International Journal of Engineering Innovation & Research
Volume 3, Issue 4, ISSN: 2277 – 5668

Harmonics Removal in Power Generators System Using Filters

Eyenubo O. Jonathan
Dept of Elect/Elect
Delta State Poly, Otefe-Oghara
Email: eyenubo63@yahoo.com

Dr. E.U. Ubeku
Dept of Elect/Elect
University of Benin, Benin-City
Email: ubiomo.ubeku@uniben

Offor Kennedy
Anambra State University
Anambra State
Email: ken.offor@gmail.com

***Abstract* – The active power filter has been proved to be an effective method to mitigate harmonic currents generated by nonlinear loads as well as to compensate reactive power. The methods of harmonic current detection play a crucial part in the performance of active power filter (APF). This paper presents a new control strategy in which an active power filter configuration is developed in order to define new simple method which requires minimum number of current measurements; and the reduction of the 3rd to 13th harmonics in power generating systems. The effectiveness of the proposed control strategies is demonstrated through results; the proposed system is implemented with MATLAB/ SIMULINK.**

***Keywords* – Harmonics, Total Harmonic Distortion, (V_{thd}), Matlab/Simulink, Filter.**

Nomenclature
Z_s = impedance seen by the source
R = resistance
f = frequency
L = inductance
C = capacitance
P = power
I = current
V = voltage
cos φ = power factor
X_{c1} = capacitive reactance
C = capacitance
f is the fundamental frequency.
V_{LL} = line voltage
I_{fun} = fundamental current
I_{imp} = impedance current
L = inductor

I. Introduction

The increasing use of solid-state power-conversion equipment (rectifiers, inverters, cycloconverters) and other power electronic-type devices (voltage controllers, motor-speed controllers) on distribution systems is causing utilities to become much more concerned about voltage and current harmonic levels [1,2]. The nonlinear characteristic of the power semiconductors results in serious harmonics and reactive power pollution in power system [3,4]. The effective methods for harmonic suppression and reactive power compensation are needed.

The Passive Power Filter (PPF) is a traditional way for harmonic suppression, which is composed of power capacitor, power inductance and resistance. PPF has been regarded as the main approach in the field based on its simple architecture, little maintenance and well-developed design. But there are several disadvantages existing in PPF: (1) filtering characteristic depends on the impedance of the power supply; (2) the impedance characteristic is deteriorated with the frequency reduce to below the lowest resonance frequency; (3) PPF cannot filter the non-characteristic harmonics entirely; (4) it is possible to result in resonance.

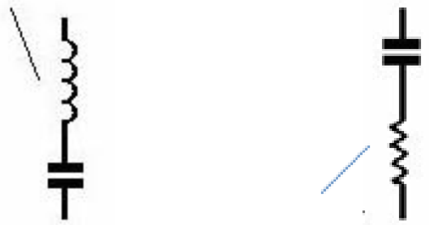
Active power filters are used to eliminate harmonic currents as well as to compensate for reactive power. **[5, 6]** Principally, the active power filter operates by detecting harmonic current to calculate the amount of the compensating current needed for feeding back to the power system in the opposite direction of the harmonic current.

In the conventional p-q theory based control approach for the shunt APF, the compensation current references are generated based on the measurement of load currents and the current feedback from the shunt APF output is also required and therefore, a minimum of four current sensors are desired in a balanced system.

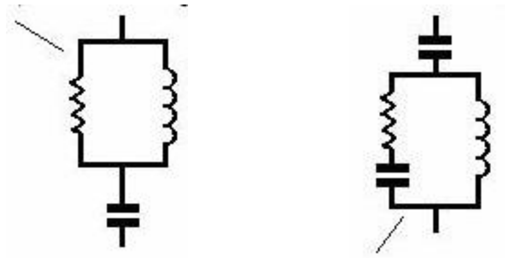
Lower order harmonics have the largest current magnitudes; therefore they require filters that have quite low impedances at these frequencies. A single tune filter is a series LC circuit and is tuned to one of the lower frequencies, for example, 3rd, 5th 11th and 13th harmonics. [7, 8]

II. Basic Concept of Active Power Filters

The higher order harmonics have smaller magnitudes and it is usually not economical to use many tuned filters to eliminate these harmonics. The high-pass passive filters offer low impedance over a broad band of frequencies, for instance – 17th and higher harmonics. Four types of filter are shown in Fig. 1.1



(a) Single Tune (b) 1st Order High-Pass



(c) 1st Order High-Pass (d) 3rd Order Low-Pass

Fig.1.1 High-pass filters (a) first-order, (b) second-order, (c) third-order, (d) C-type.

In Fig 1.1, the impedance seen by the source in this circuit is given by

$$Z_s = R + j(2\pi f L) - \frac{1}{2\pi f C} \quad (1)$$

The resonant frequency f_o is defined to be the frequency at which the impedance is purely resistive. For the reactance to equal zero, the impedance of the inductance must equal the impedance of the capacitance in magnitude. Thus, we have

$$2\pi f C = \frac{1}{2\pi\, f_0\, L} \quad (2)$$

And the resonant frequency is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (3)$$

The impedance of resonant circuit Z_p is given by the relation:

$$Z_p = \frac{1}{\frac{1}{R} + j2\pi f C - j\left(\frac{1}{2\pi f L}\right)} \quad (4)$$

The condition for resonance is given by relation of equation (2), while the resonant frequency is given by equation (3)

III. Methodology for Design of Single-TunedHarmonic Filters

In this paper, basic steps of designing a single-tuned filter are introduced, and a detailed design procedure of active low-pass power filters is presented.

3.1 Calculating the Capacitor Bank Size and the Resonant Frequency

As a general rule, the filter size is based on the load reactive power requirement for power factor correction. When an existing power factor correction capacitor is converted to a harmonic filter, the capacitor size is needed. The reactor size is then selected to tune the capacitor to the desired frequency. The capacitive reactance needed to supply the needed VARs to improve the power factor from true power factor (TPF1) (associated with φ_1) to TPF 2 (associated with φ_2) is given by:

$$Q = P\,(tan\ \varphi_1 - tan\ \varphi_2) \quad (5)$$

$$P = VICos\ \varphi_1 \quad (6)$$

$$P = \frac{V^2}{R} \quad (7)$$

The capacitive reactance X_{c1} required is obtained with the following relation:

$$X_{c1} = \frac{3V^2}{VARs} \quad (8)$$

where V is capacitor-rated line to neutral voltage and the filter capacitance is then calculated using,

$$C = \frac{1}{2\pi f\, X_{c1}} \quad (9)$$

IV. Methodology for the Design of Active Low-Pass Filters

Compared to a single-tuned filter, active low-pass filter that has a series L and a shunt C is not a tuned filter. The reactance of the L and C at the cutoff frequency is equal to the characteristic impedance, and that means the L and C happen to resonate at the cutoff frequency. The L starts to stop higher frequency signals getting from the load to the source, and the C starts to shunt higher frequency signals away from the load. [9]

Series low-pass filters are the best choice for a voltage source rectifier. This filter is applied to individual loads or groups of loads in a system. They can also be applied on SCR rectifiers, including phase control and pre-charge front ends, as well as six-pulse rectifiers using AC line reactors or DC chokes.

Harmonic passive filters are designed as needed based on the minimum reactive power and maximum harmonic current requirements. The true power factor (TPF) becomes a combination of the displacement power factor and the distortion power factor. For most typical non-linear loads, the displacement power factor will be near unity. True power factor howe[illegible] is lower because of the distortion component (harmonics). Thus, the best way to improve the poor true power factor caused by this rectifier system is to remove the harmonic currents by adding reactors first. [10, 11]

4.1 Calculation of Impedance

Reactors reduce harmonic currents. The definition of the percentage impedance of a reactor is:

$$\%\ imp. = \frac{I_{fun} * 2 * \pi * f * L * \sqrt{3} * 100}{V_{LL}} \quad (10)$$

Hence the inductance of a reactor can be calculated:

$$L = \frac{\%\ imp. * V_{LL}}{I_{fun} * 2 * \pi * f * 100 * \sqrt{3}} \quad (11)$$

4.2 Calculating the Filter Reactor Size

The filer reactor size can now be selected to tune the capacitor to the desired frequency as follows:

$$L = \frac{1}{(2\pi f\,)^2 (rh\,)^2 C} \quad (12)$$

where, *h* is the harmonic to which the filter is tuned, and *r* is an empirical factor smaller than one, the typical value of r is 0.94.

The values of the resistance, inductance and capacitance used in deigning of the filter circuit are as follows: R_1, R_2 & R_3 = 1.5453KΩ, R_4, R_5, R_6, R_7, R_8, R_9, R_{10}, R_{11}, R_{12} = 2.5755KΩ; L_1, L_2 &L_3 = 0.010mH; L_4, L_5, L_6, L_7 & L_8 = 0.0233mH, C_1& C_2 = 728.273 μF; C_3, C_4, C_5, C_6, C_7 & C_8 =2184.819μF.

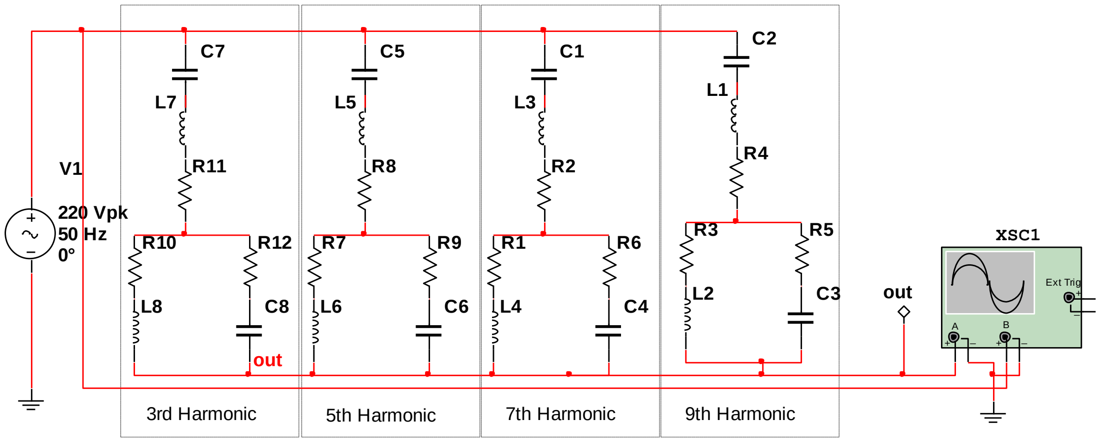


Fig. 1.2 Filter circuit for simulation

V. Results

Power source generator, 250 kVA, at frequency, F (51.188) has the following results before simulation was carried out as shown in Table 1.1

Table 1.1 250 kVA, F (51.188), before simulation is Vthd = 0.09536 = 9.536%

$$cn = \sqrt{(an)^2 + (bn)^2};\ \varphi n = tan^{-1}\left({(bn)}/{(an)} \right)$$

$$cna = \sqrt{(ana)^2 + (bna)^2};\ \varphi na = tan^{-1}\left({(bna)}/{(ana)} \right)$$

Tables 1.1: defines the Fourier coefficients mathematically as follows:

s/n	an	bn	cn	φn	scope_data
1	3852815	117106.592	3854594.69	0.030385715	-4800000
2	0	0	0	0	-4600000
3	275015.7	51691.9464	279831.576	0.185792252	-4600000
4	0	0	0	0	-4600000
5	156208.5	47672.2441	163320.929	0.296205486	-4400000
6	0	0	0	0	-4400000
7	109356.3	28615.4791	113038.286	0.255933443	-4400000
8	0	0	0	0	-4400000
9	89556.26	21664.763	92139.492	0.237352364	-4400000
10	0	0	0	0	-4400000
11	69353.82	21359.004	72568.3081	0.298754012	-4400000
12	0	0	0	0	-4200000
13	56727.82	0	0	0	-4200000
14	0	0	0	0	-4200000

Power source generator, 250 kVA, at frequency, F (51.188) has the following result carried out as shown in Table 1.2 after simulation Vthd = 0.05882 = 5.882%

Table 1.2 results after simulation

s/n	ana	bna	cna	φna	scope_data
1	3740000	1.98E-10	3740000	5.31E-17	-4800000
2	0	0	0	0	-4600000
3	220000	1.96E-10	220000	8.92E-16	-4600000
4	0	0	0	0	-4600000
5	2.86E-10	1.67E-10	3.31E-10	0.5280744	-4400000
6	0	0	0	0	-4400000
7	1.79E-10	1.16E-10	2.13E-10	0.5769072	-4400000
8	0	0	0	0	-4400000
9	1.38E-10	1.10E-10	1.77E-10	0.6730549	-4400000

10	0	0	0	0	-4400000
11	1.25E-10	1.10E-10	1.67E-10	0.7210384	-4400000
12	0	0	0	0	-4200000
13	1.04E-10	1.05E-10	1.47E-10	0.790126	-4200000
14	0	0	0	0	-4200000

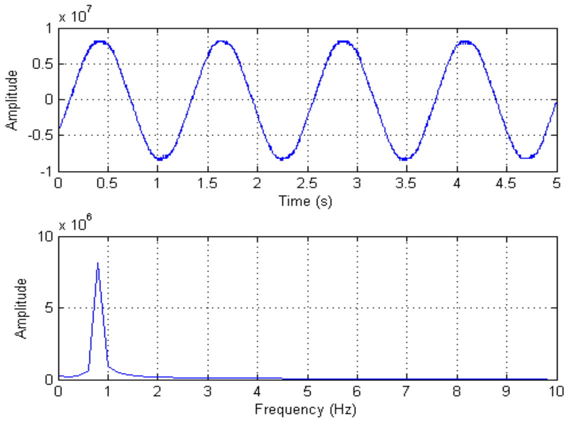


Fig.1.3. (a) Output Voltage Waveform (b) FFT Spectrum of power source

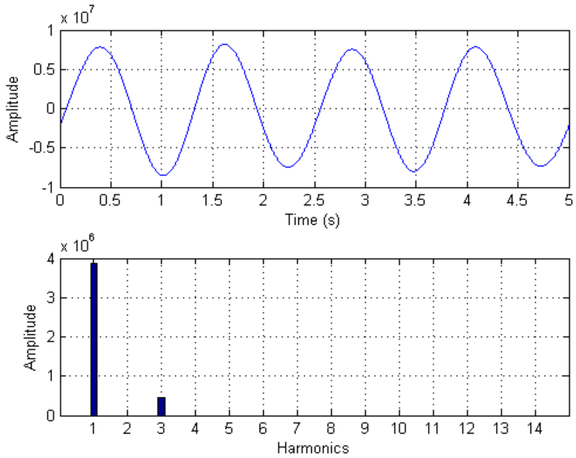


Fig.1.4. (a) Filtered signal after simulation (b) harmonic spectrum filtering

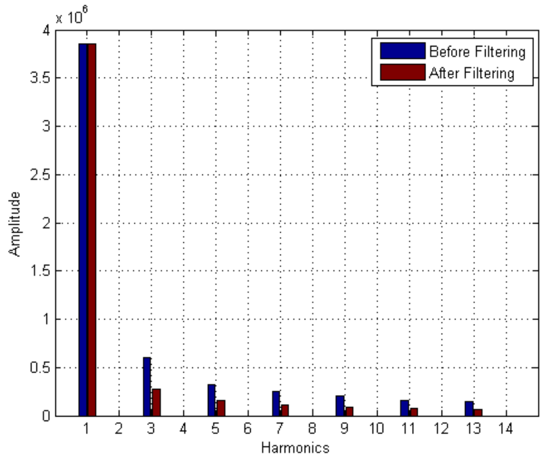


Fig.1.5. Harmonic spectrum before and after filtering V_{THD} = 0.05882 = 5.882%

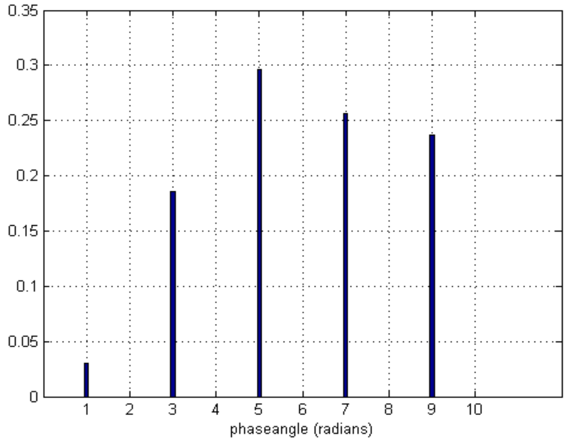


Fig.1.6. Phase_angle after filtering

VI. Discussion and Conclusion

Table 1.1show the value of total harmonic distortion before simulation was carried out was found to be V_{thd} = 0.09536 = 9.536%. This results in the output waveform shown in Fig. 1.3(a) output voltage waveform and (b) Fast Fourier Transform (FFT) spectrum of power source for 250kVA. Table 1.2 shows the filtered result after simulation that the total harmonic distortion is V_{thd} = 0.05882 = 5.882% which shows a reduction in the value of the V_{THD}, this complies with the required IEEE standard of 5%.

Fig. 1.4 shows the filtered signal and harmonic order after filtering; thus only the fundamental frequency and the third harmonic are seen, while the other frequency have been filtered off this indicates that the low-pass filter is effective. Fig. 1.5 harmonic content before filter V_{THD} = 0.05882 = 5.882%, other harmonics: the 5^{th}, 7^{th}, $9^{th,}$ 11^{th} and 13^{th} harmonics are reduced, while Fig. 1.6 shows phase_angle after filtering; the values of the filter parameters.

The harmonic order of 5^{th}, 7^{th}, 11^{th}, and 13^{th} and even higher harmonics were totally attenuated after filtering and simulation was carried out; it can be deduced that the frequency at which this data was taken is just a little higher than the 50Hz and the power source is a three-phase.

In conclusion an improvement in total harmonic distortion can be achieved if these harmonics are totally attenuated; the good choice of values for filter element - the resistor, inductor and the capacitor will enhance a more accurate result as a criterion of IEEE standard which is limited to being a collection of Recommended Practices that serve as a guide to both suppliers and consumers of electrical energy; where problems exist, because of excessive harmonic current injection or excessive voltage distortion, it is incumbent upon supplier and consumer to resolve the issues within a mutually acceptable framework. Thus IEEE 519 is to recommend limits on harmonic distortion according to two distinct criteria, namely:

1. There is a limitation on the amount of harmonic current that a consumer can inject into a utility network.
2. A limitation is placed on the level of harmonic voltage that a utility can supply to a consumer.

References

[1] Abdelmadjid C, Peng F.-Z. and Ott G. W. (1998) "Harmonic and reactive power compensation based on the generalized instantaneous reactive power theory for three-phase four-wire systems," *IEEE Trans. Power Electron.*, vol. 13, no. 6, pp. 1174–1181

[2] Adams D. J, Ogasawara S, and Kim H, (1999), "The theory of instantaneous power in three-phase four-wire systems: a comprehensive approach," in *Proc. IEEE IAS Annual. Meeting*, pp. 431–439.

[3] Akagi H, Claudio R, Domenico C, and Gabriele, (1999) "Control Methods for Active Power Filters with Minimum Measurement Requirements," IEEE APEC, Vol. 2, pp.1153-1158.

[4] Al-Haddad. K, Chandra A and Singh B, (1998) "Harmonic elimination, reactive power compensation and load balancing in three-phase, four wire electric distribution systems supplying nonlinear loads," J. Electric Power Syst. Res.,vol,44, pp. 93– 00.

[5] Bakhshai A, Singh.B, and Singh B.N, (2000) "An improved control algorithm of shunt active filter for voltage regulation, harmonic elimination, power-factor correction, and balancing of nonlinear loads," IEEE Trans. Power Electronics, Vol.15, pp. 495-507.

[6] Chu Y. C, Tey L. H, and So P. L, (2005) "Improvement of power quality using adaptive shunt filter," *IEEE Trans. Power Del.*, vol. 20, no. 2,pp. 1558-1568.

[7] Frede B, and Steffan H, (2005), "Evaluation of Harmonic Detection Methods for Active Power Filter Applications," IEEE Applied Power Electronics Conference and Exposition, Vol. 1, pp.635 – 641,

[8] Jean P. G, Fateh K.G, and Rard C, (2007) "PI Controlled Three-phase Shunt Active Power Filter for Power Quality Improvement," EPÉE proc. electric power components and systems, volume 35, Issue 12.

[9] Lucian A, and Mehl L. M, (1995), 'An Improved High Power Factor and Low Cost Three-Phase Rectifier', IEEE Applied Power Electronic Conference Proceeding (APEC'95), pp. 835-841

[10] Nam K, Gruzs T.M, and Zmood D. N, (1990), 'A Survey of Neutral Current in Three-Phase Computer Power systems', IEEE Transactions on Industry Applications, vol. 26, no.4, pp.719-725.

[11] Mannila T, and Green T M, (2005), 'Control Techniques for Active Power filters', IEEE Proceedings of electrical Power applications, vol. 153, pp.369 – 381

Author's Profile

Eyenubo O. Jonathan
received his B.Eng in Electrical/Electronic (Power & Machines) from University of Benin in 1990, He has 14 years industrial experience with the Nigerian Ports Authority, M.Eng. Electrical/Electronic (Power & Machines) from the University of Benin in 2007. He is currently with the Delta State Polytechnic, Otefe-Oghara where he has published 3 journals; he is working on his Ph.D. with the University of Benin.