HARMONIC ANALYSIS USING SHUNT ACTIVE FILTER

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ABSTRACT**:** *Power system harmonics are a menace to electric power systems with disastrous consequences. The line current harmonics cause increase in losses, instability, and also voltage distortion. With the proliferation of the power electronics converters and increased use of magnetic, power lines have become highly polluted. Active filters have been used near harmonic producing loads or at the point of common coupling to block current harmonics. Shunt filters still dominate the harmonic compensation at medium/high voltage level, whereas active filters have been proclaimed for low/medium voltage ratings. With diverse applications involving reactive power together with harmonic compensation, passive filters are found suitable .The necessary modelling and simulations are carried out in MATLAB using SIMULINK and power system block set toolboxes. Installing a filter for nonlinear loads connected in power system would help in reducing the harmonic effect. The filters are widely used for reduction of harmonics. With the increase of nonlinear loads in the power system, more and more filters are required. active filter are designed and analyzed to improve the power quality at ac mains.*

Keywords—harmonics, filter, active filter

I: INTRODUCTION

The growing use of non-linear and time-varying loads has led to distortion of voltage and current waveforms and increased reactive power demand in ac mains. Harmonic distortion is known to be source of several problems, such as increased power losses, excessive heating in rotating machinery, significant interference with communication circuits and audible noise, incorrect operation of sensitive loads . Passive filters are traditional method to eliminate harmonics, but with recent developments in power semiconductor switches and converters, coupled with developments in control techniques and analog and digital implementations, active filters are becoming an effective and commercially viable alternative to passive filters. Active filter offer the following advantages: able to cover a wide range of harmonic frequencies; do not contribute resonant frequencies to the network; harmonic attenuation is network impedance dependent . Among the various topologies the shunt active power filter based on voltage source inverter (VSI) is the most common one because of its efficiency. The performance of active power filters depends on the adoptive control approaches. Various current detection methods, such as instantaneous reactive power theory, synchronous reference frame method . The commonness of these methods is the request for generating reference current of APF, either with the load current or the mains current. The commonness of these methods is to control VSI with the difference between real current and reference current.

II: ACTIVE POWER FILTER

A flexible and versatile solution to voltage quality problems is offered by active power filters. The basic principle of APF is to utilize power electronics technologies to produce specific currents components that cancel the harmonic currents components caused by the nonlinear load. Currently they are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. Shunt active power filters operate as a controllable current source and series active power filters operates as a controllable voltage source. Both schemes are implemented preferable with voltage source PWM inverters, with a dc bus having a reactive element such as a capacitor. Active power filters can perform one or more of the functions required to compensate power systems and improving power quality.[11]

III: Types of Active Power filter

Mainly there are three types of active power filter:

- ***Based on the converter type***
  - VSI Inverter
  - CSI Inverter
- ***Based on topology***
  - Active Shunt Filter

Active series Filter
Hybrid filter

- ***Based on supply system***

1-Phase-2 wire system
3-Phase -3 wire system
3-Phase-4 wire system

3.1 SHUNT ACTIVE POWER FILTERS

Shunt active power filter compensate current harmonics by injecting equal-but-opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180o. This principle is applicable to any type of load considered a harmonic source. Moreover, with an appropriate control scheme, the active power filter can also compensate the load power factor. In this way, the power distribution system sees the non linear load and the active power filter as an ideal resistor. [11]

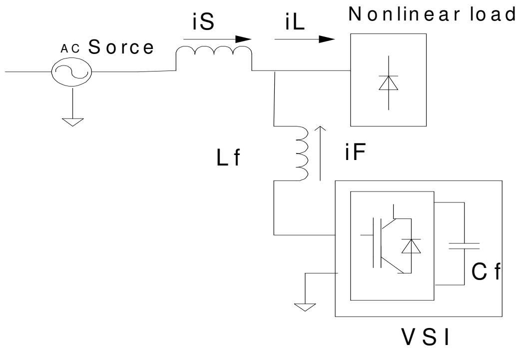

Fig 3.1 shunt active power filter [1]

3.2 SERIES ACTIVE POWER FILTER

Series APF is connected in series with the distribution line through a matching transformer. VSI is used as the controlled source, thus the principle configuration of series APF is similar to shunt APF, except that the interfacing inductor of shunt APF is replaced with the interfacing transformer. Here operation principle of series APF is based on isolation of the harmonics in between the nonlinear load and the source. This is obtained by the injection of harmonic voltages across the interfacing transformer Series APFs are less.
Here resulting high capacity of load currents will increase their current rating considerably compared with shunt APF, especially in the secondary side of the interfacing transformer. This will increase the I2R losses. Here advantage of series APFs over shunt one is that they are ideal for voltage harmonics elimination.[1]

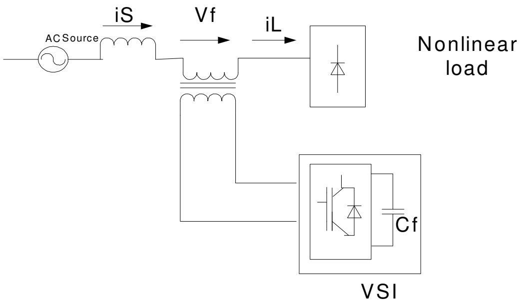

Fig 3.2 series active power filter [1]

It provides the load with a pure sinusoidal waveform, which is important for voltage sensitive devices (such as power system protection devices). With this feature, series APF is suitable for improving the quality of the distribution source voltage [1]

IV. CONTROL STRATERGIES

4.1 SRF CONTROLLER IMPLEMENTATION

The synchronous reference frame theory or d-q theory is based on time-domain reference signal estimation techniques. It performs the operation in steady-state or transient state as well as for generic voltage and current waveforms. It allows controlling the active power filters in real time system. Another important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation. The basic structure of SRF controller consists of direct (d-q) and inverse (d-q)-1 park transformations as shown in fig. These can useful for the evaluation of a specific harmonic component of the input signals .

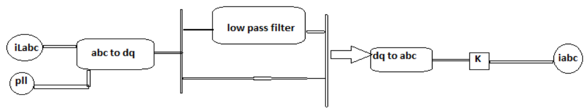

Fig 4.1 Synchronous d-q reference frame based compensation algorithm[6]

These three phase space vectors stationary coordinates are easily transformed into two axis d-q rotating reference frame transformation. This algorithm facilitates deriving id-iq(rotating current coordinate) from three phase stationary coordinate load current iLa .iLb iLc, as shown in equation[6]

$$\begin{pmatrix} i_{Ld} \\ i_{Lq} \\ i_{Lo} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \cos\theta & \cos\left(\theta - 2\pi/3\right) & \cos\left(\theta + 2\pi/3\right) \\ \sin\theta & \sin\left(\theta - 2\pi/3\right) & \sin\left(\theta + 2\pi/3\right) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{pmatrix} \begin{pmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{pmatrix}$$

The d-q transformation output signals depend on the load current (fundamental and harmonic components) and the performance of the Phase Locked Loop (PLL). The PLL circuit provides the rotation speed (rad/sec) of the rotating reference frame, where ωt is set as fundamental frequency component. The PLL circuit provides sinϴ and cosϴ. The id-iq current are sent through low pass filter (LPF) for filtering the harmonic components of the load current, which allows only the fundamental frequency components. The LPF is a second order Butterworth filter, whose cut off frequency is selected to be 50 Hz for eliminating the higher order harmonics.

In the synchronously rotating D-Q reference frame, the components at the fundamental frequency are transformed to DC quantities and all the harmonics are transformed to non DC quantities. SRF controller extracts the DC quantities by a low pass filter and hence it is insensitive to phase error. The series active filter is current controlled with the 3 phase fundamental supply current references i_{sa}, i_{sb}, i_{sc}. The SRF controller realizes the series active filter inverter as a current controlled harmonic voltage source which injects only harmonic voltage and zero fundamental frequency voltage into the supply line and consequently does not handle any fundamental VA. [5][6]

Equation used for conversion:

- Converting 3 phase to 2 phase (abc-alpha beta)

$$\begin{bmatrix} i_{S\alpha} \\ i_{S\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Sa} \\ i_{Sb} \\ i_{Sc} \end{bmatrix}$$

- Converting alpha beta to DQ

$$\begin{bmatrix} i_{SD} \\ i_{SQ} \end{bmatrix} = \begin{bmatrix} \cos(wt) & -\sin(wt) \\ \sin(wt) & \cos(wt) \end{bmatrix} \begin{bmatrix} i_{S\alpha} \\ i_{S\beta} \end{bmatrix}$$

- Converting DQ to alpha beta

$$\begin{bmatrix} i_{Sf\alpha} \\ i_{Sf\beta} \end{bmatrix} = \begin{bmatrix} \cos(wt) & \sin(wt) \\ -\sin(wt) & \cos(wt) \end{bmatrix} \begin{bmatrix} i_{SdcD} \\ i_{SdcQ} \end{bmatrix}$$

- Converting 2 phase to 3phase (alpha beta-abc)

$$\begin{bmatrix} i_{Sfa} \\ i_{Sfb} \\ i_{sfc} \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Sf\alpha} \\ i_{Sf\beta} \end{bmatrix}$$

$$\begin{bmatrix} i_{Sha} \\ i_{Shb} \\ i_{Shc} \end{bmatrix} = \begin{bmatrix} i_{Sa} \\ i_{Sb} \\ i_{Sc} \end{bmatrix} - \begin{bmatrix} i_{Sfa} \\ i_{Sfb} \\ i_{Sfc} \end{bmatrix}$$

$$\begin{bmatrix} v_{af} \\ v_{bf} \\ v_{cf} \end{bmatrix} = K \begin{bmatrix} i_{Sha} \\ i_{Shb} \\ i_{Shc} \end{bmatrix}$$

This voltage is used to produce PWM signal.

4.2 P-Q THEORY

The p-q theory is time domain method often called instantaneous reactive power theory. This theory is valid for steady state and transient operation as well as generic operation current and voltage waveform. The active power filter is expected to generate the appropriate compensating voltage/current signals that cancel the harmonic and reactive power components in the voltage/currents from the mains. The reference compensation signals are generated by making use of a control algorithm. The p-q theory is based on a set of instantaneous powers defined in the time domain. No restrictions are imposed on current or voltage wave forms and it can be applied to three phase system with or without a neutral wire. This theory is advantageous due to easy algebraic calculation.[3]

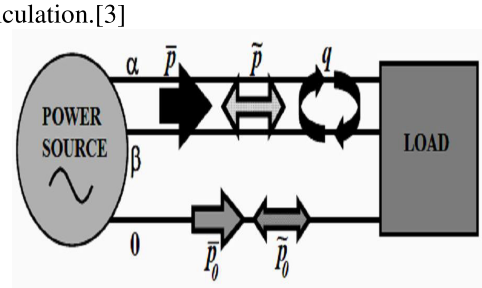

Fig 4.2 p q theory

Instantaneous reactive power theory (IRPT) uses the park transform, to generate two orthogonal rotating vectors (α and β) from the three phase vectors (a, b and c). This transform is applied to the voltage and current and is given by eqn 1.[3]

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

$$\begin{bmatrix} i_{S\alpha} \\ i_{S\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Sa} \\ i_{Sb} \\ i_{Sc} \end{bmatrix}$$

By looking at instantaneous powers, the harmonic content can be visualized as a ripple upon a DC offset representing the fundamental power. By removing the DC offset and performing the inverse park transform the harmonic current can be determined The supply voltage and load current are transformed into αβ quantities. The instantaneous active and reactive powers p and q are calculated from the transformed voltage and current as given in Eq. (2). [3]

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} i_{S\alpha} \\ i_{S\beta} \end{bmatrix}$$

(Eqn .2) [4]

Which gives,

Po= vo.io instantaneous zero sequence power

p= $v\alpha.i\alpha + v\beta.i\beta$, instantaneous real power

q= $-v\beta.i\alpha+v\alpha.i\beta$, instantaneous imaginary power

The instantaneous active and reactive powers are filtered to leave the AC components. The compensating currents are determined by taking the inverse and is given by Eq. (3) [3]

$$\begin{bmatrix} i_{Sah} \\ i_{Sbh} \\ i_{Sch} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix}$$

(Eqn. 3)

This current is then multiplied by gain (k) to produce PWM signal.

V. SIMULATION RESULT

To demonstrate the performance of these active filters feeding a three-phase converter with R load is used, these active filters are modelled in MATLAB along with SIMULINK and power system block set toolboxes.

- SYSTEM PARAMETERS

The system parameters considered for the study of active shunt filter

- AC Source Vs=415v, f=50 Hz
- Nonlinear Load 3-Φ Thyristor Rectifier
- R=10 (Ω)

- **Matlab model and results of active shunt filter**

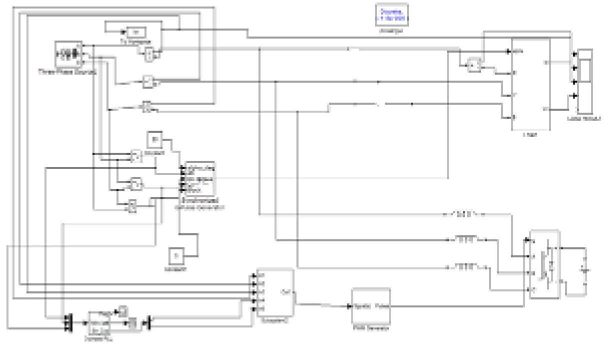

Fig 5.1 matlab model of shunt APF

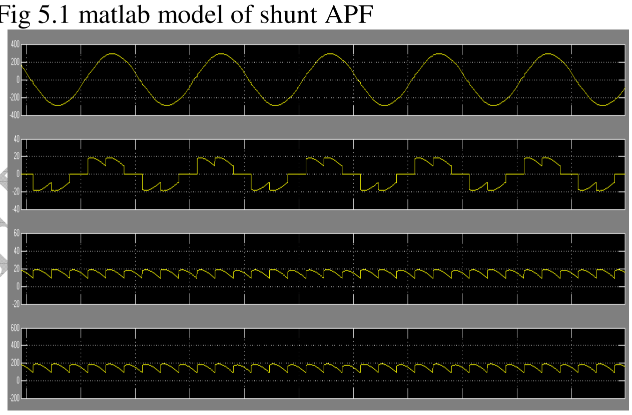

Fig 5.2 simulation result of APF

Table1 .FFT Analysis for Active Filter

alpha	5th	7th	9th	11th	Overall THD
0	3.15	1.71	0.06	0.68	3.69
30	1.40	0.90	0.02	0.21	1.92
60	2.15	1.97	0.03	0.28	3.12

VI. CONCLUSION

The MATLAB simulation has verified the effectiveness of the proposed control scheme of active filter. The distortion of power supply current is diminished to a satisfactorily level. Using active filter the total harmonic distortion is reduced from 34.97 to1.92 (for alpha=30)

VII. REFERENCES

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