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Investigation of voltage regulation in grid connected PV system

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ABSTRACT

In the present scenario the power requirement on load side is increasing day by day, so to balance the power demand and power supply various renewable energy comes to picture as the additional source of electricity generation. The power generated by various renewable resources such as solar, wind, tidal energy and geothermal sources is environmentally clean and have a less emission impact. Out of which PV system draws more attention because it generates energy with a much lower level of carbon dioxide emissions. In the proposed work the objective is to investigate the synchronisation between grid and PV system in terms of voltage and frequency. It includes P-V characteristics under the circumstances of MPPT technique such as P & O technique can able to find local maximum point. The proposed inverter is a voltage source H-Bridge inverter which is controlled using a Clarke and Park transformation to drive a controlled current into the grid to maintain the THD value within the standards. As the grid frequency is fluctuating between ±0.5%. SRF-PLL is generally used to fix the output frequency and phase of the grid. It also includes with the modelling of 3Ø H-bridge inverter as an interface between PV system and grid system. The projected work is designed and simulated in MATLAB SIMULINK 2017b environment.

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1. INTRODUCTION

The major problem that arises nowadays in the world is the increase in industrial and commercial demand due to that increase, there is necessity of new sources for generation of electricity. The generation of electrical energy from fossil fuels, natural gas, nuclear power plant, and coal results in an increase in the amount of carbon dioxide, carbon monoxide, and sulfur dioxide in the environment which leads to a different kind of health problems. Only for that reason the alternative source of energy generally known as a renewable source of energy comes in the power generation sector as a result, in the present scenario the alternative source of energy becomes more attractive rather than the conventional source of energy [1, 2]. A common example of alternative sources of energy is solar, wind, geothermal, biomass, etc. Out of which solar energy draws more attention due to certain reasons like less emission, less cost, less maintenance which overall increase the penetration into the energy market [3].

However, the generation of solar energy from the solar panel is not continuous as it depends on solar irradiance and temperature. At a particular location, the possibility of getting highest energy from the PV panel termed as a maximum power point (MPP). To locate that MPP there is a need for tracking method which is generally termed as the maximum power point tracker (MPPT). Various control schemes are present for the control of MPPT [4], out of which the Perturbation and observation (P&O) control scheme [5] for the MPPT algorithm is often used in solar systems because of its simple design of execution and its observation. Generally, the P&O algorithm oscillates around the maximum power point (MPP). It basically checks whether the change in power is less than or greater than the adjacent power, if the change in power is greater than that adjacent power it goes up to find MPP and if the change in power is less than that adjacent power it moves reverse direction.

Mostly in case of solar system connected to grid works two-stage conversion principle, basically one is to increases the voltage level according to the requirement and another is meant for DC to AC conversion for grid connection, the inverter model is the link between solar system and grid which convert dc signal into ac signal. Inverter output voltage and frequency must be synchronized with the grid voltage and frequency. Voltage source inverters (VSI) are the generally used in solar systems which is operating at unity power factor used for reactive power generation and absorption accordingly. As the proposed work deal with a converter and inverter circuit design of the filter also plays a very important role [6]. Among different types of synchronization method, PLL is the basic fundamental method whose role is to fix the generated frequency and grid voltage with a reference frequency and an inverter phase voltage [7, 8]. Synchronous Reference Frame generally employed due to precise computation voltage and phase [9]. Apart from that, this paper also deals with the reduction in THD value [10] for the whole system by using proposed control strategy.

2. SYSTEM DESCRIPTION

According to the block diagram given in the Figure 1, the proposed model is started with the PV panel. As the position of the sun is not fixed so that energy extraction from the PV module is not constant. In a particular position, it has ability to draw maximum current and voltage during that time PV produces its maximum energy. To control the tracking system various algorithms are applied, selection of control algorithm extract maximum power from PV all weather condition. The converter employed for changing the voltage level as per requirement. The next part is the design of the inverter for connecting to the grid system. Choosing an inverter is important as it contains power electronics devices which cause power quality issues in the power system. Next is the distortion of the waveform generated by the inverter that must be suppressed as it contains harmonics by filter design. After that, the system is connected to the three phase grid system. Here the challenge is to select the proper control method for MPPT also selection of inverter along with filter design.

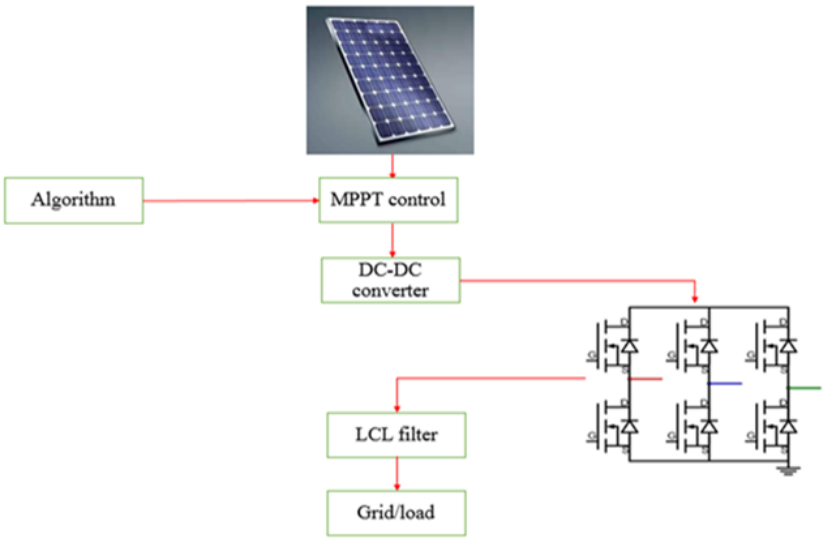

Figure 1. Fundamental block diagram of proposed model

2.1. Solar panel modeling

Equivalent circuit diagram of PV cells is shown in Figure 2, which contains of the current source (I_L), shunt resistor(R_{sh}) along with series resistor(R_s), load current (I), diode current(I_D) [11].

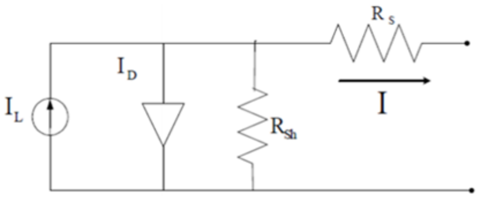

Figure 2. Equivalent circuit diagram of solar cell

From the above diagram mathematical formulation for the source current.

$$I_L = I_D + I_{R_{SH}} + I \quad (1)$$

As basically concentration given to the calculation of load current.

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

Current in the shunt resistor and current in diode can be calculated using the given (3) and (4). Finally, substitute in (2) for the calculation of total load current which is given in (5)

$$I_{R_{SH}} = \left(\frac{V+I*R_S}{R_{SH}}\right) \quad (3)$$

$$I_D = I_O * \left(e^{\frac{V+I*R_S}{n*V_T}} - 1\right) \quad (4)$$

$$I = I_L - I_O * \left(e^{\frac{V+I*R_S}{n*V_T}} - 1\right) - \left(\frac{V+I*R_S}{R_{SH}}\right) \quad (5)$$

The quantity of energy produced by the solar panel is proportional to the amount of availability in solar irradiation, temperature, size and no. of PV cells joined in series and parallel combination [12, 13]. The values of 1KW solar panel are shown in Table 1.

Table 1. PV parameters

Parameters	Values (unit)
Peak power ($\boldsymbol{P_{max}}$)	250W
Open circuit voltage ($\boldsymbol{V_{oc}}$)	34V
Short circuit voltage ($\boldsymbol{I_{sc}}$)	8.8A
Voltage at max power ($\boldsymbol{V_{mp}}$)	31V
Current at max power ($\boldsymbol{I_{mp}}$)	8.1A
No. of cells in series	4

2.2. Perturb and observe method

P & O is generally used for both the freestanding solar and grid connected system [14]. In this method, initially solar voltage and current are sensed as these are the input for P & O, then power is calculated from that at a fixed time. At first, power is very less as time increases sun irradiation and temperature also increases due to that reason power also increases with time. It basically checks whether the power obtains at a fixed time is whether less or more than the adjacent previous power. If the obtained power is more than the previous power some small constant value is added to it for the next incrimination of power. In the hand, if the obtained power is less than the previous power some small constant value is subtracted from it and return to the maximum previous power obtained [15]. This is the working principle of P & O algorithm [16, 17]. The function diagram of P & O is given in Figure 3.

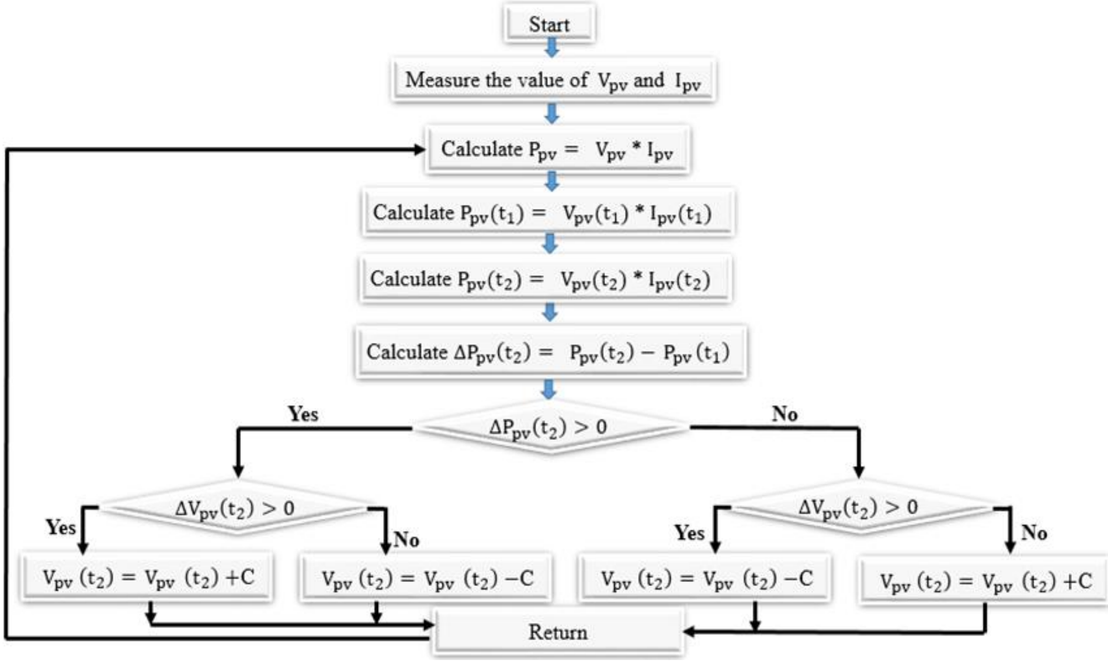

Figure 3. Flow chart of P & O method

2.3. Boost converter modeling

From the solar panel proposed in the Simulink model of this project basically it is possible to generate a voltage of 120V with the current of 8.8A as the output from the solar panel is 1KW. As in this paper work solar system is attached to the three-phase grid system, boosted the DC link voltage to 680V. Calculation of DC-link voltage given below:

$$V_{dc} = \frac{2*\sqrt{2}*V_{LL}}{\sqrt{3}*m} \tag{6}$$

where,
V_{dc} =DC link voltage
V_{LL} = Grid line to line voltage
m = modulation index
Here modulation index $m = 1$
Line to line grid voltage $V_{LL} = 420$V
From the above calculation DC link voltage (V_{dc}) = 685V

As a grid-connected solar system is a cascaded system where the output of the solar panel is given to a converter. Because the output from the solar panel is very less as compared to the required output voltage. In this proposed work boost converter is taken into account [18]. Generally, the output of the converter is fixed based on the requirements. Using the formula given below, calculation of L and C value is done

$$D = 1 - \frac{V_s}{V_o} \tag{7}$$

$$I_{out} = \frac{P}{V_{ph}} \tag{8}$$

$$\Delta I_l = 0.3 * I_{out*} \frac{V_o}{V_s} \tag{9}$$

$$L = \frac{V_s*(V_o - V_s)}{\Delta I_l*F_s*V_o} \tag{10}$$

$$C = \frac{I_{out}*D}{F_s*0.03*V_o} \tag{11}$$

where,
V_s = Input voltage
V_o = Output voltage
P_{PV} = Power from PV panel
Values of all the parameters given below in the Table 2:

Table 2. Converter parameter

Input voltage	120V
Duty ratio	82.45%
Inductor (L)	$0.0048H$
Capacitor (C)	$19.091\mu F$

2.4. Modeling of inverter

The output of solar panel is DC energy when that energy is fed to the grid system some electronics equipment like inverter are supposed to be used [19, 20]. The basic principle of the inverter is converting the DC energy coming from solar panel to 3$\emptyset$ AC system before connecting to the grid. In this paper three-phase H-bridge inverter is used. The fundamental block diagram of proposed inverter is given in Figure 4. Power to inverter is coming from converter and output of the inverter is *abc* phase. It consists of six switches with different switching pulses.

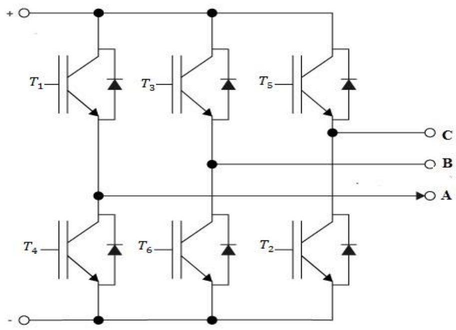

Figure 4. Block diagram of invert

3. LCL FILTER DESIGN

The operation of switches at higher frequency generates more harmonics in the system. These harmonics are distorting the fundamental signal in the grid system. So in order to suppress that harmonics different types of filters are designed generally they are classified as active filters and passive filters [21, 22]. Projected three-phase H-bridge inverter contains six switches along with a boost converter, which contain one switch. So there is a possibility of injection of harmonics into the grid. To prevent power quality issues filter must be used after the inverter for the purpose of suppressing the harmonics. As the generation of power from the DGES is different there are different standards for harmonics, given IEEE-519 and IEEE-1547 before connecting to the grid system. The base impedance (Z_b), base capacitance (C_b) is calculated using the (12) and (13). Where E_n is grid line voltage, P is output of PV power the maximum ripple current and change in ripple current can be calculated by (14) and (15):

$$Z_b = \frac{E_n^2}{P} \tag{12}$$

$$C_b = \frac{1}{2*pi*50*Z_b} \tag{13}$$

$$I_{max} = \frac{P*\sqrt{2}}{3*V_{ph}} \tag{14}$$

$$\Delta I_{max} = 0.1 * I_{max} \tag{15}$$

grid side inductor L_g and L_i inverter side inductor can be formulated by (16) and (17). The capacitor C_f and resistor R_d is calculated using the given below (18), (20):

$$L_i = \frac{V_{dc}}{6 * F_s * I_{max}} \quad (16)$$

$$L_g = \frac{6}{C_f * W_{SW^2}} \quad (17)$$

$$C_f = 0.5 * C_b \quad (18)$$

$$W_{res} = \sqrt{\frac{L_1 + L_2}{L_1 * L_2 * C_b}} \quad (19)$$

$$R_d = \frac{1}{3 * R_d * W_{res}} \quad (20)$$

Calculated values of grid parameters are given in the Table 3:

Table 3. System parameters

DC link voltage	686 V
Grid phase voltage	240 V
Line voltage	415 V
Grid frequency	50 Hz
Switching frequency	5000 Hz
Z_b	172.80 Ω
C_b	6.0149 μF
I_{max}	1.1224 A
L_i	0.2034 H
L_g	0.0202 H
C_f	9.248 μF
W_{res}	13.158
R_d	81.9164 Ω

4. CONTROL STRATEGY FOR GRID SYNCHRONISATION

With grid-connected DPGS main problem associated is synchronization between the inverter output and with the grid. In general grid is mostly influenced by the change in frequency and the voltage imbalance. To make a grid function properly the grid frequency must be within the range of 50±0.5Hz and the voltage imbalance must be between 2% from the nominal or operating voltage. Generally there are two different system associated with when DPGS system come into consideration. Different system means output of DPGS system is DC and grid is operated at AC. In order to synchronise both the system inverter is connected between both the systems. The phase locked loop (PLL) will trace difference between inverter and grid voltages phase angle and make it zero including it measures the voltage magnitude which is must be synchronized also includes a current controller to control the signals of the H-Bridge inverter. SRF-PLL [23] is an advance of conventional PLL model. SRF-PLL can capable of execute quick and exact synchronization details with respect to the large amount of protection also sensitivity to any kind problem associated with the power system. Another advantage of SRF-PLL over conventional PLL [24] is that it is mostly used for the three-phase application. General representation of PLL is given below in Figure 5.

As grid system is also a 3∅ system it's easy to implement and check grid synchronization. Basically, for SRF-PLL the input is 3∅ coming from the grid side voltages and output from the PLL is the phase angle of one of the 3∅. Generally two types of options to analyze SRF-PLL [23, 25], one is assuming the voltages coming from the grid are balanced means all the phases are 120° phase difference from each other so for checking grid synchronization take the first phase and do the operation and then shifting with +120° and -120° for remaining two phases. Another option is using three conventional PLL system for each phase. Due to design complexity first operation is recommended. General block of SRF- PLL is given in Figure 6.

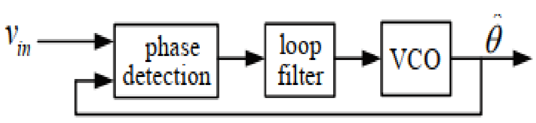

Figure 5. Conventional PLL

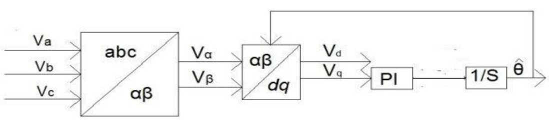

Figure 6. Block diagram of SRF-PLL

In the proposed work the design of control strategy for grid synchronisation is given in Figure 7. The internal part manages the grid current including responsible for low THD value also enhancement of power factor to unity and an external loop operate as voltage control loop including to maintain balances the power flow in the system also grid synchronisation [26-28]. In case of inner loop as it basically deal with current part, so first measure the grid current. Once grid current is sensed convert that to dq transformation. As here only active power is considered the reference of Iq has taken as 0. As shown in block diagram V_{dc}^{*} calculated from P & O algorithm. Then both V_{dc} and V_{dc}^{*} going through summation block then output of summation is given to PI block which output is I_d^* . Now I_d , I_d^* , I_q , I_q^* gone through summation block and output is given to PI block. Output of the PI is V_d^* and V_q^* which is now going through the dq to abc transformation. The generated abc sequence phase has gone to the three phase H – bridge inverter. So that using this control strategy it is able to control both voltage and current.

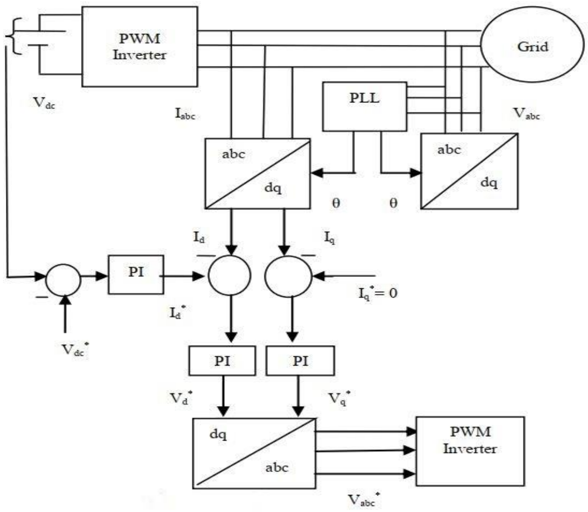

Figure 7. Control strategy

5. SIMULINK MODELS WITH RESULTS

I-V characteristics and P-V characteristics of solar panel is given in Figure 8 and Figure 9. Parameters required for design of solar panel is given in Table 1. As inverter consists of switches there must be harmonics are present. So without using filter output is given in Figure 10. After using LCL filter output waveform is proper sinusoidal as given in Figure 11.

Output of SRF-PLL is given in Figure 12. From the output it clear that grid is perfectly synchronized and amplitude of the grid and inverter output voltage are matching properly. The THD value of output current from the inverter is measured by doing FFT analysis. From the Figure 13 it can be concluded that THD value is very less and achieve simulation results is 1.63%.

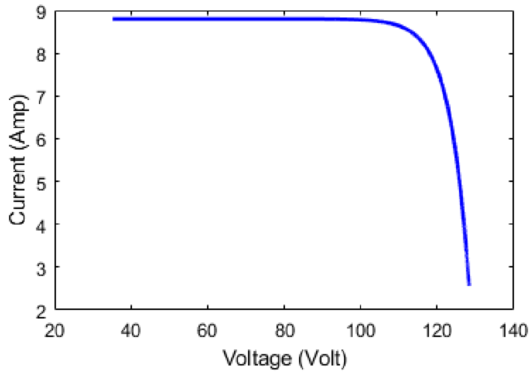

Figure 8. I-V characteristics of PV panel

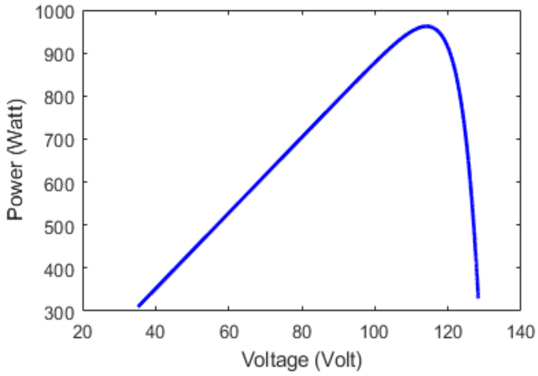

Figure 9. I-V characteristics of PV panel

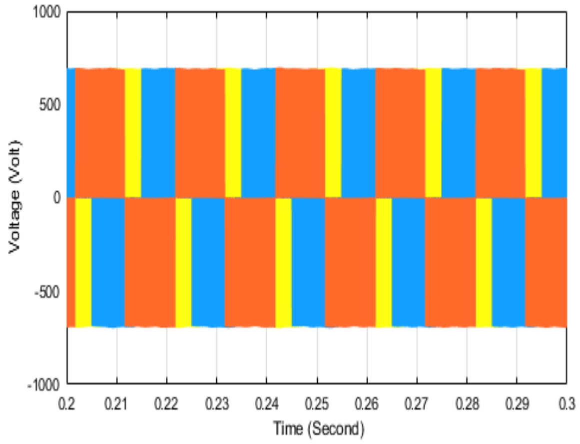

Figure 10. Output without filter

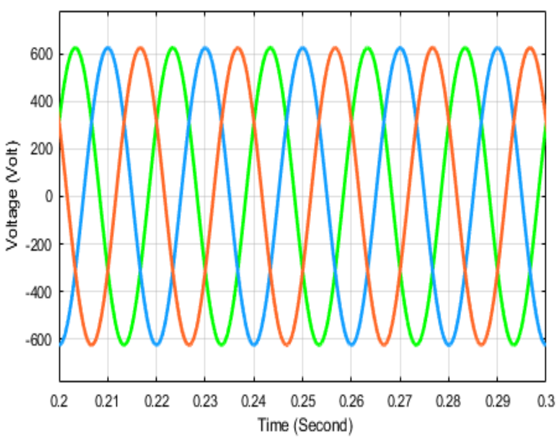

Figure 11. Output with LCL filter

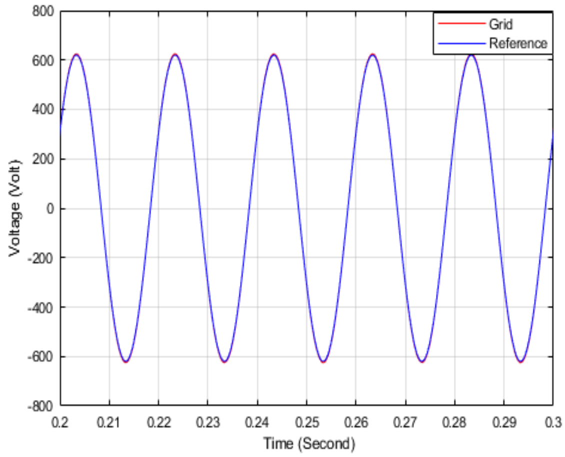

Figure 12. Grid synchronization

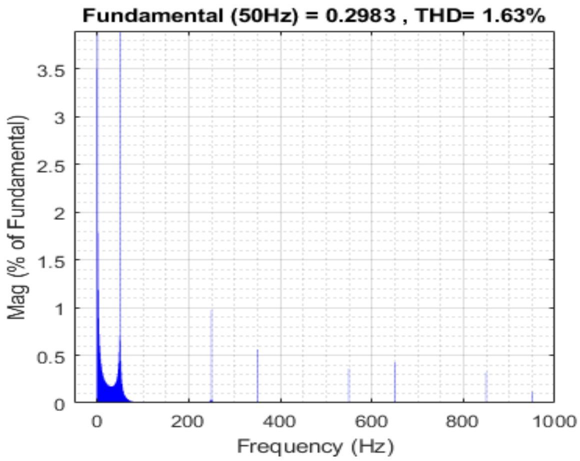

Figure 13. THD of inverter current

6. CONCLUSION

In this paper work, a 3∅ grid-connected system with PV panel has been analysed. The proposed method used the MPPT technique controlled by the P & O algorithm and I-V and -PV characteristics were taken. As shown in the results 120v was enhanced to 685v using a boost converter. In order to maintain synchronization with the grid, SRF-PLL was being introduced to match the frequency and phase angle of the grid voltage. Since boost converter along with H-Bridge inverter was used, so the influenced of THD value also investigated such that the value must be in the permissible limit as per the standard specified in IEEE1547 and IEC61727. The inverter was subjected to 180° conduction mode in order to get the above-maintained result. All these observations and results obtained by this model simulated in MATLAB SIMULINK 2017b software. The proposed work can be enhanced by different MPPT control algorithms and also using different types of inverter models

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