International Journal of Engineering & Technology, 7 (3.6) (2018) 68-73

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Grid Tied Photovoltaic System with Perturb and Observe Maximum Power Point Controller and LCL Filter

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Abstract

This paper describes a grid tied photovoltaic (PV) system along with maximum power point tracking (MPPT) and LCL filter**.** A PV model is developed using mathematical equations of solar cell. This PV module is controlled and optimized with MPPT algorithm. The maximum power point (MPP) tracking is implemented using Perturb and Observe (P&O) algorithm from the solar array and given to DC-DC boost converter. The enhancement of unfettered PV Voltage is achieved using boost converter and also used to verify the precision of MPPT technique. Using inverter controller, the boost converter DC output voltage is converted into AC voltage. The phase and frequency of the grid is tracked using phase locked loop (PLL) to integrate the inverter with the grid. In addition to this, to diminish the harmonics in the inverter output an LCL filter is used. The performance of grid tied photovoltaic system is extensively simulated with MATLAB software.

Keywords: *PV system, MPPT technique, boost converter, phase locked loop, LCL filter.*

1. Introduction

In present scenario, total power is mainly obtained using fossil fuels. So the conventional sources are decreasing very fast rate and these are causing environmental problems like carbon emissions which results to global warming. To get rid of these disadvantages, Renewable Energy Sources (RES) are alternative solution to the present power requirements. Many RES such as bio-mass energy, wind energy, hydro energy, solar energy, ocean energy etc. are available in the present world. Out of all these, PV power generation has many advantages such as non-polluting, noise free, less maintenance and renewable. As the exploration of solar cell is accelerating, the advancements in the system technologies are continuously enhancing and decrement in solar cell cost shows the great interest to researchers in the field of solar energy. But in actual practice, the PV cell efficiency is very low. So, with the intention of increasing the efficiency, focus is towards to track the MPP from the PV panel. On behalf of this reason, an efficient MPPT algorithm has to be designed.

To attain maximum power from an installed solar PV system several MPPT techniques [1][2][3][4] are anticipated in the literature. The various MPPT techniques are P&O method [5][6], Incremental conductance method [3][5], Fuzzy Logic Control method [7],Constant Voltage method[8][9], Short Circuit Current(SCC) method[8][9], Open Circuit Voltage (OCV) method[9], Artificial Neural Network method [10], Extremum seeking control(ESC) method [1][11] etc. These methods can be differentiated in many aspects including; simplicity, cost, effectiveness, sensors requirement, speed of convergence, hardware implementation and need for parameterization.

In this work, a grid tied PV system [12][13] with P&O MPPT [5][6] technique along with boost converter [14], inverter & inverter controlling technique[15] and LCL filter [16] is presented. The solar cell is modeled using the equivalent circuit [17] [18] equations. The PV system is tied to grid through boost converter and inverter. The boost converter increased PV voltage to the required level with the help of MPPT controller and output is connected to the inverter. The inverter is getting pulses from inverter controller [9] to synchronize the PV with grid using sinusoid PWM. The synchronization is obtained with the help of a phased locked loop (PLL). In this work P&O MPPT technique along with LCL filter is used to track MPP with reduced ripples in the system output.

2. Proposed System Block Diagram

In the proposed system, PV array is interfaced with grid through DC/DC boost converter and inverter through controlling technique as shown in figure 1. The generated power from PV array is send to the grid in two phases. In first phase, PV array is linked to boost converter [14] to enhance the voltage and is controlled using MPPT controller [5][6]. The MPPT controller can generate the pulses in order to achieve maximum power from the PV panel by tracking the MPP. In the second phase, the boost converter output is given to the inverter. The inverter converts DC quantity into AC quantity with the help of a SPWM technique. The inverter output is send to grid and generated power is synchronized with grid [12][13] by taking voltage and current as a reference for the inverter controller. The grid output is fed back to the inverter controller to generate pulses for the inverter switches to control the power [12].

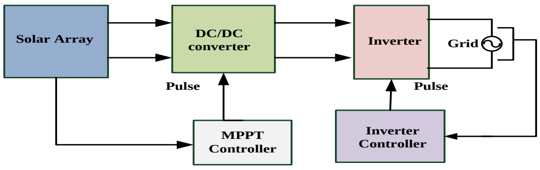


Fig. 1: Overall PV system block-diagram

Modeling of solar array

Solar array is a semiconductor device which converts light energy into electrical energy; formed by a combination of series and parallel PV cells. The expressions for solar PV voltage and current are obtained with the help of equivalent circuit [17][18] given in figure 2.

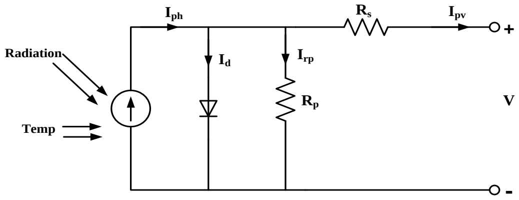


Fig. 2: PV cell equivalent circuit

From the circuit (2)

$$I_{pv} = I_{Ph} - I_d - I_{rp} \quad (1)$$

$$I_{Ph} = \frac{G}{G_r}[I_{sc} + K_i(T - T_r)] \quad (2)$$

Shockley diode equation is

$$I_d = I_o[e^{\left(\frac{V_{pv}+I_{pv}R_s}{V_t A}\right)} - 1] \quad (3)$$

$$I_{pv} = I_{ph} - I_o[e^{\left(\frac{V_{pv}+I_{pv}R_s}{V_t A}\right)} - 1] - \frac{V_{pv}+I_{pv}R_s}{R_s} \quad (4)$$

$$I_o = I_{rs}\left(\frac{T}{T_r}\right)^3 e^{\left(\frac{qE_g}{Ak}\left(\frac{1}{T_r}-\frac{1}{T}\right)\right)} \quad (5)$$

$$I_{rs} = \frac{I_{sc}}{[e^{\left(\frac{V_{oc}}{AV_t}\right)}] - 1} \quad (6)$$

The PV array output is

$$I_{pv} = N_{par}I_{ph} - N_{par}I_o[e^{\left(\frac{V_{pv}+I_{pv}R_s\left(\frac{N_{ser}}{N_{par}}\right)}{V_t A N_{ser}}\right)} - 1] - \frac{V_{pv}+I_{pv}R_s\left(\frac{N_{ser}}{N_{par}}\right)}{R_p\left(\frac{N_{ser}}{N_{par}}\right)} \quad (7)$$

DC-DC boost converter

The boost converter [14] is utilized to enhance the PV voltage to the required level. The input to boost converter is unfettered one due to the impact of temperature and irradiance, obtained from PV array. It is functioned in continuous conduction mode. The pulses are generated through MPPT controller for tracking MPP [5][6]. The boost converter capacitor value is chosen to get controlled voltage and inductance is chosen on the basis of maximum permissible ripple current at minimum duty cycle.

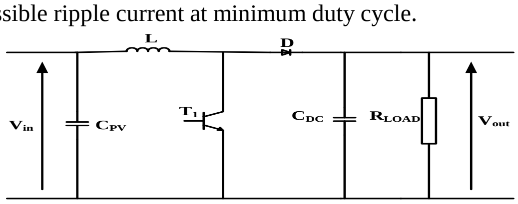


Fig. 3: Boost converter topology

P & O MPPT controller

The MPPT controller always tracks the MPP from the PV array [2]. The P&O MPPT technique [3] is implemented due to its advantage features like simple structure, easy implementation and high reliability. It works by continuously perturbing to increment or decrement the PV voltage and comparing the perturbed voltage with previous voltage. If dP>0, check dV>0; if it is yes then increment the voltage otherwise decrement the voltage. If dP<0, again check dV>0; if it is yes then decrement the voltage otherwise increment the voltage. Continue this process until get the maximum power. The operation of P & O MPPT technique is illustrated in figure 4 and its implementation algorithm is given in figure 5.

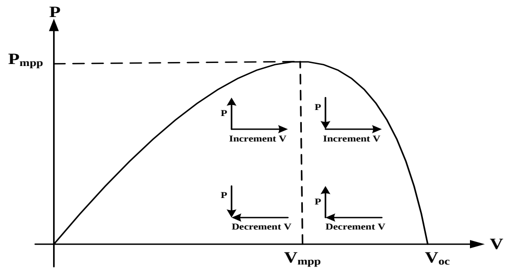


Fig. 4: Principle of P&O

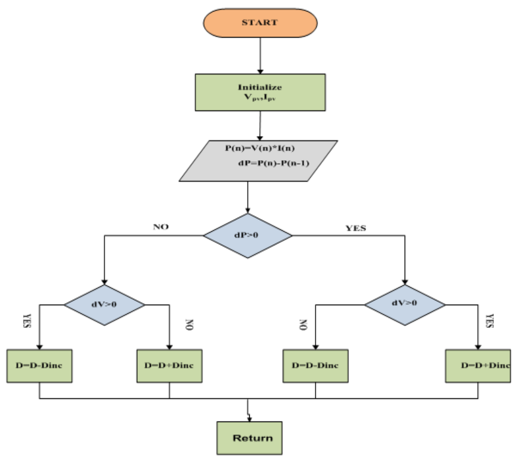


Fig. 5: P&O MPPT algorithm

Inverter controller

The inverter controller shown in figure 6 is used to obtain the gate pluses required for inverter and also for synchronization of PV system with grid [12][13]. The synchronization is realized using PLL. The PLL synchronizes the grid voltage and frequency with PV system output at inverter terminals. The inverter controller has dual control loops [11]; first one is current control loop, which controls the inverter current and also responsible for the issues from power quality such as power factor improvement and low THD & second one is voltage control loop where the DC output voltage is controlled and is answerable for power flow in the system. In this controller d-q reference frame is used to easily control the voltage and current. The active current control is done by taking DC link voltage as a reference and reactive current is set to zero such that the phase difference of voltage and current is zero and also for getting unity power factor.

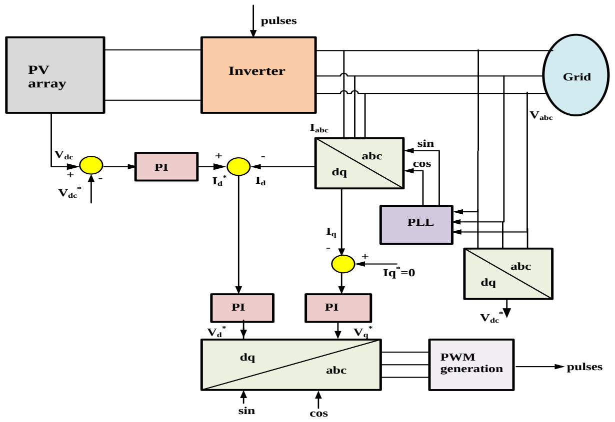


Fig. 6: Block diagram of inverter controller

3. LCL filter design

Due to power electronic devices in the system, higher order harmonics are flows into the grid. So in order to reduce these harmonics filters are used. In grid connected inverter most commonly used filter is L-type filter. To decrease the current ripple in the system L has to be increased, but filtering effect is not good because of network impedance. To overcome this effect LCL filter is used. An LCL filter has high cut-off frequency and high penetrating ability. It provides decoupling between filter and grid impedance. The design of LCL filter consists of different characteristics such as filter size, current ripple and ripple attenuation. The parameters necessary for LCL filter [16] design are inverter line voltage, output phase voltage, rated power, DC voltage, grid and switching frequencies.
The design parameters of LCL filter are as given below:

Base impedance, $$Z_b = \frac{V_{L-L}^{2}}{P} \quad (8)$$

Base capacitance, $$C_b = \frac{1}{\omega_g Z_b} \quad (9)$$

So, the filter capacitance is obtained as

$$C_i = 0.05 \times C_b \quad (10)$$

$$I_{\max} = \frac{\sqrt{2}P}{3V_{ph}} \quad (11)$$

$$\Delta I_{L\max} = 0.1 \times I_{\max} \quad (12)$$

The inverter side inductance is designed as

$$L_1 = \frac{V_{DC}}{6 f_{sw} \Delta I_{L\max}} \quad (13)$$

This inductance limits the output current ripple up to 10% of the normal amplitude. Grid side inductance is calculated as

$$L_2 = \frac{\sqrt{\frac{1}{k_a^{2}} + 1}}{C_i \omega_{sw}^{2}} \quad (14)$$

L_1=5.09321mH,L_2=0.123187mH, C_i=12.35uF

4. Results and discussion

The overall simulation diagram of proposed system using MATLAB/SIMULINK is illustrated in figure 7. Figure 8 shows the PV array characteristics of power and current for different irradiances at constant temperature. From the figure it can be concluded that as the output power increases with increasing of irradiance level i.e., the output of PV array is direct proportional to irradiance of the sun.
Figure 9 (a) shows the simulation results of the current, voltage and power output of PV array. The values of the above results are settled at 35.6A, 345V, 12kW respectively and they are constant from the simulated time of 0.14sec onwards. These DC values are now fed to the boost converter. Figure 9 (b) shows the boost converter output voltage which is boosted up to a value of 537V.
From the simulation results of figure 10 (a), it is observed that, more number of harmonics is presented in the output of three phase voltage without filter at the grid terminals. For the same, with consideration of filter at the output, the harmonics are nullified and the accurate three phase voltages are obtained as shown in figure 10 (b) and the output value is settled at 537V with 50Hz frequency.
Figure 11 (a) shows grid output voltage and figure 11 (b) have the output phase to phase inverter currents. Now these currents are fed to grid for synchronization of grid with PV system. The synchronization of inverter output with grid system is perfectly observed in figure 12.

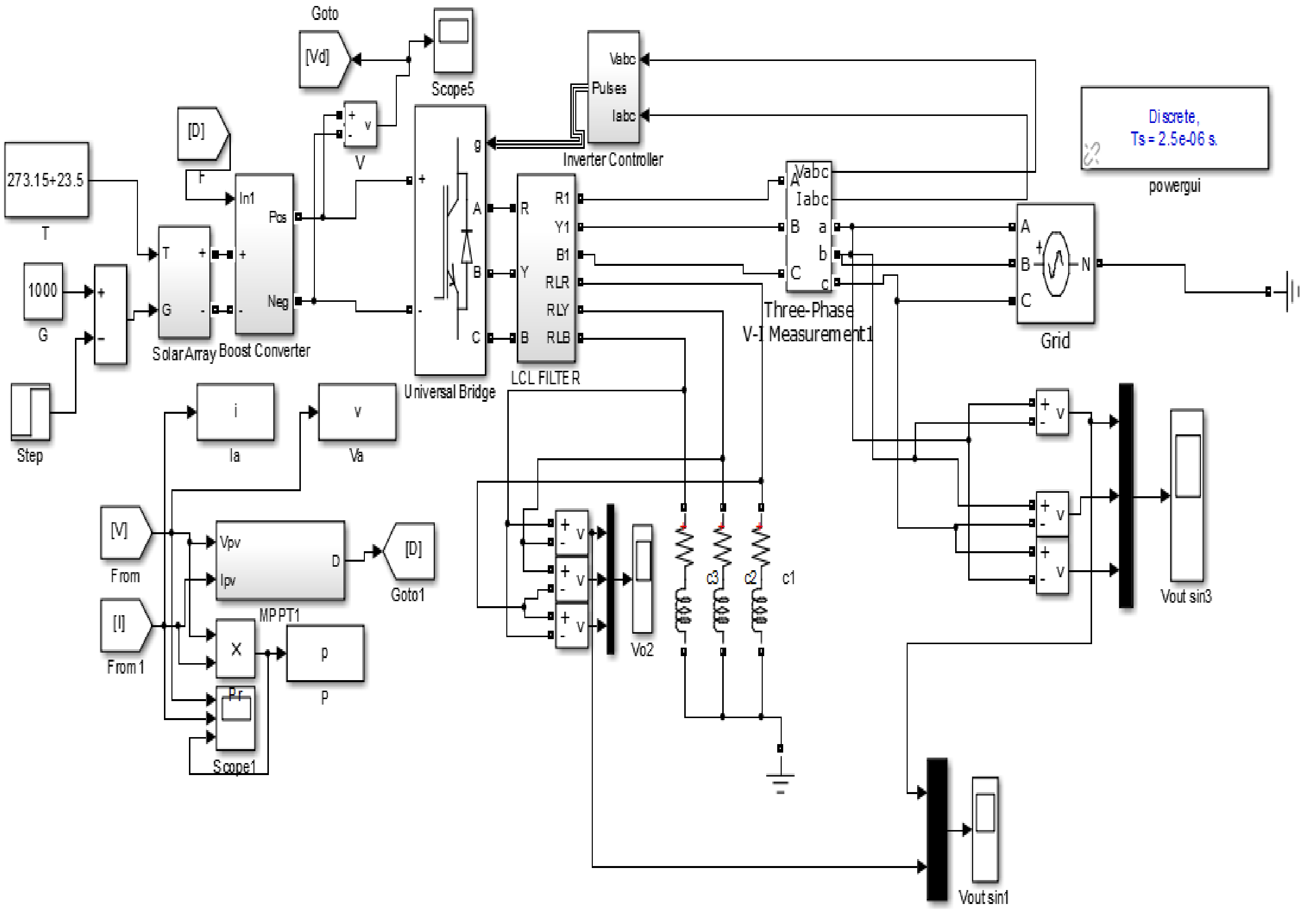
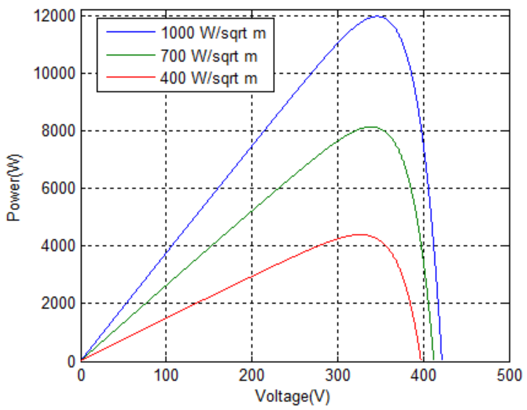
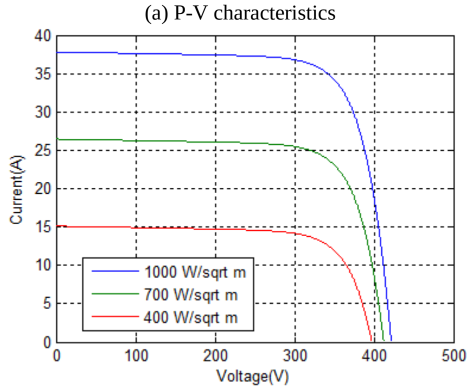


Fig. 7: Overall simulation diagram of a grid connected PV system

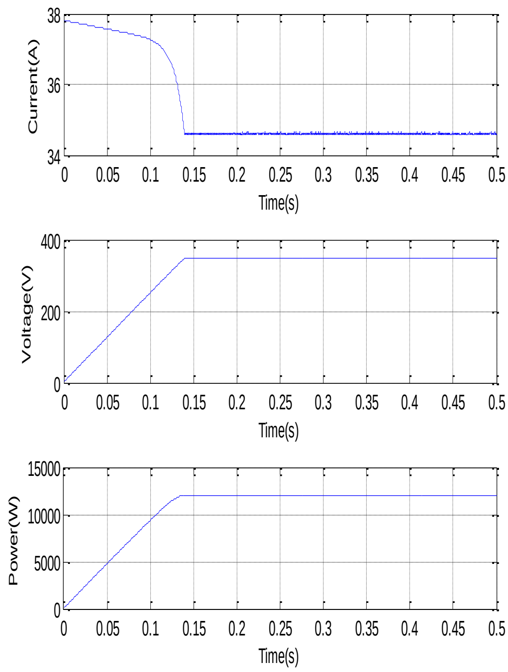


(a) P-V characteristics

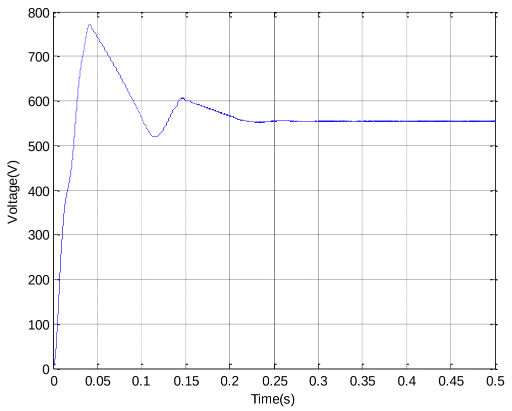


(b) I-V characteristics

Fig. 8: PV array characteristics at different irradiances

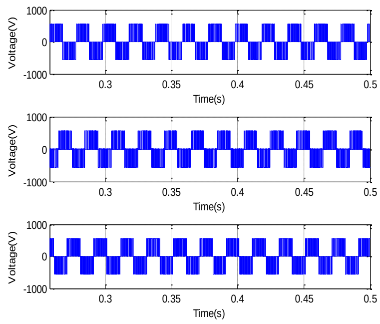


(a)Photovoltaic Power, Voltage and Current outputs

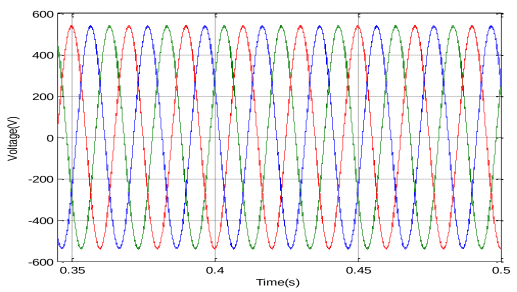


(b) Boost converter output voltage

Fig. 9: PV system and boost converter output waveforms

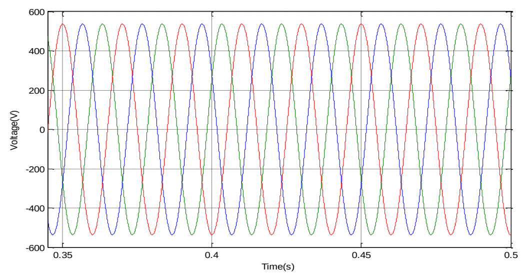


(a) 3-phase output voltage without filter

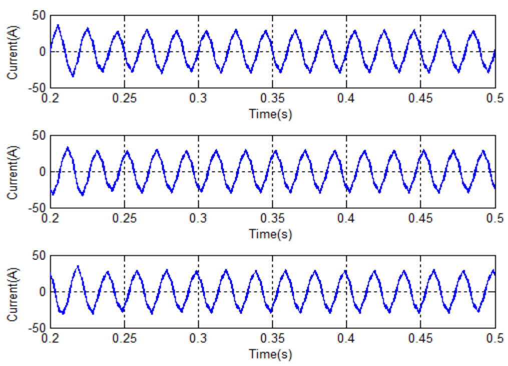


(b) 3-phase output voltage with filter

Fig. 10: Output voltage without and with filter



(a)Three phase output voltage of a Grid



(b) Phase to phase inverter output currents

Fig. 11: Three phase voltages and currents of grid and inverter

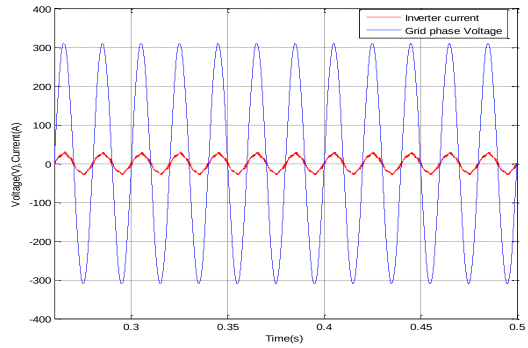
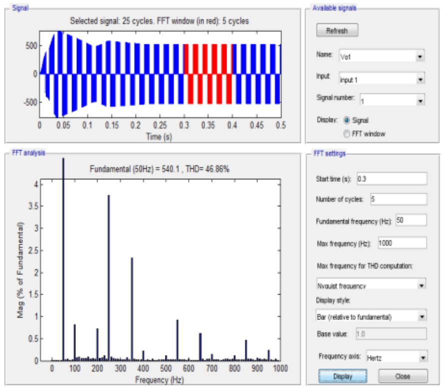
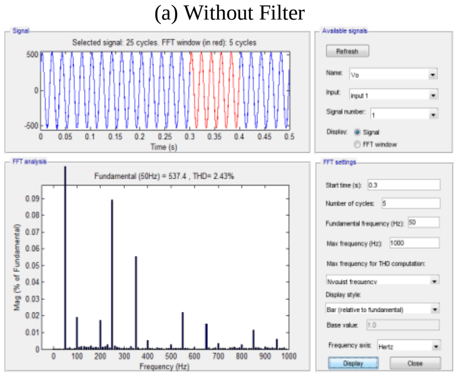


Fig. 12: Synchronization of inverter current and grid phase Voltage



(a) Without Filter



(b) With Filter

Fig. 13: FFT analysis of inverter output

The simulation results in figure 13 (a) shows the FFT analysis of inverter output voltage without filter and the corresponding THD is obtained as 46.86%. With the same system, by adding LCL filter at the output of inverter an accurate voltage is observed as shown in figure 13 (b) with THD of 2.43%. Finally the THD of the inverter output voltage is decreased from 46.86% to 2.43%. The solar cell and boost converter parameters are illustrated in Table (1) and Table (2) respectively.

Table 1: Solar cell parameters

S. No	Parameter	Symbol	Value
1	SC current	I_{sc}	3.56 A
2	MPP Current	I_{mpp}	3.87 A
3	MPP Voltage	V_{mpp}	34.5 V
4	OC voltage	V_{oc}	42.1 V
5	No. of cells in series	N_s	72

Table 2: Boost converter parameters

S. No	Parameter	Value
1	V_{in} (nom)	337 V
2	V_{out} (nom)	540 V
3	C_{in}	78.6 µF
4	L_{boost}	444 µH
5	C_{out}	154.69 µF
6	R_{load}	24.3 Ω
7	Switching frequency	10 kHz

5. Conclusion

A grid connected PV system with LCL filter has been designed and simulated using MATLAB software. The PV module is developed with the mathematical model of PV cell and simulated at different irradiances. With the use of P&O algorithm, MPP is achieved and boosted using DC-DC boost converter. In order to convert the boosted DC to AC an inverter is used with an inverter controller. The inverter controller is used to synchronize the grid with photovoltaic system. Finally LCL filter is filter out the THD from 46.86% to 2.43% in the inverter output.

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