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Importance of Passive Harmonic Filters over Active Harmonic Filters in Power Quality Improvement Under Constant Loading Conditions

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Abstract: *Harmonic filters play an important role in improving power quality. Increased use of nonlinear loads such as power electronic converters, drives, arc furnaces, induction motors injects harmonics into the power system. The disturbed power system due to harmonics will damage the sensitive loads, malfunctioning of relays, heating of the neutral conductor and so on. Harmonics filters are classified into active and passive type. Though active filters are very effective in eliminating harmonics but these are very expensive, design is complex and not useful in eliminating fixed harmonics. Passive filters are more suitable in eliminating fixed lower order harmonics as compared to active filters but these are limited to only constant loading conditions. In this proposed paper the importance of passive filter over active filter was discussed and a comparative study was made between active and one of the passive filters with the help of MATLAM SIMULINK environment.*

Keywords: *Active filters, Induction motor, Harmonics, Harmonic filters, Passive filters, Sensitive loads.*

I. Introduction

Nowadays many loads are nonlinear in nature due to the exponential use of power electronic components. These inject harmonics in to the power system. So as a result utilities are not able to provide good quality of power to its consumers. According to IEEE Recommended Practice for monitoring Power Quality (IEEE Std 1159-2009), the Power quality is defined as “concept of powering and grounding sensitive equipment in a manner that is suitable for operation of that equipment.” When harmonics are introduced into the system the sinusoidal voltage and current gets disturbed or deviated from the fundamental frequency, due to this the loads may get damaged [1]. Harmonics will result in copper loss, iron loss, dielectric loss and thermal stress in cables, transformers and rotating machines. The Power Quality can be improved by reducing Total Harmonic Distortion (THD). In distribution side, filters are used to mitigate harmonics and to improve power quality. The harmonic filters are mainly classified as active and passive filters. The passive filters are sub classified as low pass and high pass filters. Low Pass Filters (LPF) are used to mitigate current harmonics as it is connected in shunt with the load and provide low impedance path to the harmonics. High Pass Filters (HPF) are used to mitigate voltage harmonics as it is connected in series with the load and provides high impedance path to the harmonics. Passive filters compensate reactive power by eliminating harmonics and also it corrects the power factor. The advantages of passive filters are low cost, simple design, high reliability and easy to implement. The drawbacks of passive filters are dependence of filtering characteristics, source impedance, detuning, parallel/series resonance between power system components, high no-load losses, bulky size and fixed compensation [1]. It cannot solve random variations in the load current waveform. However, Passive filters are best suitable for the constant loads as it eliminates or bypasses lower order fixed harmonics (3^{rd}, 5th, 7th etc) of current or voltage by tuning the passive filters at resonance frequency. Active filters are very effective in eliminating harmonics up to 20^{th} order under dynamic loading conditions but these are not much useful in eliminating fixed lower order harmonics and for fixed loading conditions as cost of active filters are very expensive and also design of active filters are very complex [1]. In recent advancements many new passive filters are coming up such as double tuned passive filter, triple tuned filter, LC filter, LCL filter etc. these have been found more suitable than active filters in eliminating harmonics under fixed loading conditions [2]. The double tuned filters give better performance than the two parallel single tuned passive filters [3]. The shunt passive filters are classified as single tuned, double tuned, triple tuned, quadruple tuned, damped, automatically tuned filters and the series passive filters In this proposed paper the importance of various passive filters over active filters, the design of various passive filters and comparison of one of the passive filter with active filter was discussed. This paper is sectioned into four. Section II deals with design of passive filters, comparison of double tuned passive filter with shunt active filter is detailed in section III. The conclusions and scope for future work is elaborated in section IV.

II. Design Of Passive Filters

II. A Design of Single Tuned Passive Filter

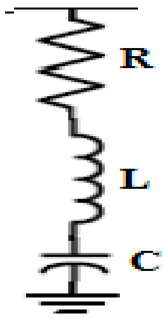

Fig. 1 Single Tuned Passive Filter

As shown in Fig. 1, Single tuned shunt passive filters mainly consists of series connected resistance, inductance and capacitance. It can be tuned to filter out lower order harmonics (3^{rd}, 5^{th}, 7th etc.) . For higher order harmonics these filters are not useful as tuning becomes difficult for higher order harmonics. At resonance condition, the inductive reactance will be equal to the capacitive reactance ($X_L = X_C$), so the total impedance is less and it provides low impedance path to that particular resonance frequency (f_n) thus eliminating the harmonics due to nonlinear loads. It also improves the power factor. When the frequency is less than the resonance frequency the circuit is capacitive in nature, and if it is more than resonance frequency the circuit is inductive in nature [3].

The impedance versus frequency curve is illustrated in Fig. 2

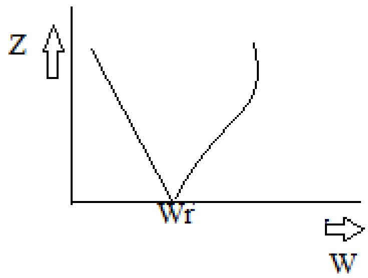

Fig. 2 Characteristics of single tuned filter

Design Procedure:

The inductive reactance X_L is given by

$$X_L = 2\pi f_n L_n \tag{1}$$

Where f_n is the n^{th} harmonic frequency

The capacitive reactance X_C is given by

$$X_C = \frac{1}{2\pi f_n C_n} \tag{2}$$

At resonance

$$X_L = X_C \tag{3}$$

$$2\pi f_n L_n = \frac{1}{2\pi f_n C_n} \tag{4}$$

The resonant frequency f_n is

$$f_n = \frac{1}{2\pi\sqrt{L_n C_n}} \tag{5}$$

The desired value of capacitance for tuning

$$C_n = \frac{1}{L_n (2\pi f_n)^2} \tag{6}$$

The desired value of inductance for tuning

$$L_n = \frac{1}{C_n (2\pi f_n)^2} \tag{7}$$

The desired value of resistance for tuning

$$R_n = \frac{L_n (2\pi f_n)}{Q} \tag{8}$$

The quality factor is

$$Q = R_n \sqrt{\frac{C_n}{L_n}} \tag{9}$$

The quality factor is between 15 to 100. The quality factor decides the sharpness of filtering. The sharpness of filtering increases with quality factor.

II.B Design of Double Tuned Passive Filter

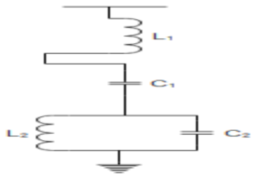

Fig. 3 Double tuned passive filter

As shown in Fig. 3, a double tuned filter having a series resonant and shunt resonant circuit. It can filter two lower order (3^{rd}, 5^{th}, 7th etc.) harmonics with a single circuit whereas for single tuned, it requires two separate parallel circuits [4]. The series circuit gives series resonant frequency (w_s) and parallel circuit gives parallel resonant frequency (w_p). These two resonance frequencies can filter two dominant lower order current harmonics from the power system with single circuit. Double tuned passive filter gives better performance when compared to the two single tuned passive filters [4]. In this paper using the parameters of two single tuned filters, a double tuned filter was designed. At resonant frequencies, the reactance of inductor is equal to the reactance of a capacitor. The double tuned passive power filter provides low impedance path to the two lower order current harmonics as shown in Fig. 4.

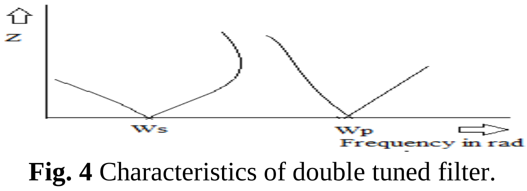

Fig. 4 Characteristics of double tuned filter.

Design Procedure:

The series circuit impedance is

$$Z_s = jwL_1 + \frac{1}{jwC_1} \tag{10}$$

The parallel circuit impedance is

$$z_p = \left(jwC_2 + \frac{1}{jwL_2} \right)^{-1} \tag{11}$$

The total impedance is

$$Z = jwL_1 + \frac{1}{jwC_1} + \left(jwC_2 + \frac{1}{jwL_2} \right)^{-1} \tag{12}$$

$$z = \frac{\left(1 - \frac{w^2}{w_s^{\ 2}}\right)\left(1 - \frac{w^2}{w_p^{\ 2}}\right) - w^2 L_2 C_2}{JwC_2\left(1 - \frac{w^2}{w_p^{\ 2}}\right)} \tag{13}$$

The series resonance frequency (w_s), parallel resonance frequency (w_p) in radians/sec can be expressed as

$$w_s = \frac{1}{\sqrt{L_1 C_1}};\ w_p = \frac{1}{\sqrt{L_2 C_2}} \tag{14}$$

Let, w_a, w_b are the resonant frequencies of two single tuned passive filters.

$$w_a = \frac{1}{\sqrt{L_a C_a}};\ w_b = \frac{1}{\sqrt{L_b C_b}} \tag{15}$$

The impedance of two parallel single tuned filters can be expressed as

$$Z_{ab} = \frac{\left(1 - \frac{w^2}{w_a^{\ 2}}\right)\left(1 - \frac{w^2}{w_b^{\ 2}}\right)}{jwc_a\left(1 - \frac{w^2}{w_b^{\ 2}}\right) + jwc_b\left(1 - \frac{w^2}{w_a^{\ 2}}\right)} \tag{16}$$

The cumulative impedance of double tuned filter is same as cumulative impedance of two single tuned passive filters [4].

$$Z = Z_{ab} \tag{17}$$

Comparing coefficient of w^4

$$w_a w_b = w_s w_p \tag{18}$$

Comparing coefficient of w

$$C_1 = C_a + C_b \tag{19}$$

Comparing coefficient of w^3

$$C_b \frac{1}{w_a^2} + C_a \frac{1}{w_b^2} = C_1 \frac{1}{w_p^2} \tag{20}$$

The parameter L_1 is given by

$$L_1 = \frac{1}{C_a w_a^{\ 2} + C_b w_b^{\ 2}} \tag{21}$$

The series resonance frequency w_s and parallel resonance frequency w_p of double tuned filter can be obtained by

$$w_s = \frac{1}{\sqrt{L_1 C_1}} \tag{22}$$

$$w_p = \frac{w_a w_b}{w_s} \tag{23}$$

Since, w_a is the zero of double tuned filter impedance. Hence Z (w_a) =0. The equation to solve L_2 is

$$\left(1-\frac{w_a^{\,2}}{w_s^{\,2}}\right)\left(1-\frac{w_a^{\,2}}{w_p^{\,2}}\right)-w^2 L_2 C_1 = 0 \tag{24}$$

The above equation can be simplified to get L_2

$$L_2 = \frac{\left(1-\frac{w_a^{\,2}}{w_s^{\,2}}\right)\left(1-\frac{w_a^{\,2}}{w_p^{\,2}}\right)}{C_1 w_a^{\,2}} \tag{25}$$

The value of C_2 can be obtained by

$$C_2 = \frac{1}{L_2 w_p^{\,2}} \tag{26}$$

Hence all the parameters needed for double tuned filter (L_1, C_1, L_2, C_2) can be calculated from the parameters of two parallel connected single tuned filters (L_a, C_a, L_b, C_b).

This double tuned passive power filter can provide better performance in eliminating lower order current harmonics than two single tuned passive filters [4]. The size of double tuned passive filter is less as compared to single tuned passive filter and also the reactive power requirement is less. Hence double tuned passive filter is the best choice for eliminating lower order current harmonics.

II.C Design of Triple Tuned Passive Filter:

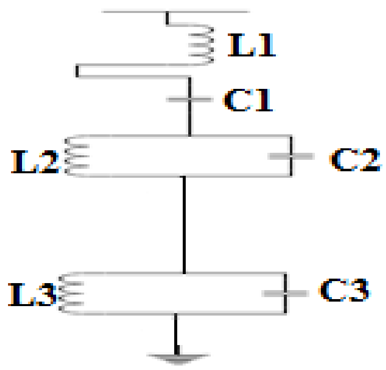

Fig. 5 Triple tuned passive filter.

Triple tuned passive filter can eliminate three lower order current harmonics with a single circuit and it gives better performance as compared to three single tuned passive filters. It is very much useful in eliminating harmonics at HVDC converter stations as size becomes very less as compared to three single tuned passive filters. It consists of one series resonant circuit and two parallel resonant circuits. Research is going on to design triple tuned passive filter with the parameters of single tuned filters of selected lower order current harmonics.

III. Comparison of Double Tuned Passive Filter with Shunt Active Filter

III.A System with Double Tuned Passive Filter

The double tuned passive filter gives better performance as compared to the two single tuned passive filters as shown in Fig. 6. The corresponding source current wave form and THD are shown in Fig.s 7 & 8.

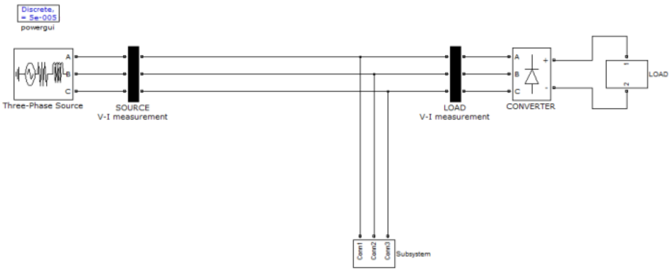

Fig. 6 System with double tuned passive filer

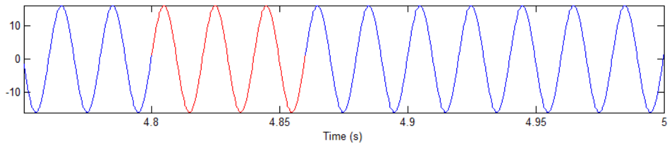

Fig. 7 Source current waveform with double tuned passive filter

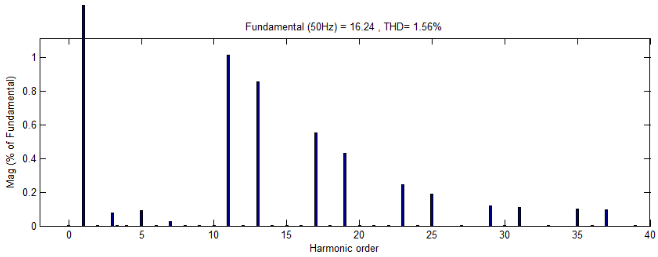

Fig. 8 THD of source current with double tuned passive filter

III.B. System with Shunt Active Filter

The shunt active filter with p-q control technique [5] provides better performance as compared to double tuned passive filter as shown in Fig. 9 . The source current wave form and THD of shunt active filter are shown in Fig.s 10 & 11.

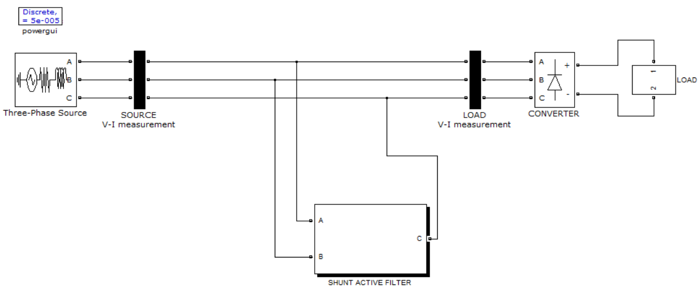

Fig. 9 System with shunt active filter

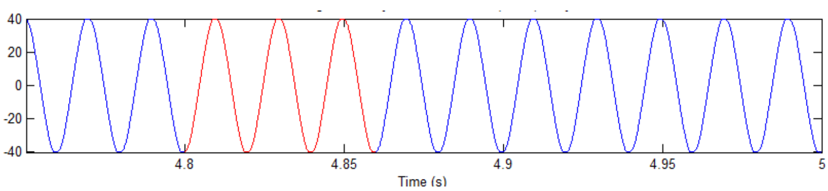

Fig. 10 Source current waveform with shunt active filter

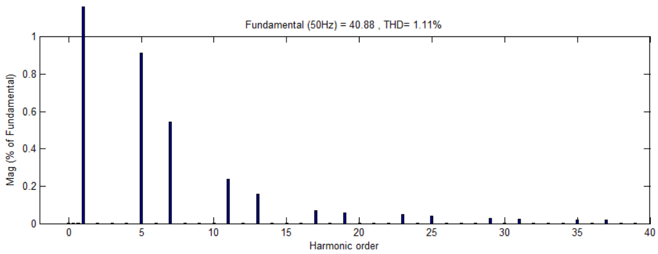

Fig. 11 THD of source current with shunt active filter

III.C Comparision

From the analysis of various parameters of both double tuned passive filter and shunt active filter, a double tuned passive filter is best suitable even though shunt active filter performance is slightly better than double tuned passive filter [6].Compared to shunt active filter the cost of double tuned filter is very less, the space requirement is less, design is easy, whereas shunt active filter modeling, controlling, design is difficult and also the cost of shunt active filter is very high.

From the MATLAB Simulink results it has been observed that both the shunt active filter and double tuned passive filter gives THD with in the acceptable standards, so a double tuned passive filter is preferable where there is a harmonics are constants i.e constant loading conditions and a shunt active filter is preferred under dynamic loading conditions.

IV. Conclusions and Future Scope

From the above discussion, it can be concluded that a double tuned passive filter is very much suitable in eliminating harmonics under constant loading conditions like in HVDC converters, domestic loads etc.

Damped double tuned filters gives better performance than conventional double tuned filter. Research is going on to determine the performance algorithm for damped double tuned passive filters.

Triple tuned filters gives much better performance than double tuned filters as it eliminates three lower order harmonics with a single circuit. Research is going on to evaluate parameters of triple tuned passive filter from the parameters of three single tuned passive filters connected in parallel.

Table 1 Parameters of proposed system

Parameters	**Value**
3 Phase voltage(V_s), Source inductance(L_s), Source resistance(R_s),Load resistance(R_l) & inductance(L_l)	415V,16.5mh,0.8929Ω,100Ω,80mH
L_1,C_1, L_2, C_2 for double tuned.	4.56mh,60μF,55.6mh,0.05μF
Copling inductor(L_c), DC-side capacitor(C_{dc}) for shunt active filter	0.01H, 1μF
THD with out any filter	16.56
THD with double tuned passive filter	1.56
THD with shunt active filter	1.11

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