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Mitigation of Harmonic Distortion of a Three Phase Circuit Using Passive Filters

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Abstract
Non-linear load in three phase circuit causes distortion of voltage and current waveform. Despite the advancement and attenuating strategy developed in modern production of power electronics loads, consumption from such network is non-linear by nature. Distortion of voltage and current creates multiples of fundamental frequencies together with the fundamental frequency within the network. Multiples of fundamental frequencies are referred to as harmonics. Production of harmonics in a network causes variation in power factor, undue heat in conductors and deterioration of busbars and protection instrument. Hence it is not desirable in any circuit since its presence reduces the efficiency of the system. The use of passive filters is one of the solutions to this problem. This paper discussed passive filters as a means through which harmonics can be mitigated. Two circuits were considered and analysed, one with passive filter connected and the other without passive filter. These circuits were modelled using Simulink in Matlab R2016a and their signals were evaluated with Fast Fourier Transform (FFT). The results obtained showed Total Harmonic Distortion (THD) of 4.26% for the circuit with passive filters but the circuit without passive filters displayed THD of 9.48%. Harmonic content of circuit with passive filters agrees with IEEE regulation and specification of 5% maximum for network of source voltage of less and up to 69KV as against the one without filters as studied.

Keywords: *Harmonics, Total harmonic distortion, Passive filters, Fast Fourier transform*

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1. Introduction

Power system voltages are delivered in sinusoidal form at a fundamental frequency of 50 Hertz cycle in Nigeria. However, it is difficult for utility operators to maintain this single frequency throughout the network due to varying distortions of current and voltage conditions (Arif et al., 2012). Voltage and current distortions create additional cycles, spikes and notches on waveform. These additional cycles, spikes and notches on waveform create multiples of fundamental frequencies which are referred to as harmonics. Waveforms with frequencies of 2f, 4f, 6f, etc are called even harmonics, and those that have frequencies of 3f, 5f, 7f, etc are odd harmonics (Bhatkar et al., 2017). Even harmonics are referred to as asymmetric waveform since the positive and negative portions of the wave are different. Whereas in odd harmonics, the positive portion of the waveform is identical to the negative portions and therefore referred to as symmetrical waveform.

Harmonics on a three-phase circuit are generated greatly by Non-linear loads. Examples of non-linear loads are computers, variable speed drives, and discharge lamps. Other causes of harmonics include transformers when it is not energized, motors with fractional pitch windings etc. The currents that are drawn by non-linear loads contain harmonics that superimposes voltage distortions on the impedance of power network and the connected loads.

Effects of Harmonics in three phase circuit causes distortions in sinusoidal waveform, heating in conductors, variation in power factor, error in instrument measurement, deterioration and premature aging in busbars and protective equipment. On the contrary, modern power network cannot be free of harmonics due to advancement and usage of power electronics among consumers, manufacturers and designers of power network.

Thus, there is need for continuous effort in curbing the spread of harmonics through attenuating procedures that can actually mitigate its existence on a network. Standards bodies have specify the voltage and current distortions allowed on a network. The IEEE 519-2014 sets the quality of power that is expected at the point of common coupling. This recommends preventive actions and specifies compliance level between utilities and customers as a measure to limit harmonic generation (Pinyol, 2017). Total Harmonic Distortion (THD) is the most significant metric for harmonic analysis and measurement. The THD in voltage and current are calculated by Equation (1) and Equation (2) respectively.

$$THD_V = \frac{\sqrt{V_2^2+V_3^2+V_4^2+\dots}}{V_1} \quad (1)$$

$$THD_I = \frac{\sqrt{I_2^2+I_3^2+I_4^2+\dots}}{I_1} \quad (2)$$

Several studies have been done on harmonic analyses of modern power system with non-linear loads. In Sher et al. (2022), harmonics and effects on power distribution network was reviewed. Different methods which include harmonic filters were prescribed as workable solutions of mitigating harmonics. Active filters were used and recommended (Gupta et al., 2012) to reduce the effect of harmonics in power system.

Application of passive filter to improve power quality and mitigate harmonics generated from induction furnaces was carried out (Arif et al., 2012). In Zhongyu et al. (2022), simulation and analysis of harmonic signal by MATLAB to analyse the problems of spectrum leakage in frequency domain was studied. Studies in Eduful and Atanga (2017) presented a MATLAB approach for the attenuation of harmonics and improvement of power factor through the use of passive filters. In Younis and Al-Yousif (2017), harmonics and effects on distribution network of Electricity Company in Ghana (ECG) was carried out. Studies in Zhongyu et al. (2022) discussed the solutions and compensations offered by shunt active filter on a distribution network.

In this study, passive filters are connected on a three-phase circuit and modelled in the MATLAB/Simulink to mitigate and reduce the effect of harmonics. The model has proven to be reliable and efficient in the reduction of harmonics as its worth is discovered in the results produced so far.

2. Materials and methods

In this paper, the following approaches were taken to mitigate the effect of harmonics on three phase circuit produced by nonlinear loads: data collection, analysis, and validation, involving both theoretical and empirical approaches. These were developed through a strategic model using MATLAB/ SIMULINK software. The selection and configuration of the system model are listed in the steps below:

1. A three phase HVDC universal bridge rectifier (nonlinear load) was configured to have a complex sine wave and connected in series to a 6-pulse thyristor.
2. A model of three phase series RLC branch linear load of 1000W was configured.
3. All the models that constitute the Network were connected.
4. The three phase Voltage–Current measurement Block Model was connected and was used to link the scope and spectrum analyser.
5. Wave distortions from the scope and spectrum analyser were observed during Simulation.
6. The fast Fourier transform series were used to evaluate two cases.
7. Case 1: Network without passive filters. The network without passive filters were obtained by disconnecting the circuit breaker in Figure 2.
8. Case 2: Network with passive filter

These steps are as shown in Figures 1 and 2

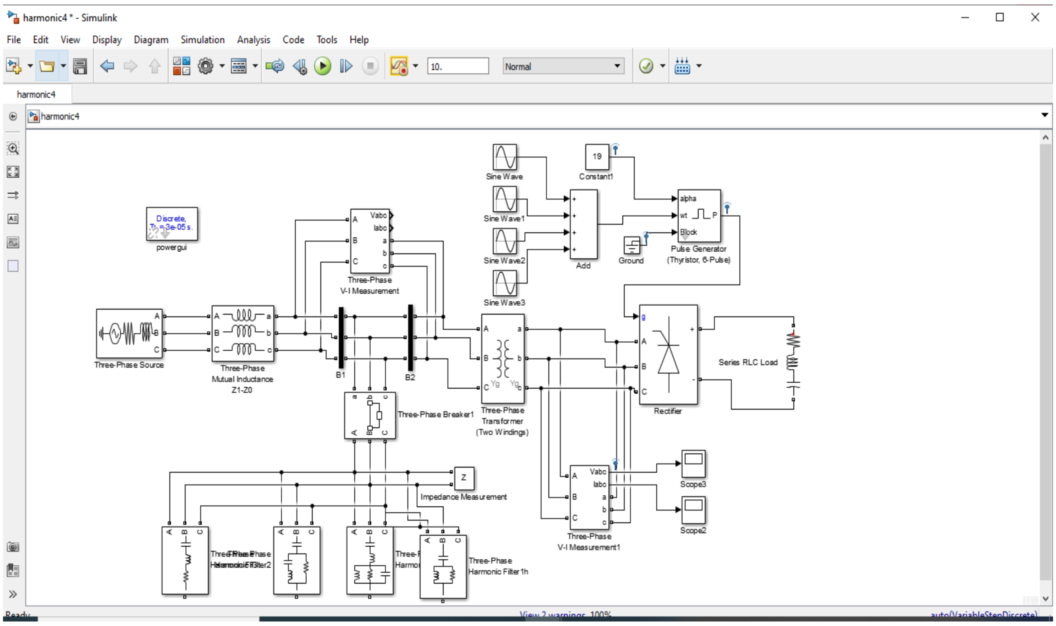

Fig 1: Network with passive filter

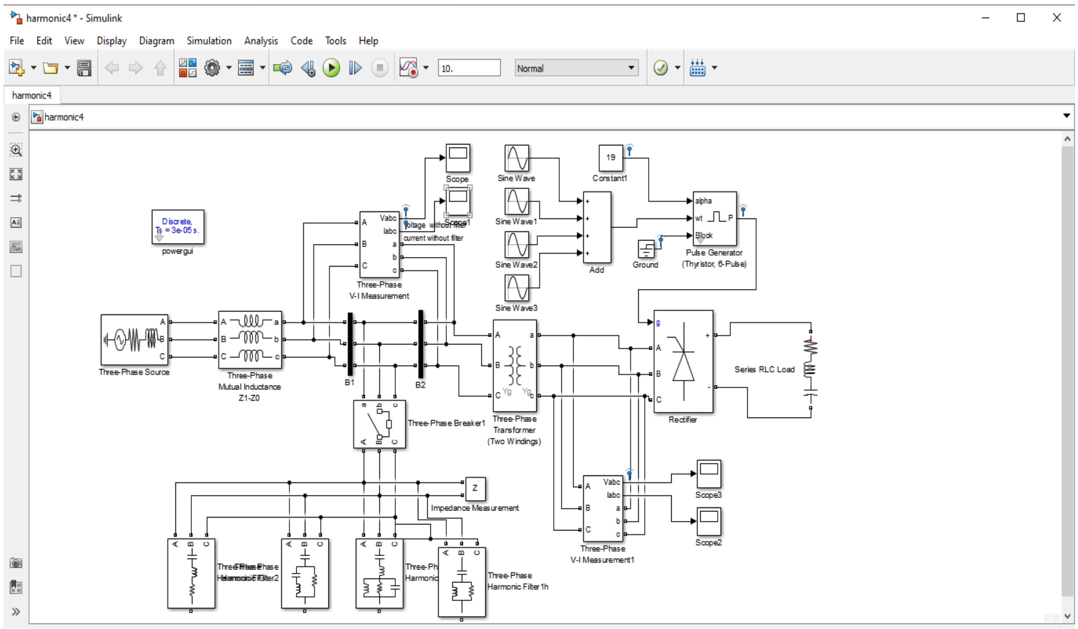

Fig 2: Network without passive filter

The detailed of the steps used in the implementation of the fast Fourier transform are as follows.

i. The model of Figure 1 and 2 were exported to workspace as structure + time data.
ii. Run the simulation to populate the workspace with the results.
iii. Under Powergui , FFT Analysis was chosen
iv. Configuration of FFT Analysis were done by setting the fundamental, the number of cycles and display style.

3. Results and discussion

Three phase circuit of 25KV source voltage with non-linear component were modelled in MATLAB Simulink R2016a without passive filter in Figure 2. Again, similar circuit were connected with passive filter in Figure 1. The signals from these circuits were analysed with fast Fourier transform which displayed the Total Harmonic Distortions of these signals. Results from these operations were compared with IEEE regulations as a guide to evaluate the performance of the circuit when passive filters are connected and when they are removed.

The total harmonic distortion obtained from simulation result of Figure 3 is 4.26% from a power source of 25KV system. Simulation result displays a minimal level of distortion which is in line with IEEE standard 519-1992 which specifies 5% maximum distortion for distribution network below and up to 69KV. Figure 4 reveals the list of harmonics (h1, h2, h3 etc) and their percentage contributions to total Harmonic distortion of 4.26%.

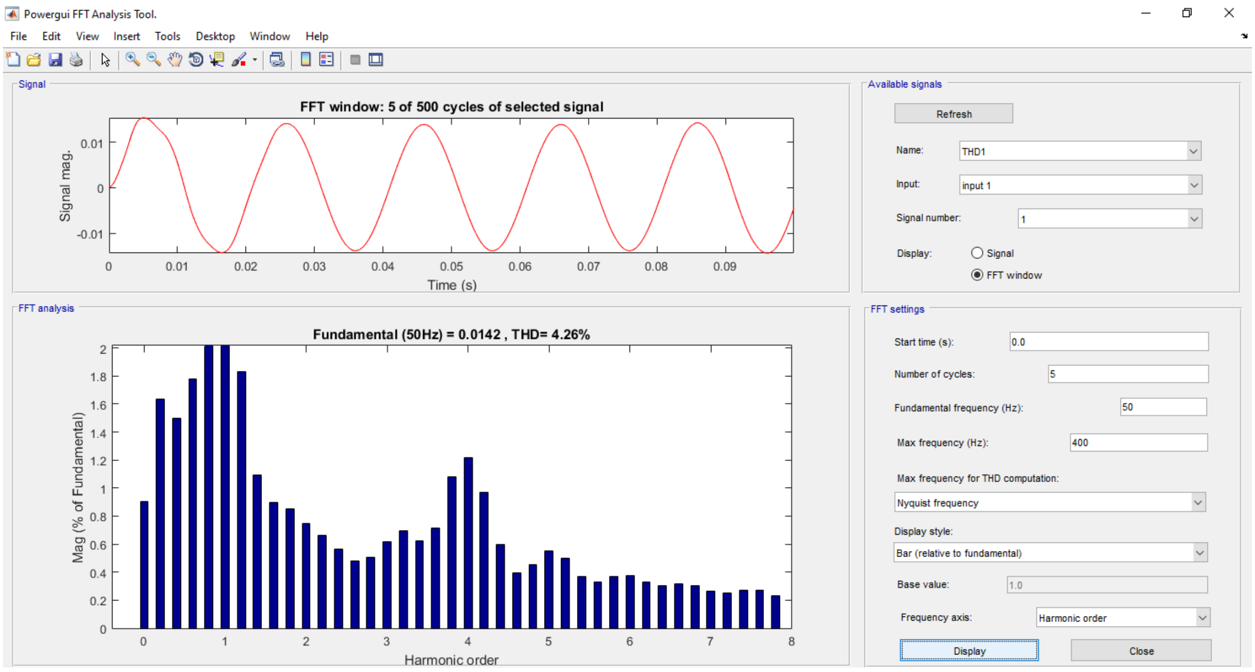

Fig 3: Total Harmonic Distortion (THD) of circuit with Passive Filters

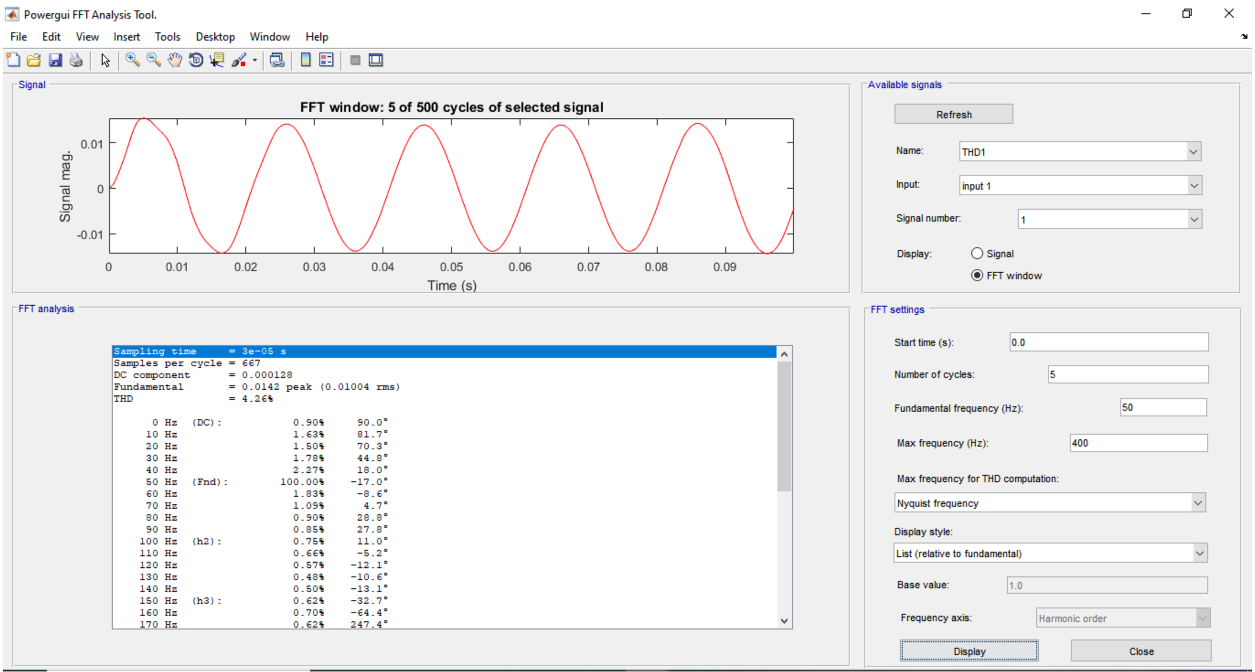

Fig 4: Harmonics and distortion percentages of circuit with passive filters

Fig. 5 reveals significant distortion in signal with total harmonic distortion of 9.48% from a power source of 25KV system. Simulation result deviates from IEEE standard 519-1992 as prescribed for distribution network under study. Fig. 6 reveals the list of harmonics (h1, h2, h3, etc) and their percentage contributions to total Harmonic distortion of 9.48%.

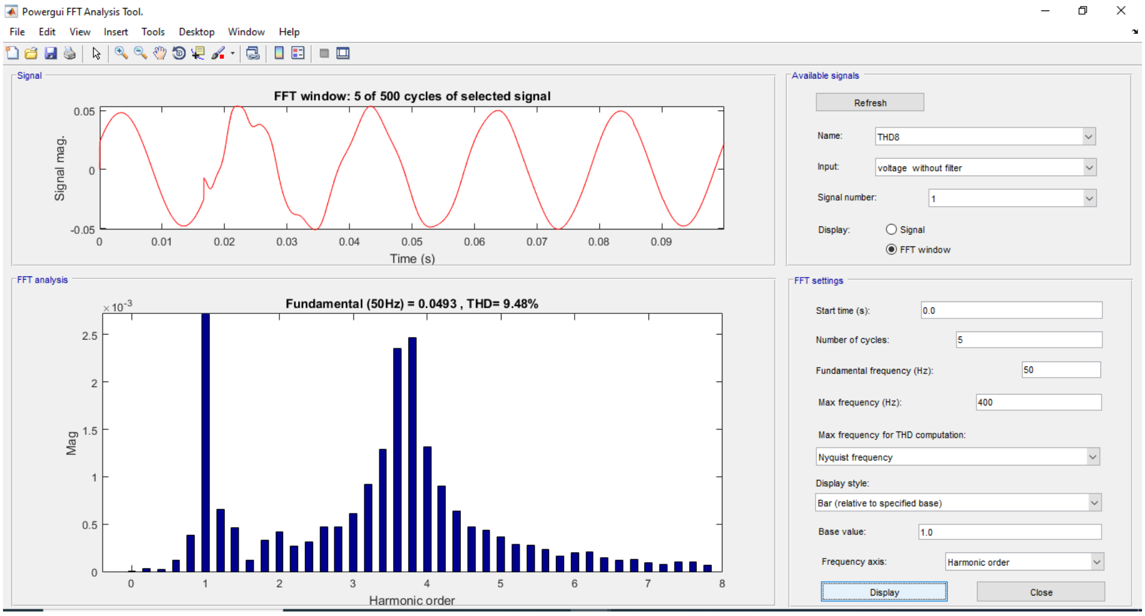

Fig 5: Total harmonic distortion (THD) of circuit without passive Filters

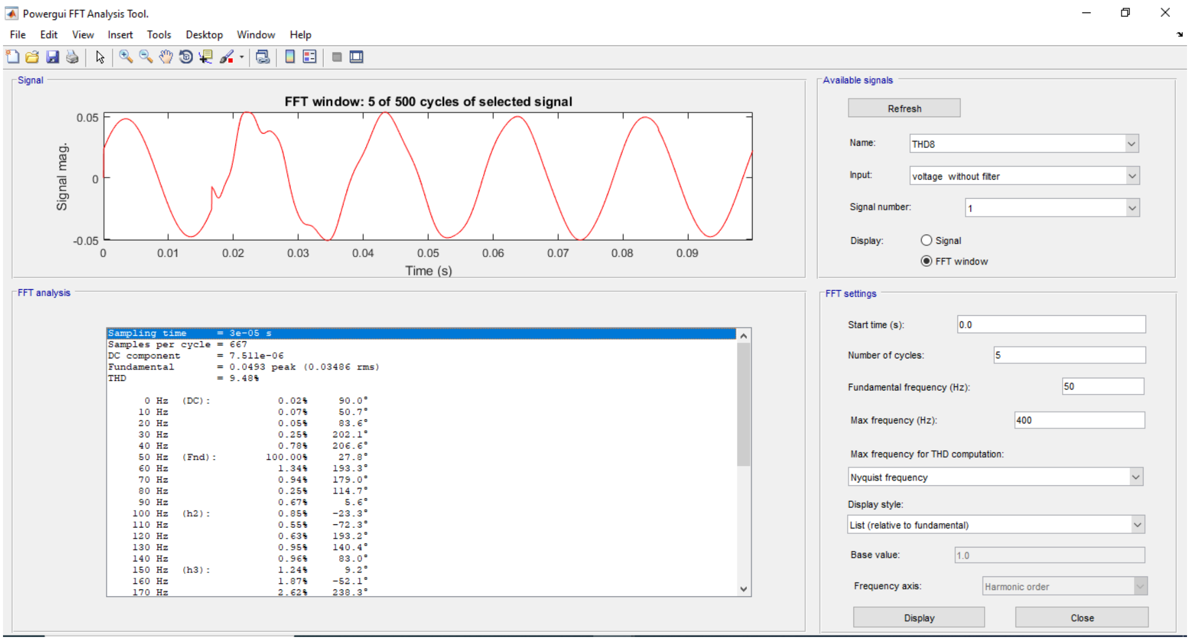

Fig 6: Harmonics and distortion percentages of circuit without passive filters

4. Conclusion

In this study, passive filters were used as a solution to mitigating harmonics in a three-phase circuit. Two circuits were considered; The first was with passive filter connected and the other were connected without passive filters. The two circuits were modelled using simulink in Matlab R2016a and their signals were analysed with Fast Fourier Transform. It is observed that the output of the three-phase circuit without passive filters were non-sinusoidal and unstable with a Total Harmonic Distortion (THD) level of 9.48%. This percentage deviates from IEEE standard 519-1992 which prescribes a maximum of Total Harmonic Distortion (THD) of 5% for the studied netwok with 25KV source voltage. With the application of passive filters, harmonics were mitigated. It can be concluded that inclusion of passive filters in a circuit do not eliminate harmonics completely but reduces harmonic to acceptable limit.

Acknowledgements

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