Performance Analysis of Fixed Shunt Passive Filters for Harmonic Mitigation

Roohi Sachan[1] and Rohan Srivastava[2]

***Abstract*—This paper presents study of harmonics and its significant effect on power system regarding the harmonic distortion caused by non-linear load such as adjustable speed drives, rectifier circuit and computers. Power quality improvement can be done effectively by using passive and/or active filter in series or shunt with the load. Although performing effectively, active filter are not cost efficient. Traditional passive filter are good alternative instead. This paper analyses performance of fixed shunt passive filter which is connected to three phase thyristor converter fed R-L load and hence required different values of reactive power as value of firing angle for thyristors is varied.**

Keywords: Fundamental Frequency, Harmonics, Total Harmonics Distortion (THD), Non-linear Load, Passive Filter, Fixed Shunt Passive Filter

I. INTRODUCTION

There is a vast use of power electronic based devices nowadays for inversion, rectification or many other applications. Besides being effective they also inject harmonics in the power system. Harmonics are simply the combination of several sine waves which have different frequencies than fundamental frequency. Ideally, the voltage and current waveforms are assumed to be pure sinusoidal having single frequency. But, the waveforms become distorted when the system is connected with any non-linear load. In a non-linear load current waveform is not proportional to the applied voltage waveform. Examples of non-linear load include static power converters (such as rectifiers), adjustable speed drives, switched mode power supply and rotating electrical machines etc. Harmonics are not desirable in general as it has wide adverse effect on the system. It causes many ill-effects such as overheating, mechanical and electrical oscillations in alternators and prime movers, malfunctioning of protective relays, interference with communication equipments and reduction in power generation, transmission and utilization efficiency. To overcome these problems, harmonic mitigation is important for both utility and consumer ends.

Using passive filters to filter out harmonics from the power system is one of the earliest and most used technologies. Due to very simple designing process and low cost factor, they are used widely. This paper investigates designing and effectiveness of shunt passive filter while the converter fed load is triggered with different angles.

II. PASSIVE FILTERS

Passive filtering is the simplest convention for harmonic mitigation in power system. Passive filters are basically topologies or arrangement of different combinations of passive elements like inductance, capacitance and resistance. They can be either employed in series or in shunt in the system with non-linear load.

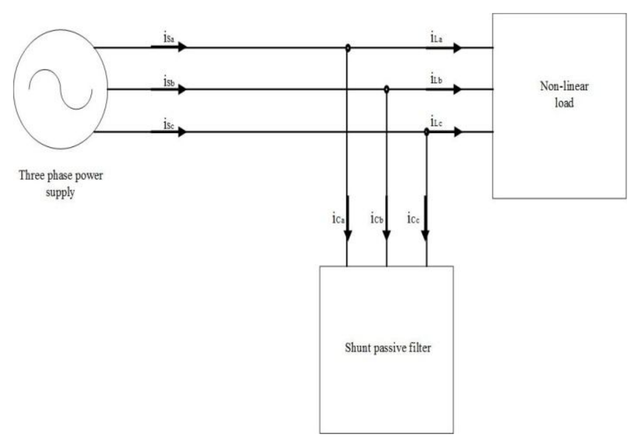

Fig. 1: Schematic Arrangement of Passive Filter Connected in the System on Input Side

Series passive filter are connected in series with system. They usually carry full load current and hence, overcurrent protection is needed for these filters.

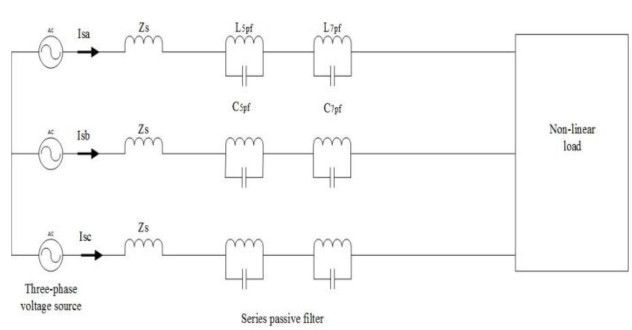

Fig. 2: Series Filter Connection with Three Phase System Having Non-linear Load

[1,2]Electrical Engineering Department, Gautam Buddha University, Greater Noida, India
E-mail: [1]roohisachan1293@gmail.com, [2]princerohan.srivastava@gmail.com

978-1-5090-2118-5/16/$31.00 ©2016 IEEE

Shunt filter also carries a little amount of series filter current and provide least impedance path to the particular harmonic current at tuned frequency. Also, series passive filter are costlier than shunt passive filter.

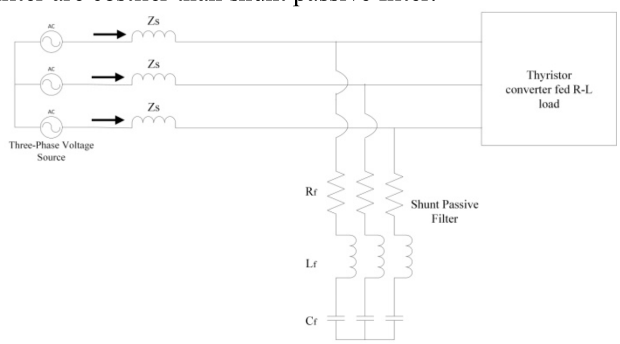

Fig. 3: Shunt Filter Connection with Three Phase System having Non-linear Load

III. SINGLE TUNED FILTER

Single tuned filter is the least expensive and simple configuration which is commonly used as compared to the other means of harmonic mitigation. These filters are connected in the shunt with the system and provide least impedance path to the harmonics of any particular frequency. Thus, the harmonic current leave the system through path provided by filter. Fig. 4 shows different types passive shunt filters.

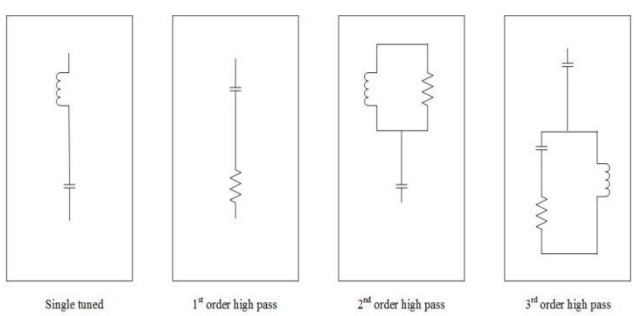

Fig. 4: Passive Filters Configurations

For designing of single tuned filter following basic equations relate:

Resonant frequency, f_r Hz:

$$f_r = \frac{1}{2\times\pi\times\sqrt{L\times C}} \quad (1)$$

The equation relating reactive power and capacitive reactance can be expressed as:

$$Q_c = \frac{V^2}{X_c} \quad (2)$$

Capacitance for the single tuned filters is determined as:

$$C = \frac{1}{2\times\pi\times f\times X_c} \quad (3)$$

To trap the harmonics of order n, the inductance should be of size

$$L = \frac{1}{(2\times\pi\times f\times n)^2\times C} \quad (4)$$

The resistance of filter can be determined by Equation (5), Q being the quality factor. Sharpness of the tuning is measured by calculating resistance of filter.

$$R = \frac{\sqrt{L/C}}{Q} \quad (5)$$

Where

f_r resonant frequency, Hz
Q_c reactive power, KVAR
V capacitor line voltage, V
X_c capacitive reactance of capacitor, Ω
C capacitance of filter, μF
L inductance of filter, H
R resistance of filter, Ω
f fundamental frequency, 60 Hz
n order of harmonics, n=5,7,11…….
Q quality factor

Range of quality factor for a single tuned filter is $20<Q<100$.

IV. 2ND ORDER HIGH PASS FILTER

In 2nd order high pass filter capacitance is connected in series whereas resistance and inductance are connected in parallel. At fundamental frequency, use of these filters decreases the energy losses.

Beside quality factor all other parameters for this filter are determined by same equations used for single tuned filter. Thus, the value of capacitance and inductances are obtained by Equation (3) and Equation (4) respectively.

Quality factor hence, resistance can be found by following equation:

$$R = \sqrt{\frac{L}{C}} \times Q \quad (6)$$

Range of quality factor for second order double tuned filter is $0.5<Q<5$.

V. SELECTION OF FILTERS

Third order harmonics are not present when three phase electronic power converter is used because unlike single phase converter they do not generate third harmonic current. Also, in three phase system even harmonics cancel each other out. Therefore, for suppressing the harmonics in the system three single tuned filter for 5th, 7th, and 11th harmonic and a second order high pass filter for higher order harmonics (13th harmonic) is used.

VI. ANALYSIS OF SIMULATION RESULT

In this paper three phase thyristor controlled converter connected to R-L load is simulated. The simulation is done by providing different values of triggering angles to the converter and the system with and without connecting passive filters. In order to provide steady dc current through the load and rectangular current pulses in the ac

978-1-5090-2118-5/16/$31.00 ©2016 IEEE

side the inductance for the load circuit is kept sufficiently large.

The value of source impedance is kept 1mH. The MATLAB/ Simulink model is made for balanced three phase supply of 240V, 60Hz which is connected to three phase 6 pulse thyristor converter fed R-L Load. The R-L load has resistance of 15Ω and inductance of 78mH.

Figure 5 shows three phase source current of the system without passive filter when angle of triggering for thyristor converter is 0°. By Fig. 6, it is clear that system contains harmonics. %THD of current is 21.76%.

TABLE 1: HARMONIC SPECTRUM OF SUPPLY CURRENT FOR THREE PHASE THYRISTOR CONVERTER FED R-L LOAD UNDER VARYING TRIGGERING ANGLES

Thyristor Converter Firing Angle (α°)	Reactive Power (VAR)	Harmonics in Source Current				
		h5 (%)	h7 (%)	h11 (%)	h13 (%)	THD (%)
0	0	3.04	1.03	0.25	1.57	3.80
20	242	3.19	1.15	0.36	2.53	5.41
40	400	3.79	1.32	0.44	3.09	7.57
60	269	5.44	1.64	0.64	3.85	11.07

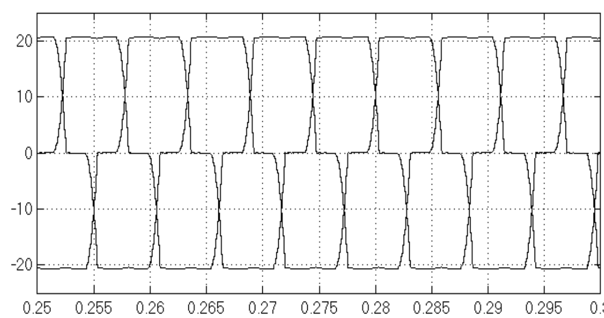

Fig. 5: Three Phase Supply Current of the System without Passive Filter when Triggering Angle is 0°

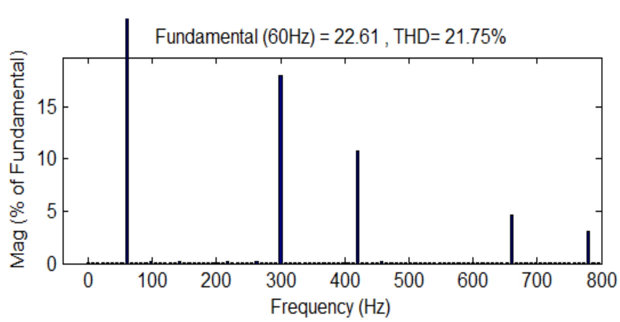

Fig. 6: Frequency Spectrum of Supply Current without Passive Filters

As per TABLE I, for the load at α = 0°, demand of three phase reactive power is approximately 400 VAR. Therefore, for mitigating harmonics of 5^{th}, 7^{th}, 11^{th} and 13^{th} order and providing demand of reactive power at this value of α, the shunt passive filters are designed with the help of equations mentioned in section 3 and 4. Values of parameters as calculated for all four order filters are given in Table 2.

TABLE 2: PARAMETERS OF FIXED PASSIVE SHUNT FILTER

Harmonics	Inductance L (H)	Capacitance C (μF)	Resistance R (Ω)
5^{th} harmonic	0.0151	18.6	0.32
7^{th} harmonic	0.0077	18.6	0.23
11^{th} harmonic	0.0031	18.6	0.14
13^{th} harmonic	0.0022	18.6	43.91

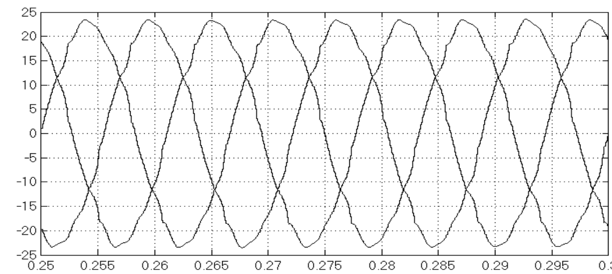

Fig. 7: Three Phase Supply Current of the System with Passive Filter when Triggering Angle is 0°

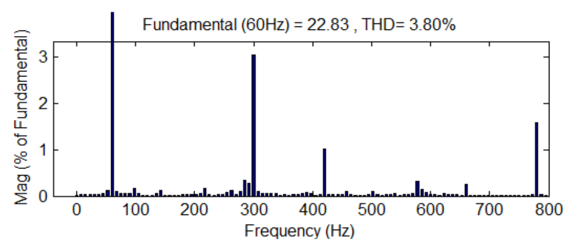

Fig. 8: Frequency Spectrum of Supply current without Passive Filters

TABLE 3: HARMONIC SPECTRUM OF SUPPLY CURRENT FOR THREE PHASE THYRISTOR CONVERTER FED R-L LOAD VARYING TRIGGERING ANGLES WITH SHUNT PASSIVE FILTER

Thyristor Converter Firing Angle (α°)	Reactive Power (VAR)	Harmonics in Source Current				
		h5 (%)	h7 (%)	h11 (%)	h13 (%)	THD (%)
0	400	17.92	10.77	4.66	3.00	21.76
20	600	19.92	12.65	7.55	5.76	25.99
40	755	21.13	12.56	8.68	6.63	28.39
60	666	22.59	11.28	9.05	6.32	29.63

The model is made to analyze the effect of varying firing angle for thyrister converter on reactive power demand. The thyristor converter firing angle (α°), in steps of 20°, is varied from 0° to 60°. Obviously, demand of reactive power is different for different values of firing angle which in turns results in different values of harmonic distortions throughout his process. The study is made to analyze harmonics in source current for various values of firing angle for triggering three phase thyristor converter. Total harmonic distortion (THD) as per recommended IEEE-519 standards, must be less than 5%. The filters that are designed for this particular system are able to fulfill these criteria when the converter is triggered at 0° angle. This is because calculations for parameters of filter are done for reactive power demand of 400VAR. This can be seen from Fig.9 and TABLE III. From TABLE III it can be seen that as firing angle increases the effectiveness of fixed passive filter decreases.

978-1-5090-2118-5/16/$31.00 ©2016 IEEE

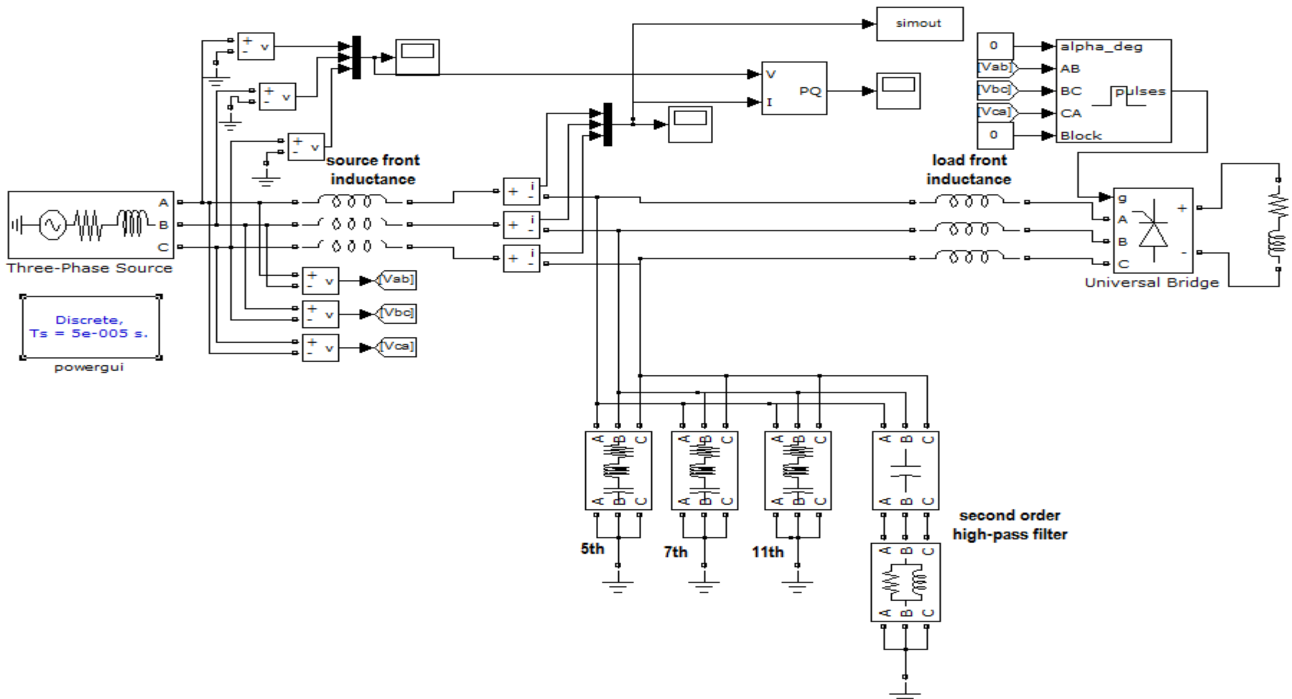

Fig. 9: Simulink Model of Three Phase Power System Connected with Thyristor Converter Fed R-L Load with Passive Filters

VII. Conclusion

This paper deals with designing and implementing mainly two passive filters namely single tuned passive filter and 2nd order passive filter. These filters are connected to power converter fed R-L load whose firing angle is controlled in order to check the performances of filter with varying firing angles. The proposed filter is able to reduce the THD of current at high level of expectation from 21.76% to 3.80% when α is 0°. But these filters are unable to give satisfying results when α is increased (or say varied) which suggests if the reactive power demand is variable there is need for an adaptive passive filter which can supply reactive power demand at all values of α. These adaptive filters can be made using several optimizing techniques for example, by using ANN technology. Although, when reactive power demand is fixed both these filter work efficiently and give satisfying results.

References

[1] Y. Cho and H. Cha, "A Single-Tuned Passive Harmonic Filter Design using Transfer Function Approach for Industrial Process Application", International Journal of Mechatronics and Automation, China, vol. 1, no. 2, p. 90, 2011.

[2] Y. Cho, B. Kim and H. Cha, "Transfer Function Approach to a Passive Harmonic Filter Design for Industrial Process Application", International Conference on Mechatronics and Automation, China, pp. 963-968, 2010.

[3] D. Gonzalez and J. McCall, "Design of Filters to Reduce Harmonic Distortion in Industrial Power Systems", IEEE Trans. on Industry Applications, vol.-23, no. 3, pp. 504-511, 1987.

[4] M. Tali, A. Obbadi, A. Elfajri, Y. Errami, "Passive Filter for Harmonics Mitigation in Standalone PV System for Non-Linear Load", Renewable and sustainable energy conference, Morocco, pp. 499-504, 2014.

[5] D. kumar and F. Zare, "Analysis of Harmonic Mitigations using Hybrid Passive Filters", Power Electronics and Motion Control Conference and Exposition, Turkey, pp. 945-951, 2014.

[6] S. Lai, N. Tse, P. Wong, L. L. Lai, "Analysis of Zero Sequence Passive Filter Harmonics Mitigation Device for Building Wiring System", Conf. on Power System Management and Control, UK, pp. 118-123, 2002.

[7] C. Fu and H. Wang, "An Efficient Optimization for Passive Filter Design", Int. conf. on industrial informatics, South Korea, pp. 631-634, 2008.

[8] M. Singh and S. Mahapatra, "Implementation of Passive Filters for Harmonics Reduction", International Journal of Advanced Science and Technology, India, vol. 78, pp. 1-12, 2015.

[9] Z. A. Memon, M. A. Uquaili and M.A. Unar, "Harmonics Mitigation of Industrial Power System Using Passive Filters", Mehran University Research Journal of Engineering & Technology, Pakistan vol. 31, no. 2, pp. 355-360, 2012.

[10] Y. Cho and H. Cha, "Single-tuned Passive Harmonic Filter Design Considering Variances of Tuning and Quality Factor", Journal of International Council on Electrical Engineering, Korea, vol. 1, no. 1, pp. 7-13, 2011.

978-1-5090-2118-5/16/$31.00 ©2016 IEEE