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Simulation and Hardware Implementation of Shunt Active Power Filter Based on Synchronous Reference Frame Theory

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Abstract

This paper describes about the Shunt Active Power Filter (SAPF) for the elimination of the current harmonics in the line side. The Active Power Filter is based on the Voltage Source Inverter (VSI) topology. The Synchronous Reference Frame (SRF) theory based control strategy is utilized for SAPF. The SAPF has the better performance for compensation of harmonics. The simulation of shunt active power filter is performed in MATLAB/Simulink. The SAPF is implemented in hardware protptype with ATMEGA 8 Microcontroller. The Simulation and Hardware result shows that the current harmonics are eliminated in the system.

***Keywords**: shunt active power filter, voltage source converters, harmonics, synchronous reference frame*

1. Introduction

Harmonics are the major disturbance in distribution system, the efficiency of the system reduces and cause damage to the equipment's. The elimination of harmonics is done by various methods used are using passive LC filter and Active Power Filters (APF) [1]-[4]. The APF can be connected as shunt and series configuration. The shunt connection gives better harmonics compensation than the series connection [5-8]. The quality of power delivering to the system to be maintained within their limits and compensation techniques also to be implemented to make the system as efficient one. The APF has the property of compensating the current and voltage related problems. The shunt active power filter is the most promising approach to compensate the current harmonics [9]-[10] in the system. The converter connected to the system which acts as the APF for the injecting the negative harmonics [11] to the system for the compensating the harmonics. The Shunt APF [12]-[13] has the converter which is based on the Voltage Source Inverter (VSI) topology using Insulated Gate Bipolar Transistor (IGBT) device. The gate pulse for the IGBT is generated by the Synchronous Reference Frame (SRF) [14] theory for the reference signal calculation and compared using the hysteresis controller [19-22].

The SAP Filter based on the VSI topology is connected through the capacitor which delivers the supply for the compensation of the current harmonics in distribution system. The Total Harmonics Distortion (THD) [15-18] has the acceptable limit for both voltage and current. The THD of instantaneous current I1, I2, I3 up to In is given by square root of the mean (average) value of the squared function of the instantaneous values.The THD limit is 5% for Voltage and 8% for Current as per IEEE 519 standards. The Current Harmonics is calculated by the Equation (1) and (2).

$$THD_{\%\,fundamental} = \left(\frac{I_{rms\,(distortion)}}{I_{fundamental}}\right) \quad (1)$$

Where, Irms (distortion) is denoted by

$$I_{rms(distortion)} = \sqrt{I_1^2 + I_2^2 + I_3^2 + \cdots} \quad (2)$$

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2. Shunt Active Power Filter (SAPF)

Expl The Shunt Active Power Filter (SAPF) has the robust control of current harmonics within the limit and makes the system to be more efficient. The Figure 1 shows the configuration of the Shunt APF [3]. The coupling transformer connected to the system for the injection of the compensating harmonics to eliminate the distortion. The switching converter is based on VSC topology of three leg configuration of IGBT components. The Capacitor C connected along the DC terminal of the converter which supplies the DC voltage VDC to the converter. The 6 pulse converters which are operated in the 1800 phase shift to the IGBT of same leg, 1200 between the two legs and 600 phase shift between the n+ 1 component.

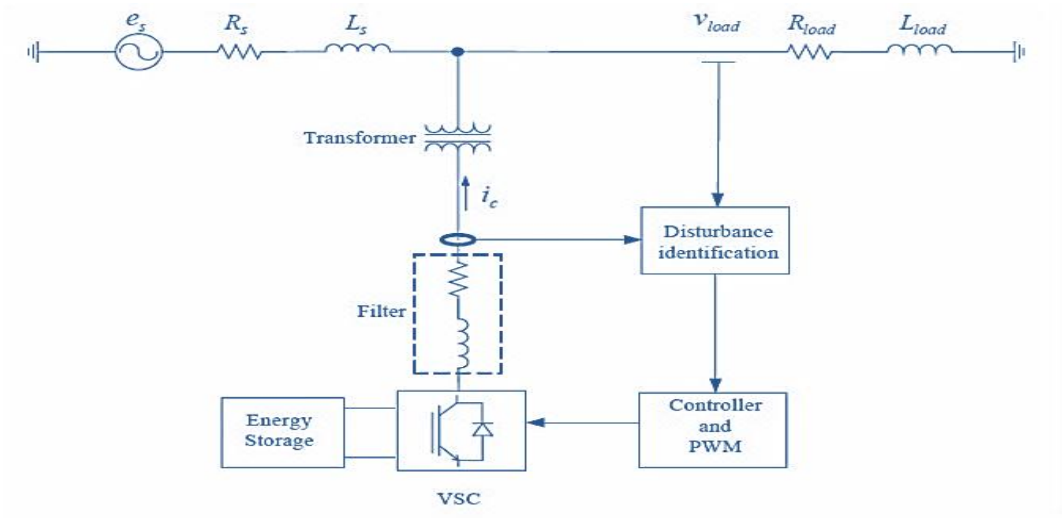

Figure 1. Shunt Active Power Filter (SAPF) Configuration

3. Control Strategy for SAPF based on Synchronous Reference Frame (SRF) Theory

The control strategy of the system is to control the converter for the injections of the negative harmonics for the compensation of the system. The converter output is controlled by the gate pulse given to the IGBT's. This is achieved by the Synchronous Reference Frame Theory [4]. The SRF [6] theory is based on the synchronous machine in which for the analysis of 3phase system is made easy. The 3phase system abc is converted to the direct and quadrature axis quantities dq0. For the shunt APF is load current is considered for the reference signal calculation and pulse is generated. The Equation (3), (4), (5) represents the current for the three phases which is converted to dq0 for the balanced state.

$$i_a = I_m sin\omega_s t \quad (3)$$

$$i_b = I_m \sin\left(\omega_s t - \frac{2\pi}{3}\right) \quad (4)$$

$$i_a = I_m \sin\left(\omega_s t + \frac{2\pi}{3}\right) \quad (5)$$

The transformation matrix for the ia, ib ic is given by Equation (6),

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta & 1 \\ cos\left(\theta - \frac{2\pi}{3}\right) & -sin\theta\left(\theta - \frac{2\pi}{3}\right) & 1 \\ cos\left(\theta + \frac{2\pi}{3}\right) & -sin\theta\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \quad (6)$$

The transformation of matrix from abc to dq0 and inverse transform of matrix dq0 to abc is simultaneously performed to calculate the reference signal for the pulse generation. The

Equations (7), (8) and (9) show the transformation of dq0 under the balanced state. The id, iq, i0 are the currents of direct, quadrature and zero axis of the system which is obtained from the inverse transformation.

$$\mathrm{i_d} = \mathrm{k_d}\frac{3}{2}\mathrm{I_m}\sin(\omega_s t - \theta) \quad (7)$$

$$\mathrm{i_q} = -\mathrm{k_q}\frac{3}{2}\mathrm{I_m}\sin(\omega_s t - \theta) \quad (8)$$

$$\mathrm{i_0} = \frac{1}{3}(i_a + i_b + i_c) \quad (9)$$

The transformation matrix for the dq0 transform is given by (10),

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} cos\theta & cos\left(\theta - \frac{2\pi}{3}\right) & cos\left(\theta + \frac{2\pi}{3}\right) \\ -sin\theta & -sin\theta\left(\theta - \frac{2\pi}{3}\right) & -sin\theta\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (10)$$

The DC voltage across the capacitor Vdc is to be kept within a range of a voltage of 705V throughout the operation of the system. The PI controller is connected to output of the voltage measurement Vdc and a constant of 705 is compared with the measured voltage of the system. The block diagram for the SRF theory implementation is represented in Figure 2.

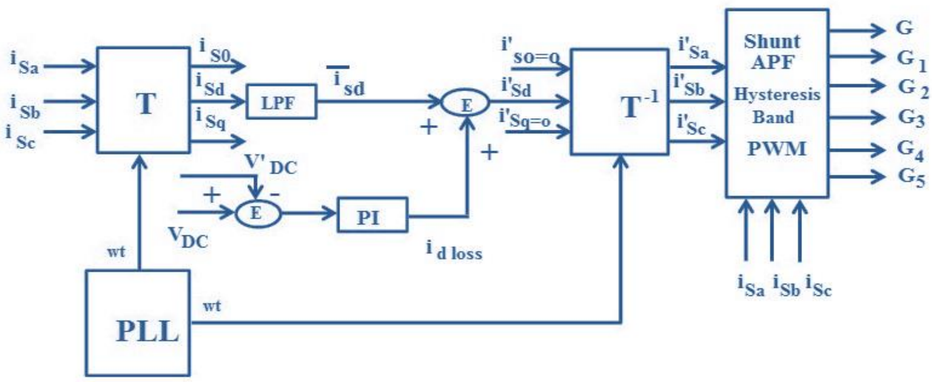

Figure 2. Block diagram representation of Synchronous Reference Frame (SRF) theory

4. Simulation of Shunt Active Power Filter

The shunt active power filter (SAPF) design for three phase systems is modelled in MATLAB. The load considered here is reftified RL and three phase RLC static load. The shunt active filter has the ability to compensate the current harmonics caused by the non linear loads in power systems. The control strategy based on SRF theory for SAPF is simulated in MATLAB/Simulink shown in the Figure 3.

The Figure 4 shows the Simulink model of the SRF theory which is used for reference signal calculation. The reference signal is compared with the measured signal by using the hysteresis band for the PWM pulse for the IGBT operation. The Figure 5 shows the simulation of the Hysteresis band for the PWM pulse generation.

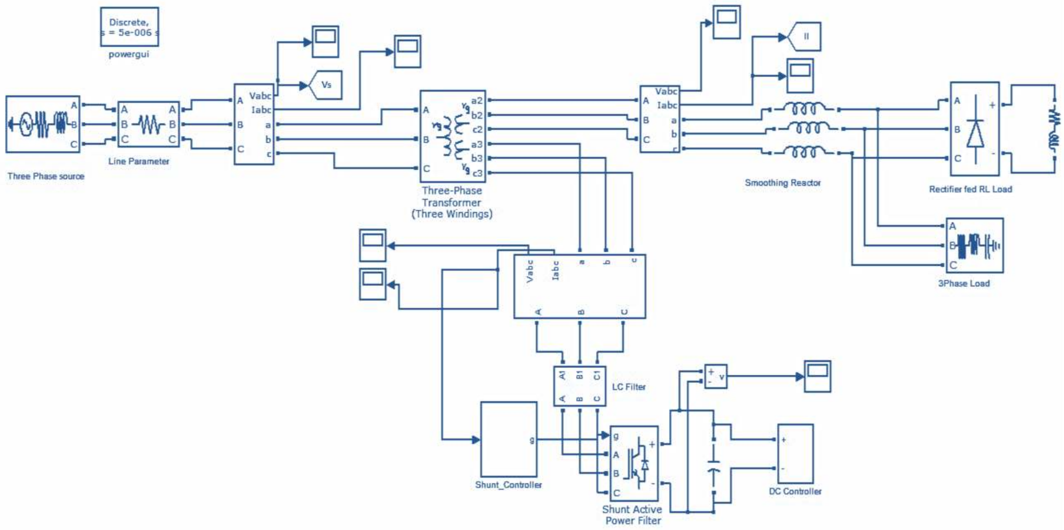

Figure 3. Simulink model of shunt active power filter

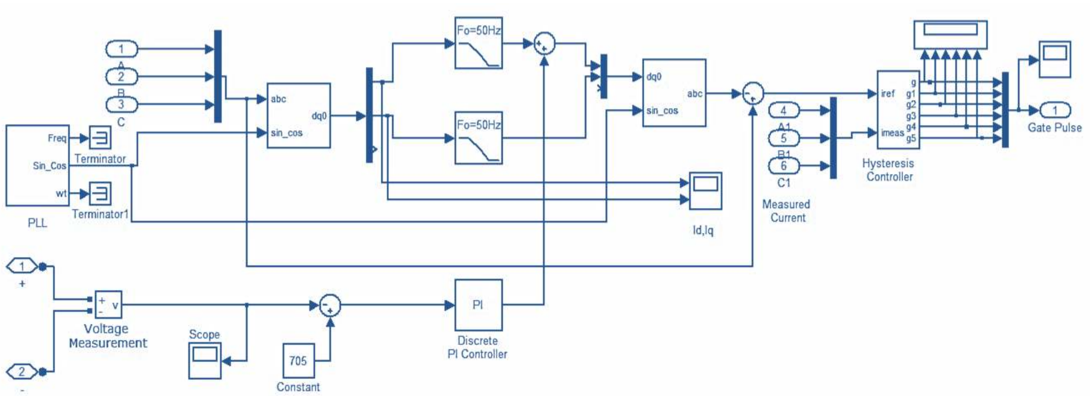

Figure 4. Simulink model of Synchronous Reference Frame (SRF) theory

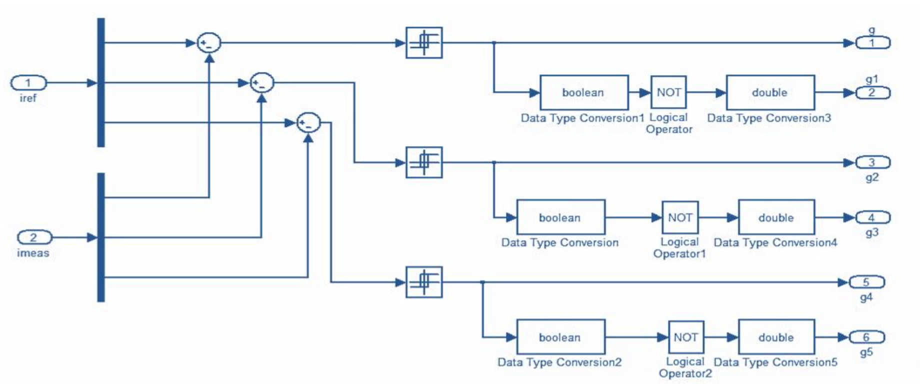

Figure 5. Simulink model of Hysteresis Controller

The simulation of SAPF is performed using the MATLAB/Simulink based on the SRF theory as control strategy. The output of the 3 phase system is shown in the Figure 6 Vabc is the source voltage of the 3phase system. Iabc is the source current which has the harmonics distortion. The Figure 7 shows the output phase Va of the distribution system.

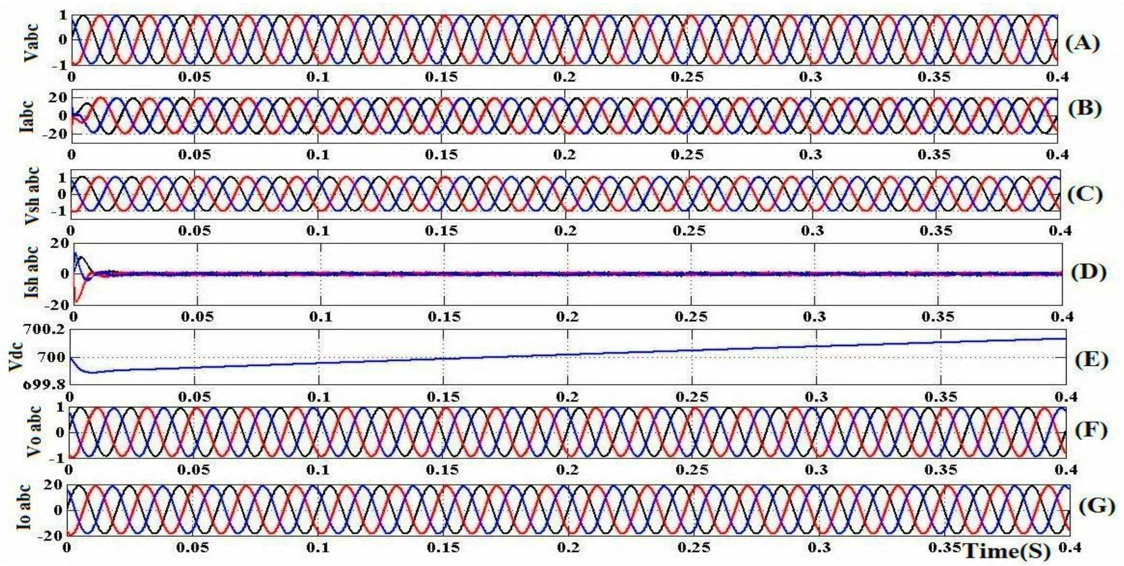

Figure 6. Output of the 3 phase shunt APF Simulation (A). Vabc Source Voltage, (B). Iabc Source Current, (C). Vsh abc Voltage of Shunt APF, (D). Ish abc Current of Shunt APF for harmonics compensation, (E). Vdc DC Voltage, (F). V0abc Output voltage, (G). I0abc Output Current of the system

The simulations:

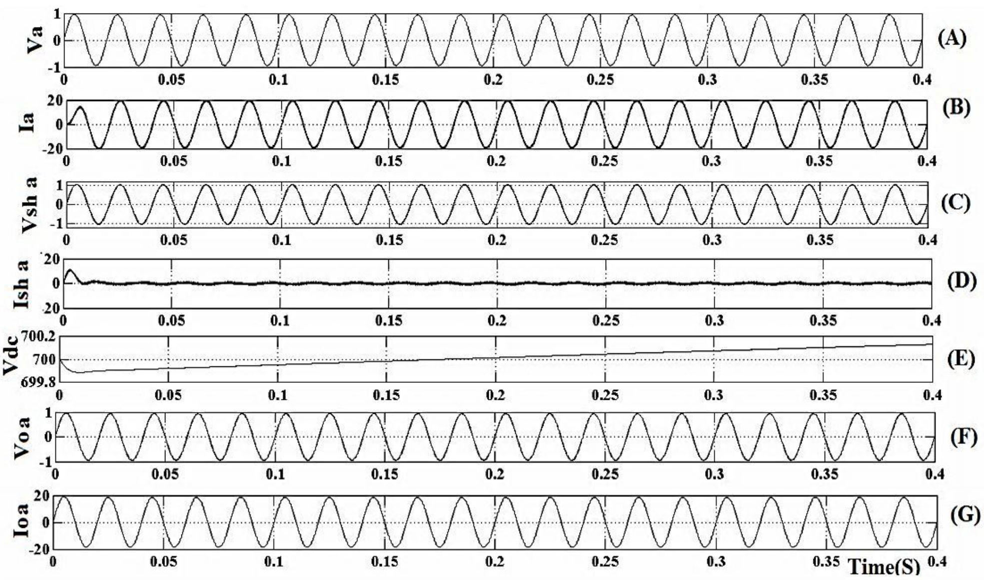

Figure.7. Output of the a phase shunt APF Simulation (A). Va Source Voltage, (B). Ia Source Current, (C). Vsh a Voltage of Shunt APF, (D). Ish a Current of Shunt APF for harmonics compensation, (E). Vdc DC Voltage, (F). V0a Output voltage, (G). I0a Output Current of the system

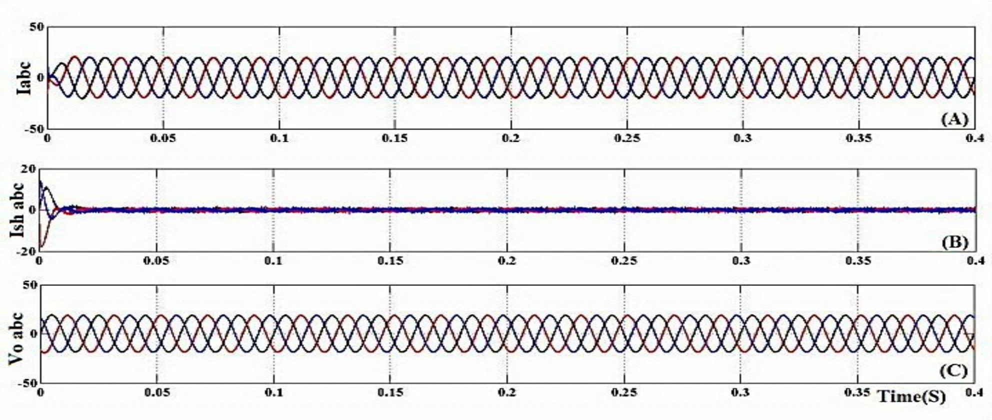

Figure 8. Shunt compensation

The harmonics is compensated by the shunt APF is shown in the Figure 8 Ish abc is the Current of Shunt APF for harmonics compensation. The harmonics THD in the system before the compensation is 18.93% with distortions. The analysis for the calculation of THD is done and shown in Figure 9.

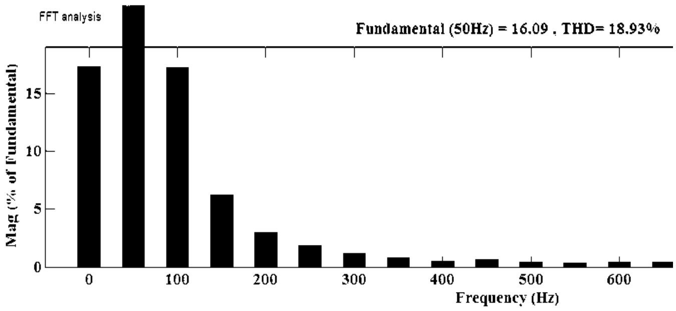

Figure 9. THD analysis before compensation

The harmonics after compensation is 0.95% and the analysis is shown in the Figure 10.

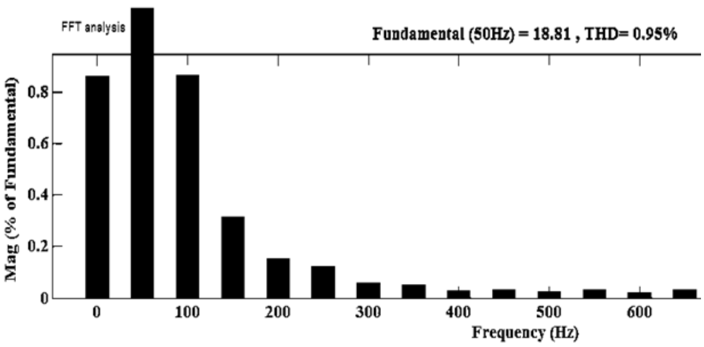

Figure 10. THD analysis after compensation

5. Real Time Implementation

The Figure 13 shows the block diagram of the Shunt active power filter (SAPF) for the elimination of harmonics. The 3φ source is connected to the Rectifier fed RL load and 3φ RL load. The ATMEGA microcontroller is connected with the system which continuously checks the current harmonics and produces the pulse signal to the active filter according to the pulse signal the active filter for the compensation of the current harmonics. The LCD shows the amount of harmonics in the line side and the amount of harmonics injecting to the line.

The prototype model is shown in the Figure 12. The active filter is designed using IGBT the pulse signal is generated by the IGBT driver circuit using the ATMEGA controller. The output voltage of the real time implementation is shown in the Figure 11. The output current is shown in the Figure 14.

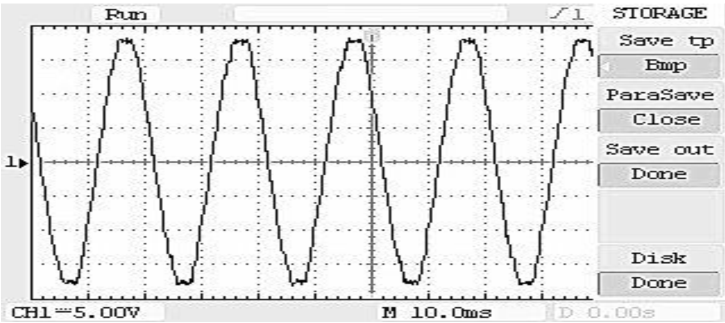

Figure 11. Output voltage of real time implementation

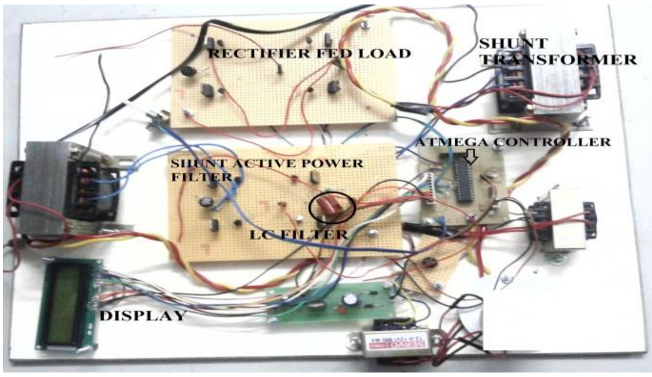

Figure 12. Real time implementation

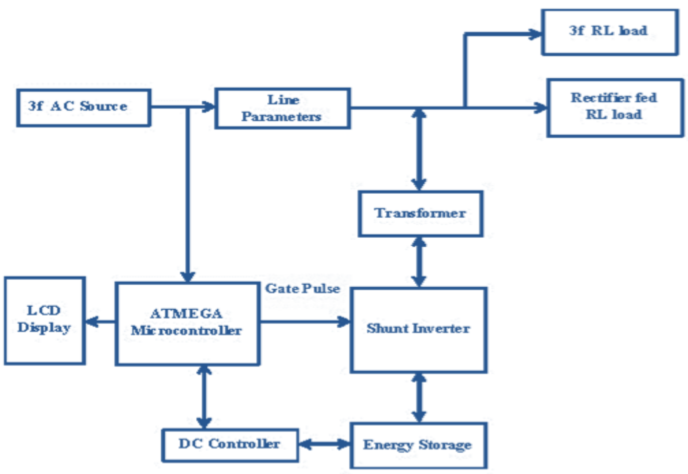

Figure 13. Block diagram of prototype

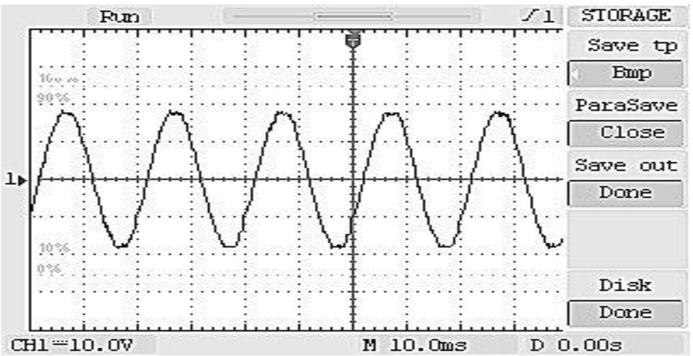

Figure 14. Output Voltage of Real Time implementation

The current harmonics is calculated and displayed in the LCD display. The THD calculated using the Controller for the hardware is 4.60 % and it is shown in the Figure 16.

Figure 16. THD calculated value for real time implementation

6. Conclusion

This paper proposes the simulation and real time implementation of the shunt active power filter (SAPF) based on the synchronous reference frame (SRF) theory and the real time implementation using ATMEGA controller. The results shows that the harmonic level in the system is maintained within the acceptable limit are about 0.95 % for the simulation and 4.60% for the real time implementation of the shunt active power filter. The further improvement can be done using various control algorithms for the elimination of harmonics of the system.

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