Analysis and Comparison of Hybrid and Single Tuned Passive Power Filters

*[1]O. Fatih Kececioglu, [2]Hakan Acikgoz and [1]Mustafa Sekkeli
*[1]Faculty of Engineering, Department of Electrical and Electronics Engineering Kahramanmaraş Sütçü İmam University, Turkey
[2] Department of Electrical Science, Kilis Vocational High School Kilis 7 Aralık University, Turkey

Abstract

In this study, a hybrid passive filter (HPF) and single tuned passive filter (STPF) are designed to power systems which consist of several current source type of nonlinear loads. The comparison between HPF and STPF used for compensate to load harmonics is presented. This paper proposes HPF for compensating current harmonics type of load instead of STPF. The proposed filter is eliminate the chances of series and parallel resonance. The power and filter systems are implemented in MATLAB/Simulink environment. Simulation results, obtained from HPF and STPF The simulation results show that the hybrid passive filter can compensate effectively all current source type of nonlinear loads.

Key words: Hybrid passive filter, Single tuned filter, Harmonics compensation

1. Introduction

Distribution system has witnessed an exponential growth of harmonics in current and voltage waveform due to proliferation of power converters catering to majority of industrial processes/ applications [1]. Nowadays we are not only increasing the amount of harmonics injected into distribution systems, but we are also using equipment that is more susceptible to be damaged by the harmonic voltages and currents. Another feature of power distribution system is that it has natural frequencies which are related to the interaction of capacitor banks and inductive loads. These natural frequencies are often in the range of the harmonics caused by nonlinear devices. In resonant condition, current oscillating is reinforced and amplified, which can cause system voltage instability and large over voltages [2].

Harmonic compensation has been suggested through passive filters, active filters and hybrid filters. By far amongst these, the passive filters have still remained popular because of their reliability, ruggedness, high efficiency low cost and less complexity as compared to active or hybrid power filters. Moreover, these passive filters are preferred where harmonics and reactive power compensation have been desired. Various topologies of passive filters have been proposed in the literature having different compensation characteristics and applications [1-5].

In order to prevent the harmonics caused by nonlinear devices from traveling back to the power system and affect other users, the IEEE 519-1992 standard has imposed specific limits on levels of current harmonics and voltage notches. In particular, it sets limits of harmonic current and

*Corresponding author: Address: Faculty of Engineering, Department of Electrical and Electronics Engineering Kahramanmaraş Sütçü İmam University, 46100, Kahramanmaraş TURKEY. E-mail address: fkececioglu@ksu.edu.tr, Phone: +903442801656 Fax: +903442801602

voltage at the point of common coupling (PCC) [2]. IEEE 519-1992 harmonic current limits are given in Table 1.

Table 1. IEEE 519-1992 harmonic current limits.

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (odd):						
I_{SC}/I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	**TDD**
<20	4.0	2.0	1.5	0.6	0.3	**5.0**
20<50	7.0	3.5	2.5	1.0	0.5	**8.0**
50<100	10.0	4.5	4.0	1.5	0.7	**12.0**
100<1000	12.0	5.5	5.0	2.0	1.0	**15.0**
>1000	15.0	7.0	6.0	2.5	1.4	**20.0**

Even harmonics limited to 25% of odd harmonic limits above.

I_{SC} : Maximum short circuit current at PCC.

I_L : Maximum demand load current (fundamental frequency) at PCC.

This paper proposes analysis and comparison of hybrid passive and single tuned passive power filters. The performance of hybrid passive power filter has been researched and compared single tuned filter for varying nonlinear loads under distorted source conditions. This paper is organized as follows: Section 2 and 3 briefly presents theory about the single tuned passive and hybrid passive filters. Section 4, presents the simulation study and the results obtained for the filter systems. The main contributions of this paper are summarized in Conclusion.

2. Single Tuned Filters

Shunt passive filter is the most common type of filters in use. There are various types of shunt passive filter configuration such as single and double tuned, band pass etc. These filters provide a low impedance trap to a harmonic to which the filter is tuned. Theoretically, the filter has a zero impedance at the tuning frequency thus absorbing the harmonic of interest. The most common type of shunt passive filters used in harmonic mitigation is the single tuned passive filter (STPF). A STPF consists of series combination of a capacitor and a reactor and is tuned to low harmonic frequencies. At the tuned harmonic, the capacitor and the reactor have equal reactances and the filter has purely resistive impedance. The configuration of a single tuned filter is depicted in Fig. 1.

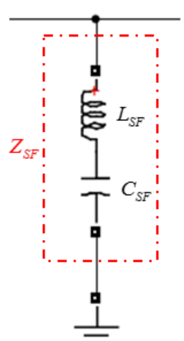


Figure 1. Single tuned filter

The major criteria in designing the filter is by selecting a proper size of capacitor that gives a reasonable power factor fundamental frequency. The capacitor reactance value, X_C and reactive power relationship is given by [6],

$$X_C = \frac{(\mathrm{V}_{cap})^2}{kVAr_{filter}} \tag{1}$$

where, V_{cap} is the line to line rated voltage of the capacitor and $kVAr_{filter}$ is the reactive power of the capacitor. The filter capacitance is then calculated using,

$$C = \frac{1}{2\pi fX_C} \tag{2}$$

where, f is the fundamental frequency. The reactor value of the filter can then be obtained from,

$$L = \frac{1}{(2\pi f)^2 (rh)^2 C} \tag{3}$$

where, h is the harmonic to which filter is tuned and r is empirical factor smaller than one, giving rh a value slightly below the harmonic frequency of concern. This factor minimizes the possibility of unwanted harmonic resonance which may take palace if system parameters change. A typical value of r for the fifth harmonic is 0.94. The filter resistance R is based on quality factor Q which is a measure of sharpness of tuning. Mathematically, quality factor is defined as,

$$Q = \frac{\sqrt{LC}}{R} \tag{4}$$

The value of this resistance may be obtained by selecting an appropriate value of quality factor in the range of $20 < Q < 30$.

The filter's impedance is capacitive for lower harmonics and inductive for higher harmonics, a consequence of which is aggravating the impedance below the lowest tuned frequency [7].

3. Hybrid Passive Filters

The hybrid passive filters (HPF) consists of a series passive filter (SPF) and a shunt passive filter (PPF). The SPF is a bandpass filter and the PPF is a bandstop filter. The nonlinear loads consist of voltage and current fed type of harmonic producing load. The PPF is suited for current-source type of nonlinear loads and the SPF is suited for voltage-source type of nonlinear loads, whereas the HPF is suited for any type of load (voltage-source and/or current-source type of nonlinear loads).

3.1. Series Passive Bandpass Filter

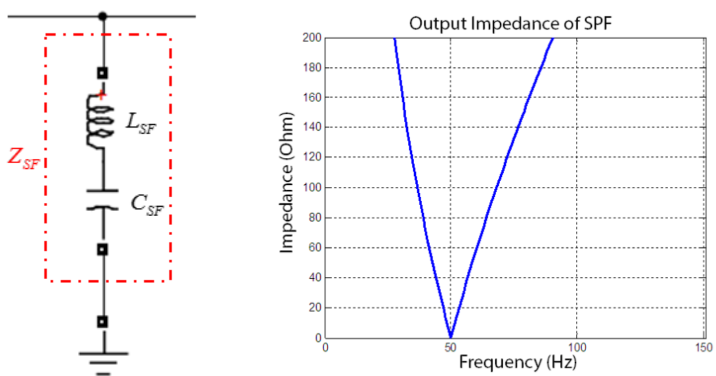
Series passive filter consists of series combination of a capacitor and a reactor. Its function is to block the flow of current type harmonics towards source side by providing high impedance path at all harmonic frequencies. At the fundamental frequency, the capacitor and the reactor have equal impedance. Single phase equivalent circuit of SPF is shown in Fig. 2a. Filter's resonant frequency is selected at a value close to the network frequency. The resonant frequency is then calculating using,

$$f_c = \frac{1}{2\pi\sqrt{L_{SF}C_{SF}}} \tag{5}$$

The filter's impedance is capacitive for lower than resonant frequency and inductive for higher frequencies. Impedance response of series passive filter is expressed as a transfer function. The transfer function is calculated for a single phase equivalent circuit. This transfer function is defined as,

$$H_F(s) = Z_{SF}(s) = \frac{s^2(L_S C_{SF} + L_{SF}C_{SF}) + 1}{sC_{SF}} \tag{6}$$

where, $H_F(s)$ is the output impedance transfer function. The output impedance response of SPF is depicted in Fig. 2b.



(a) (b)

Figure 2. Single phase equivalent circuit (a) and output impedance (b) of series passive band pass filter

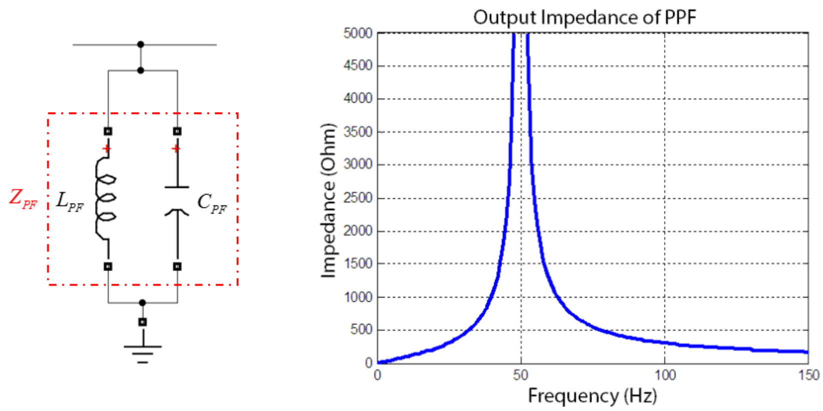
Figure 2b shows that the series passive filter presents high impedance to all higher harmonic frequencies. At the same time, SPF presents very low impedance at the fundamental frequency. This is important since significant impedance at the fundamental frequency may result in appreciable voltage drop.

3.2. Parallel Passive Bandstop Filter

The parallel passive filter is a dampen filter which consist of a parallel combination of a reactor and a capacitor. The parallel passive filter presents large impedance at fundamental frequency, however offers low impedance for all higher harmonic frequencies. Single phase equivalent circuit of PPF is illustrated in Fig. 4a. The PPF provides a low impedance sink for currents at harmonic frequencies to prevent the flow of harmonics towards source side [1-4]. The filter's characteristics is inductive for lower frequencies (below fundamental frequency) and capacitive for all higher harmonics. The output impedance transfer function of PPF is defined as,

$$Z_{PF}(s) = H_f(s) = \frac{sL_{PF}}{s^2 L_{PF}C_{PF} + 1} \tag{7}$$

The output impedance of PPF is shown in Fig. 3b. Figure 3b indicates that the impedance of the PPF is low at all harmonic frequencies and high at the fundamental frequency. The filter provides low impedance path for the all harmonic currents thus preventing the harmonics to flow through the supply while preventing the 50 Hz current from following into the passive filter.



(a) (b)

Figure 3. Single phase equivalent circuit (a) and output impedance (b) of PPF

4. Simulation Results

In order to validate the precision of the hybrid passive filter, the system is realized in MATLAB/Simulink and Sim Power System Toolbox. The performance of the designed hybrid passive filter has been simulated under current fed type of harmonic producing load and has been compared with designed single tuned filter. As shown in Fig. 4, the simulation system consists of three parts, the power supply equaled by an ideal voltage source in series with line impedance, the nonlinear loads equaled by the harmonic current sources, and passive filter system.

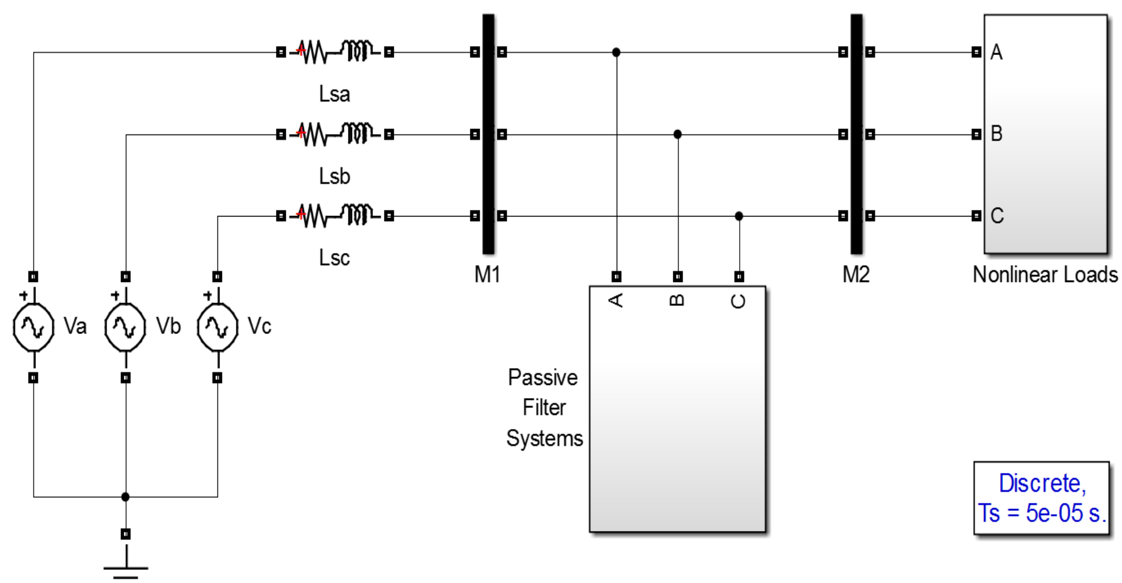
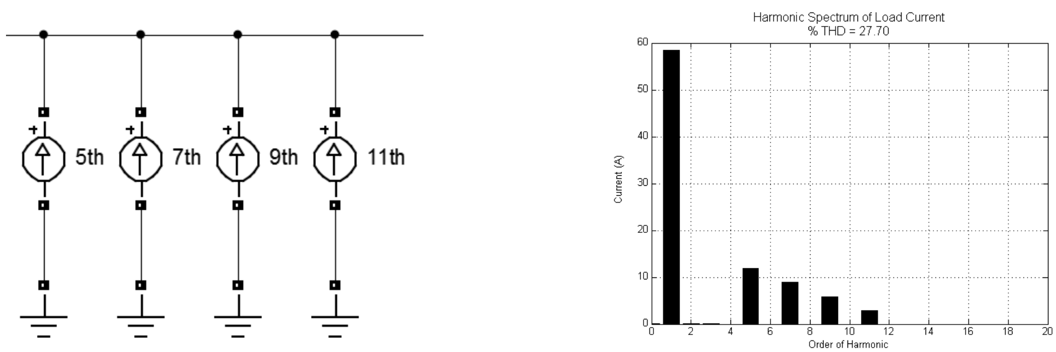


Figure 4. Simulation system for hybrid passive filter.

For the purpose of revealing the performance of hybrid and single tuned passive filter, simulation works are also realized separately for two different conditions. Passive filters are considered to be switched on and off respectively. According to the before and after compensation, total harmonic distortion of currents are measured using Simulink block separately.

4.1. Nonlinear Load Modelling

The nonlinear load is modelled using current sources which is includes 5^{th},7^{th},9^{th} and 11^{th} harmonic frequencies. Single phase equivalent circuit of nonlinear load is shown in Fig. 5a. The harmonic spectrum of nonlinear load is illustrated in Fig. 5b. As shown in Fig. 5b, total harmonic distortion of load current is 27.70%.



(a) (b)

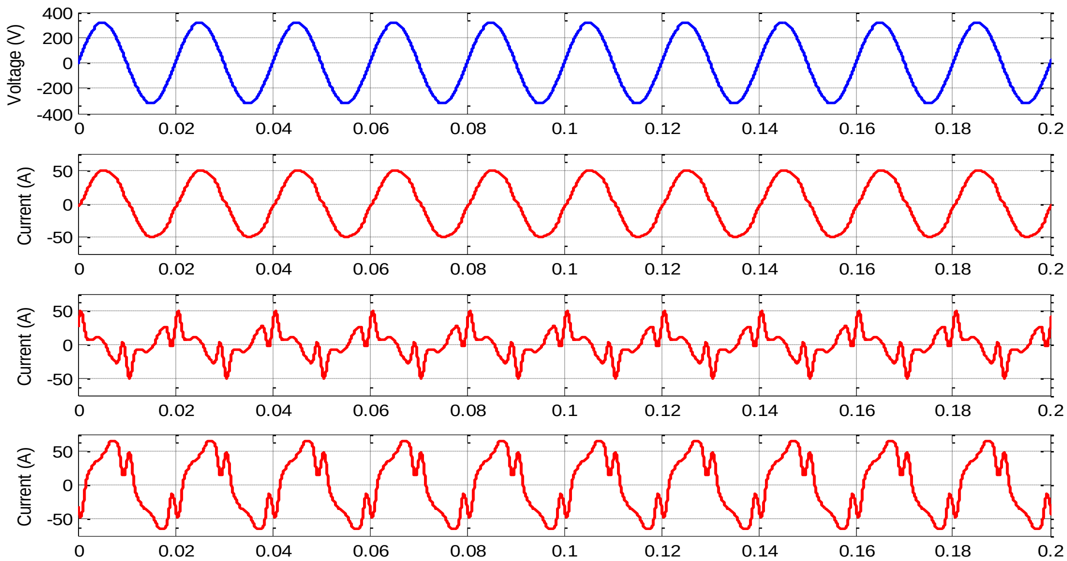
Figure 5. Single phase equivalent circuit (a) and harmonic spectrum (b) of nonlinear load.

4.2. Study 1: Single Tuned Filter

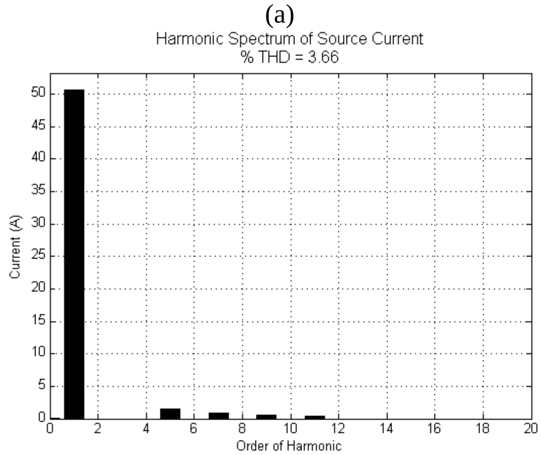
The single tuned filter parameters are calculated to harmonic spectrum of nonlinear loads. The parameters are given in Table 3. The simulation results of the system with the current source type of nonlinear load are presented in Fig. 6a. The source voltage (V_{sa}), source current (i_{sa}), single tuned filter current (i_{Fa}) and load current (i_{La}) in phase A are depicted. Figure 6b represent the harmonic spectrum of the supply current after compensation. As shown in Fig. 6b, the total harmonic distortion of source current is reduced from 27.70% to 3.66%. Although this harmonic distortion ratio in accordance with IEEE 519-1992 harmonic standards, harmonic filter wasn’t completely compensated to load harmonics.

Table 3. Single tuned passive filter parameters

Filter Parameters	5th order	7th order	9th order	11th order
L_{STF}	14.081 mH	9.643 mH	8.828 mH	11.948 mH
C_{STF}	28.78 µF	21.44 µF	14.16 µF	7.00 µF
R_{STF}	0.315 Ω	0.302 Ω	0.356 Ω	0.589 Ω



(a)



(b)

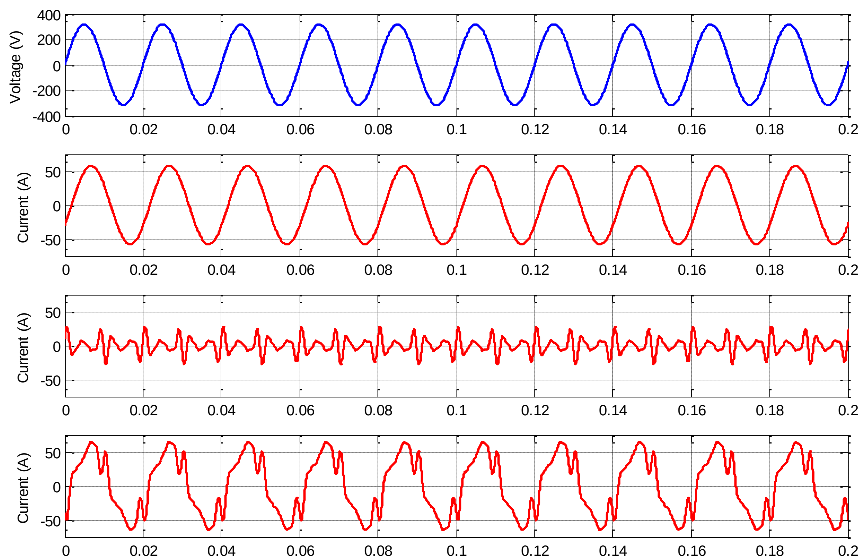
Figure 6. Source, filter and load current waveforms (a) and harmonic spectrum of source current (b) with STPF.

4.3. Study 2: Hybrid Passive Filter

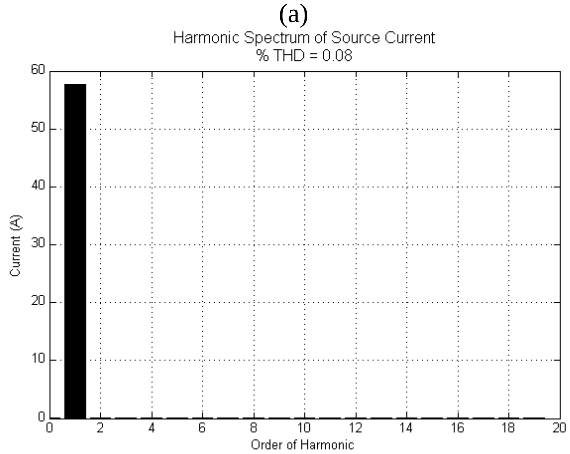
The hybrid passive filter and power system parameters are listed in Table 4. Figure 7a and 7b shows respectively current and voltage after compensation and harmonic spectrum of the supply current after compensation using HPF. The source voltage (V_{sa}), source current (i_{sa}), single tuned filter current (i_{Fa}) and load current (i_{La}) in phase A are depicted respectively. As shown in Fig. 7b, the total harmonic distortion of source current is reduced from 27.70% to 0.08%. The total harmonic distortion level in accordance with IEEE 519-1992 harmonic standards and harmonic filter is successfully compensated to load harmonics.

Table 4. Hybrid passive filter and power system parameters

Line voltage	V_{p-p}	400 V
Line frequency	f	50 Hz
Line impedance	L_s	0.5 mH
Series passive filter parameters	C_{SF}	20 μF
	L_{SF}	506.6 mH
Parallel passive filter parameters	C_{PF}	6.8733 μF
	L_{PF}	1.4743 H



(a)



(b)

Figure 7. Source, filter and load current waveforms (a) and harmonic spectrum of source current (b) with HPF.

Conclusion

Nonlinear loads are characterized into two types of harmonic sources, voltage source type of nonlinear load and current type of nonlinear load. In this study, harmonics are modelled using current source and the filter system is carried out in MATLAB/Simulink environment. The hybrid and single tuned passive filter are compared and performance of the hybrid passive filter against single tuned passive filter is illustrated in figures. Considering the total harmonic distortion level, the HPF gives obviously better compensated to harmonics than STPF. While source current THD level is calculated 0.08% using HPF, the THD level of source current is 3.66%. Moreover, it can be seen that voltage and current waveforms of source with HPF is smoothly compensate to harmonics than STPF systems. According to obtained simulation results, performance of the hybrid passive filter is better than conventional passive filters and HPF systems can effectively reduce all current harmonics.

References

[1] Singh B, Verma V, Garg V. Passive hybrid filter for varying rectifier loads. International Conference on Power Electronics and Drives Systems 2005;2:1306-11.
[2] Chen S, Joos G. Analysis and comparison of passive & active harmonic suppression filters in distribution systems. Canadian Conference on Electrical and Computer Engineering 2000;2:615-9.
[3] Rahmani S, Hamadi A, Al-Haddad K. A new single phase hybrid passive filter to dampen resonances and compensate harmonics and reactive power under distorted source conditions. Industrial Electronics IECON 2008:473-8.
[4] Rahmani S, Hamadi A, Al-Haddad K. A Hybrid Passive Filter Configuration for VAR Control and Harmonic Compensation. IEEE Transactions on Industrial Electronics 2010;57(7);2419-34.
[5] Das JC. Passive filters - potentialities and limitations. IEEE Transactions on Ind. Appl. 2004;40(1):232-41.
[6] Yousif SNAL, Wanik MZC, Mohamed A. Implementation of different passive filter designs for harmonic mitigation. Power and Energy Conference 2004:229-34.
[7] Wakileh GJ. Power system harmonics fundamentals, analysis and filter design. New York: Springer Verlag Press; 2001.