

Comparison between Two Compensation Current Control Methods of Shunt Active Power filter

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Abstract— This paper presents the analysis and simulation using Matlab/Simulink of a Shunt Active Power Filter (SAPF) for reducing the harmonics current generated by nonlinear loads and also compared the two current control method. Due to increasing the usage of power electronics equipment with linear load, the increase of the harmonics disturbance in the ac mains currents has become a major concern due to the adverse effects on all equipment mostly capacitors, transformers, and motors, causing additional losses, overloading, malfunctioning and overheating and interferences. Shunt Active Power filter is used to compensating the harmonic non-linear loads harmonics by injecting equal but opposite harmonic compensating current which gives pure sinusoidal wave.

Keywords— Power System, Harmonic Distortion, Shunt Active Power Filter, Non-Linear Loads, Total Harmonic Distortion.

INTRODUCTION

Power electronic control devices due to their inherent non linearity draw harmonic and reactive power form the supply mains. Due to wide use power electronic equipments with linear load, causes an increasing harmonics distortion in the ac mains currents. Harmonics component is a very serious and a harmful problem in Electric Power System. In three phase systems, they could also cause unbalance and excessive neutral currents.

The injected harmonics, reactive power burden, unbalance and excessive neutral currents cause low system efficiency and poor power factor and also cause transients. These transients also would affect the voltage at distribution levels. Excessive reactive power of loads would increase generating capacity of generating stations and also increase the transmission losses in lines. Hence supply of reactive power at the load ends becomes essential. Mostly non-linear loads based on solid-state converters' are like UPS, SMPS etc. These Non-linear loads draw current that is not sinusoidal and thus create voltage drops in distribution conductors.

The main adverse effect of harmonic current and voltage on power system equipment such as overheating, overloading, perturbation of sensitive control and electronic equipment, capacitor failure, communication interferences, process problem, motor vibration, resonances problem and low power factor. As a result, effective harmonic suppression from the system has become very important for both the utilities and the users. Active Power filtering constitutes the most effective proposed solutions. Active power filter (APF) can solve the problems of harmonic and reactive power at the same time. The quality of electric power is deteriorating mainly due to current and voltage harmonics, negative sequence components, voltage sag, voltage swell, etc.

In reference paper [15], the authors compared the two current control methods of shunt active power filter under unbalance and non sinusoidal condition. As per the result d-q method is the best one which used in any voltage condition.

Many theories have been developed for instantaneous current harmonics detection in active power filter such as FFT (fast Fourier technique) technique, neural network, instantaneous p-q theory (instantaneous reactive power theory), synchronous d-q reference frame theory or by using suitable analog or digital electronic filters separating successive harmonic components, PLL with fuzzy logic controller, neural network etc. This paper basically deals with the modeling and simulation of shunt active filter with hysteresis current control method for harmonic compensation and power filtering and then studied the compensation principle used for current harmonics compensation and harmonic control method provides a quick and easy response in the system. The comparative study of the current control method will do.

SHUNT ACTIVE POWER FILTER

Figure 1 shows the basic configuration of a shunt active filter for harmonic current compensation of a specific load. Shunt active filter inject harmonic current equal and opposite in phase to harmonic current produced by load into line.

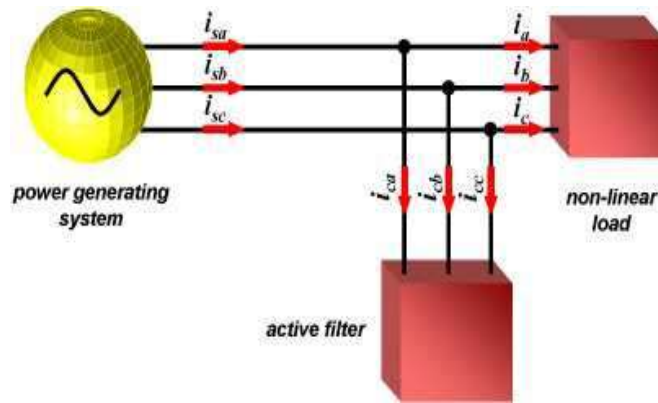


Fig. 1 Principle of Shunt Active Filter

INSTANTANEOUS REACTIVE POWER THEORY

Akagi et al. [1, 2] have proposed the "The Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", also known as instantaneous reactive power theory or p-q theory. In this theory, instantaneous three-phase current and voltages are transformed into α - β coordinates from a-b-c coordinates, known as Clarke transformation as shown in equation (1) and (2) respectively.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \dots\dots\dots (1)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \dots\dots\dots (2)$$

The instantaneous real power is defined as follows in equation 3.

$$p = v_a i_a + v_b i_b + v_c i_c \dots\dots\dots (3)$$

From above equations, the instantaneous power can be rewritten as shown below in equation (4).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \dots\dots\dots (4)$$

The instantaneous reactive power is set into opposite vectors in order to cancel the reactive component in the line current. From the above equations, yield eq. 5.

$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p_0 + p_{loss} \\ 0 \end{bmatrix} \dots\dots\dots (5)$$

The compensating current of each phase can be derived by using the inverse Clarke transformations as shown below in equation (6).

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} \dots\dots\dots (6)$$

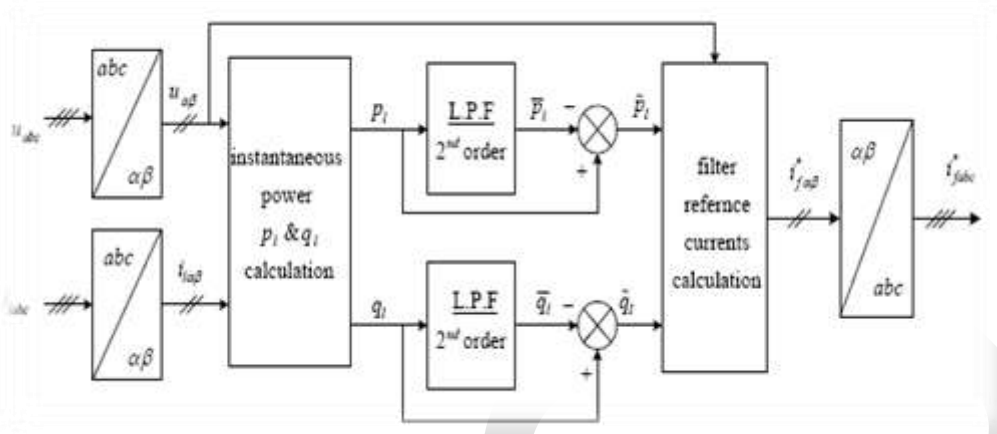


Figure 2: Principle of instantaneous active and reactive power theory.

SYNCHRONOUS REFERENCE D-Q THEORY

In this method, the park transform is used to transformed load current from three phase frame reference *abc* into synchronous reference d-q coordinate in order to separate the harmonic contents from the fundamentals.

$$\begin{bmatrix} i_{ld} \\ i_{lq} \\ i_{l0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos \theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ -\sin \theta & -\sin(\theta - \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix}$$

Where, θ is the angular position of the synchronous reference. This is a linear function of the fundamental frequency. The harmonic reference current can extract from the load currents using a simple LPF. The currents in the synchronous reference can be decomposed into two terms as:

$$\begin{cases} \tilde{i}_{ld} = \bar{i}_{ld} + \tilde{\tilde{i}}_{ld} \\ \tilde{i}_{lq} = \bar{i}_{lq} + \tilde{\tilde{i}}_{lq} \end{cases}$$

Only the alternating terms -which are related to the harmonic contents - will be seen at the output of the extraction system. The APF reference currents will be then:

$$\begin{bmatrix} i_{fd}^* \\ i_{fq}^* \end{bmatrix} = \begin{bmatrix} \tilde{\tilde{i}}_{ld} \\ \tilde{\tilde{i}}_{lq} \end{bmatrix}$$

In order to find the APF currents in three phase system, the inverse Park transform can be used as follow:

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos \theta & -\sin \theta \\ \cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{2\pi}{3}) \\ \cos(\theta + \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} i_{fd}^* \\ i_{fq}^* \end{bmatrix}$$

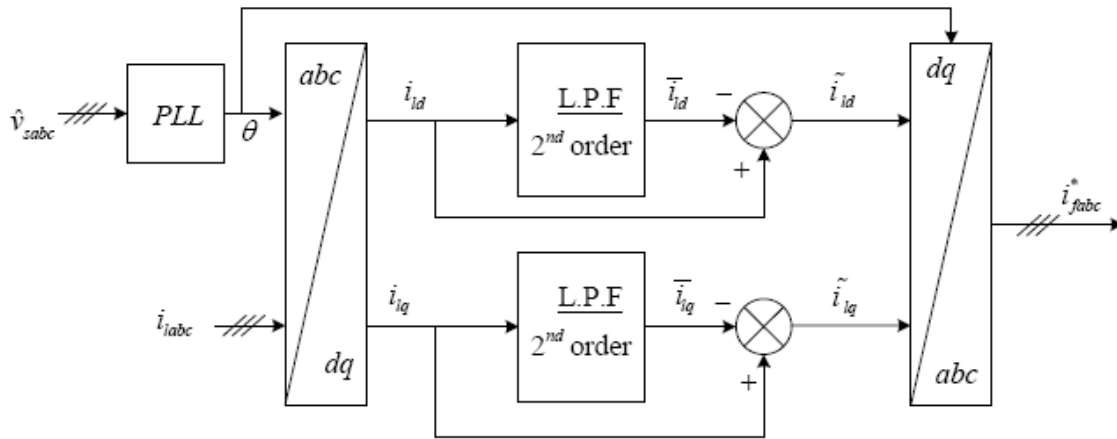


Fig 3 Principle of d-q method

HARMONIC CURRENT CONTROL METHOD

The principles of hysteresis band current control can be seen in figure 5. The difference between the reference value and the actual value will be directed to one comparator with a tolerance band. The controller generates the sinusoidal reference current of desired magnitude and frequency that is compared with the actual motor line current. Hence, the actual current is forced to track the reference current within the hysteresis band as shown in fig. 5 and fig. 6.

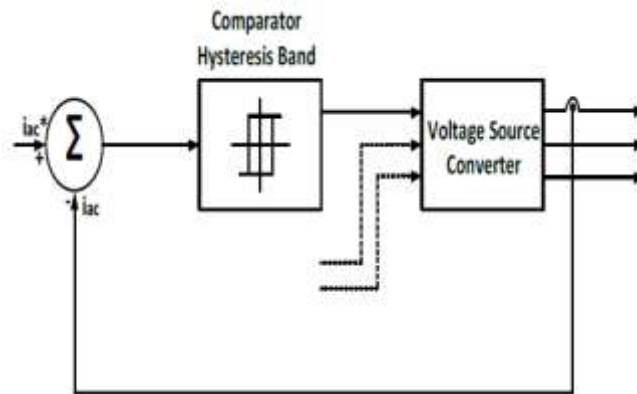


Fig.4 Basic principle of Hysteresis Current Control

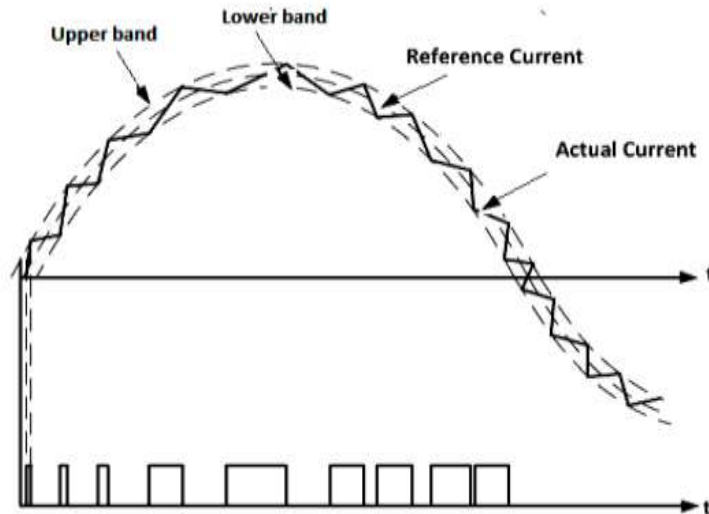


Fig.5 Hysteresis Band

SIMULINK MODEL OF THE APF

The overall system model containing the power source, the shunt active power filter and the nonlinear loads is shown in fig.6. The main components of the system are described below:

- The power source, which was designed as a three-phase 11KV/50Hz voltage sources connected together in a Y configuration with neutral and a three phase RL branch.
- The single-phase nonlinear loads are containing a single-phase uncontrolled diode rectifier supplying a series RL load for phase A, a single-phase uncontrolled diode rectifier supplying a parallel RC load for phase B, a single-phase uncontrolled diode rectifier supplying a series RL loads for phase C.
- The PWM IGBT voltage source inverter, which contains a three-leg voltage source inverter with neutral clamped DC capacitors and the control scheme, as shown in fig. 6.

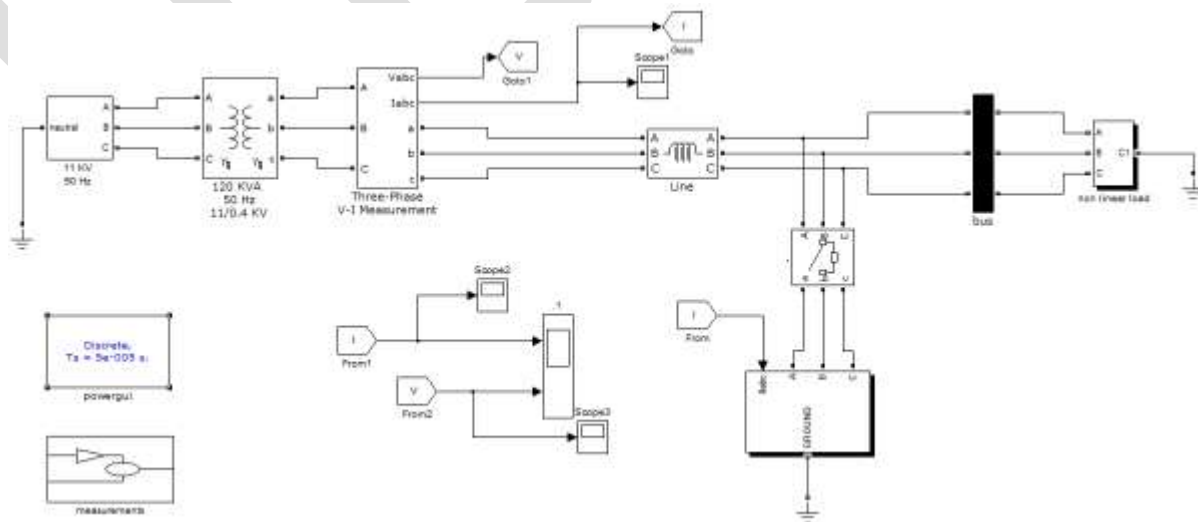


Fig. 6 system model with filter

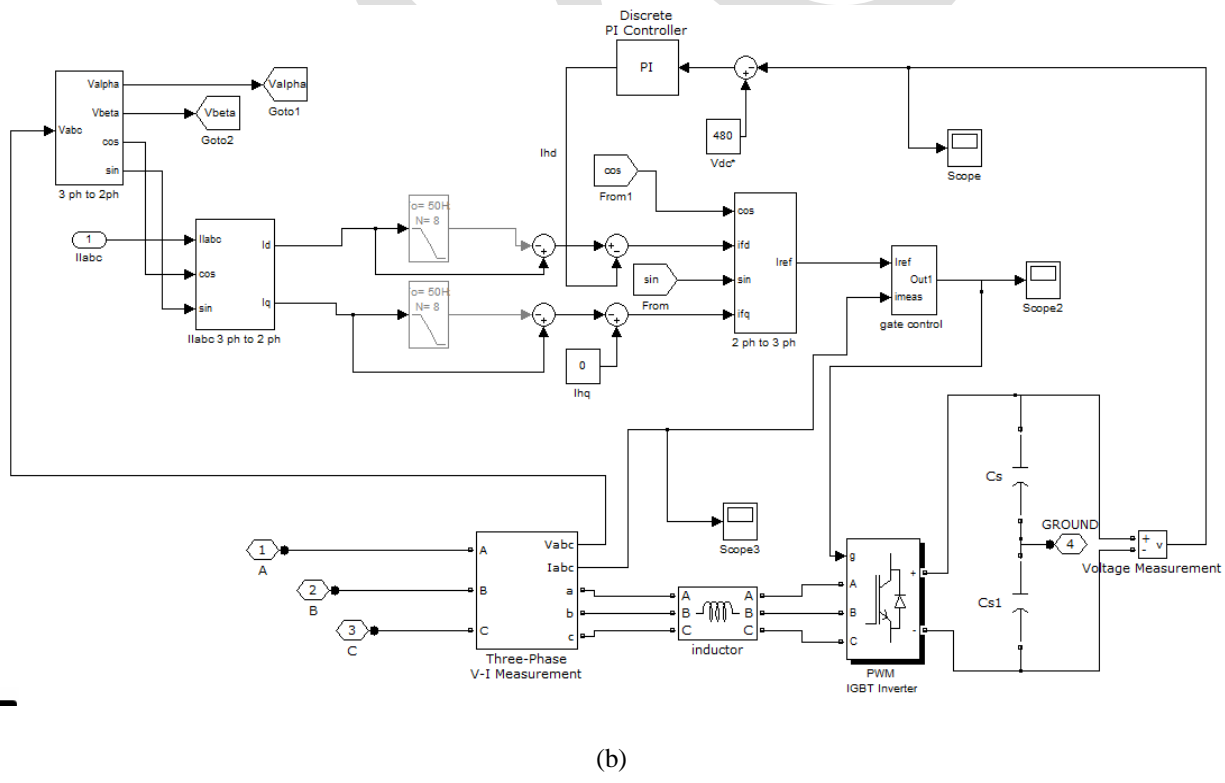
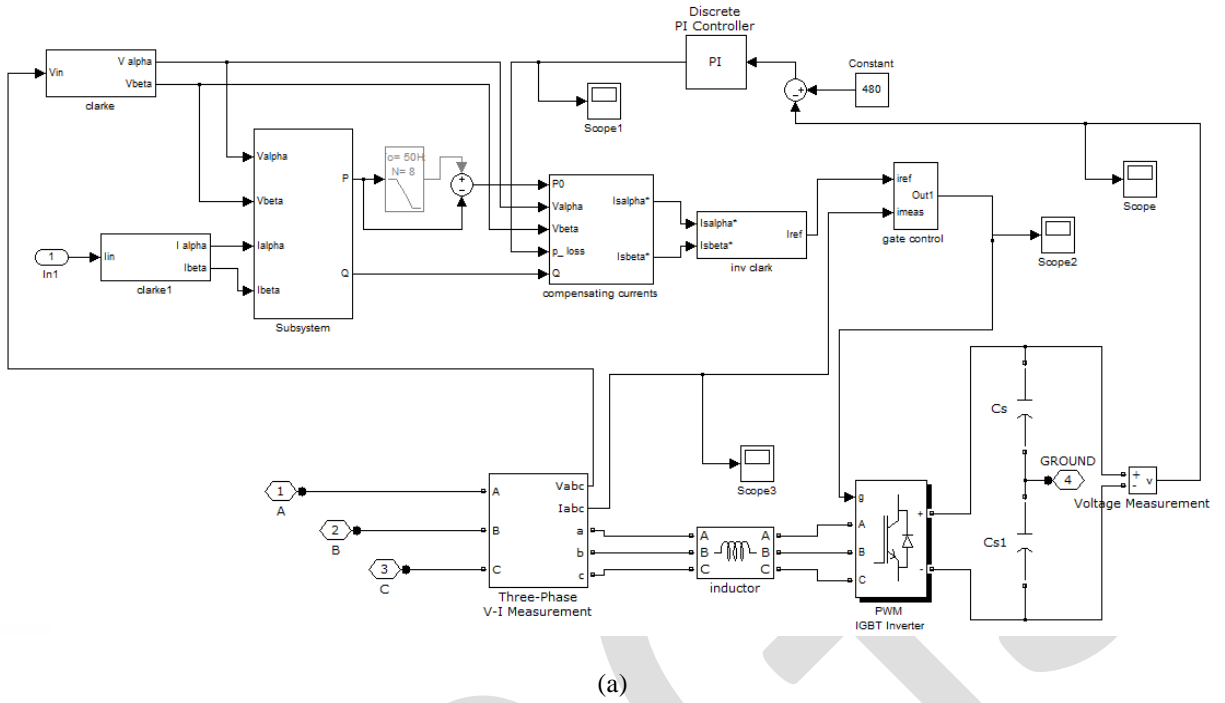


Fig.7 Model of APF (a) p-q method (b) d-q method

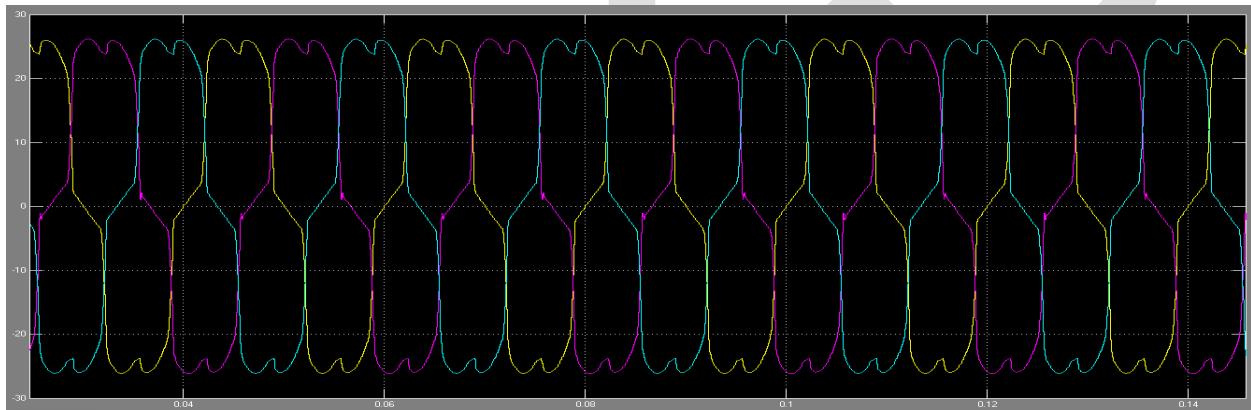
SIMULATION RESULT

The complete model of active power filter is presented in fig.6 and result were obtained by using MATLAB/Simulink Simpowersystem Toolbox software for a three phase neutral clamped APF compensating harmonics, reactive power produced by nonlinear loads.

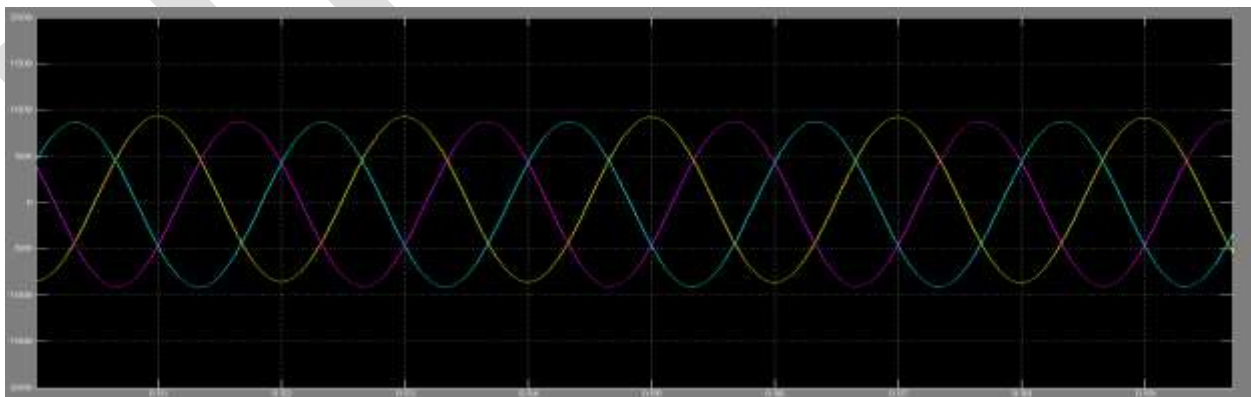
Fig 8 shows the current wave for the system with and without SAPF. Fig. 9 shows the simulation results obtained in harmonic distortion analysis of the load current, for each phase with nonlinear load. Without APF, the total harmonic distortion (THD) is 20.49%.

Fig. 10 shows the simulation result of the source current obtained with APF using p-q method to compensate harmonics created by nonlinear load. The THD of the source current is now 0.53% of the fundamental value, thus meeting the limit of harmonic standard of IEEE STD. 519-1992.

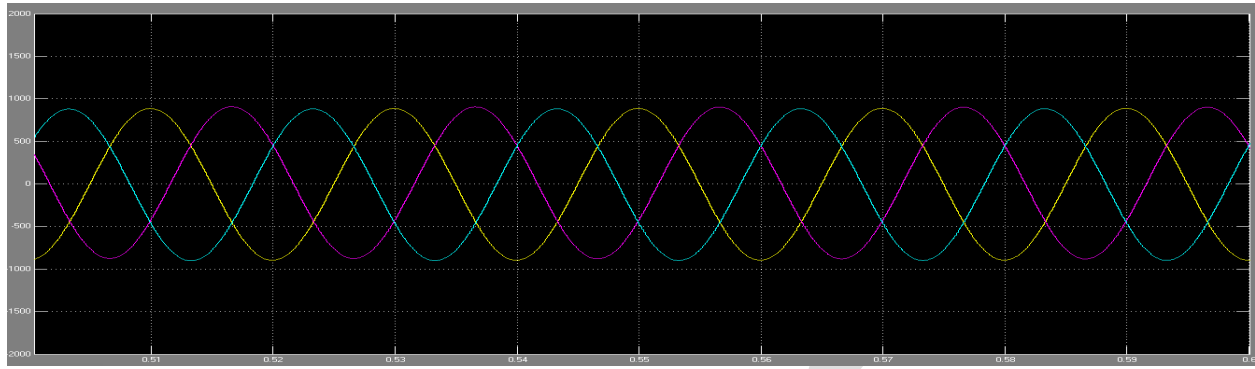
Fig. 11 shows the simulation result of the source current obtained with APF using d-q method to compensate harmonics created by nonlinear load. The THD of the source current is now 0.08% of the fundamental value, thus meeting the limit of harmonic standard of IEEE STD. 519-1992.



(a)



(b)



(c)

Fig 8: Current Waveform of system (a) without SAPF, (b) with SAPF using p-q method, (c) with SAPF using d-q method

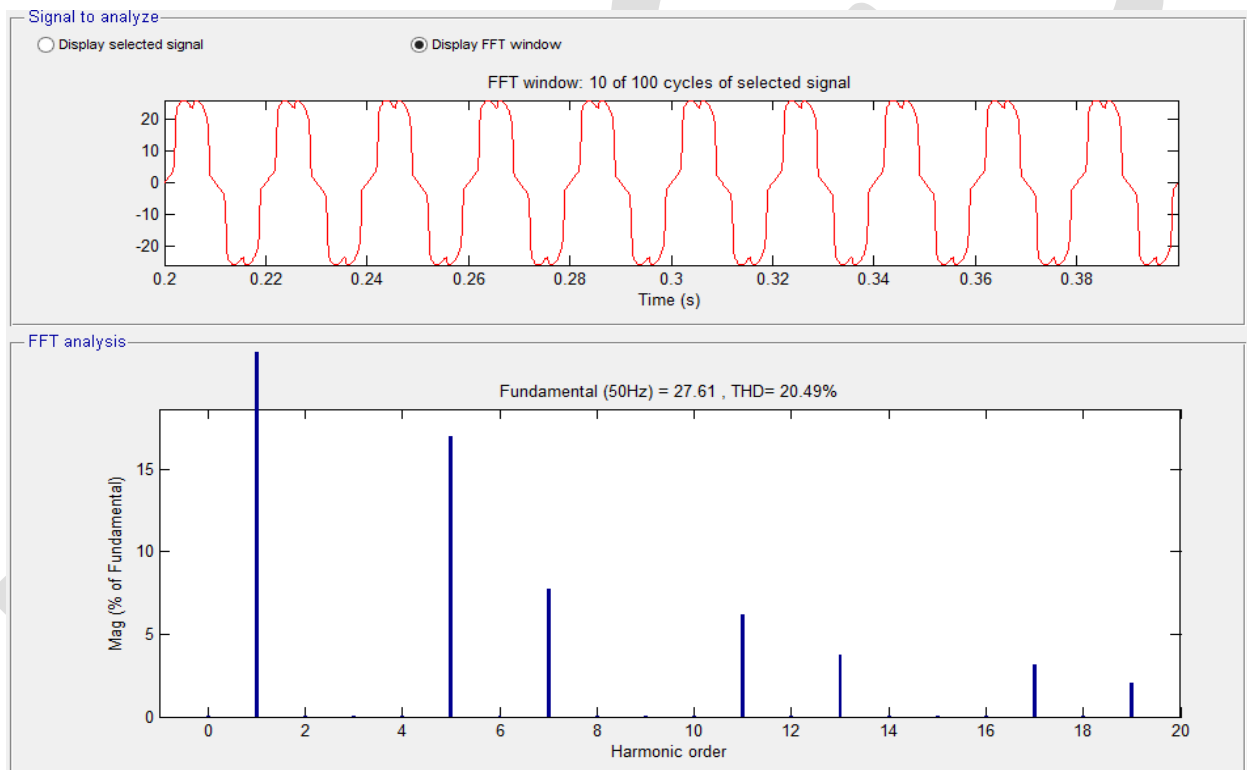


Fig. 9 Load Current (System without APF)

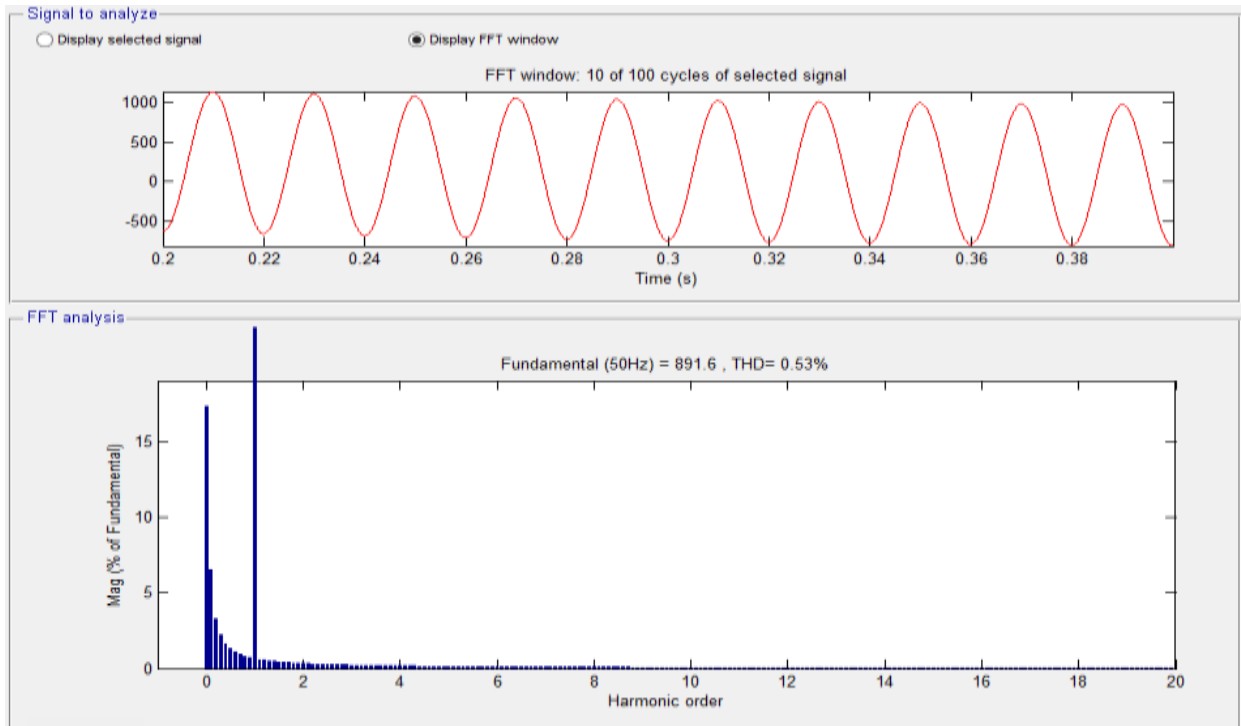


Fig.10 Source Current (System with APF using p-q method)

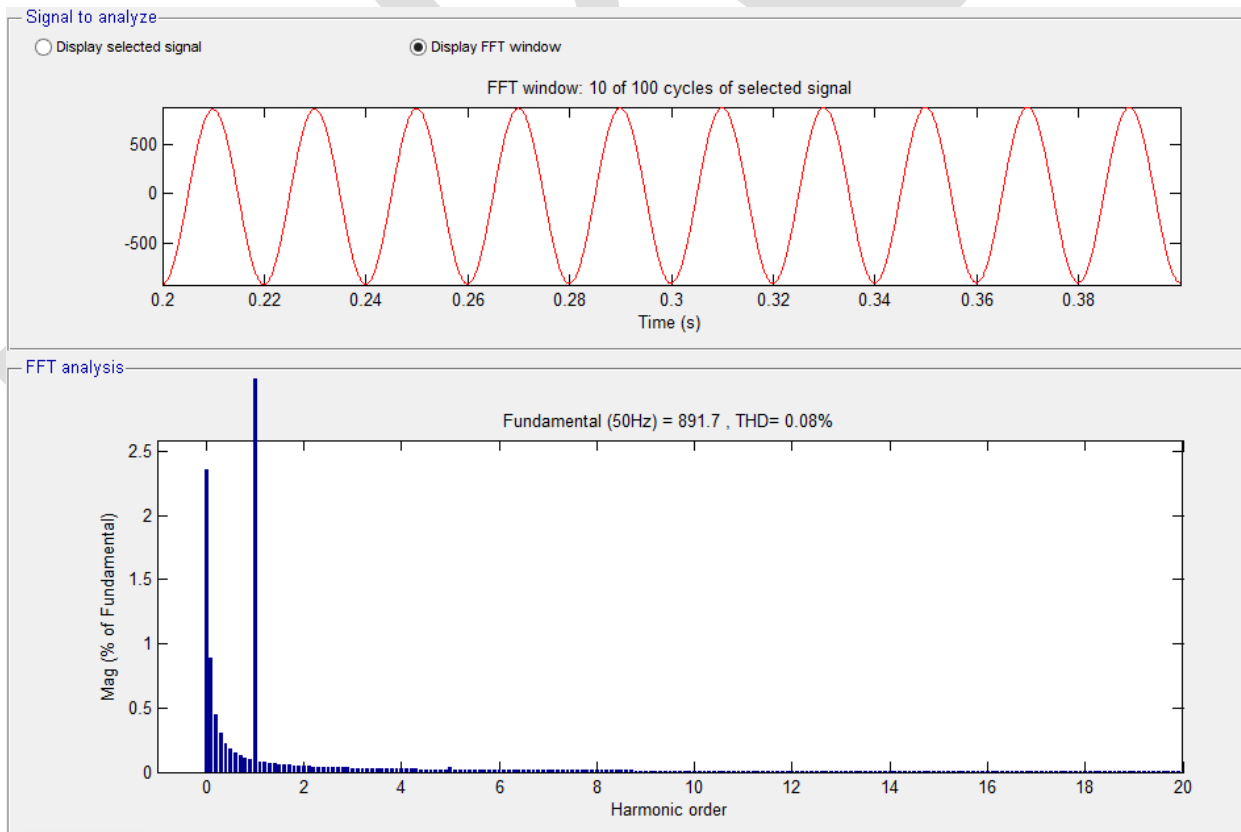


Fig.11 Source Current (System with APF using d-q method)

COMPARATIVE ANALYSIS

The comparison between system without SAPF and with SAPF using different current control method is shown in table 1 and 2. Table 1 shows the % of individual harmonics distortion present in the system and table 2 shows the Total Harmonic distortion present in the system before and after using filter with different control method. From the table 1 and 2 the system with SAPF using d-q method give the better result as compare to p-q method.

Table 1: Harmonic Improvement (in % of fundamental frequency component)

Harmonic order	System without SAPF	System with SAPF using p-q method	System with SAPF using d-q method
3rd order harmonic	0.4%	0.22%	0.03%
5th order harmonics	16.94%	0.12%	0.03%
7th order harmonics	7.76%	0.09%	0.02%
9th order harmonics	0.03%	0.07%	0.01%
11th order harmonics	6.61%	0.06%	0.01%
13th order harmonics	3.74%	0.05%	0.01%
15th order harmonics	0.03%	0.04%	0.01%
17th order harmonics	3.18%	0.04%	0.01%
19th order harmonics	2.06%	0.03%	0.01%

Table 2: Total Harmonic Distortion of System (in % of fundamental frequency component)

System	Without SAPF	With SAPF using p-q method	With SAPF using d-q method
% THD (in % of fundamental)	20.49%	0.53%	0.08%

Graph shown in figure 12 summarize the performance of the distribution system without and with shunt active power filter using different control strategies.

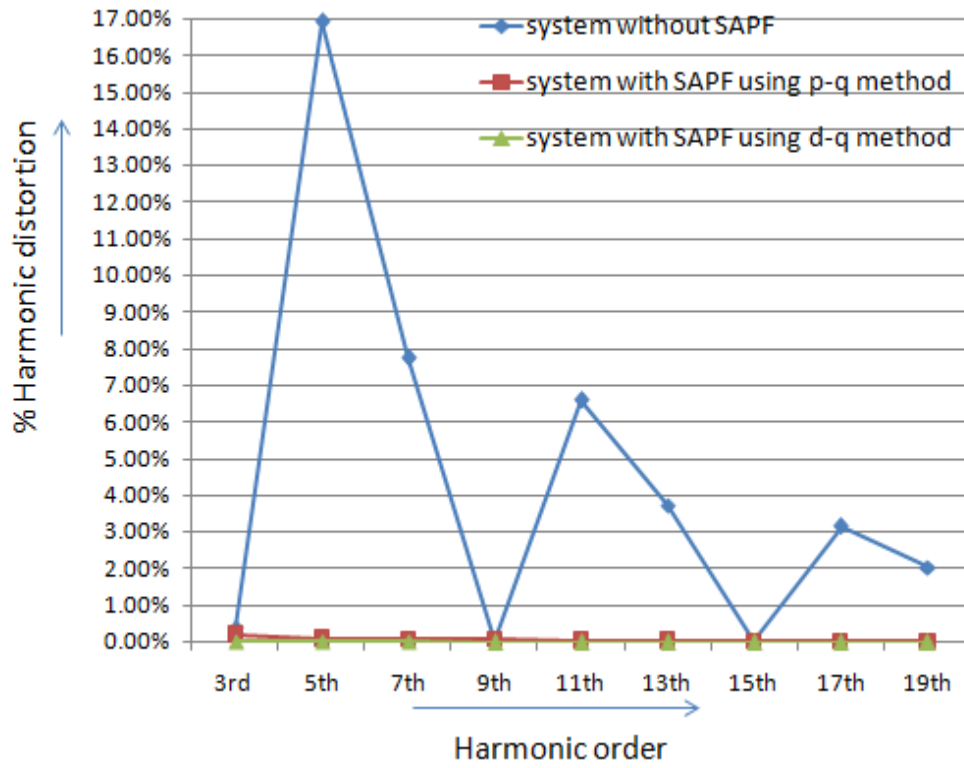


Figure 12: Comparative Graph between System without and with SAPF

Graph shown in figure 13 summarize the performance of the system with shunt active power filter using p-q and d-q methods. Results presented confirm superior performance of d-q method.

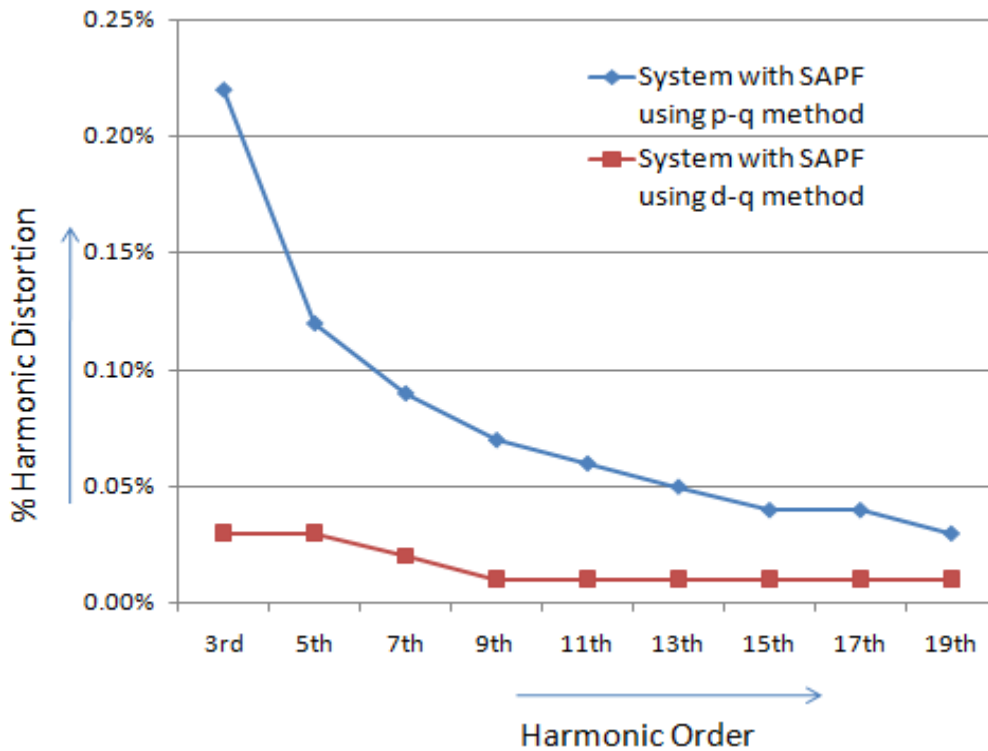


Figure 13: Comparative Graph between p-q and d-q Method

CONCLUSION

Simulation results using matlab/simulink shows that shunt active filter gives effective compensation of harmonics and reactive power. Total Harmonic Distortion of system with APF using p-q method is reduced to 0.53% and Total Harmonic Distortion of system with APF using p-q method is reduced to 0.08 % which are very below than the harmonics limit 5% imposed by the IEEE-519 standard. As per the result d-q method give better result as compare to p-q method

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