Performance Analysis of Double Tuned Passive Filter for Power Quality

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Abstract—Power system loads are classified in to linear loads and nonlinear loads. The current in linear loads varies linearly with the system voltage but in nonlinear loads the current does not vary linearly with the system voltage. Due to the increasing use of nonlinear loads like power electronic drives, bridge rectifiers, arc furnaces, air conditioners etc. the injection of harmonics (voltage & current) into the source increases, so the total harmonic distortion (THD) increases. Many harmonic mitigation techniques are available to improve the power quality. In this proposed paper a double tuned passive filter is designed with the parameters of two parallel single tuned passive filters. The results are simulated using MATLAB SIMULINK software.

Keywords— *nonlinear loads; bridge rectifiers; total harmonic distortion; single tuned filter; double tuned filter.*

I. Introduction

Now a day's many loads are nonlinear in nature due to the exponential use of power electronic components. This nonlinear load injects harmonics in to the systems and utilities are not able to give good quality of power to its consumers. According to IEEE Recommended Practice for Monitoring Power Quality (IEEE Std 1159-1995), 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 the harmonics are introduced into the system the sinusoidal voltage and current gets disturbed or deviated from the fundamental frequency due to that the loads may get damaged due to the harmonic effects. Harmonics will copper loss, iron loss, dielectric loss and thermal stress in cables, transformers and rotating machines [1]. The Power Quality can be improved by reducing 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 provided low impedance path at resonance condition(X_l = X_c) . High pass filters (HPF) are used to mitigate voltage harmonics as it is connected in series with the load and provides high impedance path at resonance condition. Passive filters compensate reactive power by eliminating harmonics and also it improves the power factor. The advantages of passive filters are low cost, simple design and easy to implement, high reliability. The drawbacks of passive filters are dependence of filtering characteristics on source impedance, detuning, parallel/series resonance between power system components, high no load losses, bulky size and fixed compensation. It cannot solve random variations in the load current waveform [2]. However, Passive filters are best suitable for the constant loads as it eliminates or bypasses fixed harmonics (3^{rd}, 5th, 7th etc) of current or voltage by tuning the passive filters at resonance frequency. Usually, there are multiple frequency harmonics in a power system, so a group of parallel tuned filters are needed to filter

harmonics [3]. The double tuned filters gives better performance than the two parallel single tuned passive filters .Usually the lower order harmonics are more dangerous than the higher order harmonics as amplitude of lower order harmonics is more than the higher order harmonics. The shunt passive filters are classified as single tuned, double tuned, triple tuned, quadruple tuned, damped, automatically tuned etc. In this proposed paper the modeling of double tuned filter was done with parameters of two separate parallel connected single tune shunt passive filters [3]. In this proposed paper the modeling of single tuned and double tuned filters was done and compared the performance with the MATLAB SIMULINK software. The double tuned shunt passive filter gives the best solution as compared to two separate parallel connected single tuned passive filters as evident form the MATLAB Simulink.
When the three phase system is balanced, then there is no flow of triplen harmonics through neutral of the system to the ground otherwise, there is a flow of triplen harmonics to the ground via neutral. When filter is connected to only one phase of three phase system, the balanced system becomes unbalanced and there is a flow of triplen harmonics to the ground via filter.

In this paper Chapter I discusses the introduction, Chapter II discusses the modeling of single tuned passive filter, Chapter III discusses the modeling of double tuned passive filter, Chapter IV discusses the results and comparison of two filters described in chapter II & III , chapter V discusses the conclusion.

II. MODELLING OF SINGLE TUNED SHUNT PASSIVE FILTER

Single tuned shunt passive filters mainly consists of series connected resistance, inductance and capacitance which is in parallel with the nonlinear load as shown in Fig.1. It can be tuned to lower order harmonics (3^{rd}, 5^{th}, 7th etc.) at resonance condition. For higher order harmonics this type of 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 provides low impedance path to that particular resonance frequency (f_n) thus by 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.

Consider a system as shown in Fig.1

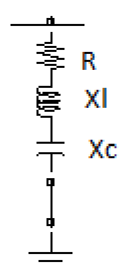

Fig.1 Single Tuned Passive Filter

The impedance versus frequency curve is given by

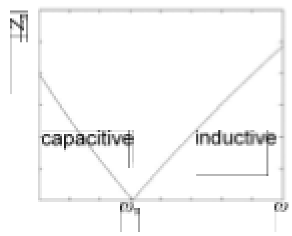

Fig.2 Characteristics of single tuned filter

Design Procedure:

The inductive reactance X_L is given by

$$X_L = 2\pi f_n L_n \qquad (1)$$

Where f_n is the nth harmonic frequency

The capacitive reactance X_C is given by

$$X_C = \frac{1}{2\pi f_n C_n} \qquad (2)$$

At resonance

$$X_L = X_C \qquad (3)$$

$$2\pi f_n L_n = \frac{1}{2\pi f_n C_n} \qquad (4)$$

The resonant frequency f_n is

$$f_n = \frac{1}{2\pi\sqrt{L_n C_n}} \qquad (5)$$

$JHJV$

The desired value of capacitance for tuning

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

The desired value of inductance for tuning

$$L_n = \frac{1}{C_n (2\Pi f_n)^2} \qquad (7)$$

The desired value of resistance for tuning

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

The quality factor is

$$Q = R_n\sqrt{\frac{C_n}{L_n}} \quad (9)$$

The quality factor lies 15 to 100. It gives the sharpness of filtering.

III. MODELLING OF DOUBLE TUNED SHUNT PASSIVE FILTERS

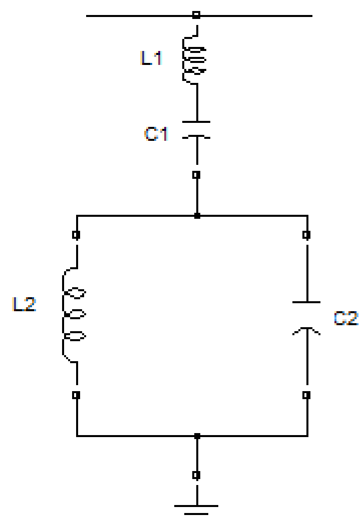

Fig. 3 Double tuned passive filter

Double tuned filter is a combination of series and parallel connection of passive elements. It can filter two lower order (3rd, 5th ,7th etc) harmonics with single circuit whereas for single tuned, it requires two separate parallel circuits. The series circuit gives one resonant frequency (W_S) and parallel circuit gives another resonant frequency (W_P). These two resonance frequencies can filter two harmonics from the power system with single circuit. Double tuned filters gives better performance when compared to the single tuned filters. In this proposed project using parameters of single tuned filter, the double tuned filter was designed [3].

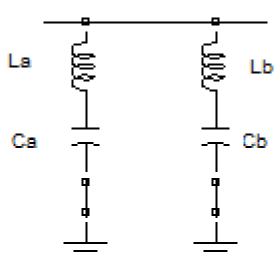

Fig.4Parallel Single Tuned Filter

The impedance versus frequency curve is given by

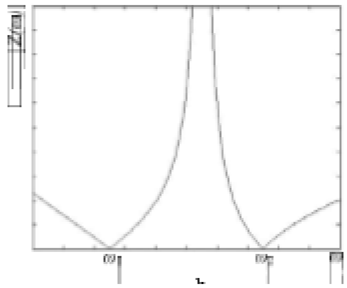

Fig.5 Characteristics of double tuned filter

Design Procedure:

The series circuit impedance is

$$Z_{S}=jwL_{1}+\frac{1}{jwC_{1}} \quad (10)$$

The parallel circuit impedance is

$$Z_{P}=\left(jWC_{2}+\frac{1}{jwL_{2}}\right)^{-1} \quad (11)$$

The total impedance is

$$Z = j\,wL_1 + \frac{1}{jwC_1} + \left(jwC_2 + \frac{1}{jwL_2}\right)^{-1} \quad (12)$$

$$Z = \frac{\left(1-\frac{W^2}{Ws^2}\right)\left(1-\frac{W^2}{Wp^2}\right)-W^2L_2C_1}{jWC_1\left(1-\frac{W^2}{Wp^2}\right)} \quad (13)$$

The series resonance frequency (*Ws*), parallel resonance frequency (*Wp*) in radians can be expressed as

$$Ws = \frac{1}{\sqrt{L_1C_1}}; \quad Wp = \frac{1}{\sqrt{L_2C_2}} \quad (14)$$

W_a and W_b are the resonant frequencies of two single tuned frequencies

$$W_a = \frac{1}{\sqrt{L_aC_a}}; \quad W_b = \frac{1}{\sqrt{L_bC_b}} \quad (15)$$

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

$$Z_{ab} = \frac{\left(1-\frac{W^2}{Wa^2}\right)\left(1-\frac{W^2}{Wb^2}\right)}{jWC_a\left(1-\frac{W^2}{Wb^2}\right)+jWC_b\left(1-\frac{W^2}{Wa^2}\right)} \quad (16)$$

The total impedance of double tuned filter is same as total impedance of two single tuned passive filters

$Z = Z_{ab}$ (17)

Comparing coefficient of W^4

$W_a W_b = W_s W_p$ (18)

Comparing coefficient of W

$C_1 = C_a + C_b$ (19)

Comparing coefficient of W^3

$C_b \frac{1}{Wa^2} + C_a \frac{1}{Wb^2} = C_1 \frac{1}{Wp^2}$ (20)

The parameter L_1 is given by

$L_1 = \frac{1}{C_a Wa^2 + C_b Wb^2}$ (21)

The series resonance frequency Ws and parallel resonance frequency Wp can be obtained by

$W_s = \frac{1}{\sqrt{L_1 C_1}}$ (22)

$W_p = \frac{W_a W_b}{W_s}$ (23)

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

$\left(1 - \frac{Wa^2}{Ws^2}\right)\left(1 - \frac{Wa^2}{Wp^2}\right) - W^2 L_2 C_1 = 0$ (24)

The above equation can be simplified to get L_2

$L_2 = \frac{\left(1-\frac{Wa^2}{Ws^2}\right)\left(1-\frac{Wa^2}{Wp^2}\right)}{C_1 Wa^2}$ (25)

The value of $C2$ can be obtained by

$C_2 = \frac{1}{L_2 Wp^2}$ (26)

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

IV. RESULTS AND DISCUSSIONS

a) System with single tuned shunt passive filer

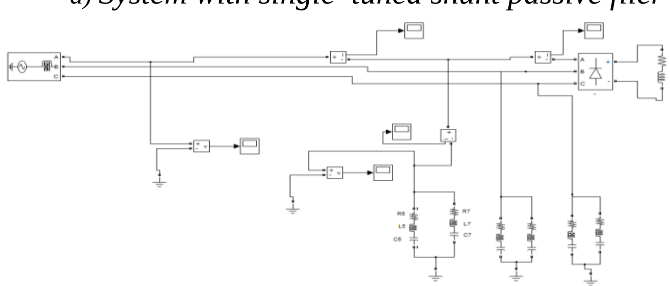

Fig.6 Single Tuned Passive Filter with RL load

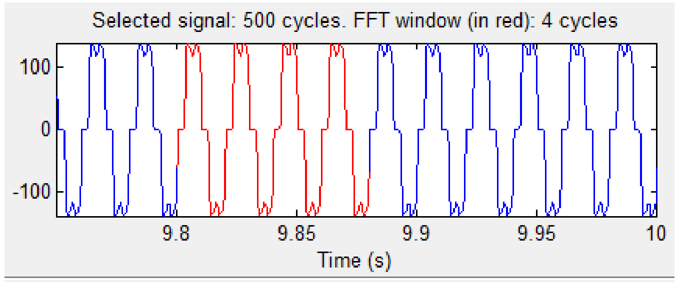

Fig.7 load current (I_l) without filter

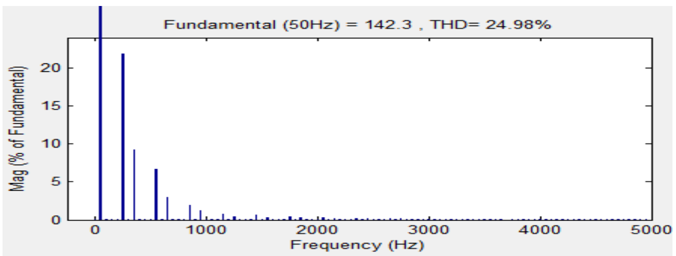

Fig. 8THD of load current (I_l) without filter

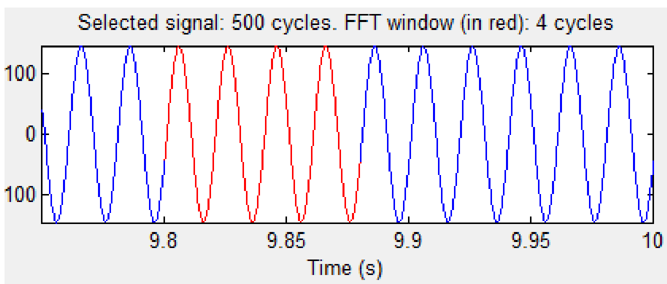

Fig.9 load current (I_l) with filter

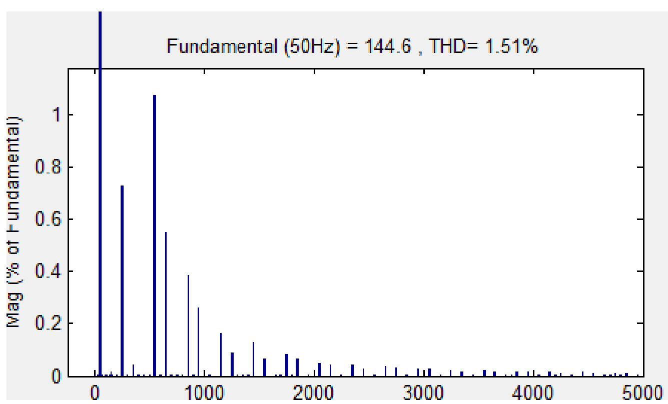

Fig. 10 THD of load current (I_l) with filter

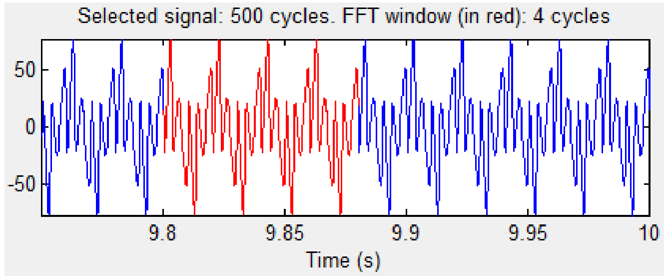

Fig.11 5th & 7th harmonic currents

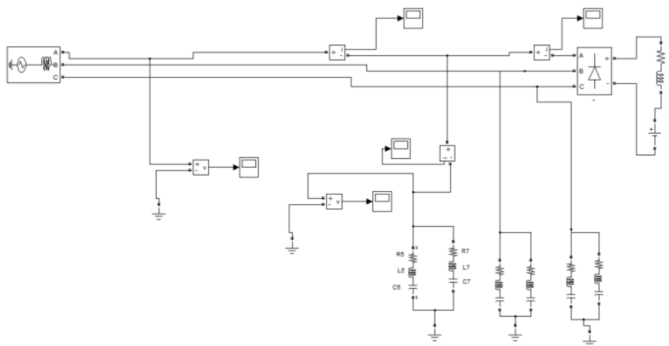

Fig. 12 Single tuned passive filter with RLE load

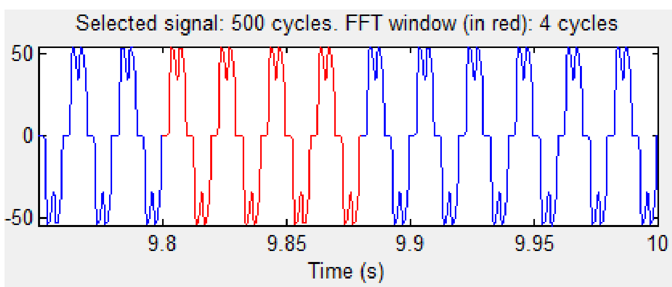

Fig. 13 load current (I_l) without filter

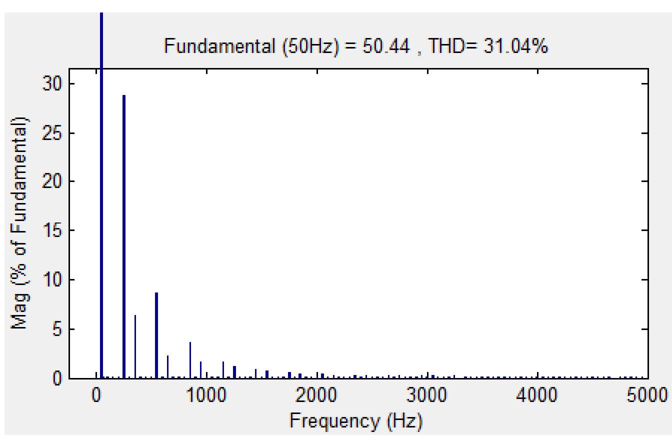

Fig.14 THD of load current(I_l) without filter

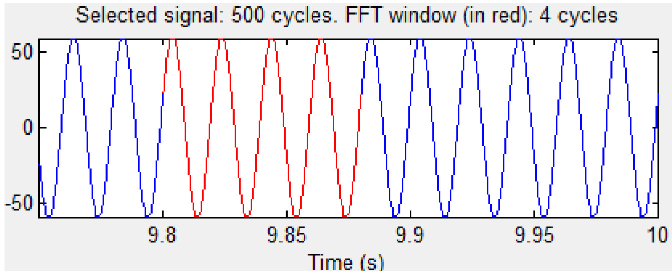

Fig.15 load current (I_l) with filter

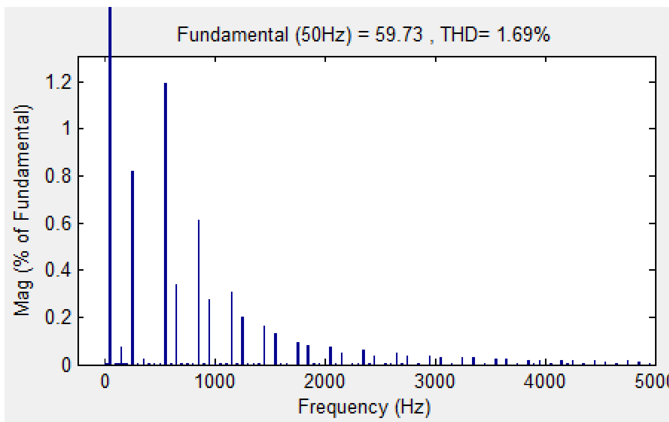

Fig.16 THD of load current (I_l) with filter

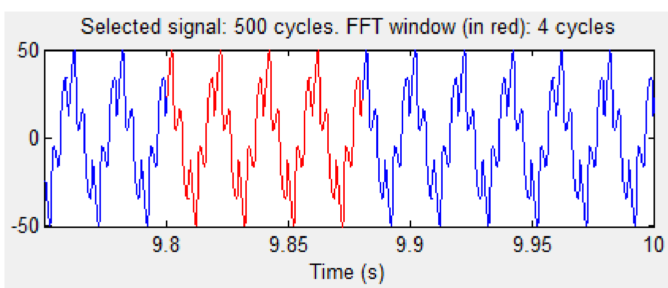

Fig.17 5^{th} & 7^{th} harmonic currents

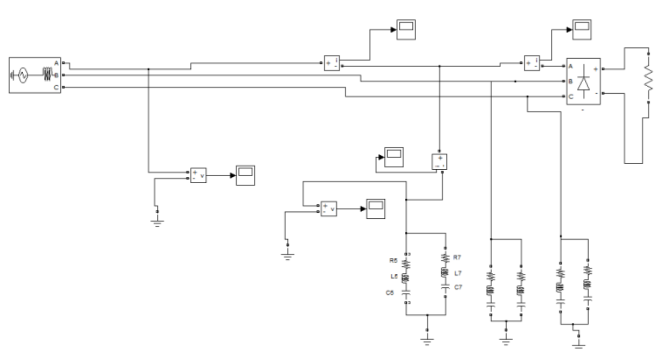

Fig. 18 Single tuned passive filter with R load

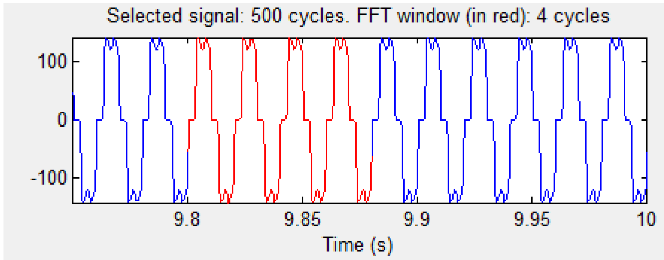

Fig.19 load current (I_l) without filter

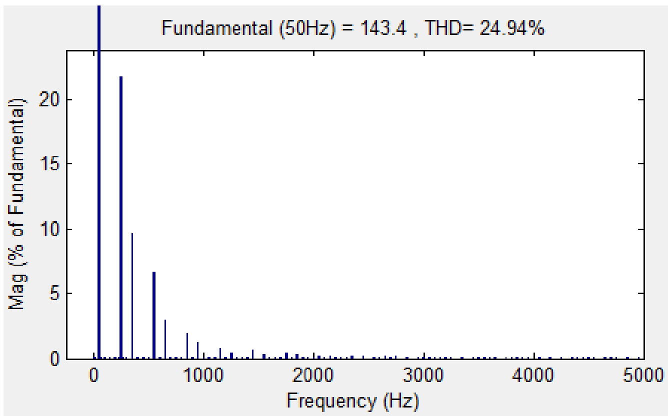

Fig. 20 THD of load current (I_l) without filter

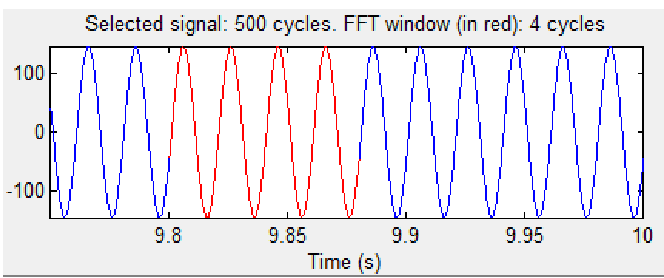

Fig. 21 load current (I_l) with filter

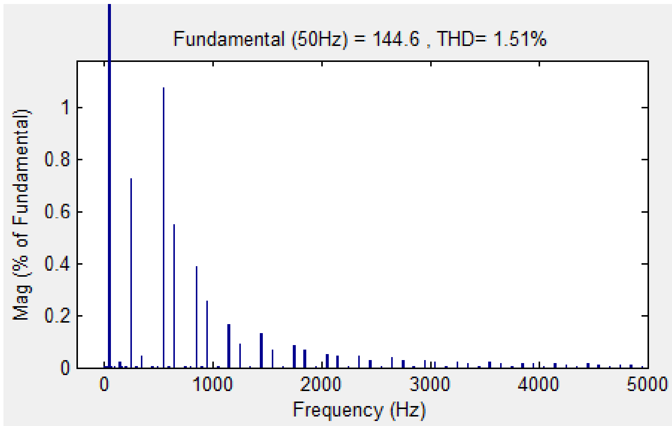

Fig.22 THD of load current (I_l) with filter

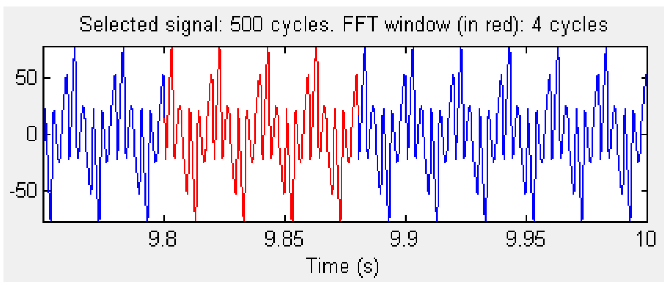

Fig.23 5th & 7th harmonic currents

Table 1. Harmonics without filter

Type of System	**Harmonics without filter**		
	3rd	***5th***	***7th***
Three phase system connected to bridge rectifier with R-L load	0	21.6	9.65
Three phase system connected to bridge rectifier with R-L-E load	0.1	28.6	6.34
Three phase system connected to bridge rectifier with R load	0	21.6	9.65

Table 2. Harmonics with filter

Type of System	**Harmonics with Single tuned shunt passive filter**		
	3rd	***5th***	***7th***
Three phase system connected to bridge rectifier with R-L load	0.	0.72	0.04
Three phase system connected to bridge rectifier with R-L-E load	0	0.82	0.02
Three phase system connected to bridge rectifier with R load	0	0.72	0.04

b) System with double tuned shunt passive filer

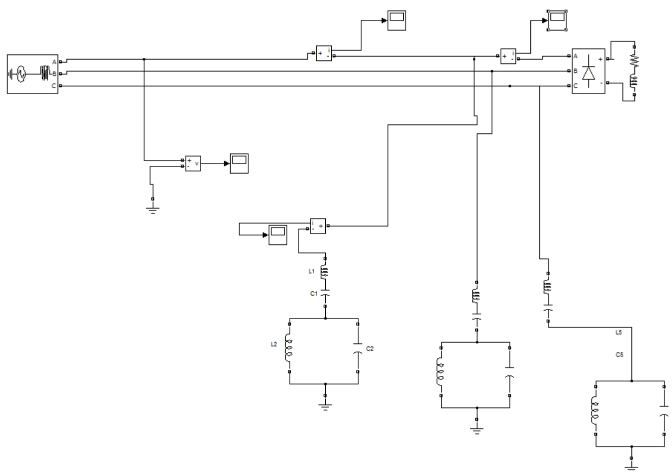

Fig.24 Double tuned passive filter with RL load

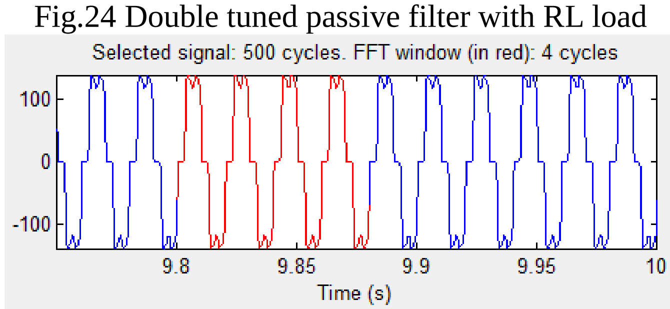

Fig.25 load current (I_l) without filter

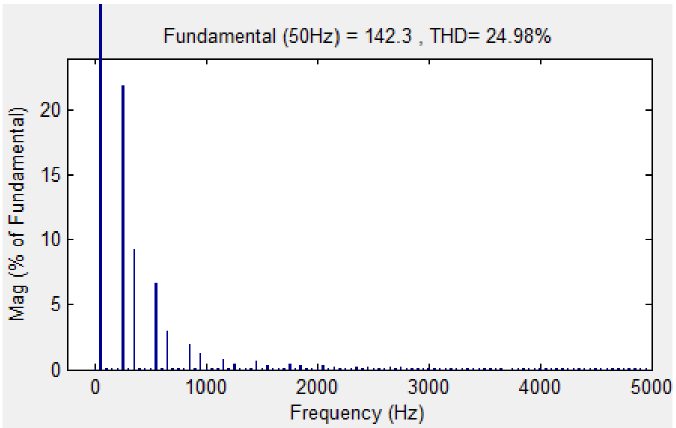

Fig.26 THD of load current (I_l) without filter

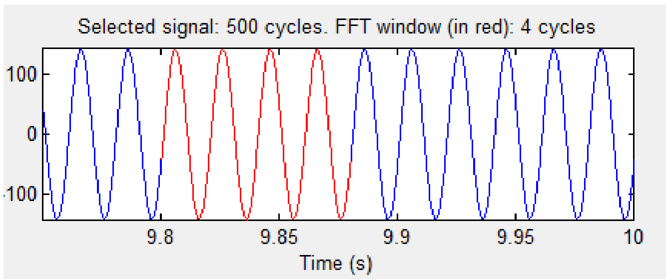

Fig.27 load current (I_l) with filter

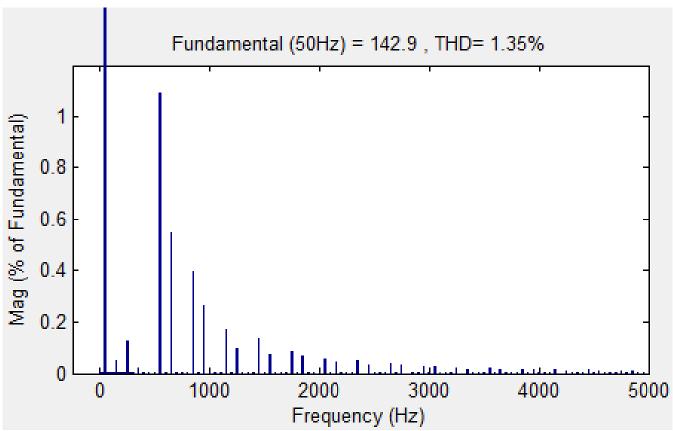

Fig. 28 THD of load current (I_l) with filter.

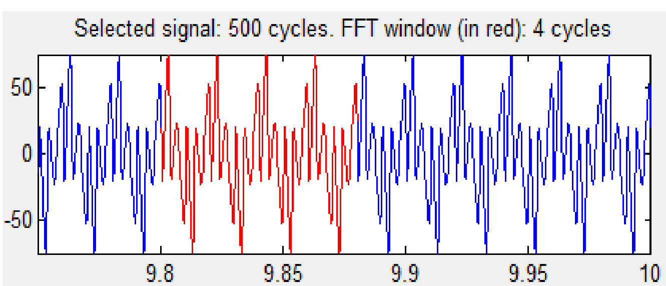

Fig. 29 5th & 7th harmonic currents

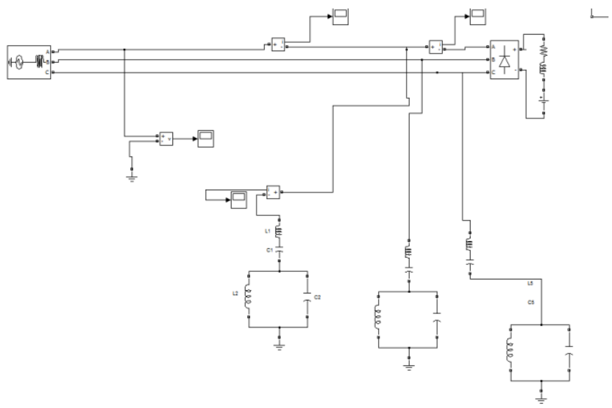

Fig. 30 Double tuned passive filter with RLE load

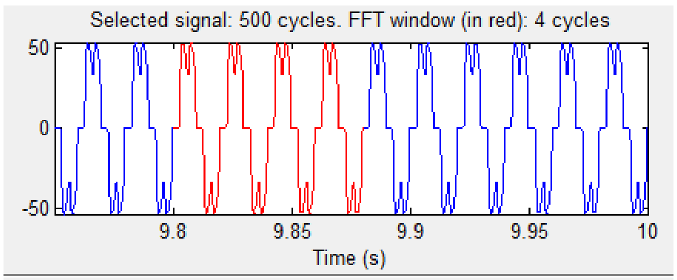

Fig. 31 load current (I_l) without filter

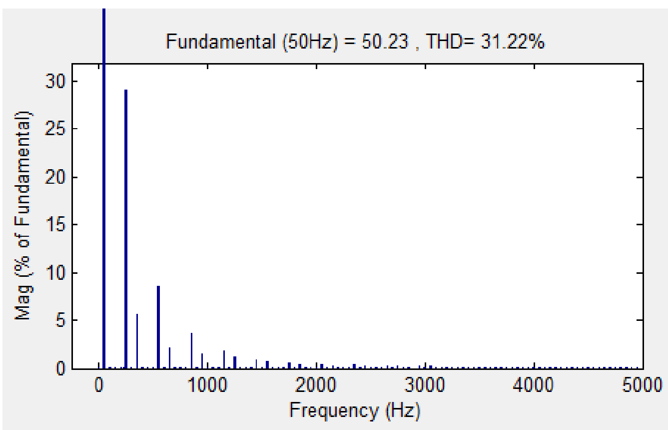

Fig. 32 THD of load current(I_l) without filter

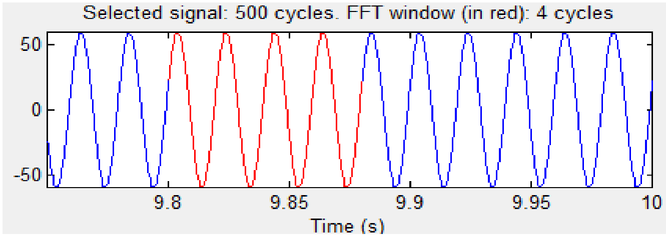

Fig.33 load current (I_l) with filter

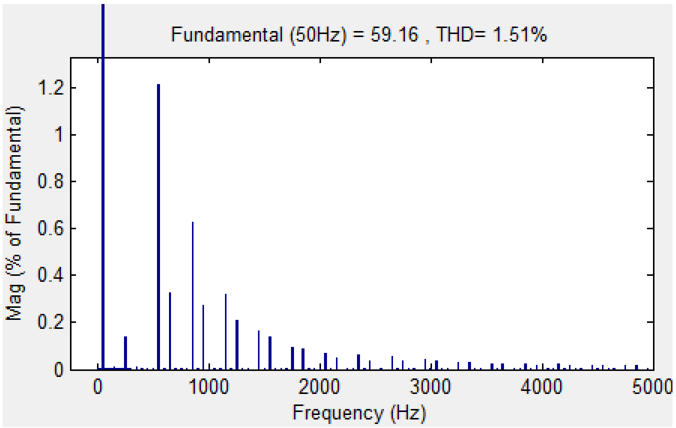

Fig. 34 THD of load current (I_l) with filter

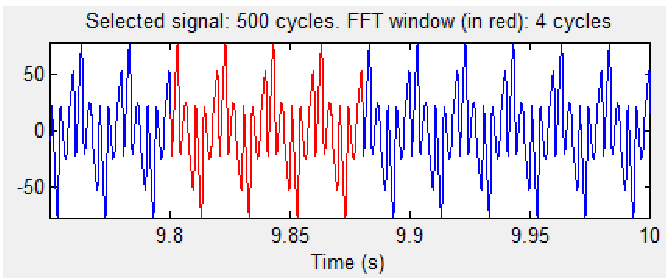

Fig.35 5th & 7th harmonic currents

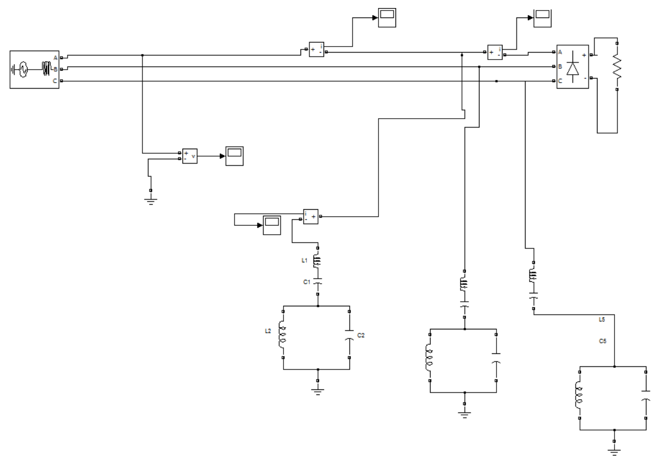

Fig. 36 Double tuned passive filter with R load

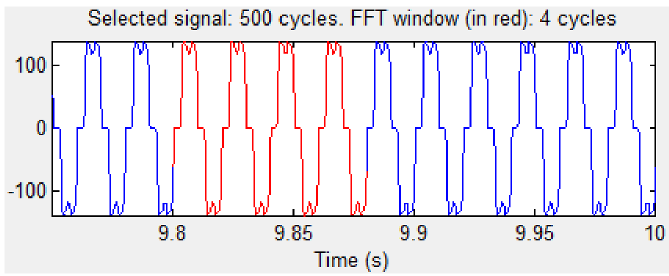

Fig.37 load current (I_l) without filter

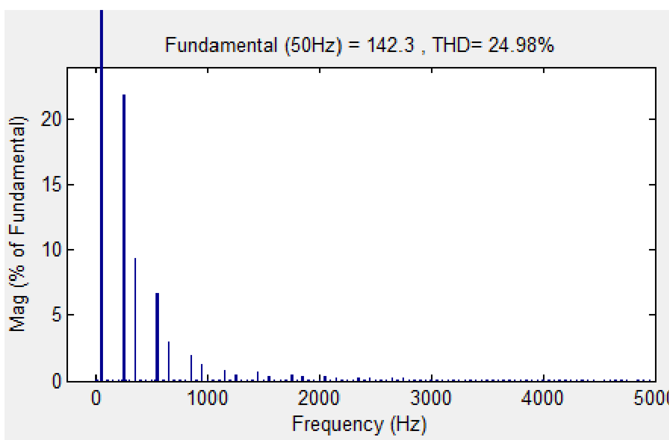

Fig.38 THD of load current(I_l) without filter

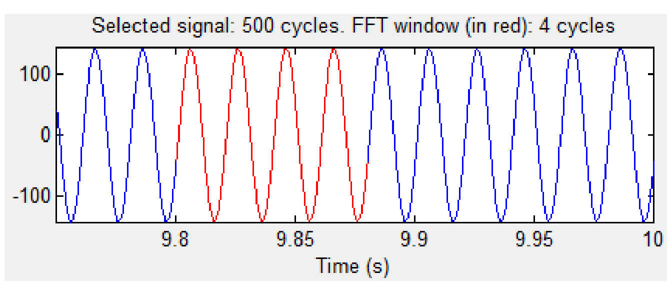

Fig.39 load current (I_l) with filter

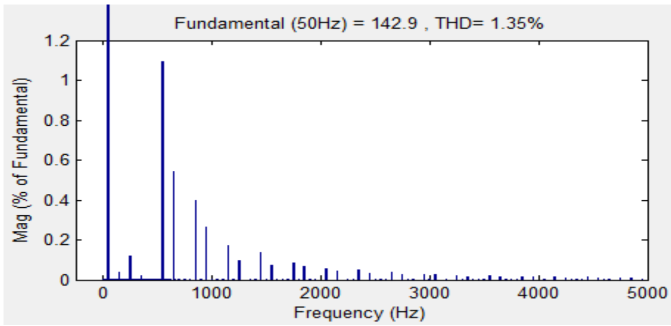

Fig.40 THD of load current (I_l) with filter

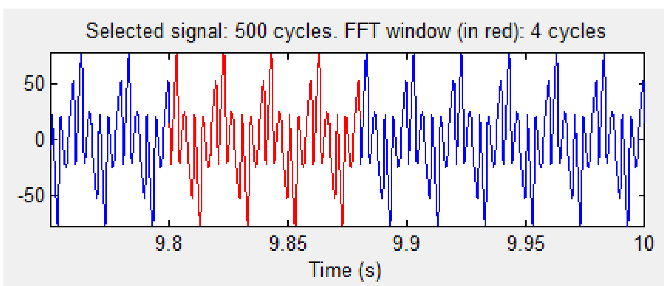

Fig.41 5^{th} & 7^{th} harmonic currents

Table 3. Harmonics without filter

Type of System	**Harmonics without filter**		
	3rd	***5th***	***7th***
Three phase system connected to bridge rectifier with R-L load	0	21.6	9.65
Three phase system connected to bridge rectifier with R-L-E load	0.1	28.6	6.34
Three phase system	0	21.	9.

Type of System	Harmonics without filter		
	3^{rd}	5^{th}	7^{th}
connected to bridge rectifier with R load		6	65

Table 4. Harmonics with filter

Type of System	Harmonics with double tuned shunt passive filter		
	3^{rd}	5^{th}	7^{th}
Three phase system connected to bridge rectifier with R-L load	0.05	0.12	0.02
Three phase system connected to bridge rectifier with R-L-E load	0.01	0.14	0.01
Three phase system connected to bridge rectifier with R load	0.05	0.12	0.02

C) Considering filter only to phase a

When a three phase system is balanced, then there is no flow of tiplen harmonics to the neutral wire to ground. triplen hrmonics are 3^{rd} multiplication of harmonics (3rd, 6^{th}, 9th etc.) but, mostly there is a flow of 3^{rd} harmonic components to the neutral of the ground. To avoid the triplen harmonics, both the supply and the load should be grounded, so that triplen harmonics cancels each other by taking reverse path from the supply and load grounds. In this paper a bridge rectifier with R,RL,RLE loads are connected across it connected to a three phase supply was used to generate harmonics, It was observed that there is no triplen harmonics in the system but there is a presence of other harmonics i.e system is balanced. When single tuned or double tuned filter is connected only to one of the phase, then there is a considerable flow of triplen harmonics to ground. Triplen harmonics causes neutral wire heating, so power loss. For a 3 phase system filters should connect to all the phases to avoid the flow of triplen harmonics to neutral wire and to get balanced condition.

Table 5. Harmonics of double tuned filter when connected to only phase ‘a’

Type of System	**Harmonics with double tuned shunt passive filter**		
	3rd	***5th***	***7th***
Three phase system connected to bridge rectifier with R-L load	3.45	0.11	0.02
Three phase system connected to bridge rectifier with R-L-E load	10.02	0.13	0.01
Three phase system connected to bridge rectifier with R load	3.47	0.11	0.02

Table 6. Harmonics of single tuned filter when connected to only phase ‘a’

Type of System	**Harmonics with single tuned shunt passive filter**		
	3rd	***5th***	***7th***
Three phase system connected to bridge rectifier with R-L load	3.47	0.67	0.04
Three phase system connected to bridge rectifier with R-L-E load	10.07	0.78	0.02
Three phase system connected to bridge rectifier with R load	3.49	0.67	0.04

V CONCLUSION

From the analysis, the double tuned filter gives better performance than single tuned filter. The size of a double tuned filter is less; harmonic elimination is more as compared to single tuned filter. It was observed that there is a flow of triplen harmonics through the ground when filter is connected to only one phase out of three phases i.e. system becomes unbalanced.

Parameters	**Value**
3 Phase voltage(V_s), Source inductance(L_s), L_5,C_5, L_7, C_7 for single tuned.	2000V,15mH,13.5mH,30µF,6.89mH,30µF

Parameters	**Value**
3 Phase voltage(V_s), Source inductance(L_s), L_1,C_1, L_2, C_2 for double tuned.	2000V,15mH,4.56 mH,60µF,5.56e^{-4}mH,5.5e^{-4}F

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