Control performance and THD Analysis of SPWM based Three Phase Single Stage Mini Grid Tie Inverter Applications

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ABSTRACT

Safe energy option can be offered in power system by introducing the concept of distributed generation system that contains grid tie inverter. However, the efficiency and performance is still under research since the control structure is a significant part for this kind of system. A simple modeling and current control strategy has been proposed in this paper for an 11kV mini grid application. First of all the control strategy has been proposed for SPWM single stage inverter by which the DC components of grid current has been minimized. Moreover, the grid voltage and inverter's output current phase difference has been minimized using PLL and PI controller. And finally Total Harmonic Distortion is calculated which came 2.03%.

Keywords: Grid Tied Inverter; PLL; PI controller; dq0 Transformation.

1 Introduction

Emergence growth of renewable energy is seen currently in modern power systems due to the increasing demand, high cost and undesirable consequences to the environment of fossil fuels. Almost all sort of renewable energy produces DC power output [1]. As a result, this DC energy is required to convert into AC power output, which is commonly achieved by using inverter. This inverter can be used in two ways; it can be used either for a standalone load or it can connect with grid as well. For grid tied inverter the voltage and frequency of grid must be same as the voltage and frequency of output of inverter. Another important aspect is the control of grid tied inverter.

The main objective is to study the response of grid voltage and line current of inverter for SPWM based grid tie inverter. In order to achieve the synchronism some control strategies must be incorporated. The control of grid tied inverter can be separated into two sections they are input-side controller and output-side controller [2]. The current control strategy in this paper is proposed for SPWM based inverter [3],[4]. The controller part contains some major blocks they are PLL, PI controller, abc-dq0 transformer and so on. The grid voltage and the line current phase angles are extracted using PLL and then compared with the reference current. As a result, an error signal is generated; using PI controller the error is minimized [5]. In order to simplify the calculation inverter abc components are transformed into dq reference frame after correcting the error signal it is transferred back to abc components [6].

The basic block diagram for the proposed system is given in Fig.1.

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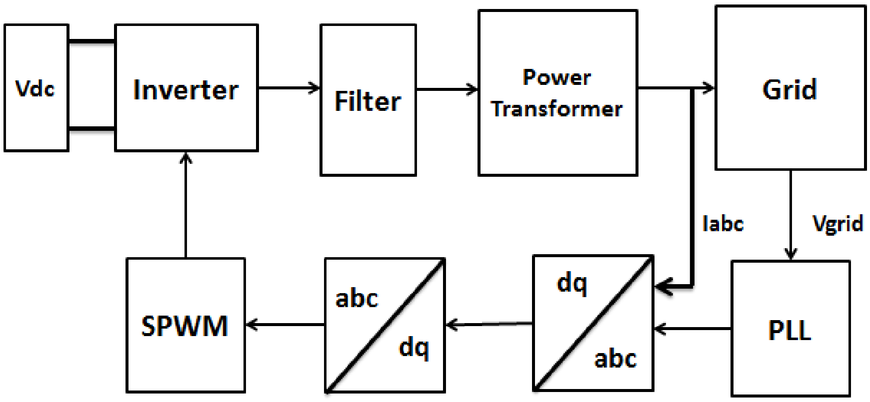

Fig 1: Basic black diagram of Grid Tie inverter system.

In this paper the basic SPWM technique and the filter topologies are discussed in section 2. Section 3 is focused on the proposed inverter model, grid model and controller design. Simulations are done by Simulink; section 4 contains the obtained results for the system. And finally section 5 is the conclusion for this paper.

2 Basic Components

2.1 SPWM technique

SPWM refers Sine Pulse Width Modulation which is commonly used switching technique for inverter switching. Here the comparison between carrier wave and sine wave generates the gate pulses for inverter. These pulses are applied to the gates of the switches, therefore AC signal generates. In this paper the carrier frequency is about 5kHz.

2.2 LC filter

The AC signal which is generated at the output terminal of the inverter is not a pure sinusoidal wave due to the consequence of additional non-linear components. This refers the inverter carries harmonics which causes signal distortion. Using passive filters these harmonic effects can be reduced. In this paper an LC filter is used with a series damping resistance which is connected in series with the capacitance. Using the proposed filter the THD is obtained 2.03%.

2.3 Grid Tie Inverter

Inverter is commonly used to transform DC signal into AC. Unlike the conventional inverter grid tie inverter is connected with the utility grid and requires to be controlled so that the real power can be injected to the grid. In order to ensure the synchronism the voltage level of grid side and inverter side must be same, the frequency should be same and the phase sequences have to be same. The inverter in this paper has been chosen SPWM type and IGBT is used as switching device. An external 400V DC link is used in this paper that comprises a parallel RC brunch that elements the DC effect from the output signal. IGBT is used as switching component and the output of the inverter is fed an LC filter.

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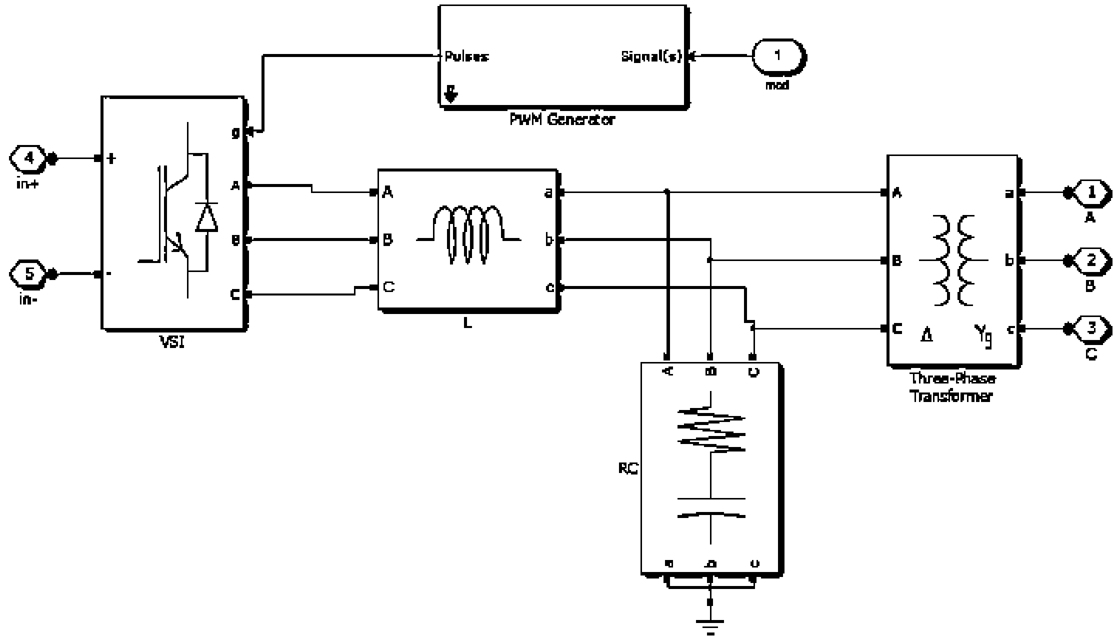

Fig 2: Three phase inverter model.

2.4 Power Grid Model

The voltage level of power grid is considered 11kV line-line. A 120kV three phase source is chosen as grid input source, which is connected with 120/25kV (delta-wye) power transformer and the output of the transformer is connected to 25/11 kV (delta-wye) transformer to the output bus.

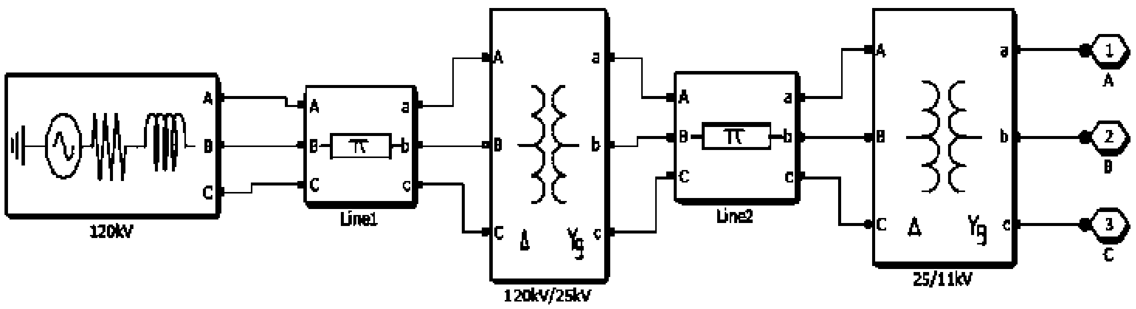

Fig 3: Proposed 11kV Grid model.

3 Controller Design

The grid voltage must be synchronized with the injected inverter current. This can be achieved by using controller. Therefore, controller is one of the significant blocks for grid tie inverter. As a result, the initial goal is to sense the phase angle from grid voltage and the feedback variable in order to generate a proper reference frame. The phase angle from the grid voltage is typically extracted using the zero crossing detection technique and Phase Lock Loop (PLL). The zero crossing detection approach is a simple way to detect the phase angle of grid voltage. However, owing to the existence of utility grid harmonics, it does not detect the phase angle very well. As a result, this approach is ineffective for extracting phase angles from utility grids. PLL, which can efficiently sense the phase angle of grid voltage despite the presence of harmonics in the grid, is a typical approach for synchronization. The suggested controller schematic diagram is shown below.

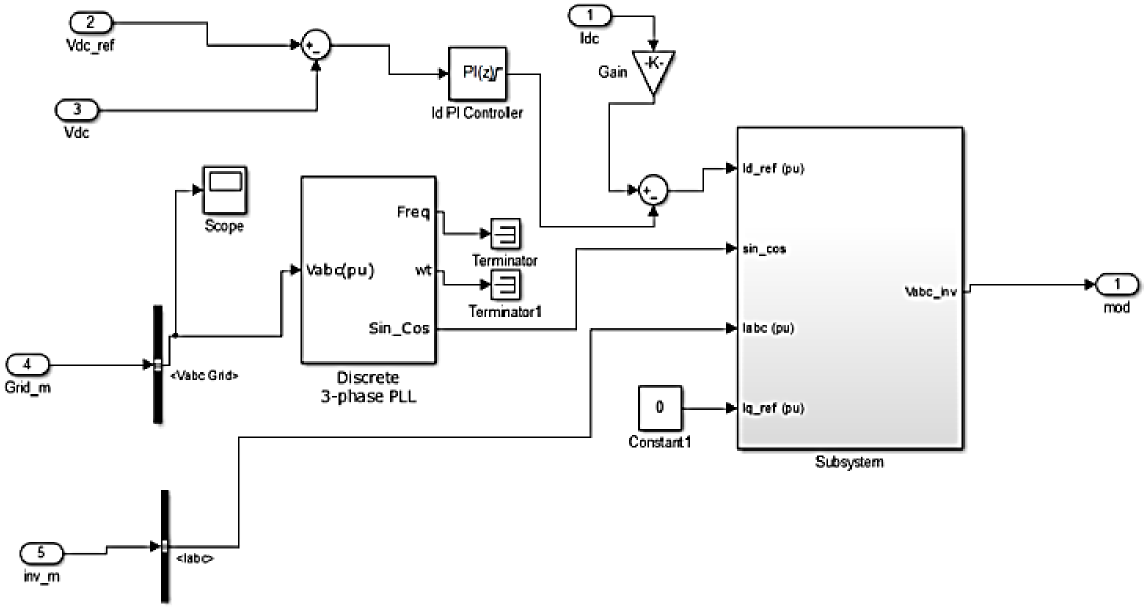

Fig 4: Controller for Grid Tie inverter.

The controller consists of PI controllers, PLL, abc-dq0 converter, dq0-abc converter and so on. Voltage is sensed from grid the phase angle is extracted by PLL. For the sake of simplicity in terms of calculation abc is transformed into dq0 reference frame. If it's voltage or current, Park's transformation may change the a-b-c to d-q reference frame circle the electrical speed of the 3-phase grid.

$$\begin{bmatrix} Id \\ Iq \\ I0 \end{bmatrix} = \sqrt{\frac{2}{3}} \times \begin{bmatrix} cos\theta & \cos(\theta - 120) & \cos(\theta + 120) \\ -sin\theta & -\sin(\theta - 120) & -\sin(\theta + 120) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \times \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \quad \text{.....................................} \quad (1)$$

The abc-dq0 transformation is accomplished out using the given equation. The unit vectors sinωt and cosωt are created as stated by the suggested sampling approach by detecting grid voltages, and the reference frames and angle θ=ωt if t = 0 instant is measured as positive peak taking place instant of the grid phase voltage.

The injected real and reactive power by the inverter to the three phase electrical grid can be calculated from the following equation.

$$P = V_d I_d + V_q I_q \qquad (2)$$

$$Q = V_d I_q + V_q I_d \qquad (3)$$

In this case output current of inverter is sensed and transformed into dq0 reference frame. The inverter output current is taken in per unit in order to avoid the serious errors. The current which is transformed into dq0 is compared with reference I_{dref} and I_{qref}. I_{qref} is considered zero and I_{dref} is generated. After comparing they generate error signals and pass through a PI controller. The PI controller minimizes the error and finally the corrected signal transformed back into abc and provided to the SWPM pulse generator with a correct angle.

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4 Simulation Results

All necessary simulations are carried out by Simulink. The Simulink model of the entire system is given as following:

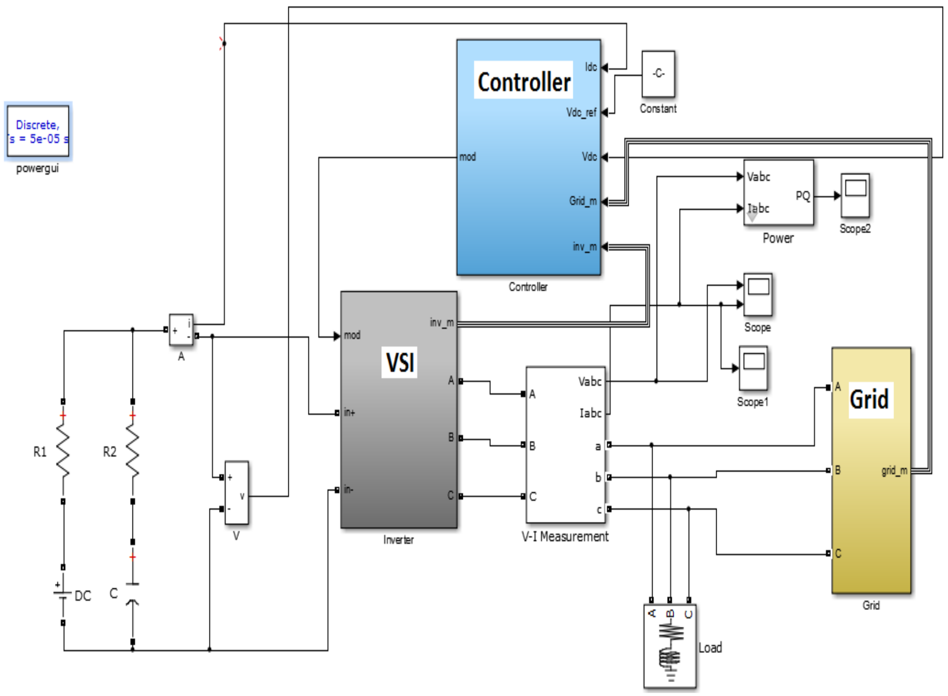

Fig 5: Proposed Simulink model.

Scope plot for inverter current and grid output voltage is shown in Fig 6. The output curves illustrate there is a little phase shift between grid voltage and inverter current although this small effect can be eliminated if the PI controller is effectively designed.

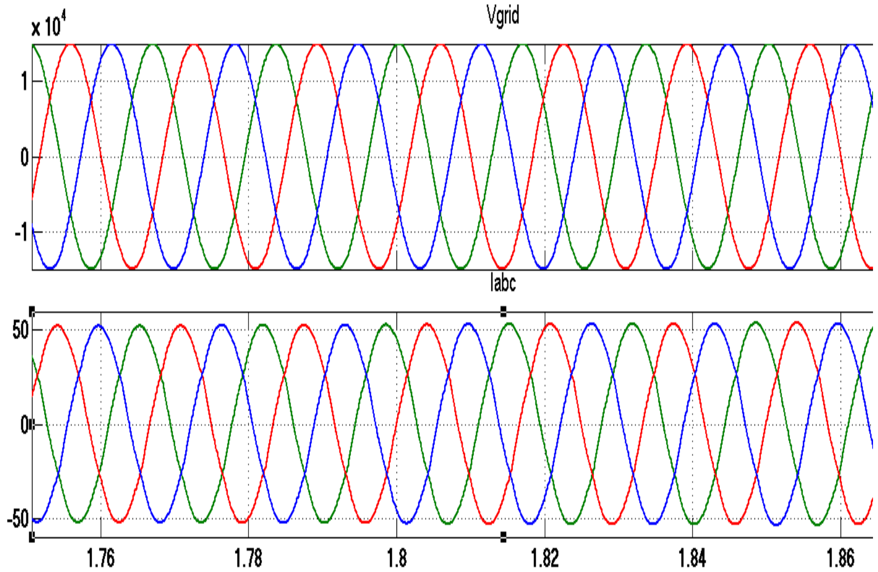

Fig 6: Grid output voltage and inverter output current.

The output voltage of the inverter is shown below. Fig 7 is the voltage wave of inverter output without using filter, and Fig 8 is the output after filter. The output results illustrate using filter the harmonic distortion can be reduced significantly.

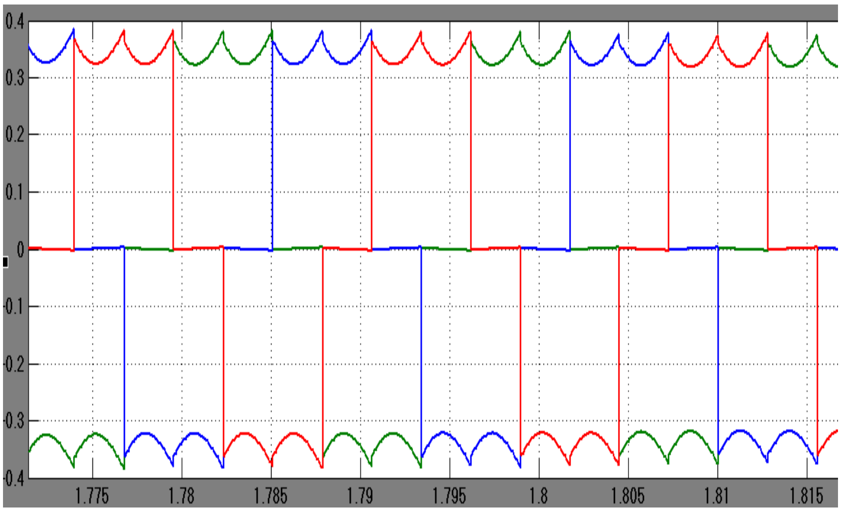

Fig 7: Output voltage of inverter in per unit without using filter.

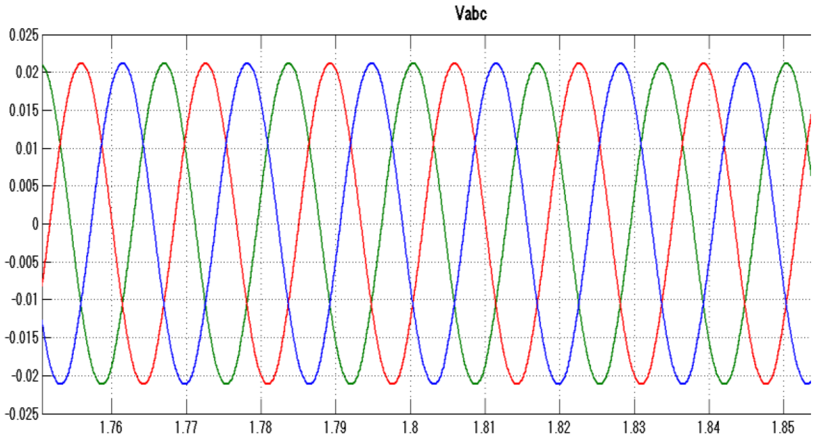

Fig 8: Output voltage of inverter in per unit using filter.

The plots of Total Harmonic Distortion are illustrate in the following figures. Fig 9 is the THD response for the inverter current is obtained about 2.03% which is an acceptable result. The THD response for the inverter voltage with and without using the passive filter is shown in Fig 10 and Fig 11. The THD is obtained about 0.47% using filter whereas without using filter it was about 32.57%.

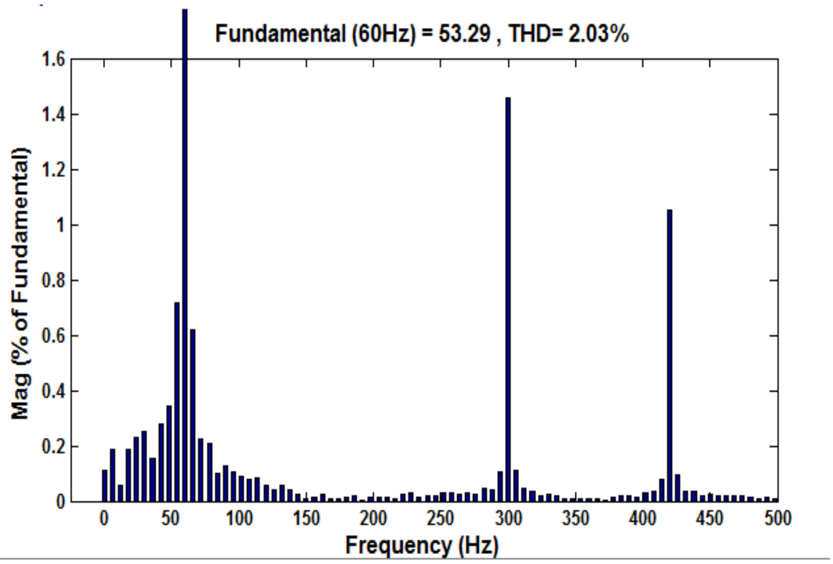

Fig 9: THD response of inverter current.

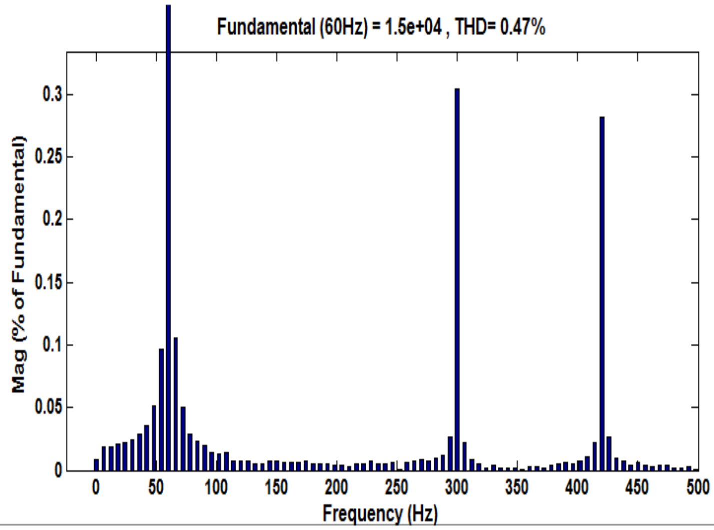

Fig 10: THD response for output voltage of inerter using filter.

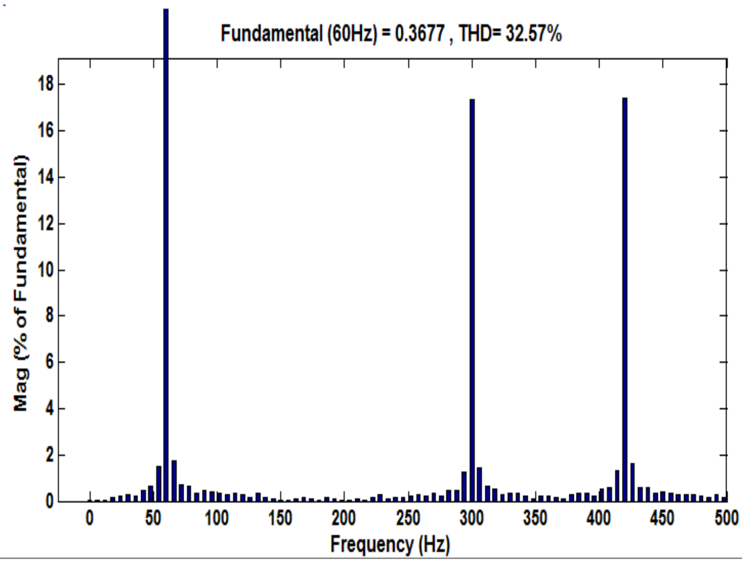

Fig 11: THD response for output voltage of inverter without using filter.

5 Conclusion

The THD response and phase shift between electrical grid output voltage and inverter current can be improved more by developing the control strategy as well as selecting more efficient filter topologies. This paper is intended to study the performance of single stage inverter and SPWM pulse generator for a mini on-grid application. The complete simulation is done by Simulink and acceptable results have been obtained. THD is about 2.03% for current of the inverter output and using passive LC filter voltage THD is obtained about 0.47% which is acceptable for a single stage SPWM inverter.

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