

PAPER • OPEN ACCESS

## Harmonic mitigation for power rectifier using passive filter combination

To cite this article: O A Monem 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **610** 012013

View the [article online](#) for updates and enhancements.

A promotional banner for the 240th ECS Meeting. The banner features a colorful striped border at the top. On the left, the ECS logo is displayed in a green circle. To the right of the logo, the text reads: "240th ECS Meeting", "Digital Meeting, Oct 10-14, 2021", "We are going fully digital!", "Attendees register for free!", and "REGISTER NOW" in bold orange letters. On the right side of the banner, there is a photograph of a diverse group of people in a professional setting, with a man in a white shirt and tie clapping and smiling.

**ECS** **240th ECS Meeting**  
Digital Meeting, Oct 10-14, 2021  
**We are going fully digital!**  
Attendees register for free!  
**REGISTER NOW**

# Harmonic mitigation for power rectifier using passive filter combination

**O A Monem**

High Institute of Engineering and Technology Al-Obour, Cairo-Belbis Desert Road,  
Cairo, Egypt

Email. [usaomar2000@hotmail.com](mailto:usaomar2000@hotmail.com)

**Abstract.** Power rectifiers are widely used in different industrial applications that deliver DC voltage supply for many types of loads like electrolysis cells, metal electroplating and other DC loads. These rectifiers act as nonlinear loads injecting harmonic currents to the AC mains with lots of troubles and negative impact on the utility grid and the load itself, like increasing losses, measurement error, protection device false tripping and distortion of the voltage at the PCC affecting other loads at the same point. For this reason, many researches focus on this problem and how to mitigate it. In this research, power analysis measurements are taken for 750 KW power rectifier feeding electrolysis cells and define the power quality indices compared to IEC 519 Standard. Passive filter is selected to mitigate the recorded harmonics. Two types of filters are designed. The first is three single tuned passive filter to mitigate the 5<sup>th</sup>, 7<sup>th</sup> and the 11<sup>th</sup> harmonics. The second type is 2<sup>nd</sup> order high pass filter to mitigate harmonics equal and greater than 13<sup>th</sup> harmonics. MATLAB simulation is performed to validate the proposed solution. The current total harmonic distortion can be reduced from 29.6 % to 1.5 % and supply voltage total harmonic distortion is also improved from 3.25 % to 0.62% which meet the international standard and improve the power quality of the voltage at point of common coupling.

**Keywords:** Power Quality Indices, Total harmonic distortion, single tuned passive filter, high pass filter, Point of Common Coupling

## 1. Introduction

Power electronic equipment has many applications in various industrial fields. Meanwhile, they are normally the main sources of power system harmonic distortion, which negatively affect the system in the following: 1) Increase losses in electric equipment and overheating (like transformers); 2) telephone interference; 3) False tripping of protection relays; and 4) error in the power meters [1]-[6]. Many researches have been published to mitigate the harmonic distortion resulted from nonlinear loads. A passive filter is generally a series-connected, parallel connected or hybrid-connected circuit. The filter LC parameters are properly tuned to make the circuit resonance at a certain frequency to mitigate the harmonic distortion. The passive filter has the advantage of a simple structure, low cost and high reliability.

Many studies have been done on designing a passive filter topology in order to meet the harmonic mitigation requirement set by IEEE 519 standard [7]. The application of a passive filter is wide. First, at the harmonic source in a distribution system, the passive filter is installed to trap the harmonic current from injecting into the transmission system [8]. Second, renewable energy sources, such as wind generator converters and photovoltaic (PV) inverters, are installed with a passive filter, which mitigates the switch-



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

frequency harmonic [9]-[12]. Third, the passive filter is also installed at the high-speed trains to mitigate its harmonic emission. Many valuable works have been done in this area [13]-[14]. The remaining sections of this paper are organized as follows. Section 2 presents the measured power quality indices; ac mains current and voltage waveform THD and individual current harmonic. Section 3 discusses the different types of passive filters and the recommended type employed in this paper. Section 4 presents the simulation results and Section 5 concludes the whole paper and introduces future research works.

## 2. Harmonics Measurements

To properly define the suitable mitigation method, the level and nature of harmonic should be determined. Actual measurement for the system have been recorded using HIOKI 3196 Power analyzer. This measurement is recorded for different load levels from 100% loading to 33% loading. Table 1 presents the measured THD for current and voltage at different loading levels. The measured values in this Table show clear deviation against IEEE 519 Standard for voltage, as the maximum permissible total harmonic distortion for low voltage defined by this standard is 3% [7] while the actual reading is around 4.5%. On the other hand the current total harmonic distortion varies between 14.5% to 24.7% which also doesn't meet the international standard. The measured power factor was very poor with value of 0.6.

**Table 1.** Measured current and voltage total harmonic distortion using HIOKI power analyzer

<b>Current (KA)</b>	12	10	8	6	4
<b>Loading Level</b>	100%	83%	67%	50%	33%
<b>Voltage total Harmonic Distortion %</b>	4.7	4.5	4.6	4.4	4.7
<b>Current total Harmonic Distortion %</b>	14.5	18.1	21	23.5	24.7
<b>PF</b>	0.6	0.6	0.6	0.6	0.6

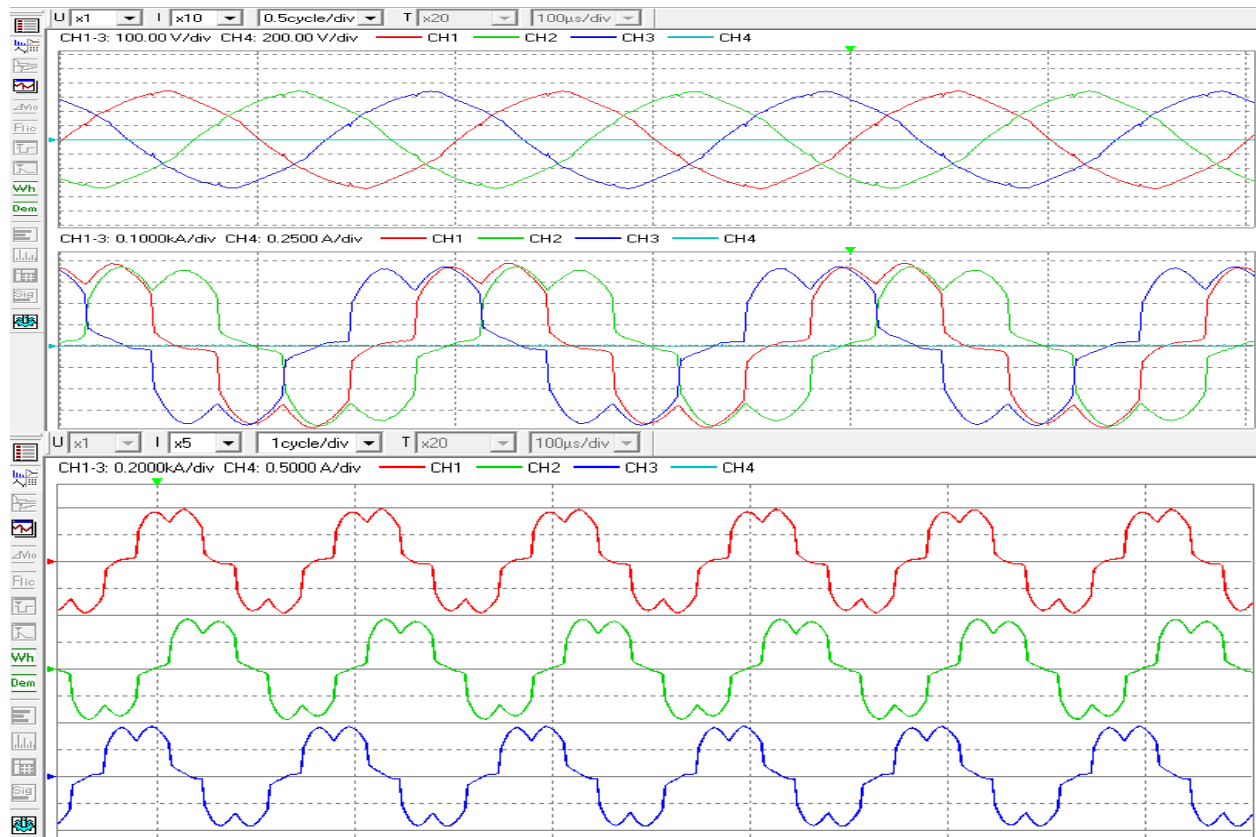
Figure 1 and figure 2 show the measured current and voltage waveforms recorded by the power analyzer. Individual harmonic of both current and voltage are indicated in Figure 3. with respect to harmonic order. The distortion of the voltage at the point of common coupling is due to the current distortion and the source inductance;  $L_s$  as per the below equation:

$$V_{pcc} = V_s - (L_s \cdot dI_s/dt) \quad (1)$$

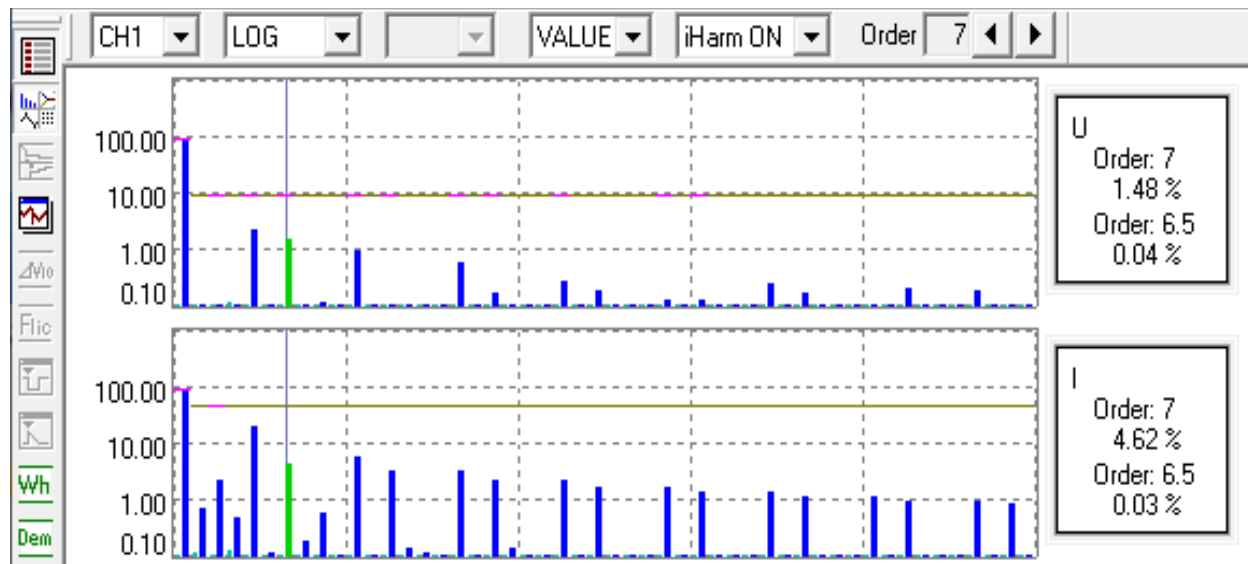
where  $V_{pcc}$  is the voltage at the point of common coupling,  $V_s$  is the supply voltage,  $L_s$  is the source inductance and  $I_s$  is the source current.

The harmonic current components multiplied by the source impedance at this frequency represent a voltage drop and cause a voltage distortion for the supply voltage affecting other consumer at the point of common coupling.

Table 2 presents break down for the detailed individual harmonic current in percentage from fundamental to the 50<sup>th</sup> harmonic order, a snap shoot is taken for the harmonics analyzed by the measuring instruments. (All even and triple multiplier harmonics are equal zero)



**Figure 1.** Source current and Voltage measured waveforms



**Figure 2.** Measured Source voltage and current harmonic spectrum

**Table 2.** Measured source current Individual Harmonic Distortion

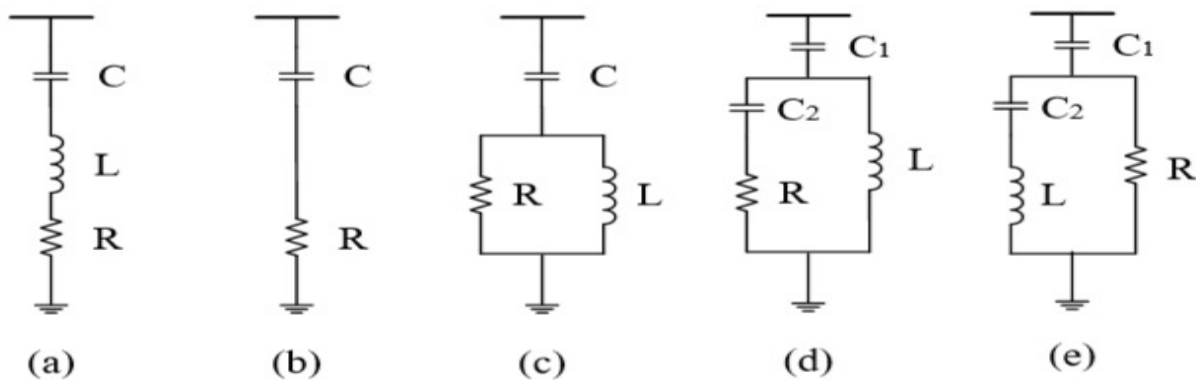
Order	(%)	Order	(%)	Order	(%)
1	100.00	18	0.04	35	1.35
2	0.73	19	2.21	36	0.05
3	2.19	20	0.14	37	1.13
4	0.49	21	0.04	38	0.09
5	21.27	22	0.06	39	0.06
6	0.12	23	2.27	40	0.06
7	4.62	24	0.06	41	1.12
8	0.20	25	1.67	42	0.05
9	0.58	26	0.10	43	0.95
10	0.09	27	0.09	44	0.08
11	6.00	28	0.05	45	0.06
12	0.06	29	1.68	46	0.05
13	3.18	30	0.04	47	0.95
14	0.14	31	1.35	48	0.04
15	0.12	32	0.09	49	0.85
16	0.08	33	0.05	50	0.06
17	3.31	34	0.05	THD	23.69
					0.32 (%)

### 3. Filter design

Harmonic mitigation by passive filter based on bypassing the harmonic current from the harmonic source by creating a low-impedance path at the specified frequency [15]. Meanwhile, the filter impedance should be high at the fundamental frequency [16].

Therefore, a well-designed harmonic filter should have the following characteristics [15], [16]: 1-Low impedance: at the tuned frequency in order to trap the harmonic current. 2- High power factor at the fundamental frequency. Otherwise it may cause over-voltage or under-voltage problems. 3-Low power loss as filter resistor is usually inserted to damp the undesired parallel resonance. However, a large resistor can lead to a high power loss.

The shunt filter is usually installed at the load bus to trap the typical harmonic current produced by the aggregated load. Common shunt filters are classified into the single-tuned filter and the high-pass filter. The single-tuned filter is aimed at filtering a single order of harmonic while high-pass filters are intended to reduce harmonics above certain frequencies. The high-pass filters have several configuration, such as the first order high pass, second order high pass, and third order high pass, shown in Figure 3 [16]. Sometimes the industry utilize the combination of several different topologies of filters to achieve desired harmonic mitigation.



**Figure 3.** Passive shunt filters configuration: (a) single tuned, (b) first order, (c) second order, (d) third order, (e) C-type

The measured current contains multiple orders of harmonics, such as the 5<sup>th</sup>, 7<sup>th</sup> and 11<sup>th</sup>. Therefore, we have two choices of filter installation: one is to use a single high pass filter such as second-order, C-type. The other is to use several parallel-connected single-tuned filters, namely a combined filter. Based on a detailed analysis, Ref. [16] concluded that it is most effective to use a set of combined single-tuned filters which is tuned to the 5<sup>th</sup>, 7<sup>th</sup> and 11<sup>th</sup> harmonic orders, respectively, in order to mitigate these three orders of harmonics. On the other hand, the second order high pass filter for harmonics from 13<sup>th</sup> ~49<sup>th</sup> is employed.

### 3.1. Single tuned filter design:

Using the below equations (2)-(6);

$$C = \frac{Q_c}{2\pi fV^2} \quad (2)$$

$$X = \frac{1}{2\pi fhC} = \sqrt{\frac{L}{C}} \quad (3)$$

$$L = \frac{X}{2hf} \quad (4)$$

$$Q = \frac{2\pi fL}{R} \quad (5)$$

$$R = \frac{1}{2\pi fC} \quad (6)$$

The Measured reactive power;  $Q_c = 23,262$  KVar, for quality factor = 50, the filter elements can be calculated for 5<sup>th</sup> order filter as follow:

$C_5 = 9.3 \mu\text{F}$ ,  $L_5 = 0.44$  mH and  $R_5 = 0.14 \Omega$ .

Similarly, for 7<sup>th</sup> and 11<sup>th</sup> order filters will be:

$C_7 = 50.6 \mu\text{F}$ ,  $L_7 = 4.1$  mH and  $R_7 = 9.1 \Omega$ .

$C_{11} = 11.6 \mu\text{F}$ ,  $L_{11} = 7.2$  mH and  $R_{11} = 0.5 \Omega$

### 3.2. Second order high pass filter:

The below equations will be applied,

$$Z(W) = \left(\frac{1}{R} + \frac{1}{jWL}\right)^{-1} + \frac{1}{jWC_1} \quad (7)$$

$$Q = \frac{R}{\sqrt{\frac{L}{C}}} = \frac{R}{X_{LN}} = \frac{R}{X_{CN}} \quad (8)$$

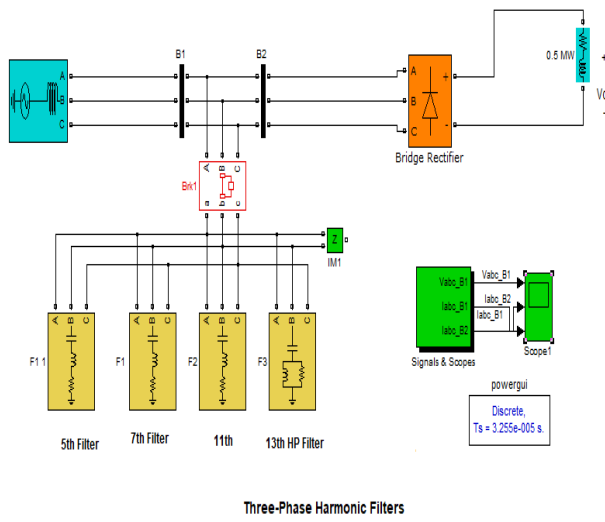
Calculated 13<sup>th</sup> order filter parameter will be as follow:

$C_{13} = 5.2 \mu\text{F}$ ,  $L_{13} = 11.4$  mH and  $R_{13} = 46.6 \Omega$ .

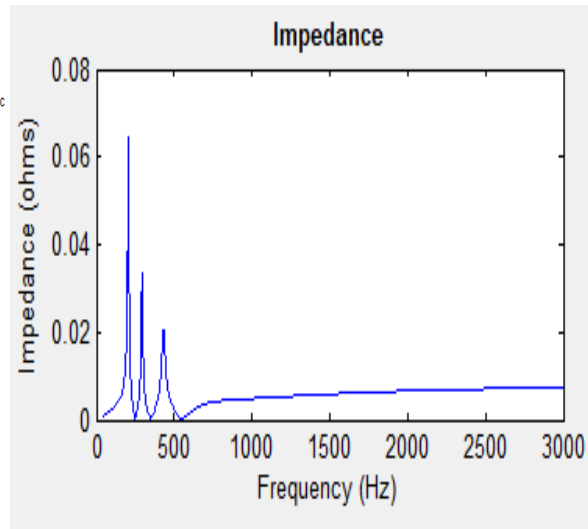
## 4. Simulation results

Simulation is performed using MATLAB 7.7 software. The below figures indicate the simulation results. Figure 4 represents the model used for simulation choosing three phase bridge rectifier to simulate the nonlinear load under study. Figure 5 shows the filter impedance characteristics and the effect of the tuning

frequencies to minimize the filter impedance at 5<sup>th</sup>, 7<sup>th</sup>, 11<sup>th</sup> orders (corner frequencies) using single tuned filters and 13<sup>th</sup> order using second order high pass filter.

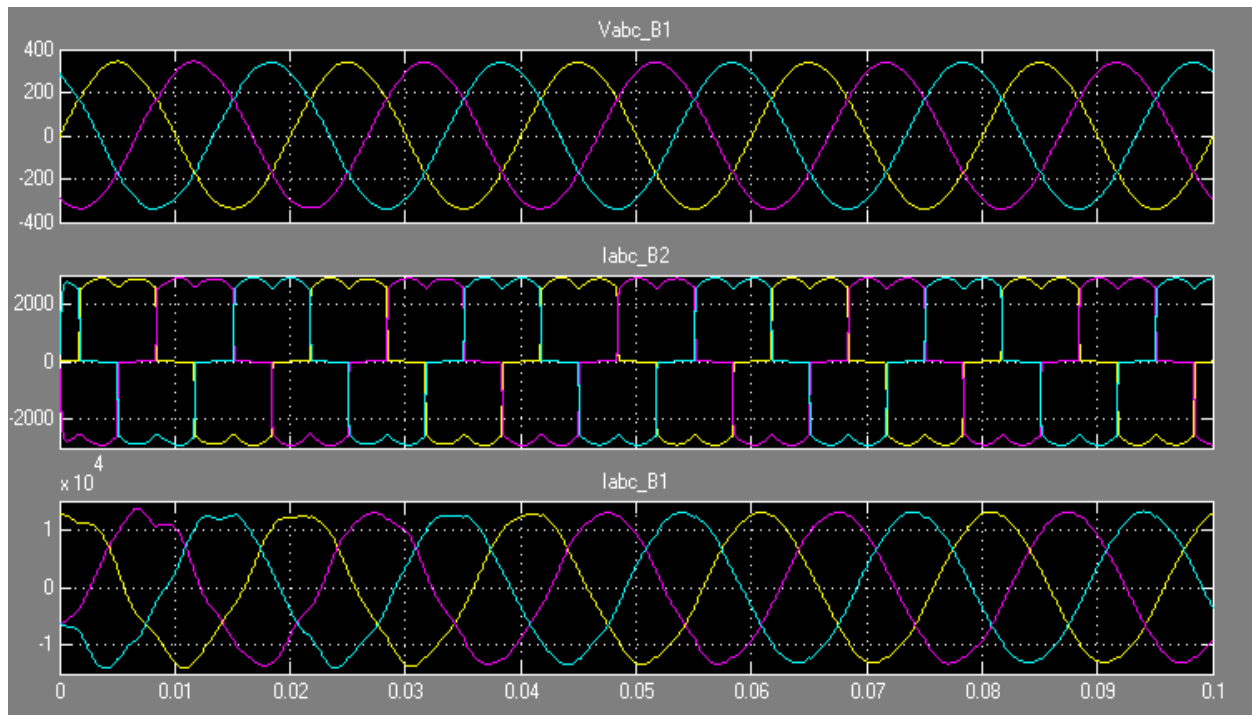


**Figure 4.** MATLAB Model



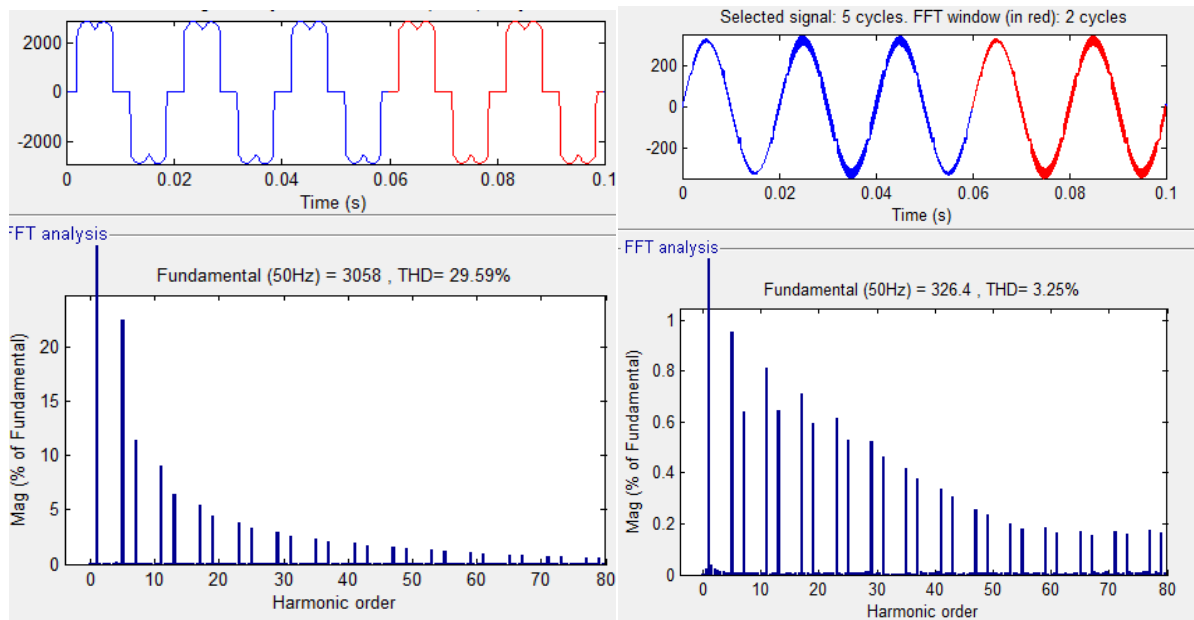
**Figure 5.** Impedance characteristics of passive filter

Figure 6 presents the simulated source current and voltage, where the current at B2 Bus is the drawn current from the nonlinear load without the filter, while the current waveform at Bus B1 is the current drawn from the supply considering the filter deliver the harmonics to the nonlinear loads. This figure shows the nearly sine wave source current waveform reflecting the improvement of the filter done by the filter.



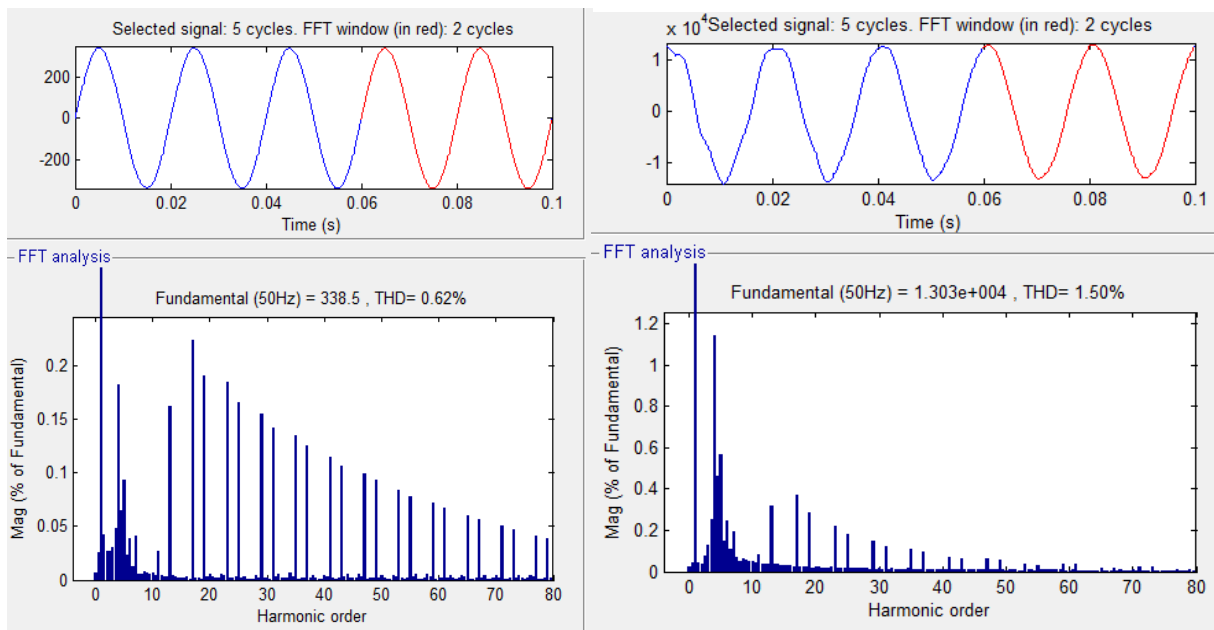
**Figure 6.** Simulated Supply voltage and current waveforms at B1 and B2 (before and after the filter)

Figure 7 shows the simulated fast Fourier transform; FFT for the source current;  $I_s$  and voltage at point of common coupling;  $V_{pcc}$ . The simulated Current total harmonic distortion;  $THD_i$  is 29.6% and the voltage total harmonic distortion  $THD_v$  is 3,25%.



**Figure 7.** Simulated Supply current and voltage harmonic spectrum before filtering

Figure 8 indicates the same simulated source current and voltage after filtering, improving the current total harmonic distortion from 29.6% to 1.5% and accordingly the voltage at point of common coupling improved from 3.25% to 0.62%



**Figure 8.** Simulated Supply current and voltage harmonic spectrum after filtering



## 5. Conclusion

In this paper, Power quality indices are analyzed for an industrial power rectifier as a nonlinear load. Harmonic distortion of source current and voltage are identified for both total and individual harmonic distortion. The measured values exceed the limits of international standard; IEEE 519 for both current and voltage. Passive filter is proposed due to its simplicity, low cost and high reliability. System parameters and measured harmonics are used to design the combination of three single tuned filter and one second order high pass filter to mitigate the 5<sup>th</sup>, 7<sup>th</sup>, 11<sup>th</sup>, and 13<sup>th</sup> frequencies respectively. The proposed filters are simulated to validate the passive filter design which improve the source current and voltage to become within the accepted level to meet the pre-defined international standard.

Employing active filter for this system instead of passive filter will provide another way of harmonic mitigation giving extra advantages that can be studied in the future work.

## Acknowledgement

The author would like to express his most sincere gratitude to those people, listed in the References, who in the past years have greatly contributed to the advancement of the technique applied in this paper. Communication and Electronics department of Obour Institute gives this research many kinds of support.

## References

- [1] Z. Wang, J. Yang, J. Liu and Y. Wang, "Harmonic mitigation and reactive power compensation," China Machine Press, Beijing, 2006.
- [2] H. Hu, Z. He, Y. Zhang and S. Gao, "Modal frequency sensitivity analysis and application using complex nodal matrix," IEEE Trans. Power Del., vol. 29, no. 2, pp. 969-971, Apr. 2014.
- [3] Z. Li, H. Hu, Y. Zhou, and Z. He. "A rapid modal analysis method for harmonic resonance using modified power iteration," IEEE Trans. Power Del., in press.
- [4] W. Pei, Y. Du, H. Xiao, Z. Shen, W. Deng, and Y. Yang, "Optimal operation of micro grid with photovoltaics and gas turbines in demand response," International Conf. on Power Syst. Technology, Chengdu, pp. 3058-3063, 2014.
- [5] J. Chai, J. Zhao, W. Yao, J. Guo, and Y. Liu, "Application of wide area power system measurement for digital authentication," IEEE Power and Energy Soc. T&D Conf. and Expo., 2016.
- [6] Task Force on Harmonics Modeling and Simulation, IEEE PES Harmonic Working Group, "Characteristics and modeling of harmonic sources-power electronic devices," IEEE Trans. Power Del., vol.16, no.4, pp.791,800, Oct. 2001.
- [7] IEEE recommended practices and requirements for harmonic control in electrical power systems, IEEE519, 1992.
- [8] T. Ding and W. Xu, "A filtering scheme to reduce the penetration of harmonics into transmission systems," IEEE Trans. Power Del., vol. 31, no. 1, pp. 59-66, Feb. 2016.
- [9] Wang, J. L. Duarte, M. A. M. Hendrix, and P. F. Ribeiro, "Modeling and analysis of grid harmonic distortion impact of aggregated DG inverters," IEEE Trans. Power Electron., vol. 26, no. 3, pp. 786-797, Mar. 2011.
- [10] R. Peña-Alzola, M. Liserre, F. Blaabjerg, R. Sebastián, J. Dannehl and F. W. Fuchs, "Analysis of the passive damping losses in LCL-filterbased grid converters," IEEE Trans. Power Electro., vol. 28, no. 6, pp. 2642-2646, Jun. 2013.
- [11] H. Hu, Q. Shi, Z. He, J. He, and S. Gao, "Potential harmonic resonance impacts of PV inverter filters on distribution systems," IEEE Trans. Sustain. Energy, vol. 6, no. 1, pp. 151-161, Jan. 2015.
- [12] Q. Shi, H. Hu, W. Xu, and J. Yong, "Low-order harmonic characteristics of photovoltaic inverters," Int. Trans. Elect. Energy Syst., vol. 26, no. 2, pp. 347-364, Feb. 2016.
- [13] H. Hu, Z. He, and S. Gao, "Passive filter design for China high-speed railway with considering harmonic resonance and characteristic harmonics," IEEE Trans. Power Del., vol. 30, no. 1, pp. 505-514, Feb. 2015.

- [14] Z. He, H. Hu, Y. Zhang, and S. Gao, "Harmonic resonance assessment to traction power supply system considering train model in China high speed railway," *IEEE Trans. Power Del.*, vol. 29, no.4, pp. 1735-1743, Aug. 2014.
- [15] J. C. Das, "Passive filters—potentialities and limitations," *IEEE Trans. Ind. Appl.*, vol. 40, no. 1, pp. 232–241, Jan. 2006.
- [16] A. B. Nassif, W. Xu and W. Freitas, "An investigation on the selection of filter topologies for passive filter applications," *IEEE Trans. Power Del.*, vol. 24, no. 3, pp. 1710-1718, Jul. 2009.