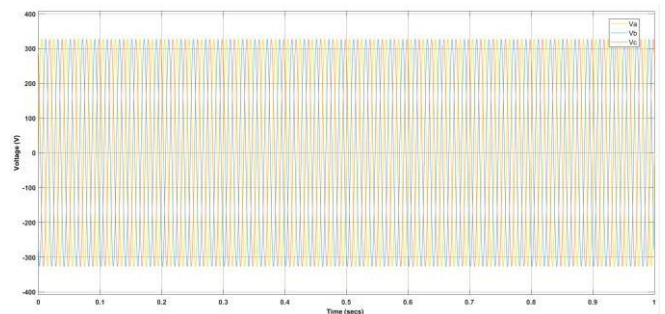


Fig. 31. grid voltage variation during the simulation time

Fig. 30 and Fig. 31 again conform that the output voltage of the boost converter and the output grid voltage are independent of the variation of irradiance

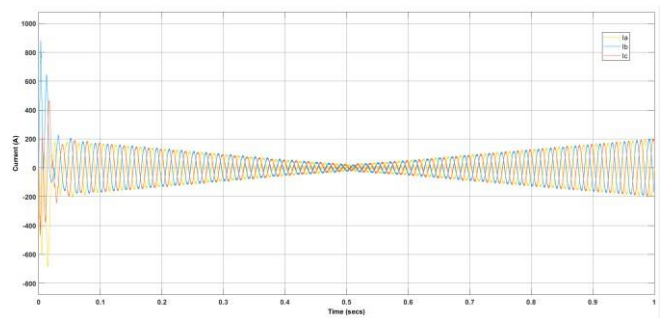


Fig. 32. grid current variation during the simulation time



Fig. 32 shows that, when the irradiance decreases, the grid current also decreases

Also, the output power is nearly 100 kW and that is the MPP value for 1000 W/m<sup>2</sup> irradiance (ending position).

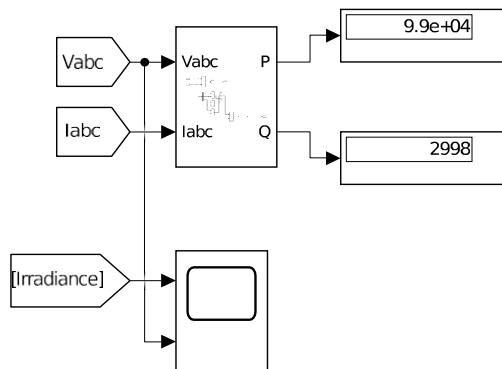


Fig. 33. Output power after one second

## IX. CONCLUSION

When a photovoltaic grid connected system is constructed, several parameters should be considered, and the system should be optimized to obtain maximum power generation. When the MPPT algorithm is applied to an accurate photovoltaic model, it has the capability of enhancing the system efficiency. Besides, a controller can be used in achieving the synchronization to the grid and to perform the power management between the electrical grid and the system. MATLAB-SIMULINK software is used to implement a photovoltaic grid connected system with control blocks and the perturb and observe MPPT algorithm. The maximum power point tracking method, simulated in the report has the ability to enhance the steady and dynamic state performance of the photovoltaic system simultaneously. To provide active power to the grid, the inverter should be controlled using synchronous d-q transformation. Grid phase and frequency are locked using PLL. By using d-q transformation in the three-phase system, the phase detection part of PLL is properly done. It can be concluded from the simulation results that the MPPT was successfully implemented by the system. The current waveforms obtained for the three scenarios indicate that the current harmonics are quickly attenuated by the LCL filter and steady states are reached within a trivial time. The frequency and phases of the inverter output is successfully synchronized with the grid through the PLL method used in the design. In addition to that, this report indicates that the proposed control topology provides an easy way of studying the performance of utility interface applications. Therefore, it can be concluded that by utilizing the proposed design, it is possible to extract the maximum power from PV panels, and produce sinusoidal voltage and current waveforms which are synchronized with the grid.

## X. FUTURE RECOMMENDATIONS

- In this research, battery banks were not utilized for the system. By connecting battery banks to the system, it is possible to store the excess energy which is produced by the proposed system. The effectiveness of the system to generate electricity for the main grid is increased by connecting battery banks. This amendment can be suggested for further development of the proposed system.
- A solar tracking system which is used to orient the PV panels towards the sun can be incorporated to the proposed system. This orientation is performed using light detecting sensors. The proposed system will be capable of tracking the maximum available solar energy throughout the day with this modification. More electricity can be generated using the solar tracking system when compared to stationary PV panels.
- When the variation of solar irradiance is rapid, perturb and observe method may take a longer time to track the maximum power point. Alternative MPPT techniques such as fuzzy logic control method can be used to track the maximum power point swiftly. This can be suggested as another method to further improve the proposed system.

## ACKNOWLEDGMENT

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