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Enhancement of Power Quality with Robust Series Active Filter under Harmonic Polluted Loading Conditions in Distribution Networks

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Abstract

The power quality can be enhanced by many novel techniques. The improvement of both voltage and current quality by means of series active filter is rare in literature. In this proposed paper two control techniques such as synchronous reference frame theory and unit vector control theory were proposed to improve the voltage and current quality by reducing the total harmonic distortion (THD) as per the IEEE standards of power quality in eliminating harmonics. In this proposed paper two nonlinear loads such as bridge rectifier and equivalent model of personal computer (PC) were considered. The MATLAB results also validates that the proposed control techniques are very robust in improving power quality under various conditions such as unbalance, parameter variations (load and source) and fault conditions.

Keywords: *Voltage quality, current quality, synchronous reference frame theory, unit vector control theory, bridge rectifier, personal computer*

1. Introduction

Power quality is defined as the maintaining the perfect voltage and current waveforms at the load bus of point of common coupling (PCC) [1]. It is one of the most down beat problem for the manufacturing industries like power semiconductor industries, tire making industries, food processing industries *etc*. Power quality is one of the most important studies in electrical engineering. It has created a great challenge to both the electric utilities and the manufacturers. Many power quality issues like voltage sags, swells, interruptions, notches, flickers, transients and harmonics will affect the performance of the power system. Most of the power quality issues are due to the loads which are non-linear in nature like bridge rectifiers, adjustable speed drives, lift elevators, fluorescent lamps, arc furnaces, induction motor *etc*., [1]. The most frequent power quality issue in power system is the generation of harmonics, which leads to the malfunctioning of circuit breaker, damaging sensitive equipment, overheating of neutral conductor, copper loss, iron loss, thermal stresses in cables, transformers and rotating machines *etc*., [1]. Power quality can be improved by either active filtering or passive filtering. Passive filtering offers cost effective solution, however few drawbacks are reported in terms of dependence on source impedance, losses, size, and flexibility in

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compensation. Active filtering can eliminate all these drawbacks, with relatively small increment in cost and size. Hence in this research paper an effective filtering techniques using series active filter as given in Figure1 with two different control techniques were used to improve the power quality of voltage and current [2]. Designing an effective control scheme for a series active filter is a challenging task, because the controller should be capable of achieving multiple control objectives simultaneously.

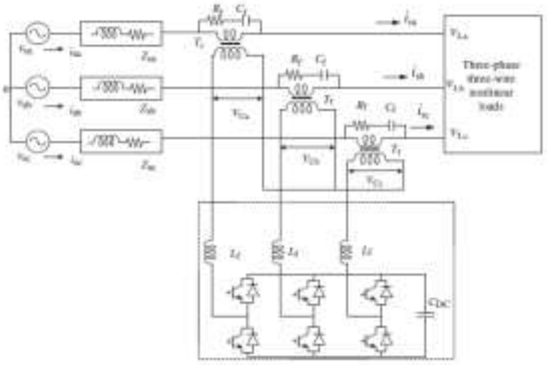

Figure1. Topology of the Proposed System

In addition to conventional control methods, many new control strategies are available to improve the series filter performance such as sliding mode control, neural network control, fuzzy control, and adaptive control, but the improvement of both voltage and current quality by series active filter is scant in the literature [2]. In this proposed paper two control techniques namely synchronous reference theory and unit vector control theory have been implemented to improve the power quality by reducing THD of both voltage and current as per the IEEE standards. In this research paper section 1 details about the introduction, Section 2 elaborates about the synchronous reference frame control theory, Unit vector control theory was explained in Section 3, The results and discussions of the proposed control techniques were explained and compared in Section 4, Section 5 deals with the conclusions and future scope.

2. Direct and Quadrature Axis Reference Frame Theory

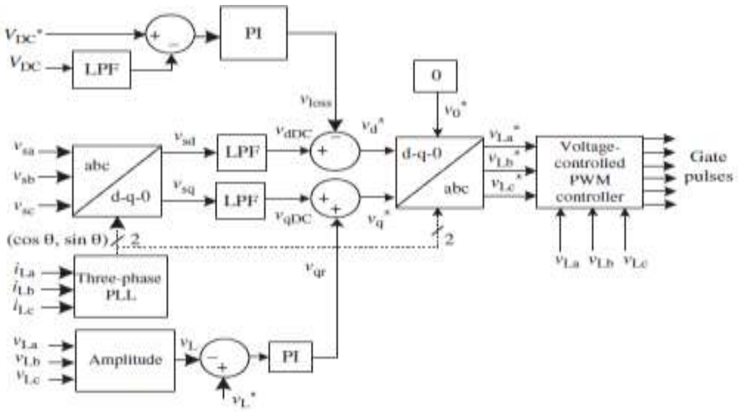

Figure 2. Control Diagram with Direct and Quadrature Axis Reference Theory

From Figure 2, the voltages at the source (Vs) are transformed to direct and quadrature voltages using the Park's transformation. Low pass filters are used in this control technique to eliminate harmonics and oscillatory components [3]. The voltages in the direct and quadrature axis are given by Eqn. (1) and (2).

$$v_{sd} = v_{dDC} + V_{dAC} \tag{1}$$

$$v_{sq} = v_{qDC} + V_{qAC} \tag{2}$$

The major use of series active filter is to improve the voltage quality at the load bus. PI controller is used to maintain the DC link capacitor voltage as constant and the output of the PI controller is $v$loss for meeting the losses [4]. Hence, the reference direct-axis load voltage (v_d^*) is given in Eqn. (3)

$$v_d^* = v_{dDC} - v_{loss} \tag{3}$$

The load voltage (v_L) is maintained to reference level (v_L^*) using PI controller. The PI controller output is v_{qr} i.e. reactive voltage for voltage control across the load. The quadrature-axis reference load voltage is given in Eqn. (4)

$$v_q^* = v_{qDC} + v_{qr} \tag{4}$$

The reference load voltages ($v_{La}^*, v_{Lb}^*, v_{Lc}^*$) can get from the inverse Park's transformation. The error between (v_{La}, v_{Lb}, v_{Lc}) and ($v_{La}^*, v_{Lb}^*, v_{Lc}^*$) is fed on a hysteresis controller to initiate gating pulses to the series active filter.

3. Unit Vector Control Theory

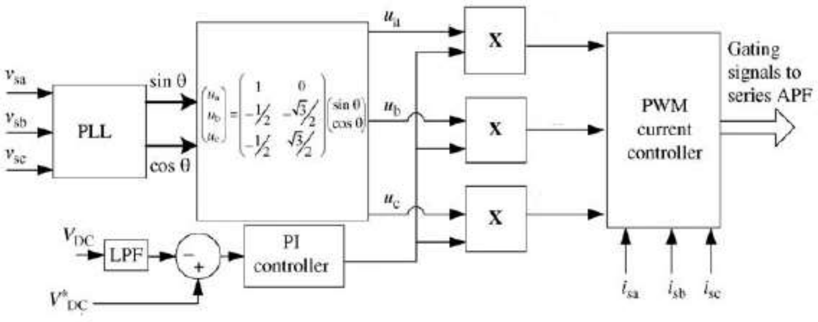

Figure 3. Unit Vector Theory Control of Series Active Filter

The unit vector control theory as shown in Figure 3 is used to control the active filter in series for mitigating the harmonics in supply voltages. The series filter injects compensating voltages (v_{Ca}, v_{Cb}, v_{Cc}) that eliminates the harmonics in the supply voltages (v_{Sa}, v_{Sb}, v_{Sc}).Phase Locked Loop (PLL) is implemented to get the synchronization with the supply voltages [4]. The supply voltages which are distorted are sensed and pass through a PLL that will give two unit vectors in quadrature with each other. The two unit vectors are used to calculate the voltages in-phase, phase angle of 120° unit vectors such as (u_a, u_b, u_c) as given in Eqn. (5)

$$\begin{pmatrix}u_a\\u_b\\u_c\end{pmatrix}=\begin{pmatrix}1 & 0\\ \frac{-1}{2} & \frac{-\sqrt{3}}{2}\\ \frac{-1}{2} & \frac{\sqrt{3}}{2}\end{pmatrix} \tag{5}$$

The reference voltages are generated by controlling the DC bus voltage. The difference between DC bus voltage V_{DC} and reference value of the DC link voltage V^*_{DC} gives voltage error. This error is fed to a PI controller to get the maximum value of reference supply voltages ($v^*_{Sa}, v^*_{Sb}, v^*_{Sc}$). This maximum value is multiplied by the unit vectors to generate the reference supply/load currents as in Eqn. (6)

$$\begin{pmatrix} v_{sa}^* \\ v_{sb}^* \\ v_{sc}^* \end{pmatrix} = V_{sm}^* \begin{pmatrix} u_a \\ u_b \\ u_c \end{pmatrix} \tag{6}$$

Hysteresis controller is used to generate switching signals for the series active filter. The hysteresis controller is connected to supply voltages (v_{Sa}, v_{Sb}, v_{Sc}) and reference supply voltages ($v^*_{Sa}, v^*_{Sb}, v^*_{Sc}$) as inputs [5].

4. Results and Discussions

The current and voltage at the source along with THD of a proposed system without series active filter are given by Figure 4 & 5. Since, the two nonlinear loads such as bridge rectifier and PC load are connected to the source, will inject good amount of harmonics into the system.

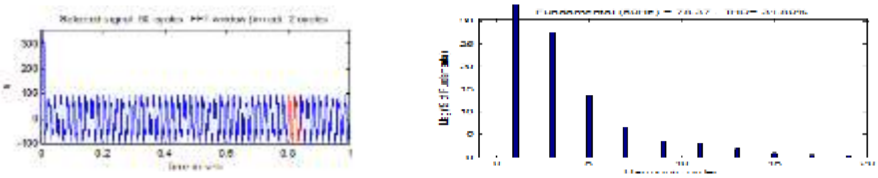

Figure 4. Waveform and THD of Source Current

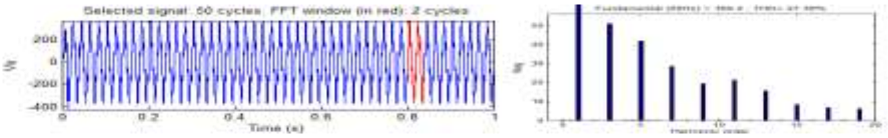

Figure 5. Waveform and THD of Source Voltage

4.1. Series Active filter with Synchronous Reference Frame Theory

The source current and voltage waveforms, when a full bridge rectifier load resistance and capacitance having the values of 2 Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10 Ω and inductance 100 mH are shown in Figures 6 &7.

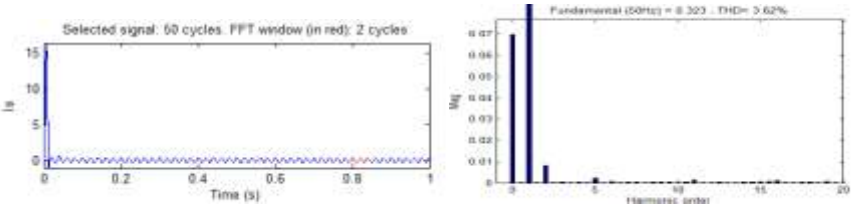

Figure 6. Waveform and THD of Current at the Source

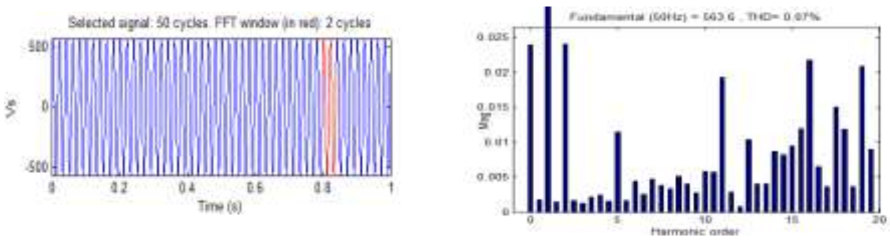

Figure 7. Waveform and THD of Source Voltage

The current and voltage at the source, when a full bridge rectifier load resistance and capacitance having the values of 6 Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10 Ω and inductance 100 mH are shown in Figure 8 &9.

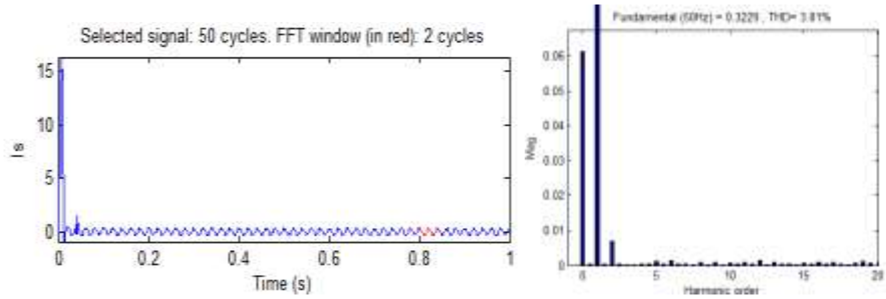

Figure 8. Waveform and THD of Source Voltage

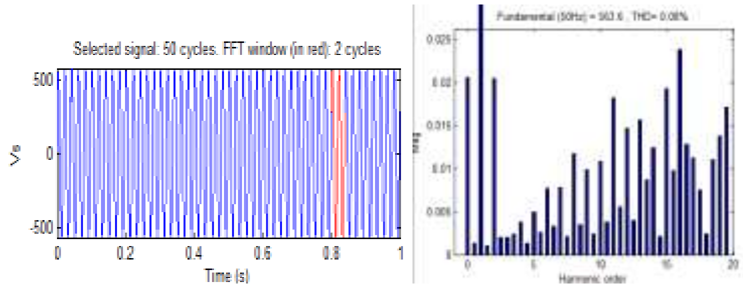

Figure 9. Waveform and THD of Voltage at the Source

The current and voltage at the source, when a full bridge rectifier load resistance and capacitance having the values of 9 Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10 Ω and inductance 100 mH are shown in Figure 10 &11.

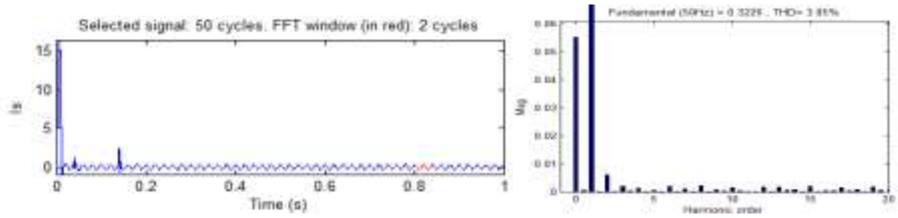

Figure 10. Waveform and THD of Current at the Source

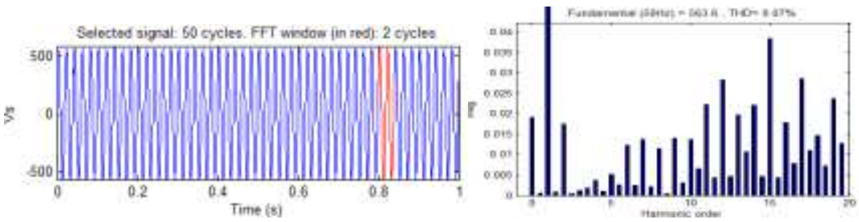

Figure 11. Waveform and THD of Voltage at The Source

4.1.1. Unbalance Condition

Here the phases R and Y are reversed and connected to non-linear loads that become unbalanced condition. The source current and voltage waveforms, when a full bridge rectifier load resistance and capacitance having the values of 9 Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10Ω and inductance 100 mH under unbalanced condition are shown in Figure 12 &13.

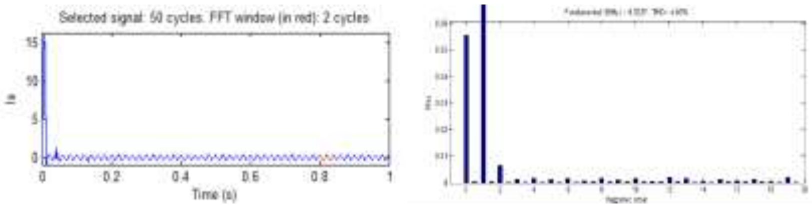

Figure 12. Waveform and THD of Current at the Source

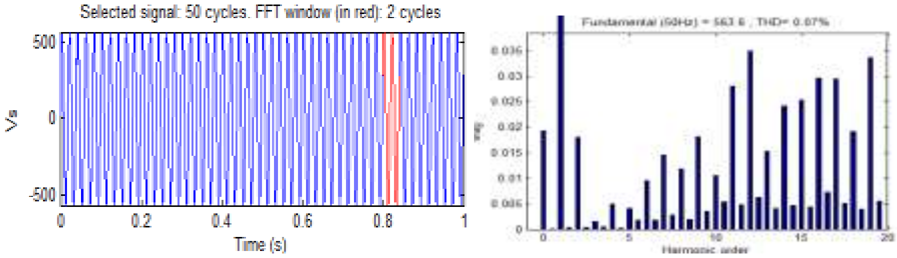

Figure 13. Waveform and THD of Source Voltage

The current and voltage at the source, when a full bridge rectifier load resistance and capacitance having the values of 6 Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10Ω and inductance 100 mH under unbalanced condition are shown in Figure 14 &15.

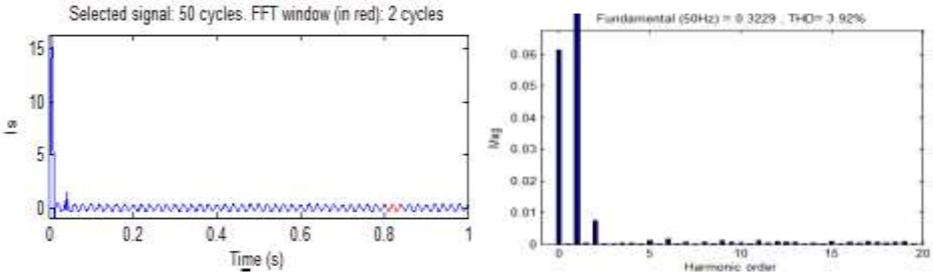

Figure 14. Waveform and THD of Current at Source

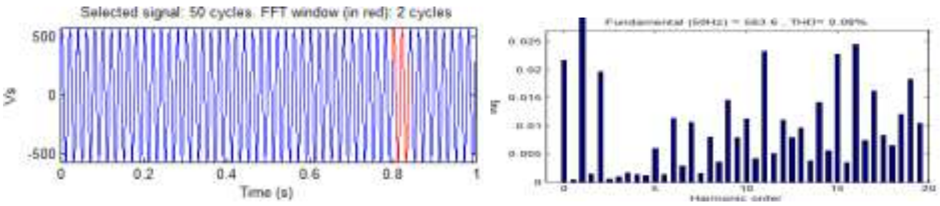

Figure15. Waveform and THD of Source Current

The current and voltage at the source, when a full bridge rectifier load resistance and capacitance having the values of 2Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10Ω and inductance 100 mH under unbalanced condition are shown in Figure 16 &17.

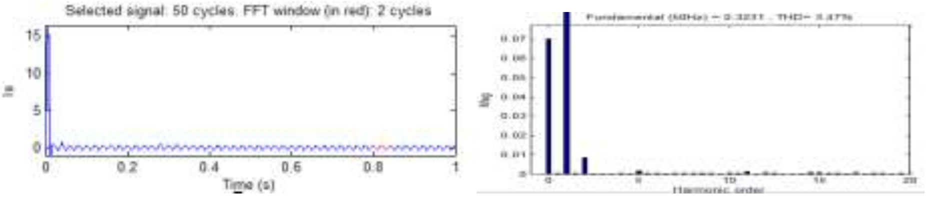

Figure 16. Waveform and THD of Current at the Source

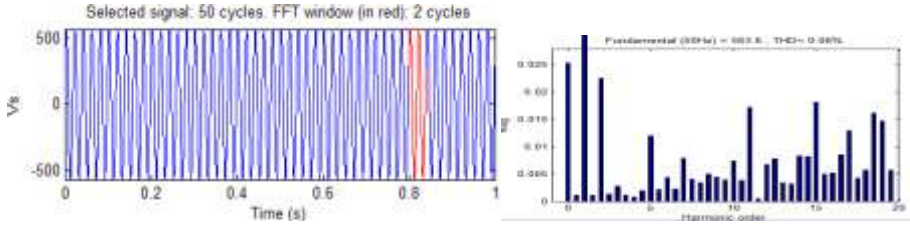

Figure 17. Waveform and THD of Voltage at the Source

From this analysis, it was evident that, the proposed series hybrid active filter is robust for changes in load parameters under balanced as well as unbalanced condition. Further it has been observed that, the proposed system also robust for changes in source parameters and under fault condition. The voltage across the capacitor bank was maintained constant throughout the changes in source and load parameters of the system under balanced as well as unbalanced condition and also during fault condition as shown in Figure 18.

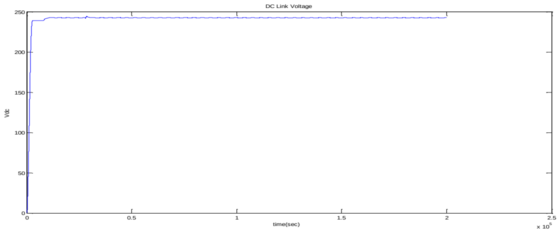

Figure 18. Voltage across the Capacitor Bank of a Series Filter

4.2. Series Active Filter with unit Vector Control Theory

The source current and voltage waveforms, when a full bridge rectifier load resistance and capacitance having the values of 2Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10Ω and inductance 100mH are shown in Figure 19 &20.

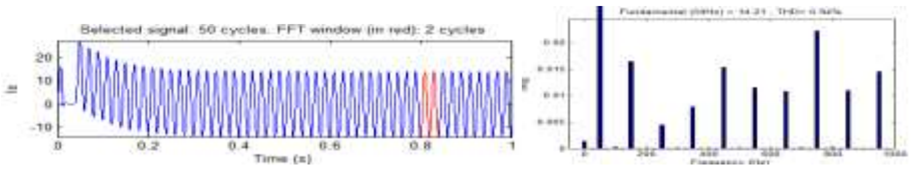

Figure 19. Waveform and THD of Current at the Source

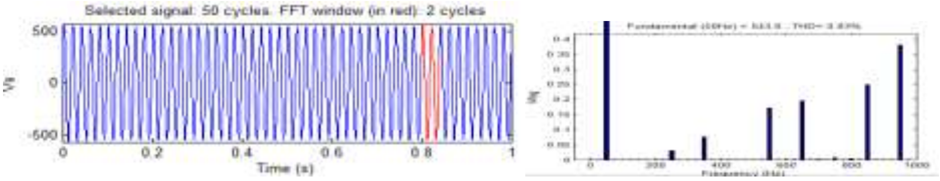

Figure 20. Waveform and THD of Series Active Filter

The current and voltage at the source, when a full bridge rectifier load resistance and capacitance having the values of 6 Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10 Ω and inductance 100mH are shown in Figure 21 &22.

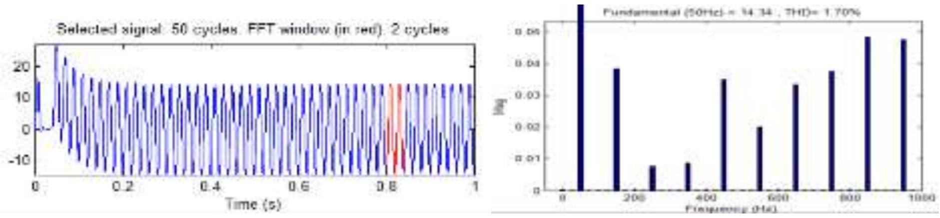

Figure 21. Waveform and THD of Current at the Source

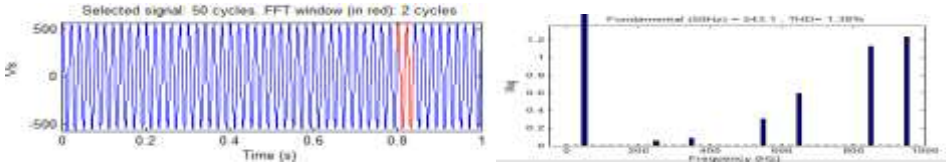

Figure 22. Waveform and THD of Voltage at the Source

The current and voltage at the source, when a full bridge rectifier load resistance and capacitance having the values of 9 Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10 Ω and inductance 100mH are shown in Figure 23 &24.

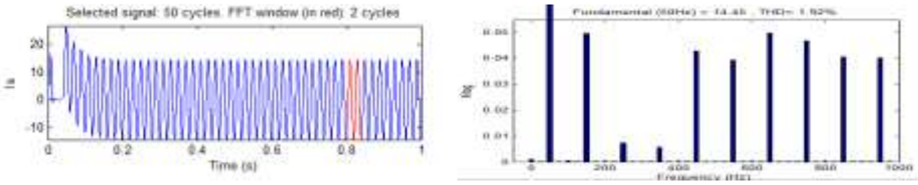

Figure 23. Waveform and THD of Current at the Source

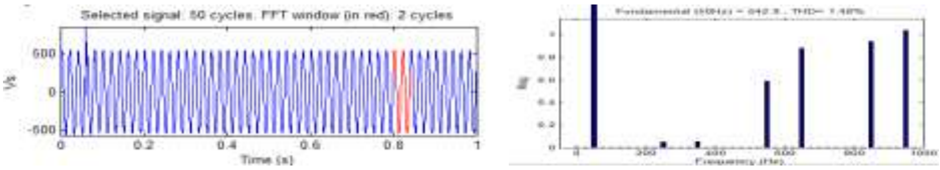

Figure 24. Waveform and THD of Current at the Source

4.2.1. Unbalance Condition

Here the phases R and Y are reversed and connected to non-linear loads that become unbalanced condition. The current and voltage at the source, when a full bridge rectifier load resistance and capacitance having the values of 9 Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10 Ω and inductance 100 mH under unbalanced condition are shown in Figure 25 &26.

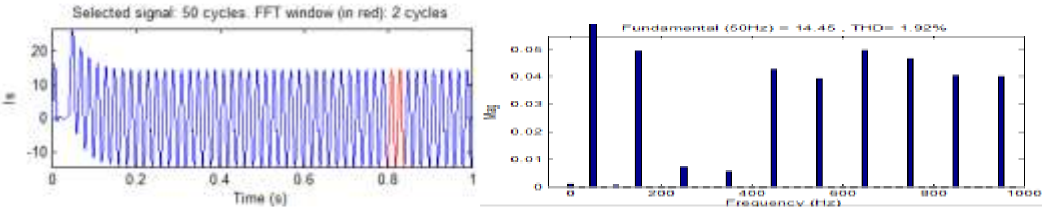

Figure 25. Waveform and THD of Current at the Source

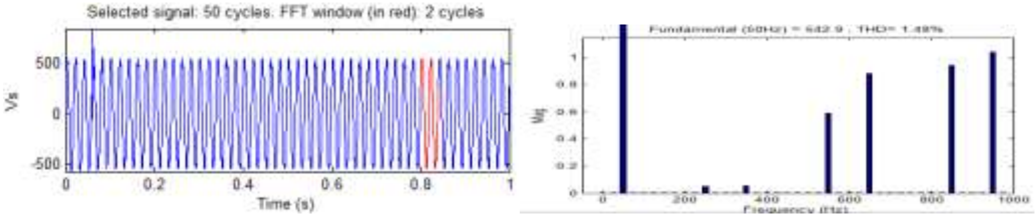

Figure 26. Waveform and THD of Voltage at the Source

The current and voltage at the source, when a full bridge rectifier load resistance and capacitance having the values of 6 Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10 Ω and inductance 100 mH under unbalanced condition are shown in Figure 27 &28.

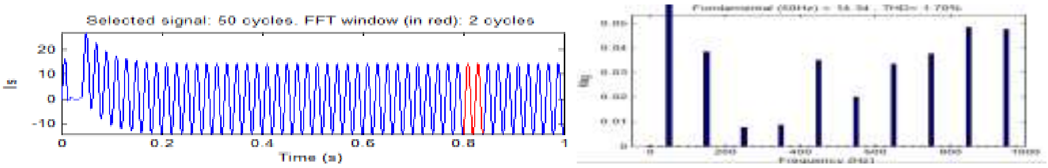

Figure 27. Waveform and THD of Current at the Source

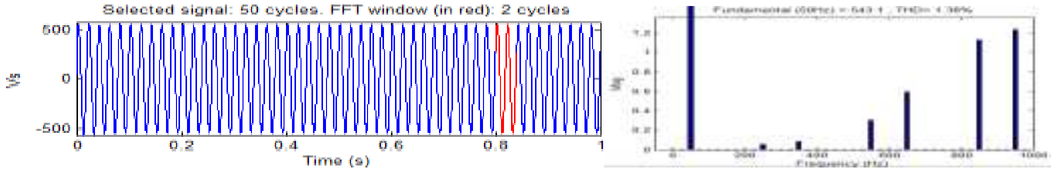

Figure 28. Waveform and THD of Voltage at the Source

When a full bridge rectifier load resistance and capacitance having the values of 6 Ω and 4000 μF with fixed three single phase PC loads each having a resistance 10 Ω and inductance 100 mH under unbalanced condition are shown in Figure 29 &30.

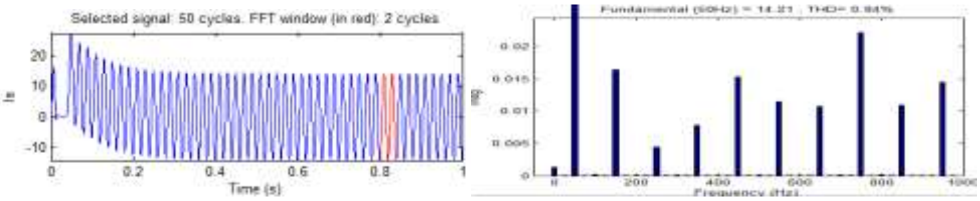

Figure 29. Waveform and THD of Current at the Source

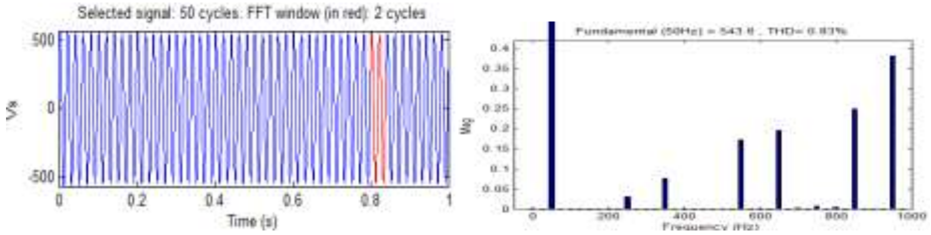

Figure 30. Waveform and THD of Voltage at the Source

From this analysis, it was evident that, the proposed series hybrid active filter is robust for changes in load parameters under balanced as well as unbalanced condition. Further it has been observed that, the proposed system also robust for changes in source parameters and under fault condition. The DC link voltage of the filter was maintained constant throughout the changes in source and load parameters of the system under balanced as well as unbalanced condition and also during fault condition as shown in Figure 31.

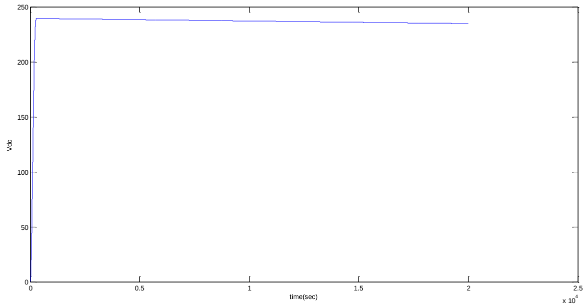

Figure 31. Voltage Across the Capacitor Bank of a Series Filter

5. Conclusions and Future Scope

From the above analysis, it has been proved that the proposed series active filter is so robust and effective for the changes in load and source parameters, fault conditions and unbalanced conditions, further the proposed series active filter works well either with synchronous reference frame theory and unit vector control theory. A fuzzy logic control either of type 1 or type 2 or the combination of both fuzzy and neural network based control will give better performance than a conventional PI control in maintaining DC link voltage constant, it is very much essential in eliminating harmonics effectively. Further, the model can be improved by Implementing of sliding mode controller along with the proposed techniques will give better performance in eliminating harmonics and to improve the quality in supply. A transformer less series active filter can be designed with the proposed control techniques. This gives a low cost solution and improved performance as compared with the original series active filter. The size of the proposed topology can be further reduced by adding tuned passive filter in shunt with it or supply. This gives cost effective solution with improved performance.

Table 1. Parameters of the Proposed Topology

Parameters	Value
Three Phase Power Supply (V_{sPh-Ph}, f, R_s,L_s)	415V(rms),50Hz,0.25Ω,0.0025H
Bridge Rectifier Load Resistance(R_L)& Capacitance(L_L)	10Ω,4700 μF
PC Load Resistance(R_L)& Inductance(L_L)	10 Ω, 100 Mh
Coupling Transformer (KVA, primary voltage, secondary voltage	7.892 kVA,75.641 Volts, 197.99 Volts
Ripple Filter resistance and capacitance	5 Ω, 5 μF
Interfacing inductance and DC link capacitance	6.3 mH, 1500 μF
PI controller parameters for DC Link Voltage (K_p, K_i)	370, 50

Acknowledgments

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Surya Kalavathi M, working as a Professor at JNTU College of Engineering, JNTU, Hyderabad. She has published more than 100 Research Papers in international and national journals. She has guided 9 Ph.D scholars and presently guiding 5 Ph.D. Scholars. She has specialized in Power Systems, High Voltage Engineering and Control Systems. Her research interests include Simulation studies on Transients of different power system equipment. She has 24 years of experience. She has invited for various lectures in institutes.