International Journal of Advanced Technology in Engineering and Science
Vol. No.6, Issue No. 05, May 2018
www.ijates.com
ijates
ISSN 2348 - 7550

AMELIORATION OF POWER QUALITY USING HYBRID POWER FILTER

[1]Lokasree B.S, [2]Kumar Reddy Ch

[1]*Electrical Power Systems, Sree Vidyanikethan Engineering College/JNTUA, India*

[2]*Electrical and Electronics Engineering, Sree Vidyanikethan Engineering College/JNTUA, India*

ABSTRACT

This paper presents the results and Total Harmonic Distortion of the Hybrid Power Filter with which a Shunt Passive Filter is used to eliminate Current Harmonics and Series Active Filter eliminating Voltage Harmonics at the source side. Harmonic Distortion is the major Power Quality problem caused by Non-Linear Loads which are degrading the power system now-a-days. To reduce the current and voltage harmonics at the source side active and passive filters are being used with different configurations. But the results were not obtained within the required ranges. In the proposed system total harmonic distortion is analyzed using Fast Fourier Transform analysis in MATLAB/SIMULINK.

keywords: Current Harmonics, Fast Fourier Transform, Harmonic Distortion, Hybrid Power Filter, Non-Linear Loads, Power Quality, Series Active Filter, Shunt Passive Filter, Total Harmonic Distortion, Voltage Harmonics.

I.INTRODUCTION

Now-a-days electrical energy is very efficient and prevailing form of energy and whole world is dependent on electric supply. As well as power quality is also at most important problem to be concerned. Both electric power supply companies and the end users are more concern about term power quality. Voltage and frequency decides the quality of power delivered to the consumers. If there is any deviation in voltage and frequency of electric power delivered from standard values then it affects the quality of power delivered [1]. So we need to maintain voltage and frequency with its standard values.

There are various power quality problems like power surges, transients, frequency variations, block outs, harmonics etc. power quality is the important issue which is produced due to harmonics. Major causes of harmonics are non-linear loads like UPS, SMPS, battery chargers etc. for the mitigation of voltage and current harmonics we use filters [2].

Aiming at parameters calculation of damped-double tuned filter, a new method is proposed to eliminate current harmonics and an active filter is connected in series to the distribution system to eliminate voltage harmonics. The design method is assessed for a typical distribution system and fast Fourier transform analysis in MATLAB/SIMULINK.

II.DESIGN OF DAMPED-DOUBLE TUNED FILTER

A damped double tuned filter is combination of conventional double tuned filter and damping resistors. The conventional double tuned filter comprises of series resonance circuit and a parallel resonance circuit, as shown in Fig.1.

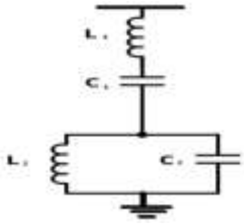

Fig.1 conventional double tuned filter [3]

The series circuit impedance is

$$: Z_s(\omega) = j(X_l - X_c) = j\left(\omega L_1 - \frac{1}{\omega C_1}\right) \quad (1)$$

Where $\omega = 2\pi f$ is the angular frequency in radians.

Hence, the series resonance frequency will be equal to

$$: Z(\omega_s) = 0 \rightarrow \omega_s = \frac{1}{\sqrt{L_1 C_1}} \quad (2)$$

On the other hand, the parallel circuit impedance is

$$: Z_p(\omega) = \left(\frac{1}{jL_2\omega} - jC_2\omega\right)^{-1} \quad (3)$$

And the parallel resonance frequency will be

$$: Z(\omega_p) = 0 \rightarrow \omega_p = \frac{1}{\sqrt{L_2 C_2}} \quad (4)$$

The Thevenin impedance of a conventional double tuned filter is, thereby, calculated through the summation of series and parallel circuits impedances. This Thevenin impedance is a function of frequency, and it will be equal to zero for tuned frequencies. Consequently, the tuned frequencies (ω_1, ω_2)are derived from

$$Z(\omega) = Z_s(\omega) + Z_p(\omega)$$

$$: Z(\omega) = j\left(L_1\omega - \frac{1}{C_1\omega}\right) + \left(\frac{1}{jL_2\omega} - jC_2\omega\right)^{-1} \quad (5)$$

Eqn. (5) can be rewritten as

$$: \omega^4 L_1 L_2 C_1 C_2 - \omega^2 (L_2 C_1 + L_1 C_1 + L_2 C_2) + 1 = 0 \quad (6)$$

Using Vida's theory, Eqn.(6) can be calculated by

$$: \omega_1 \omega_2 = \frac{1}{\sqrt{L_1 C_1}} \cdot \frac{1}{\sqrt{L_2 C_2}} = \omega_s \omega_p \quad (7)$$

Since the filter Thevenin impedance at the tuned frequencies is zero, the harmonic currents of tuned frequencies orders (ω_1, ω_2) will be suppressed by filter. These tuned frequencies are determined based on the filtering project requirements. Further, the filter impedance is infinite at the parallel frequency (ω_p), so engineer should take account of the network characteristics and select a parallel resonance frequency properly in designing procedure to prevent some harmonic current near ω_p from being amplified.Once ω_1, ω_2 andω_p are determined, $\omega_s$can be precisely calculated by (7).

Substituting (2) and (4) into (6) yields

$$:\frac{\omega^4}{\omega_s^2\omega_p^2}-\left(\frac{C_1}{C_2}\cdot\frac{1}{\omega_p^2}+\frac{1}{\omega_s^2}+\frac{1}{\omega_p^2}\right)\omega^2+1=0 \quad (8)$$

The $\omega_1$is one of the roots of (8), so replacing ω by $\omega_1$leads to the following equation between C_1 andC_2

$$:\frac{C_1}{C_2}=\frac{\omega_1^2+\omega_2^2-\omega_p^2}{\omega_s^2}-1 \quad (9)$$

Also, using (2) and (4) yield two other equations for L_1 and L_2 parameters calculation as

$$:L_1=\left(\frac{\omega p}{\omega 1\omega 2}\right)^2\cdot\frac{1}{C_1} \quad (10)$$

And

$$:L_2=\frac{1}{\omega_p^2}\cdot\frac{1}{C_2}=\frac{1}{C_1\omega_p^2}\left(\frac{\omega_1^2+\omega_2^2-\omega_p^2}{\omega_s^2}-1\right) \quad (11)$$

Providing a part of the demanded reactive power is another purpose of the double tuned filters application in HVDC converter stations. The generated reactive power of double tuned filter is $:Q=\frac{V^2}{Z(\omega_0)}$

(12)

Where V is the network fundamental rated ac voltage, ω_0 is thefundamental frequency in radians and $Z(\omega_0)$ is the filter impedance at the fundamental frequency. According to (5), $Z(\omega_0)$ is equal

$$Z(\omega_0)=Z_s(\omega_0)+Z_p(\omega_0)$$

$$:Z(\omega_0)=j\left(\omega_0 L_1-\frac{1}{\omega_0 C_1}\right)-j\left(\omega_0 C_2-\frac{1}{\omega_0 L_2}\right)^{-1} \quad (13)$$

From (12)-(13), the C_1 parameter is obtained by

$$:C_1=\left\{\begin{array}{l}-\omega f\left(\frac{\omega p}{\omega 1\omega 2}\right)^2+\frac{1}{\omega f}+\\ \frac{\omega f\left[\left(\omega_1^2+\omega_2^2-\omega_p^2\right)\omega_p^2-\omega_1^2\omega_2^2\right]}{\omega_1^2\omega_2^2\left(\omega_p^2-\omega_f^2\right)}\end{array}\right\}\frac{U^2}{Q} \quad (14)$$

To summarize, in HVDC stations with known network voltage (V) and demanded reactive power (Q), when tuned frequencies (ω_1, ω_2) and the parallel resonance frequency ω_p are determined, the parameters of the conventional double tuned filter, (L_1, L_2) and (C_1, C_2), can be designed based on (10, 11) and (9, 14)

III.HVDC EQUATIONS

Basically, an HVDC system consists of two converter stations connected by a dc overhead line or an underground (or submarine) cable. During the operation of converters (rectifiers or inverters), harmonic voltages and currents will be flowed on dc and ac sides, respectively. A converter of pulse number P generates harmonic currents/voltages of order $P_k \pm 1$ / P_k, k = 1, 2, 3, ...

The current harmonics on the ac side of a 6-pulseconverter will be of orders n= 5, 7, 11, 13, ..., which called characteristic harmonics. These current harmonics flow through the plant and utility power system and cause voltage distortion and power losses in the system. They also interact with power factor correction capacitor banks leading to equipment failures. Besides, the non-ideal conditions may lead to the generation of another harmonics with different orders, but these non-characteristic harmonics cannot significantly affect the power quality [4].

Fortunately, the amplitudes of generated characteristic current harmonics decrease with increasing harmonic order. It can be shown that the amplitude of an ac harmonic current of order n , i.e. I_n is less than I_1/n, where I_1 is the amplitude of the fundamental current. The exact RMS value of I_n with considering overlap is equal to

$$:I_n = \frac{F(n)}{nD} I_1 \tag{15}$$

Where,

$$: D = \cos(\alpha) - \cos(\beta) \tag{16}$$

$$: F(n) = \left\{ \left(\frac{\sin\left[(n-1)\beta/2 \right]}{n-1} \right)^2 + \left(\frac{\sin\left[(n+1)\beta/2 \right]}{n+1} \right)^2 - 2\left(\frac{\sin\left[\frac{(n+1)\beta}{2} \right]}{n^2-1} \right) \cos(2\alpha+\beta) \right\}^{½} \tag{17}$$

α and β are the control and overlap angles. Eqn. (15) is valid only for characteristic harmonic orders when the overlap angle does not exceed 60^0 . In the case of $60^0 < \beta < 120^0$, $\alpha > 30^0$, and $\beta + \alpha < 150^0$,

If internal converter losses are ignored ($P_{dc} = P_{ac}$) , theamplitude of I_1 in (16) is equal to

$$:I_1 = \frac{P_{dc}}{\sqrt{3} V_l \cos\phi} = \frac{V_d I_d}{\sqrt{3} V_l \cos\phi} \tag{18}$$

Where, P_{dc} is the dc side power (MW), V_d and I_d are the average dc voltage (kV) and current (kA), respectively. Also, V_L and $\cos \emptyset$ are the line-to-line ac voltage (kV) and powerfactor of the network.

The demanded reactive power of an HVDC converter is often expressed in terms of the active power of dc side, i.e.

$$:Q = P_{dc}.\tan\phi \qquad (19)$$

Where $\emptyset$ is the phase difference between the fundamental frequency voltage and current components, so $\tan \emptyset$ is equal to

$$:\tan\phi = \frac{\sin(2\alpha+2\beta)-\sin(2\alpha-2\beta)}{\cos(2\alpha)-\cos(2\alpha+2\beta)} \qquad (20)$$

Using all the above HVDC equations we can calculate the demanded reactive power of HVDC converters.

IV.DAMPED-TYPE DOUBLE TUNED FILTER

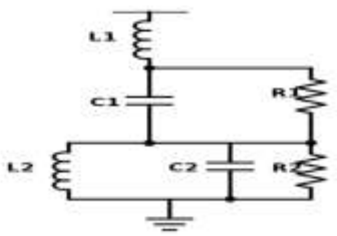

Fig.2 Damped type double tuned filter

Thevenin impedance of conventional double tuned filters is almost devoid of resistance component. Thus, if the power system reactance and the filter impedance are conjugate, the network resonance will take place. This phenomenon causes severe overvoltage harmonics on the filter and other power system components. To prevent network elements from exposing to this harsh condition, damping resistors are added to the conventional double tuned filter in different configurations. This type of filters, as shown in Fig. 2, is called damped-type double tuned filter.

$$:Z_n(\omega) = \frac{R(L_2 n\omega)^2}{(L_2 n\omega)^2 + R^2(1-L_2C_2n^2\omega^2)^2} + j\left(L_1 n\omega - \frac{1}{C_2 n\omega} + \frac{L_2 n\omega R^2}{(L_2 n\omega)^2 + (1-L_2C_2n^2\omega^2)^2}\right) \qquad (21)$$

The performance of the damped type double tuned filter is, it has limited impedance both at ω_p and above ω_2, with its parameters should meet the relationship of that $R > \sqrt{\frac{L_1}{C_1}}$. By scanning the impedance in frequency domain, it can be found that there are three pairs of tuned frequencies on each of the damped-type filters, they are:

- ✓ The minimum impedance frequencies, ω_{Z1} and ω_{Z2}
- ✓ The zero reactance frequencies, ω_{x1} and ω_{x2}
- ✓ The desired tuned frequencies of the double tuned filter by ignoring the resistance R component, ω_1 and ω_2.

Indeed, while ω_1 and ω_2 are used to calculate the filter parameters, the damped-type double tuned filter practically suppresses ω_{Z1} and ω_{Z2} or ω_{x1} and ω_{x2} frequencies components. The proposed filter design algorithm for damped-typedouble tune filter is graphically represented. According to that diagram, the resistance *R* is initially assumed regarding to the network data and demanded reactive power compensation capacity. The sort of tuned frequencies are then chosen between the minimum impedance and zero reactance tuned frequencies. Next, filter parameters, (L_1, L_2) and (C_1, C_2), are calculated based on the chosen tuned frequencies (ω_1, ω_2) and (10-12, 15). In the following step, the practical tuned frequencies of filter, (ω_{Z1},ω_{Z2}) or (ω_{x1} ,ω_{x2}), are calculated when the resistance *R* is take into account. If the difference between the practical and desired tuned frequencies is more than the permitted design error, the filter parameters are recalculated by modifying tuned frequencies (ω_1, ω_2) [5].

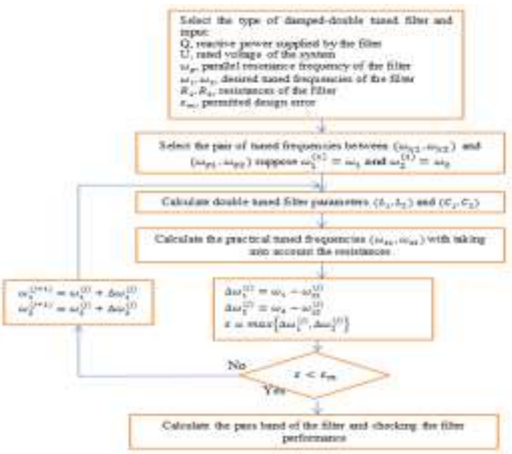

Fig.3 Algorithm of damped type double tuned filter

V.DESIGN OF SERIES ACTIVE POWER FILTER

The series APF used for the power quality improvement is realized as a Voltage Source Inverter (VSI). It can be a three-phase VSI or three single-phase VSI" s can also be used [6]. The VSI is connected in series with the source impedance through a matching transformer. A capacitor is used at the input if the VSI to provide constant input voltage to VSI. A passive filter is also connected at the PCC. This filter is tuned to eliminate higher order harmonics. In certain cases there may be two or more LC branches tuned to eliminate specific order harmonics (especially 5th and 7th). A ripple filter is used in series with VSI. The filter parameters are selected such that they do not exceed the transformer burden [7]. The design criteria is

- ✓ $X_{Crf} \ll X_{Lrf}$, such that at switching frequency the inverter output voltage drops across L_{rf}.
- ✓ $X_{Crf} \ll Z_s + Z_F$, to make the voltage divide between L_{rf} and C_{rf}.

Thus, with an efficient control strategy, the APF compensates the voltage unbalances and distortion. The control strategy is designed such that the series APF together with the passive filter act as a balanced resistive load on the overall system. In a four-wire system, the harmonic currents circulated in the neutral wire are also reduced due to series APF [8].

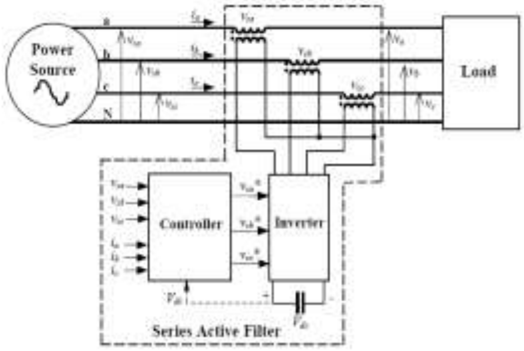

Fig.4 series active filter in three phase power system

The modeling of the series Active Power Filter is necessary in order to control the filter. In this project, the modeling of the series APF which is nothing but a three-phase VSI is carried out in 2-ϕ stationary reference frame (α-β). Thus, the three phase quantities, voltage and current vectors, are transformed into α-β co-ordinates by using Clarkes Transformation.

In a 3-ϕ three-wire system the voltage vector is represented as-

$$: V = \begin{bmatrix} V_a & V_b & V_c \end{bmatrix}^T \qquad (22)$$

The current vector in three-phase system is given as-

$$: i = \begin{bmatrix} i_a & i_b & i_c \end{bmatrix}^T \qquad (23)$$

Now these voltage and current vectors are changed into two-phase system using the transformation matrix-

Therefore, the instantaneous value of real power in the *0-α-β* frame can be calculated as-

$$: p_{3\phi}(t) = v_\alpha i_\alpha + v_\beta i_\beta + v_0 i_0 \qquad (24)$$

Here in equation (24) v_0, i_0 represent the zero sequence voltage and zero sequence current respectively. Their product gives the zero sequence power denoted as p_0. Thus, the equation (24) can be written as-

$$: p_{3\phi}(t) = p + p_0 \qquad (25)$$

Here P represents the instantaneous real power and is written as-

$$: p = v_\alpha i_\alpha + v_\beta i_\alpha \quad (26)$$

The power can be represented in vectorial form using dot product. Hence the active power when represented in vector form can be written as-

$$: p = i_{\alpha\beta}^{T} v_{\alpha\beta} \quad (27)$$

Here $i_{\alpha\beta}^T$ the transposed current vector in α-β coordinates and $v_{\alpha\beta}$ is the voltage vector in α-β coordinates and are given by equations (28) and (29) respectively.

$$: i_{\alpha\beta} = [i_\alpha \quad i_\beta]^T \quad (28)$$

$$: v_{\alpha\beta} = [v_\alpha \quad v_\beta]^T \quad (29)$$

In a three-phase three-wire system, the zero sequence power will be zero and hence the term p_0 in equation (25) can be neglected. The instantaneous imaginary power can be obtained by the equation (30) as-

$$q = v_\alpha i_\beta - v_\beta i_\alpha \quad (30)$$

The above equation can be expressed in vector form as-

$$q = i_{\alpha\beta\perp}^{T} v_{\alpha\beta} \quad (31)$$

Where $i_{\alpha\beta\perp}^{T}$ is the transposed current vector perpendicular to $i_{\alpha\beta}$ and is giving by equation (32) as-

$$i_{\alpha\beta\perp} = [i_\beta \quad -i_\alpha]^T \quad (32)$$

When the instantaneous real and reactive power in equations (27) and (30) are expressed in matrix form then the matrix equation is-

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} i_{\alpha\beta}^{T} \\ i_{\alpha\beta}^{T} \end{bmatrix} v_{\alpha\beta} \quad (33)$$

The voltage vector can be decomposed in its orthogonal projection on the current vector axis as shown in Fig.5.

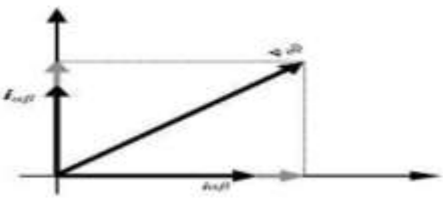

Fig.5 Voltage Vector Decomposition

With the help of the current vectors and the real and imaginary instantaneous power, the voltage vector can be written as [9]-

$$: v_{\alpha\beta} = \frac{p}{i^2_{\alpha\beta}} i_{\alpha\beta} + \frac{q}{i^2_{\alpha\beta}} i_{\alpha\beta\perp} \quad (34)$$

In case of three-phase four-wire system, there will be an extra term in the above equation corresponding to the zero sequence current components.

This theory takes into account the instantaneous reactive power arises from the oscillation of power between source and load and it is applicable for sinusoidal balanced/unbalanced voltage but fails for non-sinusoidal voltage waveform. It basically 3 phase system as a single unit and performs Clarke's transformation (a-b-c coordinates to the α-β-0 coordinates) over load current and voltage to obtain a compensating current in the system by evaluating instantaneous active and reactive power of the network system. The p-q method control strategy in block diagram form is shown in Fig.6.

This theory works on dynamic principal as its instantaneously calculated power from the instantaneous voltage and current in 3-phase circuits. Since the power detection taking place instantaneously so the harmonic elimination from the network take place without any time delay as compared to other detection method[10].

Although the method analysis the power instantaneously yet the harmonic suppression greatly depends on the gating sequence of three phase IGBT inverter which is controlled by different current controller such as hysteresis controller, PWM controller, triangular carrier current controller. But among this hysteresis current controlled method is widely used due to its robustness, better accuracy and performance which give stability to power system.

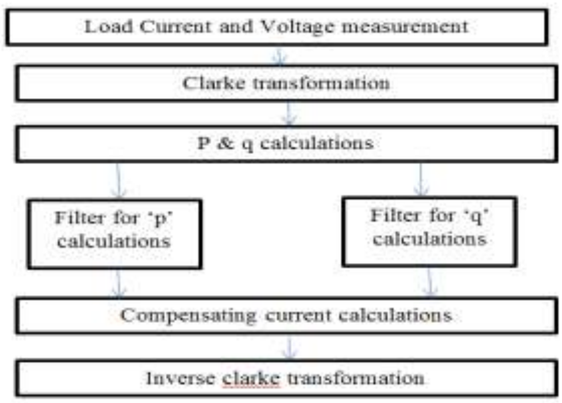

Fig.6 Flow chart for P-Q theory

In 1983, *Akagi et al.* have proposed the "The Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", also known as instantaneous power theory , or p-q theory. It is based on instantaneous values in three-phase power systems with or without neutral wire, and is valid for steady-state or transitory operations, as well as for generic voltage and current waveforms [11][12]. The p-q theory consists of an algebraic transformation (Clarke transformation) of the three-phase voltages and currents in the *a-b-c* coordinates to the α-β-*0* coordinates, followed by the calculation of the p-q theory instantaneous power components:

$$:\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad (35)$$

$$:\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (36)$$

$: p_0 = v_0 \cdot i_0$ instantaneous Zero-sequence power (37)

$: p = v_\alpha \cdot i_\alpha + v_\beta \cdot i_\beta$ instantaneous real power (38)

$: q = v_\alpha \cdot i_\beta - v_\beta \cdot i_\alpha$ instantaneous imaginary power (39)

The power components p and q are related to the same α-β voltages and currents, and can be written together:

$$:\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (40)$$

VI.DESIGN OF HYBRID POWER FILTERS

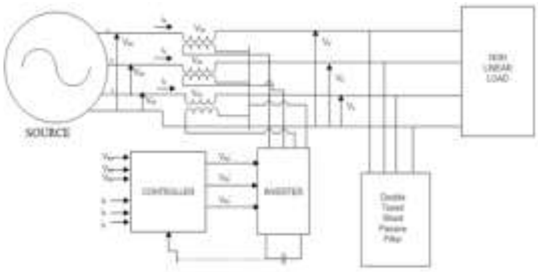

Fig.7 Block diagram of Hybrid Power Filter [13]

Fig.7 is the block diagram of hybrid power filter, and it is connected to a non-linear load. An active filter is connected in series to the source side which eliminates the voltage harmonics inducing at source side, passive filter is connected in shunt to the system which eliminated current harmonics.

VII.SIMULATION RESULTS

In order to evaluate the performance of the Hybrid Power Filter, a test system which consists of a three phase voltage source connected controlled bridge rectifier load through filter is considered. The Test system parameters are as shown in Table 1.

Table 1

SYSTEM PARAMETERS OF TEST MODEL

Parameter	**Values**
Source voltage (V_s)	415V

ISBN: 978-93-87793-26-2

Source frequency (f)	50HZ
Damped-Double Tuned Filter ($L_1, C_1, L_2, C_2, R_1, R_2$)	0.53718mH, 509.721μF, 0.0631494mH, 4846.64μF 476Ω, 2744Ω
DC link capacitance	500μF
Source resistance & inductance (R_s, L_s)	0.8929Ω, 16.58Mh

Table 2

COMPARISION OF RESULTS

Type of filter	THD of source voltage (%)	THD of source current (%)
Without filter	28.84	30.48
Hybrid power filter	1.41	0.27

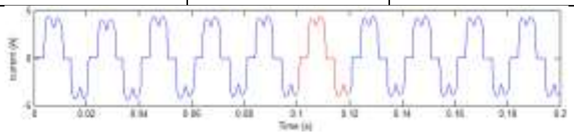

Fig.8 Current Waveform of Basic System

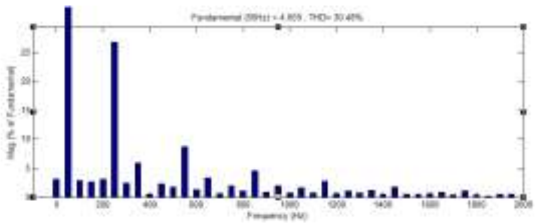

Fig.9 FFT Analysis of Current to Basic System

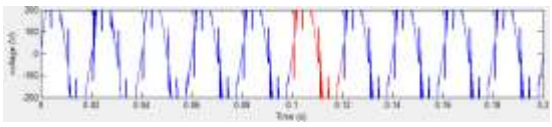

Fig.10 Voltage Waveform of Basic System

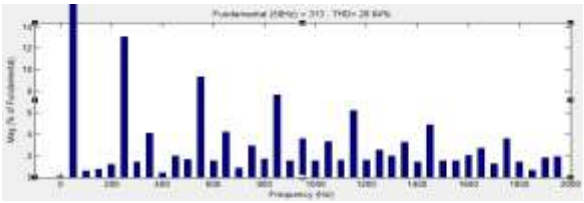

Fig.11 FFT Analysis of Voltage to Basic System

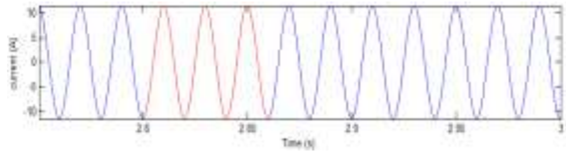

Fig.12 Current Waveform of System with Hybrid Power Filter

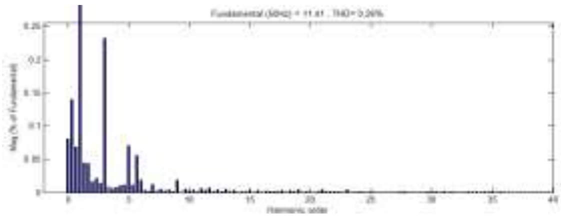

Fig.13 FFT Analysis of Current to System with Hybrid Power Filter

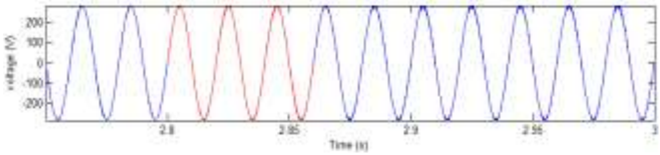

Fig.14 Voltage Waveform of System with Hybrid Power Filter

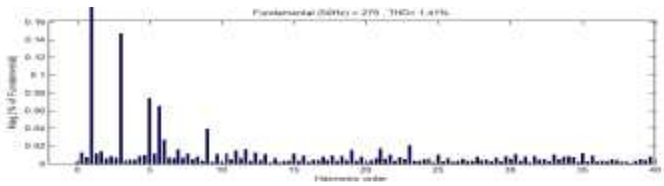

Fig.15 FFT Analysis of Voltage to System with Hybrid Power Filter

VIII.CONCLUSION

Most of the loads connected to the system are non-linear which draws non-linear currents from the supply. To compensate the load harmonics a filter is connected at the PCC which injects the compensating currents. To achieve this problem a Hybrid Power Filter with series connected APF and shunt connected Passive Filter is used. The connection of APF improves the passive filter characteristics in addition to improve the system performance.

From the MATLAB/SIMULINK models it has been observed that when compared to using a separate series active filter and a shunt passive filter, on using Hybrid Power Filter we can mitigate both voltage and current harmonics as per IEEE-519-2014 standards.

REFERENCES

[1] Sushree Diptimayee Swain, and Pravat Kumar Ray, Improvement of Power Quality using Robust Hybrid Series Active Power Filter, *IEEE Trans. Power Electronics*, *Vol. pp. Issue: 99*, June 2016.

[2] S. Diptimayee Swain, P. K. Ray, and K. Mohanty, Voltage Compensation and Stability Analysis of Hybrid Series Active Filter for Harmonic Components, *Indian Conference 2013 Annual IEEE*, *pp. 1-6, IEEE*, 2013.

[3] M.A.Zamain, M.Mohseni, Damped-Type Double Tuned Filter Design for HVDC Systems, *9th International conference on Electrical Power Quality and Utilization, Barcelona*, *9-11*, October 2007.

[4] CIGRE WG 14-30, Guide to the Specifications and Design Evaluation of AC Filters for HVDC systems, *Technical Brochure 139*, April 1999.

[5] Xia Yao, Algorithm for the Parameters of Double Tuned Filter, *IEEE International conference on Harmonic and Quality of Power,* Greece, October 1998.

[6] Roger C, Dugan, *electrical power system quality* TATA McGraw-Hill Education Private Limited, NEW DELHI, 3rd Edition, 2012.

[7] K. Srinivas, S.S.Tulasi Ram, Enhancement of THD in HVDC system using Shunt Active Power Filters, *International Journal of Computer Applications*, *Vol. 77, No. 14, pp.19-25,* September 2013.

[8] Azmera Sandeep, *Study of Hybrid Active Power Filter for Power Quality Improvement*, Ph.D. Thesis, National Institute of Technology, Rourkela, 2014.

[9] Nehakumari, IshaAwashthi, Harmonic Compensation using Shunt Active Power Filter in power system using MATLAB, *International Journal of Scientific Engineering and Research,* Vol. 2, Issue. 1, January 2014.

[10] Elisabett Lavopa, *A Novel Control Technique for Active Shunt Power Filter*, Ph.D. Thesis, University of Nottingham, United Kingdom, June 2011.

[11] Joao Afonso, Carlos Couto, Julio Martins, Active Filter with Control based on the p-q Theory, *IEEE Industrial Electronics Society Newsletter, Vol. 47, pp. 5-10*, September 2000.

[12] Reyes S. Herrera and Patricio Salmeron, Instantaneous Reactive Power Theory: A Comparative Evaluation of Different Formulations, *IEEE Trans. on Powr Delivery*, *Vol. 22, No. 1*, January 2007.

[13] Bhim Singh, Kamal H-Hadded, *power quality problem and mitigation technique* John Wiley and Sons Limited, The Atrium, Chichester, West Sussex, United kingdom, 2015.