Chapter 5

Simulation and Performance Investigation

5.1 Introduction

In this chapter extensive simulation study is carried out to investigate the performance of the shunt active power filter, series active power filter and the unified power quality conditioner during transients as well as in steady states for different configurations. The simulation models of the shunt APF(STATCOM) , series APF (DVR) and the UPQC have been developed using MATLAB^{TM} and its POWER SYSTEM BLOCKSET in SIMULINK. Simulation results are obtained using hysteresis control technique for diode rectifier with (a) R-L Load and (b) dc machine with variable load torque, on its DC side as its non-linear load. In power system block set we can find different variety of blocks which represent inverters, passive elements and measurements.

The models developed in MATLAB, the corresponding results and their performances are shown in this chapter.

The MATLAB models have been operated /run for different loads. First the R-L load is applied and the output of the filters are seen and then the load is changed to dc machine with variable load torque and all the other parameters are kept unchanged. Then the performance of these filters is compared /analyzed. For getting clear idea about the total harmonic distortion (THD) the power-gui block has been used so that the FFT analysis could be carried out and the performance of the filters can be analyzed. The different models and their respective outputs have been shown in this chapter. First the simulation analysis of shunt active power filter is presented then the simulation analysis of series active power filter is presented and then the simulation analysis of the unified power quality conditioner is presented.

5.2 Simulation and performance investigation of Shunt APF

In this section the simulation analysis of shunt APF is described, first for R-L load and then for DC machine load and the FFT analysis has been carried out simultaneously [22,23,24].

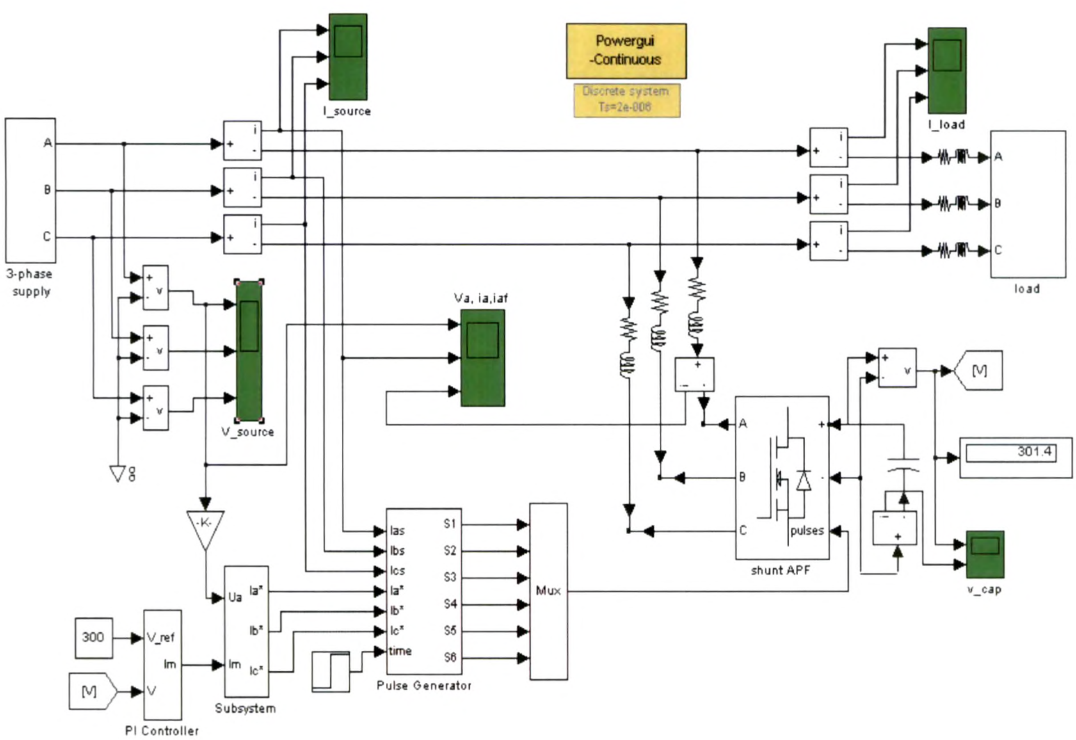

*Fig 5.1 MATLAB model for **Shunt** active power filter*

5.2.1 Extraction of Unit Vector Template and Pulse Generation Technique

The input source voltage at PCC is sensed and *rms* value of the voltage is measured. This rms value is multiplied by square root of two. This peak voltage id divided by input supply voltage. This will give us the unit vector template of the three phases. Further delayed by 120^0 to get the reference current for the phase c. these reference currents are now compared with the actual source currents and the error is processed in the hysteresis

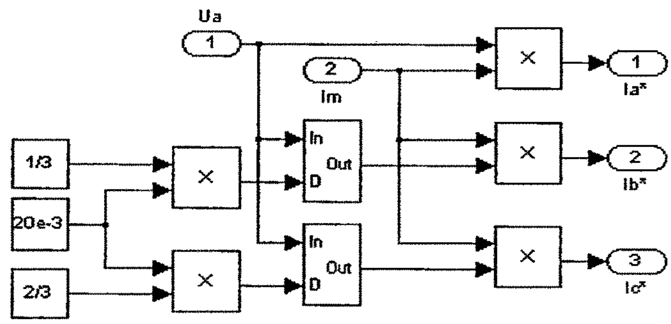

Fig 5.2 STATCOM Reference current generation

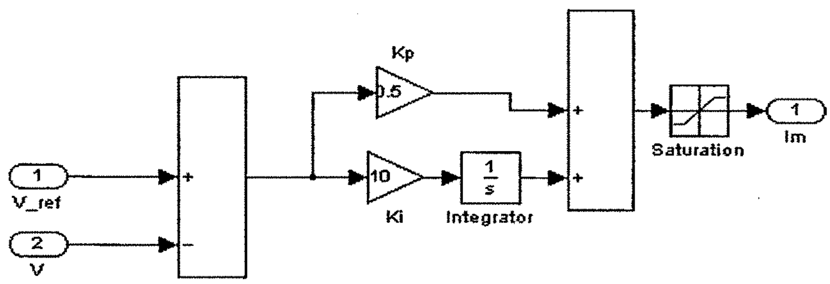

Fig 5.3 Calculation of maximum value of reference current using PI controller

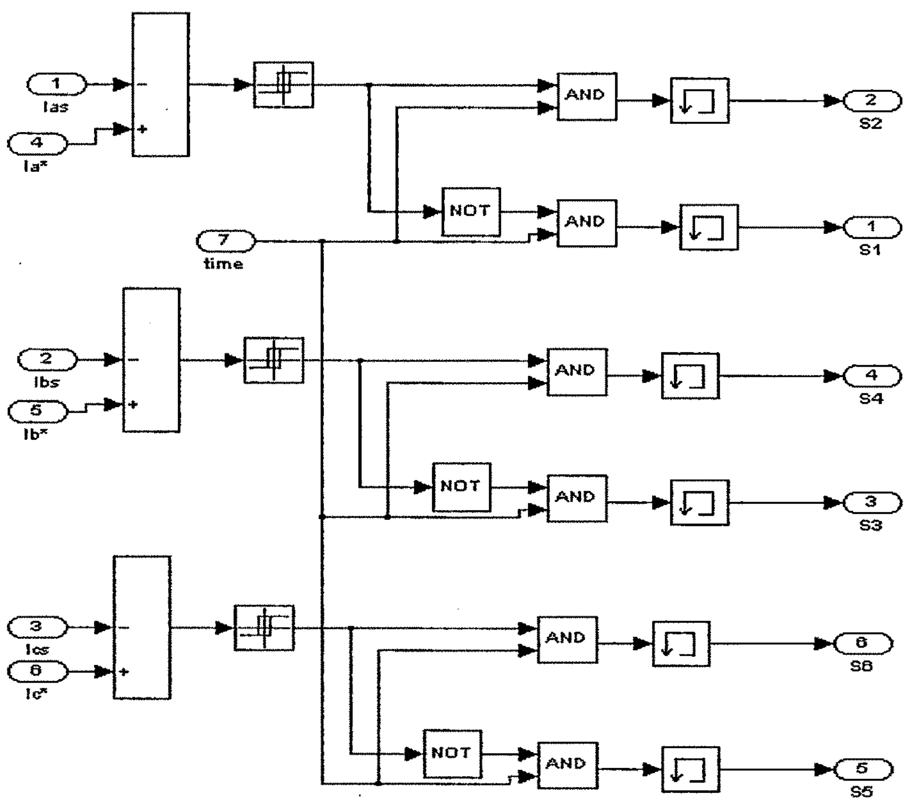

Fig 5.4 STATCOM Pulse generation diagram

controller to generate the firing pulses for the switches of the inverter. Pulse generation is main and important part of this technique. Here we have used hysteresis technique for switching technique .

5.2.2 Simulation result analysis of Shunt APF (STATCOM)

The performance of proposed STATCOM model is carried out on RL load and DC machine. Fig. 5.7 shows load current and Fig 5.8 shows effect of compensation. It shows Source current before and after compensation. Same way phase A shows Source voltage, source current and filter current effect. FFT analysis is carried out on load current and source current. Harmonics number and information is explain in fig. in 5.11 and 5.12

Fig. 5.9 shows the supply voltage, supply current and injected current wave forms of the line current before the shunt current and after the shunt current injection. The overall simulation run time is 0.3 sec. the control strategy is started after 0.1 sec. After 0.1 sec the PI controller acted to settle the reference DC link voltage and current from the shunt converter injected to make the supply current sinusoidal. It is observed that after the control strategy started the wave shape of the line current at the input side is improved in term of the harmonic distortion. It is also observed that the supply voltage does not affected. Fig.5.6 and Fig.5.7 shows the Load voltage and current remain unaffected throughout the operation.

Fig. 5.8 shows the current on the main line side before injection and frequency contain in it. Fast Fourier Transformation (FFT) analysis of the same current is carried out and the Total Harmonic Distortion (THD) in this case is 21.83%. FFT analysis of the same current is carried out the THD in this case is 0.42%.

Same way STATCOM also tested on DC machine and explains all the effects in Fig. 5.13 to 5.18. The final FFT result shows up in Fig. 5.19 and Fig. 5.20. The performance of STATCOM is encouraging as same RL load

For RL Load

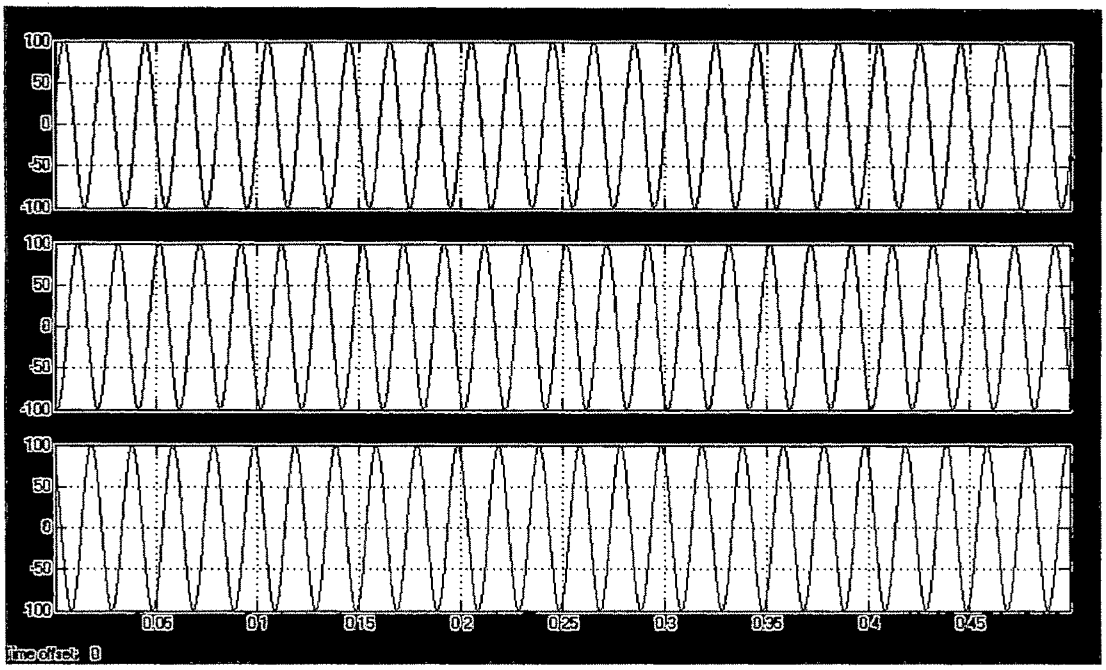

Fig 5.6 Three phase supply voltages

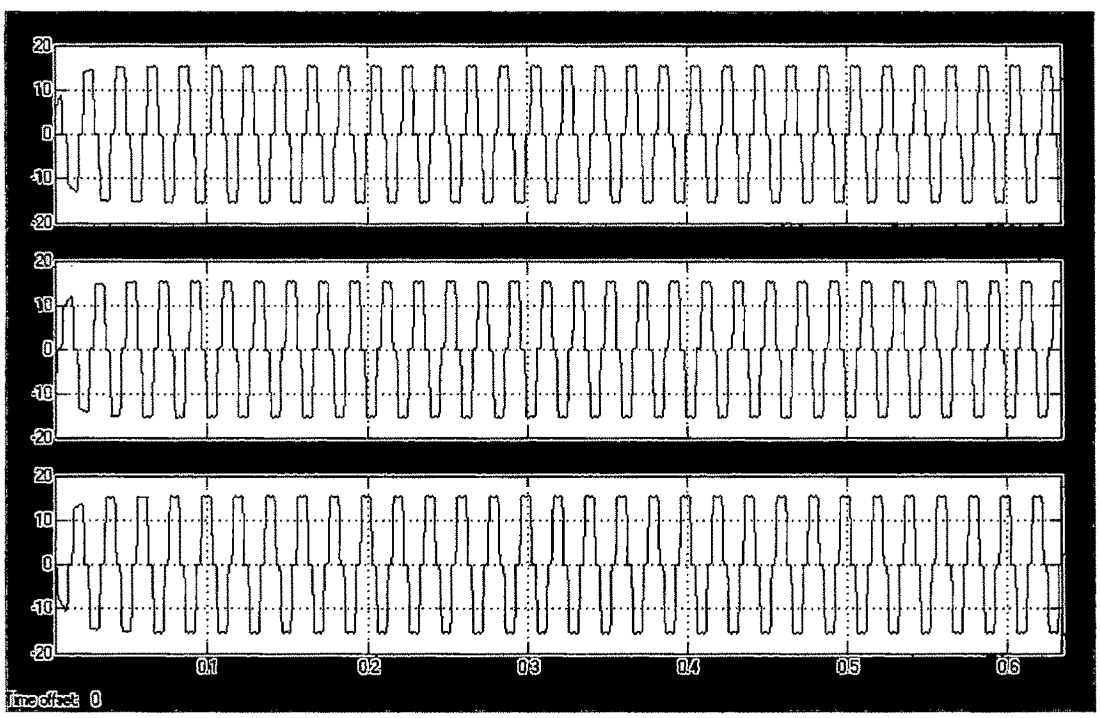

Fig 5.7 Load current

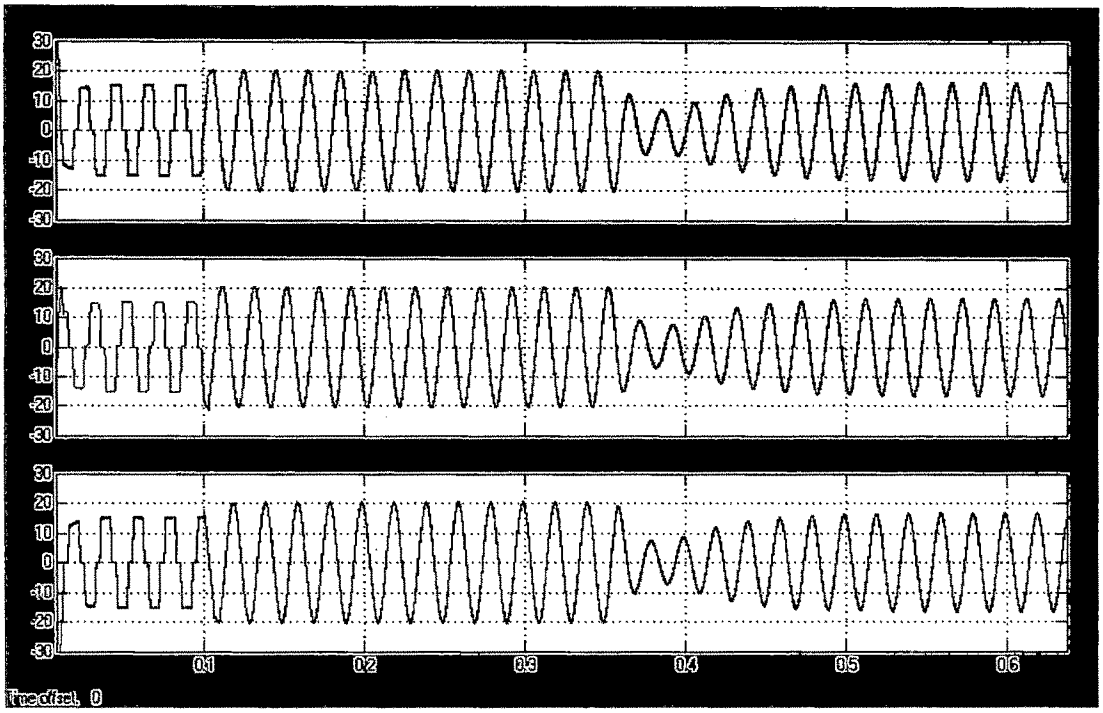

Fig 5.8 Source current before and after compensation

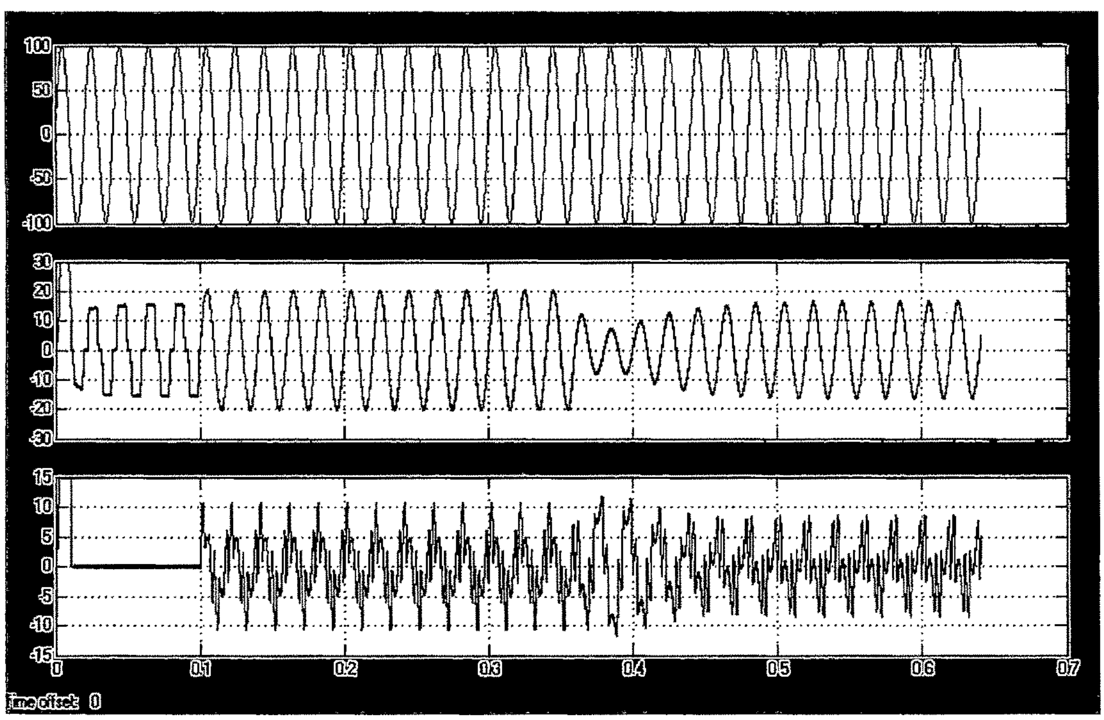

Fig 5.9 Source voltage, source current and filter current for phase A

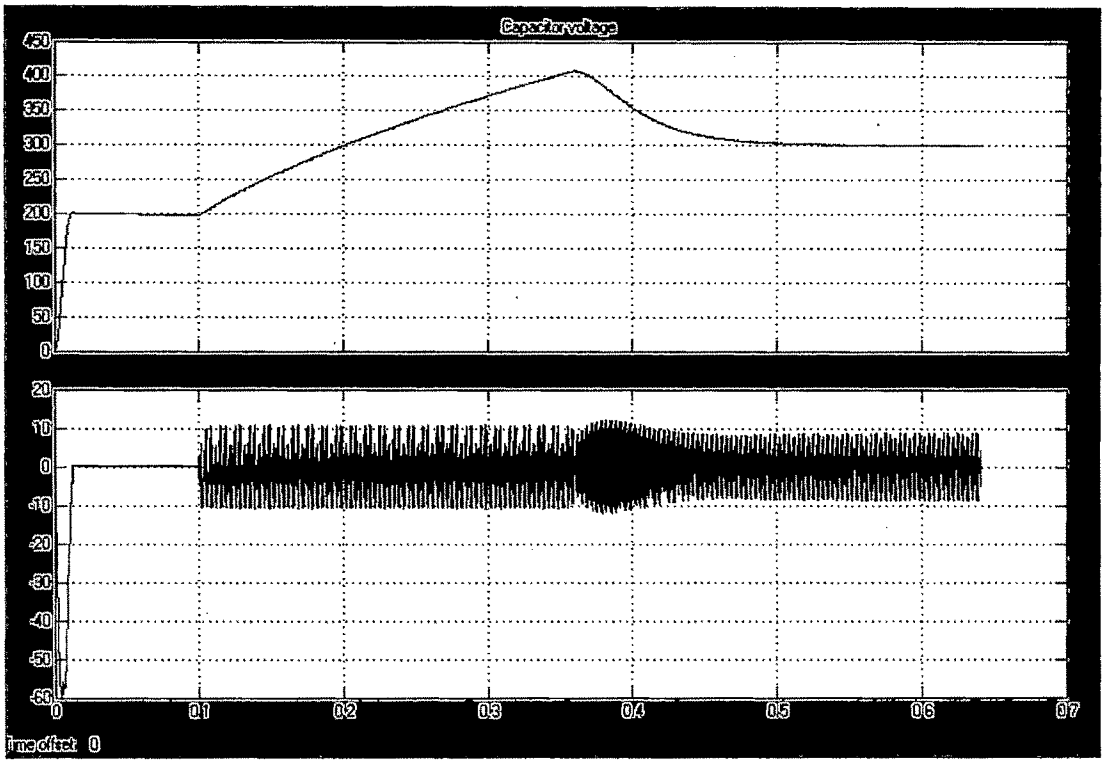

Fig 5.10 Capacitor voltage and capacitor current

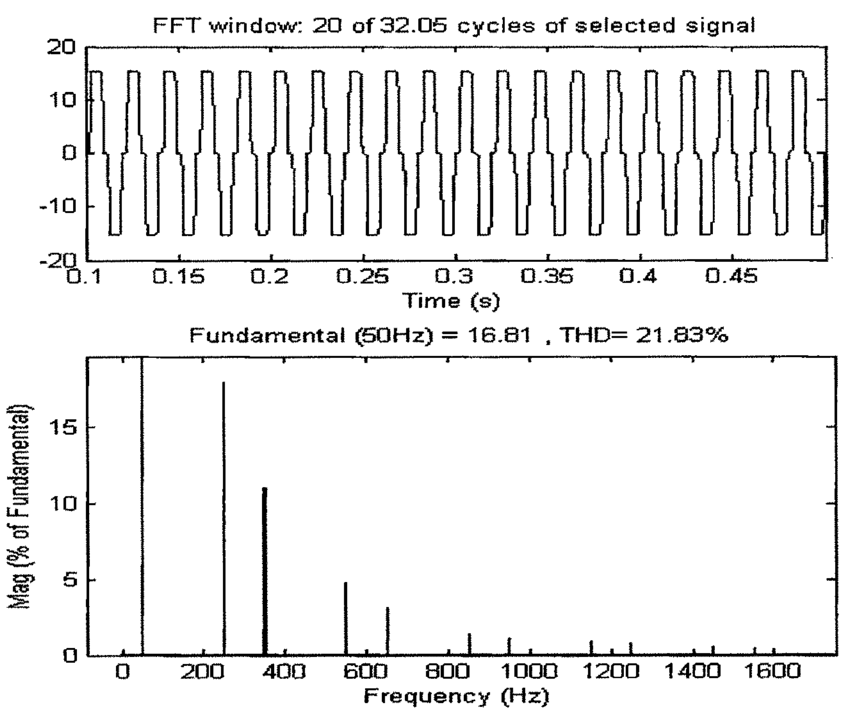

Fig 5.11 FFT Analysis for load current

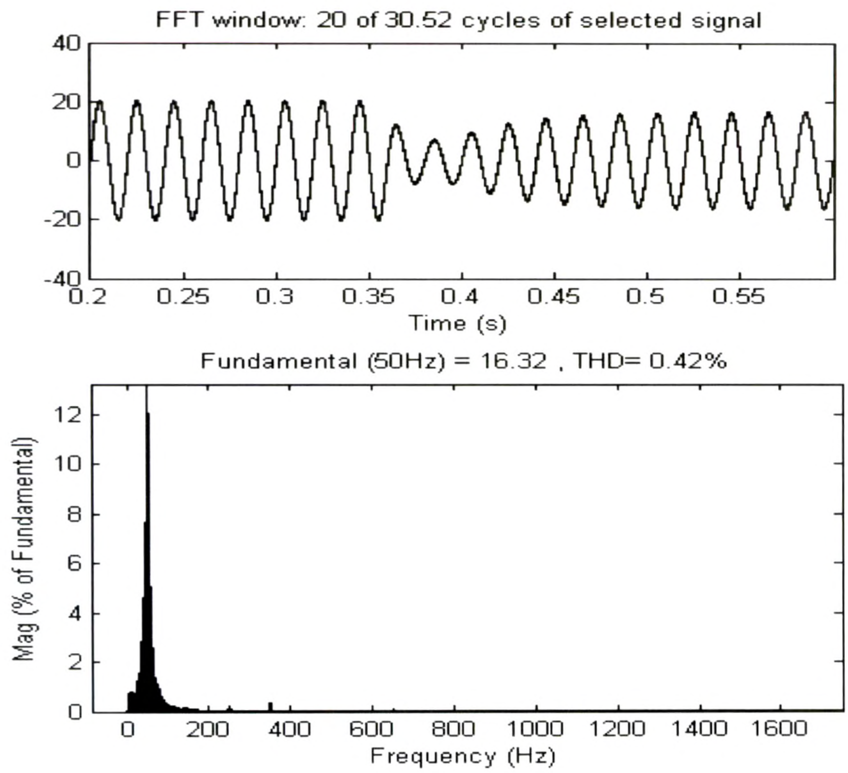

Fig 5.12 FFT Analysis for source current

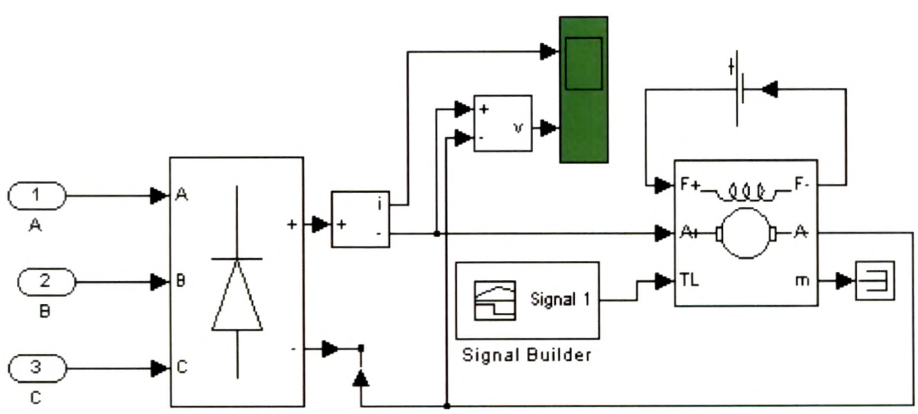

Fig 5.13 DC machine with variable load torque

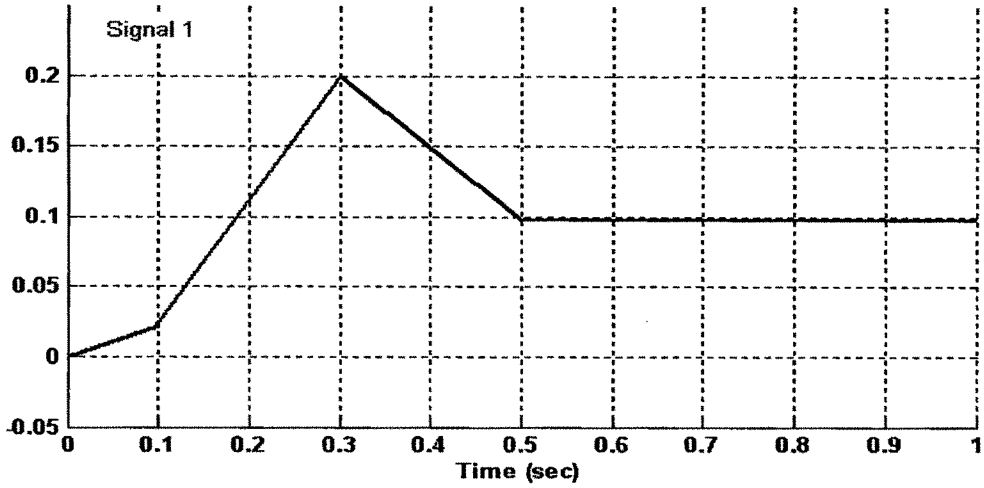

Fig 5.14 Waveform of the torque applied to dc machine

For DC Machine Load

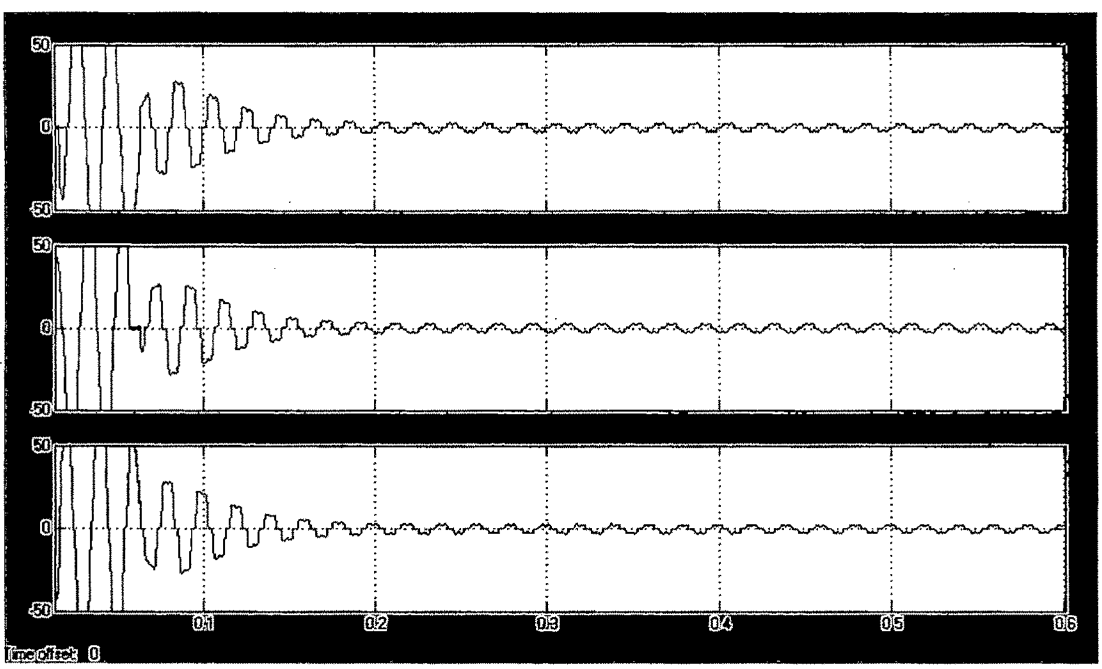

Fig 5.15 Load current

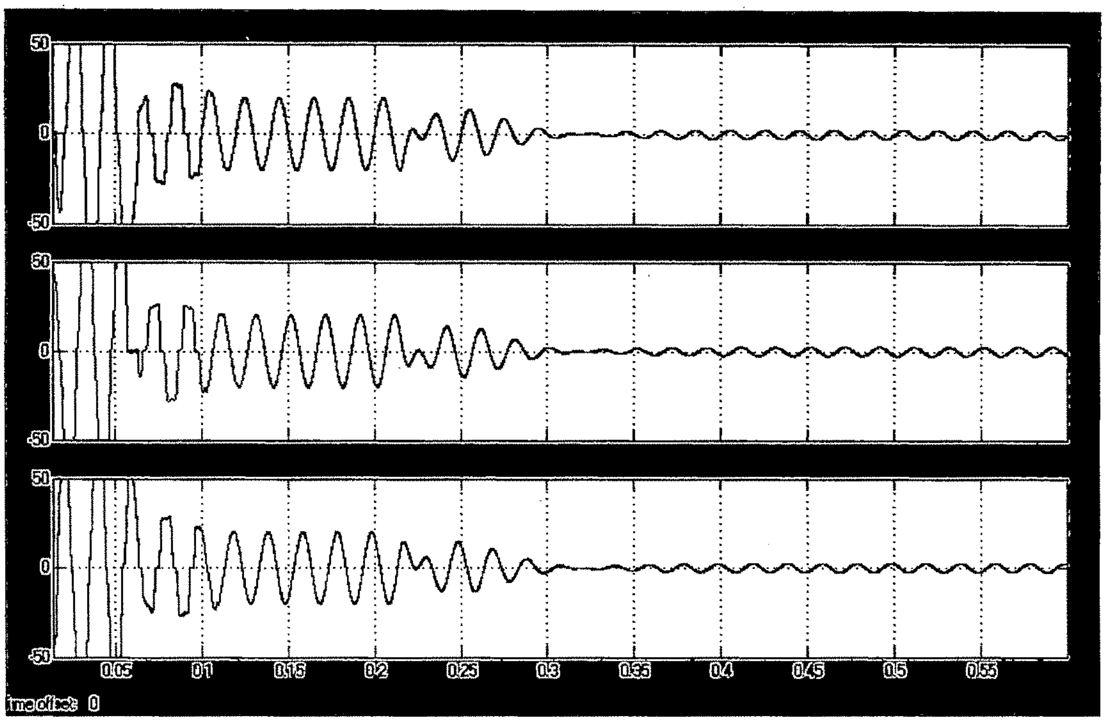

Fig 5.16 Source current before and after compensation

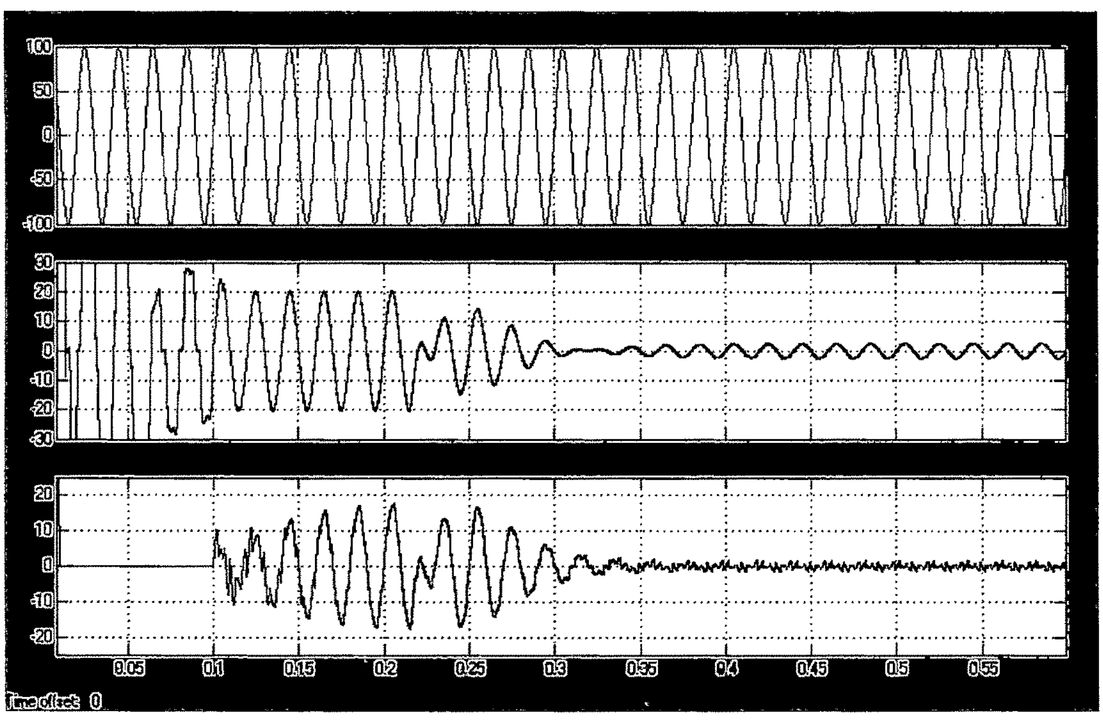

Fig 5.17 Source voltage, source current and filter current

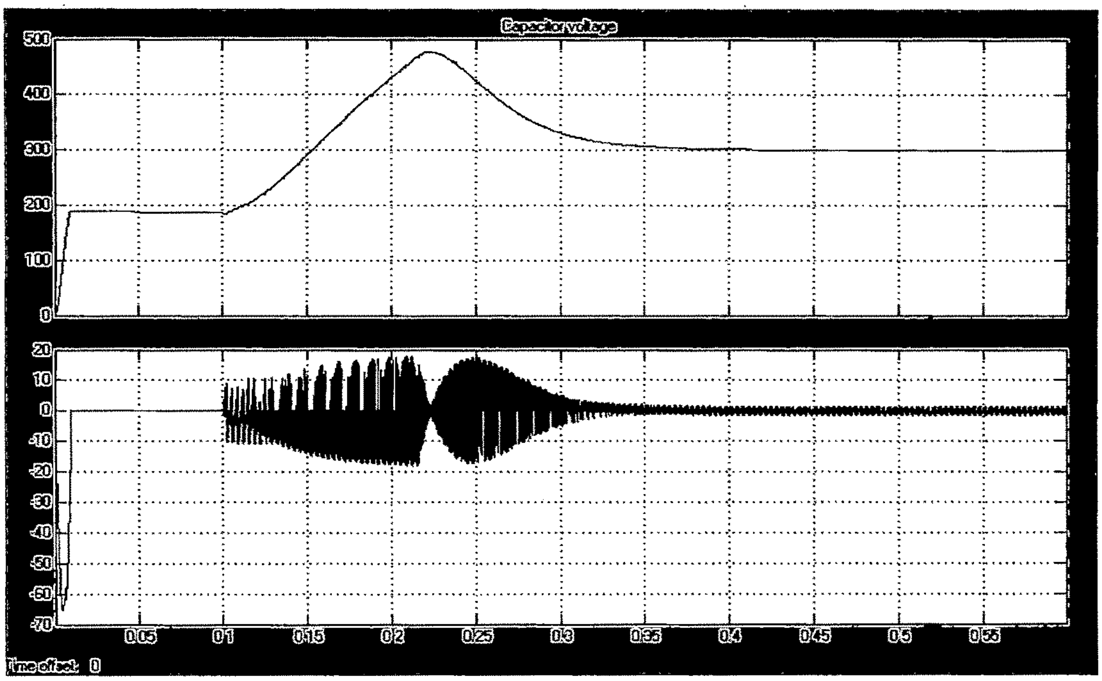

Fig 5.18 Capacitor voltage and capacitor current

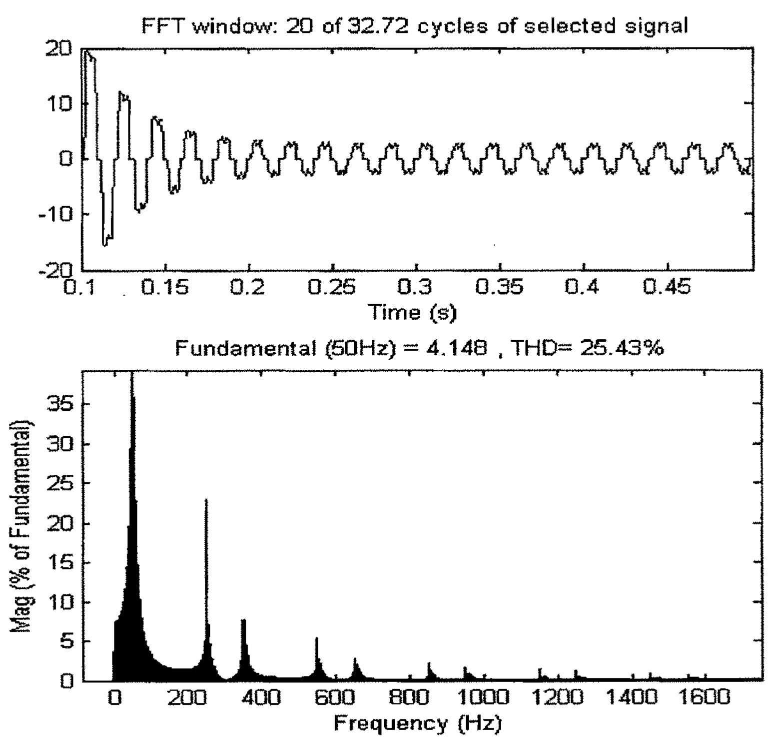

Fig 5.19 FFT Analysis for load current

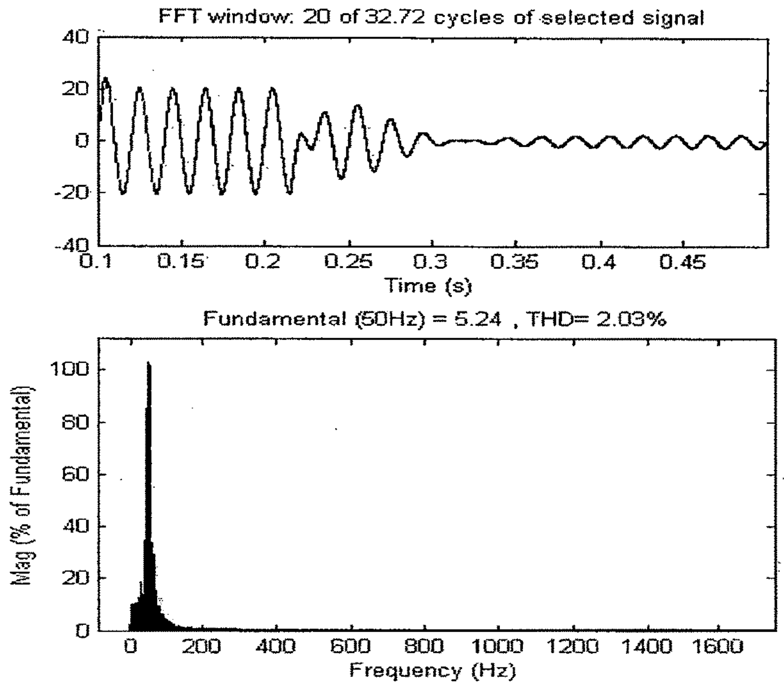

Fig 5.20 FFT Analysis for source current

Table 5.1: THD analysis for different loads, for shunt active power filter

Load type	THD (%) load current	THD (%) source current
R-L load	21.83	0.42
DC machine load	25.43	2.03

It is clear from the table 5.1 that the performance of the system improves and the THD is reduced up to very large extent. Also, it is seen from the simulation results that the source current and the source voltages are in same phase i.e. the input power factor is unity and there is no reactive power from the source.

5.2.3 Performance of STATCOM

A MATLAB based model of the shunt active power filter has been simulated for RL and DC machine load using the hysteresis control technique. The simulation results show that the current harmonics caused by non-linear load are compensated very effectively by using the shunt active power filter.

5.3 Simulation and Performance Investigation of Series APF (DVR)

In this section the simulation analysis of series APF is described, first for R-L load and then for DC machine load and the FFT analysis has been carried out simultaneously [35, 37,38] .

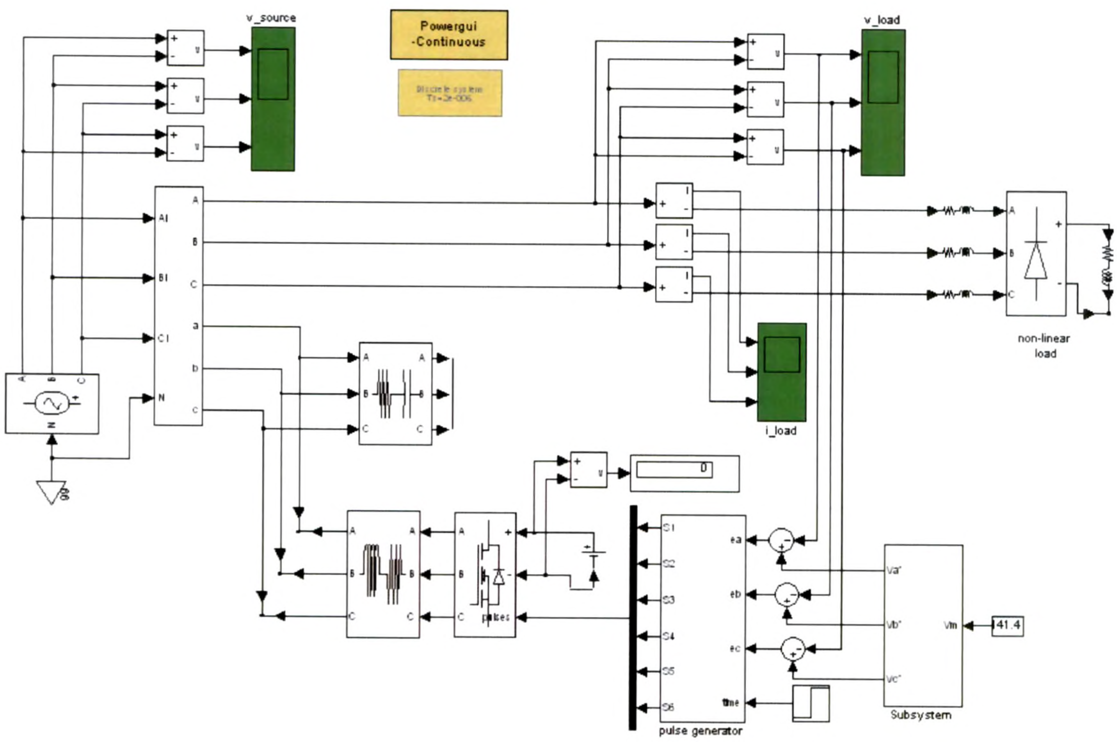

*Fig 5.21 MATLAB model for **Series** active power filter*

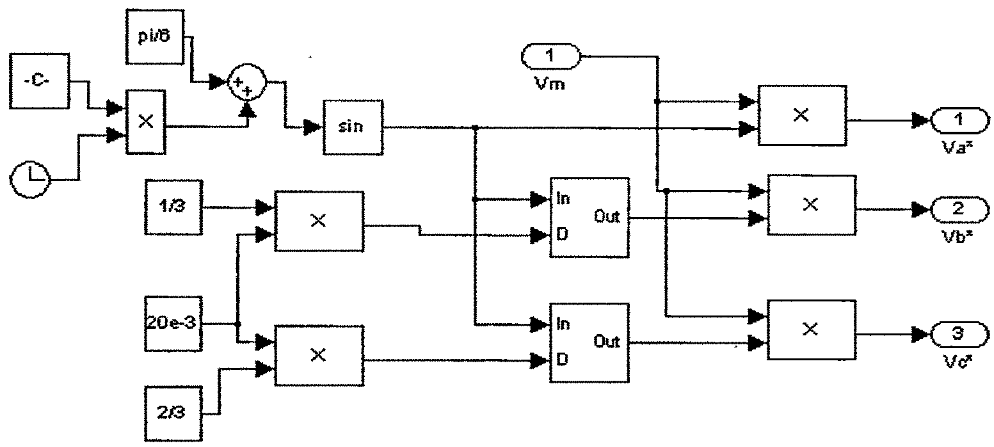

Fig 5.22 Reference voltage generation

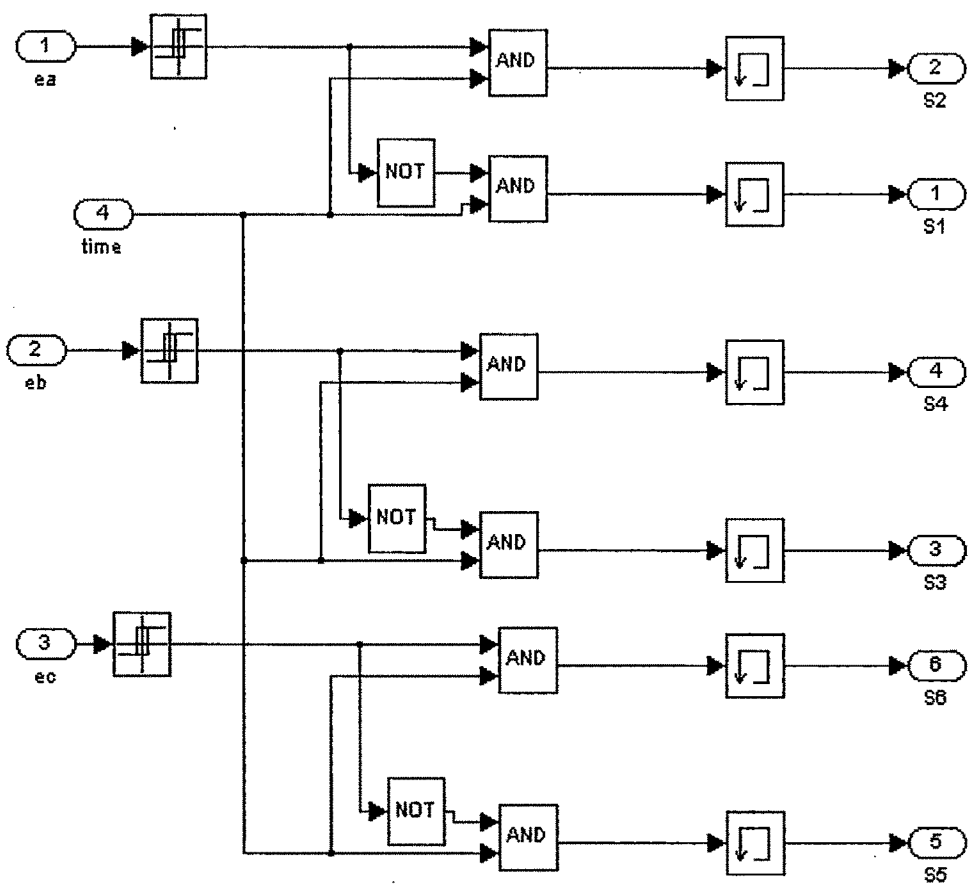

Fig 5.23 Pulse generation diagram

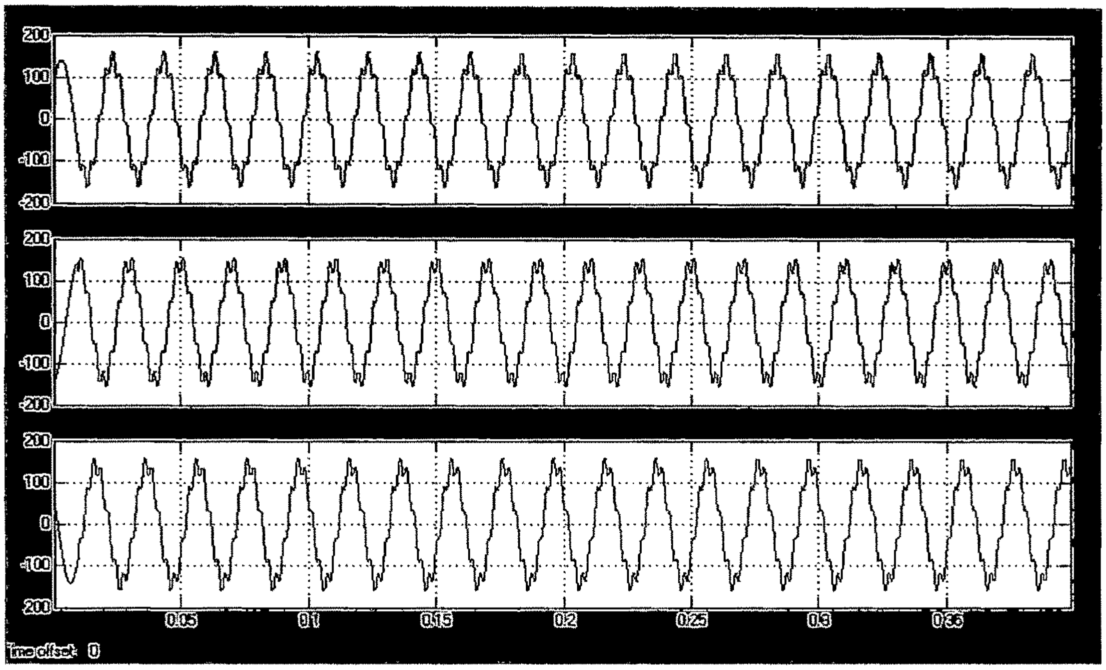

Fig 5.24 Source voltage containing harmonics

For RL Load

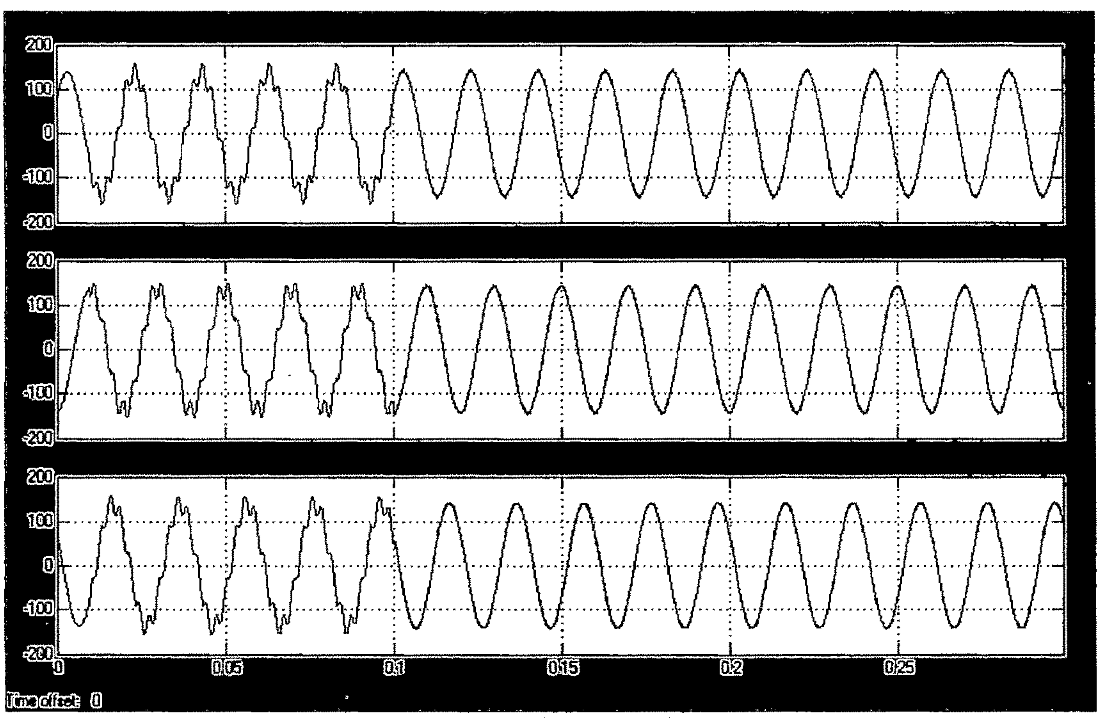

Fig 5.25 Load voltage before and after compensation

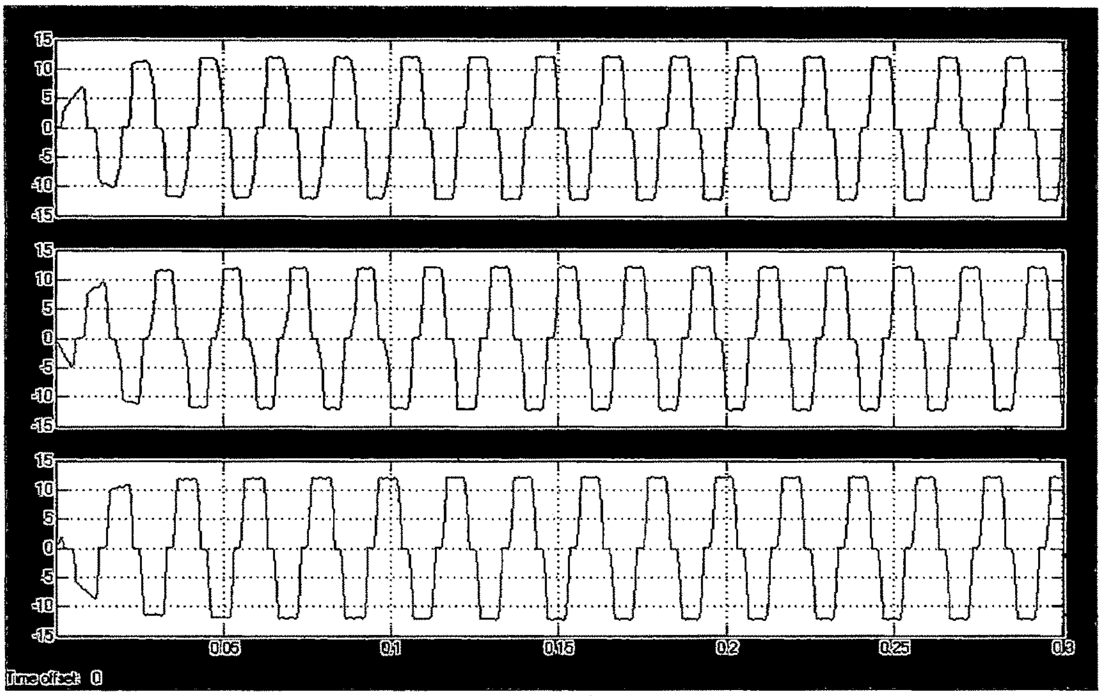

Fig 5.26 Load current

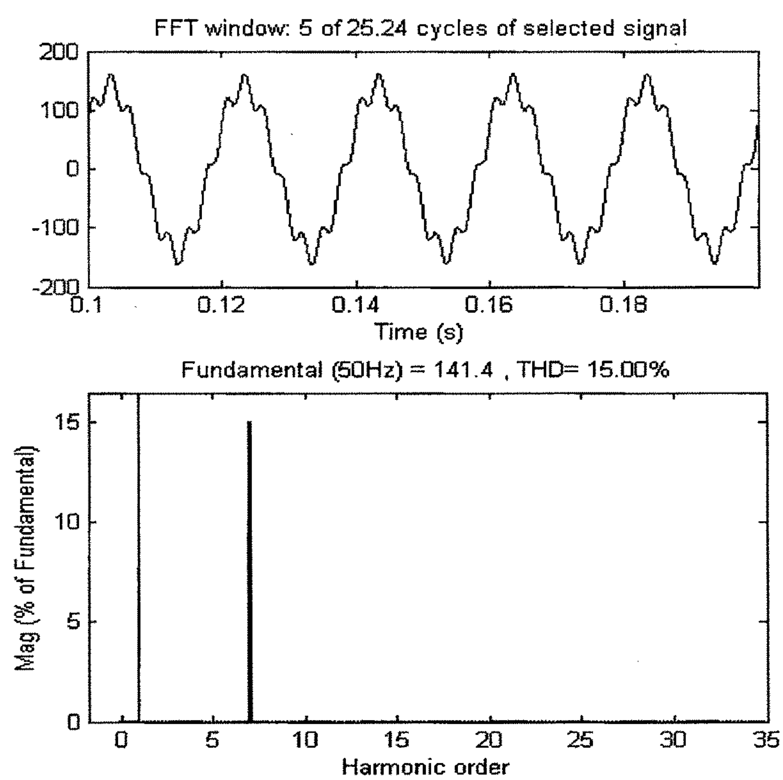

Fig 5.27 FFT Analysis for source voltage

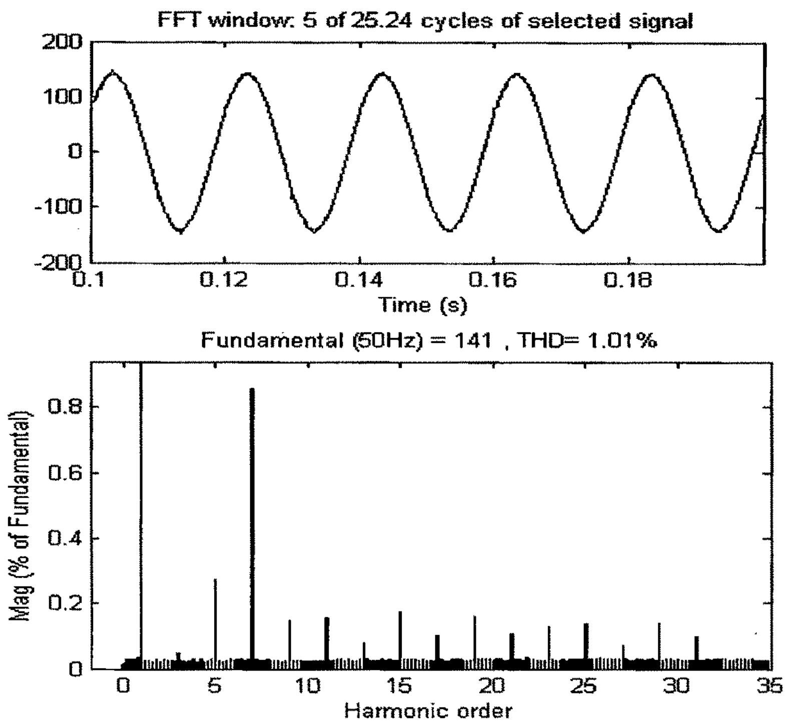

Fig 5.28 FFT Analysis for load voltage

For DC Machine Load

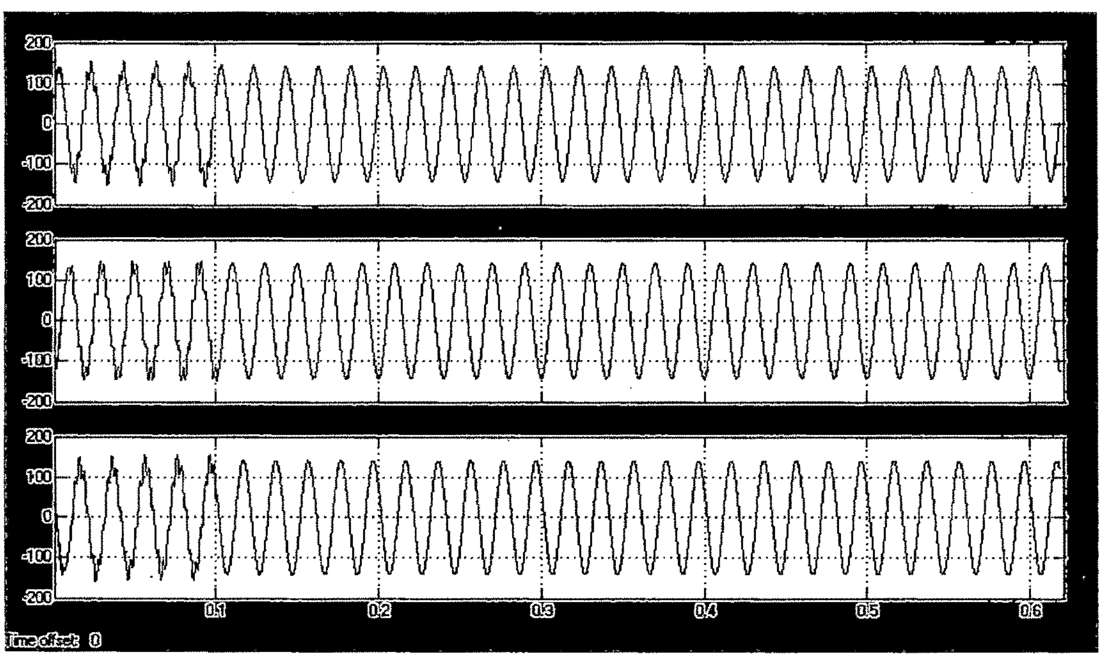

Fig 5.29 Load voltage before and after compensation

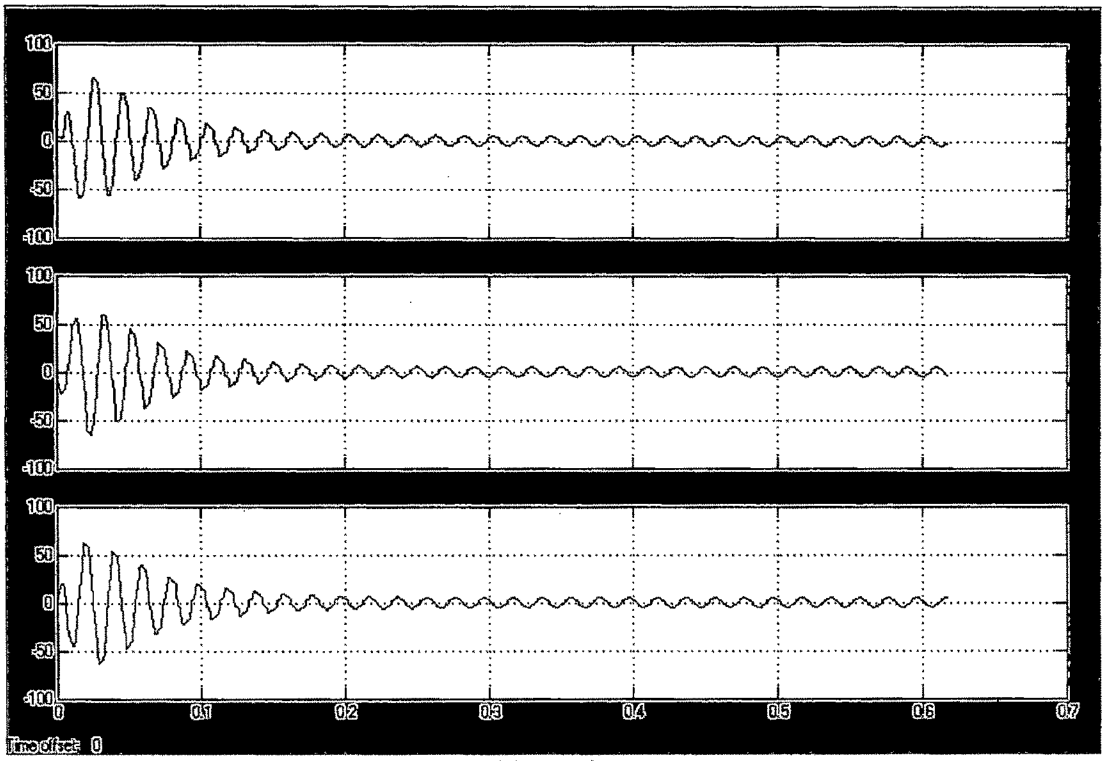

Fig 5.30 Load current

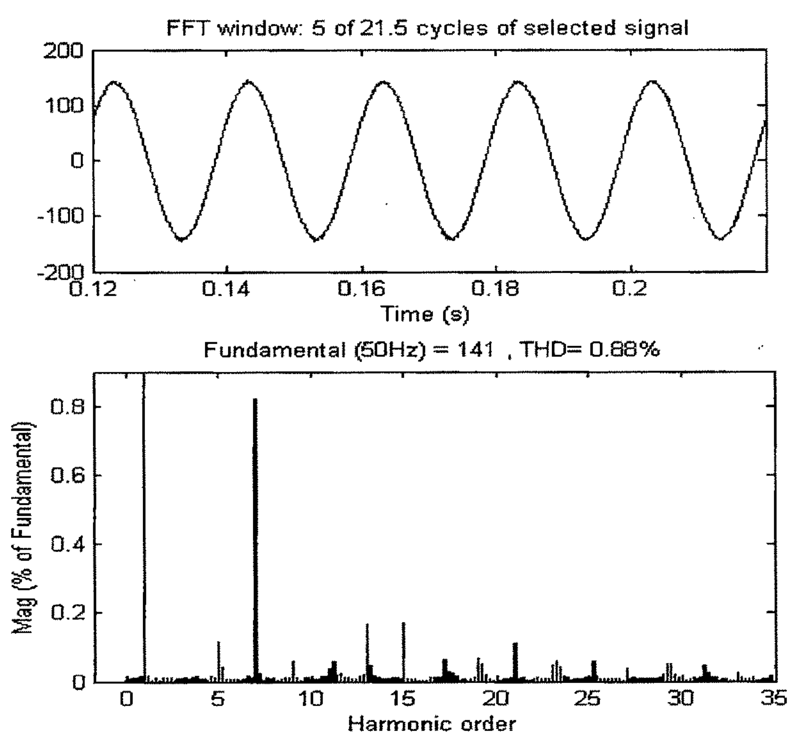

Fig 5.31 FFT analysis for load voltage

Table 5.2: THD analysis for different loads, for series active power filter

Load type	THD (%) source voltage	THD (%) load voltage
R-L load	15	1.01
DC machine load	15	0.88

The table 5.2 shows the THD analysis for the source voltage and the load voltage. It is clear from the table that the performance of the system improves and the THD is reduced up to very large extent. The THD changes as the load is changed. The values of different parameters used for this model have been given in appendix II.

5.3.1 Performance of DVR

A MATLAB based model of the series active power filter has been simulated for RL and DC machine load using the hysteresis control technique. The simulation results show that the input voltage harmonics are compensated very effectively by using the series active power filter.

5.4 Simulation and Performance Investigation of UPQC

In this section the simulation analysis of UPQC is described, first for R-L load and then for DC machine load and the FFT analysis has been carried out simultaneously. In this two filters are used i.e. shunt active power filter and series active power filter. The control circuits for these two filters are same as shown in sections 5.2 and 5.3[45,46]. The shunt active power filter compensates for the source current harmonics and also it maintains the dc link voltage unchanged in steady state, while the series active power filter compensates for the load voltage harmonics.

5.4.1 Simulation Result Analysis of UPQC

The performance of proposed UPQC model is carried out on RL load and DC machine. Fig. 5.33 shows load current and Fig 5.35 shows effect of compensation. It shows Source current before and after compensation [45, 48]. Same way phase A shows Source voltage, source current and filter current effect. FFT analysis is carried out on load current and source current. Harmonics number and information is explain in fig. in 5.51 and 5.52

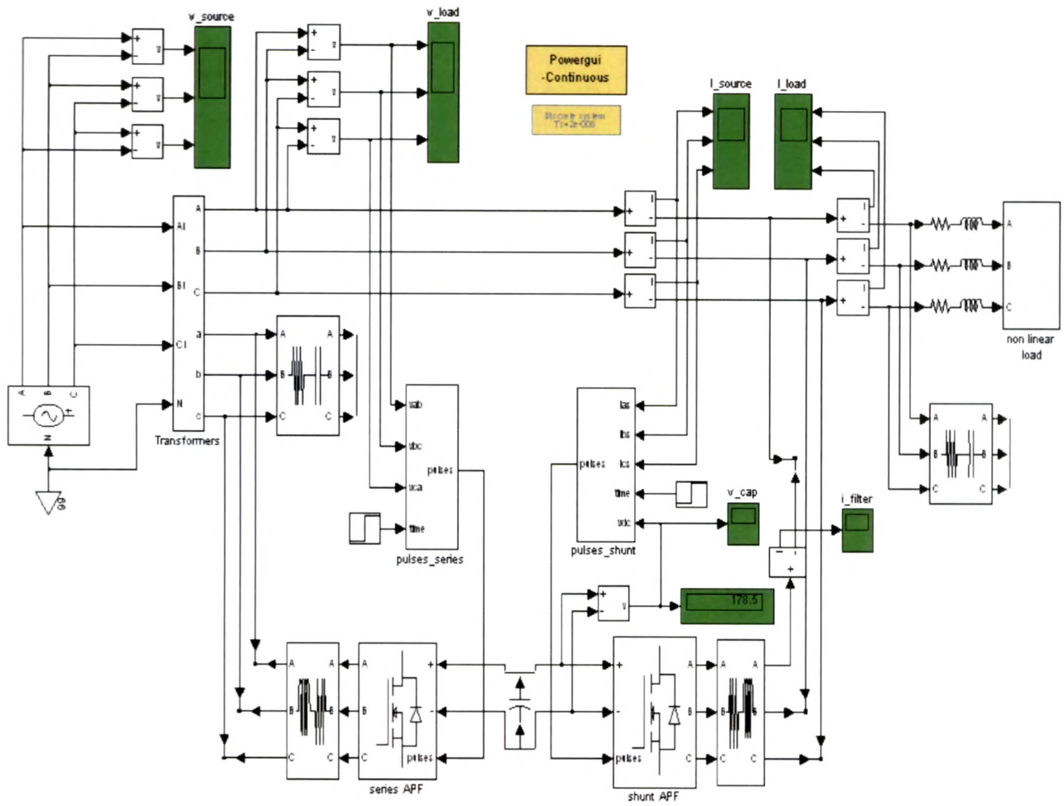

Fig 5.32 MATLAB model for Unified power quality conditioner (UPQC)

Fig. 5.32, 5.36 and 5.37 shows the supply voltage, supply current and injected current wave forms of the line current before the shunt current and after the shunt current injection. The overall simulation run time is 0.3 sec. the control strategy is started after 0.1 sec. After 0.1 sec the PI controller acted to settle the reference DC link voltage and current from the shunt converter injected to make the supply current sinusoidal. It is observed that after the control strategy started the wave shape of the line current at the input side is improved in term of the harmonic distortion. It is also observed that the supply voltage does not affected. Fig. 5.35 shows the Load voltage and current remain unaffected throughout the operation.

Fig. 5.51 shows the current on the main line side before injection and frequency contain in it. Fast Fourier Transformation (FFT) analysis of the same current is carried out and the Total Harmonic Distortion (THD) in this case is 14.75%. Fig. 5.51 shows the current on the main line side after injection and frequency contain in it. FFT analysis of the same current is carried out the THD in this case is 0.17%.

For RL Load

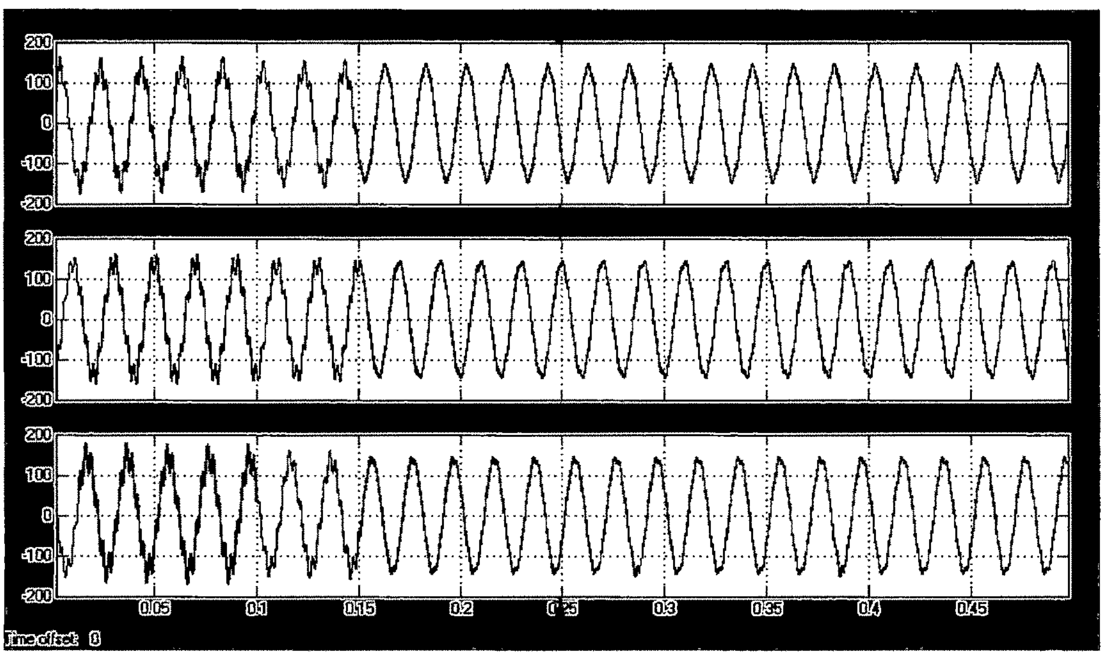

Fig 5.33 Load voltage before and after compensation

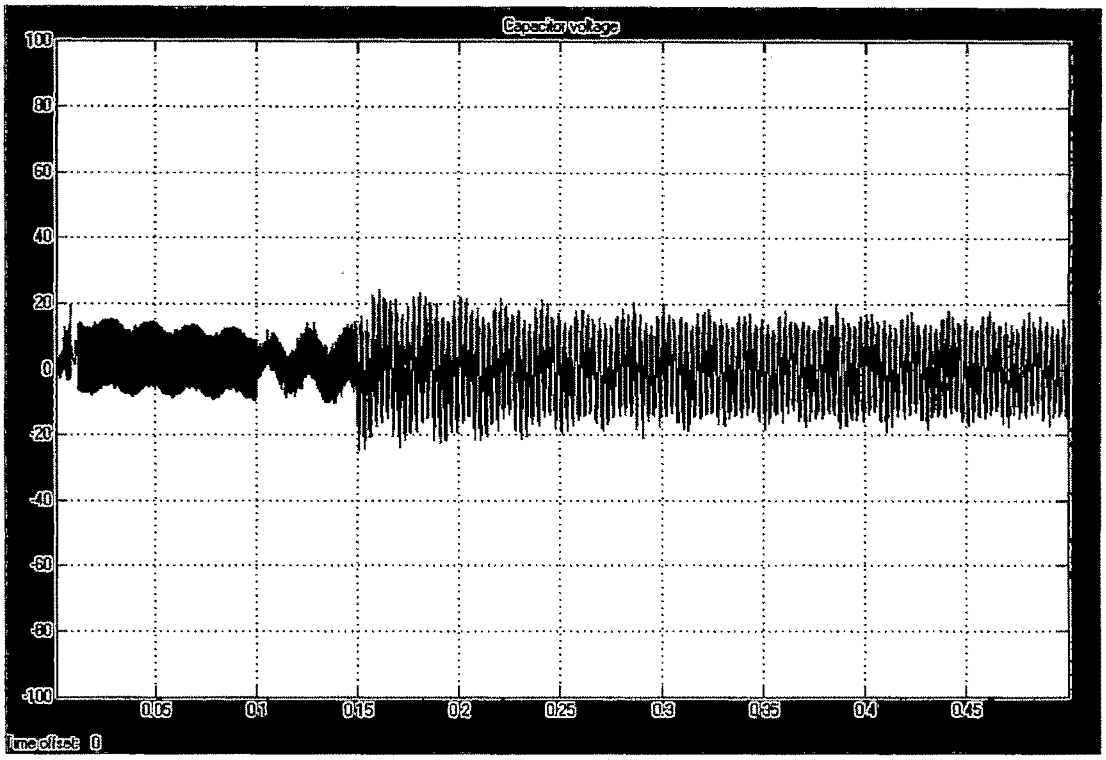

Fig 5.34 Compensating voltage for phase 'A'

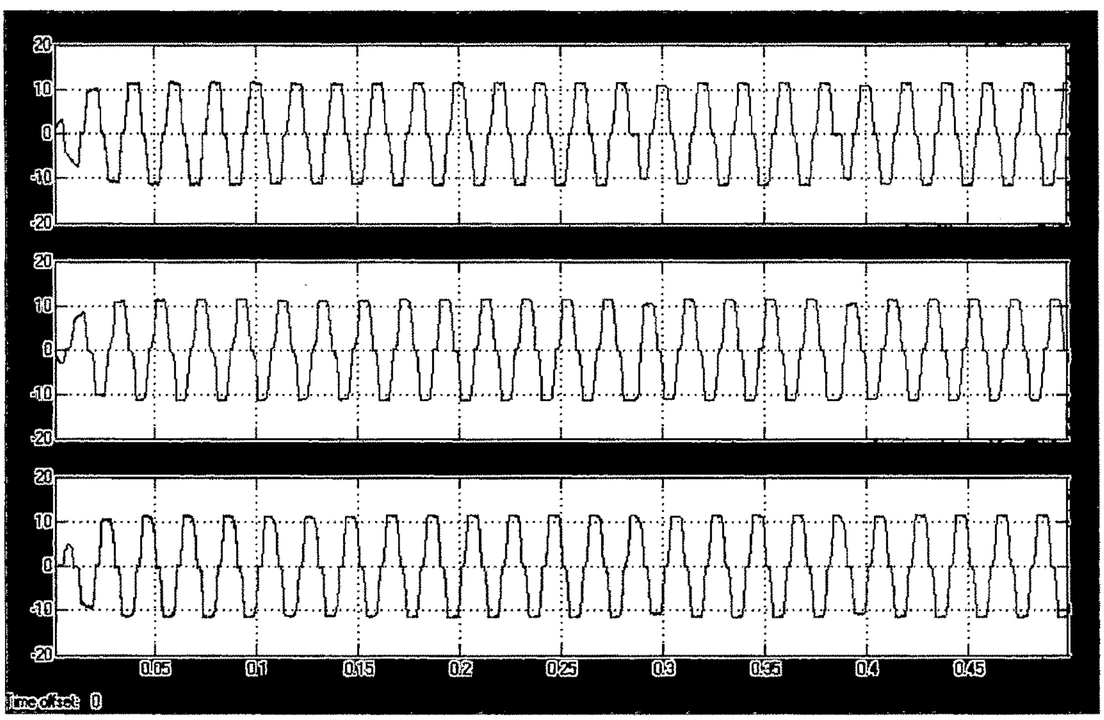

Fig 5.35 Load current

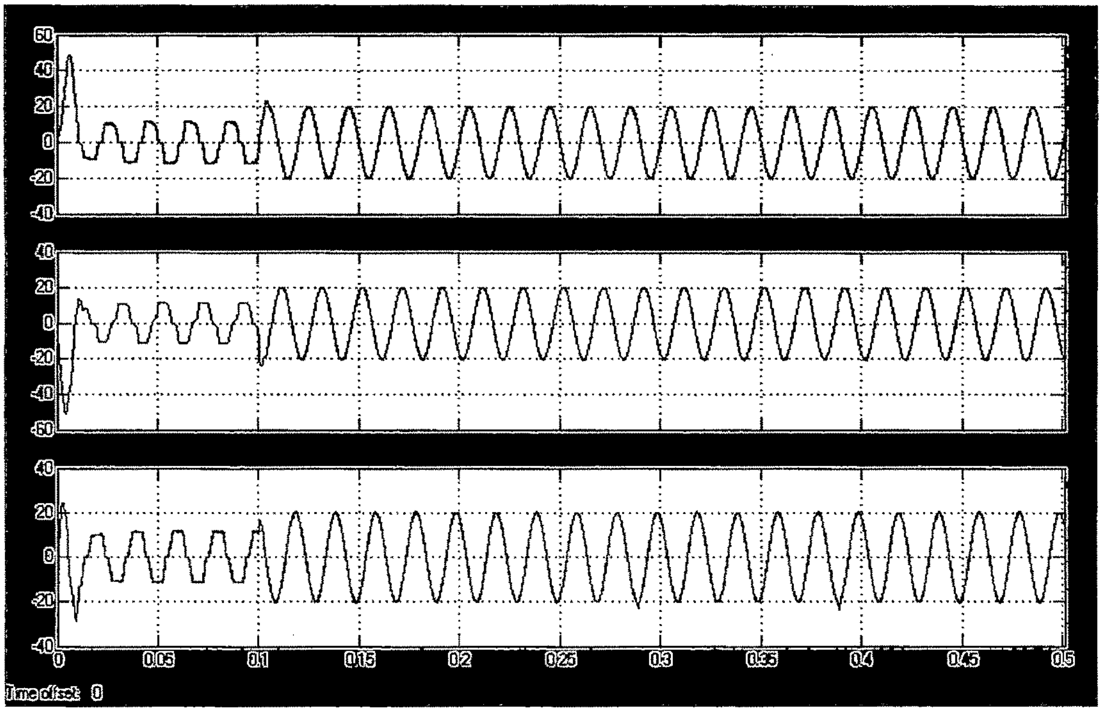

Fig 5.36 Source current before and after compensation

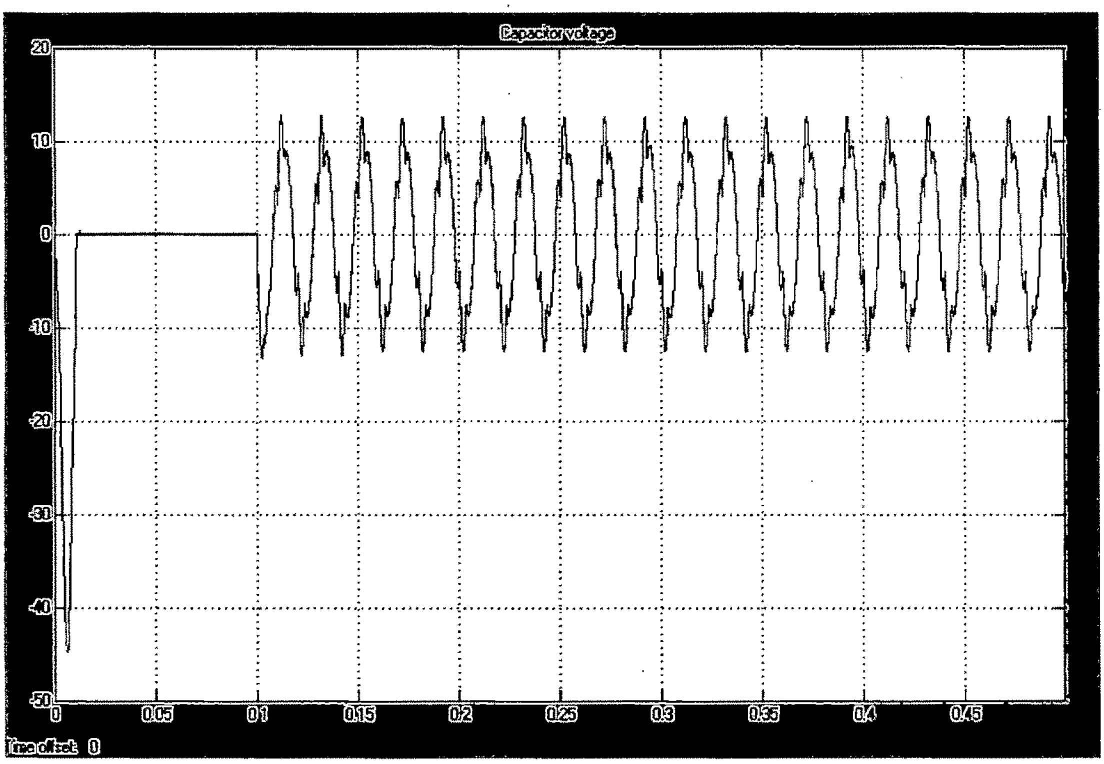

Fig 5.37 Compensating current for phase 'A'

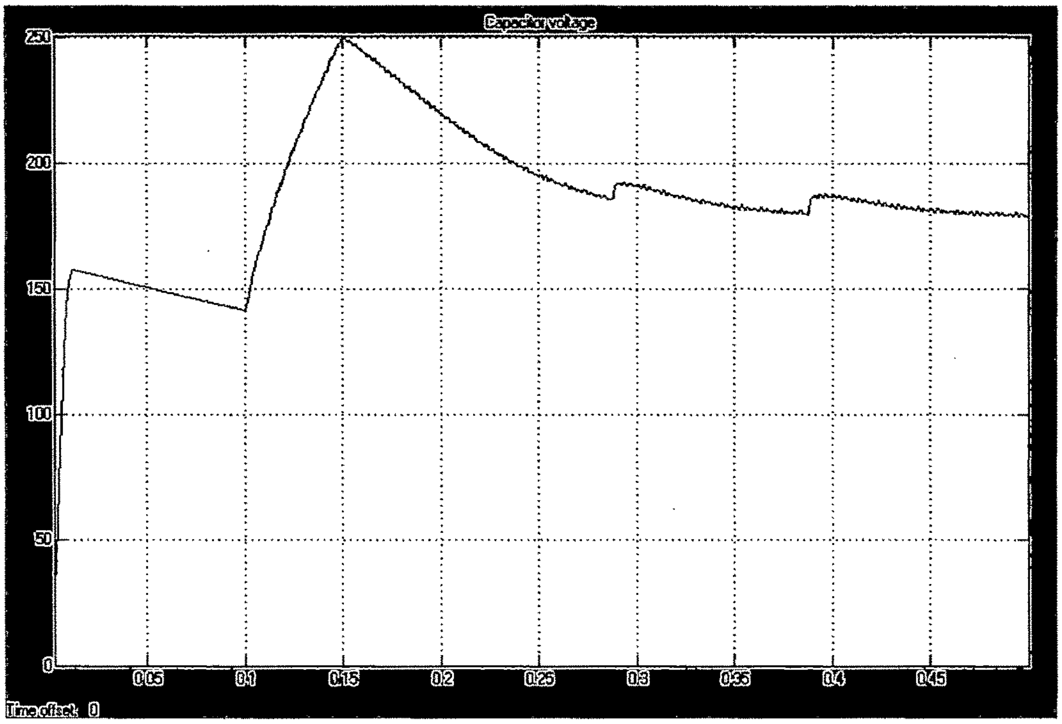

Fig 5.38 Capacitor voltage

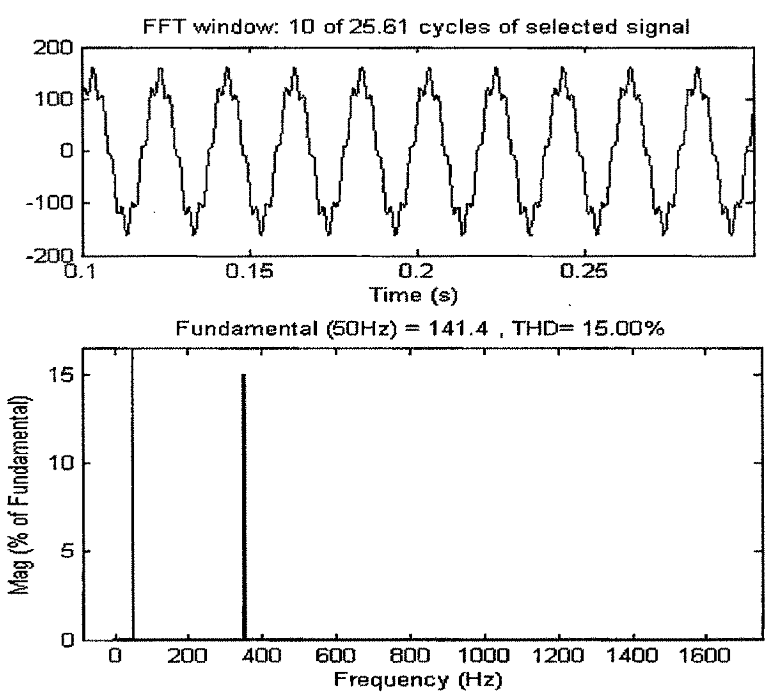

Fig 5.39 FFT analysis for source voltage

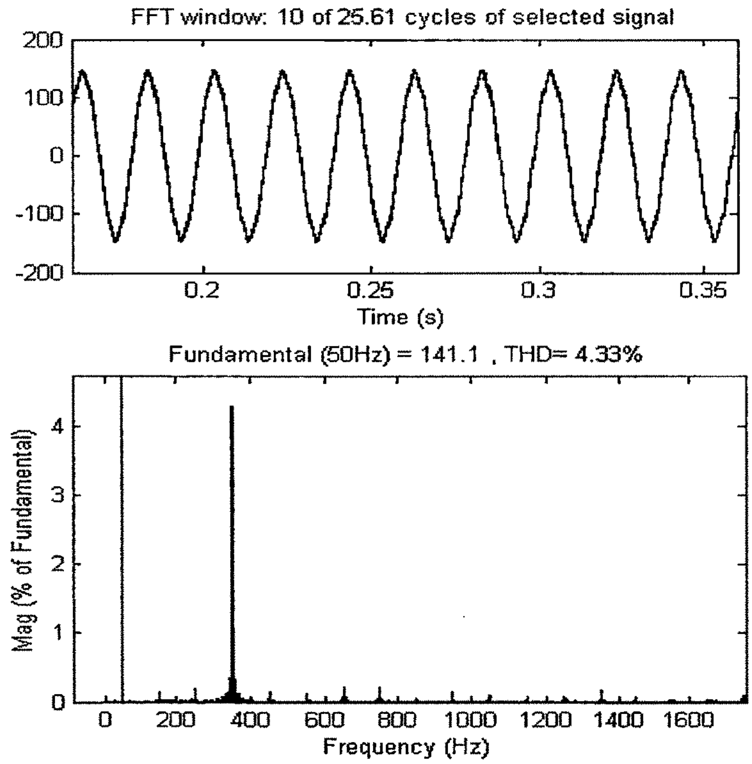

Fig 5.40 FFT analysis for load voltage

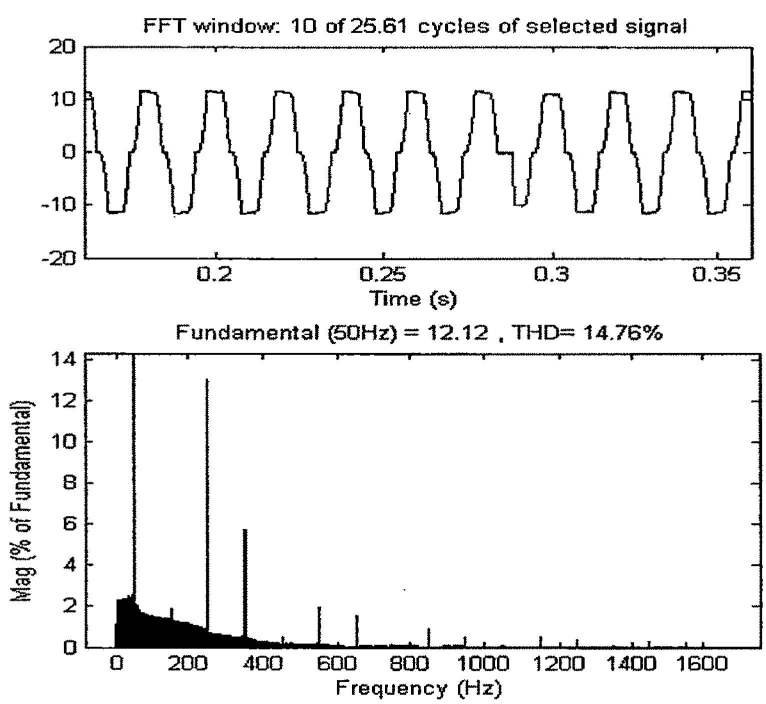

Fig 5.41 FFT analysis for load current

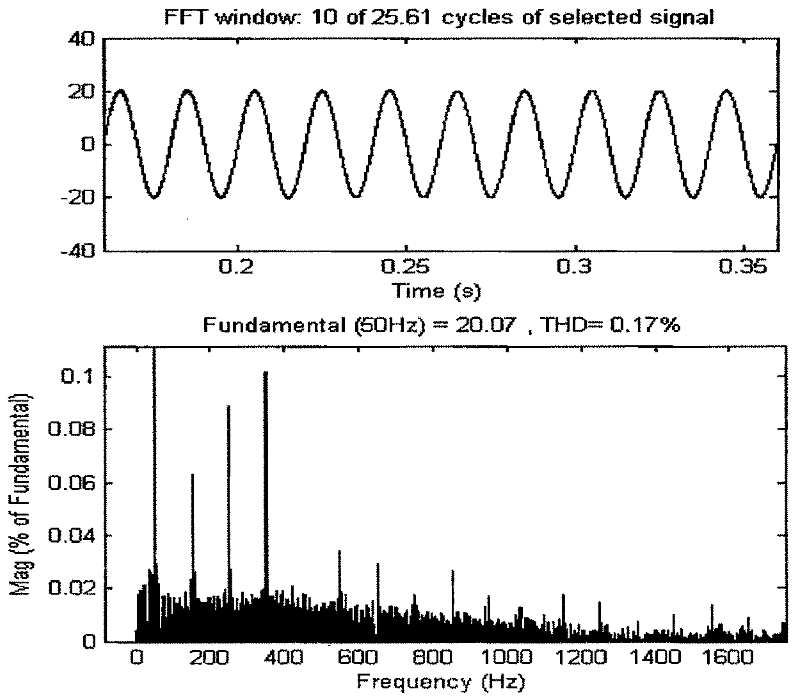

Fig 5.42 FFT analysis for source current

For DC Machine Load

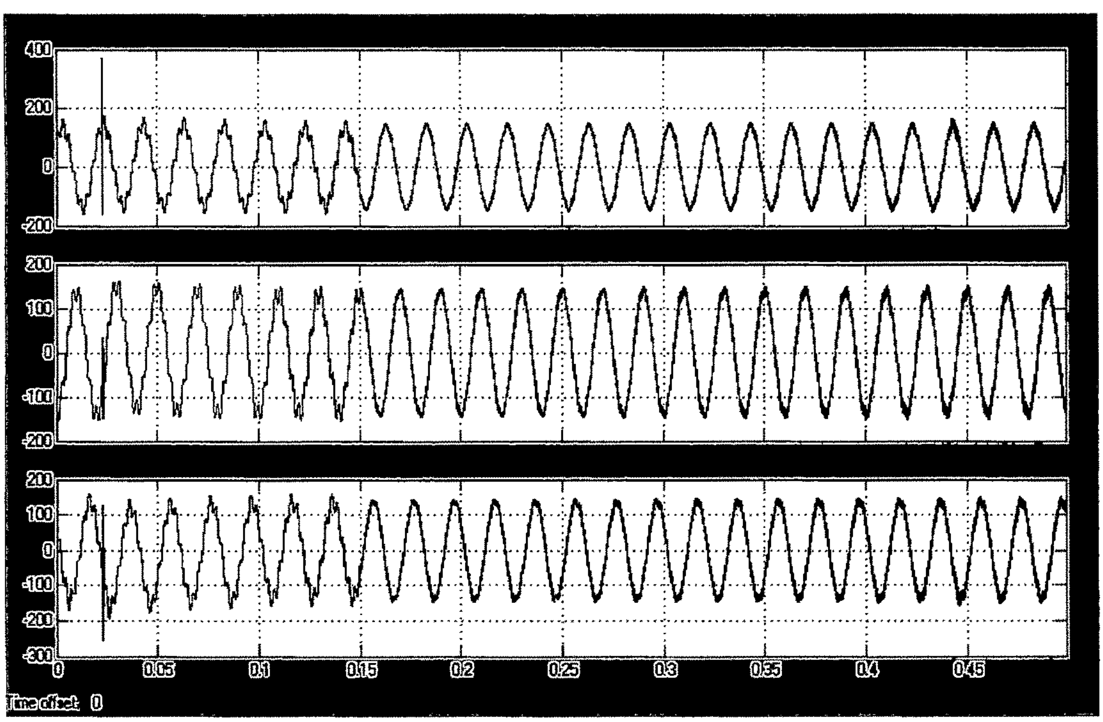

Fig 5.43 Load voltage before and after compensation

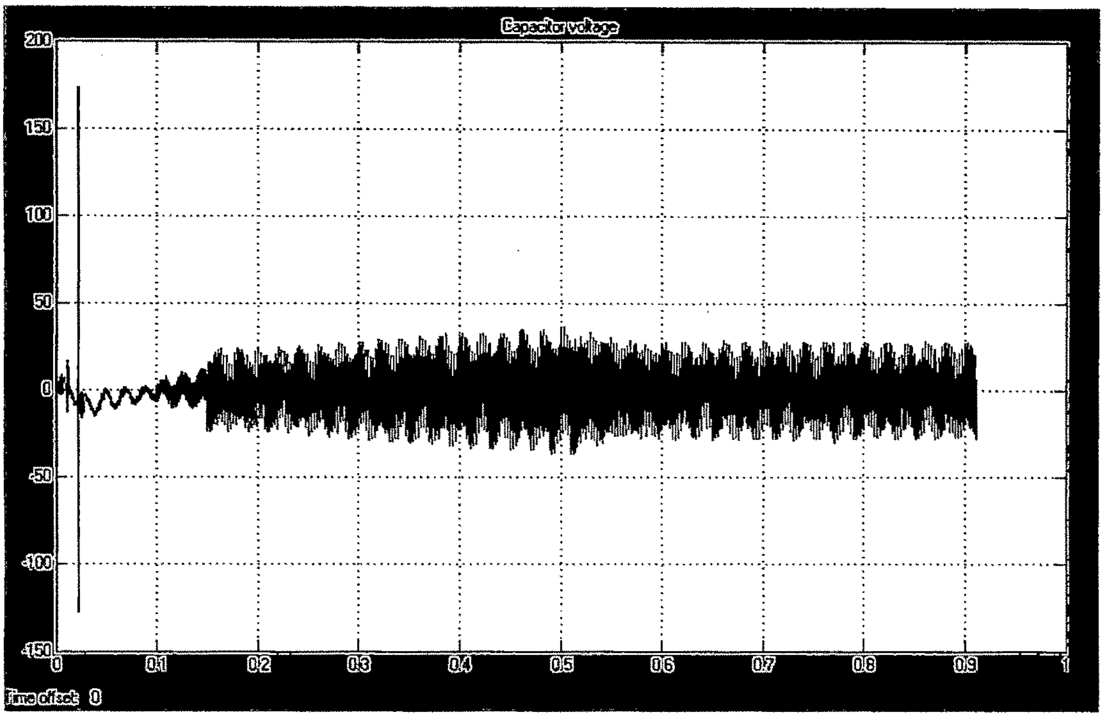

Fig 5.44 Compensating voltage for phase 'A'

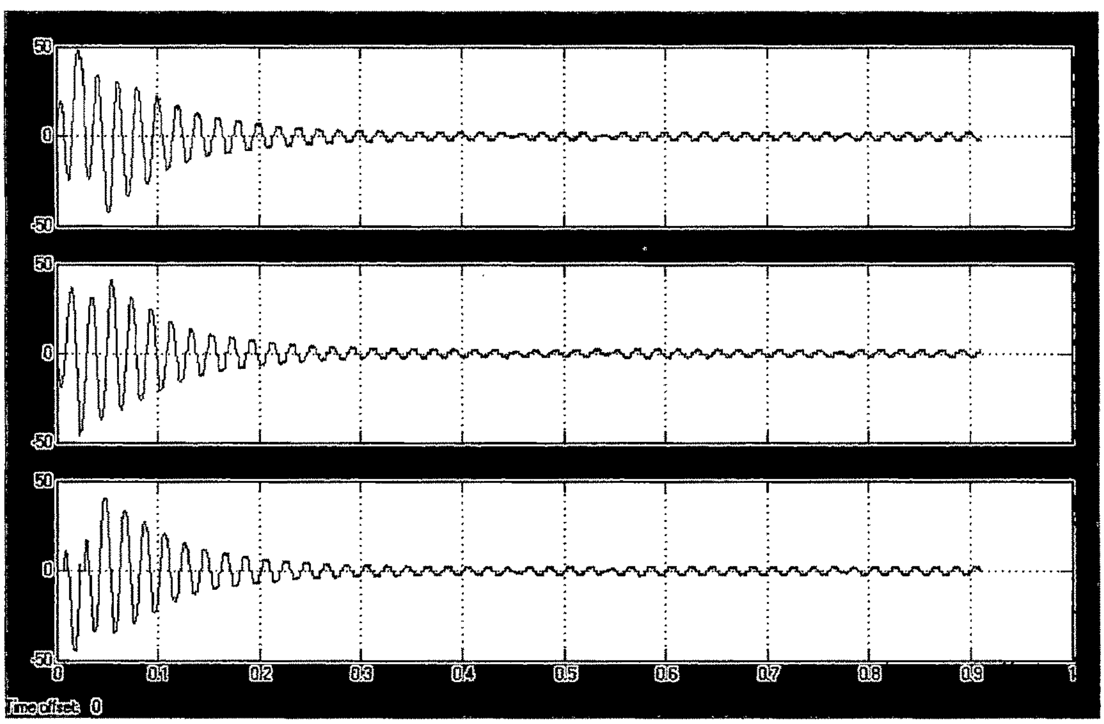

Fig 5.45 Load current

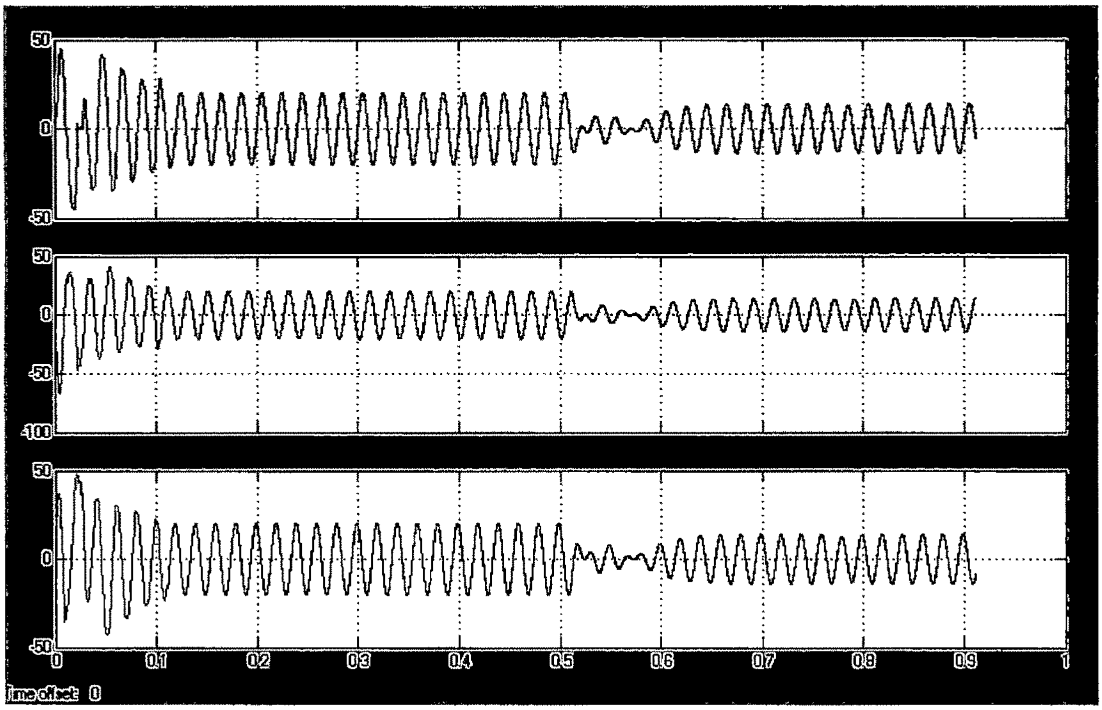

Fig 5.46 Source current before and after compensation

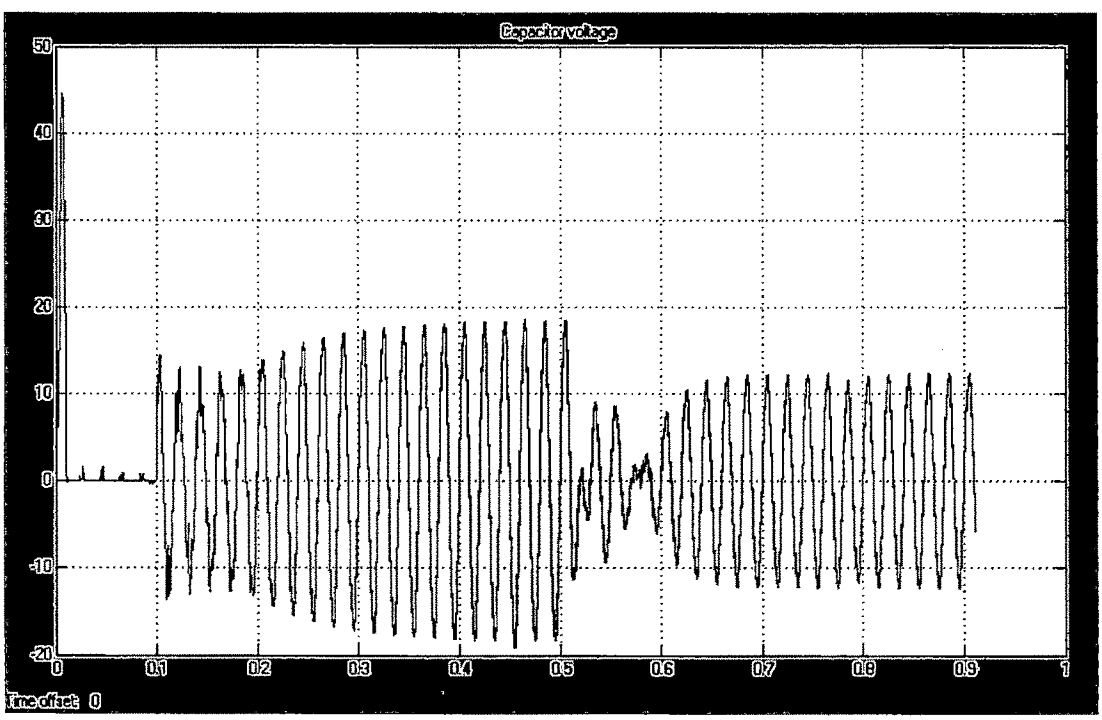

Fig 5.47 Compensating current for phase 'A'

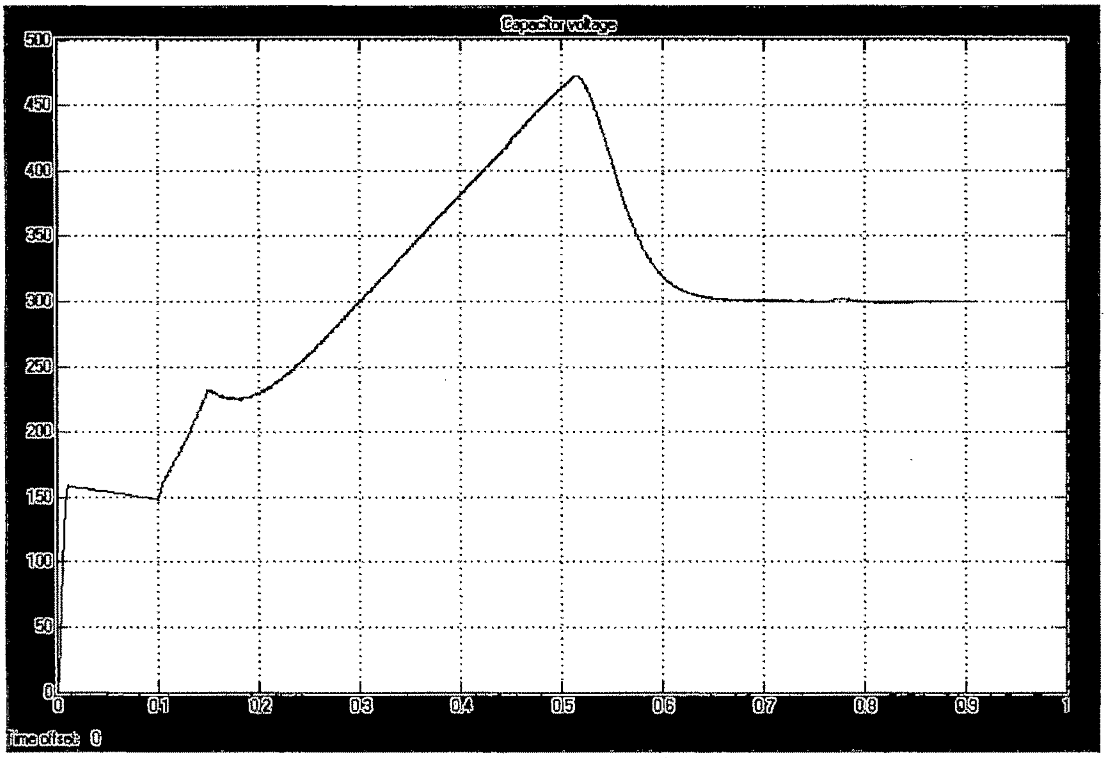

Fig 5.48 Capacitor voltage

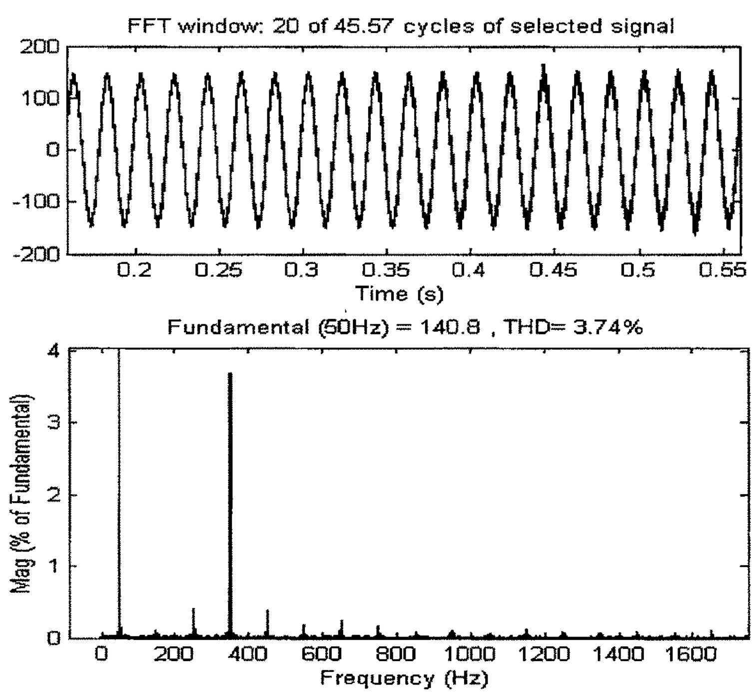

Fig 5.49 FFT analysis for load voltage

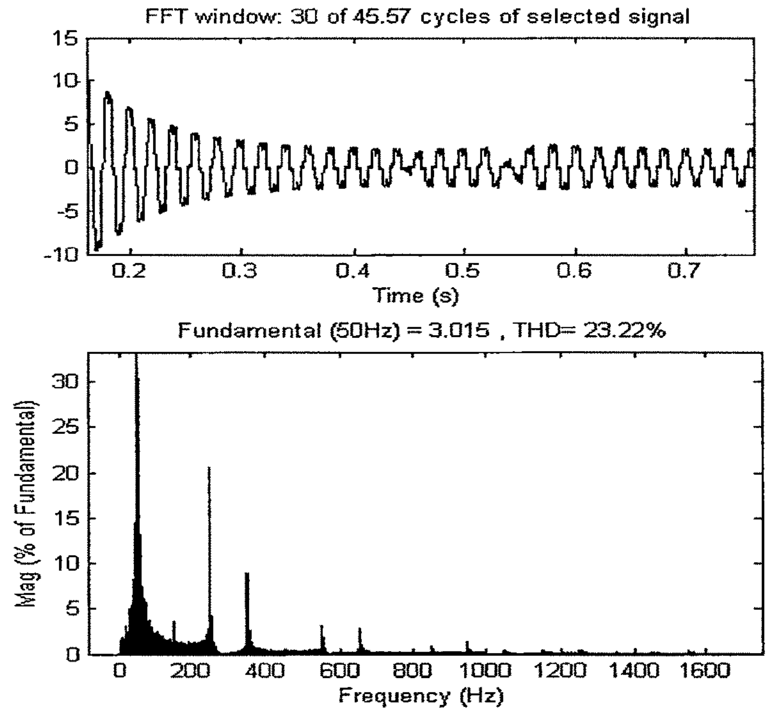

Fig 5.50 FFT analysis for load current

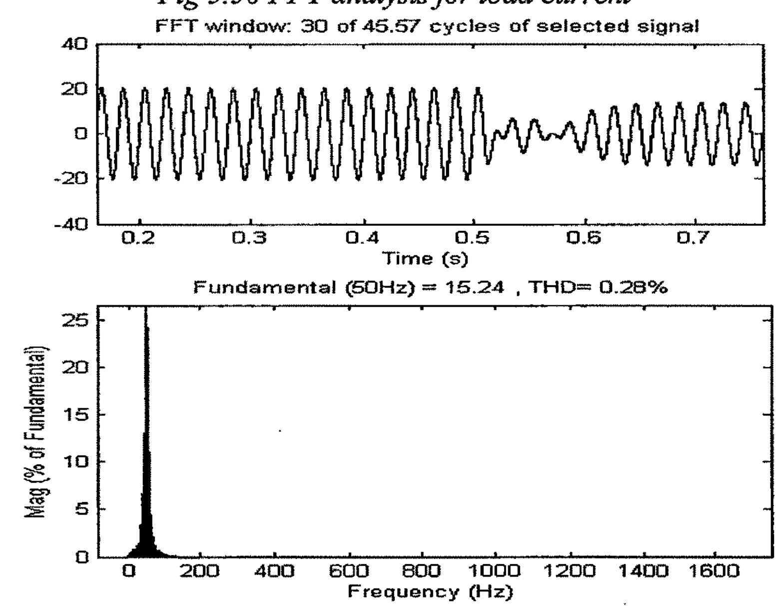

Fig 5.51 FFT analysis for source current

Table 5.3 :THD analysis of load and source currents for different loads, for UPQC

Load type	THD (%) load current	THD (%) source current
R-L load	14.75	0.17
DC machine load	23.22	0.28

The table 5.3 shows the THD analysis for the load current and the source current. It is clear from the table that the performance of the system improves and the THD is reduced up to very large extent. The table 5.4 shows the THD analysis for the source voltage and the load voltage.

Table 5.4 :THD analysis of load and source currents for different loads, for UPQC

Load type	THD (%) source voltage	THD (%) load voltage
R-L load	15	4.33
DC machine load	15	3.74

5.4.1 Performance of UPQC

A MATLAB based model of the UPQC has been simulated for RL and DC machine load using the hysteresis control technique. The simulation results show that the input voltage harmonics and the current harmonics caused by non-linear load are compensated very effectively by using the UPQC.