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Grid Tied Solar Power Generation with Active Power Filter for Nonlinear Loads

Koppineni RNV Subbarao[1], K. Kranthi Pratapsingh[2]

[1]M.Tech scholar, EEE Department, ASRIET, Tadepalligudam, A.P, India

[2]HOD, EEE Department, ASRIET, Tadepalligudam, A.P, India

Abstract: ***In this contribution, grid tied solar power generation is connected to nonlinear loads based on Active Power Filter (APF) by providing predictive control scheme. The solar power (photovoltaic PV array) generation is increasingly well liked in the polluted world, while a typical load requires high-power quality. when connected to non-linear loads in commercial and industries applications can produce harmonics in the electrical power systems. An active power filter carried out with a four-leg voltage-source inverter (four leg -VSI) using a predictive control scheme is presented. The use of a four-leg VSI allows the compensation of current harmonic components, as well as unbalanced current generated by single-phase nonlinear loads. This solar power generation including a detailed PV generator, dc/dc boost converter to extract maximum radiation power using maximum power point tracking(MPPT). Finally grid tied PV system for nonlinear loads results analyzed in MATLAB/SIMULINK.***

Keywords: Active Power Filter (APF), Current Harmonic Components, Maximum power point tracing (MPPT), Predictive control, Voltage source inverter.

1. Introduction

World power production scenario shows pollution percentage in the world. 41%, 20% and 6% of coal, gas and oil in the overall power production. largest generation power from coal at the same time that much of pollution produced. this is killing a living organisms. now a days solar power sitting for a good remedy of non renewable sources. even that a small problem like, not avaliable for a day. New independent power generation could provide low expensive, better efficient, and smaller-scale power plants are well placed in the era. The direct current (DC) voltage of PV plans is connected to a DC-DC boost converter using a maximum power point tracking (MPPT) controller to enhance their produced energy. Then, output of DC-DC converter is coupled to a DC-AC voltage source converter (VSC) to let the PV system push electric power to the AC utility[4].

In the recent years, there has been an increment of solar power generators linked to grids by advanced digital controller helps to improve power quality with fast switching characteristics devices means of power electronics converters. Non linear loads can generate undesirable characteristics in power system like harmonics in current waveform, poor power factor, etc., Although active power filters enforced with three-phase four-leg voltage-source inverters (four leg -VSI) have been presented in the literature [2]–[6]. The major implement of this active power filter controlling is a predictive control. Generally, pre-tuned controllers are used for active power filters, such as Proportional Integral (PI) -type or adaptive, for the current as well as for the dc-voltage loops [5]. With the quick response of microcontrollers available in a day, predictive control applications in electrical drives and power converters are a high powerful and better alternative to classical controllers. The application of predictive control offers a more advantages: very intuitive approach, no need for modulators and linear controllers, easy inclusion of nonlinearities and restrictions, etc. PI controllers must be controlled based on the equivalent linear model, while for nonlinear models using predictive controller, predictive control is near to real time operating conditions. Optimal model obtained using predictive controllers improves the functioning of the active power filter, because it can response on the current-reference signal quickly while maintaining a constant dc-voltage. In this paper, solar power plant is connected to grid; it is operated under peak loads. Predictive control scheme is very useful for better performance of Active power filter. MATLAB/SIMULINK was used for simulation and analysis of current harmonics under non-balanced load conditions and over load grid tied solar power.

2. Solar Power generation

The PV array has *'n'* strings of modules connected in shunt, each string consists of *'m'* modules tied in series to get a need power rating. Equivalent circuit of PV cell is shown in figure 1.

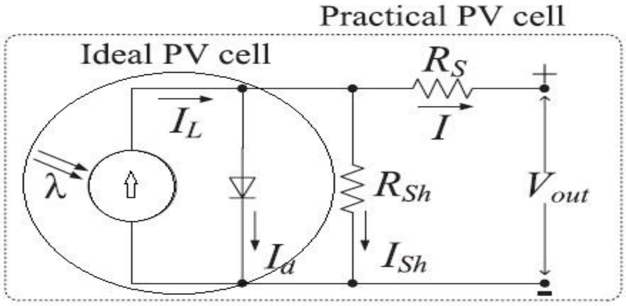

Figure 1: Equivalent circuit of Photovoltaic cell.

In an ideal PV cell, series resistance (R_s) =0 (no series loss) and shunt resistance (R_{sh}) = infinite (no leakage to ground). The terminal current *(I)* is equal to the light produced current (I_L), less the diode current (*Id) and* the shunt leakage current (or ground-shunt current, I_{sh}). The series resistance (R_s) represents the internal resistance to the current flow. The shunt resistance (R_{sh}) is inversely related to leakage current to the ground.

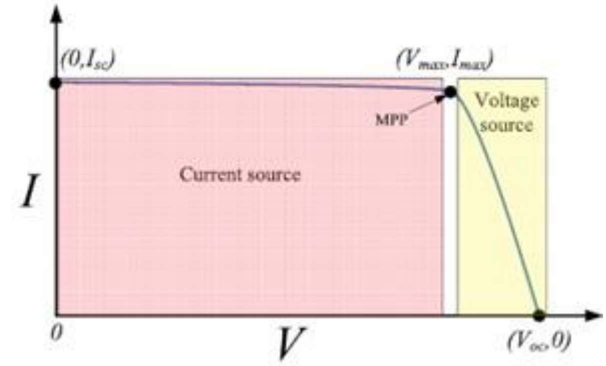

Figure 2: V-I characteristics of PV power of maximum power point

The PV cell generates the optimal power at voltage corresponding to the knee point of the *V-I* curve is as shown in Figure2. *Imax and Vmax* are current and voltage at maximum power point respectively. The dc-dc converter (Boost converter) is connected to operate at maximum voltage to achieve maximum power by MPPT.

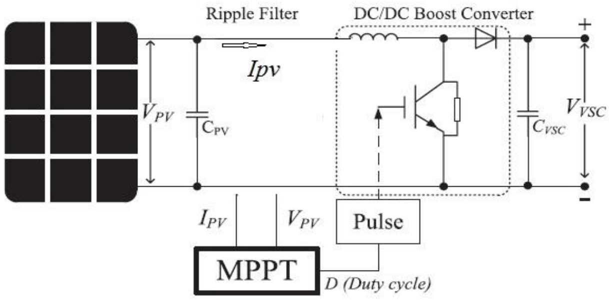

Figure 3: MPPT based DC-DC boost converter.

The motive of MPPT technique is to automatically get MPP operation under different atmospheric conditions. DC-DC boost converter is a converter used for the applications of requires voltage of output to be more than input voltage. The DC-DC boost converter consists of an IGBT/MOSFET switch, passive components and a diode. Passive components are inductor (L) and capacitor (C) and resistance (R). The dc-dc boost converter operation consists of two states: ON state in which the switch is trigged and OFF state in which the switch is turned off.

ON State

$$L\frac{di_L}{dt} = V_{PV}$$

$$C_{VSC}\frac{dv_{VSC}}{dt} + \frac{V_{VSC}}{R} = 0 \quad 1$$

OFF State

$$L\frac{dI_L}{dt} + V_{VSC} = V_{PV} \quad 2$$

$$I_L - C\frac{dV_{VSC}}{dt} - \frac{V_{VSC}}{R} = 0 \quad 3$$

The ratio of the ON and OFF times to the operation time can be modulated using different techniques and called pulse width modulation (PWM). In this paper triangular pulse is used for compare with the duty ratio which is the control signal.

3. Active Power Filter for Non-Linear load

3.1 Four Leg converter circuit

This two level four leg converter circuit is near to the conventional six pulse three-phase converter with the fourth leg connected to the neutral bus of the system as shown in figure 4.

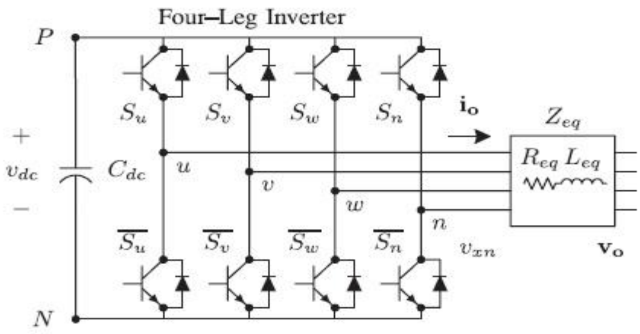

Figure 4: Two Level Four leg Converter Circuit

The voltage measured from the neutral point (*n*) to in any leg (*x)* of the converter, can be written in the form of switching order, as follows:

$$s_{xn} = s_x - s_n dc \quad x = u, v, w, n$$

3.2 Predictive Control

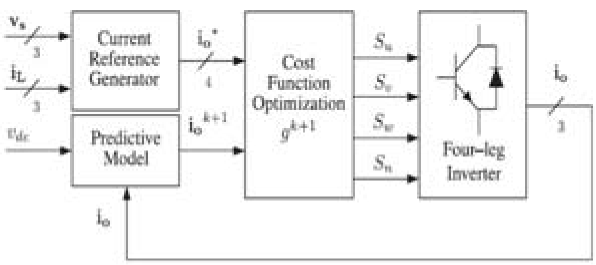

Figure 5: Predictive Control block Diagram.

The characteristic of predictive control is applied for the system model to predict the future behavior of the variables to be controlled [4]. The controller uses this data to select the better switching state that will be enforced to the power electronics converter. The predictive control is easy to implement and to understand, and it can be implemented with three main blocks, as shown in Figure 5. The discrete time switching states and control variables at instant kT_s, it is possible to predict the next states at any instant $[k + 1]T_s$. A sufficiently accurate first-order approximation of the derivative is considered in this paper.

$$\frac{dx}{dt} = \frac{x[k+1] - x[k]}{T_s} \quad 4$$

In order to predict the output current $\boldsymbol{i_o}$ at the instant $(k + 1)$, the input voltage value $\boldsymbol{v_o}$ and the converter output voltage, are required. The 16 possible output current predicted values can be obtained [6].

$$i_0[k+1] = \frac{T_s}{L_{eq}}(v_{xn}[k] - v_0[k]) + \left(1 - \frac{R_{eq}T_s}{L_{eq}}\right) i_0[k] \quad 5$$

Cost function optimization in order to select the better switching order that must be applied to the power converter, the 16 predicted values obtained for $\boldsymbol{io}[k+1]$ are compared with the reference using a cost function[6]. A dq-based current reference generator scheme is used to obtain the active power filter current reference signals. This scheme presents a fast and accurate signal tracking capability. This characteristic avoids voltage fluctuations that deteriorate the current reference signal affecting compensation performance. This module calculates the reference signal currents required by the converter to compensate reactive power, current harmonic and current imbalance. The displacement power factor (sin $\varphi(L)$) and the maximum total harmonic distortion of the load (THD(L)) defines the relationships between the apparent power required by the active power filter, with respect to the load, as shown6.

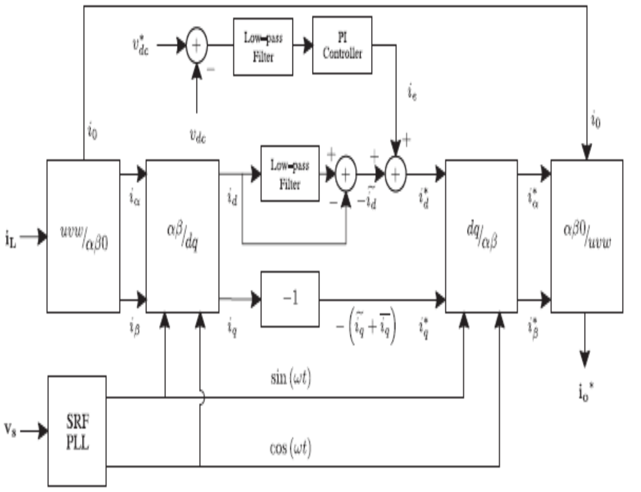

Figure 6: dq-based current reference generator block diagram

$$\begin{matrix} i_d \\ i_q \end{matrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin wt & \cos wt \\ -\cos wt & \sin wt \end{bmatrix} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Lu} \\ i_{Lv} \\ i_{Lw} \end{bmatrix} \qquad 6$$

In order to keep the dc-voltage constant, the amplitude of the converter reference current must be modified by adding an active power reference signal ie with the d-component, as will be explained [4]. The resulting signals i_d^* and i_q^* are transformed back to a three-phase system by applying the inverse Park and Clark transformation, as shown in (7).

$$\begin{bmatrix} i_{ou}^* \\ i_{ov}^* \\ i_{ow}^* \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sin wt & -\cos wt \\ 0 & \cos wt & \sin wt \end{bmatrix} \begin{bmatrix} i_0 \\ i_d^* \\ i_q^* \end{bmatrix} \qquad 7$$

$$i_{on}^* = -(i_{Lu} + i_{Lv} + i_{Lw})$$

DC voltage control is design with a general PI controller. This is an important issue in the evaluation, the current references help to the cost function design, in way to remove of weighting factors. Generally, these weighting factors are obtained experimentally, and they are not well defined when different operating conditions are required. Additionally, the slow dynamic response of the electrolytic capacitor voltage does not affect the current transient response. For this reason, the PI controller indicates a simple and effective option for the dc-voltage control [4].

4. Simulation Results

In the PV model block contains the boost converter and voltage source inverter (VSC) converters are presented by MATLAB/SIMULINK as shown in figure 7, voltage source inverter generating the AC voltage averaged over one cycle of the switching frequency. This boost converter operate PWM signal which is from maximum power point tracing (MPPT) signal compare with triangle wave.

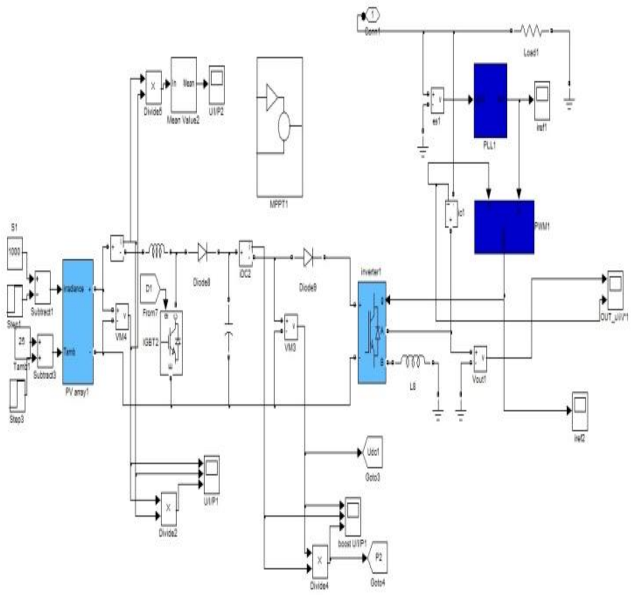

Figure 7: MPPT based PV arrays model in MATLAB.

This solar abundantly available, benign in Nature, solar power operate at peak loads, in this model solar power connected on 0.1 sec to 0.2 sec. voltage and current waveforms of solar connected as shown in figure 12. Grid tied solar power generation model shown in figure 8, a nonlinear load as source of harmonics, which affect the remaining loads and also source. Active power filter placed for compensation of harmonic currents, this is connected at grid PCC. In this model PV solar act for peak loads and this PV system has boost and VSI converter for boost dc voltage convert to AC source.

Figure9 shows the three phase results for nonlinear load affected source current, load current, four leg three phase inverter injected current and source voltage. This shown the active power filter work on 0.06 seconds at this time source current improved. DC side voltage maintain at that time. Single phase waveforms and DC side voltage are available in figure 10.

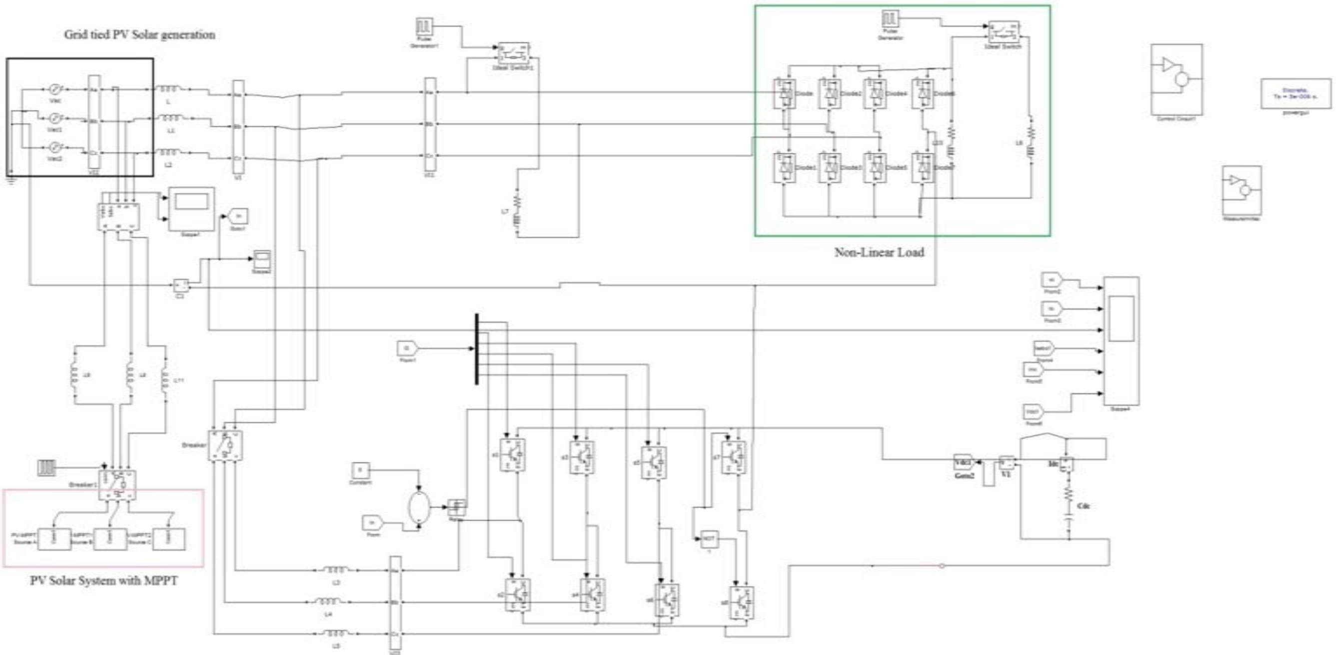

Figure 8: Grid tied Solar Power Generation with APF in MATLAB/SIMULINK

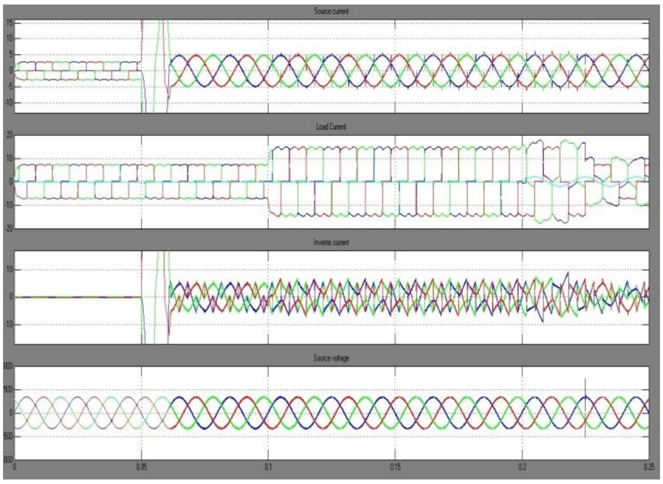

Figure 9: Simulation results of grid tied solar power with Active power filter a) Source current, b) Load current, c) APF Injecting current, d) Source Voltage.

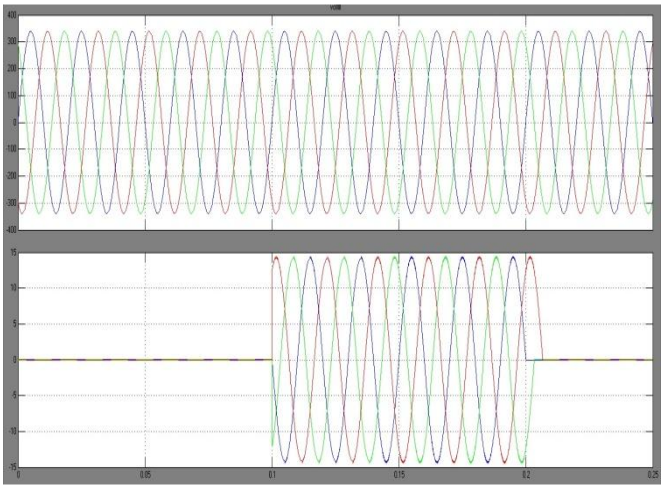

Figure 12: Solar Power is connected at peak loads (0.1 sec to 0.2 sec) which shows a) Voltage across PCC point, b) current waveform.

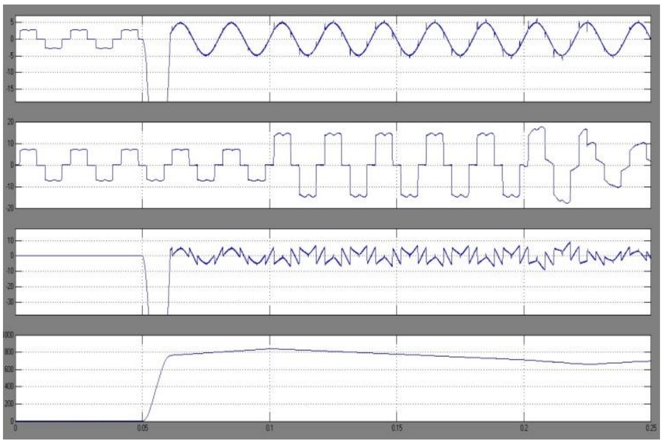

Figure 10: Single Phase Results a) Source Current, b) Load Current, c) Injecting current, d) DC voltage.

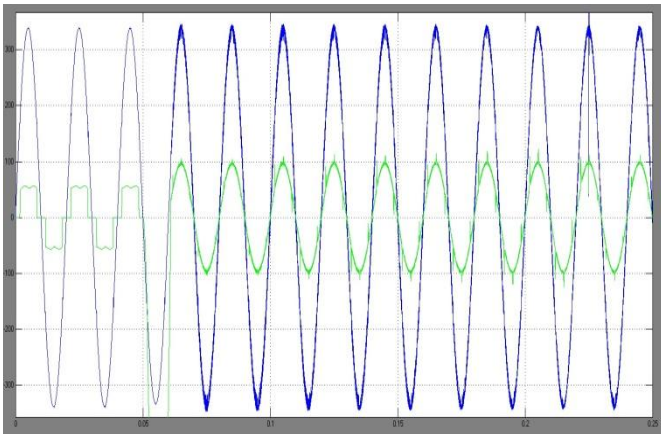

Figure 13: Power factor at load.

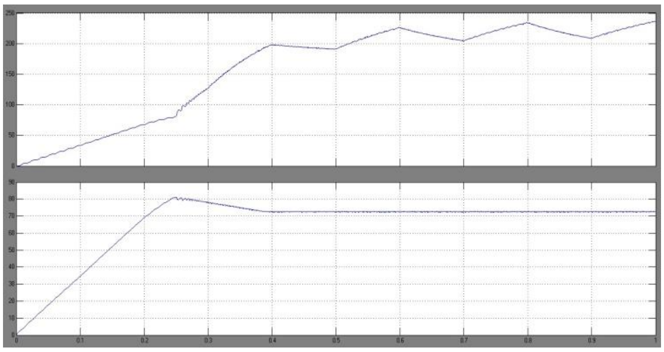

Figure 14: a) DC-DC converter output voltage, b) DC-DC converter input or PV solar output voltage.

Total Harmonic Distortion (THD%) of source current is 2.47% as per IEEE standards shown in figure 11. PV system operating on peak times voltage and current waveform shown in figure 12. Unbalance load condition presented, this active power filter maintains power factor unity in transmission.

Solar system DC voltage and DC – DC boost converter output voltage as shown in figure 14. Dc-dc boost converter voltage 280 volts and solar dc voltage is 75 volts. Voltage source inverter has single phase two leg getting pulses from on utility grid voltage. This voltage always measures grid phase voltage.

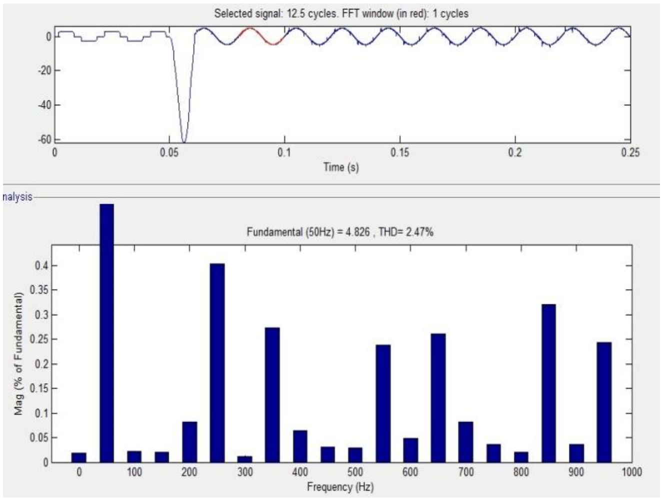

Figure 13: THD Value of Source Current.

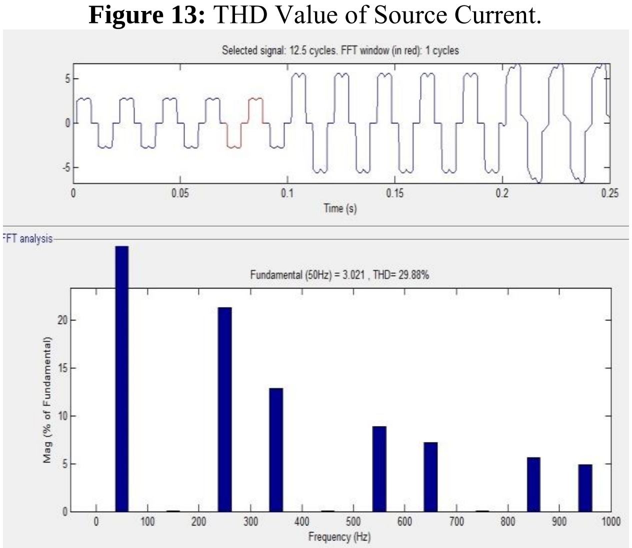

Figure 14: THD % without APF.

Table 1: THD% of Current source

Source Current	THD %	5rd Harmonic %
Without Active power filter	29.68	21.26
With Active Power Filter	2.57	0.44
Grid tied PV system with Active Power Filter	2.42	0.4

5. Conclusion

Simulation results guaranteed that proposed four leg three phase active power filter best solution of reducing current harmonics for grid utility. The predictive controller for the converter current loop is improving current tracking capability and transient response. This controller is better alternative of classical controller. The predictive current control algorithm is a stable and robust solution. This APF topology is optimal root for grid connected PV Power systems because of VSI generated harmonics also reduces.

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