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PERFORMANCE ANALYSIS OF HARMONIC REDUCTION BY SHUNT ACTIVE POWER FILTER USING DIFFERENT CONTROL TECHNIQUES

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ABSTRACT

In modern day power systems the introduction of harmonics due to the presence of non-linear load such as inverters, rectifiers, saturation transformer, electromagnetic interference etc., affects the power quality in distribution systems. This paper is aimed at improving the power quality using shunt active power filter (SAPF). Active filters implemented with the different control techniques under different load conditions are simulated by MATLAB-SIMULINK and their performances are compared.

Keywords: *Harmonics, Power Quality, Active Filter, Non-Linear, Matlab-Simulink.*

1. INTRODUCTION

Harmonics in power system causes increased line current, neutral current, transformer rating, telephone interference etc. The main cause for the occurrence of harmonics in power system is the usage of non-linear loads [1]-[2]. These non-linear loads inject harmonics in the power system whose frequency is the integral multiple of fundamental frequency. The harmonics due to non linear load causes increased power loss in power system components such as transformer, transmission line etc., which results in increased heat liberation in the power system components and reduction of self life time of the components. Two types of filters are used for the reduction of harmonics i.e. Active power filter (APF) and passive power filter (PPF) [3]-[4]. PPF uses passive elements such as capacitor, inductor etc...This results in increased power loss, problem of resonance and requirement of separate filter for each harmonic frequency. APF uses active sources such as voltage or current source and power electronic switches to reduce harmonics. APF can be implemented using different techniques. In this paper SAPF is implemented using Instantaneous Reactive Power (IRP) theory and Synchronous Reference Frame (SRF) theory[5]-[8]. The main reason for using APF over passive filter is due to its wide range of functions such as harmonic elimination, power factor correction, voltage regulation etc. [9]-[10].

2. MODELING OF SAPF

The SAPF used in this paper is a voltage source inverter (VSI) which is connected to the load through an interface reactor. Here the harmonic elimination is achieved by injecting harmonic current into the line, which is equal in magnitude and out of phase to load current harmonics.

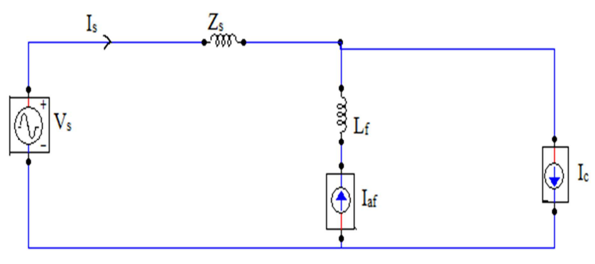

Figure 1: Generalized Block Diagram of SAPF

2.1 IRP Theory

In the IRP theory the reference currents are generated by transforming the source voltage e_a, e_b, e_c and load current $i_{aL} i_{bL}, i_{cL}$ from a,b,c to α,β,0 co-ordinates from which the reactive power, harmonic frequency and active power are

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calculated [2]. The calculated reference current has to be generated by the SAPF and injected to the main line [10].

$$\begin{bmatrix} e_\alpha \\ e_\beta \\ e_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} i_{aL} \\ i_{bL} \\ i_{cL} \end{bmatrix} \quad (2)$$

The instantaneous powers at the output side are obtained as follows

$$\begin{bmatrix} p_0 \\ p_{\alpha\beta} \\ q_{\alpha\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} e_0 & 0 & 0 \\ 0 & e_\alpha & e_\beta \\ 0 & -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (3)$$

$$p_0^* = -p_0 \quad (4)$$

$$p_{\alpha\beta}^* = p_0 \quad (5)$$

$$q_{\alpha\beta}^* = -q_0 \quad (6)$$

The instantaneous current in α, β, 0 co-ordinates are given by

$$i_{c\_0} = \frac{p_0^*}{e_0} = -i_0 \quad (7)$$

$$i_{c\_\alpha} = \left(\frac{e_\alpha}{e_{\alpha\beta}^2}\right).p_{\alpha\beta}^* + \left(\frac{-e_\beta}{e_{\alpha\beta}^2}\right).q_{\alpha\beta}^* \quad (8)$$

$$i_{c\_\beta} = \left(\frac{e_\beta}{e_{\alpha\beta}^2}\right).p_{\alpha\beta}^* + \left(\frac{e_\alpha}{e_{\alpha\beta}^2}\right).q_{\alpha\beta}^* \quad (9)$$

Where $e_{\alpha\beta} = \sqrt{e_\alpha^2 + e_\beta^2}$

$$i_{ca} = 0.577.i_{c\_0} + 0.82.i_{c\_\alpha} \quad (10)$$

$$i_{cb} = 0.577.i_{c\_0} - 0.41i_{c\_\alpha} + 0.707i_{c\_\beta} \quad (11)$$

$$i_{cc} = 0.577.i_{c\_0} - 0.41i_{c\_\alpha} - 0.707i_{c\_\beta} \quad (12)$$

Where i_{ca}, i_{cb}, i_{cc} are the compensating currents for a, b and c phase

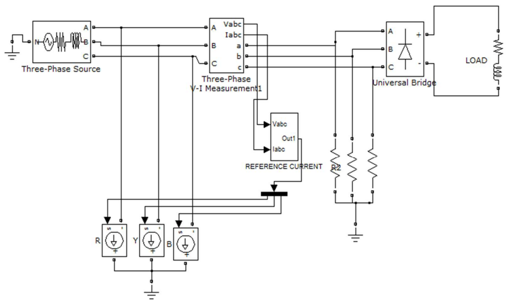

Figure 2: Ideal SAPF

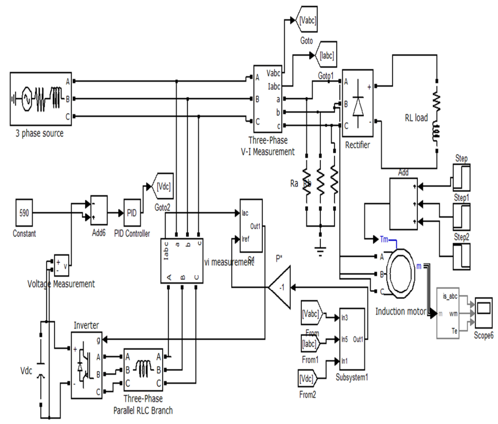

Figure 3: SAPF

2.2 SRF Theory

In the SRF theory the three source currents i_{aL}, i_{bL} and i_{cL} are transformed from three phase (a,b,c) reference frame to two phase's $(\alpha$-$\beta)$ stationary reference frame currents $i_{\alpha L}$ and $i_{\beta L}$ [5].

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{aL} \\ i_{bL} \\ i_{cL} \end{bmatrix} \quad (13)$$

The currents in α-β reference frame are again transformed to d-q reference frame as follows

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \sin(\theta) & -\cos(\theta) \\ \cos(\theta) & \sin(\theta) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (14)$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \bar{i}_d & + & i_d^* \\ \bar{i}_q & + & i_q^* \end{bmatrix} \quad (15)$$

The current i_d and i_q are resolved into a.c and d.c components

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$$\begin{bmatrix} i_{\alpha-ref} \\ i_{\beta-ref} \end{bmatrix} = \begin{bmatrix} \sin(\theta) & -\cos(\theta) \\ \cos(\theta) & \sin(\theta) \end{bmatrix}^{-1} \begin{bmatrix} i_d + i_{dc} \\ i_q \end{bmatrix} \quad (16)$$

The compensating reference current in a, b, c frame is given by

$$\begin{bmatrix} i_{a-ref} \\ i_{b-ref} \\ i_{c-ref} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{\alpha-ref} \\ i_{\beta-ref} \end{bmatrix} \quad (17)$$

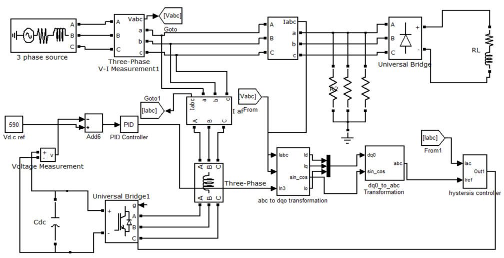

Figure 4: SAPF Based on SRF Theory

3. SIMULATION RESULTS

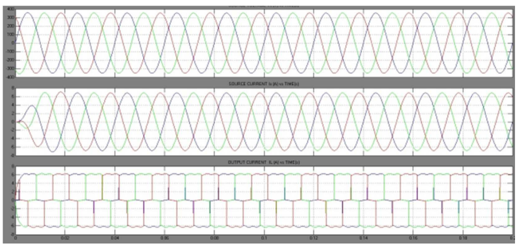

Figure 5: (a) Source Voltage E_S (V) (b) Source Current I_S (A) (c) Output Current I_L (A) for Ideal SAPF with Balanced Load

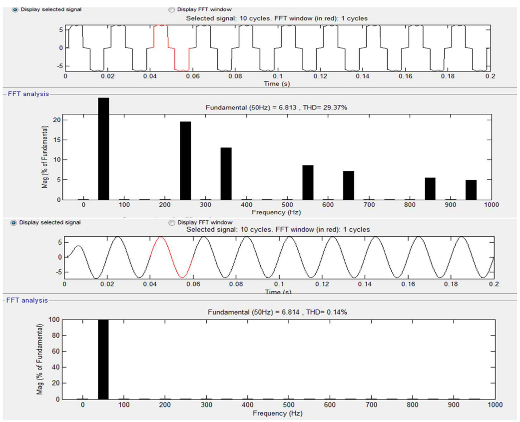

Figure 6: FFT Analysis for Source Current I_S (A) in R Phase of Ideal SAPF with Balanced Load (a) Before Compensation (b) After Compensation

Figure 5 shows the source voltage, source current and load current in case of ideal SAPF and figure 6 shows the FFT analysis of source current for 'R' phase of ideal SAPF before and after harmonic compensation.

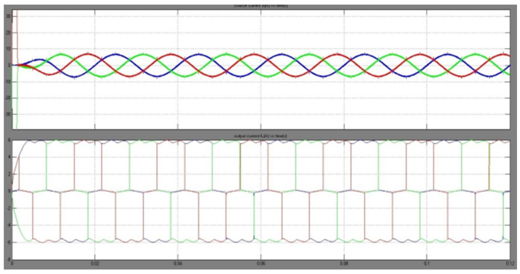

Figure 7: (a) Source Current I_S (A), (b) Output Current I_L (A) for SAPF using IRP Theory with Balanced Load

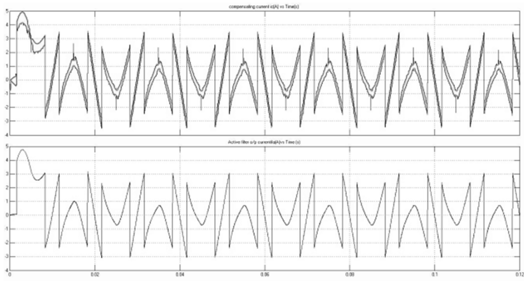

Figure 8: (a) Compensating Current I_C (A) ,(b)Filter Output Current I_F (A) in R Phase of SAPF using IRP Theory with Balanced Load

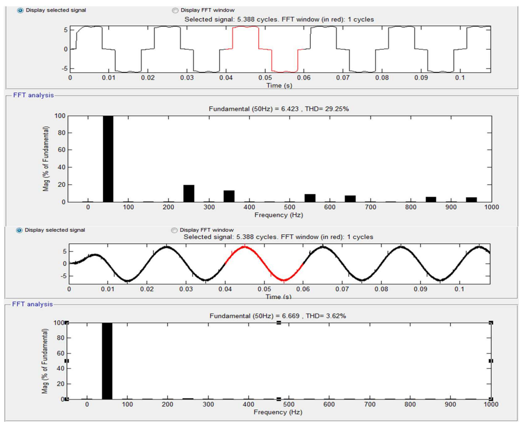

Figure 9: FFT Analysis for Source Current I_S (A) in R Phase of SAPF using IRP Theory with Balanced Load (a) Before Compensation (b) After Compensation

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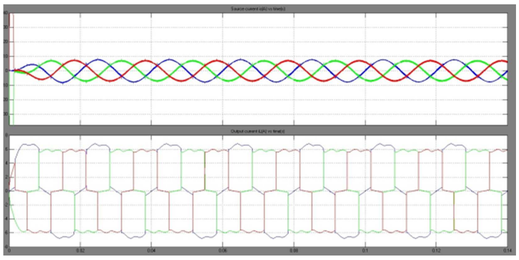

Figure 10: (a) Source Current I_S (A) (b) Output Current I_L (A) for Shunt Active Filter using IRP Theory with Unbalanced Load

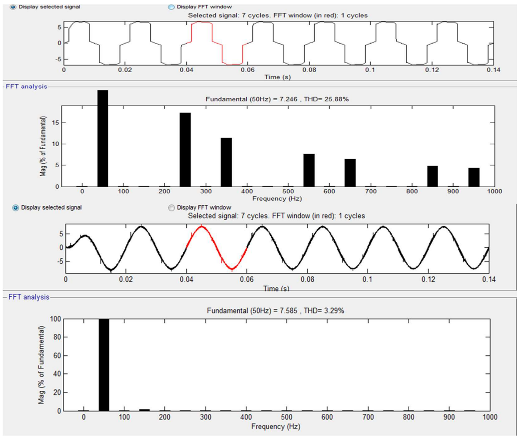

Figure 11: FFT Analysis for Source Current I_S (A) in R Phase of SAPF using IRP Theory with Unbalanced Load (a) Before Compensation (b) After Compensation

Figure 7 and 10 shows the source current and output current for SAPF using IRF theory with balanced and unbalanced load respectively. Similarly Figure 9 and 11 shows the FFT analysis for 'R' phase of source current for SAPF using IRF theory with balanced and unbalanced load. Figure 8 shows the compensating current reference and actual output of the SAPF using IRF theory with balanced load.

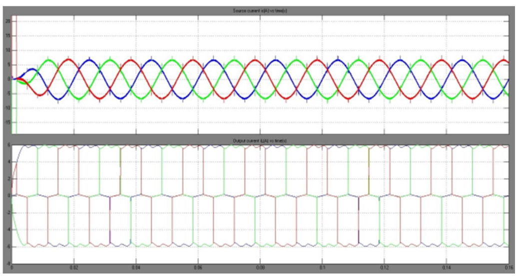

Figure 12: (a) Source Current I_S (A) (b) Load Current I_L (A) for SAPF using SRF Theory with Balanced Load

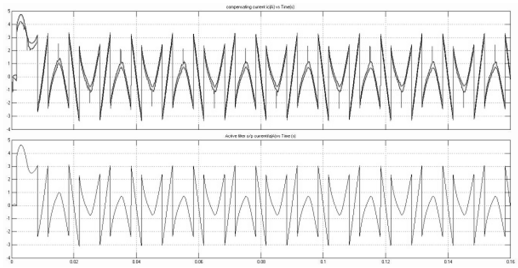

Figure 13: (a) Compensating Current I_C (A), (b) Filter Output Current I_F (A) in R Phase of SAPF using SRF Theory with Balanced Load

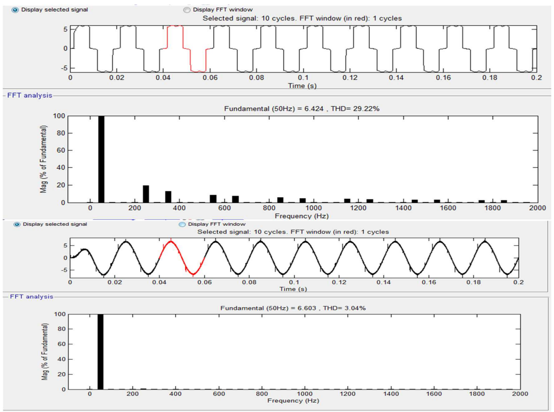

Figure 14: FFT Analysis for Source Current I_S (A) in R phase of SAPF using SRF theory with balanced load (a) Before compensation (b) After compensation

Figure 12 and 16 shows the source current and output current of SAPF using SRF theory with balanced and unbalanced load. Figure 13 shows the compensating current reference and actual output current of SAPF using SRF theory with balanced load. Figure 14 and 16 shows the FFT analysis of source current before and after harmonic compensation by SAPF using SRF theory with balanced load and unbalanced load.

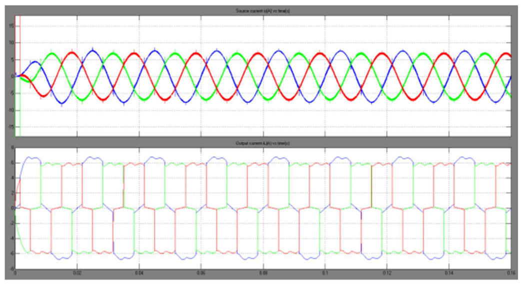

Figure 15: (a) Source Current I_S (A) (b) Load Current I_L (A) for SAPF using SRF Theory with Balanced Load

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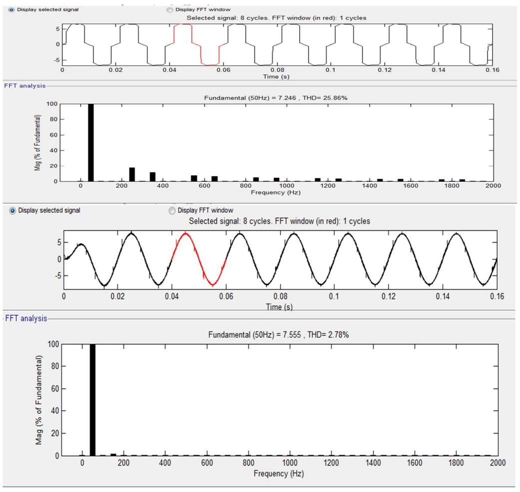

Figure 16: FFT Analysis for Source Current I_L (A) in R Phase of SAPF using SRF Theory with Unbalanced Load (a) Before Compensation (b) After Compensation

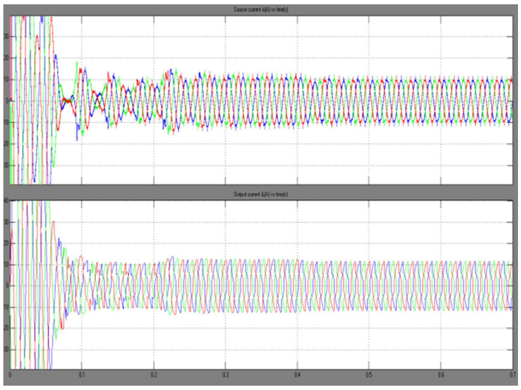

Figure 17: (a) Source Current I_S (A), (b) Load Current I_L (A) For SAPF using SRF Theory with Dynamic Load (Induction Motor)

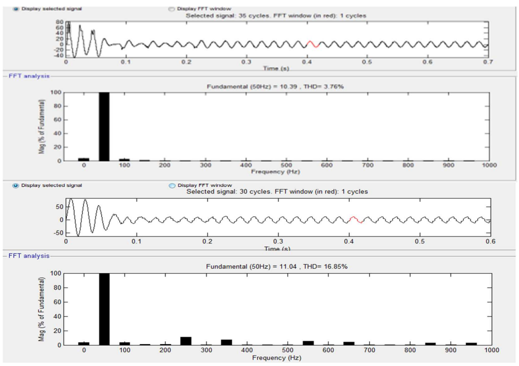

Figure 18: FFT Analysis for Source Current I_S (A) in R Phase of SAPF Using SRF Theory with Dynamic Load (Induction Motor) (a) Before Compensation (b) After Compensation

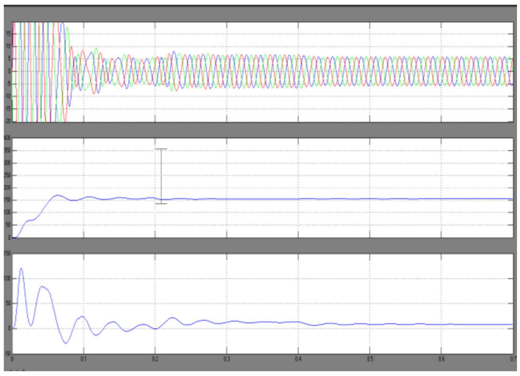

Figure19: (a) Stator Current (A) (b) Speed (rad-s) (c) Torque (N-m) For 3-Phase 5 H.P Induction Motor with SRF Theory Based SAPF

Figure 17 shows the source current and Load current for SAPF using SRF filter with 5H.P induction motor under dynamic load condition i.e. the load torque is 2 N- m at 0.03s and 12N-m at 0.2s and 8 N-m at 0.4s. Figure 18 and 21 shows the FFT analysis of source current before and after harmonic compensation by SAPF using SRF and IRP theory with dynamic load. Figure 19 and 20 shows the stator current, speed and torque of three phase induction motor under dynamic load condition with SRF and IRP based SAPF.

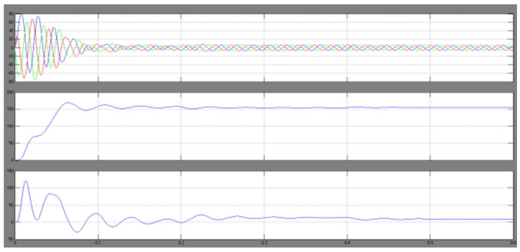

Figure20: (a) Stator Current (A) (b) Speed (rad/s) (c) Torque (N-m) For 3-Phase 5 H.P Induction Motor IRP Theory Based SAPF

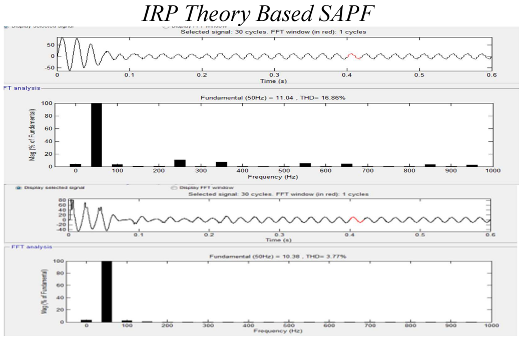

Figure 21: FFT Analysis for Source Current I_S (A) in R Phase of SAPF using IRP Theory with Dynamic Load (Induction Motor) (a) Before Compensation (b) After Compensation

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Table 1: Comparison Of Results

S.NO	CONTROL TECHNIQUE	TYPE OF LOAD	I_S THD_i (R PHASE) BEFORE COMPENSATION (%)	I_S THD_i (R PHASE) AFTER COMPENSATION (%)
1	IRP Theory(Ideal)	Balanced load and nonlinear load	29.37	0.14
2	IRP Theory	Balanced load and nonlinear load	29.25	3.62
4	IRP Theory	Unbalanced load and nonlinear load	25.88	3.29
5	IRP Theory	Non sinusoidal voltage and nonlinear load	16.86	3.77
6	SRF Theory	Balanced load and nonlinear load	29.22	3.04
7	SRF Theory	Unbalanced load and nonlinear load	25.86	2.78
8	SRF Theory	Dynamic load	16.85	3.86

From the comparison table it is found that for ideal SAPF using IRP theory, the source current Total harmonic distortion (THD_i) reduced from 29.37% to 0.14% .Incase of SAPF using IRP theory the THD_i reduced from 29.25% to 3.62% for balanced load and 25.88% to 3.29% for unbalanced load. For SAPF using SRF theory with balanced load the source current THD_i reduced from 29.22% to 3.04%.(All THDi are measured for R phase).For Dynamic load condition the source current THD_i reduced from 16.86% to 3.77% in SAPF using IRP theory and the source current THD_i reduced from 16.85% to 3.86% in SAPF using SRF theory.

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5. CONCLUSION

Modeling of SAPF using IRP theory and SRF theory is done using MATLAB-SIMULINK and THD_i of source current is analysed for before and after compensation for various load condition and obtained conclusions are summarized as follows (1) source current THD_i is reduced to a considerable amount of around 3% which is within the limits of IEEE 519 standards.(2)Both IRP and SRF theories are found to be efficient in eliminating harmonics in case of dynamic load.

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