Journal of Power and Energy Engineering, 2023, 11, 1-14
https://www.scirp.org/journal/jpee
ISSN Online: 2327-5901
ISSN Print: 2327-588X

Simulation Model for Passive Harmonic Filters Using Matlab/Simulink: A Case Study

Yonis Elmi[1], **Diaa Salman**[2]

[1]Faculty of Engineering and Technology, Benadir University, Mogadishu, Somalia
[2]Department of Electrical and Electronic Engineering, Cyprus International University, Nicosia, Northern Cyprus, Mersin, Türkiye
Email: dean-engineering@bu.edu.so, Diyasalman70@gmail.com

How to cite this paper: Elmi, Y. and Salman, D. (2023) Simulation Model for Passive Harmonic Filters Using Matlab/Simulink: A Case Study. *Journal of Power and Energy Engineering*, **11**, 1-14.
https://doi.org/10.4236/jpee.2023.113001

Received: January 30, 2023
Accepted: March 20, 2023
Published: March 23, 2023

Abstract

Electrical grid power quality is a global issue. The grid must supply electricity at sinusoidal voltages and currents without frequency or amplitude fluctuations. Harmonics from non-linear loads change the stable reference point voltage waveform and cause other problems. Harmonic reduction is essential for grid health. Electrical and electronic equipment users, manufacturers, and suppliers all contribute. This article presents a case analysis of the plastic processing industry, which has historically struggled with a difficulty related to the fifth harmonic. Unwanted harmonics are reduced by using a single-tuned passive filter, a double-tuned passive filter, and a second-order damped filter. The total harmonic distortion is almost identical, but the second-order damped filter provides the best harmonic mitigation, meeting the requirements of the IEE 519-1992 Standard.

Keywords

Harmonic, Filters, Power System Quality, Mitigation

1. Introduction

The existence of harmonics on the electrical grid is among the most significant factors in poor power reliability. Harmonic currents flow inside the power system when non-linear loads are connected [1], distorting the voltage level waveforms at the common coupling point due to source impedance [2]. One significant effect of harmonics is the potential harm they pose to PCC-connected loads. Joule effect losses are exacerbated in conductors by current harmonics [2]. When a transformer is subjected to harmonics, the losses in its copper windings and core are amplified, leading to an increase in temperature that shortens the transformer's useful life. Harmonics can limit useable torque and performance in electric motors. Circuit breakers and other safety mechanisms may trip unexpectedly due to harmonics [3]. Harmonics are also problematic for transmission systems. Certain vibrations can cause distortion or disturbance in communications lines [4]. This varies depending on the frequency, the degree of connection, and the responsiveness of the equipment. Still worse, harmonics can cause blackouts by spreading through interconnected electrical sub-grids and causing a breakdown.

Power networks are experiencing significant levels of undesired harmonic distortion as a consequence of the greater use of non-linear loads and power electronics. It results in more losses, shorter equipment life, and interference with system control, communications, and security [5]. Passive and active filters can be used to enhance power factors and reduce harmonic components. Active filters offer a lot of flexibility, but they also add to the system's cost and complexity [6]. Passive filters are easier to use and less expensive, and they provide both power factor adjustment and larger current filtering capability [7]. In deployments, when the supply voltage is disrupted, they also minimize harmonic voltages.

Passive filtering is the most basic conventional approach for reducing harmonic distortion [8]. The passive filters use passive elements such as resistance, inductance, and capacitance to modulate the harmonics. **Figure 1** depicts popular types of passive filters and their setups.

The single-tuned filter has been the most often used passive filter. When compared to other techniques of minimizing harmonic difficulties, this filter is the simplest and lowest cost [10]. The most frequent and least costly kind of passive filter is the single-series filter. This filter is shunt-connected to the main distribution system and is set to provide low impedance to a certain harmonic frequency. As a result, harmonic currents are redirected from the lowest impedance channel via the filter. It is critical to select the suitable capacitor value for the single-tuned filter design in order to achieve a good power factor at the power

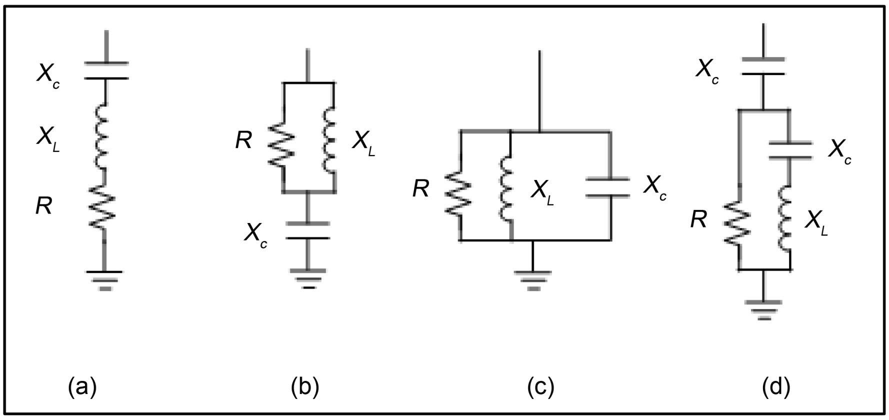

Figure 1. Filter configurations. (a) Series filter; (b) High-Pass filter; (c) Band-Pass filter; (d) C-Type filter [9].

system [9].

The purpose of this research is to discuss the usage of single-tuned passive filters in minimizing harmonics in the plastics manufacturing sector. According to IEEE 519-1992 requirements, the system simulation utilizing Matlab/Simulink simulations resulted in total harmonic distortion (THD) of 15.55 percent, which may be decreased to 4.77 percent harmonics. According to the simulated results, A single-tuned passive filter has the capability of reducing the harmonic currents by 82.23 percent, in addition to a large number of other ordered harmonics ranging from 7% to 8%. This reduction is possible because the current harmonics need to be lowered.

Reducing equipment harmonic emission, enhancing equipment harmonic sensitivity, and employing other harmonic mitigation strategies are all viable ways to address harmonic issues. The choice between constructing nonlinear devices for low levels of waveform distortion and putting harmonic compensation equipment at the terminals, for instance, needs to be decided during the planning phase of installing nonlinear facility components. This is achieved, for instance, by phase-shifting transformers, converter-bridge control, switch-device off-on capabilities, and filtering [11].

On the other hand, Harmonic voltage distortion mitigation techniques and harmonic current distortion mitigation techniques are two subsets of the overall mitigation techniques. Their implementation, through standardization and similar means, is connected to the principle as a whole in order to minimize interference. Harmonic voltage distortion is governed by standard limits. The responsibility for ensuring certain thresholds are not crossed lies with the network operator. The network operator, in turn, might impose restrictions on the amount of harmonic current that can be emitted by structures or large pieces of machinery. Standards establish permissible levels of emissions from portable devices. Moreover, to create a low-impedance channel for a certain harmonic frequency [12], a tuned LC and high-pass filter circuit is connected in series or parallel to create a passive harmonic filter. If a parallel-connected filtration is installed further upstream in the electricity network, it will increase daily costs in the conductors and other plant items that carry the harmonic currents, despite the fact that eliminating harmonics at their source is the most effective method of reducing harmonic losses in the separated power grid, as stated by [13]. The tournament filter, however, exhibits losses.

Harmonics mitigation was carried out in this study in the plastic processing industry. The processing machinery that is utilized consists of components of the electrical system that are categorized as either linear load or non-linear load. On the basis of previous studies, a single-tuned passive filter will be utilized to bring about a reduction in harmonics [14].

2. Procedure

2.1. System Description

In this particular investigation, the removal of harmonics was carried out at a business that processed plastic. The working machine that is used is composed of electrical components that may be categorized as either linear load or non-linear load. A passive filter with a single tuning will be used to cut down on harmonics, as indicated by previous studies.

The assessments of the research object's harmonic properties were carried out with the assistance of portable measurement instruments and a PCC panel. As a piece of measuring apparatus, we made use of a Metrel MI 2392 Power Q Plus Power Quality Analyzer. In order to get accurate readings from the research item, detailed observations on the PCC load were used. The results of the measurements are presented in **Table 1**, which may be accessed here.

In this study, it has been assumed that a load with three phases is balanced, although the analysis has only been performed on a single phase. As a direct consequence of this, the data that was utilized for calculating and analyzing was the result of measurements that were made during phase L1.

2.2. Identifications of Single-Tuned Passive Filter

The R, L, and C filters were calculated in this study, to reduce the amount of current harmonics while still making use of the maximum possible current harmonics, which surpassed the harmonic constraints specified by the IEEE 519-1992 standard. The only harmonics of roughly the fifth order that need to be reduced are those. When evaluating the loads for all three stages, a balanced condition is assumed. As a consequence of this, modeling and analysis of the data are only carried out on a single phase, and phase L1 is the one that is selected.

To calculate the capacitor capacity (Q_c), the power factor is supposed to be enhanced from $pf_1 = 0.94$ to $pf_2 = 0.99$. As a harmonic filter is used, the capacitor capacity required must be calculated [15]:

Table 1. Measurement results on the PCC panel using power quality particles [14].

Symbol	Name	Phase 1	Phase 2	Phase 3	Total
I	Current	365.94	396.54	383.27	−A
V	Voltage	234.45	235.11	238.2	−V
THD V	Voltage THD	2.1836	1.8068	2.2791	−%
THD V	Voltage THD	5.1187	4.2477	5.4279	−V
THD I	Current THD	54.004	53.819	58.332	−A
THD I	Current THD	14.93	13.707	15.399	−%
Q	Reactive Power	29.65	27.498	31.694	88.842 kVAR
P	Active Power	80.508	89.085	85.617	255.21 KW
DPF	Displacement Facto	0.95 ind	0.96 ind	0.95 ind	0.95 ind
PF	Power Factor	0.94 ind	0.96 ind	0.94 ind	0.94 ind
S	Apparent Power	85.794	93.233	91.295	270.23 kVA

$$Q_c = P\left\{\tan\left(\cos^{-1} pf_1\right) - \tan\left(\cos^{-1} pf_2\right)\right\} \quad (1)$$

The capacitor's reactance (X_c) can be calculated as in Equation (2) and the capacitance of the capacitor (C) can be calculated as in Equation (3) [15]:

$$X_C = \frac{V^2}{Q_C} \quad (2)$$

$$C = \frac{1}{2\pi f_0 X_C} \quad (3)$$

Equation (4) is used to calculate the inductor's reactance (X_l), L can be calculated as in Equation (5), moreover the value of X_n can be calculated as Equation (6) [15]:

$$X_L = \frac{X_C}{h_n^2} \quad (4)$$

$$X_L = w_0 L \quad (5)$$

$$X_n = \sqrt{X_C X_L} \quad (6)$$

Considering that the quality factor of a single passive filter (Q) is 100, the resistance (R) in the filter can be calculated as follows [15]:

$$R = \frac{X_n}{Q} \quad (7)$$

Finally, the total harmonic distortion can be calculated as follows [15]:

$$THD_I = \sqrt{\left[\frac{I_{rms}}{I_{1,rms}}\right]^2 - 1} \quad (8)$$

3. Results and Discussions

3.1. Case 1: Non-Filtered Power System Simulation

According to the findings of the measurements, **Figure 2** depicts a succession of simulated object research systems. **Figure 2** shows a simulation of a circuit without a filter. Individual harmonics are displayed in **Table 2** and **Figure 3** of the circuit modelling results.

Table 2 illustrates the simulation results without the use of a harmonic filter; the respondents indicated current harmonic is 15.57 percent, which is 0.62 percent less than the true measurement of 14.95 percent. The simulation circuit of the state of the harmonics in the plastics business, which represents the subject of the research, is illustrated in **Figure 2**. Only the first five harmonic orders of the present IHD are shown to be much higher than the IEEE 519-1992 defined range of 14.97 percent, with the permissible limit being set at 7 percent. This is shown in **Table 2**.

3.2. Case 2: Single-Tuned Filter Case

Figure 4 is a representation of the circuit schematic that was created using

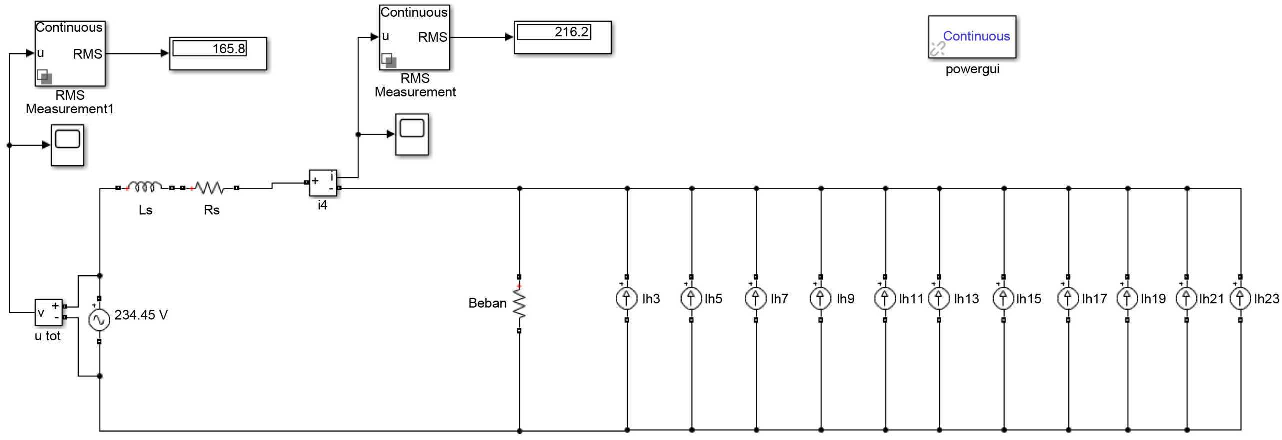

Figure 2. Simulation in Matlab/Simulink without the use of a Filter.

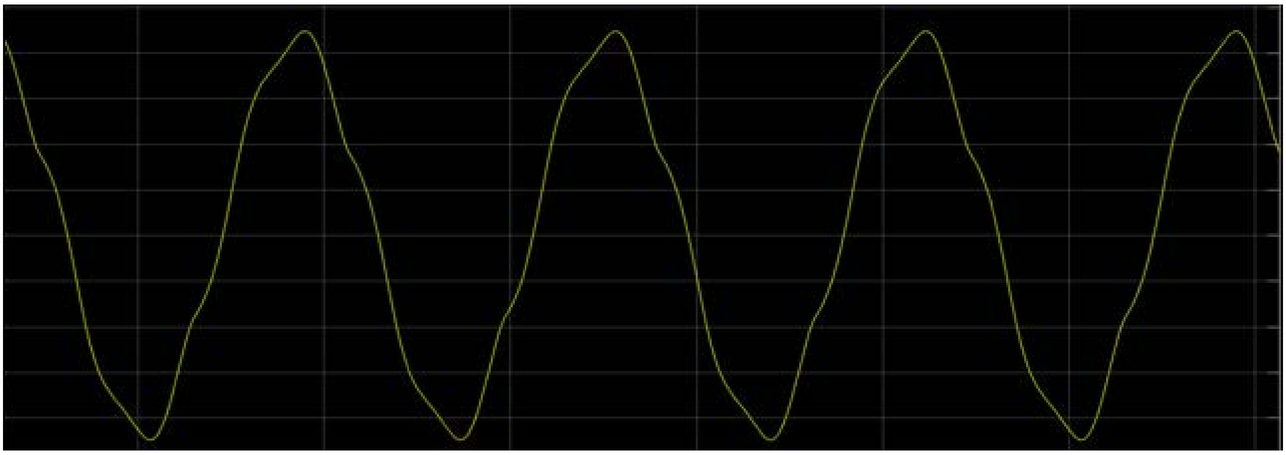

Figure 3. Test results for non-filtered modeling graph of waveforms.

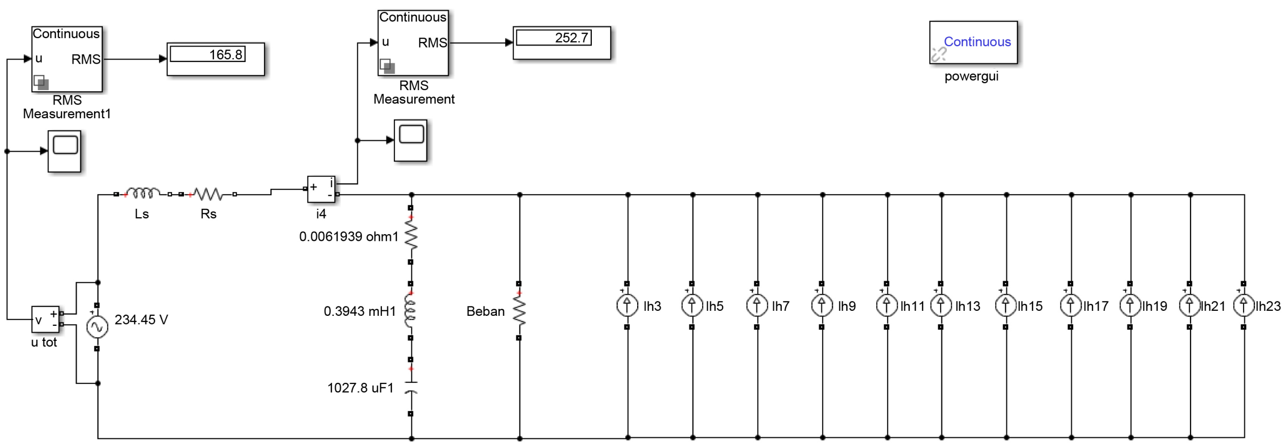

Figure 4. Single-tuned passive filter simulation model.

Matlab Simulation using a Single-tuned Passive Filter. The components *R*, *L*, and *C* are shown. In a manner analogous to that of the non-filtered simulation, a Single-tuned Passive filter simulation is carried out in a number of steps, and it is then completed by adding an RLC filter in parallel with the load. The RLC

Table 2. Simulation results in the absence of harmonic filters (IHDi %).

IHD Order	Measurement	Non-Filtered Simulation	IEEE 519-1992 Standard
1	100.00	100	
3	2.20	2.35	7.0
5	14.22	14.99	7.0
7	2.35	2.48	7.0
9	0.84	0.91	7.0
11	1.21	1.25	3.5
13	1.03	1.03	3.5
15	0.49	0.52	3.5
17	0.84	0.85	2.5
19	1.02	1.03	2.5
21	0.24	0.28	2.5
23	0.81	0.82	1.0
THD	**14.95**	**15.57**	

value was calculated, and the findings revealed that it was equal to R = 0.0061939, C = 1027.8 F, and L = 0.3943 mH. This value was utilized for the function of the block parameter in the RLC filter.

The amplitude of a certain harmonic flow is shown in **Table 3**, which was produced as a consequence of current harmonic reduction achieved by simulation with a single-tuned passive filter. The results of modeling the removal of current harmonics using a single-tuned passive filter are presented in **Table 3**. This filter has the potential to reduce the overall percentage of current harmonics from 15.57 percent to 4.7793 percent. The results of the simulation show that the IEEE 519-1992 criteria for the whole IHD Order of harmonics have been satisfied when assessed from individual harmonic currents.

The waveform of the current that was generated by Matlab/Simulink with a single-tuned passive filter is displayed in **Figure 5**. The sinusoidal shape of the resultant waveform signal indicates that the distortion has been isolated from the present harmonic distortion.

3.3. Case 3: Double-Tuned Filter Case

The schematic representation of a Double Tuned Filter used in Matlab Simulation is shown in **Figure 6**. This filter consists of series components of R, L, and C, all of which are connected in series with parallel R, L, and C. The simulation of the Double Tuned Filter is carried out in a number of phases, much as the simulation of the non-filtered case, and then a double-tuned filter is added in parallel with the load. The RLC value has been determined and acquired by computation.

Table 3. Simulation results for a single-tuned passive filter (IHDi %).

IHD Order	Single-Tuned Passive Filter Simulation [14]	Single-Tuned Passive Filter Simulation "Our Results"	IEE 519-1992 Standard	Description
1	100.00	100		
3	2.31	2.3104	7.0	Match
5	2.66	2.6693	7.0	Match
7	2.20	2.2013	7.0	Match
9	0.80	0.7998	7.0	Match
11	1.17	1.175	3.5	Match
13	1.00	1.009	3.5	Match
15	0.47	0.46	3.5	Match
17	0.81	0.8099	2.5	Match
19	0.99	0.987	2.5	Match
21	0.23	0.23	2.5	Match
23	0.78	0.775	1.0	Match
THD	**4.77**	**4.7793**		

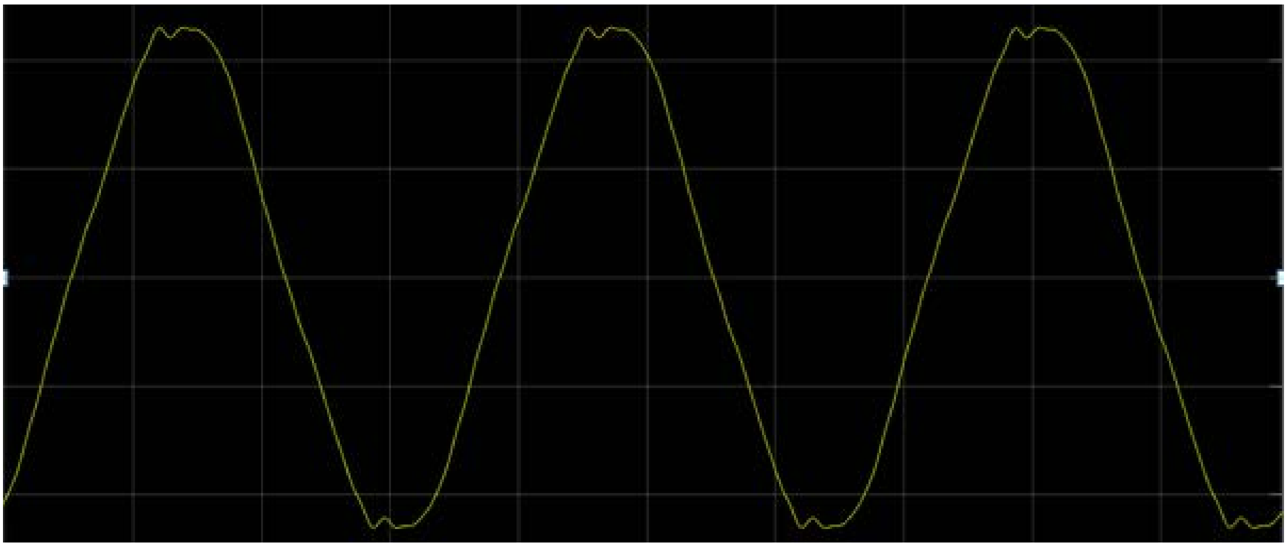

Figure 5. Simulation results for a single-tuned passive filter graph of waveforms.

Table 4 is an illustration of the size of individual harmonic flow that occurs as a consequence of current harmonic reduction achieved by simulation utilizing a double-tuned filter. The results of modeling current harmonic reduction using a double-tuned filter are presented in Table 4. This filter may reduce total current harmonics from 15.57 percent to 4.82096 percent, therefore achieving the goal of current harmonic minimization. When looked at from the perspective of single harmonic currents, the results of the simulation show that the IEEE 519-1992 criteria has been satisfied by the whole IHD Order of harmonics.

Figure 7 is a representation of the current waveform that was generated by

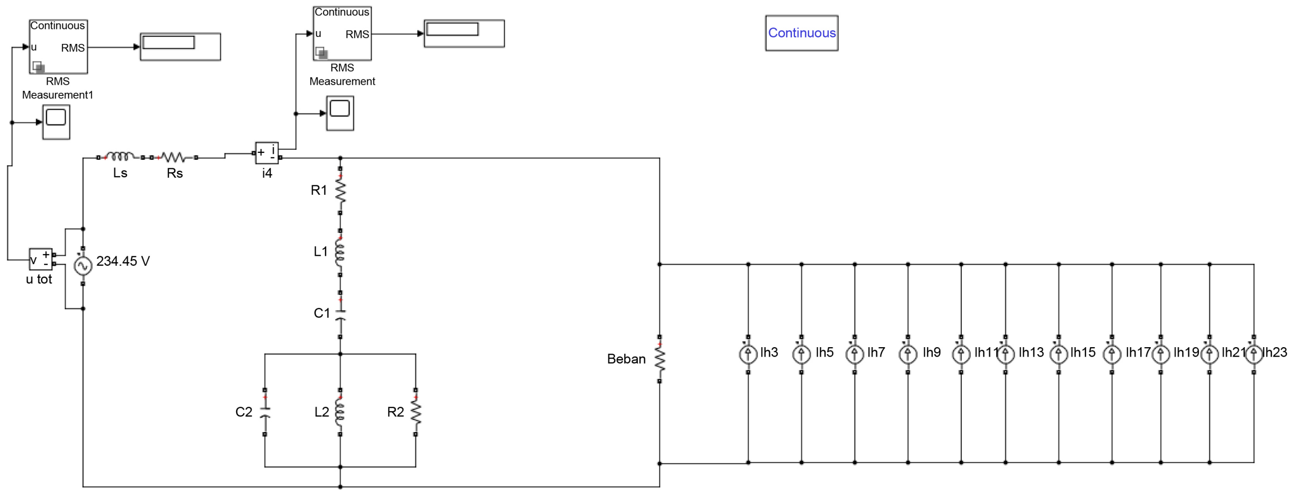

Figure 6. Matlab/Simulink simulation for double tuned filter.

Table 4. Double tuned filter simulation results (IHDi %).

IHD Order	Double Tuned Filter	IEE Standard	statues
1	100		
3	2.3114	7.0	Satisfied
5	2.6594	7.0	Satisfied
7	2.25	7.0	Satisfied
9	0.797	7.0	Satisfied
11	1.275	3.5	Satisfied
13	1.00	3.5	Satisfied
15	0.47	3.5	Satisfied
17	0.81	2.5	Satisfied
19	0.98	2.5	Satisfied
21	0.24	2.5	Satisfied
23	0.78	1.0	Satisfied
Total THD	**4.82096**		

Matlab/Simulink while using a double-tuned filter. This waveform demonstrates that the resultant signal has a sinusoidal shape, which is an indication that the system has been isolated from current harmonic interference.

3.4. Case 4: Second Order Damped Filter Case

Figure 8 depicts the Matlab Simulation circuit drawing employing a second-order damped filter with series components of *C* and parallel *R*, *L*. Second Order Damped Filter simulation is performed in numerous stages, similar to non-filtered simulation, and then augmented with second-order damped filter in tandem with the load. The RLC value was computed as follows:

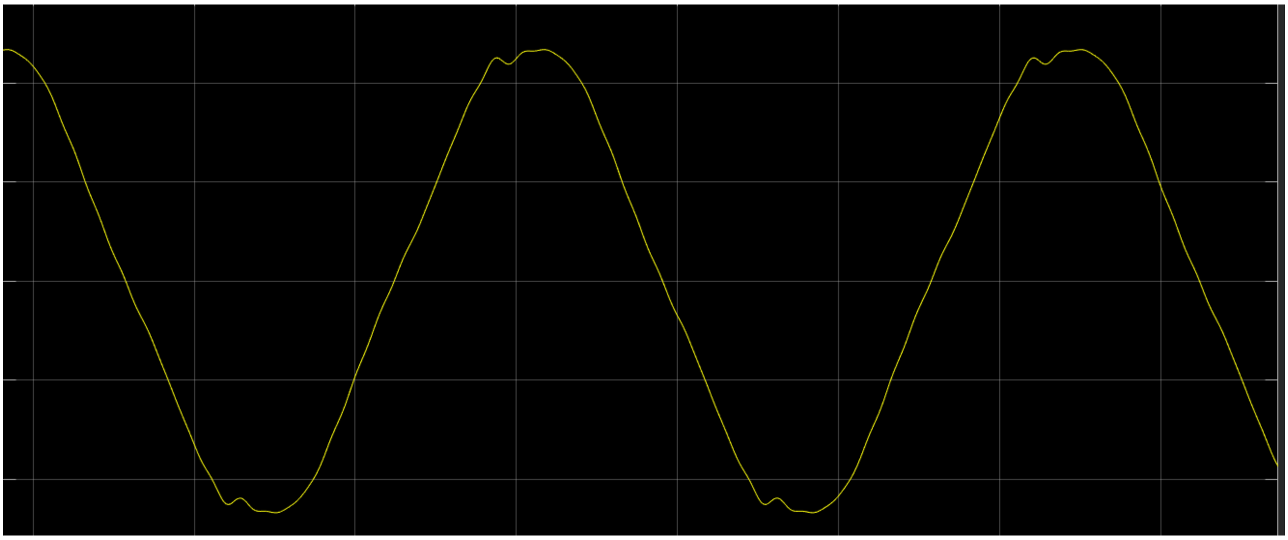

Figure 7. Test results for a double tuned filter graph of waveforms.

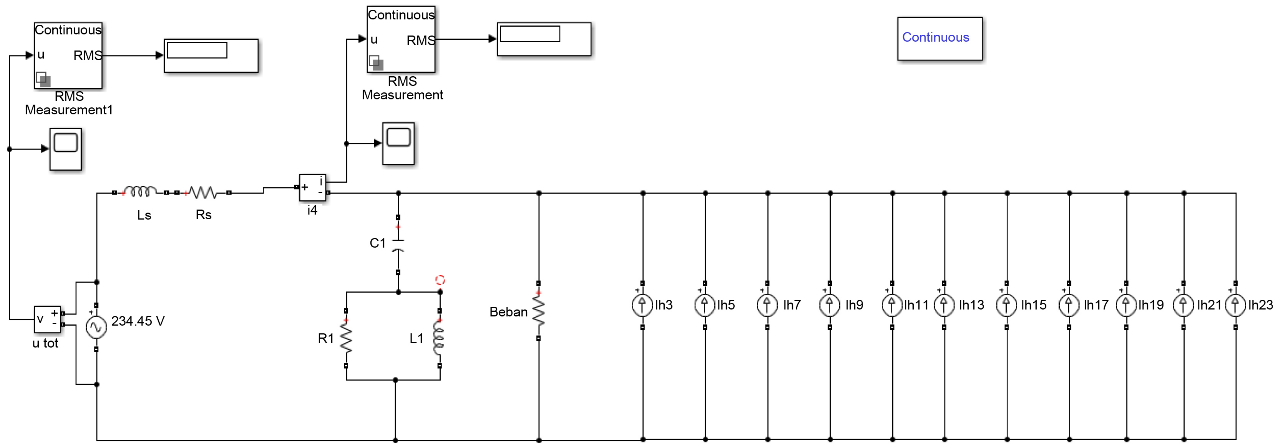

Figure 8. Second order damped filter simulation model.

The following values that are taken from the single-tuned filter are the same as what we need for the second-order damped filter:

$$X_C = 3.0969423\ \Omega$$

$$C = 1027.8\ \mu\text{F}$$

$$X_L = 0.12385692\ \Omega$$

$$L = 0.3943\ \text{mH}$$

$$X_n = 0.6193365278$$

If we assume that the quality factor of a single-tuned passive filter, denoted by *Q*, is equal to five, then we may compute the value of resistance, denoted by *R*, in the filter as follows [15]:

$$R = X_n Q \tag{9}$$

Then, $R = 0.6193365278 \times 5 = 3.096682639\ \Omega$.

Table 5 displays the intensity of single harmonic flow as a result of current harmonic reduction by simulation using a second-order damped filter. Table 5 shows the results of modelling current harmonic elimination with a second-order damped filter, which may minimize overall current harmonics from 15.57 percent to 4.677307 percent. The simulation findings reveal that the complete IHD Order of harmonics has met the IEEE 519-1992 requirement when viewed from single harmonic currents.

Figure 9 is a depiction of the current waveform that was created using Matlab/second Simulink's order damped. This waveform reveals that the resultant signal has a sinusoidal shape, which indicates that the system has been isolated from harmonic current interference.

Table 5. Second order damped filter simulation results (IHDi %).

IHD Order	Second Order Damped Filter	IEE Standard	Statues
1	100		
3	2.3	7.0	Satisfied
5	2.52	7.0	Satisfied
7	2.2	7.0	Satisfied
9	0.73	7.0	Satisfied
11	1.270	3.5	Satisfied
13	1.00	3.5	Satisfied
15	0.48	3.5	Satisfied
17	0.80	2.5	Satisfied
19	0.97	2.5	Satisfied
21	0.25	2.5	Satisfied
23	0.7	1.0	Satisfied
Total THD	**4.677307**		

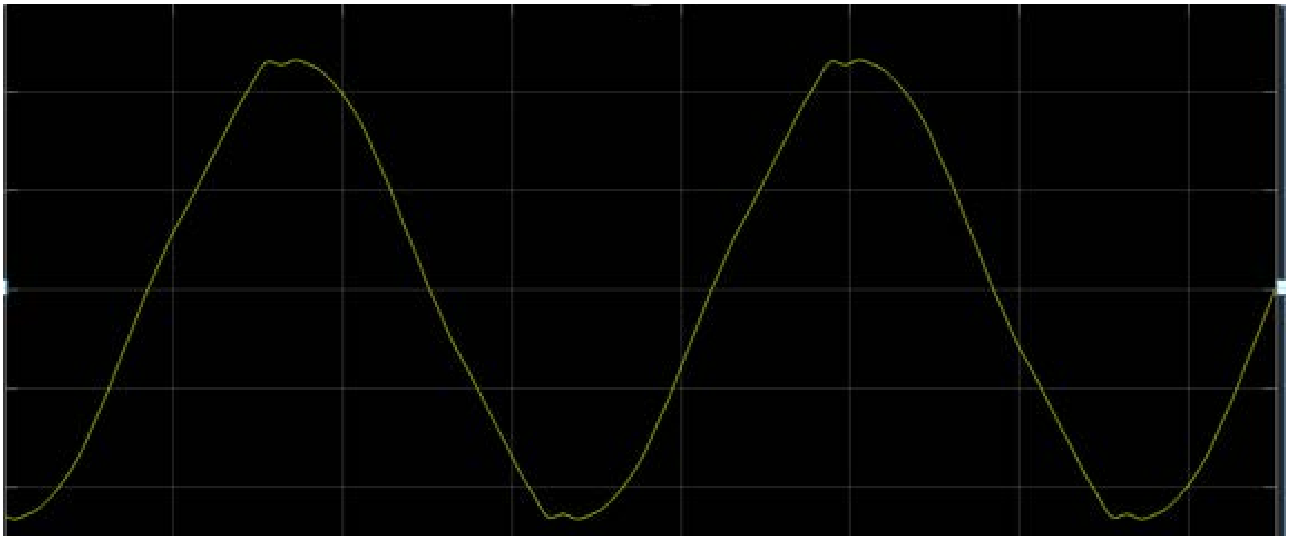

Figure 9. Waveform graph of the second order damped filter simulation test results.

Table 6. Comparison between the four cases.

IHD Order	Non-Filtered Simulation	Single-Tuned Passive Filter	Double Tuned Filter	Second Order Damped Filter	IEE 519-1992 Standard	Description
1	100	100	100	100		
3	2.35	2.3104	2.3114	2.3	7.0	Match
5	14.99	2.6693	2.6594	2.52	7.0	Match
7	2.48	2.2013	2.25	2.2	7.0	Match
9	0.91	0.7998	0.797	0.73	7.0	Match
11	1.25	1.175	1.275	1.270	3.5	Match
13	1.03	1.009	1.00	1.00	3.5	Match
15	0.52	0.46	0.47	0.48	3.5	Match
17	0.85	0.8099	0.81	0.80	2.5	Match
19	1.03	0.987	0.98	0.97	2.5	Match
21	0.28	0.23	0.24	0.25	2.5	Match
23	0.82	0.775	0.78	0.7	1.0	Match
THD	**15.57**	**4.7793**	**4.82096**	**4.677307**		

3.5. Comparison between the Four Cases

Table 6 shows the final comparison between the three filters single-tuned passive filter, double-tuned filter and the second-order damped filter and non-filtered case. Since the filters were designed to overcome the fifth harmonic effect which does not match the IEE standards. The results for all filters satisfy the requirements and give almost similar results of harmonic mitigation; however, the second-order damped filter outperforms the other filters.

4. Conclusion

Harmonics are periodic waves with frequencies that are integral multiples of the basic power line frequency component. They are consequences of contemporary electronic components. Hence it is vital to mitigate harmonics and provide harmonic reduction measures. This research provides a case study of the plastic processing industry which used to face a problem in terms of the fifth harmonic. Three filters were used to mitigate the undesirable harmonics: single-tuned passive filter, double-tuned filter and second-order damped filter. The results give almost similar THDi, however, the second-order damped filter provides the optimum harmonic mitigation, which satisfies IEE 519-1992 Standard.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Lumbreras, D., Gálvez, E., Collado, A. and Zaragoza, J. (2020) Trends in Power Quality, Harmonic Mitigation and Standards for Light and Heavy Industries: A Review. *Energies*, **13**, Article 5792. https://doi.org/10.3390/en13215792

[2] Salmerón, P. and Litrán, S.P. (2010) Improvement of the Electric Power Quality Using Series Active and Shunt Passive Filters. *IEEE Transactions on Power Delivery*, **25**, 1058-1067. https://doi.org/10.1109/TPWRD.2009.2034902

[3] Boynuegri, A.R., Uzunoglu, M., Erdinc, O. and Gokalp, E. (2014) A New Perspective in Grid Connection of Electric Vehicles: Different Operating Modes for Elimination of Energy Quality Problems. *Applied Energy*, **132**, 435-451. https://doi.org/10.1016/j.apenergy.2014.07.050

[4] Mahela, O.P. and Shaik, A.G. (2016) Electrical Power and Energy Systems Power Quality Improvement in Distribution Network Using DSTATCOM with Battery Energy Storage System. *International Journal of Electrical Power & Energy Systems*, **83**, 229-240. https://doi.org/10.1016/j.ijepes.2016.04.011

[5] Chitsazan, M.A. and Trzynadlowski, A.M. (2016) Harmonic Mitigation in Interphase Power Controller Using Passive Filter-Based Phase Shifting Transformer. 2016 *IEEE Energy Conversion Congress and Exposition* (*ECCE*), Milwaukee, WI, 18-22 September 2016, 1-5. https://doi.org/10.1109/ECCE.2016.7855139

[6] Beres, R.N., Wang, X., Blaabjerg, F., Liserre, M. and Bak, C.L. (2016) Optimal Design of High-Order Passive-Damped Filters for Grid-Connected Applications. *IEEE Transactions on Power Electronics*, **31**, 2083-2098. https://doi.org/10.1109/TPEL.2015.2441299

[7] Huang, M., Wang, X., Loh, P.C. and Blaabjerg, F. (2016) LLCL-Filtered Grid Converter with Improved Stability and Robustness. *IEEE Transactions on Power Electronics*, **31**, 3958-3967. https://doi.org/10.1109/TPEL.2015.2467185

[8] Das, J.C. (2004) Passive Filters—Potentialities and Limitations. *IEEE Transactions on Industry Applications*, **40**, 232-241. https://doi.org/10.1109/TIA.2003.821666

[9] Memon, Z.A., Uquaili, M.A. and Unar, M.A. (2016) Harmonics Mitigation of Industrial Power System Using Passive Filters. *Mehran University Research Journal of Engineering and Technology*, **31**, 355-360.

[10] Buła, D. and Pasko, M. (2011) Dynamical Properties of Hybrid Power Filter with Single Tuned Passive Filter. *Przegląd Elektrotechniczny*, **87**, 91-95. https://doi.org/10.1109/ISNCC.2010.5524521

[11] Schwanz, D., Bollen, M. and Larsson, A. (2016) A Review of Solutions for Harmonic Mitigation. 2016 17*th International Conference on Harmonics and Quality of Power* (*ICHQP*), Belo Horizonte, 16-19 October 2016, 30-35. https://doi.org/10.1109/ICHQP.2016.7783422

[12] Kazem, H.A. (2013) Harmonic Mitigation Techniques Applied to Power Distribution Networks. *Advances in Power Electronics*, **2013**, Article ID: 591680. https://doi.org/10.1155/2013/591680

[13] Sîrbu, A., Alexa, D. and Goraş, T.C. (2015) Rectifiers with Near Sinusoidal Input Currents—MATLAB/Simulink Model Case Studies. 2015 *International Symposium on Signals*, *Circuits and Systems* (*ISSCS*), Iasi, 9-10 July 2015, 1-4. https://doi.org/10.1109/ISSCS.2015.7203981

[14] Fahmi, M.I., Baafai, U., Hazmi, A. and Nasution, T.H. (2018) Harmonic Reduction by Using Single-Tuned Passive Filter in Plastic Processing Industry. *IOP Conference Series*: *Materials Science and Engineering*, **308**, Article ID: 012035.

https://doi.org/10.1088/1757-899X/308/1/012035

[15] Badrzadeh, B., Smith, K.S., Member, S. and Wilson, R.C. (2011) Designing Passive Harmonic Filters for an Aluminum Smelting Plant. *IEEE Transactions on Industry Applications*, **47**, 973-983. https://doi.org/10.1109/TIA.2010.2103544