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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 was 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.

1. 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 leads to 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 into active and passive filters. The passive filters are sub classified into 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 ($X_1 = X_c$). 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.

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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 Proposed research 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.

2. 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

The impedance versus frequency curve is given by

Design Procedure:

The inductive reactance X_L is given by

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

Where f_n is the n^{th} harmonic frequency

The capacitive reactance X_C is given by

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

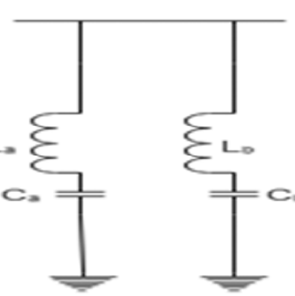

Figure 1: Single Tuned Passive Filter

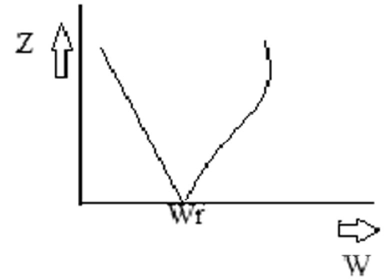

Figure 2: Characteristics of single tuned filter

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 lies 15 to 100. It gives the sharpness of filtering.

III. MODELLING OF DOUBLE TUNED SHUNT PASSIVE FILTERS

Double tuned filter is a combination of series and parallel connection of passive elements. It can filter two lower order (3^{rd},5^{th}, 7^{th} 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].

The impedance versus frequency curve is given by

Design Procedure:

The series circuit impedance is

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

The parallel circuit impedance is

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

The total impedance is

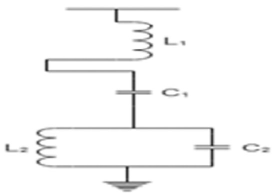

Figure 3: Double tuned passive filter

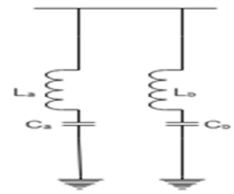

Figure 4: Parallel Single Tuned Filter

Figure 5: Characteristics of double tuned filter

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

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

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

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

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

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

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

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

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 and parallel resonance frequency 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 is the zero of double tuned filter impedance, so $Z(\ ) = 0$. 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

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

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 can be calculated from the parameters of two parallel connected single tuned filters.

4. RESULTS AND DISCUSSIONS

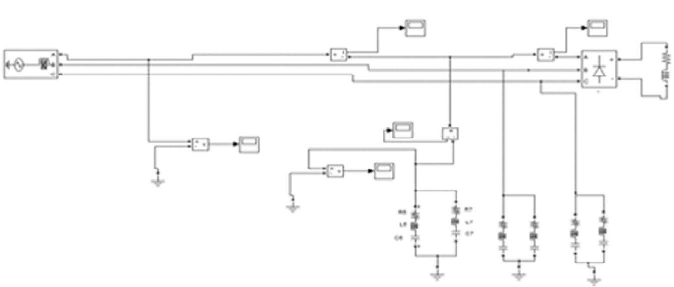

Figure 6: Single Tuned Passive Filter with RL load

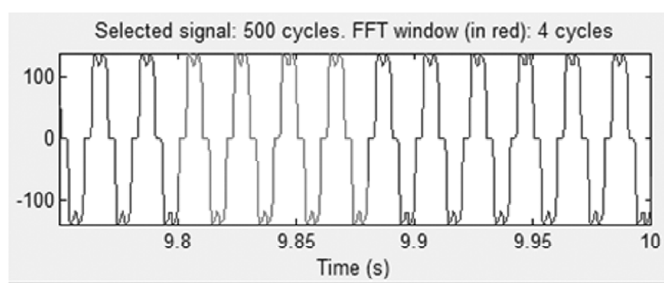

Figure 7: Source current (I_s) without filter

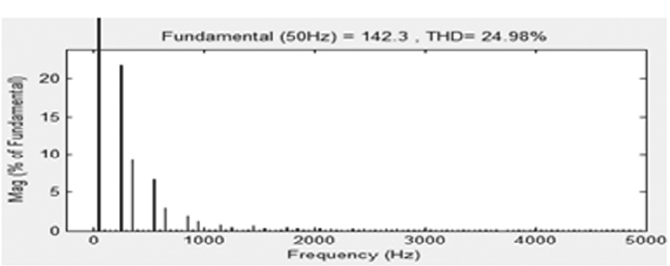

Figure 8: THD of Sourcecurrent (I_s) without filter

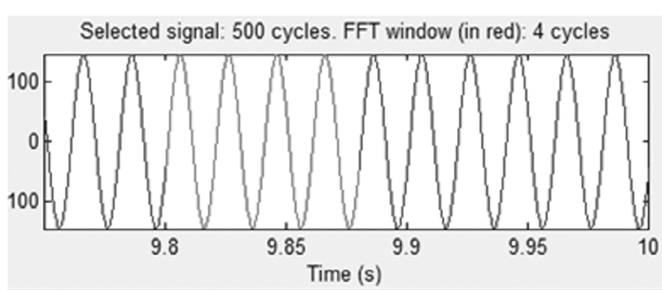

Figure 9: Source current (I_s) with filter

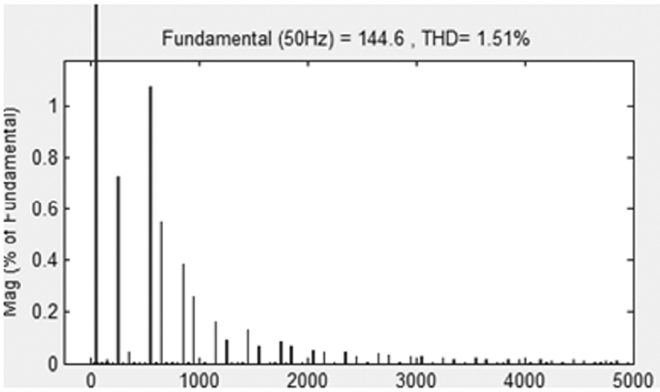

Figure 10: THD of Source current (I_s) with filter

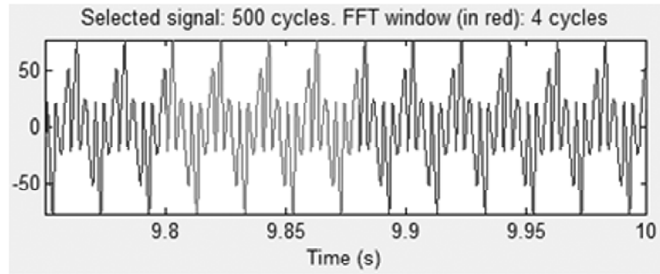

Figure 11: 5th& 7th harmonic currents

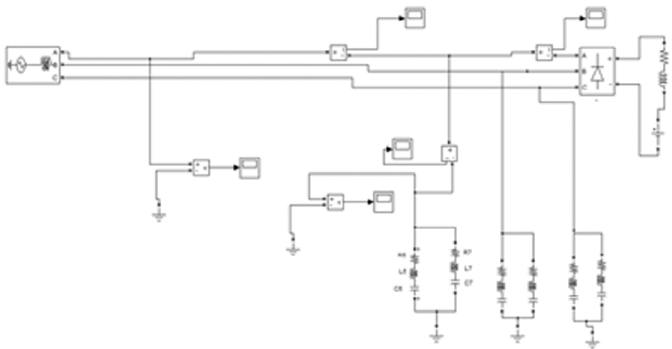

Figure 12: Single tuned passive filter with RLE load

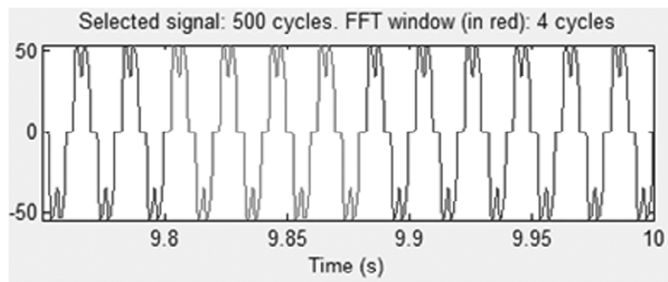

Figure 13: Source current (I_s) without filter

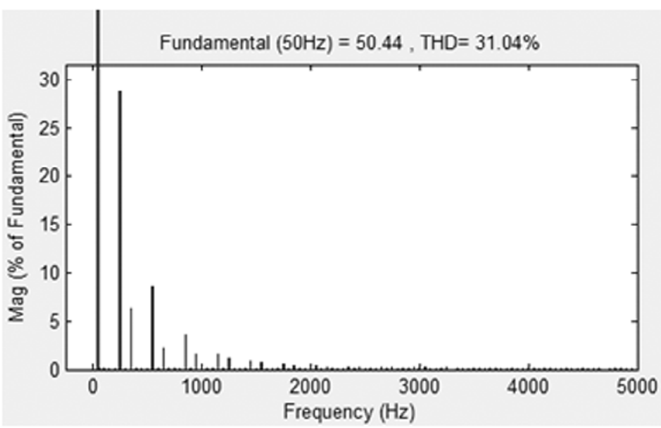

Figure 14: THD of Source current (I_s) without filter

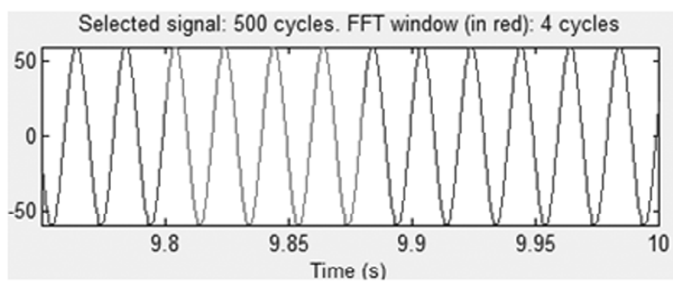

Figure 15: Source current (I_s) with filter

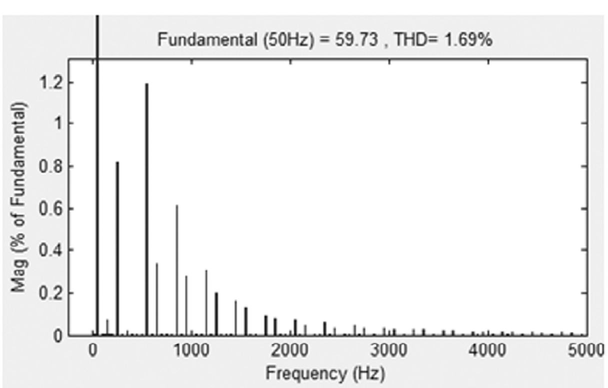

Figure 16: THD of Source current (I_s) with filter

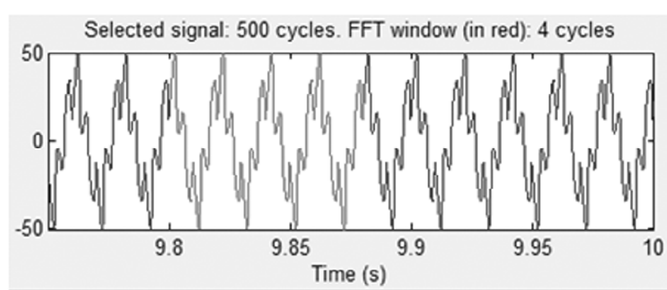

Figure 17: 5th& 7th harmonic currents

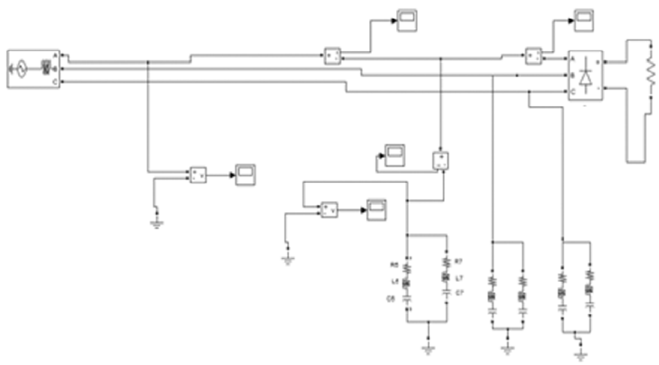

Figure 18: Single tuned passive filter with R load

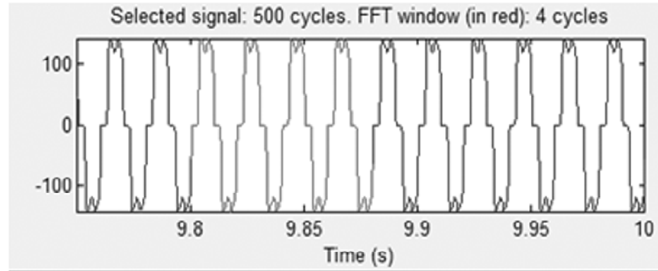

Figure 19: Source current (I_s) without filter

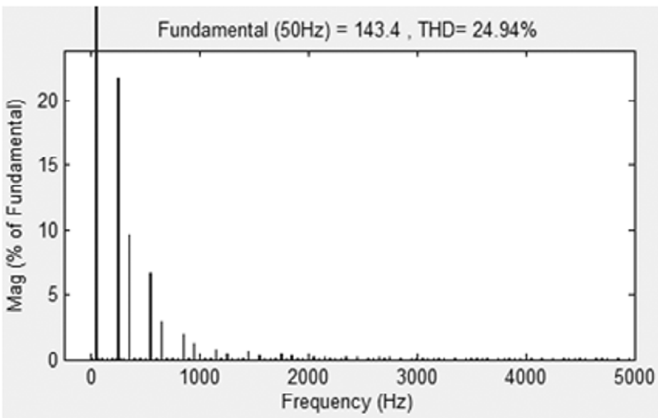

Figure 20: THD of Sourcecurrent (I_s) without filter

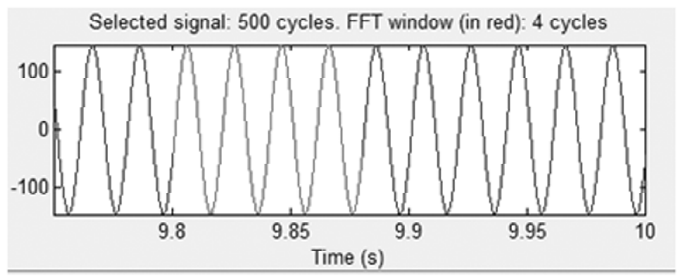

Figure 21: Source current (I_s) with filter

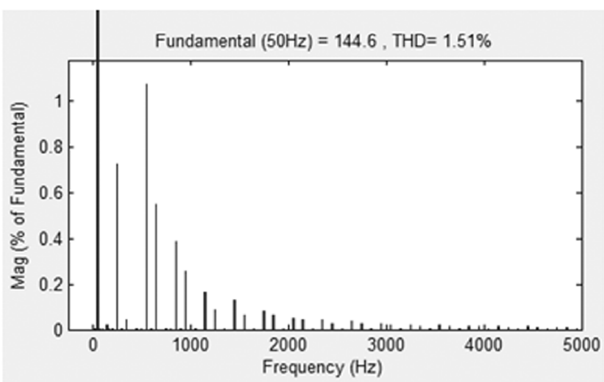

Figure 22: THD of Source current (I_s) with filter

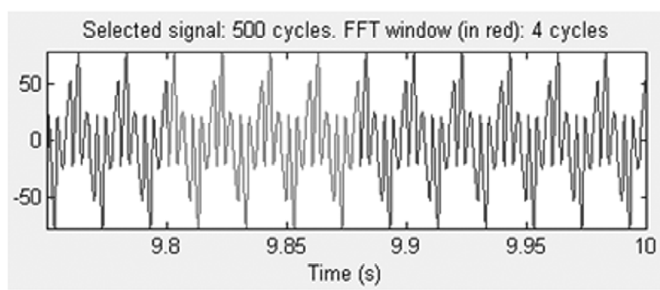

Figure 23: 5^{th}& 7^{th} harmonic currents

Table 1
Harmonics without filter

Type of System	*Harmonics without filter*		
	3^{rd}	*5^{th}*	*7^{th}*
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*		
	3^{rd}	*5^{th}*	*7^{th}*
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

4.1. System with single tuned shunt passive filer

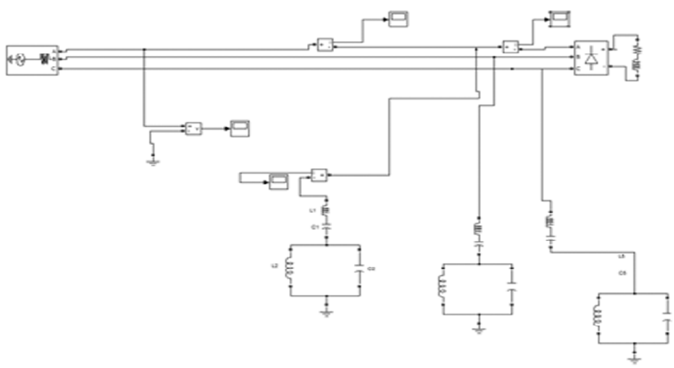

Figure 24: Double tuned passive filter with RL load

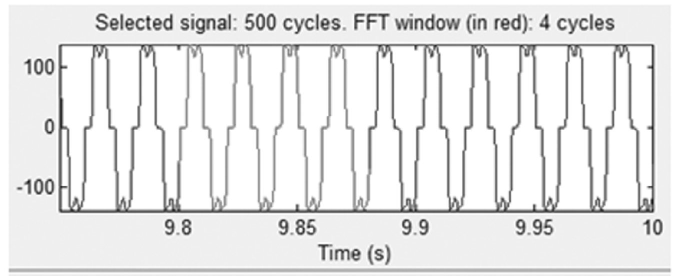

Figure 25: Source current (I_s) without filter

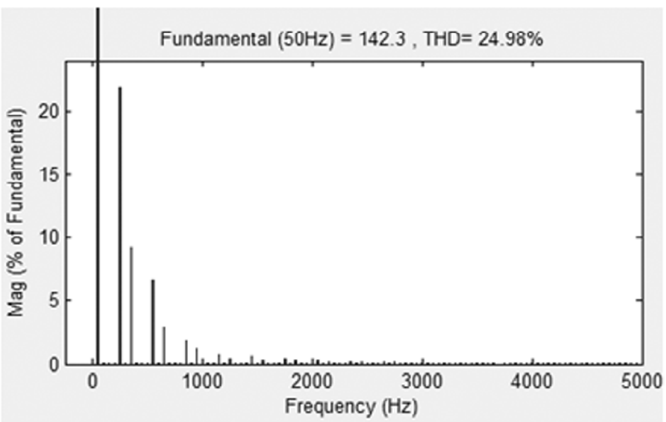

Figure 26: THD of Sourcecurrent (I_s) without filter

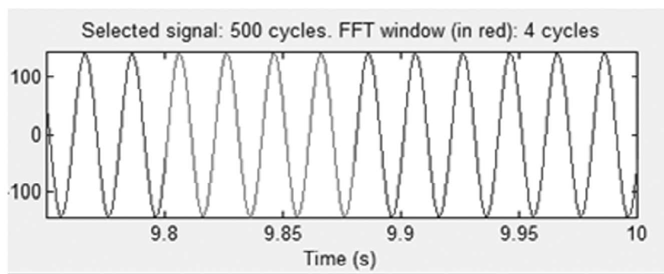

Figure 27: Source current (I_s) with filter

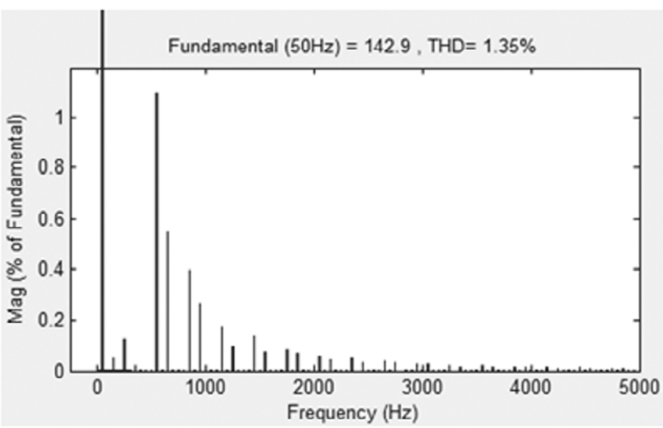

Figure 28: THD of Source current (I_s) with filter.

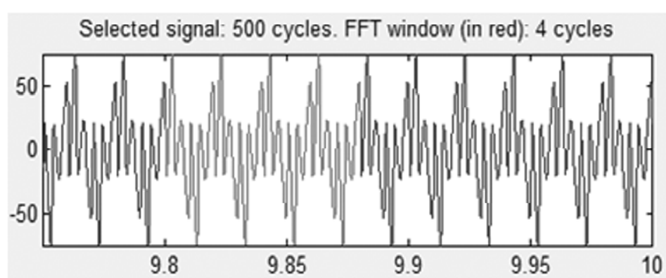

Figure 29: 5th& 7th harmonic currents

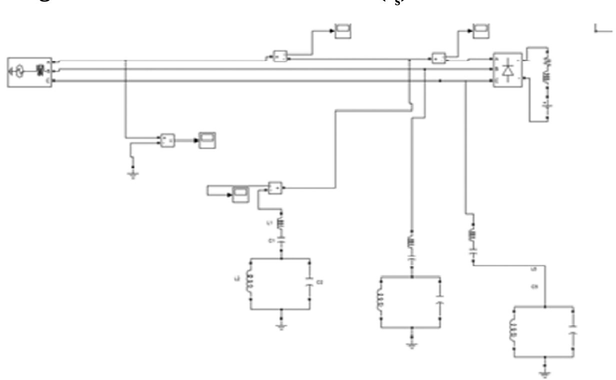

Figure 30: Double tuned passive filter with RLE load

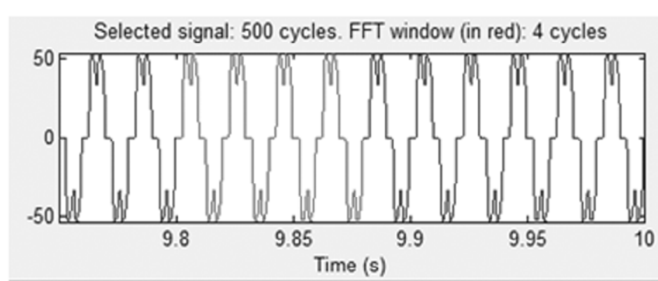

Figure 31: Source current (I_s) without filter

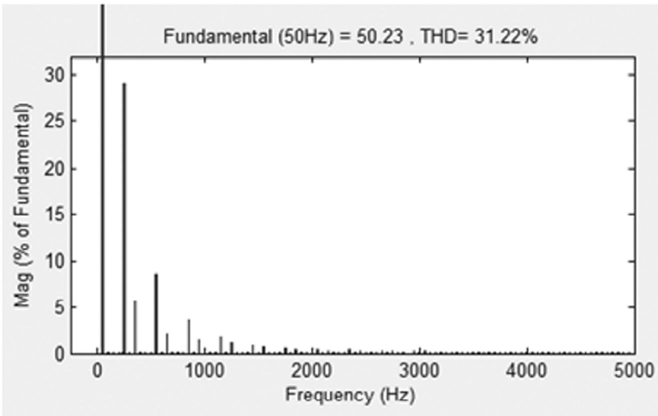

Figure 32: THD of Sourcecurrent (I_s) without filter

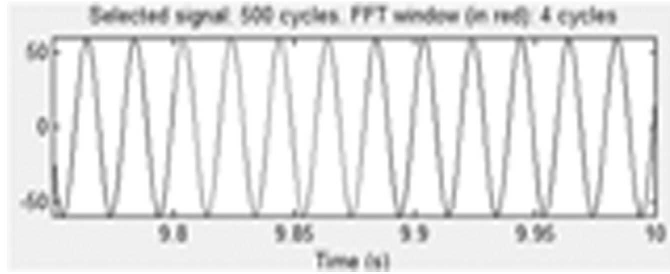

Figure 33: Source current (I_s) with filter

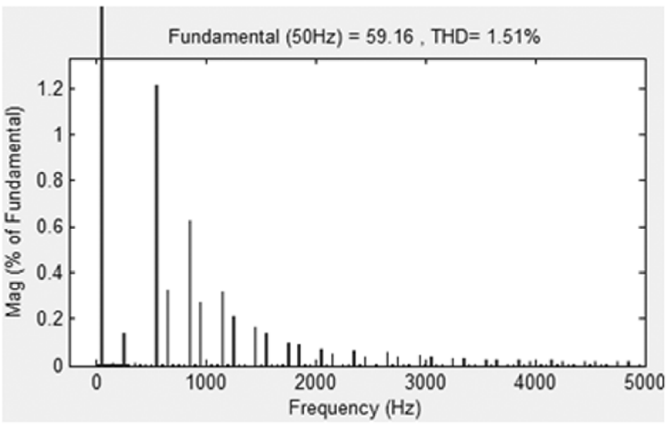

Figure 34: THD of Source current (I_s) with filter

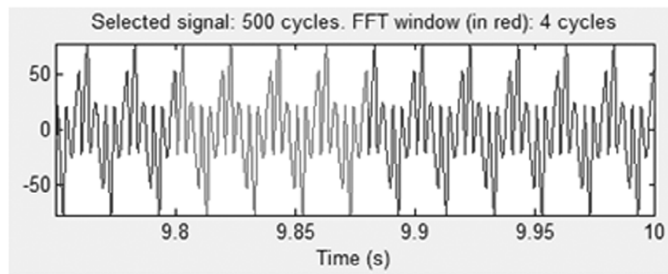

Figure 35: 5th& 7th harmonic currents

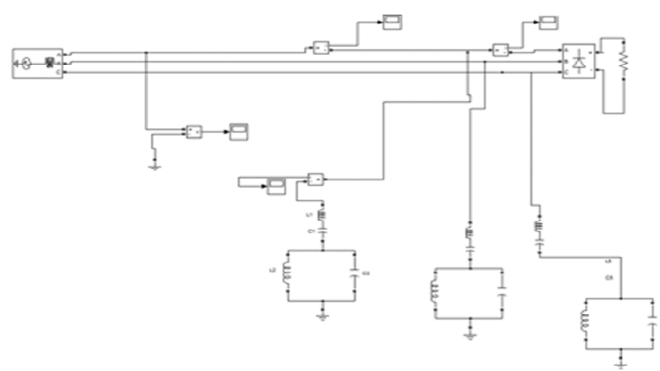

Figure 36: Double tuned passive filter with R load

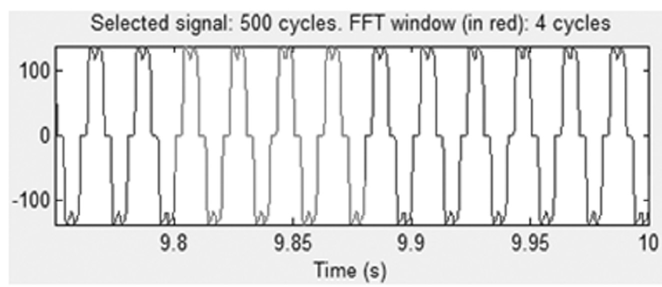

Figure 37: Source current (I_s) without filter

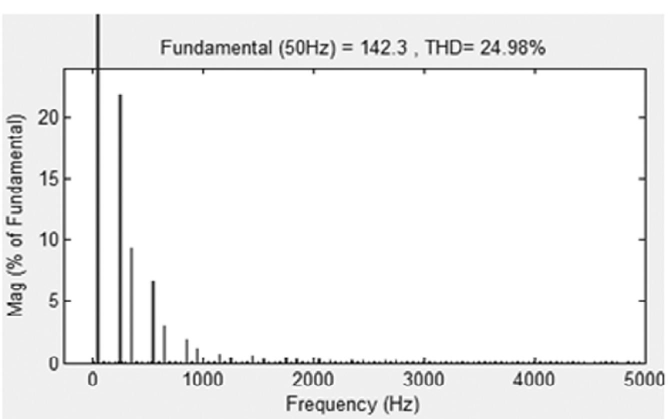

Figure 38: THD of Source current (I_s) without filter

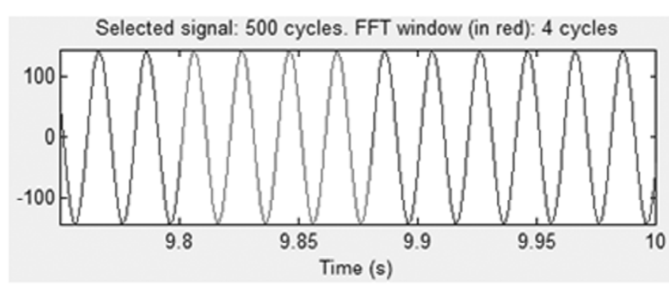

Figure 39: Source current (I_s) with filter

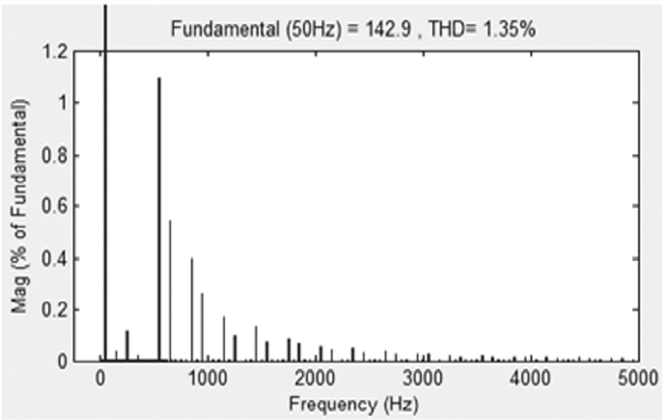

Figure 40: THD of Source current (I_s) with filter

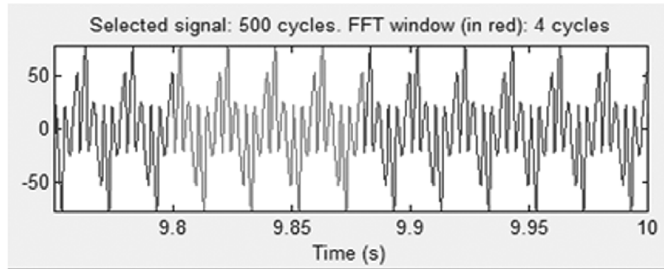

Figure 41: 5th& 7th harmonic currents

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 connected to bridge rectifier with R load	0	21.6	9.65

Table 4
Harmonics with filter

Type of System	*Harmonics with double tuned shunt passive filter*		
	3rd	*5th*	*7th*
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

4.2. System with double tuned shunt passive filer

4.3. 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 3rd multiplication of harmonics (3rd, 9th, 15th etc.) but, mostly there is a flow of 3rd 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

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

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.

5. 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, $_{C5}$, L_7, C_7 for single tuned.	2000V,15mH,13.5mH,30μF,6.89mH,30μF
3 Phase voltage(V_s), Source inductance(L_s), L_1, $_{C1}$, 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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