

# MITIGATION OF HARMONICS USING SHUNT ACTIVE POWER FILTER IN THE DISTRIBUTION SYSTEM

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**ABSTRACT**-One of the most important concerns in the power system network is harmonics, which is mainly developed with the huge usage of non-linear loads and power electronic equipment. These harmonics lead to damage in the supply system. Therefore, to protect the supply system, shunt active power filters (SAPF) are being used because of their ability to fulfill the harmonic demand of the non-linear loads.

But, the performance of SAPF depends on the control strategies which plays a vital role in mitigation of power quality issues. There are different traditional control strategies/techniques like Instantaneous Reactive Power Theory(P-Q theory) for mitigation of harmonics but they are unable to reduce harmonics to an ideal level under non-sinusoidal supply voltage conditions. This paper presents a comparative study of the traditional technique with an improved/modified technique i.e. Modified Synchronous Reference Frame Theory/(Id-Iq theory) which mitigates the harmonics in the system under different source voltage conditions. The system has been modeled and simulated using MATLAB/SIMULINK and the results are validated with IEEE Std. 519-1992.

**KEYWORDS**-Harmonics, Shunt Active Power Filter, Instantaneous Reactive Power Theory, Modified Synchronous Reference Frame Theory.

## 1. INTRODUCTION

Earlier equipment was designed to withstand disturbances such as lightning, short circuits, and sudden overloads without extra expenditure [1]. Current power electronics (PE) prices would be much higher if the equipment was designed with the same robustness. Pollution has been introduced into power systems by nonlinear loads such as transformers and saturated coils; however, perturbation rate has never reached the present levels. Due to its nonlinear characteristics and fast switching, Power electronic (PE) devices create most of the pollution issues. Most of the pollution issues are created due to the nonlinear characteristics of power electronic devices and their switching action. Approximately 50% to 60% of today's energy is processed by PE; the percentage is estimated to reach 80% to 90% by the year 2020, due mainly to the fast growth of PE capability. Increase in such non-linearity causes different undesirable features like low system efficiency and poor power factor [2].

Classically, passive filters, consisting of tuned LC high passive filters are used to suppress the harmonics up to certain extent and power capacitors are employed to improve the power factor[4]. But they have the limitations of fixed compensation, large size and can also excite resonance conditions.

Active power filters are considered as a viable alternative over the classical passive filters, to compensate source current harmonics produced by the non-linear loads[4]. The objective of the active filtering is to meet the reactive power demand and maintain the harmonics according to IEEE Std. 519-1992[3].

Shunt Active Power Filter(SAPF) can be used with different current control strategy such as Synchronous reference frame method, Instantaneous reactive power theory, Unit vector template method, Fuzzy logic controller, Neural networks. Each control strategy has its own advantages and disadvantages in reducing the harmonics from the system [5]. The paper mainly focus on the comparison of two different control strategies Instantaneous Reactive Power(IRP) theory and Modified Synchronous Reference Frame(MSRF) theory which reduces the harmonics under different source voltage conditions.

For generation of gate pulse signals Hysteresis Current Controller (HCC) is used which are given to drive the switches of the Shunt Active Power Filter and inject the required compensation signal. Proportional-Integral controller is used to compensate the losses of the SAPF.

## 2. SHUNT ACTIVE POWER FILTER

Based on the topology, the Shunt active power filters are classified into three types Series Active Filter, Shunt Active Filter, Hybrid Active Filter; Here Shunt Active Power Filters are used for mitigation of current harmonics produced by the load and make the source current in phase with the source voltage.

Fig.1. shows the basic block diagram of Shunt Active Power Filter. The shunt-connected active power filter, with a self-controlled dc bus and an inductive filter has a topology similar to that of a static synchronous compensator (STATCOM) used for reactive power compensation and mitigation of harmonics in power transmission systems. It is called as DSTATCOM in distribution systems. Shunt active power filters compensates load current harmonics by injecting an equal-but opposite harmonic compensating current. In this case the shunt active power filter operates as a current injecting device which injects the harmonic components generated by the load but phase-shifted by  $180^\circ$ .

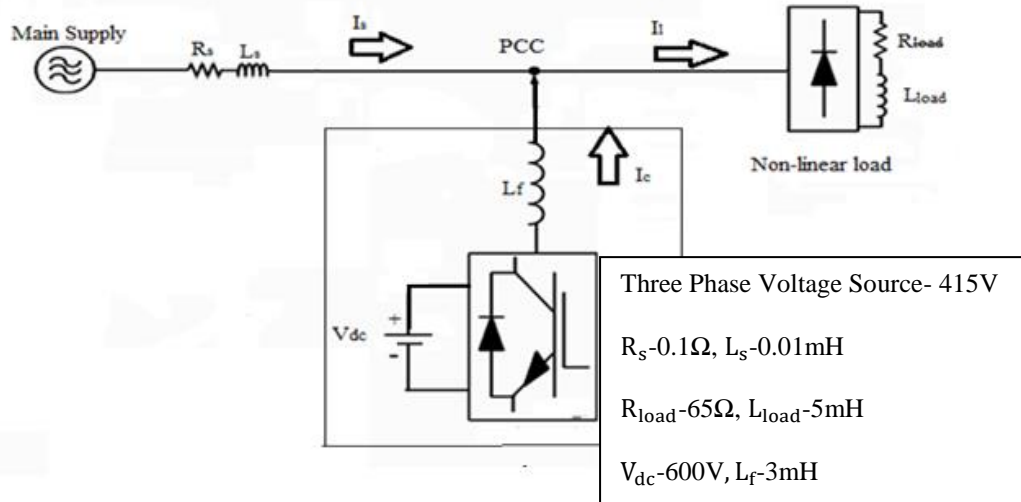


Fig 1: Block Diagram of Shunt Active Power Filter

### 3. ACTIVE POWER FILTER CONTROL STRATEGIES

#### 3.1 INSTANTANEOUS REACTIVE POWER THEORY (IRP)

Fig.2. represents the flowchart of Instantaneous Reactive Power theory. Traditional power theories for single phase, sinusoidal systems are well established. But these concepts do not explain under non-linear load conditions. IRP theory is also known as instantaneous reactive power theory/p-q theory which is based on abc-αβ0 transformation. Compensates harmonic power in balanced and sinusoidal supply voltage systems, but not so good with unbalanced and non-sinusoidal supply voltage conditions.

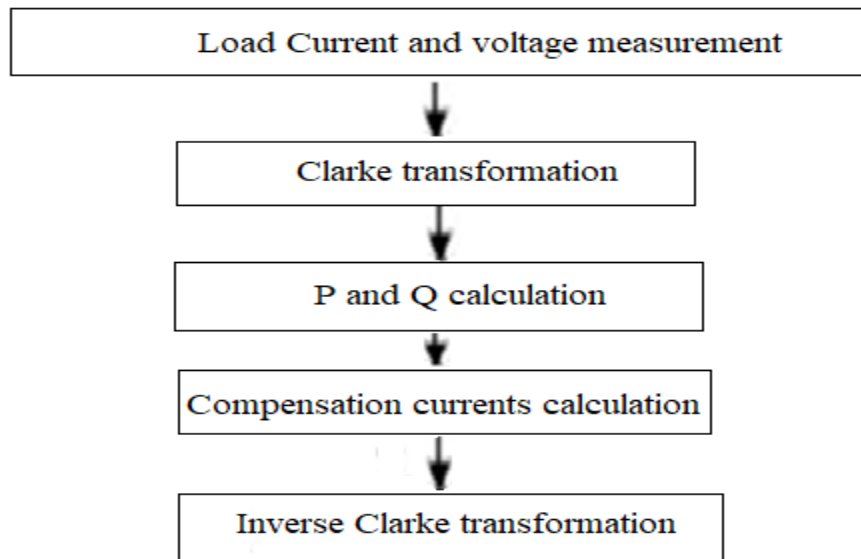


Fig 2: Flow Chart Representation of PQ theory

The load currents ( $I_{la}, I_{lb}, I_{lc}$ ) and source voltages ( $V_a, V_b, V_c$ ) are taken and converted into  $\alpha - \beta$  orthogonal quantities using Clark's transformation. The Clarke transformation is expressed by the following equations (1) & (2).

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} I_{la} \\ I_{lb} \\ I_{lc} \end{bmatrix} \tag{2}$$

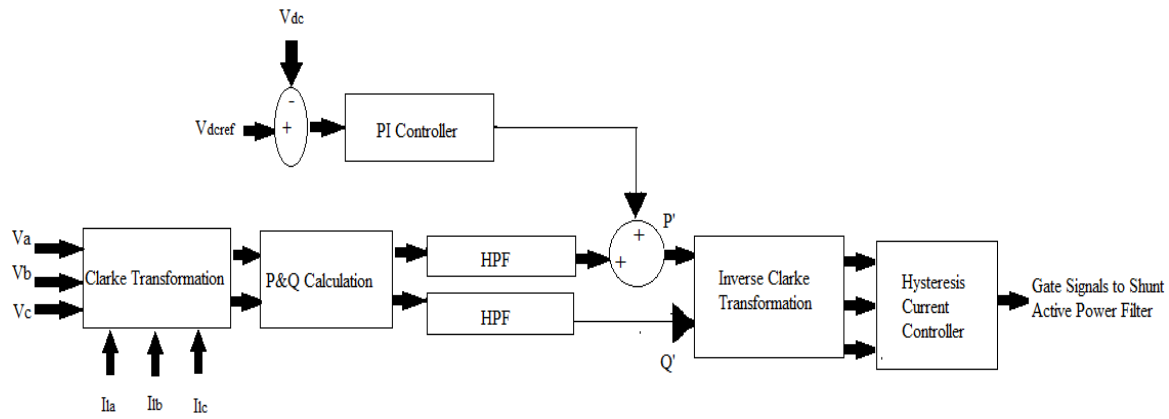


Fig 3: Schematic Representation of IRP Theory

The compensating powers P&Q are calculated using the below formulae. These P and Q values consist of both fundamental and harmonic components. The fundamental components are filtered out using High Pass Filters and losses of the shunt active power filter are added for making the system more effective.

$$P = (V_{\alpha} * I_{\beta} + V_{\beta} * I_{\alpha}) \quad Q = (-V_{\beta} * I_{\alpha} + V_{\alpha} * I_{\beta})$$

The required compensation currents are calculated using the following equation(3).

$$\begin{bmatrix} I_{\alpha}^* \\ I_{\beta}^* \end{bmatrix} = \frac{1}{V_{\alpha}^2 + V_{\beta}^2} \begin{bmatrix} V_{\alpha} & V_{\beta} \\ -V_{\beta} & V_{\alpha} \end{bmatrix} * \begin{bmatrix} P' + P_{loss} \\ Q' \end{bmatrix} \tag{3}$$

These currents are transformed back into a-b-c axes using Inverse Clarke transformation(4).

$$\begin{bmatrix} I_a^* \\ I_b^* \\ I_c^* \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} I_{\alpha}^* \\ I_{\beta}^* \end{bmatrix} \tag{4}$$

**3.2 MODIFIED SYNCHRONOUS REFERENCE FRAME THEORY (MSRF)**

Fig 4. represents the schematic diagram of Modified Synchronous Reference frame theory, it is also known as  $I_d - I_q$  theory which is based on Clark’s and Park’s transformation. It is widely applied in three phase power systems and it is considered as one of the simple and most preferred techniques. It achieves fast and accurate extraction of harmonic content under different source voltage conditions. Compensates harmonic power both in balanced and unbalanced sinusoidal voltage systems and also with non-sinusoidal voltage conditions. Traditionally Phase Locked Loops(PLL) are used for generation of transformation angle  $\theta$ , but to avoid the synchronization problems of PLL’s in MSRF unit vector method is used for generating the transformation angle.

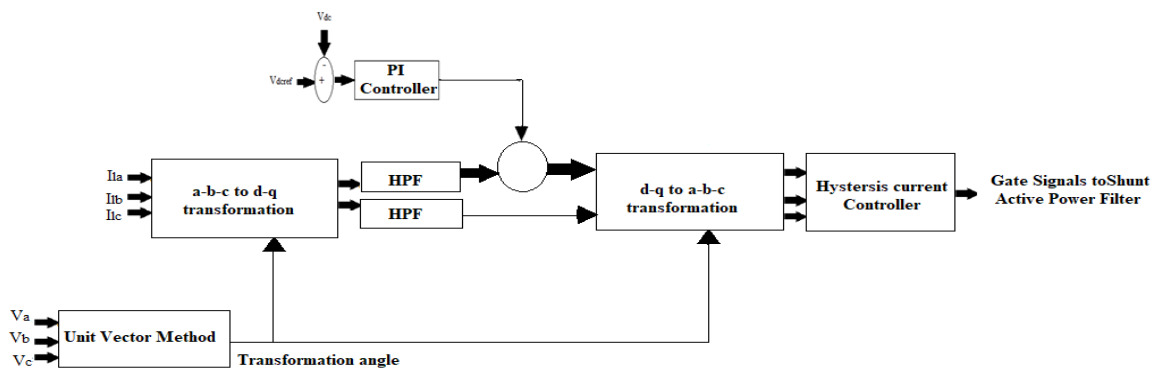


Fig 4: Schematic Representation of MSRF theory

The transformation from a-b-c to d-q-0 is performed using equations (5) & (6).

$$\begin{bmatrix} I_{\alpha} \\ I_{\beta} \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} I_{Ia} \\ I_{Ib} \\ I_{Ic} \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \begin{bmatrix} \cos \theta & \sin \theta \\ -\sin \theta & \cos \theta \end{bmatrix} * \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \tag{6}$$

The transformation angle  $\theta$  is calculated using source voltages of the ac network as expressed in equation(7). To make the system insensitive to voltage harmonics low pass filters are used throughout the process.

$$\theta = \sin^{-1} \frac{V_\beta}{\sqrt{V_\alpha^2 + V_\beta^2}} \tag{7}$$

Output of the Park's transformation gives both oscillating component and average component. To eliminate average component high pass filters are used. And added with the losses of the shunt active power filter. The required compensation currents are calculated using equations (8) & (9).

$$\begin{bmatrix} I_\alpha^* \\ I_\beta^* \end{bmatrix} = \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} * \begin{bmatrix} I_d \\ I_q \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} I_a^* \\ I_b^* \\ I_c^* \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} I_\alpha^* \\ I_\beta^* \end{bmatrix} \tag{9}$$

#### 4. DC VOLTAGE CONTROL

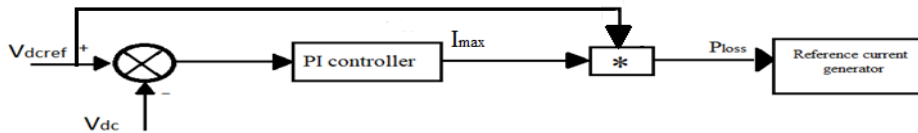


Fig 5: DC Voltage Controller

Fig 5 shows the structure of PI Controller. The actual capacitor voltage is compared with a set reference value the error signal  $e(t)$  is then processed through a PI controller, which contributes to zero steady state error. The output of the PI controller is considered as peak value of the current ( $I_{max}$ ), which contributes to the losses of shunt APF. This  $I_{max}$  is multiplied with the  $V_{dcref}$  and  $P_{loss}$  is given to the reference current generation block. This  $P_{loss}$  is added to the active power component of the compensating current to calculate the required compensation currents.

$$e(t) = V_{dcref} - V_{dc} \tag{10}$$

#### 5. HYSTERESIS CURRENT CONTROLLER

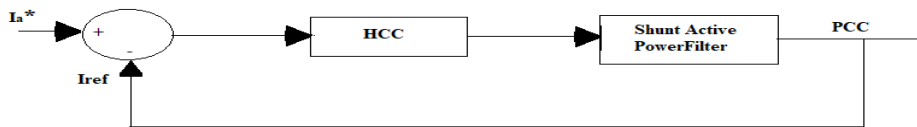


Fig 6: Schematic Diagram of Hysteresis Current Controller

Fig.6. shows the schematic diagram of Hysteresis current controller (HCC). HCC is used for gate pulse generation for triggering the six IGBT's.  $I_{ref}$  is the reference current taken from the output of the shunt active power filter ( $I_{sh}$ ) which is used as a feedback in hysteresis controller and compared with other three inputs  $I_a^*$ ,  $I_b^*$  and  $I_c^*$  generated from reference current generation block which makes it superior compared to other generation techniques. If the actual signal greater than reference signal it will operate positive gate signals otherwise using a NOT operator switches on the negative gate signals.

#### 6. PROPOSED DISTRIBUTION SYSTEM WITH ASHUNT ACTIVE POWER FILTER

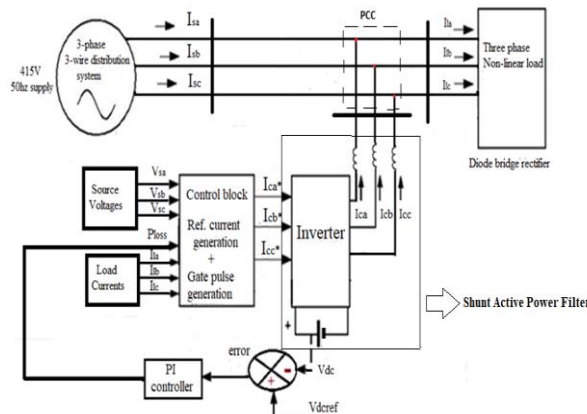


Fig 7: Single-line diagram of the proposed distribution system with a Shunt Active Power Filter connected to non-linear load.

Fig.7. shows the single line diagram of the proposed distribution system with a Shunt Active Power Filter. The Shunt Active Power filter is connected in parallel with non-linear load. The distorted three phase load currents and source voltages are given as inputs to the two control techniques in this proposed work. First technique is Instantaneous Reactive Power Theory, in which source voltages are directly used so any distortion in source voltages leads to distortions in the compensation signal. In IRP only Clark's transformation is performed. Second technique is Modified Synchronous Reference Frame theory. In this technique both Clarke and Park Transformation is used. Source voltages are used only for calculation of transformation angle  $\Theta$  and low pass filters are used for filtering out any distortions in the source voltages. PI controller is used to reduce the errors in the SAPF. Hysteresis Current Controller is used for generating the required gate signals to drive the voltage source inverter.

6.1 PARAMETERS OF THE PROPOSED SYSTEM

Table 1. Parameters of the Proposed System

Parameter	Value
Source Voltage	415V
Frequency	50Hz
Non-Linear Balanced Load	$R_{load} = 65\Omega, L_{load} = 5mH$
DC Link Voltage	600V
Filter Inductance $L_f$	3mH
Hysteresis band	$\pm 0.2A$
DC Link Capacitance( $C_{dc}$ )	1000 $\mu F$
Source Inductance &Resistance	$R_s = 0.1\Omega, L_s = 0.01mH$

7. RESULTS AND DISCUSSIONS

7.1 SIMULATION OF THE PROPOSED SYSTEM WITHOUT SAPF

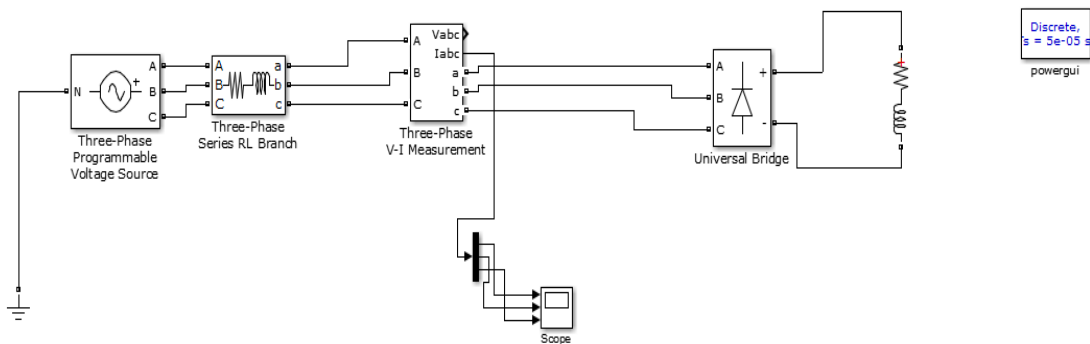


Fig 8: Simulation of the proposed system without SAPF

Fig.8. shows the simulation of the proposed system without Shunt Active power Filter.

7.2 SIMULATION OF THE PROPOSED SYSTEM WITH SAPF USING CONTROL STRATEGIES

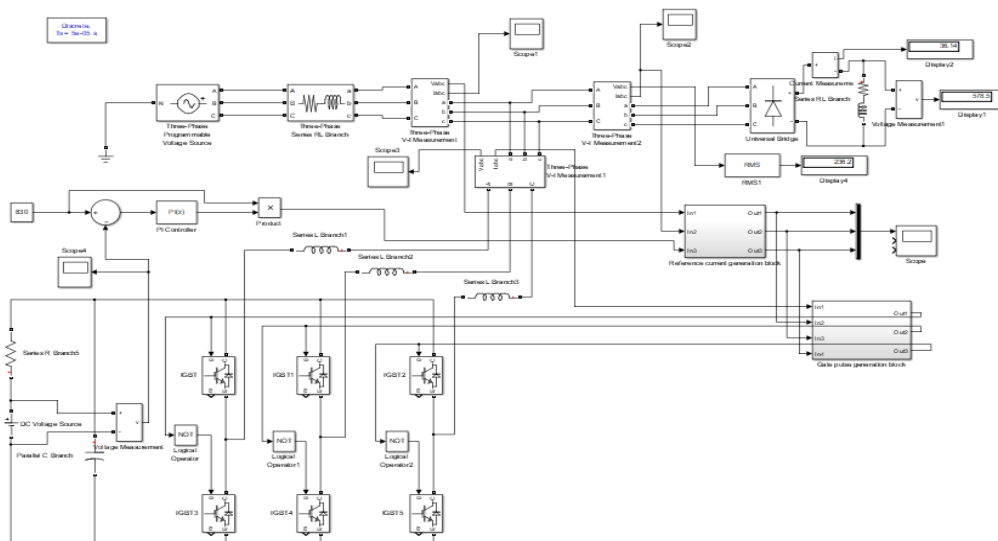


Fig 9: Simulation of the Proposed System with SAPF using Control Strategies

Fig.9. Shows the simulation of the Proposed system with Shunt Active Power Filter using control strategies.

7.3 FFT ANALYSIS

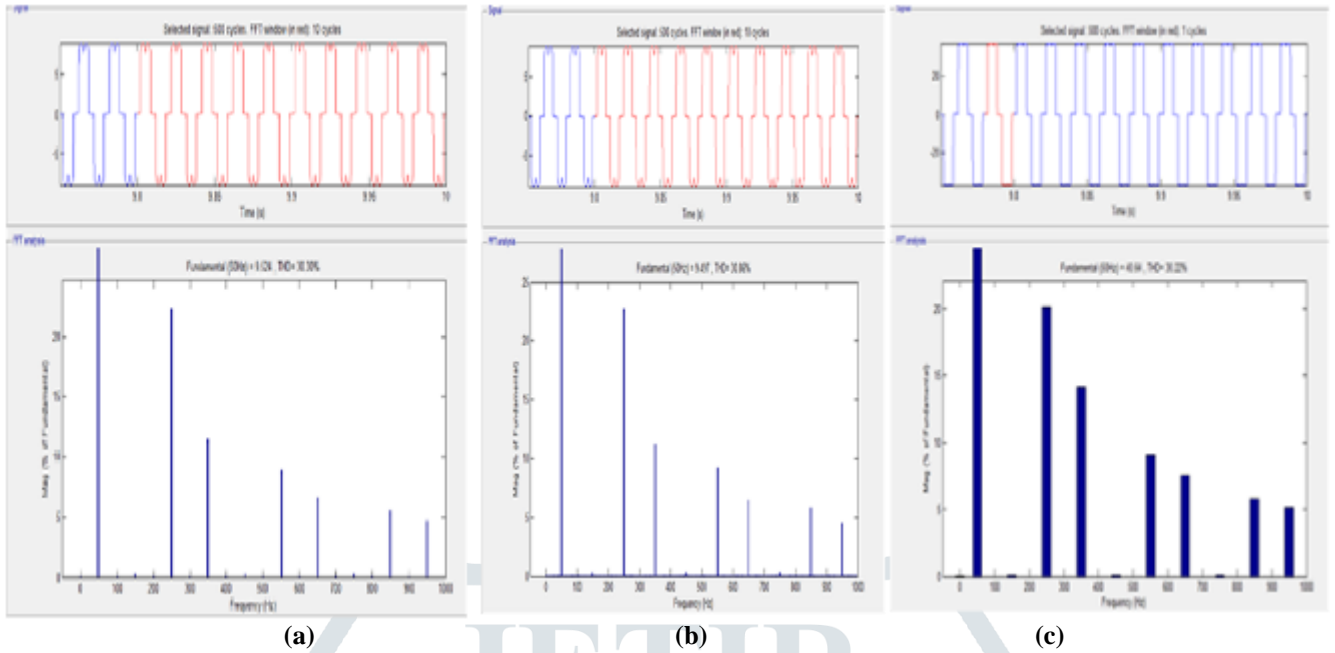


Fig 10: FFT Analysis without SAPF

Fig.10 represents the FFT analysis without SAPF in three different cases and %THD is very high not within the limits. So, two different theories are used in order to reduce %THD within IEEE limits.

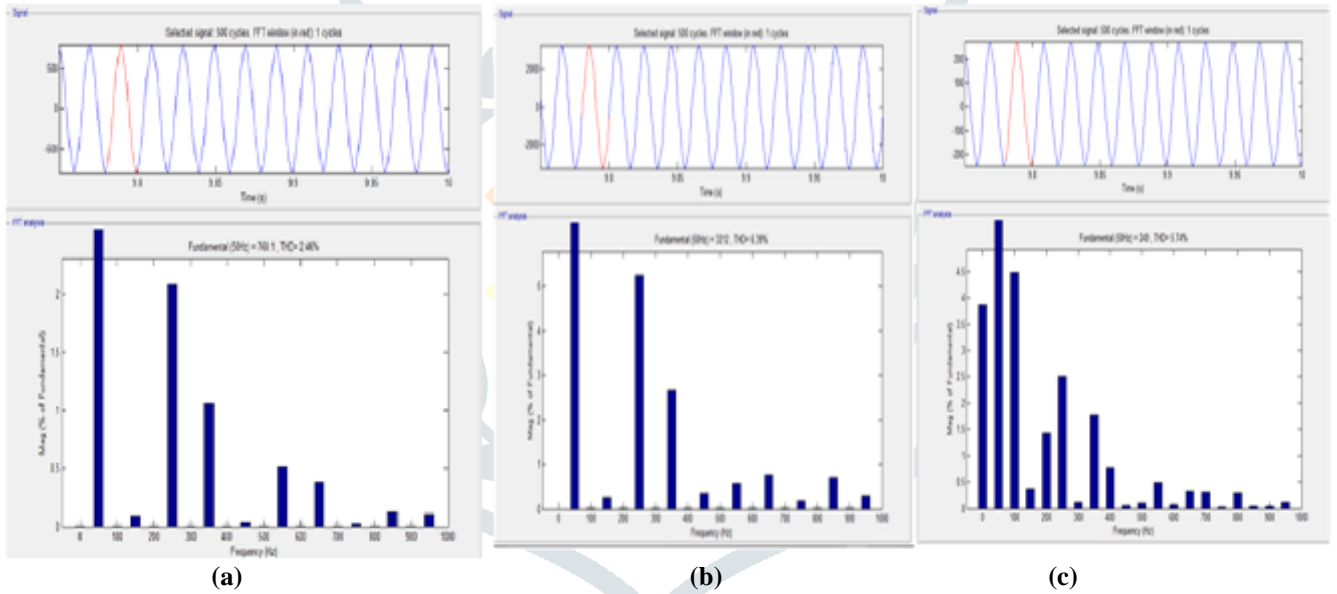


Fig 11: FFT Analysis with SAPF using IRP Theory

Fig.11. shows the FFT analysis with SAPF using IRP theory in three different cases. Under balanced & sinusoidal source voltage condition IRP theory reduces the %THD within IEEE limits 519-1992. In unbalanced & Non-sinusoidal source voltage condition using IRP theory %THD cannot reduce to the desired level.

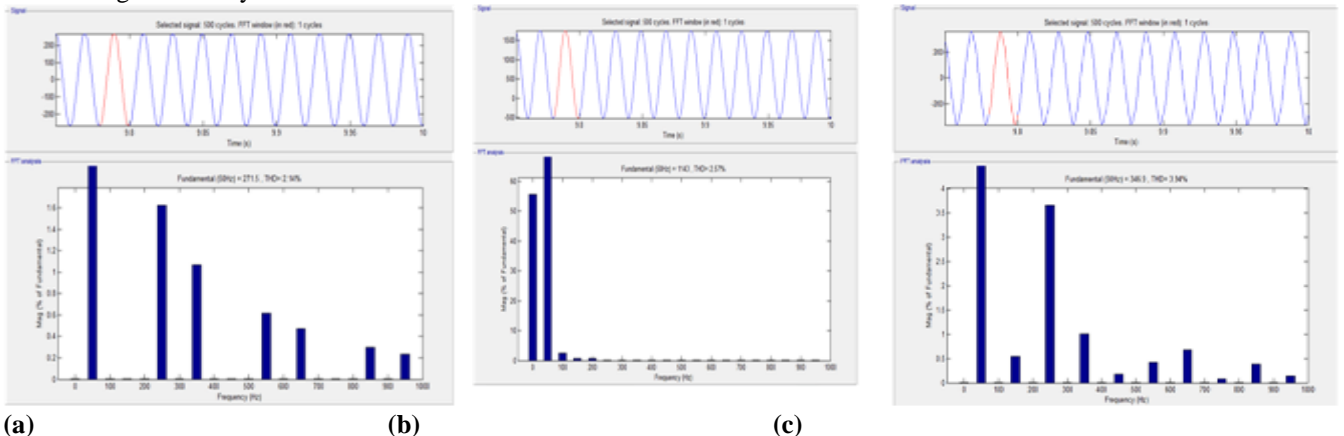


Fig 12: FFT Analysis Using MSRF Theory

From Fig.12 it is clear that using MSRF theory, %THD is within IEEE std 519-1992, in all the three cases.

Case(a): Under Balanced & Sinusoidal Source Voltage Condition

Case(b): Under Balanced & Non-Sinusoidal Source Voltage Condition

Case(c): Under Unbalanced & Sinusoidal Source Voltage Condition.

**Table 2. Simulation Results for Non-Linear Load Under Balanced & Sinusoidal Supply Voltage Condition**

SOURCE CURRENT	BEFORE COMPENSATION	AFTER COMPENSATION	
		IRP	MSRF
$I_s$	30.30%	2.46%	2.14%

Table.2. shows the simulation results under balanced & Sinusoidal Supply voltage condition without SAPF(before compensation) and with SAPF(after compensation) using IRP &MSRF.

**Table 3: Simulation Results for Non-Linear Load Under Balanced & Non-Sinusoidal Supply Voltage Condition**

SOURCE CURRENT	BEFORE COMPENSATION	AFTER COMPENSATION	
		IRP	MSRF
$I_s$	30.86%	6.39%	2.57%

Table.3. shows the simulation results under balanced & Non-Sinusoidal Supply voltage condition without SAPF(before compensation) and with SAPF(after compensation) using IRP &MSRF.

**Table 4: Simulation Results for Non-Linear Load Under Unbalanced Supply Voltage Condition**

SOURCE CURRENT	BEFORE COMPENSATION	AFTER COMPENSATION	
		IRP	MSRF
$I_s$	30.22%	5.74%	3.94%

Table.4. shows the simulation results under Unbalanced & Sinusoidal Supply voltage condition without SAPF(before compensation) and with SAPF(after compensation) using IRP &MSRF.

## 8. CONCLUSION

In this paper, a Modified Synchronous Reference Frame Theory (MSRF) has been used for the better performance of the three-phase three wire distribution SAPF system to improve the performance under balanced, unbalanced and non-sinusoidal source voltage conditions. Three test cases are designed to compare the performance of the proposed control strategies(IRP &MSRF).Simulation results show that the compensation strategies IRP and MSRF theories show similar results under balanced and sinusoidal supply voltage conditions. But under non-sinusoidal and unbalanced supply voltage conditions both the methods give different results. The MSRF method has the ability to reduce the source current harmonics to the desired level according to IEEE Std. 519-1992 and is insensitive to supply voltage conditions.

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