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# Shunt Active Power Filter for Compensation of System Harmonics

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***Abstract:** The abundant use of power electronics based equipment/systems have produced an important impact on the power quality of electric power supply distribution system. The non-linear type domestic and industrial loads injects harmonics in the system voltages. Besides, many of the equipment causing the harmonic distortions are sensitive to the deviations from the ideal sinusoidal line voltage. Shunt active power filters are well known to compensate the system harmonics. This paper presents the classification of active filters, simulation of shunt active power filter based on p-q theory control strategy and results in the form of waveform of source current before compensation and after compensation have been shown.*

***Keywords:** Shunt Active Harmonic Power Filter, Harmonics, Non-Linear Load, P-Q Theory, PWM Inverter , FFT Analysis.*

## I. INTRODUCTION

With significant development of power electronics technology, the increase of nonlinear loads such as static power converters has decreased power quality in power transmission and distribution systems. Notably, voltage harmonics resulting from current harmonics produced by the nonlinear loads have become a serious problem in many countries. Harmonics in power systems have been suppressed so far by shunt passive filters. However, shunt passive filters have many problems to discourage their applications. As shown in Fig. 1, a shunt passive filter exhibits lower impedance at a tuned harmonic frequency than the source impedance to reduce the harmonic currents flowing into the source. The impedance ratio of the source decides the filtering characteristics of the shunt passive filter. Therefore the shunt passive filter has the following problems.

i) The source impedance, which is not accurately known and varies with the system configuration strongly influences filtering characteristics of the shunt passive filter.

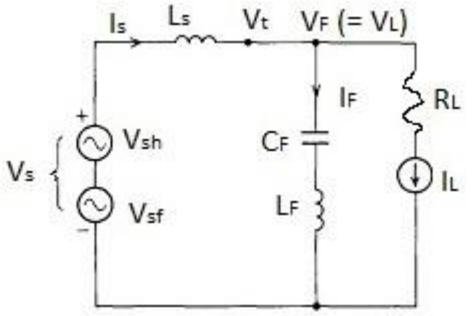

Fig. 1 Basic Principle of Shunt Passive Filter

ii) The shunt passive filter acts as a current sink to the harmonic voltage included in the source voltage $V_S$. In the worst case, shunt passive filter falls in series resonance with the source impedance [3].

To cope up with these demerits of shunt passive filter continuous efforts have been put by power electronics researchers on development and design of shunt active power filter [7].

In shunt active power filter, the harmonic component and reactive power required by the non-linear load is fed separately so that the source has to supply only sinusoidal component. In other words, harmonic current component being fed by shunt active power filter into the line is 180 degree phase opposition to the harmonic component drawn by non-linear load and they get cancel out [8].

The general schematic of shunt active power filter is shown in Fig. 2.

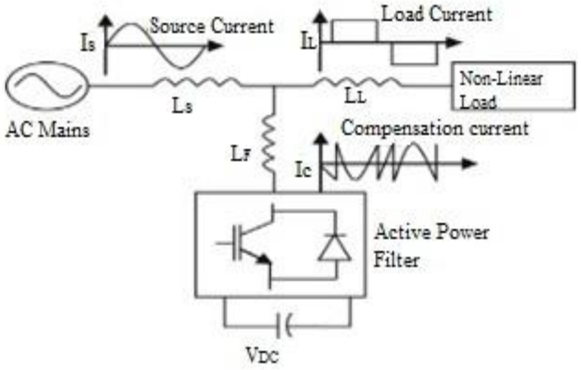

Fig. 2 General Schematic of Shunt Active Power Filter

In this paper simulation of shunt active power filter incorporating control topology based on reactive power p-q theory is presented .The shunt active power filter considered here satisfactorily compensates the harmonic contents of source current.

## II. CLASSIFICATION OF ACTIVE FILTER

In many technical literatures, various types of active filters have been proposed. The classification of active filters is done in many ways. Active filters are classified mainly in two types, ac and dc filters. Active dc filters have been designed to compensate for current and/or voltage harmonics on the dc side of thyristor converters for HVDC systems and on the dc link of a PWM rectifier/inverter for traction systems**.** The term “active filters” refers to active ac filters in most cases.

### A. *Classification by Objectives: Who Is Responsible for Installing Active Filters?*

The objective of "who is responsible for installing active filters" classifies them into the following two groups:

- Active filters installed by individual consumers on their own premises near one or more identified harmonic producing loads
- Active filters installed by electric power utilities in substations and/or on distribution feeders.

The main purpose of the active filters installed by individual is to compensate current harmonics and current imbalance of their own harmonic producing loads. On the other hand, the primary purpose of active filters in the near future will be to compensate voltage harmonics and voltage imbalance, or to provide "harmonic damping" throughout power distribution systems. In addition, active filters have the function of harmonic isolation at the utility consumer point of common coupling in power distribution systems.

### B. *Classification by System Configuration :*

#### *1) Shunt Active Filters and Series Active Filters*

A system configuration of a shunt active filter when it is used alone is shown in Fig. 4, which is one of the most fundamental system configurations. The shunt active filter is controlled to draw a compensating current, $I_{AF}$ from the utility, so that it cancel current harmonics on the ac side of a general purpose diode rectifier with a dc link inductor [4] or a PWM rectifier with a dc link capacitor for traction systems [6]. The shunt active filter has the capability of damping harmonic resonance between an existing passive filter and the supply impedance [2].

A system configuration of a series active filter used alone is shown in Fig. 5. The series active filter is connected in series with the utility through a matching transformer, so that it is applicable to harmonic compensation of a large capacity diode rectifier with a dc link capacitor. Table I shows comparison between the shunt and series active filters.

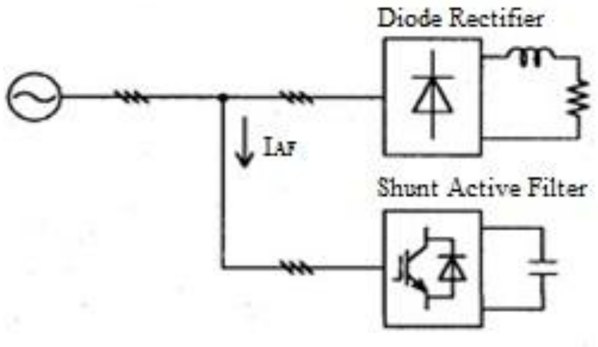

Fig. 4 Shunt Active Filter Used Alone

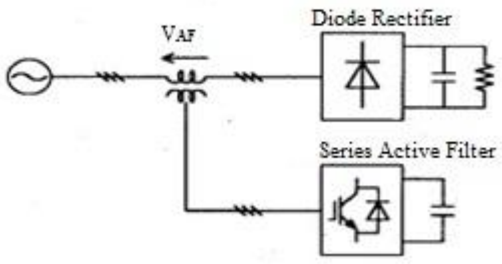

Fig. 5 Series Active Filter Used Alone

Table I. Comparision of Shunt And Series Active Filter Used Alone

| | Shunt Active Filter | Series Active Filter |
|---|---|---|
| System Configuration | Figure 4 | Figure 5 |
| Power Circuit Of Active Filter | Voltage Fed PWM Inverter with Current Minor Loop | Voltage Fed PWM Inverter without Current Minor Loop |
| Active filter acts as | Current source: $I_{AF}$ | Voltage source: $V_{AF}$ |
| Additional Function | Reactive Power Compensation | Ac Voltage Regulation |
| Present Situation | Commercial Stage | Laboratory Level |

#### *2) Hybrid Active/Passive Filters:*

Three types of hybrid active/passive filters are shown in Figs. 6-8. To reduce initial cost and to improve efficiency are the main purpose of these hybrid active/passive filters. The shunt passive filter consists of one or more tuned *LC* filters and/or a high-pass filter. Table II shows comparison among three hybrid filters, in which the active filters are different in function than the passive filters. The combination of shunt active and passive filters have already been applied to harmonic compensation of large rated cycloconverters for steel mill drives [2]. The combined filters (shown in Fig. 4 and in Fig. 5) will be practically applied in the near future, not only for harmonic compensation but also for harmonic isolation between supply and load, and for voltage regulation and imbalance compensation. They are considered prospective alternatives to shunt or series active filters used alone. Comparison of Shunt active filter plus shunt passive filter, Series active filter plus shunt passive filter and Series active filter connected in series with shunt passive filter is shown in Table II.

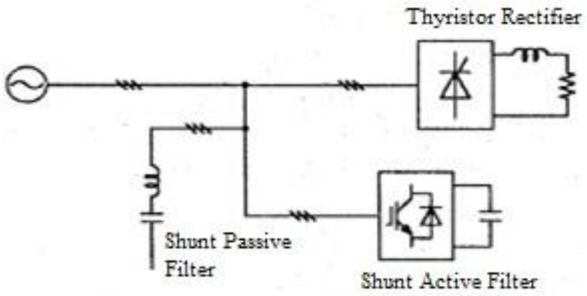

Fig. 6. Combination of Shunt Active Filter and Shunt Passive Filter

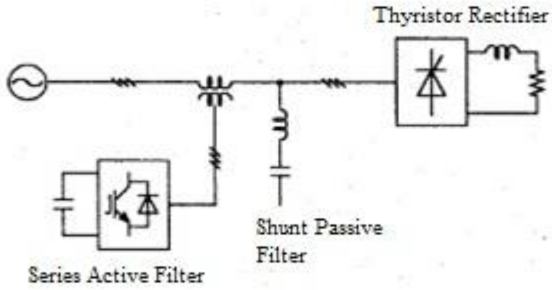

Fig. 7. Combination of Shunt Passive Filter and Series Active Filter

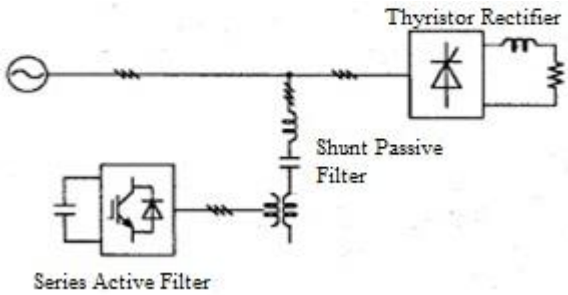

Fig. 8. Active Filter Connected in Series with Shunt Passive Filter

Table II.

| | Shunt active filter plus shunt passive filter | Series active filter plus shunt passive filter | Series active filter connected in series with shunt passive filter |
|---|---|---|---|
| System configuration | Figure 6 | Figure 7 | Figure 8 |
| Function of active filter | Harmonic compensation or harmonic damping | Harmonic isolation and harmonic damping | Harmonic compensation or harmonic damping |
| Advantage | Reactive power controllable | No harmonic current flowing through active filter | Easy protection of active filter |
| Problems or issues | Share compensation in frequency domain between active filter and passive filter | Difficult to protect active filter against overcurrent and no reactive power control | No reactive power control |
| Present situation | Commercial stage | Field testing | Coming in market |

### C. *Classification by Power Circuit :*

There are two types of power circuits used for active filters: a voltage-fed PWM inverter [2] and a current-fed PWM inverter [1]. These are similar to the power circuits used for ac motor drives. They are, however, different in their behavior because active filters act as non-sinusoidal current or voltage sources. The voltage-fed is preferred to the current-fed PWM inverter because the voltage-fed PWM inverter is higher in efficiency and lower in initial cost than the current-fed PWM inverter [5].

## III. INSTANTANEOUS REACTIVE POWER P-Q THEORY

In this paper p-q theory is presented for determining the compensation current need to be injected into the network at the **P**oint of **C**ommon **C**oupling (PCC) feeding non-linear loads.

It involves an algebraic transformation of three-phase power system voltages and currents in a-b-c coordinates to α-β coordinates. In a-b-c coordinates, the a, b and c axis are fixed on the same plane, apart from each other by $2\pi/3$.

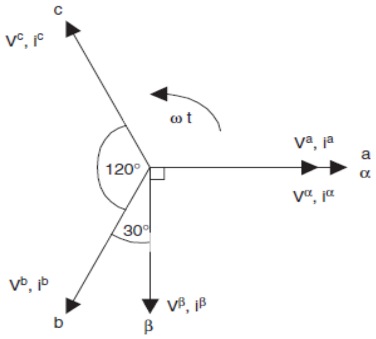

Fig. 9. Clarke Transformation

In the Clark transformation, three phase system is converted into two phase stationary frame of reference system. From this transformation the voltage and current parameters can be expressed as the sum of two self-dependent vectors which are orthogonal to each other. The instantaneous values of system voltage and current in α-β coordinates is as follows.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = [A] * \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \; and \; \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = [A] * \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (1)$$

Where,

$[A]$ = Transformation matrix

$$[A] = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}$$

$$V(t) = V_\alpha(t)i + V_\beta(t)j \qquad (2)$$

$$I(t) = I_\alpha(t)i + I_\beta(t)j \qquad (3)$$

The active power is the dot product of voltage and current whereas reactive power is the cross product of voltage and current

$$p(t) = V(t).I(t) \qquad (4)$$

$$q(t) = V(t) \times I(t) \qquad (5)$$

$$p(t) = V_\alpha(t)I_\alpha(t) + V_\beta(t)I_\beta(t) \qquad (6)$$

$$q(t) = V_\alpha(t)I_\beta(t) - V_\beta(t)I_\alpha(t) \qquad (7)$$

p(t) and q(t) are divided into two parts namely average part which is non-oscillating whereas the other part is oscillating.

$$p(t)=P(t)+P'(t) \qquad (8)$$

$$q(t)=Q(t)+Q'(t) \qquad (9)$$

Since component $P'(t)$ does not involve in any energy transfer from supply to load, it must be compensated. Similarly $q(t)$ which is reactive power it also does not involve in any energy transfer from supply to load it also must be compensated. We have to also compensate switching losses of the inverter which is known as $P_{loss}$. Now Referring $P'(t)$ $+P_{loss}$ and $q(t)$, the reference current can be generated which decides the switching state of inverter.

The reference current of the shunt active power filter must include the values of $P'(t)$, $P_{loss}$, $Q(t)$ and $Q'(t)$. In this case, the reference currents required by the shunt active power filter are calculated as follows

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} . \begin{bmatrix} P'(t) + P_{loss} \\ Q(t) + Q'(t) \end{bmatrix} \qquad (10)$$

Now, this is in α-β co-ordinate but we need reference compensation current in a-b-c co-ordinate, by taking inverse clarke transformation we get,

$$\begin{bmatrix} i_{ac} \\ i_{bc} \\ i_{cc} \end{bmatrix} = [A] * \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} \qquad (11)$$

Where,

$$[A] = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}$$

## IV. SIMULATION OF SHUNT ACTIVE POWER FILTER

### A. *Simulation Model:*

The simulation model with and without Shunt Active Power Filter has been developed based on P-Q theory for harmonic compensation as Shown in Fig. 10.

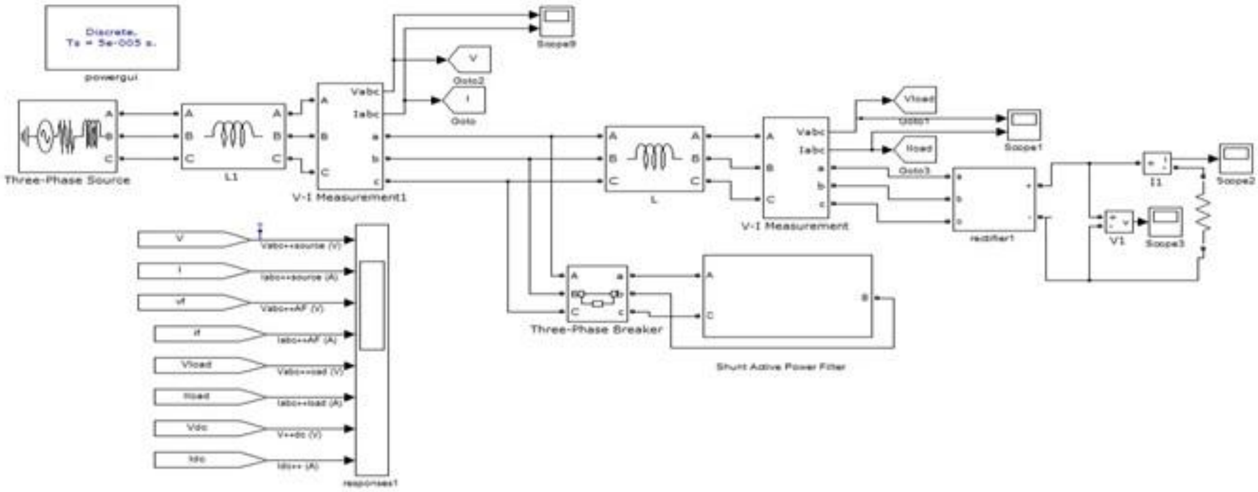

Fig. 10. Simulation Model of Shunt Active Power Filter

The various subsystems of the active harmonic power filter circuit configuration have been simulated and the gate drive signals for the switching devices have been appropriately generated for the Pulse Width Modulation (PWM) inverter.

### B. *Simulation Results:*

The topology of active harmonic filter discussed in the previous section has been investigated and subsequently validated through simulation software and the results (waveforms) obtained are shown in Fig. 11 and Fig. 13 for an electrical network, in which source current before compensation and after the compensation have been plotted.

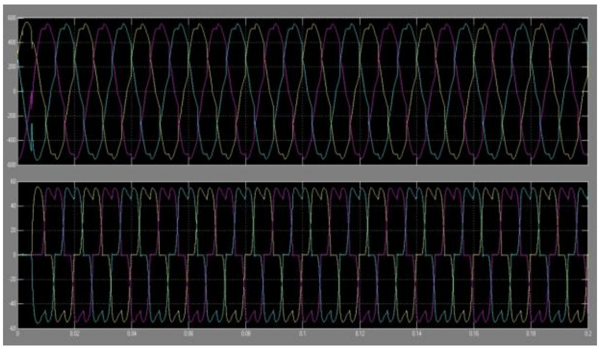

Fig. 11. Source Current before Harmonic Current Compensation

The three phase six pulse bridge rectifier with resistive load is considered as a nonlinear load connected to the feeder line giving the **T**otal **H**armonic **D**istortion (THD) of 22.62% as shown in Fig. 12. The dominant harmonics in this system are 5th and 7th (as per np±1 where n is integer and p is number of pulses).

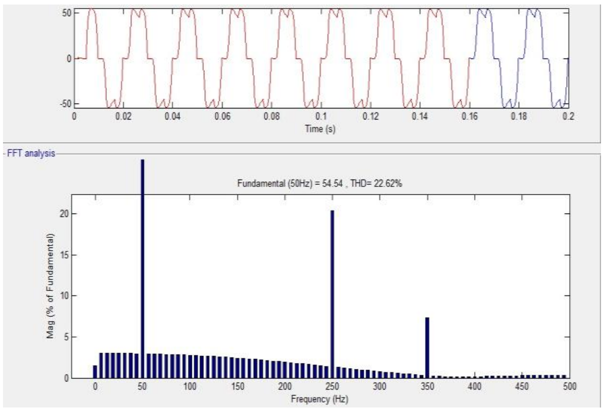

Fig. 12. FFT Analysis before Harmonic Current Compensation

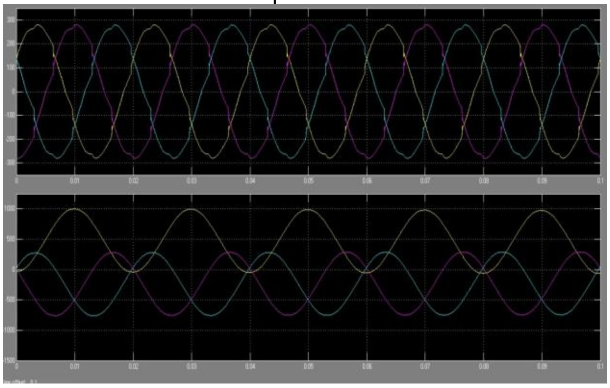

Fig. 13. Source Current after Harmonic Current Compensation

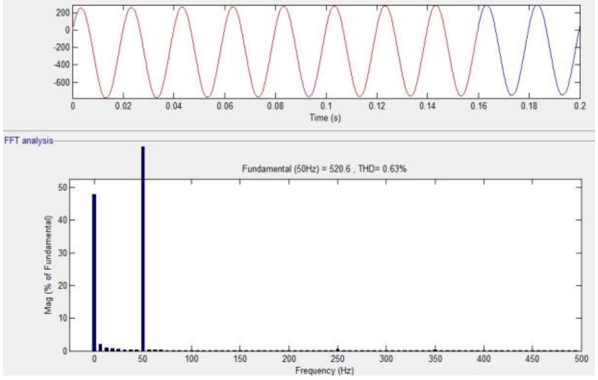

Fig. 14 FFT Analysis after Harmonic Current Compensation

The waveform of source current after harmonic current compensation is shown in Fig. 13. The reference current should contain all these harmonics for the requirement of actual compensation in out of phase manner. Thus, the **T**otal **H**armonics **D**istortion (THD) obtained after the compensation is found reduced to 0.63%.

## V. CONCLUSION

Simulation model of shunt active power filter has been simulated with the help of control topology based on p-q theory for three phase system and results are found satisfactory. On the basis of results obtained it is concluded that the harmonic level of the system is reduced from 22.62% to 0.63% after application of shunt active power filter, meeting IEEE: 519 guidelines.

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