Reactive Power Compensation in Power Systems, Harmonic Analysis and Elimination with Passive Filters

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Abstract

Power quality problems in power systems result from lack of compensation and harmonic distortions. Harmonic distortions are problems which affect continuity of energy, energy productivity and business security in networks. They are power quality incidents prevailed in distribution network. Characteristics of nonlinear loads are the most important source of formation of harmonic. In this study in MATLAB® Simulink® simulation program an application which is nonlinear loads in an industrial system with harmonic disruptions that occurred due to the passive by harmonics to decontaminate for has been realized. At first it is examined the system reactive power necessity and harmonic characteristics, then it is given required relation for designing single tuned filter. Effects of designed filters harmonic distortion and power factor of system is examined in each steps. When designed filter implements dominant harmonics, it is also seen reducing other harmonic amplitudes. The results are presented in tables and charts.

Key words: Power quality, harmonic distortion, compensation, passive filters, single tuned filters.

1. Introduction

Nonlinear elements in electric power systems, transmission and distribution systems lead to serious harmonic distortion and negatively affect the quality of the energy supplied to the consumer. Technical and economic issues that have an impact and the unknown effects of harmonics from these analyzes both in terms of quality as well as energy in terms of business continuity is very important. Harmonic current components generating nonlinear loads cause the formation of harmonic voltage in the system. As to harmonic voltages are shed harmonic currents connected to the system via linear and nonlinear loads. It should be carried out in terms of investigation of this negativity of harmonic components and removing detailed analysis in harmonic systems [1]. To reduce harmonic problems and improve the power quality problems is very important to establish line-conditioning systems. These systems are known as passive and active power filters. Passive filters are filters most commonly used in industry [12]. It is more economical compared to other methods [5]. Industrial power system harmonic reduction techniques examined in the study were examined active and passive power filters. Passive filters are more economical than other methods but specific harmonic components are designed to be

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applicable to the situation because it has been stated that varying harmonics. Active filters are a good system performance and provide a reduction in current harmonics, but because it is the power electronics-based devices are very expensive compared to passive filters and it is indicated that they are not suitable for application in small plants [7]. Industrial power system harmonic reduction presented the study single tuned filters have been studied for their effectiveness in harmonic elimination. In addition, in the study it is examined that the placement of the filters, power capacitors and load changes effects of harmonic distortion.

In this study, an industrial medium-voltage level for the system harmonic analysis, reactive power compensation and for eliminating harmonics in the system is made for single tuned filters designed.

2. Passive Filters

Passive filters are formed interposed between source and receiver and which destroy components other than the fundamental frequency combination of capacitor and inductor connected in series. It may be needed connected passive filters in parallel for eliminating different components. Operating logic of passive filters as parallel arms designed passive filter mechanism creating resonance frequency values of the harmonic series is designed harmonic currents to ground without damaging the system transfers. Ohmic resistance can be added in some circuits. The purpose of passive filters is to identify the values L and C will resonate at a frequency harmonic component [1]. For each harmonic component is required that separated filter will bring resonance. Figure 1 shows that the circuit diagram relates to a passive filter.

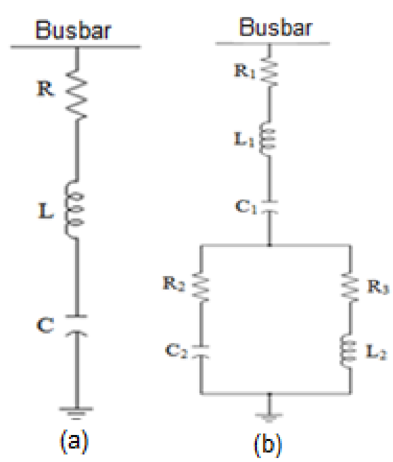


Figure 1. Passive filters a) Single tuned, b) Doubled tuned

2.1. Single tuned filters

Single tuned filters are set to play a role as a low impedance path for effectively suppressing harmonic currents. Creating low impedance or short circuit they provide for the set-up frequency suppression of harmonic currents. This process typically is performed to a single frequency value.

Single tuned filters are composed of a series RLC circuit. Filter impedance is expressed as follows.

$$Z = R + j(wL - \frac{1}{wC}) \tag{1}$$

X_L and X_C on the brink of capacitor and inductor reactance in the fundamental frequency filter size is expressed as follows,

$$S = \frac{V_s^2}{X_c - X_L} \tag{2}$$

The inductive and capacitive reactance of the filter reactance for n. harmonic is expressed as follows,

$$X_o = n.X_L = \frac{X_C}{n} \tag{3}$$

Quality factor of filter (Q) determines the sharpness of the filter settings. Viewed from this angle designed filters may be low Q or high-Q filter type. Single tuned filter quality factor given as follows [6].

$$Q = \frac{X_0}{R} \tag{4}$$

C values of the system can be found at the following relationship. Where n is the harmonic degree, I_h is to show the total value of harmonic currents [11],

$$C_n = C(I_n/I_h) \tag{5}$$

$$X_{rn} = \frac{1}{n.2.\pi.f.C_n} \tag{6}$$

$$L = \frac{X_{rn}}{2.\pi.f.n} \tag{7}$$

relations can be given. According to International IEC 519-1992 standards adopted in harmonic distortion values (THD) are determined for voltage 3%, for current 5% [4]. These limit values for harmonic ratios, electrical systems located on the dangerous and large material damages may pose to problems. Determining the level of electrical energy quality deterioration some relationship was determined by the standard used [9].

Total harmonic distortion for voltage (THD_V),

$$THD_V = \frac{\sum_{h=2}^{\infty} V_h^2}{V_1} \tag{8}$$

Total harmonic distortion for current (THD_i),

$$THD_i = \frac{\sum_{h=2}^{\infty} I_h^2}{I_1} \tag{9}$$

relations are described.

3. Computer Simulations

In this study the system located figure 2 is modeled in MATLAB® Simulink® setting. Power factor of the system before you apply filters is 0.44 due to harmonic currents generating sources. Unfiltered system's harmonic amplitudes are given in table 1. Here it is observed that 36.81% of current harmonics distortion, 6.11% of current harmonics distortion. Also, the system harmonic distortion occurring in the current and voltage waveforms are shown in figure 3 and harmonic degrees of unfiltered system are shown in figure 4.

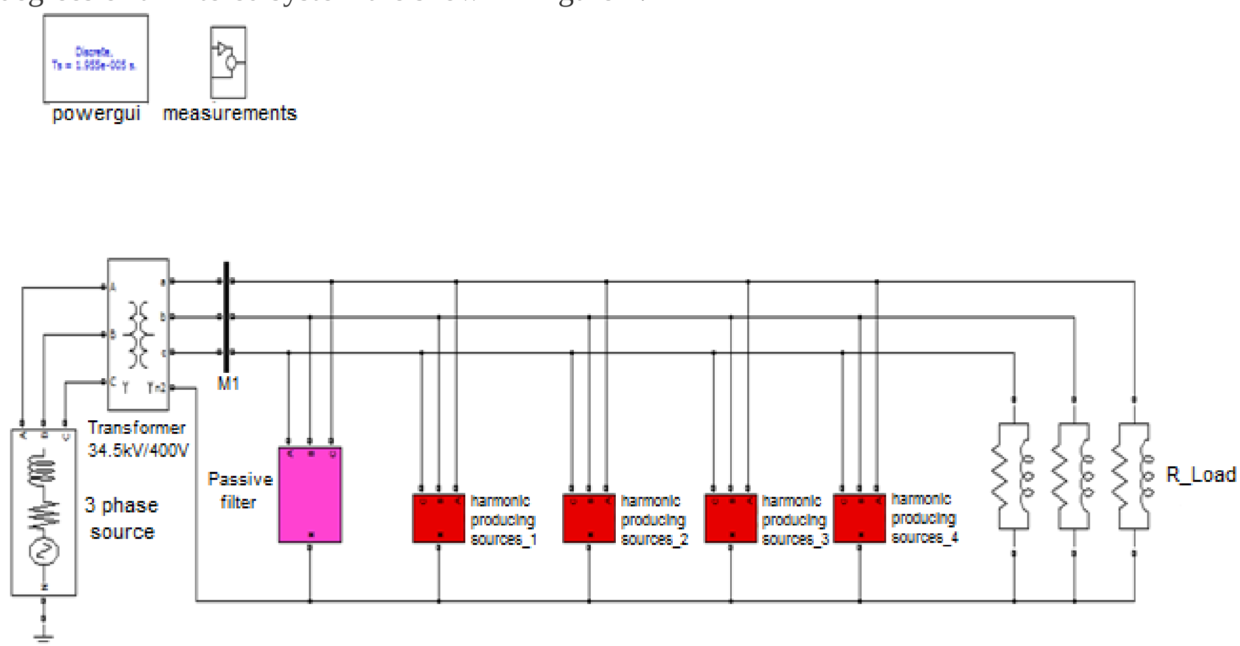


Figure 2. Simulink model of system

Table 1. Before the harmonic amplitudes of filtering and THD(%)

Harmonic degree	1	3	5	7	11	THD(%)
Current(A)	303.86	49.14	73.49	48.77	48.11	36.81
Voltage(V)	556.82	6.74	16.80	15.61	24.20	6.11

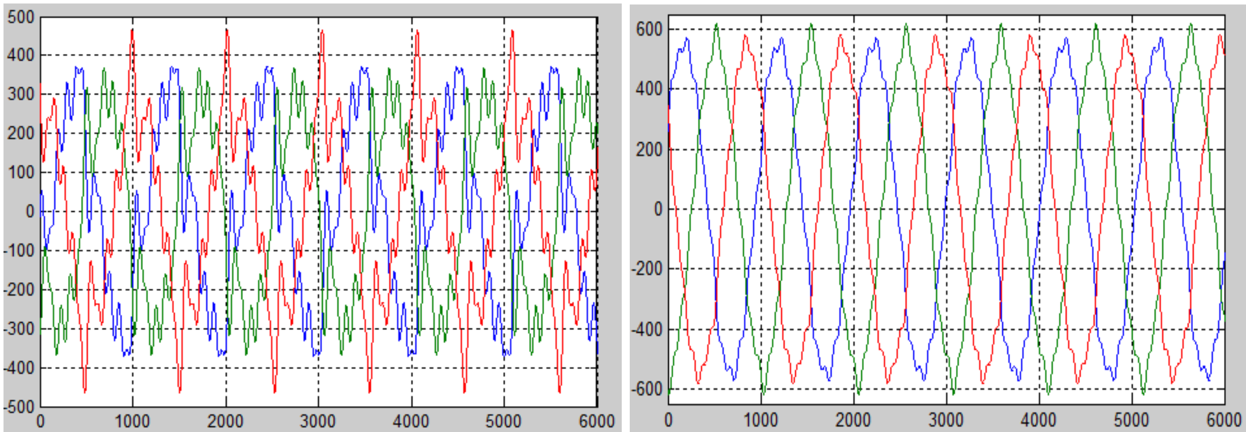
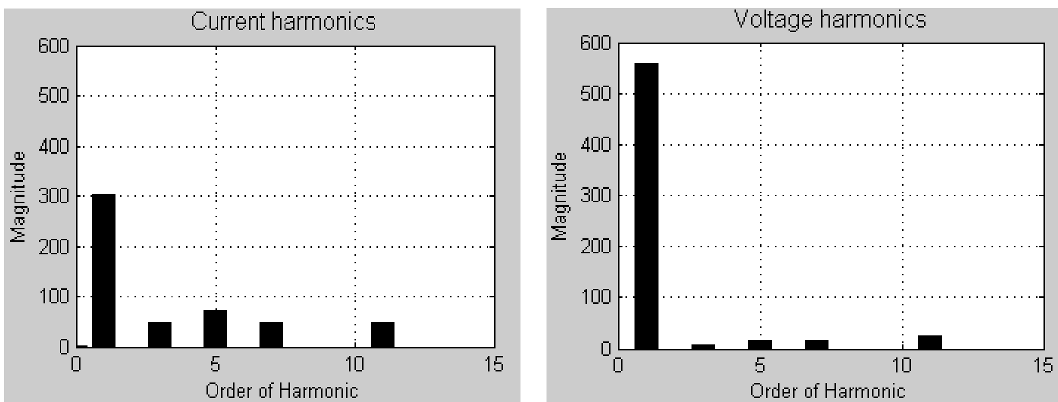

(a) (b)

Figure 3. (a) Current wave exchange of unfiltered system, (b) Voltage wave exchange of unfiltered system



(a) (b)

Figure 4. (a) Current harmonics of unfiltered system, (b) Voltage harmonics of unfiltered system

4. Single Tuned Filter Design and Implementation

Initially power factor calculation of system will be practiced for filter design. In that filters are used in fundamental frequency for reactive power compensation. The reactive power requirement is calculated as follows.

$$Q_C = P(\tan\varphi_1 - \tan\varphi_2) \qquad (10)$$

Power factor of system is 0.44. This value will be upgraded to 0.9995. According to equation (8) reactive power requirement of the system is calculated as 217765.59 VAr. Accordingly, required reactance of the capacitor is calculated as in equation (11).

$$X_C = \frac{V_s^2}{Q_C} \qquad (11)$$

As to equation (3), reactance of the filter is calculated at the time of resonance. In table 1 the amplitude of the harmonic current rating value is different for each parallel branch, designed in the value of the amplitude of the harmonic current capacity must be designed to carry. Therefore needs to be connected to the system to handle the allocation of the total value of C will be that of equation (12).

$$C_n = C(I_n/I_h) \tag{12}$$

According to calculations using the above equations which must be connected to the system of R, L and C values are shown in table 2. After filtering, harmonic degree is shown in table 3.

Table 2. Filter values

Filter	R(Ω)	L(H)	C(F)
3th harmonic	0.014908	0.001107	0.001017
5th harmonic	0.026425	0.001178	0.000344
7th harmonic	0.035004	0.001114	0.000186
11th harmonic	0.033949	0.000688	0.000122

Table 3. After filtering the current and voltage values

Harmonic	1th	3th	5th	7th	11th	THD(%)	Cosφ
Current	287.5	10.36	6.07	3.62	2.26	4.428	0.9995
Voltage	571.5	1.420	1.38	1.16	1.14	0.449	0.9995

Filters generated by calculated for each parallel arm R, L and C values and connection diagram simulation circuit of these filters prepared in MATLAB is seen figure 5. For 3th and 5th harmonic filters in system designed connection diagram is shown figure 6.

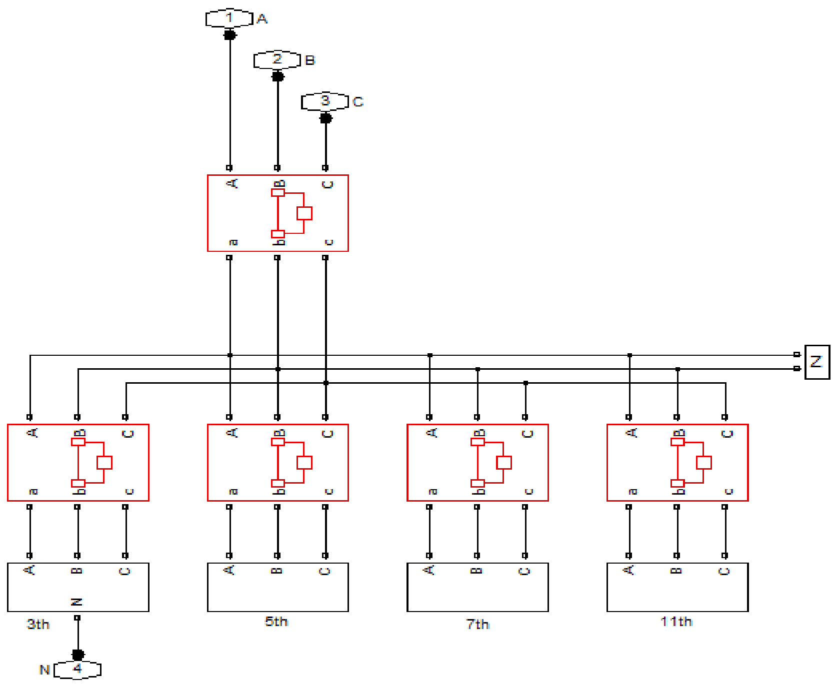


Figure 5. Filter connection diagram

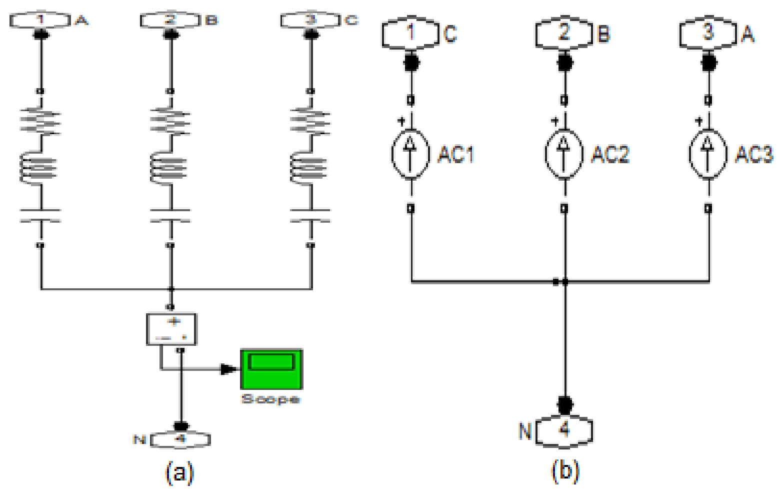


Figure 6. (a) 3th harmonic filter connection diagram, (b) 5th harmonic producing current sources

After filtering, the system harmonic distortion occurring in the current and voltage waveforms are shown in figure 7 and harmonic degrees of filtered system are shown in figure 8.

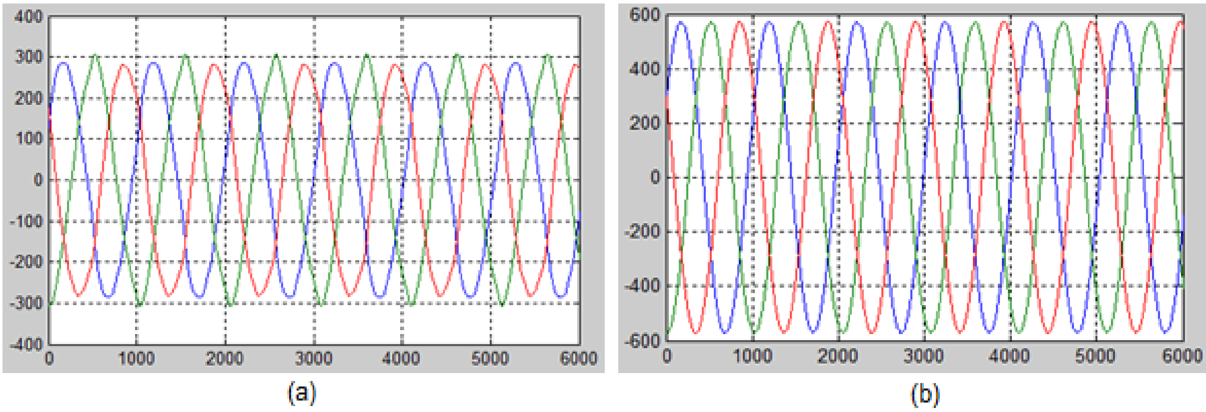


Figure 7. (a) Current wave exchange of filtered system, (b) Voltage wave exchange of filtered system

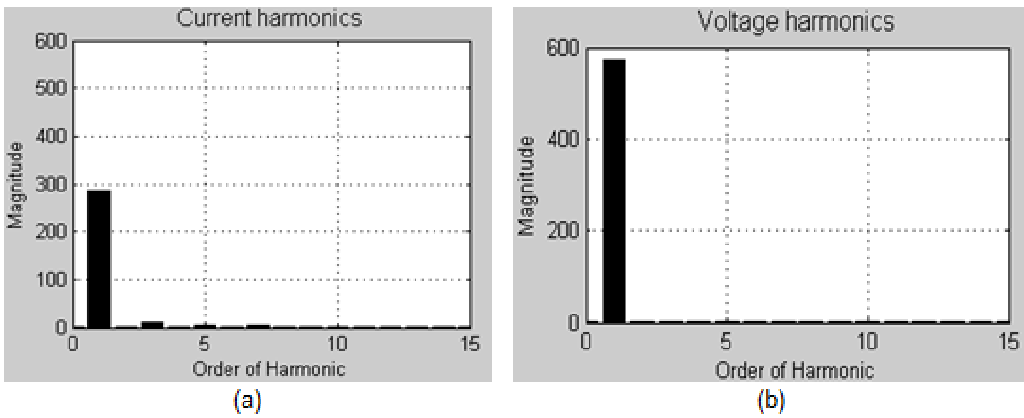


Figure 8. (a) Current harmonics of filtered system, (b) Voltage harmonics of filtered system

After applying the filters in the system, resulting harmonic amplitudes THD and power factor values are given in table 3. As there is no filter in the system THD value of current harmonics is 36.11%. When the filters are applied to the system, this value was decreased to be seen to 4.428%. However unfiltered harmonic amplitudes are also observed to decrease with respect to unfiltered system. Compensation effect of single tuned filter at fundamental frequency is clearly seen in the table. While current value is 303.8604 in unfiltered system, after applying the filter to this value is 287.5782. As expected a decrease to be seen along with compensation. As to fundamental value of voltage is observed to increase from 556.8273 V to 571.5479 V. However, the power factor value 0.44 in unfiltered systems has been increased by 0.9995. When filters added to the system, amplitude of current and voltage was gradually decreased. As for THD values of voltage harmonics is observed to decrease from 4.428% to 0.4493%. Before and after the filtering system values are shown in table 4.

Table 4. Before and after filtering system parameter values

	Voltage (V)	THD_V(%)	Current (A)	THD_I(%)	cosφ	P (kW)	Q (kVAr)
Before filtering	394.5	6.11	229	36.81	0.44	128.43	236.065
After filtering	404.1	0.4493	203.5	4.428	0.9995	246.678	8.139

Conclusions

Along with the development of power electronic components, starting to use more common creating distortion or affected by distortion for users with each passing day more and more open to loss and damage power quality problems has led to the need to focus more aggressively on. In this study, in order to prevent the loss or damage to an industrial power system harmonic analysis, single tuned passive filter design and implementation was carried out in MATLAB. Single tuned filters have been applied to the system. Consequently, it is also observed the unfiltered harmonic amplitudes reduced. With the implementation of the filter voltage and current THD has come to an acceptable level. Single tuned harmonic filters should be applied to dominant harmonic degree. Besides, these filters are used in the compensation process. In design equations it is utilized requirement of compensation. Single tuned filters are the most economical filter for medium voltage levels.

Appendices

Values of the generated power system

Source voltage	34.5 kV
Frequency	50 Hz
Transformer power	1600 kVA, 50 Hz
Transformer voltage ratio	34.5 kV / 400 V
Loads	40 kW, 30 kVAr

Index of abbreviations	
R	Resistance
L	Inductance
C	Capacitance
Z	Filter impedance
S	Filter size
Q	Quality factor
THD_V	Total harmonic distortion (for voltage)
THD_I	Total harmonic distortion (for current)
Q_C	Reactive power requirement
C_n	Filter capacitor values
I_n	n. harmonic current amplitude
I_T	The sum of all the harmonic currents in the system

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