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Performance Analysis of Different Mitigating Circuits For Power Quality Improvement

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ABSTRACT: This paper work presents a comprehensive analysis of different types of passive filter configurations and Single phase Shunt Active Power Filter (SAPF) using digital notch filter and high pass filter modeled in MATLAB/SIMULINK. The controlling strategy employed in the Shunt Active Filter is, Hysteresis current controller. Hysteresis controller has been modeled using the relay block in MATLAB. The filter performances have been analyzed based on their harmonic mitigation capability and also on the problem of source loading that they might impose.Total harmonic distortion is found out by performing Fast Fourier Transform (FFT) analysis of each kind of filter. All the analysis have been made considering an AC-DC converter (α=0), i.e a Diode Bridge Rectifier.

KEYWORDS: Active power filters, harmonics, quality factor, hysteresis current controller, power quality.

I.INTRODUCTION

Power quality is the main scope of interest in electrical power generation, transmission and consumption. Modern electrical equipments are intricate and sensitive to voltages. Not only are the equipments sensitive, but they also introduce a lot of disturbances into the power system. Compromise in the power quality would mean damage to these electrical equipments, wastage of power due to losses. So, eventual aim is to provide consumers with uninterrupted power supply at standard voltages. Power quality degrades because of the non linear loads and also due to power electronic converters which are used in the power system. These non linear loads cause voltage interruptions, introduce harmonics, reactive power disturbances etc. Overheating, overloading, motor vibration, capacitor failure, low power factor, resonance problems are some of the consequences of harmonics. So, harmonics reduction is a prime concern. Passive filters provide harmonic compensation for particular order harmonics. Passive filters like double tuned filters can provide harmonic compensation at two different frequencies**.** Whereas the active filters compensate harmonics by injecting them to the system. Different control strategies like PI controllers, hysteresis controllers are used in active filters to detect the harmonics. Active and passive filters are essentially used as mitigating circuits for harmonics reduction. The type of filter to be used depends on the extent of harmonics, the environment where the filter is used.

II.PASSIVE FILTERS

A.Tuned RLC filter:

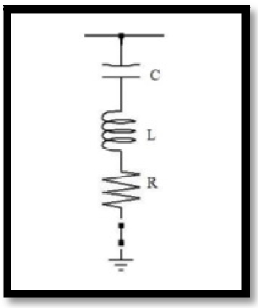

Fig 1.1: Tuned RLC filter

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The parameters considered while designing the tuned RLC filter are Q factor, damping ratio, damping frequency. Quality factor (Q) = $2\pi[\frac{Energy\ stored\ in\ one\ cycle}{Power\ dissipated\ in\ one\ cycle}]$. To avoid losses in the system it is required to choose higher values of Q. But a greater Q factor will make the system slower by decreasing the overall bandwidth of the system. Considering these tradeoffs an optimal value of Q =11 is chosen.
And due to the fact that power systems are susceptible to very high currents and voltages, it is not viable to use very small resistance in the series RLC circuit, as this will cause high amounts of currents to flow when the corresponding harmonic is encountered and the system might be under threat. So an optimally safe value of R=5 ohms is chosen.
Design:
For 3rd Harmonic Filtering,
Q = 11, $\omega = 942.4778\, rad/sec$ and $R = 5\, ohm$.

$$Q = \frac{\omega L}{R} \quad (1)$$

From (1), we get value of L=$58.35 mH$
To find C:

$$C = 1/(4\pi^2 f^2 L), \quad (2)$$

Where f is the resonant frequency for 3rd harmonic ($150\ HZ$)
Using the value of L, we get C =$19.29 \mu F$.

Damping factor given by $\delta = [R/2][\sqrt[2]{\frac{C}{L}}]$ (3)

Hence from (1) , (2) and (3) $\delta = 0.04545$.

$$\omega_d = \omega_n \sqrt[2]{1-\delta^2}\ . \quad (4)$$

Hence,$\omega_d = (99.8\%)\omega_n$, which means that the system has not been *detuned* by adding resistance in this design. It can be noted that by removing the current limiting resistor the harmonics can be eliminated much more significantly, but it causes severe *source loading* which is highly undesirable. On the same lines, for *elimination of 5th harmonic content*, i.e f=300Hz, the values of C =$11.575 \mu F$ and L =.$35.014 mH$ are chosen.

Fig 1.2 gives FFT analysis and THD for the bridge load without any filter. Fig1.3 and 1.4 gives us the performance of a Tuned RLC filter. In order to achieve 3rd and 5th harmonics elimination, two Tuned RLC circuits are designed. Fig 1.3 shows that the Tuned RLC reduces THD to 8.03%.Fig 1.4 (a) and (b) shows source current without filter, after using Tuned RLC filter and also the load DC current respectively.

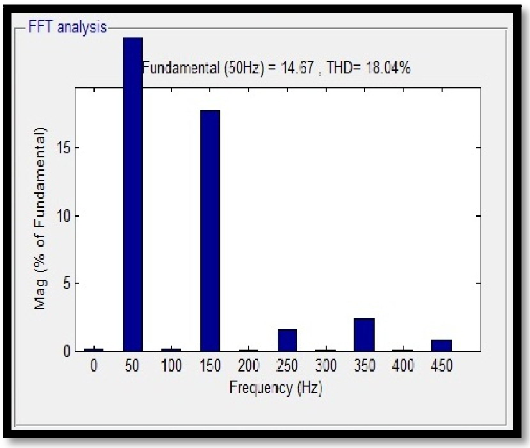

Fig 1.2: FFT without any filter.

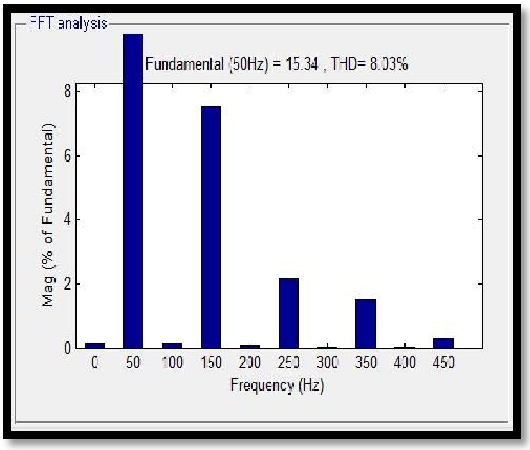

Fig 1.3: FFT with tuned RLC after compensating 3rd and 5th

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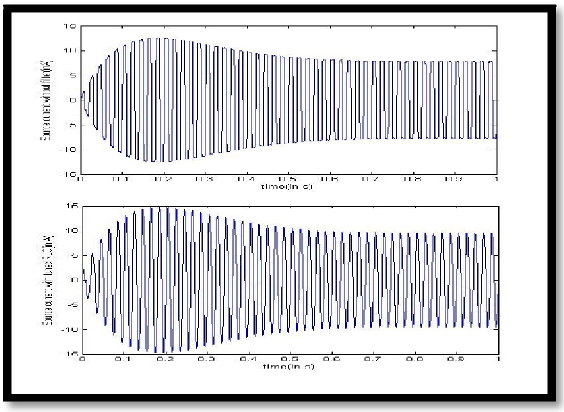
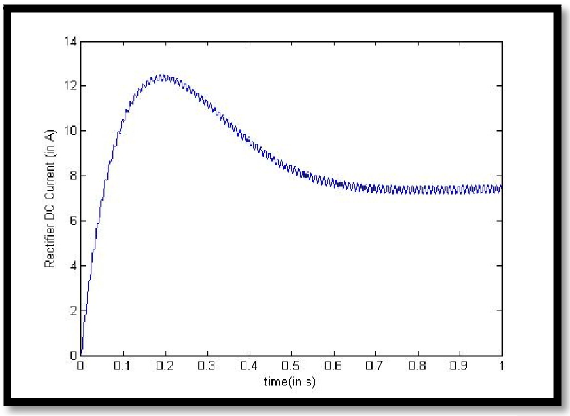


(a) Source Current before and after filtering



(b) Load current before and after filtering.

Fig 1.5 shows the double tuned filter and fig 1.6 shows the equivalent circuit of double tuned filter.

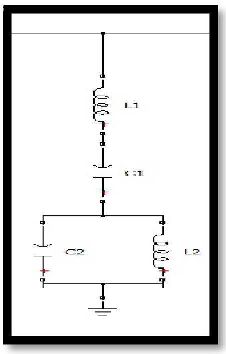


Fig 1.5: Double tuned filter

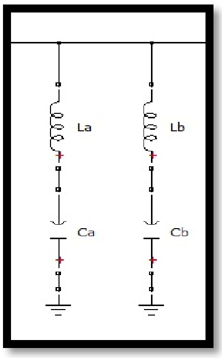


Fig 1.6: Double tuned filter

Design: [1]

$$\omega_a = [\frac{1}{\sqrt[2]{L_a C_a}}] \quad (1)$$

$$\omega_b = [\frac{1}{\sqrt[2]{L_b C_b}}] \quad (2)$$

$$\omega_a \omega_b = \omega_s \omega_p \quad (3)$$

$$C_1 = C_a + C_b \quad (4)$$

$$[\frac{C_b}{\omega_a^2} + \frac{C_a}{\omega_b^2}] = \frac{C_1}{\omega_p^2} \quad (5)$$

$$L_1 = [1/(C_a\omega_a^2 + C_b\omega_b^2)] \quad (6)$$

$$\omega_s = [\frac{1}{\sqrt[2]{L_1 C_1}}] \quad (7)$$

$$\omega_p = [\frac{(\omega_a\omega_b)}{\omega_s}] \quad (8)$$

$$L_2 = [\frac{\{1-(\frac{\omega_a^2}{\omega_s^2})\}\{1-(\frac{\omega_a^2}{\omega_s^2})\}}{C_1\omega_a^2}] \quad (9)$$

$$C_2 = [\frac{1}{L_1\omega_p^2}] \quad (10)$$

From equations (1) to (10) and basic circuit analysis techniques, and taking values of ω_a and ω_b as $150Hz$ and $250Hz$ for 3rd and 5th harmonics respectively, and assuming, $C_a = 1mF$, $C_b = 1m\,F$ we get ,$L_a = 1.1mH$ and $L_b = 4.0528mH$. $C_1 = 2mF$, $C_2 = 1.371mF$, $L_1 = 11.7mH$ and $L_2 = 22.04mH$.

The transfer function for the double tuned filter T.F is found to be,

$$T.F = \frac{L_2C_1C_2s^3 + C_1s}{L_1L_2C_1C_2s^4 + (L_1C_1 + L_2C_2 + L_2C_1)s^2 + 1} + \frac{1}{R} \quad (11)$$

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Fig 1.7 shows that the THD gets reduced to 5.88% by using double tuned filter, whereas the source loading happens when using a double tuned filter, thus the load current has reduced to almost half of its original value. Fig 1.8 (a), (b) shows the source current and load current before and after using double tuned filter.

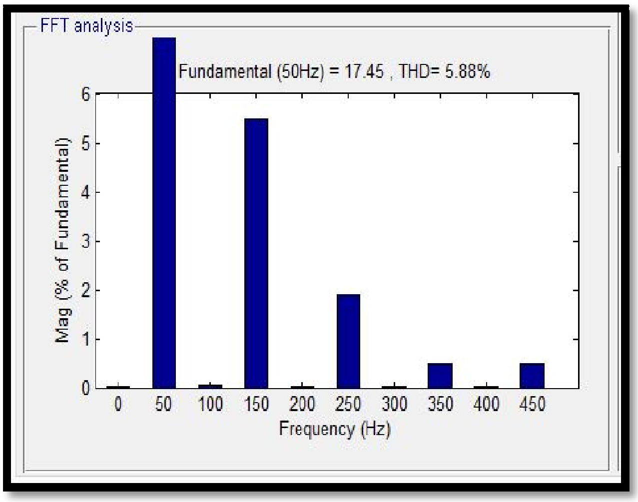
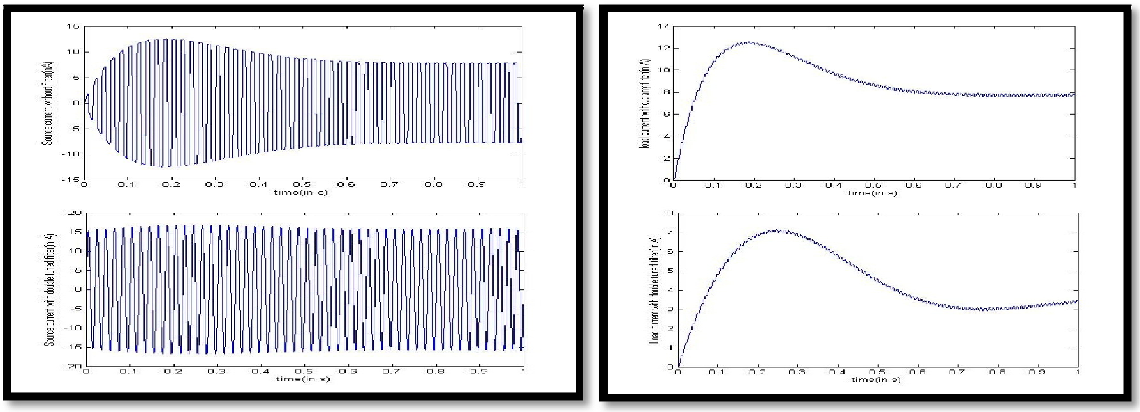


Fig 1.7: FFT analysis after use of Double tuned filter.



(a) Source Current before and after filtering (b) Load current before and after filtering.

Fig 1.8 Waveforms for Double tuned filter

C.High pass filter (RLC):

The characteristic of high pass filters is to offer low impedance path to all the high frequencies beyond a cutoff frequency. The second order high pass filter shown in fig 1.9 is typically cascading of two 1st order High pass filters. These first order high pass filters are RC and RL high pass filters.

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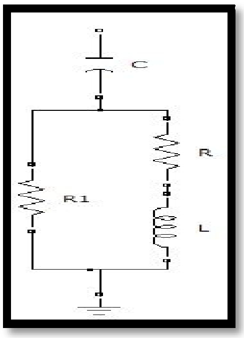


Fig 1.9: High Pass Filter(RLC)

Design:

$$f = \frac{1}{2\pi RC} = \frac{1}{2\pi \frac{L}{R}} \quad (1)$$

For R=R1=5 ohm and f=50Hz, we get L=15.95mH and C=0.6333mF.

From the fig 1.9 the transfer function of the high pass filter can be written as

$$T.F = \frac{s^2}{s^2 + s[\frac{1}{RC} + \frac{R}{L}] + \frac{1}{LC}} \quad (2)$$

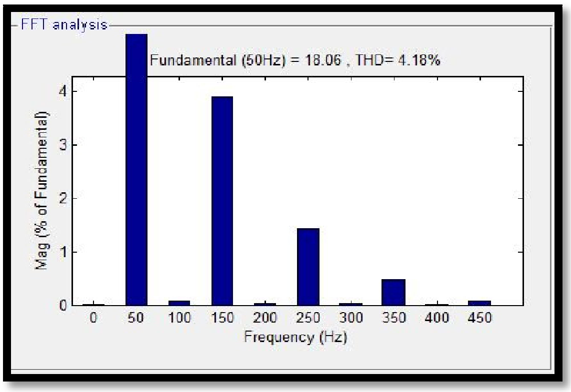
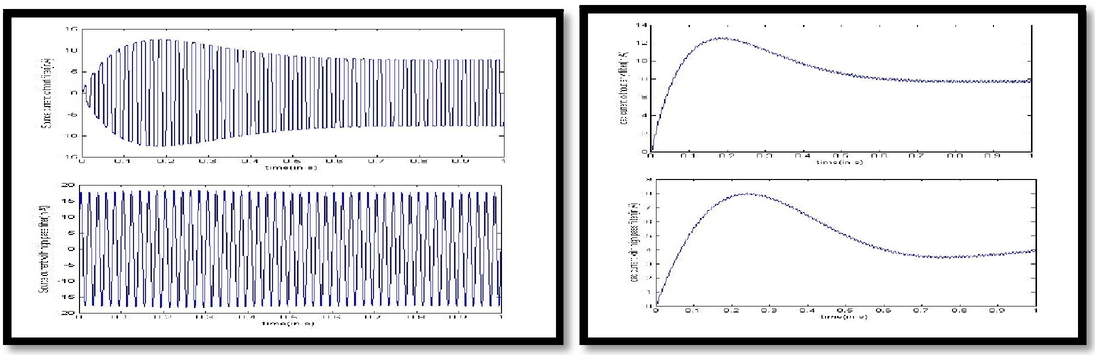


Fig 1.10: FFT analysis after use of RLC High Pass filter.

THD reduces to 4.18% from a high pass filter and is shown in fig 1.10. The source current waveforms and load current waveforms before and after using the filter is shown in fig1.11 (a), (b) respectively.



(a) Source Current before and after filtering

(b) Load current before and after filtering.

Fig 1.11: Waveforms for high pass filter(RLC)

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D. High Pass Filter (RC):

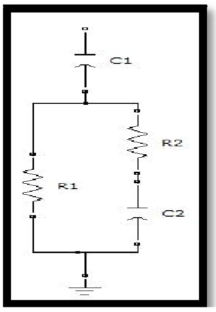

Fig 1.12. High pass filter.(RC)

Fig 1.12 shows a RC filter. For obvious reasons such as noise and weight it could be undesirable to employ inductors in some of the networks. So a case of cascading two RC high pass filters is presented. Cascading two first order filters provides better frequency response in terms of attenuation of unwanted frequencies. However, based upon requirement, more such filters can be cascaded to obtain the desired results by analyzing the suitable tradeoffs that might exist.

Design:

$$f = \frac{1}{2\pi RC} \quad (3)$$

For R1=R2=5ohm, we get C1=C2= 0.6333mF.

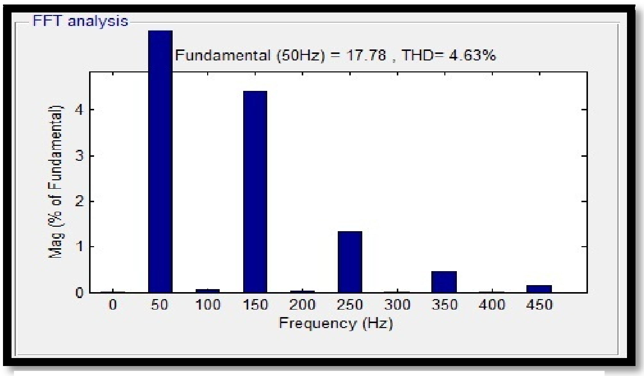

Fig 1.13:FFT plot after use of RC High pass filter

Fig 1.14 shows the comparison of source current before and after using RC filter, Fig 1.15 shows the comparison load current before and after using RC filter.

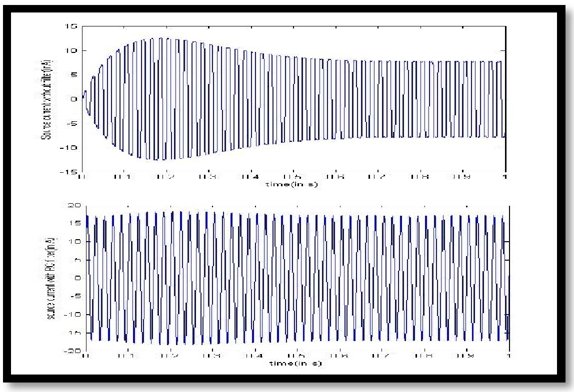

Fig 1.14 Source current before and after using RC filter

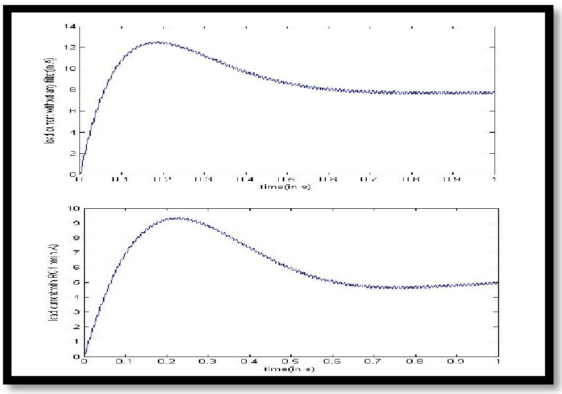

Fig1.15 load current before and after using RC filter.

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III ACTIVE FILTERS

Active filters can be classified into two types according to their circuit configurations as series and shunt active filters. Fig 1.16 shows a shunt active filter circuit designed in MATLAB. The bridge rectifier is a practical load which is very commonly used in any power system, which induces harmonics in the source side as a result of rectification of sinusoidal voltage and currents. The rectifier circuit has been coupled with an LC filter which is used to reduce the current and voltage ripple on the output side. The values of C and L for the filter are designed from equations (1) and (2) respectively, allowing a ripple of 1%.The source inductance and resistance also has been taken care (Z_{01}).

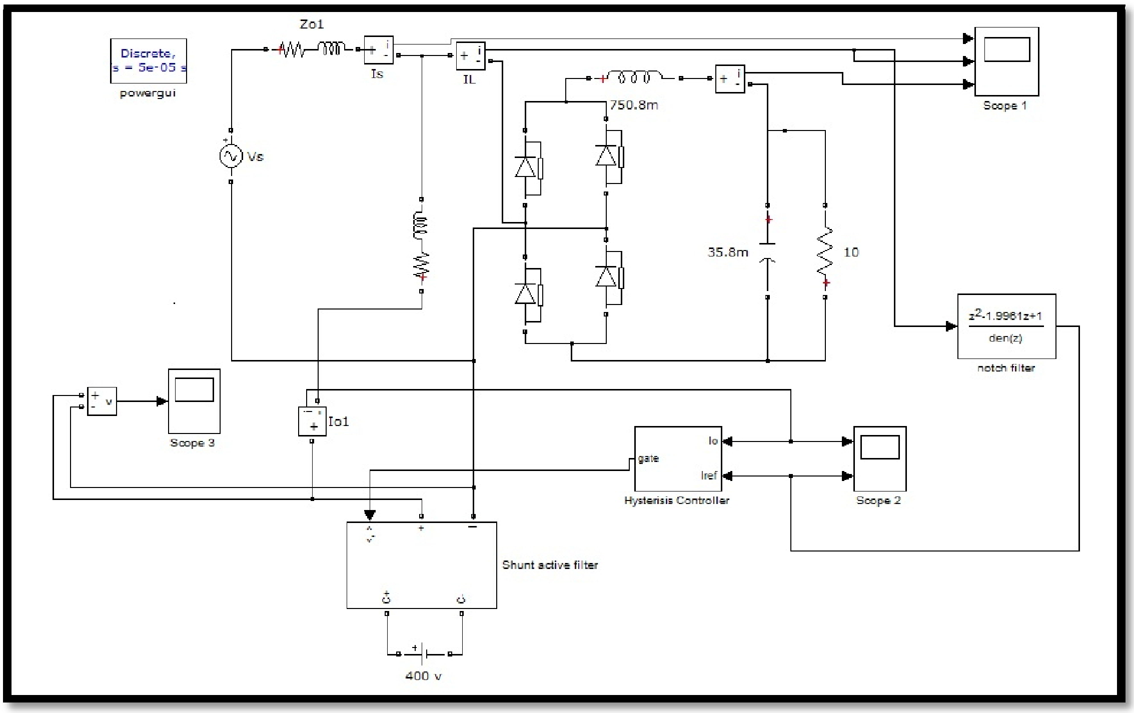

Fig 1.16: MATLAB modeling of SAPF

$$RF(C) = \frac{1}{[\sqrt{2}(2 f_o RC - 1)]} \qquad (1)$$

$$RF(L) = \frac{0.4714}{\sqrt{\left(1+\left(\frac{4\pi f_i L}{R}\right)^2\right)}} \qquad (2)$$

Where, f_o is the output ripple frequency and f_i is the input frequency and RF is $Ripple\ Factor$.

Mathematical modelling of Notch Filter:

A Notch filter is nothing but a band stop filter, which filters out very sharp range of frequencies. The Generalised transfer function of a notch filter is given by

$$\frac{Y(s)}{(X(s)} = \frac{(s^2+w^2)}{(s^2+\left(\frac{w}{Q}\right)s+w^2)} \qquad (3)$$

For, Q=12.5, w = 314 rad/sec

$$\frac{Y(s)}{(X(s)} = \left(\frac{(s^2+314^2)}{(s^2+25s+314^2)}\right) \qquad (4)$$

The equivalent Z domain transfer function is obtained by taking bilinear transformation and sampling frequency

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of 5000Hz, is given by,

$$\frac{Y(z)}{X(z)} = \frac{z^2-1.9961z+1}{z^2-1.9262z+1} \qquad (5)$$

Similarly a *high pass filter* can also be used instead of a notch filter to serve the same purpose. Z domain transfer function for Second Order High Pass Filter at a sampling frequency of 5000Hz, is given by,

$$\frac{Y(z)}{X(z)} = \frac{z^2-2z+1}{z^2-1.862z+0.8677} \qquad (6)$$

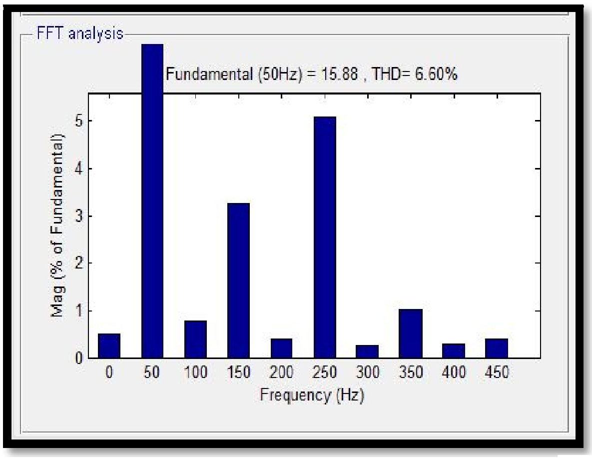

Fig 1.17: FFT plot for SAPF with HIGH pass filter

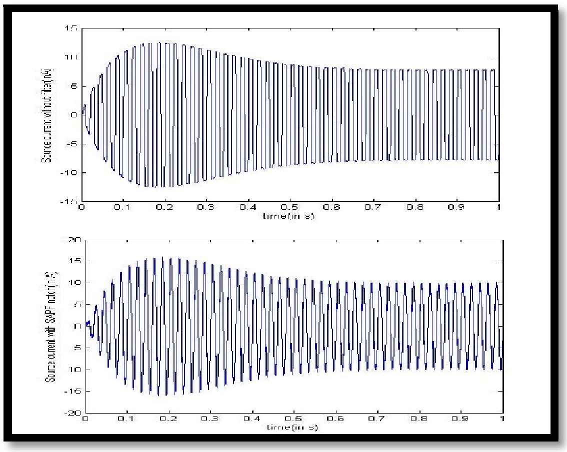

Fig 1.18: Source current before and after using SAPF with HIGH pass filter

Fig 1.17 shows that the THD reduces to 6.60% using a SAPF with High Pass filter and using SAPF with notch filter THD reduces to 6.57% as shown in Fig 1.19. Fig 1.18 and 1.20 shows the source current before and after filtering using SAPF with High Pass and Notch filter respectively.

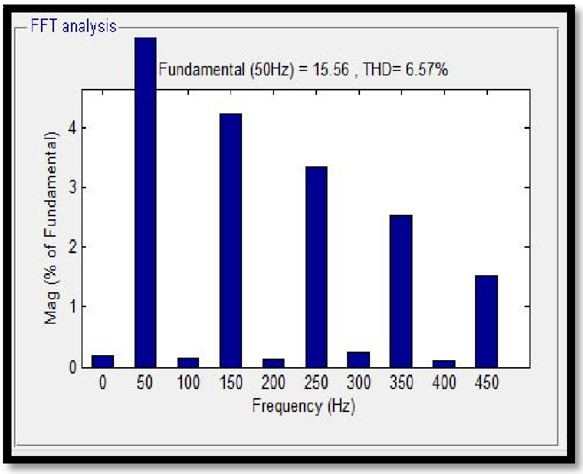

Fig 1.19: FFT for SAPF with notch filter

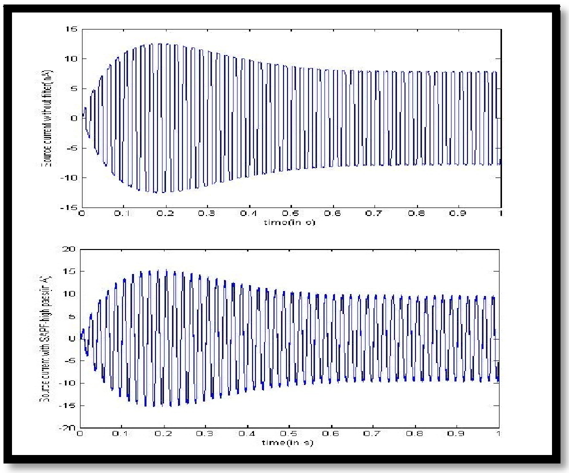

Fig 1.20: Source current before and after using SAPF with notch filter filtering.

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IV.RESULTS

The Table-I, shows the comparison of all the filters that has been analysed in this paper, based on the THD reducing capacity of various filters and also indicates the presence of source loading. All the filters have been analysed considering a Diode Bridge Rectifier load.

Filters	THD without Filter	THD with Filter	Effect on Load Current
Tuned RLC	18.04%	8.03%	Not affected
Double tuned filter	18.04%	5.88%	Exists
High pass filter (RLC)	18.04%	4.18%	Exists
High pass filter (RC)	18.04%	4.63%	Exists
Shunt active power filter(with high pass filter)	18.04%	6.60%	Not affected
Shunt active power filter(with notch filter)	18.04%	6.57%	Not affected

Table-I

V.CONCLUSION AND FUTURE SCOPE

It may be noted that in case of application of passive filters for harmonic reduction, like tuned RLC filters, it is required to know in prior as to which order harmonics are being introduced into the network, which becomes a drawback, considering the fact that the power system is a huge entity and constantly feeds variety of non-linear loads at once. However, if High pass filters are used, extra care should be taken with respect to impending source loading that could pose serious problems. But with active power filters, the above mentioned drawbacks are neutralised. The ability of Active Filter to reduce THD is largely limited by the controlling technique that is being employed. Need for better controlling techniques never diminishes. It may be noted that by using active and passive filters in tandem (Hybrid Filters) harmonic reduction can be done to a greater extent, with proper design even source loading problem can be taken care.

REFERENCES

[1]**A New Method of Designing Double-tuned Filter** HE Yi-hong, SU Heng, Jiangmen 529020, China. Proceedings of the 2nd International Conference on Computer Science and Electronics Engineering (ICCSEE 2013).

[2] **Filter Design for AC to DC** Converter Sudeep Pyakuryal, Mohammad Matin Department of Electrical and Computer Engineering University of Denver.

[3] **Adaptive Notch Filter for Harmonic Current Mitigation** T. Messikh, S. Mekhilef, and N. A. Rahim

[4] **Decomposition of current through active power filter for compensating harmonics current and reactive currents** V.Pardha Saradhi1, P.Dhana Selvi2 1Scholar M.Tech, EEE,AP,India,pardhume@gmail.com, 2Assistant professor, EEE, NBKRIST, AP, India

[5] **Direct Current Control of an Active Power Filter for Harmonic Elimination, Power Factor Correction and Load Unbalancing Compensation** Helder J. Azevedo, José M. Ferreira, António P. Martins, Adriano S. Carvalho FACULTY OF ENGINEERING OF THE UNIVERSITY OF PORTO

[6] **Single-Phase Shunt Active Power Filter Using Indirect Control Method** Anzari M1, Rejil Chandran2 and ArunKumar R3 123PG Scholar, School of Electrical Engineering 123 VIT University, Chennai Campus, Tamil Nadu, India

[7] **Improvement of the Electric Power Quality Using Series Active and Shunt Passive Filters** P. Salmerón and S. P. Litrán.