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Fixing a Shunt Passive Power Filter as a Harmonic Reduction Technique to Improve the System's Power Quality

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Abstract:

Harmonics are primarily generated by nonlinear loads, such as electrical machines, personal computers, rectification, adjustable speed drive controllers, mechanical lighting ballasts, and all kinds of power electronics devices. This study focuses on mitigating a particular harmonic, known as the third harmonic or tripled harmonic, which is frequently present in power systems and can lead to several problems, including higher losses, component overheating, and shortened equipment lifespans. The suggested mitigation method efficiently removes the unwanted frequency at the power system's point of common connection by using a passive power filter, more precisely an L-C filter. The overall goal of the study is to shed light on how well an L-C filter, a passive power filter, works in power systems to mitigate the third harmonic, enhancing power quality and lessening the damage that harmonic distortion does to electrical equipment. The initial study is carried out in the MATLAB/Simulink environment to eliminate the 3rd harmonics by designing the filter. The L-C filter is designed and implemented to eliminate the harmonics.

Keywords: Non-linear loads, Passive Harmonic Filter, Total Harmonic Distortion (THD).

1. Introduction:

When various kinds of non-linear loads are coupled to the power source, the system voltage waveform becomes distorted[1]. Examples include lighting ballasts, computers, switching mode power supplies (SMPS), uninterruptible power supplies (UPS), spinning electrical machines, adjustable speed drives, and all varieties of semiconductor (PE) devices, including rectifiers, inverters, and converters[2].Electrical system issues including equipment overheating, power outages, and electromagnetic interference can be brought on by harmonics[3]. Electrical frequencies called harmonics are multiples of the power supply's fundamental frequency[4]. Different kinds of harmonic ordering exist in electrical power networks[5].

One tool for lowering the amount of harmonic distortion in an AC power supply is an AC power filter[6]Harmonic filters, including passive filters like LC filters and active filters, are designed to reduce harmonic distortion in AC power systems caused by nonlinear loads[7]. They work by providing a low impedance path to specific harmonic frequencies, thereby diverting these harmonics away from the rest of the electrical system and mitigating their effects on equipment and power quality. Fig. 1 represents the signature of the waveform including order of harmonics during the running operation of non-linear load[7][8][9][10].

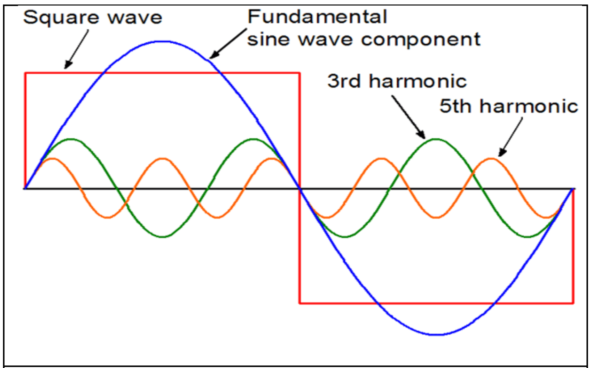


Fig. 1 Distorted waveform caucus is Harmonics

The harmonics can be Calculated as follows.

Fn=(n) * Fundamental frequency. Where, n= Integer value

3^{rd} order harmonic (F3)= 3* 50= 150 Hz, 5^{th} order harmonic (F5) = 5* 50=250 Hz and 7^{th} order harmonic (F7)= 7*50=350 Hz etc.

2. Methodology to mitigation Harmonic:

To filter harmonics, a variety of AC power filters can be utilized, including passive, active, and hybrid filters[8][11].

1. Passive filters: These are made composed of passive components such as capacitors and inductors, are commonly employed to remove low-order harmonics.
2. Active filters: It make use of electronic components like transistors to actively cancel out higher-order harmonics.
3. Hybrid filters:It filter out a broad range of harmonics by combining passive and active components.

This study is based on a specifically designing and implementationof passive power filter, while the single-phase converter-fed load is triggered at various angles.

2.1 Mathematical calculation to design of Passive Harmonic Filter:

Figure 2 depicts the basic structure of the passive filter. It comprises of a single-phase power supply, a passive filter, and a nonlinear load.In passive filters, diverse topologies or configurations utilizing different combinations of passive elements, such as resistors, capacitors, and inductors, have been used[12]. It can be connected in series or disconnected from the electrical system's nonlinear load[12].

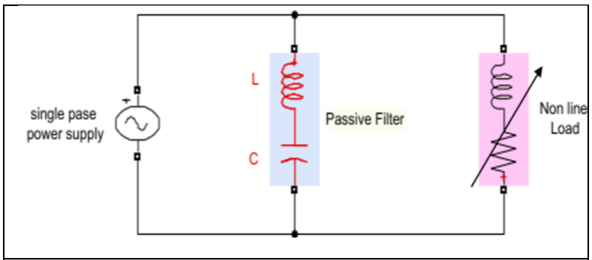


Fig.2 Schematic arrangement of Passive Filter

The following parameters are taken for the simulation**:**

Supply Voltage: - 230 V, the load current is 3.0 A, Real power consumption is 371 W and the reactive power is +467 Var.

When an R-L load is connected to a 230-volt system, it can Consume up to 467 Var of reactive power. To minimise that much inductive var, apply that much negative capacitive var against it. The value of the capacitor based on the quantity of capacitive var is calculated as follows.

Inductive VAR= 467 var

VAR= $\frac{V^2}{(Xc)}$ X_c= $\frac{V^2}{(VAR)}$

$=\frac{(230)^2}{(467)}$ =113.27 **Ω** $\boldsymbol{X_c = 113.27\,\Omega}$

X_c= $\frac{1}{2\pi fc}$ C=$\frac{1}{2\pi f Xc}$

C=$\frac{1}{2*3.14*50*113.27}$ **C = 28.11 µF**

To reduce the inductive variable, use a capacitor value of 28.11 µF for capacitive variable. However, according to the standard value of a capacitor, that value is not attainable; so, the capacitor must be close to its normal value. With 36 µF available in our lab, we created a 30.57 µF capacitor using a series parallel combination. The capacitor value of 30.57 µF is close to the required value for capacitive variables.

- **Parameters Value Calculation:**

Now find the value of L according to 3rd order harmonic and the value of capacitor. We have a value of capacitorC=30.57 µF and fed to supply voltage V=230v. Getting the value of Capacitive var.

Calculation For Inductor (L)	**Calculation For Capacitive VAR**
Fr=150 Hz C=30.57µF L=? Fr= $\frac{1}{2\pi\sqrt{LC}}$ ∴ 150= $\frac{1}{2\pi\sqrt{L*30.57\times10^{-6}}}$ ∴ $\sqrt{L*30.57\times10^{-6}}$= $\frac{1}{2*\pi*150}$ ∴ $\sqrt{L*30.57\times10^{-6}}$= $\frac{1}{(942)^2}$ L= $\frac{10^6}{887364*30.57}$ L= 0.03686 **L= 36.86mH**	**C=30.57 µFV=230v** Xc= $\frac{1}{2\pi f c}$ = $\frac{1}{2*3.14*50*30.57\times10^{-6}}$ **Xc=104.17 Ω** Var= $\frac{V^2}{(Xc)}$ = $\frac{(230)^2}{(104.17)}$ **VAR=507.78 var (capacitive var)**

Based on our calculations, we have determined that the inductor value is L=36.86 mH and the capacitive reactive power is Var=507.78, effectively offsetting the impact of the +467 inductive reactive power.

2.2 Simulated circuit and results in MATLAB/Simulink Environment:

In this study, a single-phase inverter used as a nonlinear load (RL load) with and without a passive filter is modelled using MATLAB/Simulation as shown in Fig. 3.

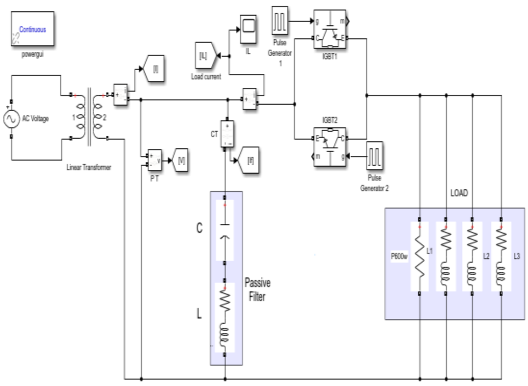
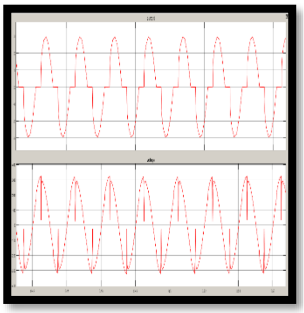


Fig. 3 simulation model of Passive Filter with Nonlinear loads

Fig. 4 represents the simulated results of total harmonics distortion in voltage.



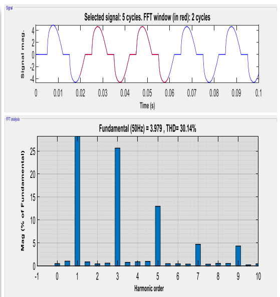
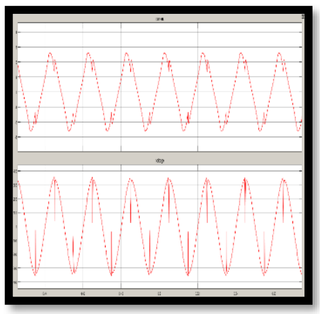


Fig. 4 waveform without a filter at the point of common coupling

Fig. 5 FFT analysis without filter



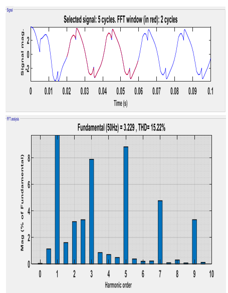


Fig. 6 FFT analysis with filter

Fig. 7 FFT analysis with filter

Figure (5) shows the distorted output waveform that happens when our system is connected without a passive harmonics filter. Following that, we perform an FFT analysis on them, and at the point of common coupling (PCC), we obtain 30.14% (ITHD).

A nearby sin wave may be obtained by connecting the passive filter to our nonlinear load in order to improve power quality. The resulting waveform, which is a purely near-by sine wave with 15.22% (ITHD) on the point of common coupling (PCC), should next be subjected to an FFT analysis.

In this simulation, the total harmonic distortion (THD), which is made up of voltage THD and current THD, was studied with and without a passive power filter in our system. Table 2 shows the circuit parameters utilized throughout the simulation.

2.3 L-C Filter Hardware based Experimental Setup and Results

Harmonics in electrical systems can cause distortions in voltage and current waveforms. To reduce these impacts, researchers conducted studies on different harmonic mitigation strategies, including as filters, active power filters, and static VAR compensators[5], [12], [13]. The shunt passive power filter approach is utilized to mitigate harmonic production and measurement in this experimental setting as shown in Fig. 8.Here, a construction site for an experimental harmonic generation, measurement, and mitigation system is being established. Our approach to harmonic abatement involves the development of a passive power filter. Choose the appropriate mix of capacitor and inductor in the passive power filter.

Fig. 8 Experimental Hardware setup

Three parameters—harmonics creation, measurement, and mitigation—are the main emphasis of this experiment. By changing the phase angle, we can control the PCC voltage in harmonic generation. In our case, a variable resistor was used to trigger the voltage at a 90-degree phase angle. An antiparallel thyristor circuit and a gate triggering circuit are used to achieve that kind of firing angle. This waveform's power quality is now measured with a Digital Oscilloscope meter (DSO). With Total Harmonic Distortion, an FFT analysis of the output waveform produces a certain number of harmonic orders, which is presented in Fig.9. Following that, a shunt passive filter—composed of an inductor and a capacitor—lowers the harmonic order of the system.Inductive and resistive loads are combined to form the system load. Because the inductor is linked in parallel, the inductive load is 223mH whereas the resistive load is 600W. A voltage waveform at the PCC prior to the addition of a passive filter is shown in Fig.10.

By converting pure sinusoidal voltage at the PPC side into such kind of warped wave pattern. We now have the FFT analysis of number and harmonic order.

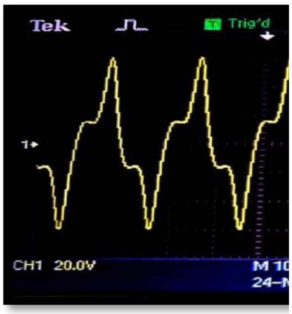


Fig. 9 Output waveform at PCC side without filter

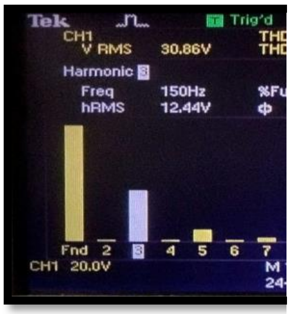


Fig. 10 FFT analysis of output wave form at PPC without filter

FFT analysis yielded 45.6% Total voltage THD. Only third-order harmonics account for 44.2% of total THD. The L-C combined passive filter is installed to enhanced the power quality due to harmonics suppression, which is presented in Fig.11. In this system, set a specified objective for 3rd order harmonics and construct a passive filter to mitigate them. The L and C values of the passive filter are only important for the third harmonic. Fig.12 depicts the output waveform of the PCC side after installing a passive filter into our system.

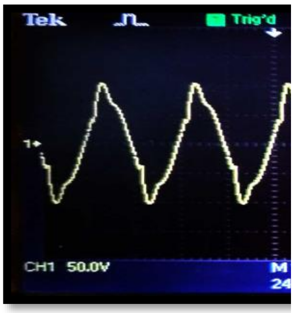


Fig. 11 Output waveform at PCC side with filter

Fig. 12 FFT analysis of output waveform at PPC side with filter

As demonstrated in the waveform after putting the filter on the PCC side, it is near pure sinusoidal waveform. If the system's FFT analysis is obtained after filtering, 30 to 35% of the overall THD is reduced. Figure 12 shows that after filtering, voltage THD is just 15.7%, down from 45.6% of total THD previously. The THD for the third order is just 11.6%, down from 44.2% previously. So, in this example, target only the third order harmonic and achieve 30% harmonic mitigation while enhancing system power quality.The following Fig. 13 shows thecomparativeresults of Ithd (%) with and without passive filter. The total distortion is reduced from 45.6% to 15.75 and the 3rd harmonics component is reduced from 44.2 % to 11.6%.

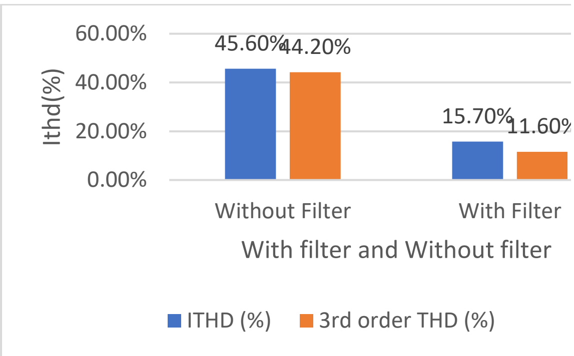


Fig.13 Comparative results for Ithd(%) with filter and Without filter.

3. Conclusion:

The work discussed focuses on the development and use of passive filter tuning with the goal of reducing a system's third order harmonics. One of the most efficient ways to lower harmonic distortion in the system is to use a shunt passive filter. This filter has a built-in gate triggering circuit that provides power to an R-L load with a 90-degree firing angle. Reducing Total Harmonic Distortion (THD) in the system is the main goal of using this shunt passive filter. The filter has been shown to be able to achieve a large decrease in total harmonic content (THD), with a reduction of up to 30%. Furthermore, improving the power system's voltage profile helps to raise power quality overall. Overall, the effectiveness of this passive filter tuning technique in resolving harmonic problems and improving power system performance is demonstrated by its successful deployment.

References:

1. [1] S. Rustemli, M. A. Satici, G. Şahin, and W. van Sark, “Investigation of harmonics analysis power system due to non-linear loads on the electrical energy quality results,” *Energy Reports*, vol. 10, no. September, pp. 4704–4732, 2023, doi: 10.1016/j.egyr.2023.11.034.
2. [2] M. Kumar, M. A. Uqaili, Z. A. Memon, and B. Das, “Experimental Harmonics Analysis of UPS (Uninterrupted Power Supply) System and Mitigation Using Single-Phase Half-Bridge HAPF (Hybrid Active Power Filter) Based on Novel Fuzzy Logic Current Controller (FLCC) for Reference Current Extraction (RCE),” *Adv. Fuzzy Syst.*, vol. 2022, 2022, doi: 10.1155/2022/5466268.
3. [3] A. Taghvaie, T. Warnakulasuriya, D. Kumar, F. Zare, R. Sharma, and D. M. Vilathgamuwa, “A Comprehensive Review of Harmonic Issues and Estimation Techniques in Power System Networks Based on Traditional and Artificial Intelligence/Machine Learning,” *IEEE Access*, vol. 11, pp. 31417–31442, 2023, doi: 10.1109/ACCESS.2023.3260768.
4. [4] X. Wang and F. Blaabjerg, “Harmonic Stability in Power Electronic-Based Power Systems: Concept, Modeling, and Analysis,” *IEEE Trans. Smart Grid*, vol. 10, no. 3, pp. 2858–2870, 2019, doi: 10.1109/TSG.2018.2812712.
5. [5] R. Arghandeh, A. Onen, J. Jung, and R. P. Broadwater, “Harmonic interactions of multiple distributed energy resources in power distribution networks,” *Electr. Power*

Syst. Res., vol. 105, pp. 124–133, 2013, doi: 10.1016/j.epsr.2013.07.018.

6. [6] K. Kularbphettong and C. Boonseng, "HPFs filtering solutions for reduced the harmonic current generated by SMPS and ac drive systems," *Energy Reports*, vol. 6, pp. 648–658, 2020, doi: 10.1016/j.egyr.2019.11.133.
7. [7] R. Aljarrah, M. Ayaz, Q. Salem, M. Al-Omary, I. Abuishmais, and W. Al-Rousan, "Application of Passive Harmonic Filters in Power Distribution System with High Share of PV Systems and Non-Linear Loads," *Int. J. Renew. Energy Res.*, vol. 13, no. 1, pp. 401–411, 2023, doi: 10.20508/ijrer.v13i1.13860.g8692.
8. [8] C. S. Azebaze Mboving, Z. Hanzelka, and A. Firlit, "Analysis of the Factors Having an Influence on the LC Passive Harmonic FilterWork Efficiency," *Energies*, vol. 15, no. 5, 2022, doi: 10.3390/en15051894.
9. [9] A. Ko, "Analysis of Harmonic Distortion in Non-linear Loads," no. June, pp. 1–6, 2011.
10. [10] A. Konkani, R. Bera, and S. Paul, *Lecture Notes in Electrical Engineering 442 Advances in Systems, Control and Automation*, vol. ETAEERE-20. 2016. [Online]. Available: http://www.springer.com/series/7818
11. [11] S. R. Das *et al.*, "A comprehensive survey on different control strategies and applications of active power filters for power quality improvement," *Energies*, vol. 14, no. 15, 2021, doi: 10.3390/en14154589.
12. [12] P. S. Sanjan *et al.*, "Enhancement of power quality in domestic loads using harmonic filters," *IEEE Access*, vol. 8, pp. 197730–197744, 2020, doi: 10.1109/ACCESS.2020.3034734.
13. [13] Z. Salam, P. C. Tan, and A. Jusoh, "Harmonics mitigation using active power filter: a technological review," *Elektrika*, vol. 8, no. 2, pp. 17–26, 2006, [Online]. Available: http://eprints.utm.my/46/1/paper4dec06.pdf

Annexure

14. Simulation and hardware parameters :

15. Supply Voltage (v) = 230 v RMS, Supply Frequency (F) = 50 Hz, Targeted Harmonic order = 3^{rd}, Filter Inductor (L) = 37.56 mH, Filter Capacitor (C) = 30 µF, Filter internal Resistance (R) = 6.75 Ω