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COMPARATIVE STUDY ON DIFFERENT CONTROL STRATEGIES USING SHUNT ACTIVE POWER FILTER FOR CURRENT HARMONICS MITIGATION

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Abstract: In the effort to reduce the harmonic disturbances generated by the non-linear loads the select of the active power filters comes out to improve efficiency of filter and to solve many problems existing with classical passive filters. One of the main points for a suitable implementation of an active filter is use a good method for current or voltage reference generation. There exist various implementation supported by different theories (either in time or frequency–domain), which incessantly consideration their performances offering ever better solutions. This paper provides a review of common used theories. This paper present, the shunt active power filter the control strategies is based on Unit Vector Template (UVT), while a comparison is made for the three control strategies namely UVT, Instantaneous Real and Reactive Power Theory or "p-q theory" and d-q theory for shunt active power filter. In three of the control strategies the control is made over the fundamental supply current in its place of the fast changing active filters current. In this paper, different harmonic control strategy is applied to compensate the current harmonics in the system. A detail study about the harmonic control method has been used by shunt active filter techniques.

Keyword: power quality, shunt active filter, harmonics, current harmonic mitigation

I. INTRODUCTION

In routine life, there are loads that generate harmonic currents. The nonlinearity of the power electronics devices and the higher switching frequency are mostly responsible for these harmonic currents which can interrelate harmfully with a wide range of power system equipment, control systems, circuit protection, and other harmonic sensitive loads. Cause of the harmonics can tripping of source supplies, overheat building wirings and can result in failure of total equipment. Few years ago the passive filter is used to compensate the harmonics, but passive filter have some drawbacks are given below [4]:

- Toughly affect filter characteristics by source impedance
- At specific frequencies, Shunt resonance between a source and passive filter effects amplification of harmonic current on the source side
- A passive filter may decrease into series resonance with a source therefore that voltage distortion created unnecessary harmonic current flowing into Passive filter.

There are many techniques to reduce the effect of harmonics. The active power filters to mitigate harmonic problems [1, 2]. Then, the application and concepts of active power filters have become more popular and have attracted great attention [6, 8]. Concept of harmonic mitigation technique in which, reference current is generated by using the distorted waveform. Many theses have been developed like instantaneous reactive power theory (p-q theory), d-q theory, neural network etc. In this paper, we have used the SAF technique for power filtering and also studied about the compensation principle used for current harmonics suppression and harmonic control method is applied as it provides an easy and quick response in the system.

II. SHUNT ACTIVE FILTER

The SAPF (shunt active power filter) is a device that is joined in parallel to and cancels the reactive and harmonic currents from a nonlinear load. The total resulting current drawn from the ac main is sinusoidal waveform. Preferably, the active powers filter (APF) requirements to create just sufficient harmonic current to compensate the nonlinear loads in the line. Shown in Fig. in an APF, a current controlled voltage source inverter is used to create the compensating current and is injected into the utility power source line. This cancels the harmonic components drawn by the nonlinear load and preserves the utility line current (is) sinusoidal.

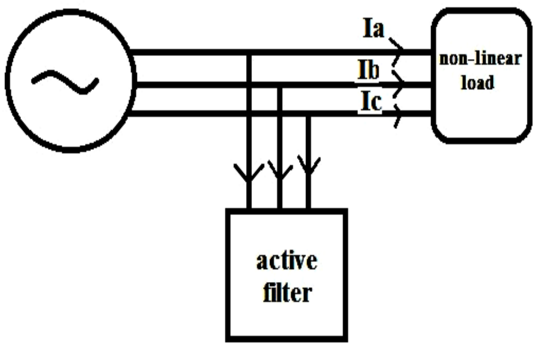

Fig. 1: shunt active power filter [3]

SAPF (Shunt active power filter) compensate current harmonics by introducing equal but opposite harmonic compensating current. In this circumstance the shunt active power filter (SAPF) works as a current source injecting the harmonic Components created by the load but phase shifted by 180o

III. SHUNT ACTIVE POWER FILTER

The leading purpose of the active power filter connection by different consumers is to mitigate current harmonics creating by non-loads. Additional that, the purpose of the active power filters connection by the suitability is to mitigate for voltage and current imbalance, voltage and current harmonics imbalance to the power distribution systems.

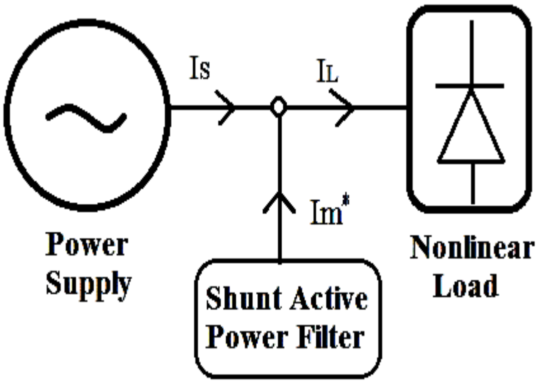

Fig. 2 Topology of Shunt Active Power Filter [3]

In the electrical power supply system, the active power filter will draw and inject the mitigating current, Im* to the line based on the variations of the load. The current source is equivalent to the load and filtering current and is specified by the following equation as [3]:

Im*+IL=IS ….1

Usually Control strategy of Active filter is the heart of the active filter and is executed in three different Steps [9]:

Step 1: In the first step, the basic voltage and current signals are sensed using PT's, current transformers (CT's), and hall-effect sensors.

Step 2: In the second step, compensating instructions signals in expressions of current or voltage levels are derived based on control methods and configurations of active filter.

Step 3: In the final step, the gating signals for the solid-state devices of the active filter are produced using hysteresis, pulse-width modulated control techniques.

IV. HARMONIC DETECTION METHODS

The classification of shunt active power filter methods can be done relative to the domain where the mathematical model is developed **[1].** Therefore, two major ways are define here, the time domain and the frequency-domain methods. Such classification is given Table.

TABLE 1: classification of the most used harmonic detection in Active Power Filter

Frequency-domain	- Discrete Fourier Transform (DFT) - Fast Fourier Transform (FFT) - Recursive Discrete Fourier Transform (RDFT)
Time-domain	- Instantaneous real and reactive power "pq-theory" - Synchronous reference frame theory - Unit Vector Template

V. SYNCHRONOUS REFERENCE FRAME THEORY

The shunt active power filter is used SRF method to extract the three-phase reference current (ima*, imb*, imc*) [5]. Illustrate in figure, the basic block diagram of synchronous d-q reference frame method, used for harmonic mitigation.

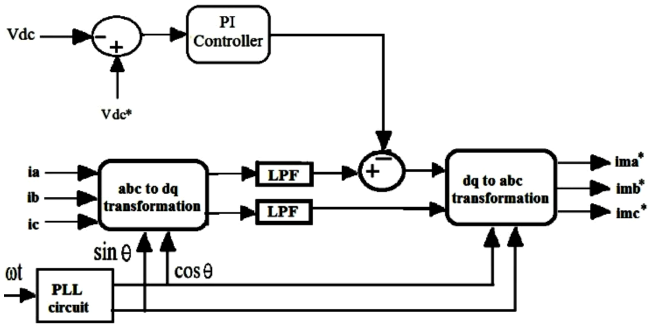

Fig. 3 Basic Block Diagram of SRF Method [12]

Fig.3 Basic block diagram of d-q method based on the instantaneous reactive power theory In this technique, the first source currents (ia, ib, ic) are sensed and transformed into two-phase stationary frame (αβ-0) from the three phase stationary frame (a-b-c), as per equation (2) [7].

$$\begin{bmatrix} i\alpha \\ i\beta \\ i0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \quad ....2$$

Now, using equation (3) the 2-phase current quantities (iα and iβ) of stationary αβ-axes are transformed into 2-phase synchronous frame, where cosθ and sinθ signifies the synchronous unit vector which can be produced using PLL (phase-locked loop) system [7].

$$\begin{bmatrix} id \\ iq \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \quad ....3$$

The harmonic component can easily extracted using a low pass filter, as implemented in figure 3. In SRF method, the d-q currents thus achieved involves of AC and DC parts. The fundamental current component is represented by the fixed DC part and the harmonic component is represented by AC part. Illustrate in figure 3, the harmonic component can be easily removed using low pass filter (LPF) [7].

Now inverse Clark transformation is implemented to transform the current from two-phase synchronous frame (d-q) into two-phase stationary α-β as per equation (4) [7].

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} idh \\ iq \end{bmatrix} \quad ....4$$

In final step the current from two phase stationary frame to transformed back into three-phase stationary frame according to equation (5) and compensation reference currents (ima*, imb*, imc*) are achieved [7].

$$\begin{bmatrix} ima* \\ imb* \\ imc* \end{bmatrix} = \left[Tabc\right] \begin{bmatrix} i\alpha \\ i\beta \\ i0 \end{bmatrix} \qquad \text{....5}$$

Here

$$\left[Tabc\right] = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 & 1/\sqrt{2} \\ -1/2 & \sqrt{3}/2 & 1/\sqrt{2} \\ -1/2 & -\sqrt{3}/2 & 1/\sqrt{2} \end{bmatrix} \qquad \text{....6}$$

VI. UNIT VECTOR TEMPLATES (UVT) METHOD

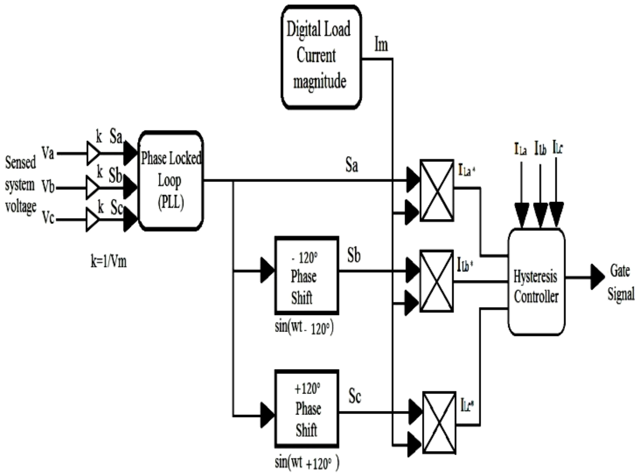

Fig. 4 Block Diagram of Unit Vector Template method [13]

The main objective of control algorithms for SAPF is to calculate mainly the three-phase reference currents at the load terminal (Ia*, Ib* and Ic*). The controlled of shunt active filter is such that it injects currents, which cancel out the distortions existing in the supply currents (Ia, Ib and Ic), thus creating the current at load terminals perfectly sinusoidal with the desired amplitude. The control scheme for the shunt active power filter is presented in fig. Then, the supply current is distorted; a phase locked loop is used to achieve synchronization with the supply current [11].

Now first sensed 3Ø-phase distorted supply current and given to PLL which creates two quadrature unit vectors (cosθ, sinθ). The outputs of the in-phase cosine and sine from PLL are used to compute the supply in phase, displaced three unit vector using eqn. (7) as [10]:

$$\begin{bmatrix} Sa \\ Sb \\ Sc \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \sin\theta \\ \cos\theta \end{bmatrix} \qquad \text{....7}$$

The calculated three in-phase unit vectors then multiplied with the desired peak value of the point of common coupling (PCC) phase current (Im*), which develops the three-phase reference PCC currents as [10]:

$$\begin{bmatrix} Ia* \\ Ib* \\ Ic* \end{bmatrix} = \mathrm{Im}* \begin{bmatrix} Sa \\ Sb \\ Sc \end{bmatrix} \qquad \text{....8}$$

The consideration of desired peak value of the PCC current is 400V (= 230*sqrt(3)). The calculated reference current from eqn. (8) are then given to the hysteresis controller together with sensed three phase PCC currents. The hysteresis controller output is switching signals to the six switches of shunt active power filter. The hysteresis produces the switching signals such that the current at point of common coupling develops the desired sinusoidal reference current [10].

VII. SIMULATION

The shunt active power filter shown in figure 5 is a Current controlled voltage source inverter (VSI), which is connected in shunt filter. Shunt active power filter is used to compensate the current related problems. In this simulation R-L load is connected and FFT analysis has been take-out simultaneously.

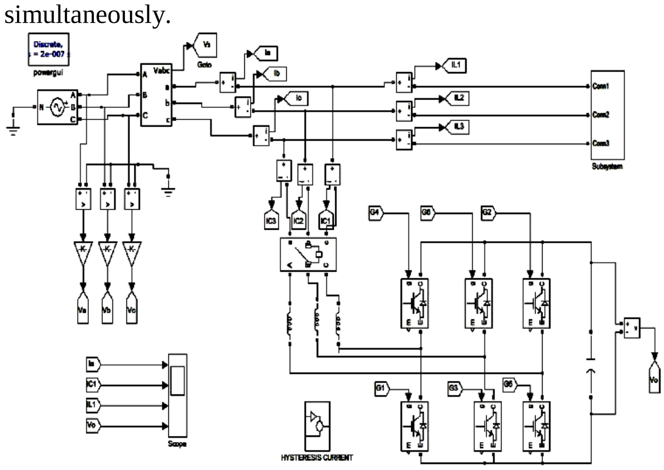

Fig. 5 Simulink Modal

VIII. SIMULATION RESULT

A. Synchronous Reference Frame (SRF) method:

Figure 6 & 7 show the SRF method FFT analysis results of the phase A of load side current.

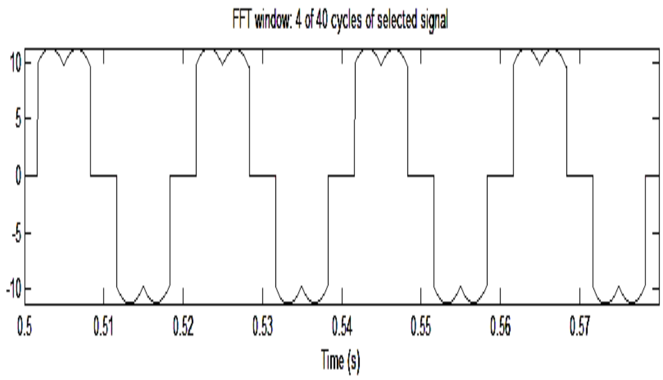

Fig. 6 Load side Current Waveform

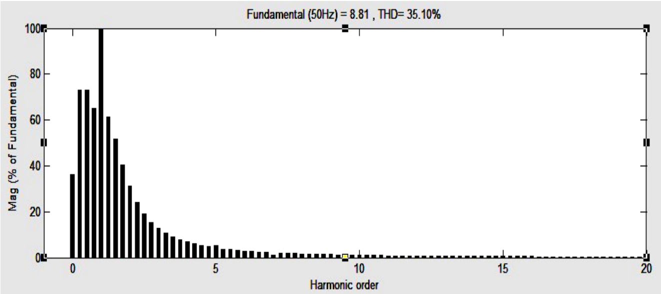

Fig. 7 Load Side FFT Analysis result

Here THD of load side current is 35.10% and harmonic content present in individual harmonic order is shown in the figure. Now consider the first control method is synchronous reference frame method. Figure 8 & 9 shows the FFT analysis results of the SRF method of source side current.

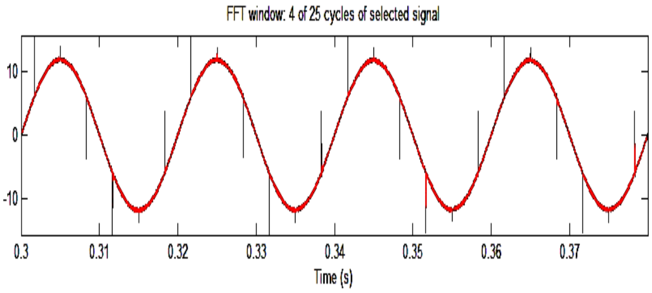

Fig. 8 Source side current waveform

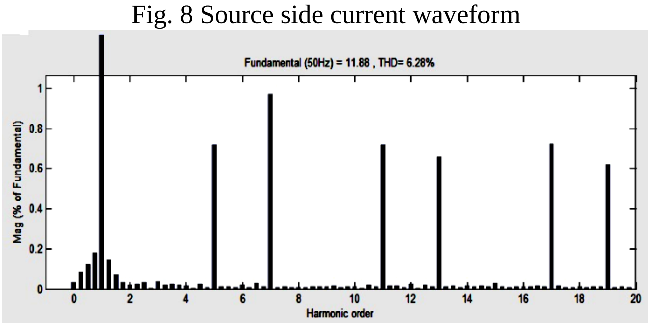

Fig. 9 source Side FFT Analysis result

Here THD of source side current is 6.28% using SRF method and harmonic content present in individual harmonic order is shown in the figure.

B. Unit Vector Template (UVT) Method:

In the second control method is unit vector template method. Figure 10 & 11 show the UVT method FFT analysis results of the phase A of load side current.

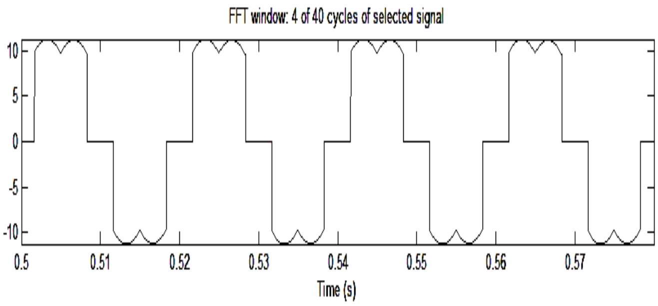

Fig. 10 Load side Current Waveform

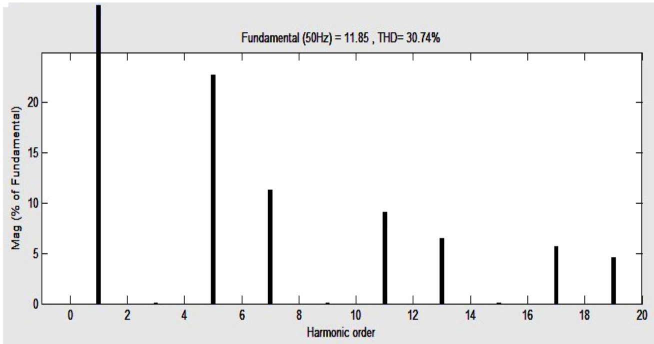

Fig. 11 Load Side FFT Analysis result

Here THD of load side current is 30.74% and harmonic content present in individual harmonic order is shown in the figure. Figure 12 & 13 shows the FFT analysis results of the UVT method of source side current.

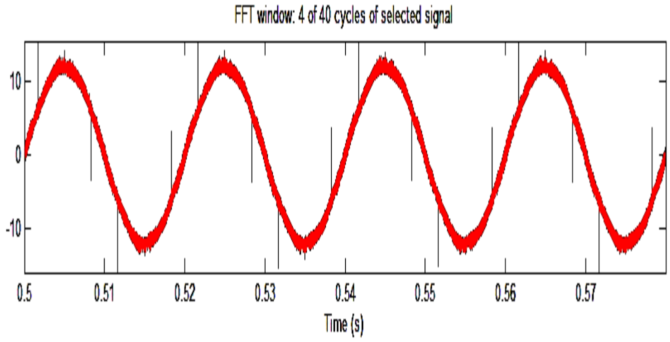

Fig. 12 Source side current waveform

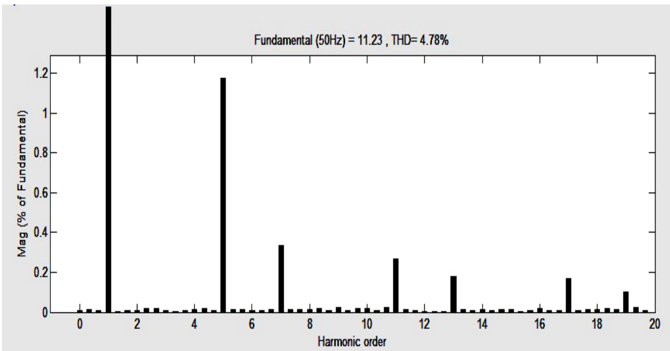

Fig. 13 Source Side FFT Analysis result

Here THD of source side current is 4.78% using UVT method and harmonic content present in individual harmonic order is shown in the figure. The comparative performance for SRF and UVT techniques is tabulated in terms of THD of current in load side and source side compensation in table 2.

Table 2 THD analysis of Load side current and Source Side Current

Control Technique	**Load Side Current**		**Source side Current Component**	
	SRF	UVT	SRF	UVT
THD%	35.10%	30.74	6.28%	4.78%

IX. CONCLUSION

The effectiveness of three control schemes namely d-q theory and UVT (unit vector template) theory for the shunt active filter of single phase has been compared for current harmonic mitigation. On the other has the UVT technique is exploited for the compensation of current harmonics by SAPF (shunt active power filter). The p-q theory is complicated as compared to UVT. Also advantages of UVT method is low switching losses, less calculation, use less memory and very high speed compare other methods. From THD analysis of current compensation, it is clear that using of the Shunt Active Filter with Unit vector template method reduction of the harmonic is 30.74% to 4.78%. Harmonic distortion can be reduced by using shunt active filter and when Shunt Active Filter were used THD reduce 25.96% and according to IEEE-519 standard THD should be below 5%,therefore, Shunt Active Filter with Unit Vector Template method is appropriate method to compensate the harmonics.

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