Improved Active Power Filter Performance by Instantaneous Power Theory

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Abstract— ***In this paper, a three-phase four-wire system connected a nonlinear load, dc/ac four leg voltage source converter to act as a four leg Active Power Filter (APF) using of instantaneous power theory is presented. The use of a four-leg voltage-source inverter allows the compensation of current harmonic components, as well as unbalanced current generated by single-phase nonlinear loads. The instantaneous power theory is applied to design the APF controller, which shows reliable performances. The MATLAB/SimpowerSystems tool has proved that the proposed control technique compensate the harmonic current drawn by nonlinear loads and controls the reactive power flow.***

Index Terms— **Active Power Filter (APF), Instantaneous power theory, Nonlinear load, Voltage Source converter.**

I. INTRODUCTION

Power supply and power quality has been critical issues in power system recently. The grid-connected photovoltaic (PV) generator has nowadays become more popular because of its reliable performance and its ability to generate power from clean energy resources**.** Renewable generation affects power quality due to its nonlinearity, since solar generation plants and wind power generators must be connected to the grid through high-power static PWM converters [1]. The non-uniform nature of power generation directly affects voltage regulation and creates voltage distortion in power systems. This new scenario in power distribution systems will require more sophisticated compensation techniques.

Active power filters implemented with three-phase four-leg voltage-source inverters (VSI) have already been presented in the technical literature [2]-[4]. The primary contribution of this paper is a instantaneous power balance theory control designed and implemented specifically for this application [5]. The APF system helps the utility supply a unity power factor and pure sinusoidal currents to the local nonlinear loads by generating the oscillating and imaginary components. The controller based on instantaneous power theory and instantaneous power balance is proposed to replace the conventional *dq*-current controller.

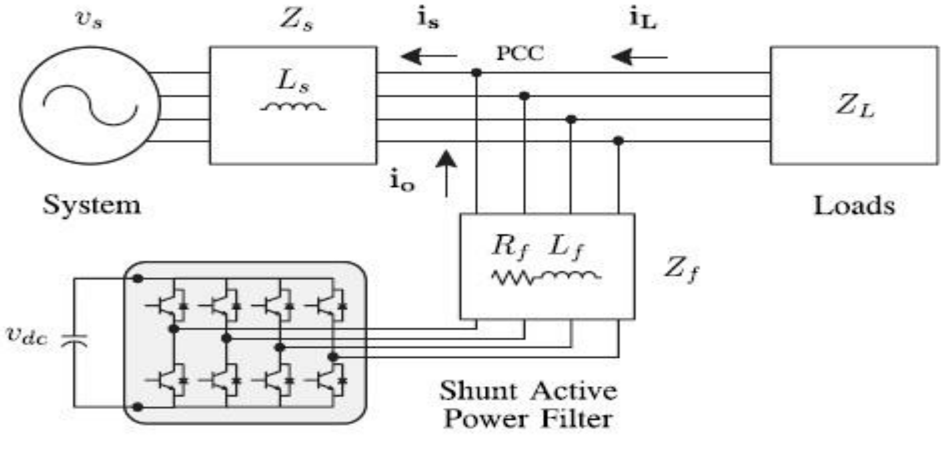

Fig.1. Three Phase four wire equivalent circuit of the proposed shunt Active Power Filter.

This paper presents the mathematical model of the 4L-VSI and the principles of operation of the proposed instantaneous power control scheme, including the design procedure. Figure.1. shows the three phase four wire equivalent circuit of the proposed shunt active power filter. Finally, the proposed active power filter and the effectiveness of the associated control scheme compensation are demonstrated simulation results by MATLAB/SIMULINK.

II. Four Leg Converter Model

In the power system, the electrical energy consumption behavior is random and unpredictable, and therefore, it may be single- or three-phase, balanced or unbalanced, and linear or nonlinear. An active power filter is connected in parallel at the point of common coupling to compensate current harmonics, current unbalance, and reactive power. It is composed by an electrolytic capacitor, a four-leg PWM converter, and a first-order output ripple filter, as shown in Fig. 1. This circuit considers the power system equivalent impedance Z_s , the converter output ripple filter impedance Z_f , and the load impedance Z_L .

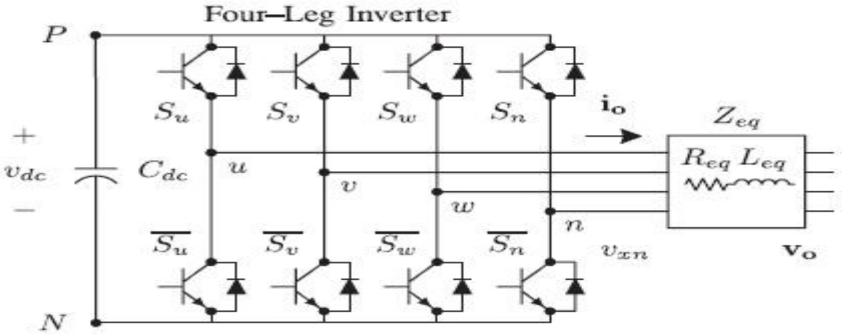

Fig.2. Four leg PWM VSI topology.

The four-leg PWM converter topology is shown in Fig. 2. This converter topology is similar to the conventional three-phase converter with the fourth leg connected to the neutral bus of the system. The voltage in any leg *x* of the converter, measured from the neutral point (*n*), can be expressed in terms of switching states, as follows:

$$v_{xn} = S_x - S_n\, v_{\mathrm{dc}}, \qquad x = u,\ v,\ w,\ n. \tag{1}$$

$$\mathbf{v_o} = v_{xn} - R_{\mathrm{eq}}\,\mathbf{i_o} - L_{\mathrm{eq}}\frac{d\,\mathbf{i_o}}{dt} \tag{2}$$

$$Z_{\mathrm{eq}} = \frac{Z_s Z_L}{Z_s + Z_L} + Z_f \approx Z_s + Z_f. \tag{3}$$

The mathematical model of the filter derived from the equivalent circuit shown in Fig. 2. Where R_{eq} and L_{eq} are the 4L-VSI output parameters expressed as Thevenin impedances at the converter output terminals Z_{eq}. Therefore, the Thevenin equivalent impedance is determined by a series connection of the ripple filter impedance Z_f and a parallel arrangement between the system equivalent impedance Z_s and the load impedance Z_L. For this model, it is assumed that $Z_L >> Z_s$, that the resistive part of the system’s equivalent impedance is neglected.

III. CONTROLLER OF INSTANTANEOUS POWER THEORY

Instantaneous power flow among the parts of the APF system is simplified in Fig. 3.The dc/ac VSC keeps a significant role in implementing a given control duty. At the dc side, the power concept is consistent. However, at the ac side, the instantaneous power includes both the active part (p_{VSC}) and the imaginary part (q_{VSC}) [8].

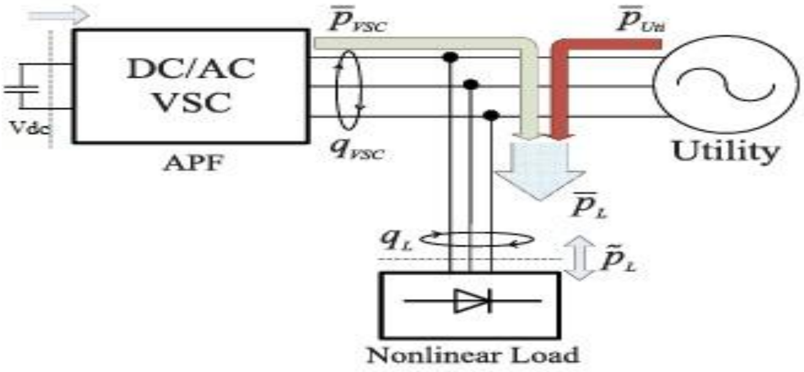

Fig.3. Instantaneous power flows among APF system.

The load demand includes real power and imaginary power. The dc/ac VSC supplies harmonic and imaginary parts for the nonlinear loads (q_L). Different from pure linear loads that consume only average active power component, the nonlinear loads also consume the oscillating components. The APF function results in pure sinusoidal currents from the utility. There is an instantaneous power balance among the three parts at the point of common coupling (PCC).

The dc/ac VSC integrated by an APF function should provide the harmonic elimination and reactive power compensation. The controller is established based on the instantaneous power theory, where all the parameters are processed instantaneously. The input signals of that controller include utility voltages (v_{abc}), nonlinear load currents (i_{abcL}), output currents of dc/ac VSC ($i_{abc\mathrm{VSC}}$), utility injected currents ($i_{abc\mathrm{Uti}}$), and dc-link voltage V_{VSC} (to prevent overcharge dc-link capacitor). Instantaneous power balance at the dc/ac VSC-utility-load connection point makes.

$$\begin{aligned} p_L &= p_{\mathrm{VSC}} + p_{\mathrm{Uti}} \\ q_L &= q_{\mathrm{VSC}} + q_{\mathrm{Uti}}. \end{aligned} \tag{4}$$

Since the target is laid on the load, its consuming power is continuously measured and analyzed. Using the Clarke transformation, the instantaneous real power (p_L) and imaginary power (q_L) of the load can be calculated, as shown in the following equations:

$$\begin{bmatrix} v_\alpha\ (i_\alpha) \\ v_\beta\ (i_\beta) \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a\ (i_{aL}) \\ v_b\ (i_{bL}) \\ v_c\ (i_{cL}) \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}. \quad (6)$$

The topology is well-known APF controllers based on instantaneous power theory. The APF applications mentioned in [7] use this Akagi technique. The utility currents are not measured by this controller. Only the load currents and the output currents of the APF are measured. Which are oscillating powers as in

$$\begin{cases} p_{\mathrm{VSC}}^{\mathrm{ref}} = \tilde{p}_L + \bar{p}_{\mathrm{loss}} \\ q_{\mathrm{VSC}}^{\mathrm{ref}} = \tilde{q}_L \end{cases} \text{or} \begin{cases} p_{\mathrm{VSC}}^{\mathrm{ref}} = \tilde{p}_L + \bar{p}_{\mathrm{loss}} \\ q_{\mathrm{VSC}}^{\mathrm{ref}} = q_L. \end{cases} \quad (7)$$

In this case, the utility must supply the constant dc-link voltage regulation p_{loss}. After finding out the reference power for dc/ac VSC, using the reverse Clarke transformation[9], the reference current values in the three phases are generated as seen in the following equations:

$$\begin{bmatrix} i_{\alpha\mathrm{VSC}}^{\mathrm{ref}} \\ i_{\beta\mathrm{VSC}}^{\mathrm{ref}} \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_{\mathrm{VSC}}^{\mathrm{ref}} \\ q_{\mathrm{VSC}}^{\mathrm{ref}} \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} i_{a\mathrm{VSC}}^{\mathrm{ref}} \\ i_{b\mathrm{VSC}}^{\mathrm{ref}} \\ i_{c\mathrm{VSC}}^{\mathrm{ref}} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha^{\mathrm{ref}} \\ i_\beta^{\mathrm{ref}} \end{bmatrix}. \quad (9)$$

The hysteresis control technique is used to switch insulated-gate bipolar transistor gates [10].

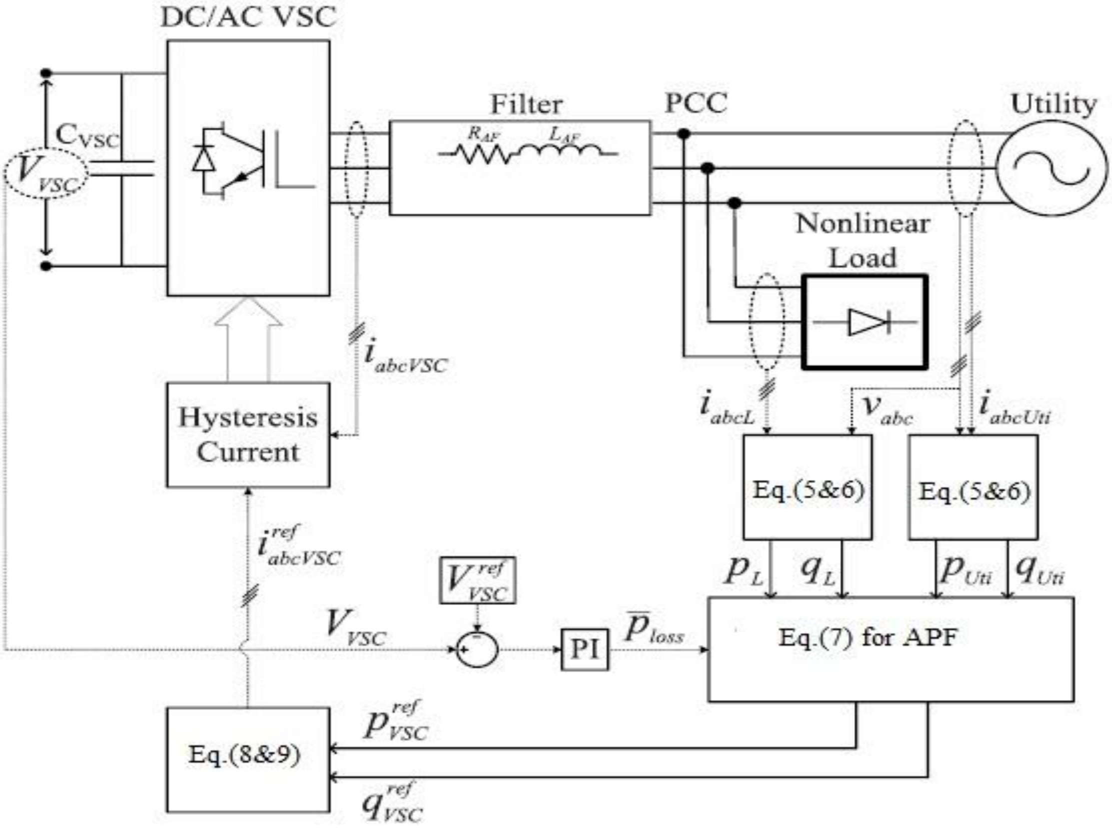

Fig.4. Controller topology of dc/ac VSC in the APF.

IV. SIMULATED RESULTS

A simulation model for the three-phase four-leg PWM converter has been developed using MATLAB-Simulink. The objective is to verify the current harmonic compensation and real power flow effectiveness of the instantaneous power theory control scheme under different operating conditions. A six-pulse rectifier was used as a nonlinear load.

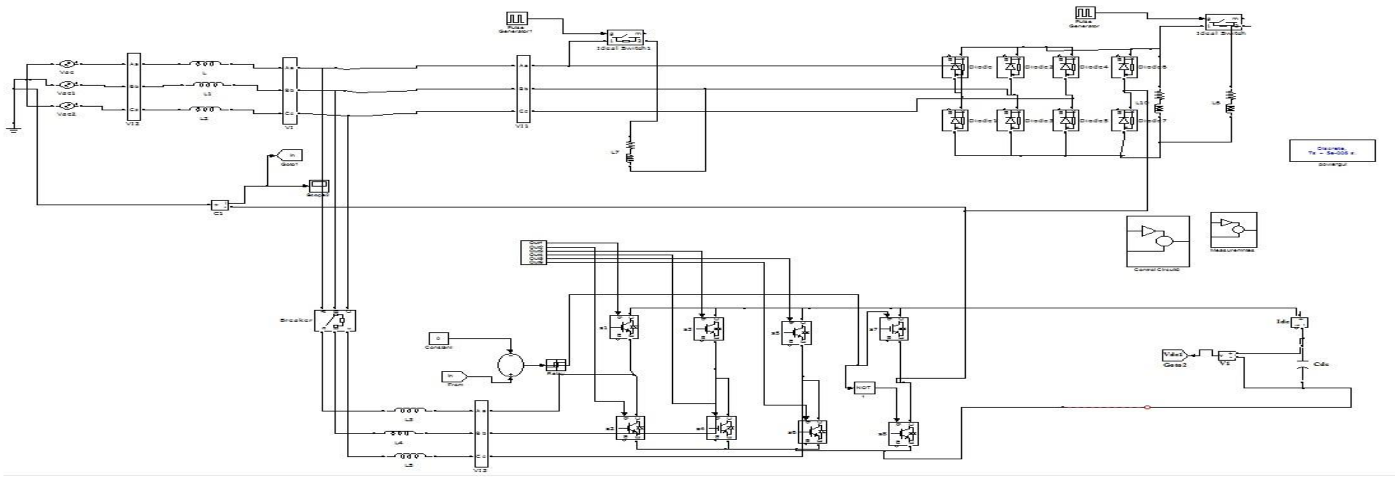

Fig.5. Simulated circuit diagram of Active Power Filter (APF) by the proposed control topology.

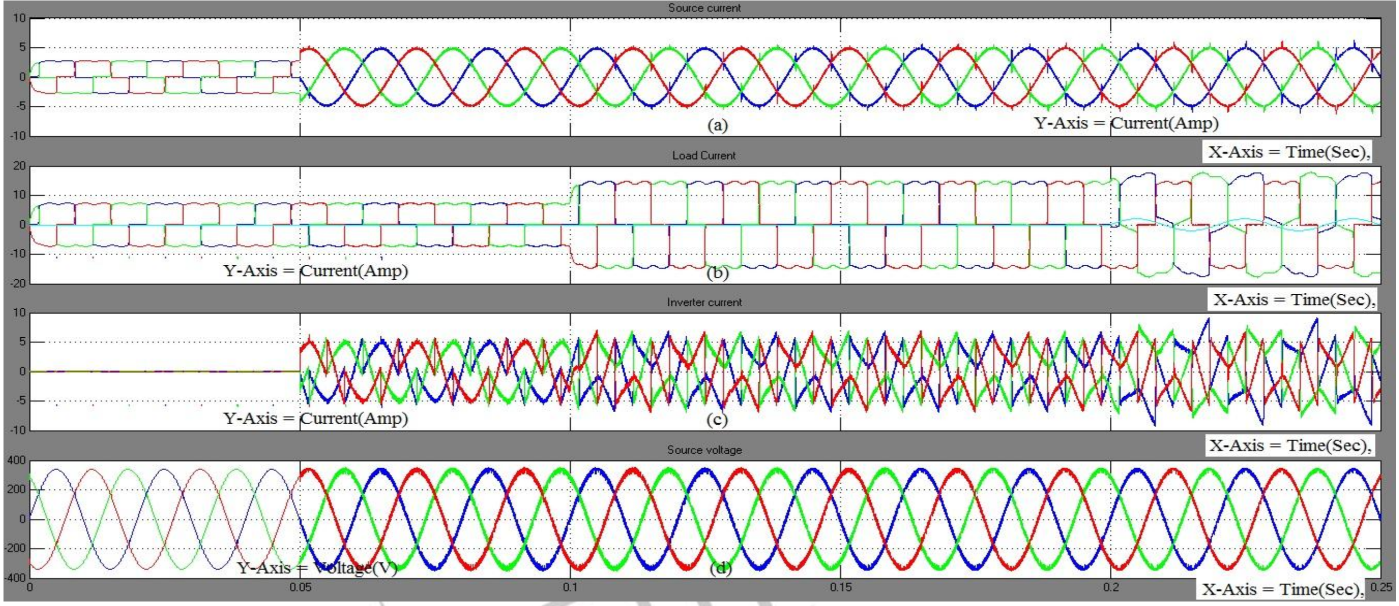

Fig.6. Simulated waveforms of the proposed control scheme a) Source Current, b) Load Current, c) VSC Injecting Current, d) Grid Voltage.

In the simulated results shown in Fig. 6, the active filter starts to compensate at *t* =0.05 sec. At this time, the active power filter injects an output current to compensate current harmonic components, current unbalanced, and neutral current simultaneously. During compensation, the system currents **is** show sinusoidal waveform, with low total harmonic distortion (THD = 2.65%). At *t* = *0.1 sec*, a three-phase balanced load step change is generated. The compensated system currents remain sinusoidal despite the change in the load current magnitude. Finally, at *t* = 0.2 sec, a single-phase load step change is introduced in phase which is equivalent to current imbalance.

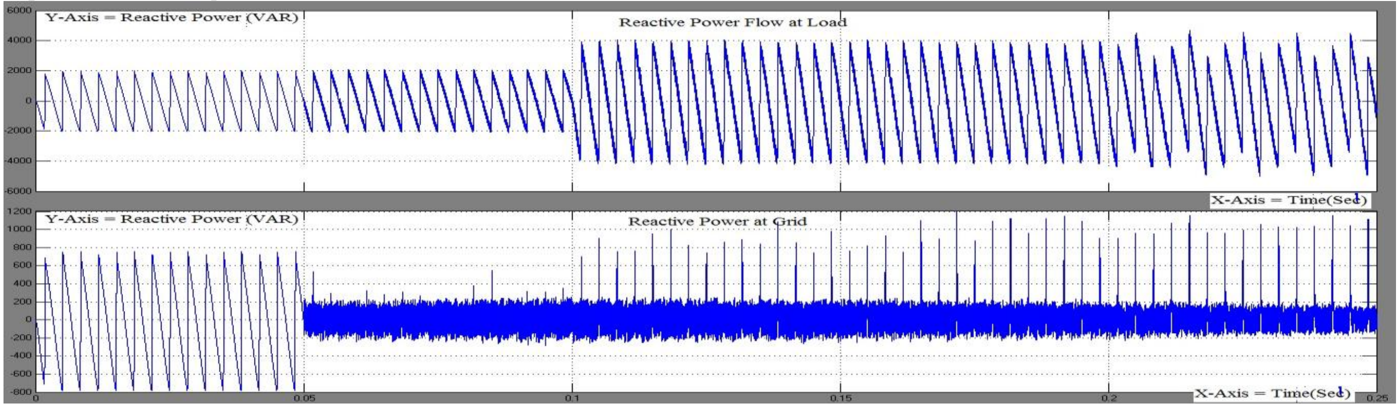

Fig.7. Simulated waveforms with proposed: a) Reactive power flow at load, b) reactive power at grid.

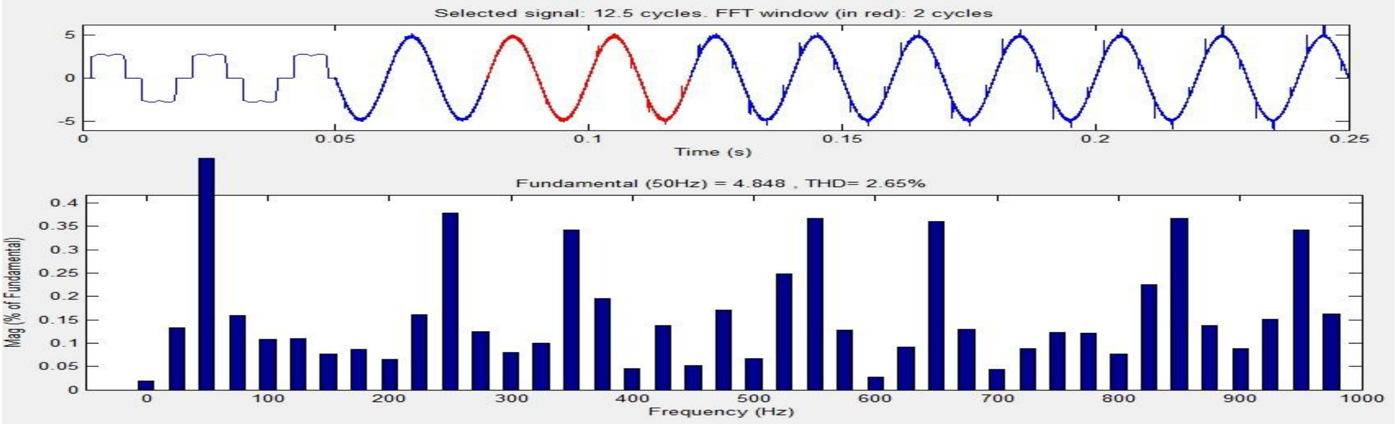

Fig.8. THD% in source current.

Fig. 6 shows that the line current becomes sinusoidal when the active power filter starts compensation, and the dc-voltage behaves as expected. Fig.7. shows the reactive power at load and grid, grid side reactive power has controlled by proposed controller.

V. CONCLUSION

The simulation results shown the dynamic current harmonics and a reactive power compensation scheme for power distribution systems with generation improve the current quality of the grid. Advantages of the proposed scheme are related to its simplicity, modeling, and implementation. Instantaneous power theory control enhancement the source current waveform and reactive power effectively reduced. This APF topology is optimal root for grid connected Power systems because of VSI generated harmonics also reduces. In power system with active power filter total harmonic distortion is very low in source current.

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