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Different approaches for designing the passive power filters

Streszczenie. *Celem artykułu jest prezentacja analizy porównawczej różnych metod projektowania pasywnych filtrów LC. Rozważono sześć powszechnie stosowanych metod wyznaczania parametrów technicznych układu filtracyjnego. Podstawą oceny różnych metod są badania symulacyjne. Różne metody projektowania energetycznych filtrów pasywnych.* ***Różne metody projektowania pasywnych filtrów LC***

Abstract. *Paper aims to present the comparison of different computation methods of passive LC filters. Six methods commonly used to design the filters group parameters will be considered. Basis for evaluating the various methods are simulation studies.*

Słowa kluczowe: filtry pasywne, odkształcenie napięcia i prądu, moc bierna, projektowanie filtrów LC
Keywords: passive filters, voltage and current distortion, reactive power, LC filter design

Introduction

In recent years the increase of power electronic devices has become a serious problem for the electrical grid because of the production of harmonic disturbances. The harmonics generate by the nonlinear loads can inter alia cause the overloading, overheating and malfunction or even damage of electrical grid elements and the loads connected to the supply system. To maintain the equilibrium of the grid, many devices for harmonic disturbances mitigation e.g. passive filters are applied.

The single-tuned filter is one of the most popular passive filter used to compensate the reactive power (for basic harmonic) and to reduce the current harmonics flowing through the supply network. To prevent more than one harmonic from entering the electrical grid, the group of single-tuned filters is needed.

The goal of this paper is to compare different design methods of LC parameter calculation of the filters group. The comparison is mainly focused on filter power losses and the reduction of voltage and current distortion. The set of criteria for the comparison does not include the production and operation cost of the filters.

The simulation studies presented in the article have been done in the environment of MATLAB/SIMULINK.

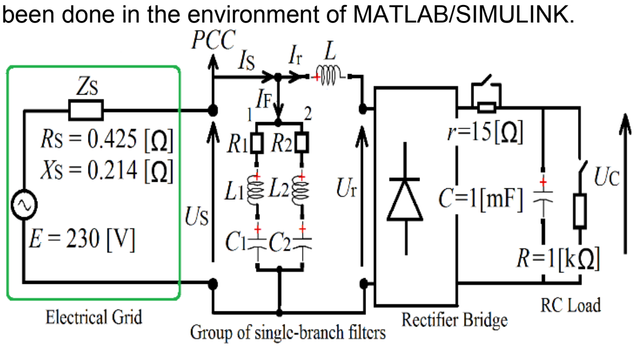


Fig. 1. Simulated power system

Simulated power system

The LC filters are mainly used in three-phase electrical grid, for high power loads, both symmetrical; this allows to limit the analysis to one phase electrical system.

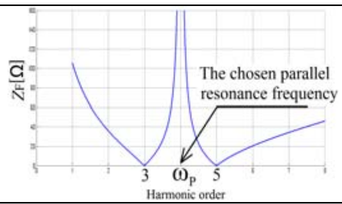
Description of the system

It consists of one-phase electrical power source with internal impedance (R_S, L_S) feeding not-controlled rectifier bridge with *RC* load at its DC side and input reactor (*L*) at AC side (Fig. 1). The passive filters group is constituted of two parallel connected single-branch filters. Each filter in the group is the series connection of resistance, reactor and capacitor. The rest of symbols used in the paper are explained in the Fig. 1.

Simulation assumptions

The filters are respectively tuned to the frequencies lower than the frequencies of the 3rd and 5th harmonic (2.9rd and 4.85th). The analysis is more focus on the filtration of 3rd and 5th harmonic which are the lowest generated current harmonic by the load.

Table 1. Methods of parameters computation

Method A - equal reactive power for each filter	$h = 2$ $Q_1 = Q_2 = \frac{Q_F}{2}$
Method B - the reactive power of filters is inversely proportional to the harmonic order	$Q_F = Q_1 + Q_2$ $\frac{Q_1}{Q_2} = \frac{n_2}{n_1} \to 3Q_1 = 5Q_2$ $Q_2 = \frac{3}{8} Q_F$
Method C - the reactive power of filters is inversely proportional to the square of harmonic order	$\frac{Q_1}{Q_2} = \frac{n_2^2}{n_1^2} \to 9Q_1 = 25Q_2$ $Q_1 = \frac{25}{34} Q_F$
Method D - the reactive power of filters is calculated on the base of the shaping the filter impedance frequency characteristic [12]	
Method E - the reactive power of filters is calculated on the base of the assumption that the filter reactors in group are identical	$L_1 = L_2 = \frac{U^2}{\omega Q_F}\left(\frac{1}{(1-3^2)}+\frac{1}{(1-5^2)}\right)$ $Q_1 = \frac{Q_F}{(1-3^2)\left(\frac{1}{(1-3^2)}+\frac{1}{(1-5^2)}\right)}$
Method F (optimization) - the reactive power of filters is calculated on the base of research the minimum of the function *y*	$\phi_1 = \frac{U_{a(3)before}}{U_{b(3)after}} = \frac{Z_{S(3)}}{Z_{x(3)}}$ $\phi_2 = \frac{U_{a(5)before}}{U_{b(5)after}} = \frac{Z_{S(5)}}{Z_{x(5)}}$ $y = 1-(1-\phi_1)(1-\phi_2)$

The resistances R_1 and R_2 in the filters group branches represent the equivalent parameters of air core reactors, whose inductances are respectively L_1, and L_2. The equivalent resistances are computed by considering the same value of quality factor (q = 85) for each reactor. The resistances of the capacitors C_1 and C_2 are neglected. The reactive power (basic harmonic) of the filter group, adopted arbitrarily (Q_F = -500 Var capacitive) is the same for each method of parameters computation.

Table 2. Parameters of filter number 1

Methods	Q_F = - 500 [Var]				
	n_1 = 2.9				
	C_1[μF]	L_1 [mH]	R_1 [Ω]	$Z_{(3)}$ [Ω]	Q_1 [Var]
Method A	13.254	90.9	0.3360	5.6261	-250
Method B	16.589	72.6	0.2684	4.4950	- 312.90
Method C	19.527	61.7	0.2280	3.8188	-368.31
Method D	18.620	64.7	0.2391	4.0049	-351.2
Method E	19.946	60.4	0.2232	3.7385	-376.22
Method F	16.053	75.0	0.2774	4.6451	-302.79

Table 3. Parameters of filter number 2

Methods	Q_F= - 500 [Var]				
	n_2 = 4.85				
	C_2[μF]	L_2 [mH]	R_2 [Ω]	$Z_{(5)}$ [Ω]	Q_2 [Var]
Method A	14.403	29.9	0.1105	2.7784	-250
Method B	10.779	40.00	0.1477	3.7126	- 187.09
Method C	7.586	56.8	0.2098	5.2748	-131.68
Method D	8.5731	50.2	0.1857	4.6680	-148.80
Method E	7.1314	60.4	0.2232	5.6117	-123.77
Method F	11.362	37.9	0.1401	3.5222	-197.20

Computation methods of filters group parameters

Design methods description

Table 1 presents six methods used to compute the parameters of the filters group; h is the number of filters, n - filtered harmonic order, Z_F - total impedance of filter group, ω_P - the chosen system parallel resonance frequency (Method D), ϕ_1, ϕ_2 - optimization coefficients, $U_{a(3)}$, $U_{a(5)}$, $U_{b(3)}$, $U_{b(5)}$ - are respectively voltages of 3rd and 5th harmonics before and after the filters group connection, $Z_{S(3)}$, $Z_{S(5)}$ - are respectively the impedances of 3rd and 5th harmonic of filters group, $Z_{x(3)}$, $Z_{x(5)}$ - are respectively the equivalent impedances (filters group & electrical grid) of 3rd and 5th harmonic.

The parameters of the filters group, calculated in accordance with the principle of methods A-F are presented in the Table 2 and 3. The resistance of each single branch filter is computed by (1).

$$R_1 = \frac{\omega_{(1)} L_1}{q} \quad (1)$$

$\omega_{(1)}$ - angular frequency of the fundamental harmonic. Although the quality factor is the same for each filter in the group, the impedances of the 3rd and 5th harmonic are different for each method. In Table II, method E presents the lowest value of 3rd harmonic impedance and in Table 3, method A presents the lowest value 5th harmonic impedance.

The comparison criterias

The comparison criteria of the computation methods of the filters group is based on the frequency impedance characteristics of the filter groups and power system, the amplitude of grid voltage and current harmonics and filter power losses (Table 15).

Simulation results

Figure 2 presents the impedance frequency characteristics of filter groups whose parameters have been computed by the six methods**.**

It can be observed that method A presents the higher value of impedance for 3rd harmonic and the lowest value of impedance for 5th harmonic (Fig. 2). The 3rd harmonic is better filtered than the 5th harmonic using method E and the 5th harmonic is better filtered than the 3rd harmonic using method A. Focusing the comparison only on the 3rd and 5th harmonic, it is difficult to choose which method of parameters computation is the best.

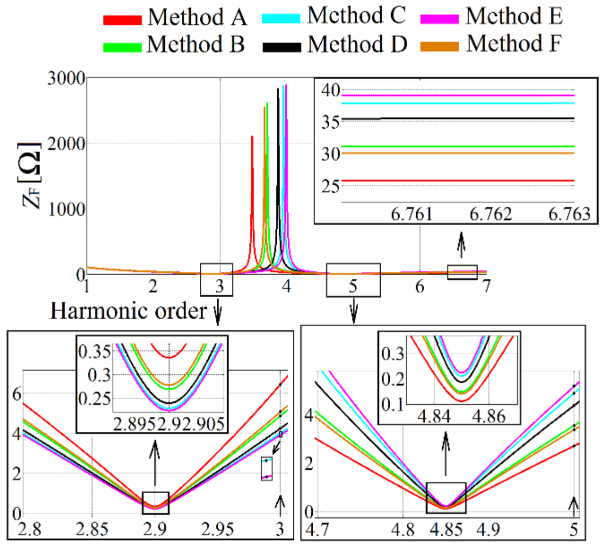


Fig. 2. Filter frequency impedance characteristics for each method

Considering the filtration of the components with order higher than 5th, method A is the best because it can more effectively reduce the harmonics in a wide frequency range compering with others methods. According to this concept, after method A comes method F, then methods B and D, at the end methods C and E.

Figure 3 presents the filter frequency impedance for each method on the complex plan. The contact point of the characteristics with the zero axis represents the detuned frequencies.

The amplitude of the fundamental harmonic of grid (U_S) and rectifier input voltage (U_r) have changed for each method after the filters group connection (Table 4-6). Methods A and B present the highest value of fundamental harmonic amplitude (Fig. 4c).

Table 4. Parameters of grid voltage

$U_{S\,max}$ [V]						
n	Before the filter group connection		Method A		Method B	
	Ampl.	phase	Ampl.	phase	Ampl.	phase
1st	326.27	30.0	326.95	29.7	326.95	29.7
3rd	0.47	124.0	0.43	126.6	0.41	127.5
5th	0.63	0.1	0.45	5.1	0.48	4.0
7th	0.71	229.7	0.69	229.3	0.69	229.1
9th	0.71	95.8	0.69	94.8	0.70	94.6
11th	0.63	-41.3	0.62	-42.6	0.62	-42.8
THD [%]	0.53		0.50		0.50	

Table 5. Parameters of grid voltage

$U_{S\,max}$ [V]				
n	Method C		Method D	
	Amplitude	phase	Amplitude	phase
1st	326.94	29.7	326.94	29.7
3rd	0.40	128.1	0.40	127.9
5th	0.51	2.9	0.50	3.3
7th	0.70	228.9	0.69	229.0
9th	0.70	94.6	0.70	94.5
11th	0.62	-43.0	0.62	-42.9
THD [%]	0.51		0.51	

Table 6. Parameters of grid voltage

$U_{S\,max}$ [V]				
n	Method E		Method F	
	Amplitude	phase	Amplitude	phase
1st	326.94	29.7	326.94	29.7
3rd	0.40	128.2	0.41	127.3
5th	0.52	2.7	0.47	4.2
7th	0.70	228.9	0.69	229.1
9th	0.70	94.4	0.70	94.6
11th	0.62	-43.0	0.62	-42.8
THD [%]	0.51		0.51	

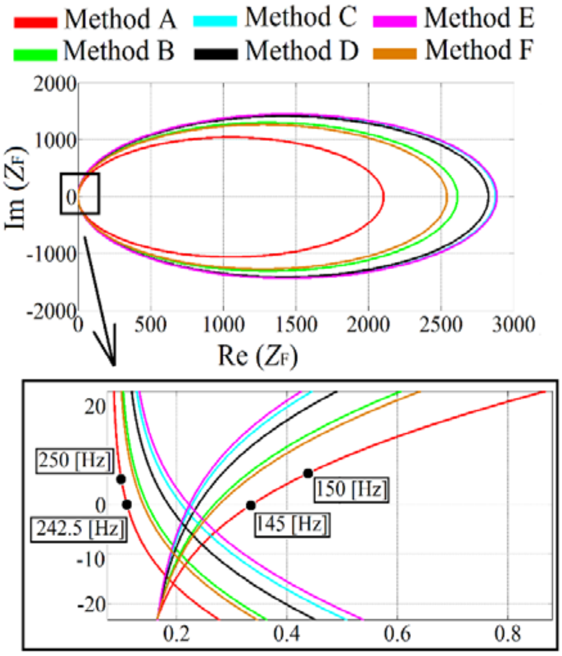


Fig. 3. Filter frequency impedance characteristics in the complex plan

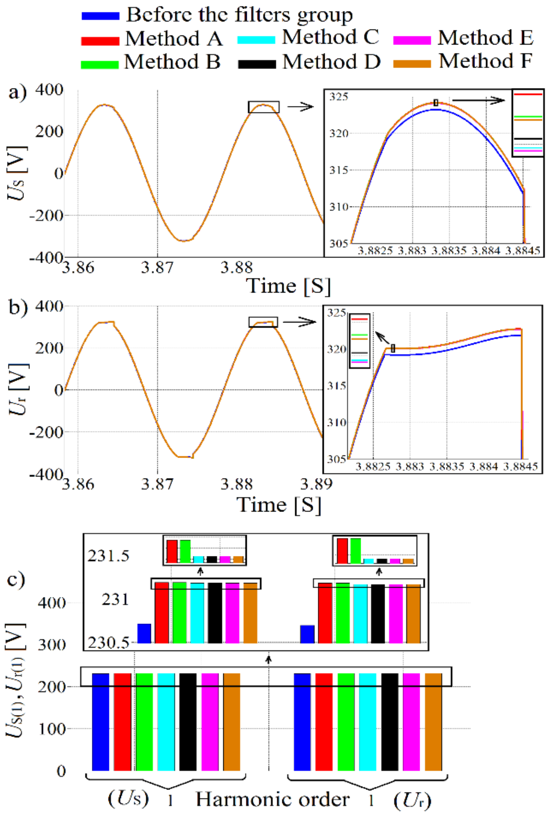


Fig. 4. a) grid voltage; b) voltage at the input of rectifier; c) first harmonic amplitude of grid and rectifier input voltage.

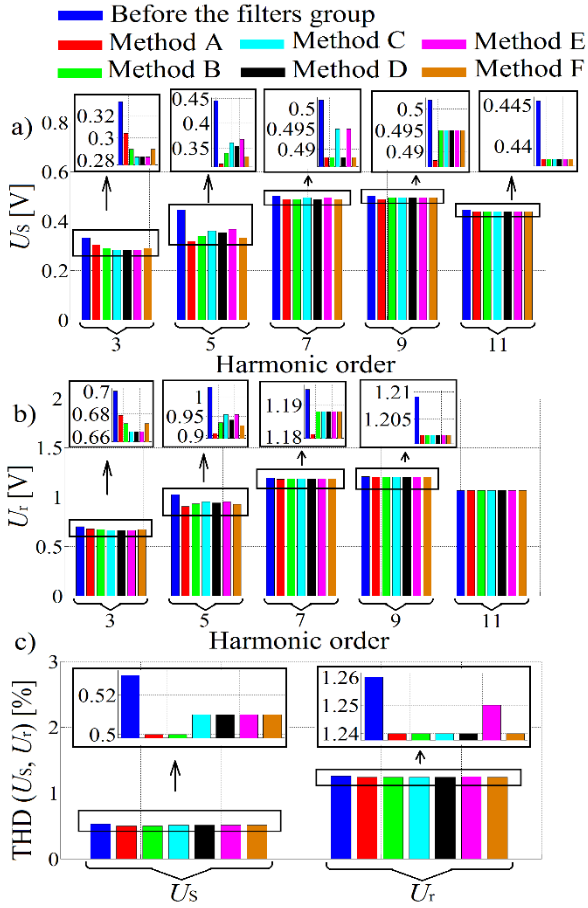


Fig. 5. Spectrum a) of the grid voltage; b) of rectifier input voltage; c) *THD* of grid and rectifier input voltage

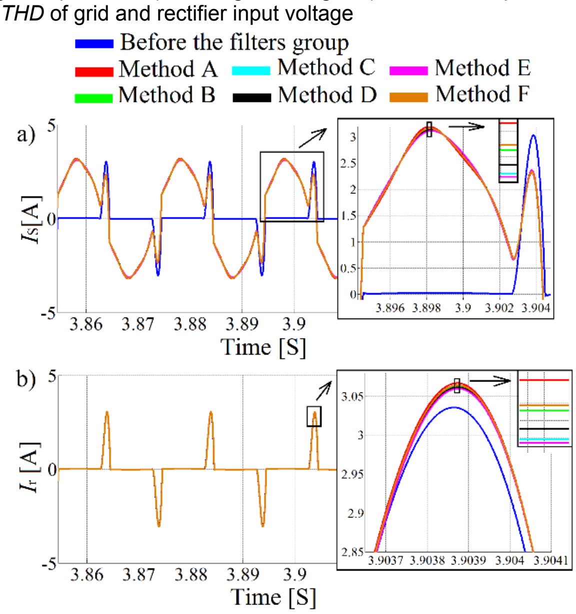


Fig. 6. a) grid current; b) current at the input of rectifier

According to the grid voltage THD, method A and B are the best because they have the lowest amplitude (Fig. 5c). The THD of input rectifier voltage is almost the same for each method apart of method E.

The filters group has improved the waveform of grid current (Fig. 6a) reducing the amplitudes of 3rd and 5th harmonic (Table 9-11).The waveforms of grid voltage, current and voltage at the input of rectifier are almost the same for each method (Fig. 4ab and 6b). The amplitude of harmonics of grid voltage and voltage at the input of rectifier has decreased after the filters group connection (Fig. 5ab and 5c). Observing the grid current spectrum (Fig. 7b), method A presents the higher value of 3rd harmonic and the lower value of 5th, 7th, and 9th harmonic. The spectrum harmonic of the current at the rectifier input is still almost the same before and after the filters group connection and for each method. It can be observed a little increase of the 7th and the 9th harmonic after the filters group connection because of the overcompensation (Fig. 7c).

Table 7. Reactive and active power of power system

	Grid (PCC)	Filter group
Before the filter group connection	P_S= 102.6 [W] Q_S = 9.438[Var]	- -
Method A	P_S = 103.7 [W] Q_S = -495.8[Var]	P_F = 0.533 [W] Q_F= -505.2[Var]
Method B	P_S =103.7 [W] Q_S = -495.8 [Var]	P_F = 0.600 [W] Q_F = -505.2 [Var]
Method C	P_S =103.8 [W] Q_S = -495.8 [Var]	P_F = 0.660[W] Q_F = -505.2 [Var]
Method D	P_S = 103.7 [W] Q_S = -495.7[Var]	P_F = 0.6418 [W] Q_F = -505.2[Var]
Method E	P_S = 103.8 [W] Q_S = -495.7[Var]	P_F = 0.6687 [W] Q_F = -505.2[Var]
Method F	P_S = 105.7 [W] Q_S = -495.7[Var]	P_F = 0.5897 [W] Q_F = -505.1[Var]

Table 8. Reactive and active power of power system

	Inductor (*L*)	Input of rectifier
Before the filter group connection	Q_L = 0.062[Var]	P_r = 102.6[W] Q_r = 9.375[Var]
Method A	Q_L = 0.063 [Var]	P_r =103.1 [W] Q_r = 9.323[Var]
Method B	Q_L = 0.063[Var]	P_r = 103.1[W] Q_r = 9.342 [Var]
Method C	Q_L =0.063 [Var]	P_r = 103.1[W] Q_r = 9.356[Var]
Method D	Q_L =0.063 [Var]	P_r = 103.1 [W] Q_r = 9.35 [Var]
Method E	Q_L =0.063 [Var]	P_r = 103.1 [W] Q_r = 9.358 [Var]
Method F	Q_L =0.063 [Var]	P_r = 103.1 [W] Q_r = 9.337 [Var]

A. The overcompensation of the power system

The reactive power measured at the input of rectifier is small inductive because of the commutation and the input reactor (Table 7 and 8). The reactive power used to compute the parameters was capacitive and is larger in comparison with the reactive power measured at the input of rectifier. The excess of filter group reactive power overcompensates the power system.

In practice, it exists the issue of the selection of filter with minimum reactive power. That means the filter with ability to eliminate harmonics and with minimal reactive power that do not overcompensate the load. In this paper, this issue is not taken into account.

The overcompensation has caused the increase of amplitude of first harmonic of grid voltage and current and voltage at the input of rectifier (Fig. 4c and 9a), the shift between the characteristics before and after the filters group connection (Fig. 4a,b, 6b). The reactive power at the PCC has turned to capacitive.

Harmonic amplitude

The coefficient $D_{(n)}$ of grid current (Fig. 8a) and rectifier input voltage was computed respectively by (2):

(2) $$D_{(n)I_S} = \frac{I_{S(n)}}{I_{S(1)}} \qquad D_{(n)U_r} = \frac{U_{r(n)}}{U_{r(1)}}$$

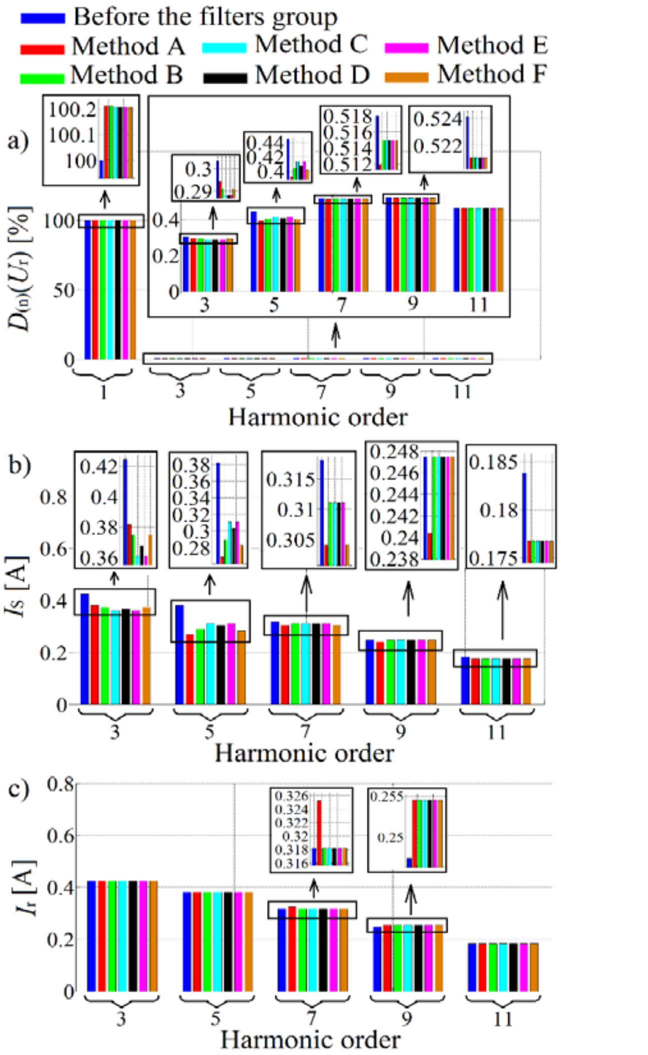


Fig. 7. a) spectrum (p.u.) of rectifier input voltage; b) grid current; c) current at the input of rectifier

Table 9. Parameters of grid current

$I_{S\,max}$ [A]						
n	Before the filters group connection		Method A		Method B	
	Ampl.	phase	Ampl.	phase	Ampl.	phase
1st	0.63	24.7	3.10	107.9	3.01	107.9
3rd	0.60	247.1	0.54	249.7	0.53	250.6
5th	0.54	111.5	0.38	116.5	0.41	115.3
7th	0.45	-24.7	0.43	-25.0	0.44	-25.3
9th	0.35	198.0	0.34	197.1	0.35	196.9
11th	0.26	58.9	0.25	57.5	0.25	57.3
THD [%]	165.91		29.97		30.15	

Table 10. Parameters of grid current

$I_{S\,max}$ [A]				
n	Method C		Method D	
	Amplitude	phase	Amplitude	phase
1st	3.10	107.9	3.10	107.9
3rd	0.51	251.2	0.52	251.0
5th	0.44	114.2	0.43	114.6
7th	0.44	-25.5	0.44	-25.4
9th	0.35	196.7	0.35	196.7
11th	0.25	57.1	0.25	57.2
THD [%]	30.38		30.27	

Table 11. Parameters of grid current

$I_{S\,max}$ [A]				
n	Method E		Method F	
	Amplitude	phase	Amplitude	phase
1st	3.10	107.9	3.10	107.9
3rd	0.51	251.3	0.53	250.4
5th	0.44	114.1	0.40	115.5
7th	0.44	-25.5	0.43	-25.3
9th	0.35	196.7	0.35	196.9
11th	0.25	57.1	0.25	57.3
THD [%]	32.42		30.08	

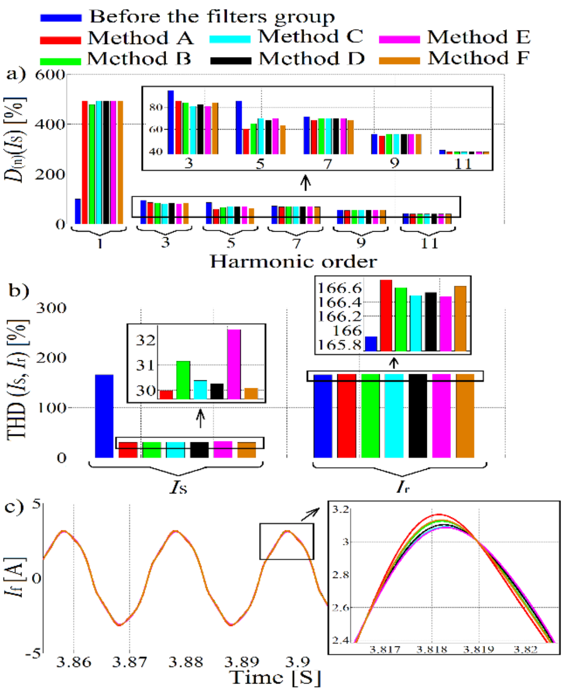


Fig. 8. a) Harmonic of grid current (p.u.); b) THD of grid current and current at the input of rectifier; c) filter current

In Fig. 7a and 8a, the coefficient $D_{(1)}$ of the voltage at the input of rectifier, grid current measured after the filters group connection (for each method) are higher than 100% because of the overcompensation. The coefficient $D_{(3)}$ is the lower for methods C and E and the higher for method A; the coefficient $D_{(5)}$ is the lower for method A and the higher for methods C and E.

Table 12. Parameters of filter current

$I_{f\,max}$ [A]						
n	Before the filters group connection		Method A		Method B	
	Ampl.	phase	Ampl.	phase	Ampl.	phase
1st	0.63	24.7	3.09	119.7	3.09	119.7
3rd	0.60	247.1	0.07	40.5	0.09	47.2
5th	0.54	111.5	0.17	-82.7	0.13	-83.9
7th	0.45	-24.7	0.02	139.5	0.02	139.3
9th	0.35	198.0	0.01	4.9	0.01	4.7
11th	0.26	58.9	0.01	227.5	0.01	227.3
THD [%]	165.91		5.86		5.21	

Table 13. Parameters of filter current

$I_{f\,max}$ [A]				
n	Method C		Method D	
	Amplitude	phase	Amplitude	phase
1st	3.09	119.7	3.09	119.7
3rd	0.10	41.7	0.10	41.6
5th	0.10	-85.0	0.12	-84.5
7th	0.02	139.1	0.02	139.1
9th	0.01	4.5	0.01	4.6
11th	0.01	227.1	0.01	227.2
THD [%]	4.75		4.94	

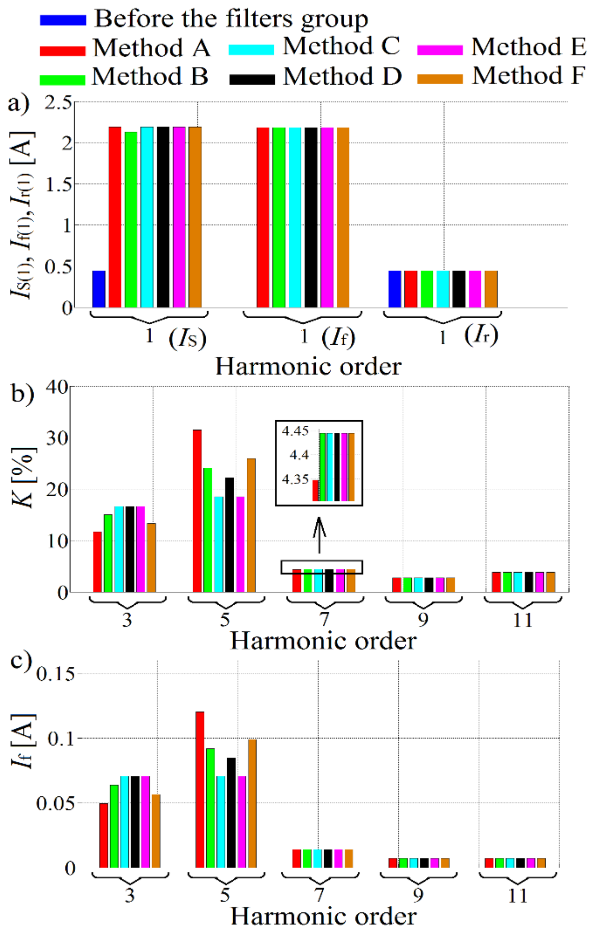


Fig. 9. a) fundamental harmonic of grid current (I_S), filter current (I_f) and current at the input of rectifier (I_r); b) the coefficient of filters group effectiveness (*K*); c) spectrum of filter current

Table 14. Parameters of the current at the rectifier input

$I_{f\,max}$ [A]				
n	Method E		Method F	
	Amplitude	phase	Amplitude	phase
1st	3.09	119.7	3.09	119.7
3rd	0.10	41.8	0.08	41.1
5th	0.10	-85.2	0.14	-85.6
7th	0.02	139.0	0.02	139.3
9th	0.01	4.5	0.01	4.7
11th	0.01	227.1	0.01	227.3
THD [%]	4.70		5.37	

Method A presents the lowest value of *THD* of grid current after come method F and D, then methods C and B and at the end method E (Fig. 8b). The current at the input of rectifier presents the lowest value of THD for the methods E and C after comes method D, then methods B and F and at the end method A.

The coefficient of effectiveness of filters group (K)

The coefficient of effectiveness is computed by (3).

(3) $$K = \frac{I_{f(n)}}{I_{r(n)}} \qquad 0 \le I_{f(n)} \le I_{r(n)}$$

At the input of rectifier, the current of *n*-th order harmonic ($I_{r(n)}$) is supposed to be constant after the filter connection and the current of *n*-th order harmonic flowing through the filter ($I_{f(n)}$) is supposed to change (increasing or decreasing) depending to the filter resistance and the application of the method of filter design. The single branch filter is more effective when the coefficient (K) is close to one and less effective when it is close zero.

In Fig. 9b, it can be observed that the filters groups designed by method C, D and F are more effective for the 3rd harmonic and less effective for the 5th harmonic. The filters group using method A is more effective for the 5th harmonic and less effective for the 3rd harmonic.

The active power of the filters group is lower for method A and the higher for methods C and E (Fig. 10a). At the PCC, it is lower for methods A and B, and higher for method F. Because of the low power losses, method A is the best. Before the filter group connection, the phase shift between the fundament harmonic of current and voltage at the PCC was positive. After the filter group connection it has changed to negative and its module has increased (Fig. 10b).

Methods A, B and C present the highest value of reactive power at the PCC and methods A, B, C, D and E present the highest value of reactive power at the filters group (Fig. 11a). The overcompensation caused by the filters group connection has increased the voltage of capacitor at the DC side of rectifier (Fig. 11b).

The measurement of the power system impedance at the input of rectifier is presented in Fig. 12. It can be observed the series and parallel resonance around each frequency to which the filters group is tuned. The series resonance has occurred because of the filter group connection and the parallel resonance because of the parallel connection between the filter group capacitors and the electrical grid reactor.

The series resonance has occurred for the frequencies lower than the 150 Hz and 250 Hz because the filters was designed to be tuned to 145 Hz and 242.5 Hz. In practice, the parameters of passive filters are not computed by the exact frequency of harmonic to be eliminated (e.g. 3rd) but by the frequency of harmonic close and lower than harmonic to be eliminated (2.9). Because the resonance point moves with the filter aging and temperature [3].

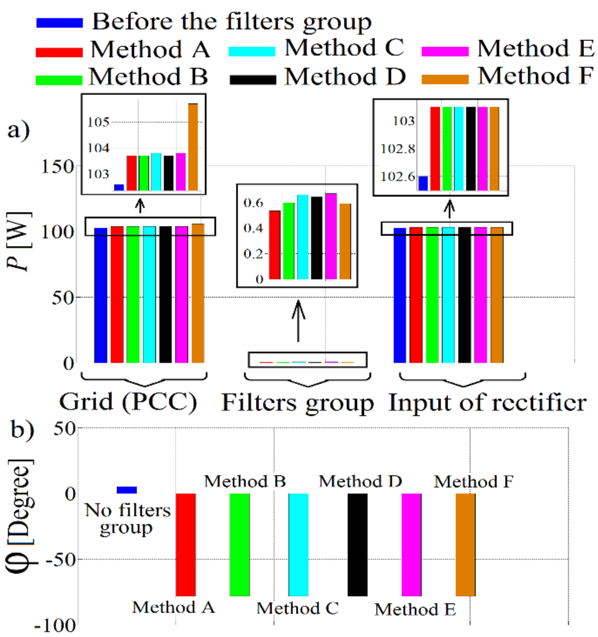


Fig. 10. a) active power measured at the PCC; input of rectifier and terminals of filters group; b) phase shift between the fundament harmonic of current and voltage at the PCC

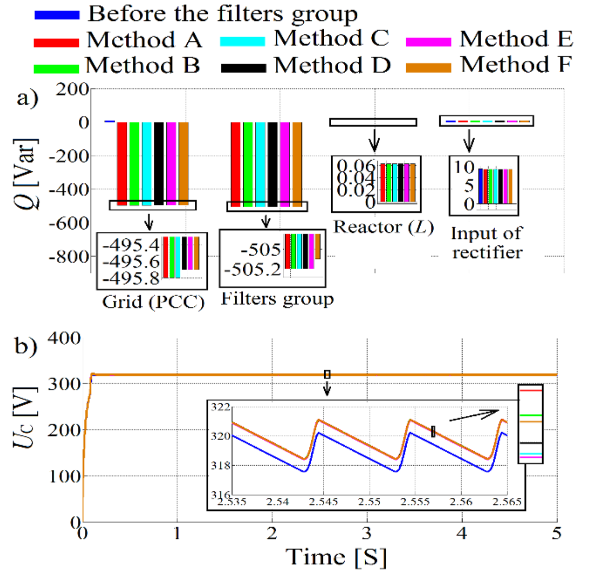


Fig. 11. a) reactive power measured at the PCC, input of rectifier, terminal of filters group and reactor; b) voltage at the DC side of rectifier

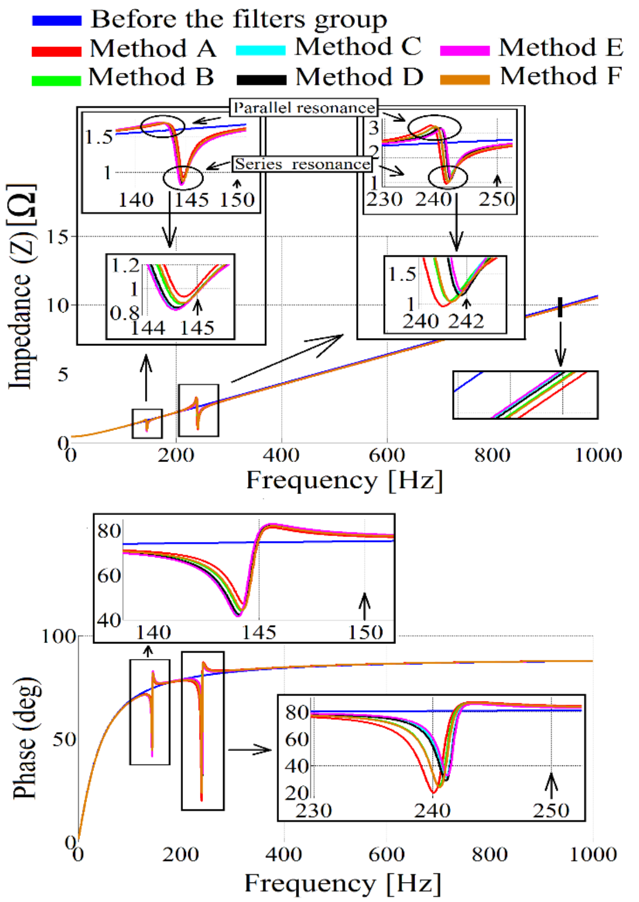


Fig. 12. Frequency impedance characteristics measured at the input of rectifier bridge

The parallel resonance always occurred at the frequency lower than the frequency to which the filter is tuned (Fig. 12). The shift between the characteristics of impedance before after the filter connection is due to the overcompensation of the filter group (Fig. 12).

Conclusion

Table XV presents the comparison of all analysed methods. The filters group was tuned to the frequencies lower than the frequencies of the 3rd and 5th harmonic (2.9rd and 4.85th) but the analysis was focused on the filtration of 3rd and 5th harmonic.

Method A is the best because it has the lower value of filters group power losses, amplitude of 5th harmonic and THD of grid voltage despite the fact that it presents the lower filtration efficiency for the 3rd harmonic.

Table 15. Comparison criteria of the filter group tuned to the frequencies lower than the frequencies of the 3rd and 5th harmonic (2.9rd and 4.85th)

	Meth. A	Meth. B	Meth. C	Meth. D	Meth. E	Meth. F
$U_{S(3)}$[V]	0.43	0.41	0.40	0.40	0.40	0.41
$U_{S(5)}$[V]	0.45	0.48	0.51	0.50	0.52	0.47
THD_{Us}[%]	0.50	0.50	0.51	0.51	0.51	0.51
ΔP_F [w]	0.533	0.600	0.660	0.6418	0.6687	0.5897

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REFERENCES

[1] Abu-Rubu H., Iqbal A., Guzinski J.: *High Performance Control of AC Drives with MATLAB/SIMULINK Models*, John Wiley & Sons, 2012.
[2] Arrillaga J., Bradley D.A., Bodger P.S.: *Power System Harmonic*, John Wiley & Sons, cop. 1985.
[3] Hanzelka Z.: *Selected aspects of the design of passive harmonic filters* (in Polish), Automatyka, Elektryka, Zakłócenia, Infotech conference. Jurata, 23-26 June 2010.
[4] Klempka R.: *Improving the power quality supply with the use of genetic algorithms* (in Polish), AGH. Krakow 2013.
[5] Herbert L. Ginn III, Leszek S. Czarnecki.: *An optimization Based Method for Selection of Resonant Harmonic Filter Branch Parameters*, IEEE Transactions on Power Delivery, Vol. 21, No.3, July 2006, PP. 1445-1451.
[6] Liserre M., Blaabjerg F., Hansen S.: *Design and Control of an LCL-filter based Three-Phase Active rectifier*, IEEE Industry Application conference, Chicago, IL, USA, vol. 1, 2011, pp. 299-307.
[7] Liserre M., Aquila A.D., Blaabjerg F.: *Stability Improvement of an LCL-filter Based Three-phase Active Rectifier*, IEEE Power Electronics Specialists Conference, vol. 3, 2002, pp. 1195 - 1201.
[8] S. Sakar., S. H. E. Abdel Aleem., M. E. Balci., A. F. Zobaa.: *A Filter Design Approach to Maximize Ampacity of Cables in Nonsinusoidal Power Systems*, IEEE International School on Nonsinusoidal Current and Compensation (ISNCC), Conference 2015, Łagów, Poland.
[9] M. Rusli., M. Ihsan., D. Setiawan.: *A Single Tuned Harmonic Filter Design as Total Hamonic Distortion (THD) Compensator*, CIRED Interbational Conference on Electrical Distribution, Lyon 2015.
[10] Sik.Cho Y., Cha H.: *Single-tuned Passive Harmonic Filter Design Considering Variances of Tuning and Quality Factor*, Journal of International Council on Electrical Engineering, vol. 1, no. 1, 2011, pp. 7-13.
[11] S. Sakar., A. D. Karaoglan., M. E. Balci., S. H. E. Abdel Aleem, A. F. Zobaa.: *optimal Design of Single-Tuned Passive Filters Using Response Surface Methodology*, IEEE International School on Nonsinusoidal Current and Compensation (ISNCC), Conference 2015, Łagów, Poland.
[12] Klempka. R.,: *Designing a group of single-branch filters taking into account their mutual influence*, Archives of Electrical Engineering Vol. 63(1), pp. 81-91, 2014.
[13] Wojciechowski D.: *high-power Parallel active compensators*, (in Polish), Gdynia Maritime University. Gdynia 2013.

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