Comparison of Various Configurations of Hybrid Active Power Filter

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Abstract— This paper presents a comparative analysis of Hybrid Active Filter with Instantaneous p-q theory control strategy method. A comparative evaluation of three configurations of hybrid filter is carried out with balance and unbalance load. A PI controller is used to control the dc capacitor voltage. The modeling of different filter topologies is done using MATLAB/Simulink.

Key words: Active filters (AF), Passive filters, Hybrid filter, Instantaneous reactive power theory (p-q).

I. INTRODUCTION

Large number of power electronic applications is used nowadays in industrial as well as for household applications. Nonlinear load draw non sinusoidal current due to which the source current get distorted suffers with the problem of poor power quality [4, 7]. They draw harmonic currents as well as reactive power. To mitigate these problems various types of filters are designed [5]. These filters are classified into mainly two categories- passive filters and active filters. Passive filters are mainly consists of resistance, inductance and capacitance placed in such a fashion that it acts as a frequency discriminator. Accompanying with advantages of low maintenance cost, high efficiency and easy to implement, they suffer from various drawbacks such as changing system conditions then they are unsuitable. The source impedance changes with the change in system parameters and it affects its filtering characteristics. Due to problem of ageing and temperature effects detuning of filter occurs. There is a problem of parallel resonance between filter and system [6].

Due to these problems of passive filters development of power electronic devices based filter is encouraged known as Active filters. Active filters also suffer from some of the disadvantages like they are more expensive than the passive filters. High rating of active filters also leads to high cost. Therefore, attention of researchers is shifted to hybrid active filters.

II. CONFIGURATIONS OF HYBRID ACTIVE FILTER

Hybrid1: Combination of shunt active and shunt passive Filter

This configuration is most commonly uses because this provides the excellent compensation characteristics. The main advantage with this configuration is relative independence between active and passive filters. Passive filter always provides filtering action even if active filter is out of service. The presence of passive type filter alters the impedance characteristics of the whole system, therefore Proper coordination between the two needs to be maintained. The other advantage is that the rating of the active filter is reduced and hence the configuration is more economical compared to shunt active filter used alone.[11]

The passive filters are mainly employed to filter the lower order harmonics and for reactive power compensation. The rest of higher order harmonics is compensated by the active filter. But due to the presence of passive filter impedance characteristics of the system changes and there is a possibility that passive filter could start taking current by the

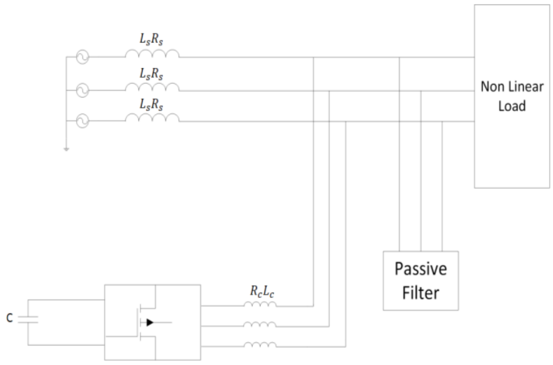

Fig. 1: Hybrid filter with active and passive both in shunt

Active filter. This will make both active and passive filters overloaded

Hybrid2: Combination of shunt active and series passive Filter

In this configuration a series passive filter and a shunt passive filter are connected. The operating principle of this configuration is almost same as that when the shunt active filter is connected in parallel with the shunt passive filter [8]. This is generally used when the source voltage is contained with some harmonic contents.

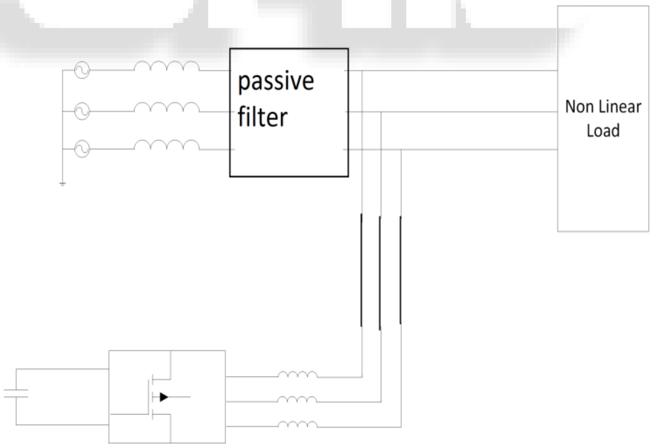

Fig. 2: Hybrid filter with active in shunt and passive in series

Hybrid3: Active filter in series with the parallel passive Filter

This is one of best scheme of hybrid filters. In this the active filter is connected in series with the passive filters. There are two ways by which this connection can be made, one is either by using transformer [1] and other is transformerless. Initially, configuration was implemented with transformer but it was not cost effective so transformer-less configuration was designed.

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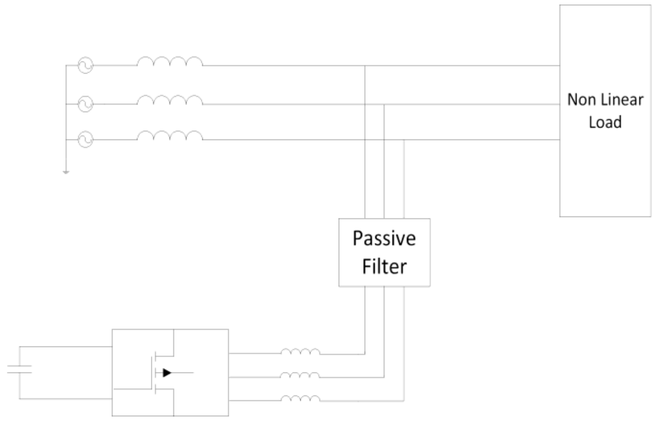

Fig. 3: Hybrid filter with passive in series with active shunt filter

The main advantage of this configuration is that the rating of active filter is greatly reduced because the value of dc capacitor is of very less value. In this configuration the the harmonics is imposed and zero impedance is posed for the fundamental component.

III. EXPLANATION PQ THEORY CONTROL STRATEGIES

A. *Instantaneous p-q Theory*

It is based on instantaneous power defined in time domain. The p-q theory is applicable to both three phase three wire system as well as three phase four wire system. Since it is based on instantaneous power calculation, it is valid both in steady state as well as transient state. This theory uses the concept of Clark's transformation[10]. In this transformation the three instantaneous voltages in abc is transformed in αβ0 axes.

The Clarke Transformation for the three phase voltage is represented in matrix form as

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 0.707 & 0.707 & 0.707 \\ 1 & -0.5 & -0.5 \\ 0 & 0.866 & -0.866 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

Similarly the Clarke Transformation for three phase current is represented as

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 0.707 & 0.707 & 0.707 \\ 1 & -0.5 & -0.5 \\ 0 & 0.866 & -0.866 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

If the load is balanced then V_O and i_o can be neglected in the equation represented above in the matrix form and the instantaneous voltage vector can be define as

$$e = V_\alpha + jV_\beta$$
$$i = i_\alpha + ji_\beta$$

The instantaneous complex power can be defined as product of voltage vector and conjugate of current vector and it can be represented as

$$s = e * i^* = \left(V_\alpha + jV_\beta\right) * \left(i_\alpha + ji_\beta\right)$$
$$= \left(V_\alpha i_\alpha + V_\beta i_\beta\right) + j(V_\beta i_\alpha - V_\alpha i_\beta)$$

The real part of the complex power is defined as *p* and the imaginary part is represented as *q*. Because of the fact that instantaneous voltage and current values are used there is no restriction in *s*, so it can be applied during steady state or transient conditions. The matrix representation of *p* and *q* is given as

$$\begin{pmatrix} p \\ q \end{pmatrix} = \begin{pmatrix} v_\alpha & V_\beta \\ -V_\beta & v_\alpha \end{pmatrix} \begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix}$$

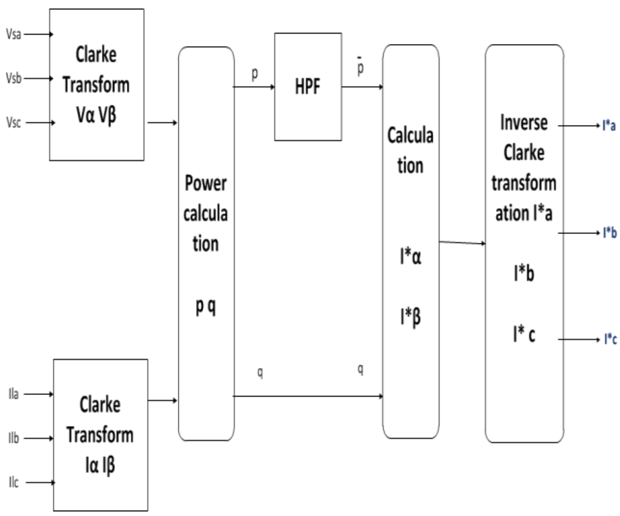

Fig. 4: Block diagram of Instantaneous reactive power theory

The calculated value of *p* is separated into two parts. One is its average part represented as $\overline{p}$ and the other is the oscillating part represented as $\tilde{p}$. Similarly the load imaginary power *q* can be divided into two parts $\overline{q}$ and $\tilde{q}$. The undesirable components of real and imaginary power are chosen for the compensation. These compensated powers are known as $(-p_c)$ and $(-q_c)$. There is a reason of using the negative sign in powers. This is because active filter should draw a compensating current in such a way that it will produce exactly inverse of the undesirable powers drawn by nonlinear load. The $\alpha - \beta$ current calculation is done by using the following expression.

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} -p_c \\ -q_c \end{bmatrix}$$

Now, the inverse Clarke Transformation is carried out to get the value of three phase compensation current.

IV. SIMULATION RESULTS

For the simulation analysis of active hybrid filters the following parameters of the system are selected:

Supply phase voltage= 40 V peak
Source impedance: Rs=0.001ohm , Ls=0.001 mH
Coupling inductance=10 mH
Load resistance=20 ohm
Load inductance=10 mH

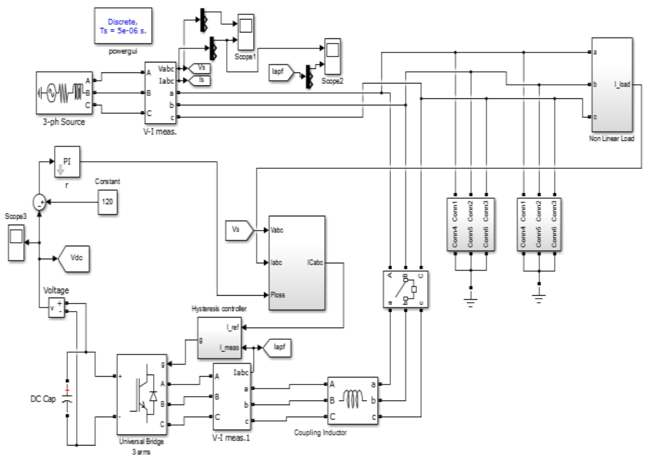

Fig. 5: Simulation model of Hybrid Active Filter configuration 1

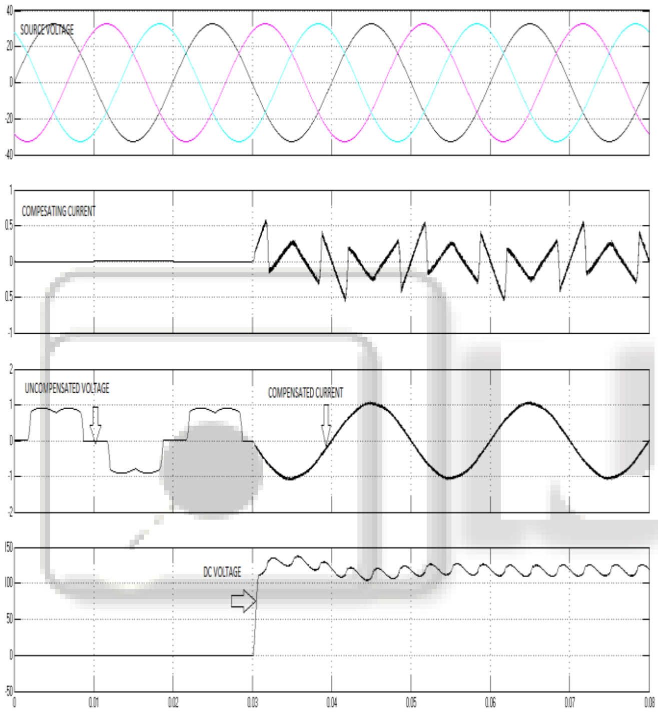

Fig. 6: Waveforms of source voltage ,compensating current, compensated source current and DC voltage

When a nonlinear load (diode bridge rectifier) is connected alone the waveform of the source current is as shown in the figure 7 and the THD of the source current is 28.38%.

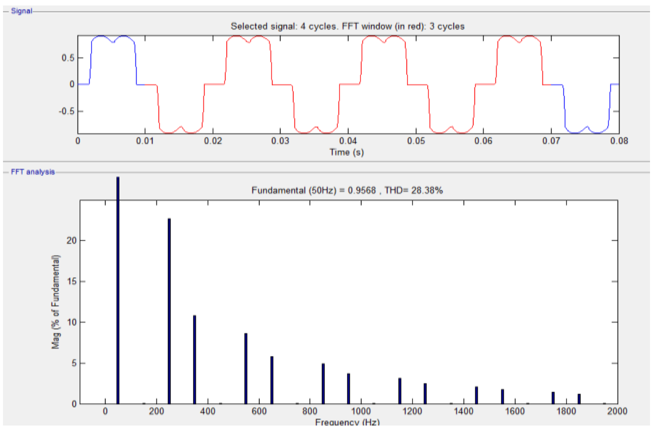

Fig. 7: THD% analysis without Filter

Now to eliminate these harmonics hybrid filters are used with three configurations as explained above with balance and unbalance load.

When the configuration 1 with balance load and unbalance load is used the THD% reduces to 1.04% and 2.67% respectively shown in fig. 8 and fig.

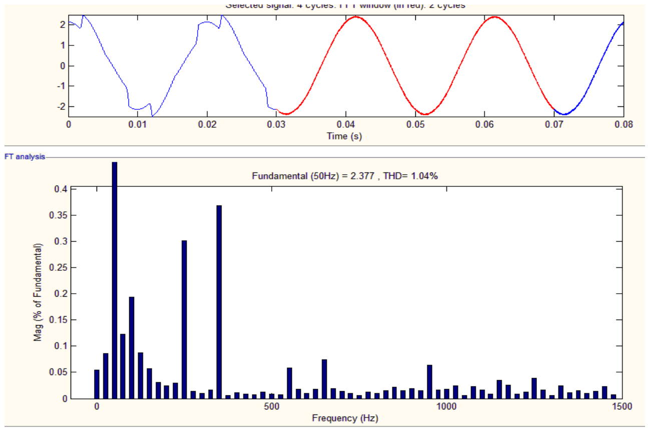

Fig. 8: THD% analysis with Configuration 1 Hybrid Filter with balance load

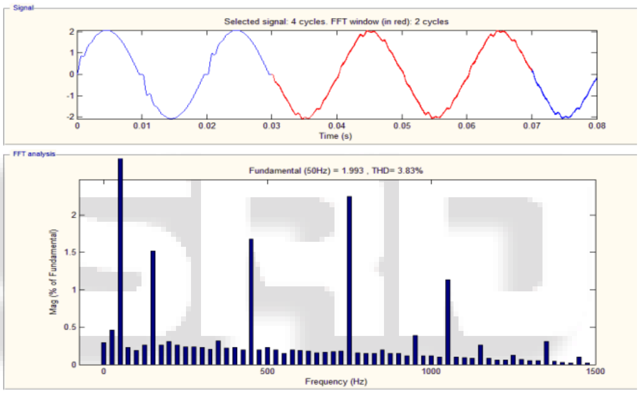

Fig. 9: THD% analysis with Configuration 1 Hybrid Filter with unbalance load

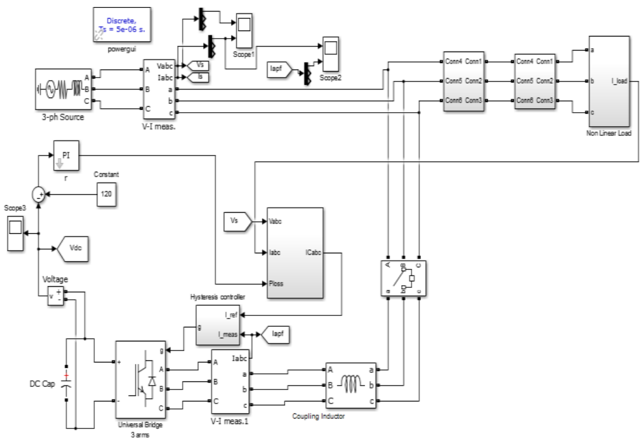

Fig. 10: Simulation model of Hybrid Active Filter configuration 2

When the configuration 2 with balance load and unbalance load is used the THD% reduces to 2.30% and 4.73% respectively shown in fig. 11 and fig. 12.

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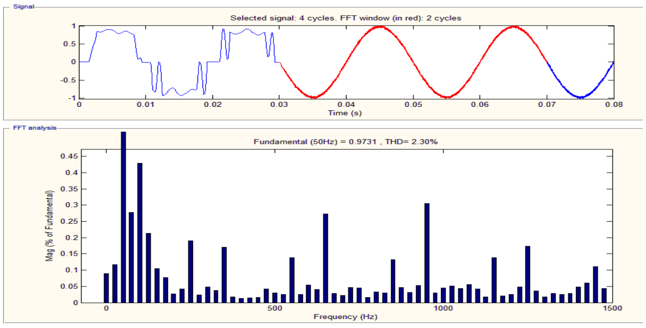

Fig.11: THD% analysis with Configuration 2 Hybrid Filter with balance load

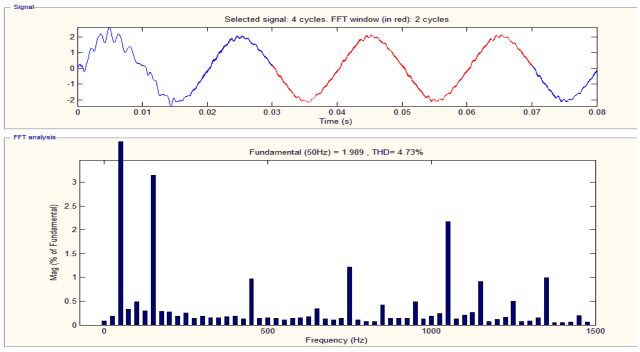

Fig. 12 THD% analysis with Configuration 2 Hybrid Filter with unbalance load

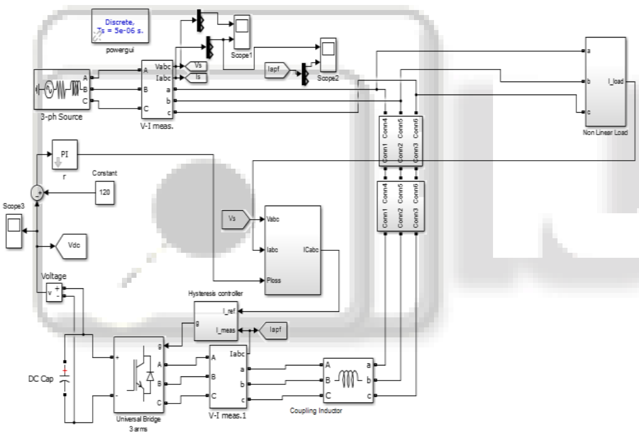

Fig.13 Simulation model of Hybrid Active Filter configuration 3

When the configuration 2 with balance load and unbalance load is used the THD% reduces to 2.17% and 4.15% respectively shown in fig. 14 and fig. 15.

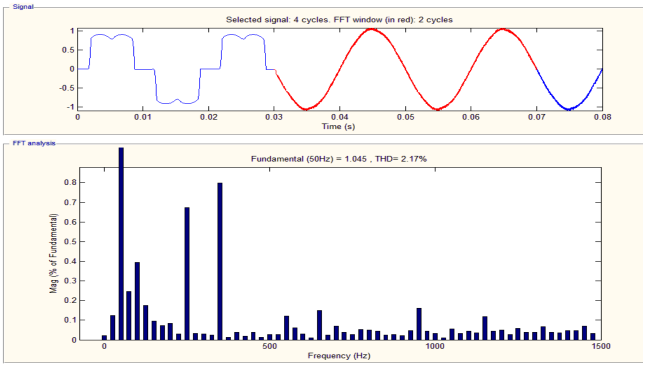

Fig. 14 THD% analysis with Configuration 3 Hybrid Filter with balance load

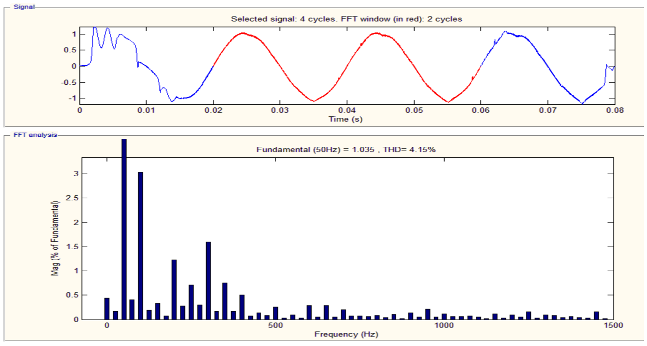

Fig. 15 THD% analysis with Configuration 3 Hybrid Filter with unbalance load

LOAD	THD%(Configuration1)	THD%(Configuration2)	THD%(Configuration3)
Balance load	1.04%	2.30%	2.17%
Unbalance load	2.67%	4.73%	4.15%

Table 1

V. CONCLUSION

Simulations and the comparison among the Hybrid Filter configuration is done. The harmonics in the source current gets reduced using different configurations of hybrid filter. By analyzing the results of various simulations of hybrid filter it is concluded that configuration 1 is best.

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