Active Shunt Filter For Power Quality Improvement At Load Side

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Abstract

Nowadays, the extreme use of power electronic device and other non-linear load introduce the problem of power quality deterioration in voltage and current waveforms. Passive filters are used widely to solve this problem owning to their simplicity in operation and low cost. But they face the major drawback of its dependency of performance on the system parameters as well as resonance problem. Active Shunt Filter(ASF) are widely used to overcome these problem. This paper presents Active Shunt Filter comprising of Instantaneous real and reactive power(p-q) theory for Power Quality Improvement. Hysteresis current controller is used for PWM pulse generation for VSI. The simulation is carried out in MATLAB/SIMULINK and results indicate the effectiveness of Active Shunt Filter for reduction of harmonics(THD) up to permissible limit as specified by IEEE 519 and reactive power compensation.

Keywords: *Power Quality, Harmonics, Active Shunt Filter, Voltage source inverter (VSI), p-q theory.*

INTRODUCTION

The use of power electronics devices is increasing tremendously because of the advancements in the semiconductor technology. Due to use of power electronics devices, problems like harmonic generation, reactive power disturbance, poor power factor, heating of devices, etc. are increased. So the international standards concerning electrical power quality IEEE 519, IEC 61000 among others impose that electrical equipment and facilities should not produce harmonics greater than specified limit, and also specify distortion limits to supply voltage.

Traditionally series-parallel passive filters used were widely as a solution to above problem which can be tuned for particular frequency. The passive filters are cheap, easy in design and reliable but they have more disadvantages because of their large size, resonance problem, tuning for fixed frequency, Fixed Reactive Power Compensation etc. The active shunt filter is the best solution in comparison to passive filter, as they have more advantages like no resonance problem, elimination of any type of harmonics, reactive power compensation and reliable operation.

ACTIVE SHUNT POWER FILTER

A. Active shunt filter basic principle

Active shunt filter (ASF) is connected at Point of common coupling (PCC) and injects a compensating current IF in such a way that it eliminates currents harmonics on AC side [2]. In other words, ASF produces harmonic currents with same magnitude but 180 degrees apart to those harmonics which are present in the power grid [2].

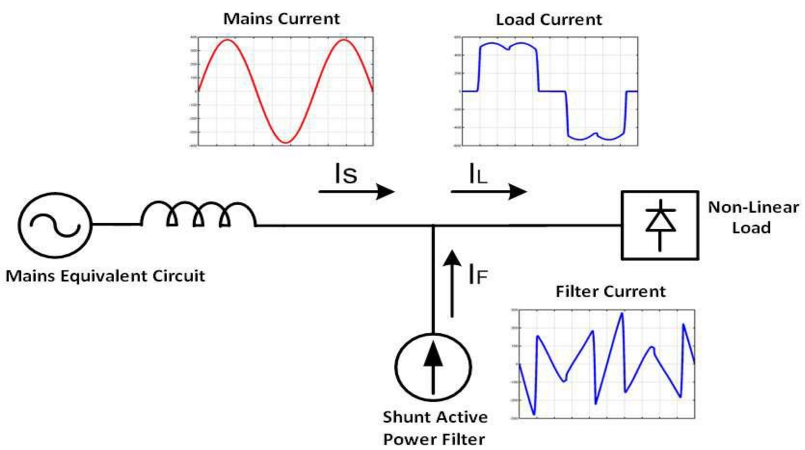

Fig. 1: Basic diagram of ASF

B. Instantaneous real and reactive power(p-q) theory

The instantaneous real and reactive power (p-q) theory is one of the very efficient, flexible and widely used method for generation of reference current for active filters [6]. This paper presents the simulation of active shunt filter based on p-q theory.

In p-q theory the electrical grid voltages (Va, Vb, Vc) and the load currents (ia, Ib, ic) must be converted to α-β reference frame by applying the Clarke transformation [1] [6].

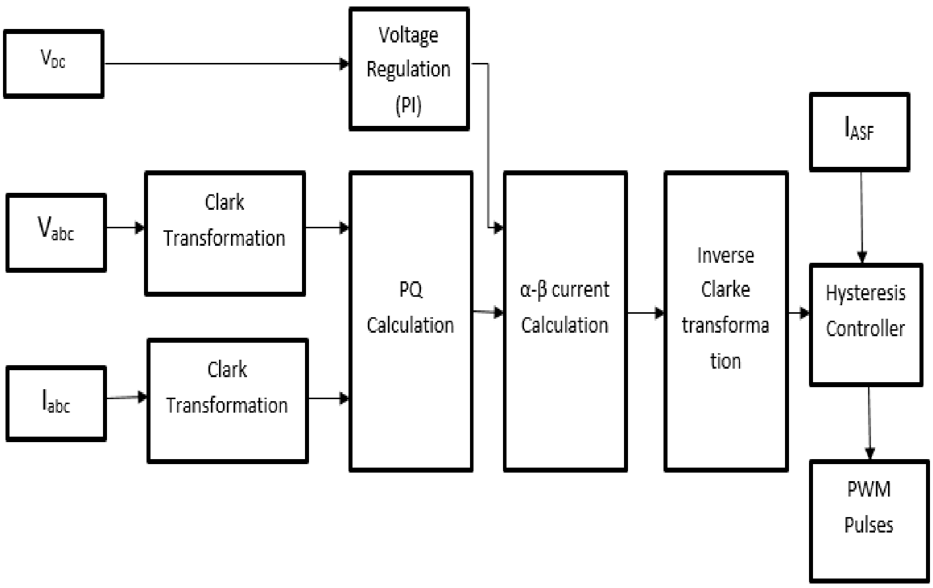

Fig. 2: Control strategy using Instantaneous real and reactive power(p-q) theory

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \text{ -----(1)}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \text{ ----- (2)}$$

The p-q theory power components are calculated using the expressions (3), where p is the instantaneous real power, and q is the instantaneous imaginary power [6].

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \cdot \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \text{ ----- (3)}$$

Each instantaneous power components can be separated into an average value and an oscillating value [6].

The α-β current calculation is done as shown in equation (4). Then to find out reference compensation currents in a-b-c coordinate the inverse Clarke transformation is carried out as shown in equation (5).

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} -\overline{P} + \overline{P_{loss}} \\ -q \end{bmatrix} \text{ -----(4)}$$

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \text{ -----(5)}$$

C. PI controller

In active shunt filter, output voltage of the inverter is controlled by changing the gate pulses. This causes a flow of instantaneous power into the VSI which charges or discharges the VSI input capacitor causing the capacitor voltage to vary. The PI controller is used to regulate constant DC voltage across input capacitor of VSI [9].

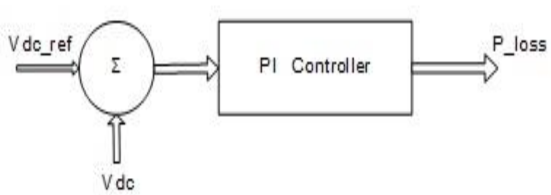

Fig. 3: PI controller

D. Hysteresis Controller

Hysteresis current control method is used to get required compensating current to be injected at point of common coupling(PCC) [4]. There are also various other current controlled techniques for active shunt filter available, but Hysteresis current control (HCC) method is easily to implement and it gives quick control of current. So in the proposed system, HCC is used. Whenever the current error that is fed to the HCC exceeds the fixed band, the switching operation begins. Narrower the band better the accuracy. The switch in the upper inverter arm gets turned on if the current is over reached and switch in lower arm gets turned on if the current is below limit. The working principle is shown below [2].

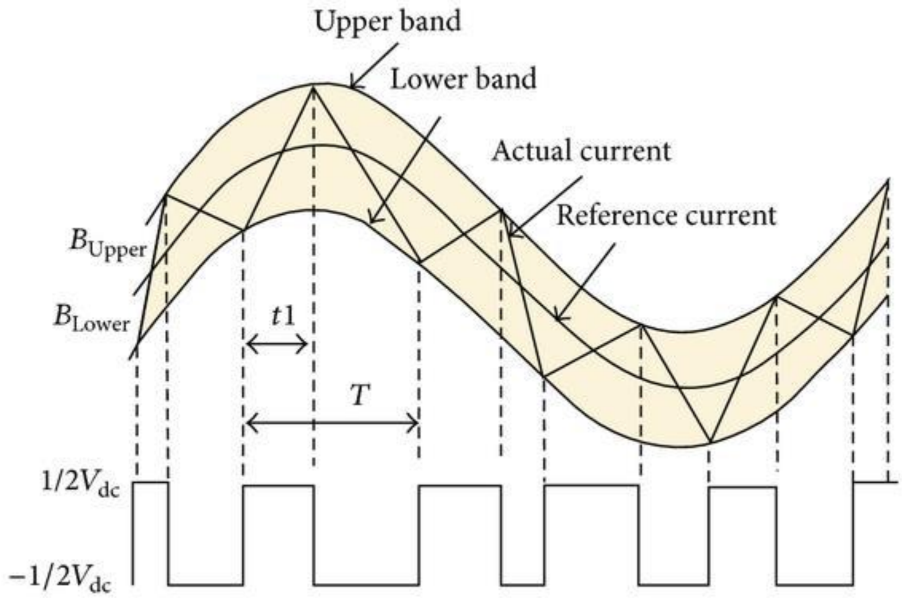

Fig. 4: Hysteresis Controller

E. Parameters of ASF

There are two parameters which play a vital role in active shunt filter operation [9],

1) Interfacing inductor
   The size of coupling inductor of an ASF is expressed in eq. (6).

$$\frac{V_{dc\_bus}}{8f_s(Level-1)\Delta I_r} \le L \le \frac{\delta_v V_{dc\_bus}}{r\omega I_c} \quad \text{-----(6)}$$

   A smaller inductor reduces the cost so it is suggested to select a value of inductor close to lower boundary. Due to conflict between the requirement of current speed and suppressing current ripple, sometimes the upper limit obtained of inductor is smaller than lower limit [8].

2) DC link capacitor
   DC link capacitor used as energy storage element and maintain DC voltage with small ripple. The size of capacitor is determined based on the energy storage principle [3]. The capacitance of capacitor can be found from energy storage equation (7).

$$\frac{1}{2}C_{DC}(V_{DCref}^2 - V_{DC}^2) = 3V_{ph}aIt \quad \text{-----(7)}$$

The capacitor voltage is maintaining to its reference value is given by following equation [3].

$$V_{dc} = 2\sqrt{\frac{2}{3}}\frac{V_{LL}}{m} \quad \text{-----(8)}$$

SIMULATION MODEL AND RESULTS

A. Simulation Parameters

Table 1: Simulation Parameters

Supply Voltage	440V, 3 Phase
Supply Frequency	50Hz
Non-linear Load	150 Ohm.
Coupling Inductor	20 mH
Dc capacitance	10e-6 F

B. Simulation Model

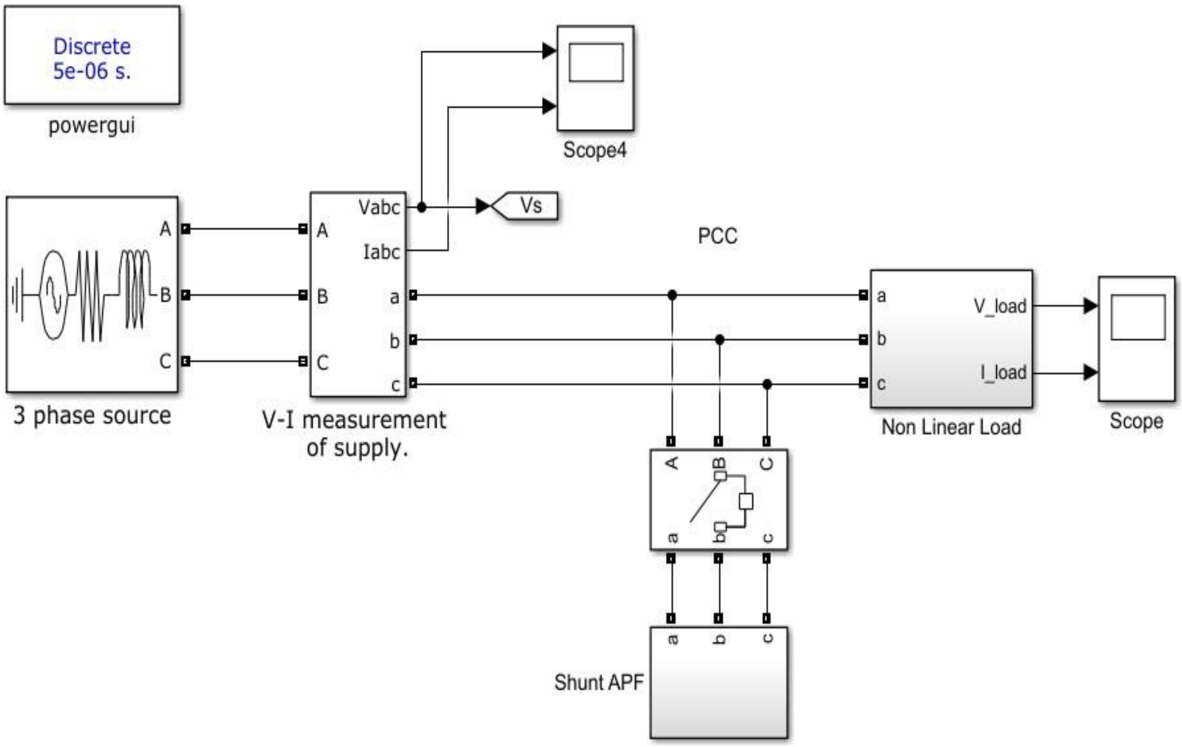

Fig. 5: MATLAB simulation diagram of ASF for p-q Theory

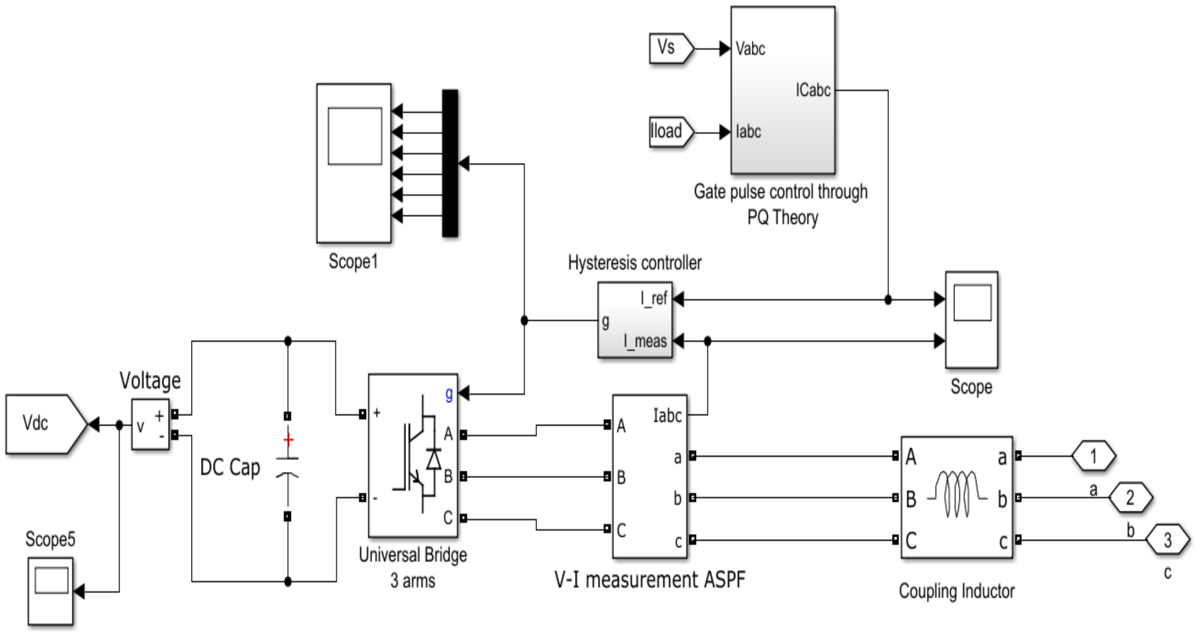

Fig. 6: subsystem of active shunt filter

C. Results

The simulation is carried out using above parameters and simulation results are as shown below. Fig.7 shows load voltage and load current waveforms when non-linear load is connected. As shown in Fig.7 from 0 to 0.2 load is constant at 0.2 another non-linear load is added so that current is increased. In Fig.10 supply side voltage and currents wave forms are shown. As shown in Fig.10 before 0.1 sec when ASF is not connected distortion in current waveform is more after 0.1 sec when the ASF is turned on distortion in current waveform is reduced. ASF is effective even when load is increased at 0.2 sec as shown in Fig10. THD without ASF and with ASF is as shown in Fig.11 and Fig.12,13 respectively.

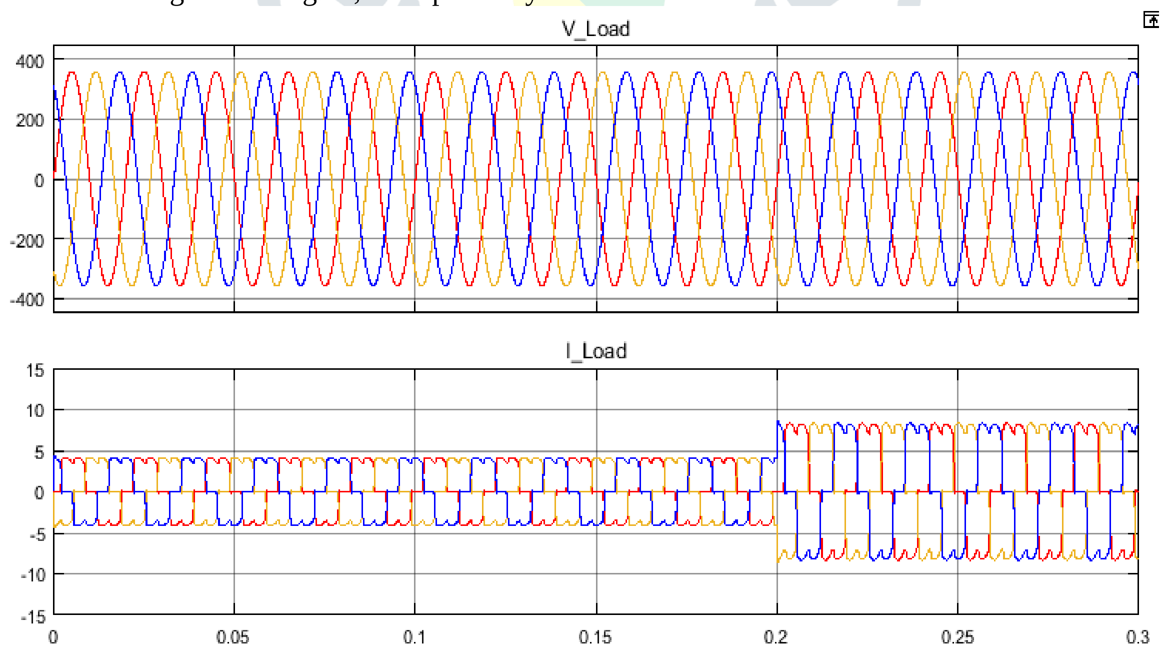

Fig. 7: Load side V and I waveform

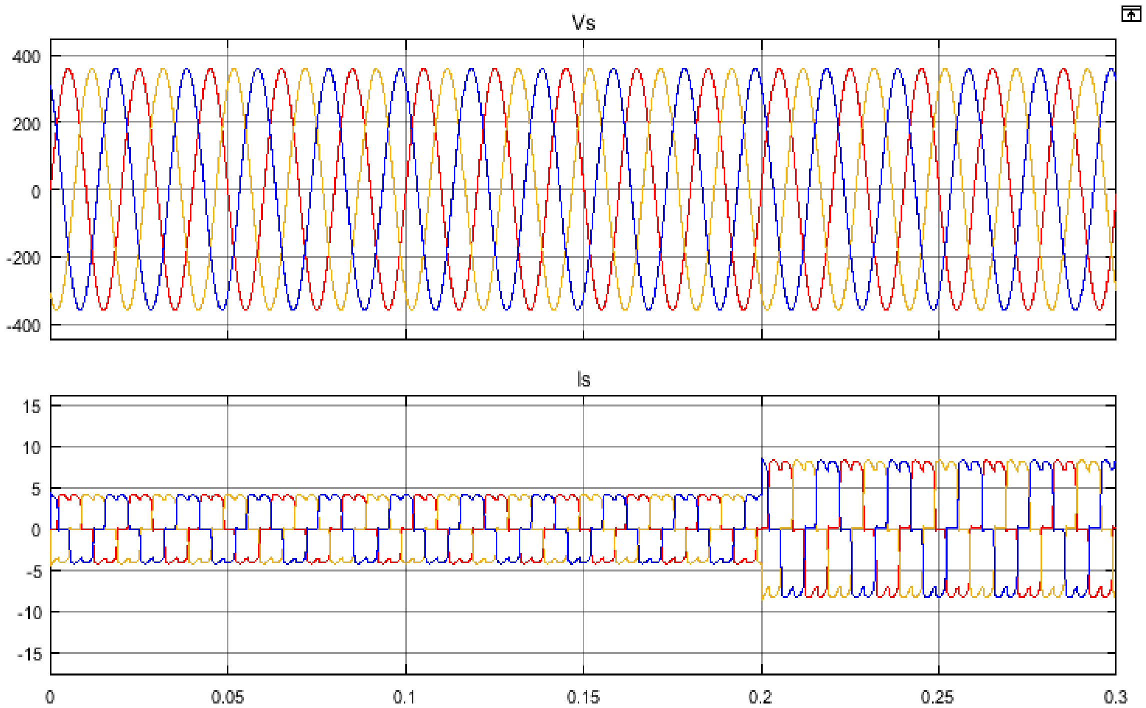

Fig. 8: Supply Side Voltage and Current waveform without ASF

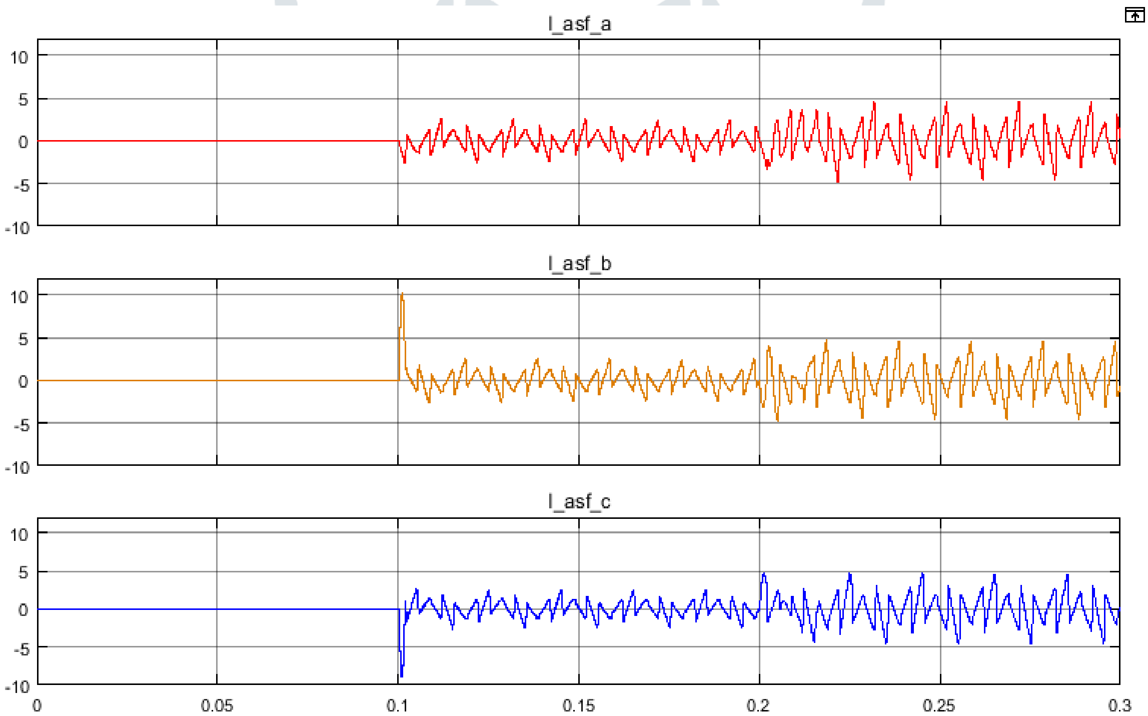

Fig. 9: Compensating Current supplied by ASF

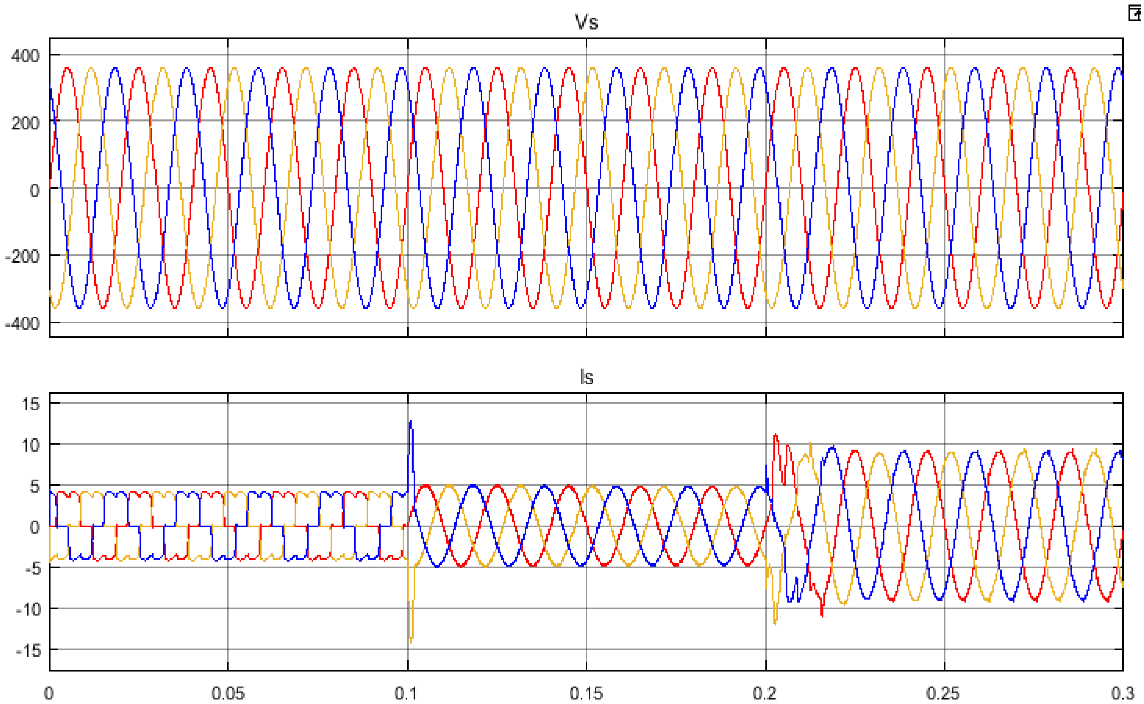

Fig. 10: Supply Side Voltage and Current waveform with ASF

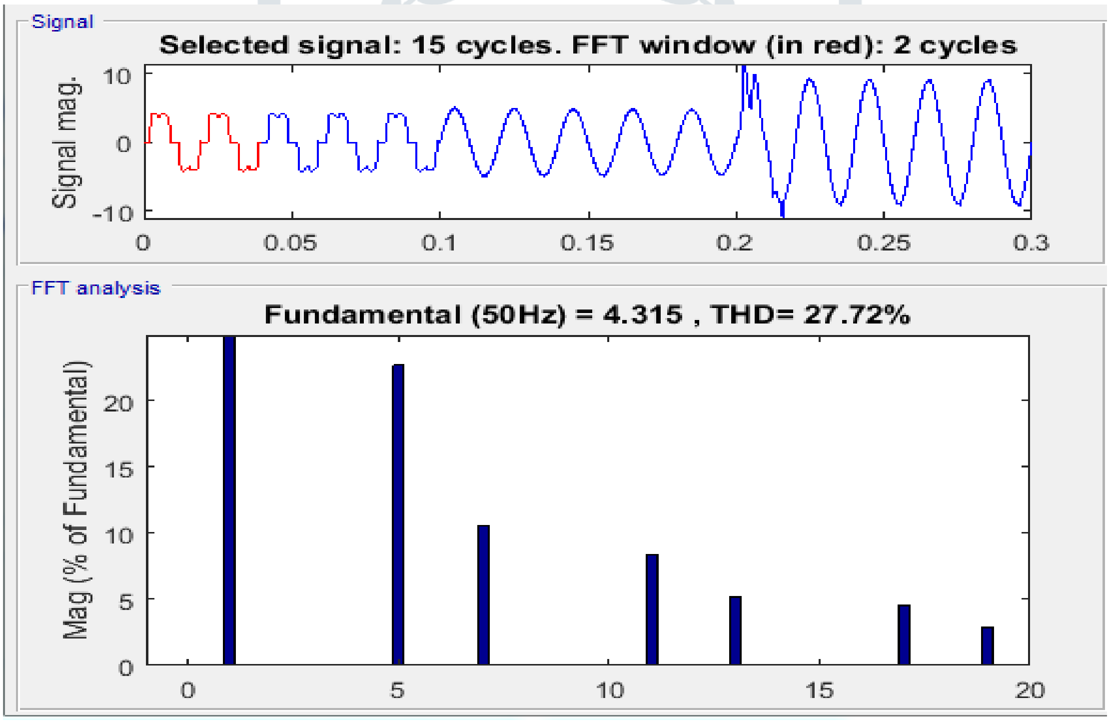

Fig. 11: THD Without ASF

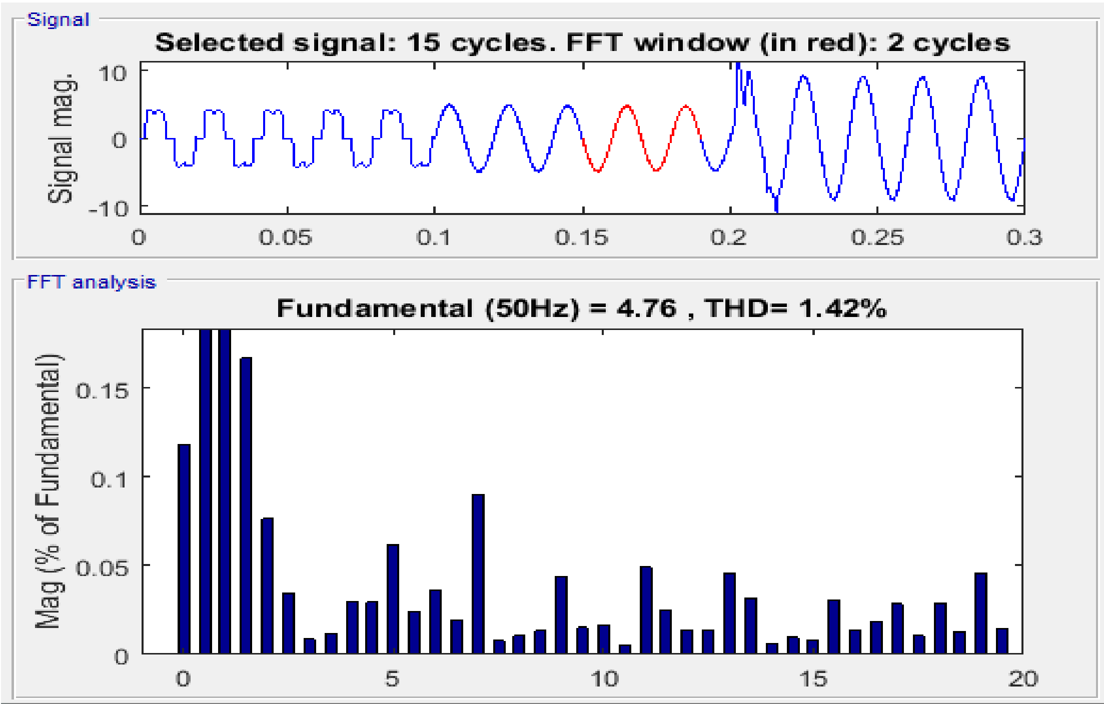

Fig. 12: THD with ASF

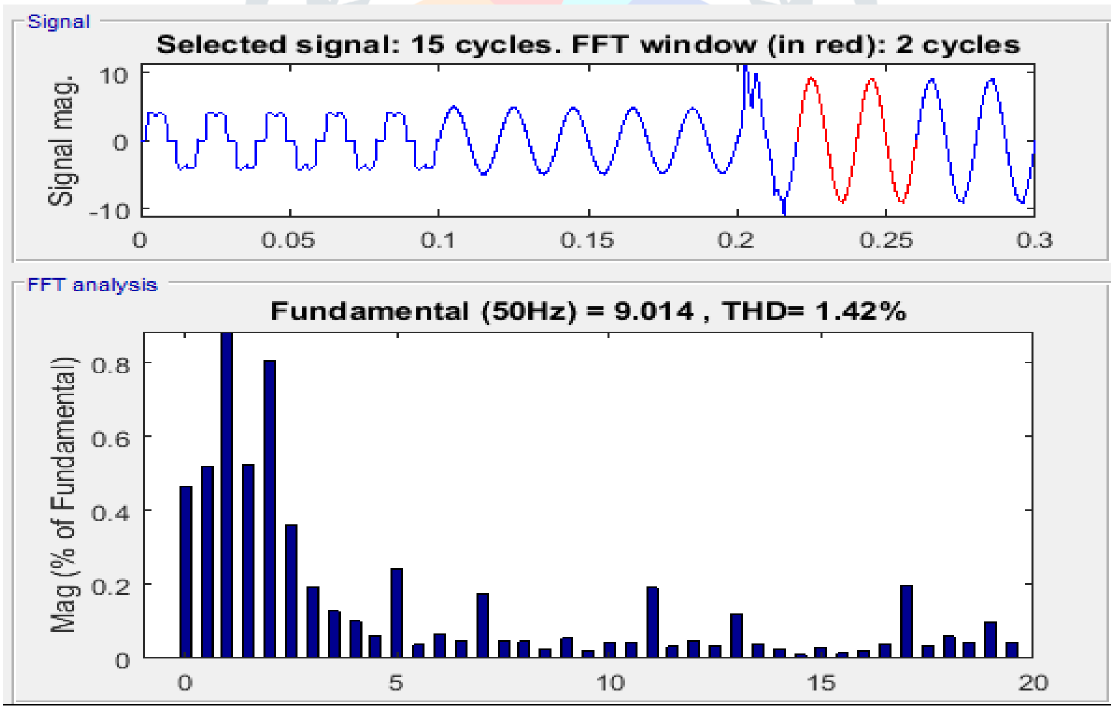

Fig. 13: THD after increase in Load with ASF

CONCLUSIONS

The Voltage source inverter (VSI) based active shunt power filter is simulated in MATLAB/SIMULINK using the Instantaneous real and reactive power (p-q) theory. The FFT analysis of shunt active power filter is carried out. Without ASF the THD in current waveform is 27.72% and after connecting ASF the THD is reduced up to 1.42%.

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