International Journal of Real-Time Applications and Computing Systems (IJORTACS)

Volume 2, Issue II, February 2023, **No. 41, pp. 427-435**

Submitted 30/3/2023; Final peer review 24/4/2023

Online Publication 4/5/2023

Available Online at http://www.ijortacs.com

IMPROVING THE QUALITY OF POWER SUPPLY IN MARYLAND 11KV DISTRIBUTION NETWORK USING PASSIVE HARMONIC FILTERING SCHEME

[1]Ozi Emmanuel O., [2]Ibekwe Basil

[12] Department of Electrical and Electronic Engineering
Enugu State University of Science and Technology (ESUT), Enugu State, Nigeria.
For correspondence contact: engrozi123@gmail.com

ABSTRACT

This paper presents improving the quality of power supply in 0.75MVA, Maryland 33/11kv distribution network using passive harmonic filtering scheme. The aim is to improve the quality of power supply which has been impacted by the effect of harmonics. To achieve this aim, the case study transformer was characterized and the harmonics percentage was determined as 14.17% which is not good as it did not satisfy the requirement for Nigerian Electricity Regulation Commission (NERC) which required tolerance of 5% as maximum for harmonics in distribution transformers. The study utilized passive filter which used single tuned, double tuned, high pass and C-type filter to mitigate harmonics from the 3rd to 24th order. The filter was implemented on the 33/11KV transformer using simulation and then tested. The result showed that harmonics was mitigated to 0.01394% which is good as it satisfied the NERC standard requirements. The filter was then integrated on the distribution transformer and tested for consecutive 19 hours on load. The result showed that the harmonics percentage is 7.8%. The implication o the result showed that it did not satisfy the requirements of the NERC and IEEE for harmonics mitigation power system network. The reason was due to the old age of the transformer and poor maintenance factor which has seriously affected the reliability of the system. However, the transformer with the passive filter connected to it was able to achieved better quality of power supply with harmonic reduction from 14.17% to 7.8% which gives a percentage improvement in quality of power supply at 44.95%.

Keywords: Power; 33/11KV Distribution Network; Passive Harmonic Filtering; C-type filtering;

1. INTRODUCTION

Over the years, the demand and population of electrical energy users have increased rapidly and hence the average load also increases mainly due to exponential increase in robust design of energy consuming device. This coincidentally increases the rate supply and demand chain for distribution of power regularly in most areas (Gonen and Foote, 2011).

Recently, there have been many notable transformations in the power system sector, recording series of functional epistemologies to increase the system reliability and efficiency. This transformation has been today expanded more as a result of the introduction of new methodologies employing advanced communication and control tools, new generation sources, semiconductor technologies and the integration of flexible loading scheme that provides the regulation of frequency, in the pursuit of energy efficiency (Jizhong, 2009). Unfortunately, these methodologies despite its huge contribution to the electrical power system draw non-sinusoidal current which affects the quality of power production.

Dynamic (Nonlinear) load is classified by the two main types of power system harmonics sources which are the harmonic voltage source and the harmonic current source. Katiraei et al. (2006) opined that with the penetration increase of dynamic loads nature, the power factor degradations of the loads, reduction in the efficiency of transmission network and maximization of the transmission line losses among other factors are all expected, and as a result, the harmonic distortion of the power system distributive network rises significantly.

In (Jizhong (2009); Alejandro and Gustavo (2019); Sanjib et al., (2015); Daniel et al., (2018); Ashitha et al., (2017); Jonathan and Daniel (2017); Geena and Kanchan (2016)), their research works proposed techniques for the reduction of these harmonic distortions. However, this is not without its limitations. The passive power filter and the other techniques they proposedare not adaptive to the dynamic changes in nonlinear loads and hence a control technique to minimize these harmonic distortions is of vital importance for power system operational optimization and quality of service.

This work presents a novel solution to this challenge using the passive filter designed with RLC components, the filters are connected in parallel to the power system. This is a passive harmonic filter designed using capacitor elements employed in power system for the correction of power factor and control of voltage distortion induced in power system as a result of nonlinear power electronics devices. The harmonic filter proposed in this work minimizes losses, distortion, through the diversion of harmonic current in low impedance paths, also the produce reactive power employed for the correction of power factor, since they are capacitive at fundamental frequency.

.

The methodology used for the research is the Experimental and simulation method. The study characterized the Maryland 33/11KV distribution transformer and identifies the percentage harmonic in the system for analysis. The harmonic problem identified was mitigated using a tuned passive filter compensator which resistor, inductor and capacitor to harmonize voltage flow and correct power actor. The filter was connected on the primary side of the transformer and then used for the mitigation of harmonics. The performance of the filter on the transformer was tested through simulation and the result analyzed based on the Nigerian Electricity Regulatory Commission (NERC) and International Electrical Electronics Engineering (IEEE) standards for harmonic percentage in distribution systems.

2. CHARACTERIZATION OF THE POWER SYSTEM UNDER STUDY

This study characterized the EEDC 11/33KV Maryland transformer. The aim was to measure the percentage of harmonic current in the transformer and propose a solution to the problem. The parameters considered for the characterization are the harmonic current, load, voltage and orders of harmonic as they occur in the transformer. The method of the characterization process used the clamp instrument to connect to the three phases of the transformer on load at the primary side and then used the harmonic analyzer meter to read the harmonic percentage in the transformer. The data was collected for 19hours with an hour interval consecutively on the 19, June, 2021. The figure 1 presented the result;

Figure1: Harmonic test of 33/11kv distribution transformer

The model used to determine the percentage harmonic in the transformer was based on the K-factor technique in equation 1.

$$K = \sum_{h=1}^{\infty}(I_{hX}^2\, h^2);\sum_{h=1}^{\infty}(V_{hX}^2\, h^2) \qquad 1$$

Here his the harmonic order and $I_h^2$is the harmonic current and V_h^2harmonic voltage of order h expressed in p.u. of the fundamental frequency. As expressed by Equation (1), K factor takes into account the effect of (I^2R) and V^2/R which relates to losses, for every harmonic current and voltage component.

This is a relevant parameter on the assessment of premature aging of transformer windings because dissipated heat in the form of copper and core losses due to spectral components of the current. Because K factor takes into account the frequency parameter, it is regarded as the most precise method to estimate the harmonic content of nonlinear loads for the specification of distribution systems.

3. SYSTEM MODELING

Under purely sinusoidal conditions, the calculation of losses in a power system is straightforward because it is based in conventional power flow studies that assume linear impedances throughout the system. The increasing waveform distortion in power systems due to the proliferation of nonlinear loads requires losses to be calculated using more suitable techniques. These involve time series in which voltage and current quantities are expressed comprising the most relevant frequency components other than the fundamental frequency of the system as shown in equation 2 – 5;

$$P = \frac{1}{T}\int_0^T p(t)dt = \sum_{h=1}^{\infty} V_h I_h \cos(\theta_h - \partial_h) = \sum_{h=1}^{\infty} P_h \qquad 2$$

$$Q = \frac{1}{T}\int_0^T q(t)dt = \sum_{h=1}^{\infty} V_h I_h \sin(\theta_h - \partial_h) = \sum_{h=1}^{\infty} Q_h \qquad 3$$

$$\mathrm{S = V}I_{rms} \qquad 4$$

$$S^2 = P^2 + Q^2 + D^2 \qquad 5$$

Also, to determine the total harmonic of the system, equation 5 was used according to Alejandro et al (2013), where P is power, Q is the impedance, V$_h$ is the voltage harmonic, T is harmonic, I$_h$ is the harmonic current and I$_i$ is the current in the power components;

$$THDi = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_i} \qquad 6$$

$$I_{RMS} = \sqrt{\sum_{h=2}^{\infty} I_h^2} = \sqrt{I_i^2 + \sum_{h=2}^{\infty} I_h^2} \qquad 7$$

$$THD_i^2 = \frac{\sum_{h=2}^{\infty} I_h^2}{I_I^2} = \frac{I_{RMS}^2 - I_h^2}{I_i^2} \qquad 8$$

$$I_{RMS} = \sqrt{I_i^2\,(THD_i^2 + 1)} \qquad 9$$

3.1 Tuned passive Filter Design

The tuned passive filter is designed using a resistor, inductor and capacitor (RLC) shunt element for decreasing harmonic voltage and correction of power factor. The resistance, inductance, and capacitance values are determined from the filter type and from the following parameters:

- Reactive power at nominal voltage
- Tuning frequencies
- Quality factor. The quality factor is a measure of the sharpness of the tuning frequency. It is determined by the resistance value.

The tuned passive filter design involves a parallel connection of the single, double and high-pass filters to the power system. Nonlinear elements such as power electronic converters generate harmonic currents or harmonic voltages, which are injected into the power system. The resulting distorted currents flowing through the system impedance produce harmonic voltage distortion. Harmonic filters reduce distortion by diverting harmonic currents in low impedance paths. Harmonic filters are capacitive at the fundamental frequency, so they are also used for producing reactive power required by converters and for power factor correction.

To achieve an acceptable distortion, several banks of filters of different types are connected in parallel. The most commonly used filter types are:

- Band-pass filters, which are used to filter lowest order harmonics such as 5th, 7th, 11th, 13th. Band-pass filters can be tuned at a single frequency (single-tuned filter) or at two frequencies (double-tuned filter).
- High-pass filters, which are used to filter high-order harmonics and cover a wide range of frequencies. A special type of high-pass filter, the C-type high-pass filter, is used to provide reactive power and avoid parallel resonances. It also allows filtering low-order harmonics (such as 3rd), while keeping zero losses at the fundamental frequency.

The four types of filters that can be modeled with the Three-Phase Harmonic Filter block are shown below:

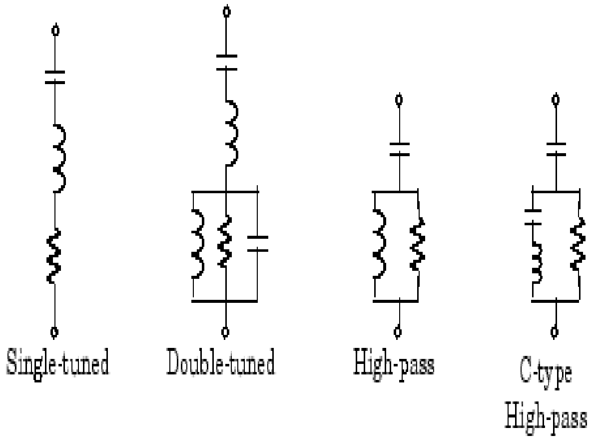


Figure 2: the four types of filters

The simplest filter type is the single-tuned filter. The following figure 2 – 5 gives the definition of the quality factor Q and practical formulae for computing the reactive power Q_C and losses (active power P). The quality factor Q of the filter is the quality factor of the reactance at the tuning frequency $Q = (nX_L)/R$. The quality factor determines the bandwidth B, which is a measure of the sharpness of the tuning frequency with the design parameters in table 1;

Table 1: filter design parameters

Filter parameters	Models	Definition o variables
Tuned harmonic order	$n = f_n/f_1 = GXC/XL$	f_1 = fundamental frequency; $\omega = 2\pi f_1$ = angular frequency; f_n = tuning frequency n = harmonic order = (f_n/f_1); V = nominal line-line voltage; X_L = inductor reactance at fundamental frequency = $L\omega$; X_C = capacitor reactance at fundamental frequency = $1/(C\omega)$
Quality factor	$Q = nX_L/R = X_C/(nR)$	
Bandwidth	$B = f_n/Q$	
Reactive power at f_1	$Q_C = (V^2/X_C)\cdot n^2/(n^2 - 1)$	

The double-tuned filter performs the same function as two single-tuned filters although it has certain advantages: its losses are much lower and the impedance magnitude at the frequency of the parallel resonance that arises between the two tuning frequencies is lower.

The double-tuned filter consists of a series LC circuit and a parallel RLC circuit. If f_1 and f_2 are the two tuning frequencies, both the series circuit and the parallel circuit are tuned to approximately the mean geometric frequency fm=Gf1f2.

The quality factor Q of the double-tuned filter is defined as the quality factor of the parallel L, R elements at the mean frequency f_m: $Q= R /(L \cdot 2\pi f_m)$.

The high-pass filter is a single-tuned filter where the L and R elements are connected in parallel instead of series. This connection results in a wide-band filter having an impedance at high frequencies limited by the resistance R.

The quality factor of the high-pass filter is the quality factor of the parallel RL circuit at the tuning frequency: $Q= R /(L \cdot 2\pi f_n)$.

The C-type high-pass filter is a variation of the high-pass filter, where the inductance L is replaced with a series LC circuit tuned at the fundamental frequency. At fundamental frequency, the resistance is, therefore, bypassed by the resonant LC circuit and losses are null.

The quality factor of the C-type filter is still given by the ratio: $Q =R / (L \cdot 2\pi f_n)$.

The following figures give R, L, C values, and typical impedance versus frequency curves obtained for the four types of filters applied on a 50Hz network. Each filter is rated 315 kV, 49 Mvar and this value was determined based on the parameters of the transformer like the active and reactive power.

4. SIMULATIONS OF THE MODEL

This section discusses the implementation of the proposed using Simulink, power system simscape, power system toolbox and instrumentation tool. The figure 3 presents the complete model of a power system with the tuned passive filter connected at various harmonic order in parallel. Harmonic filters reduce distortion by diverting harmonic currents in low impedance paths. Harmonic filters are capacitive at the fundamental frequency, so they are also used for producing reactive power required by converters and for power factor correction.

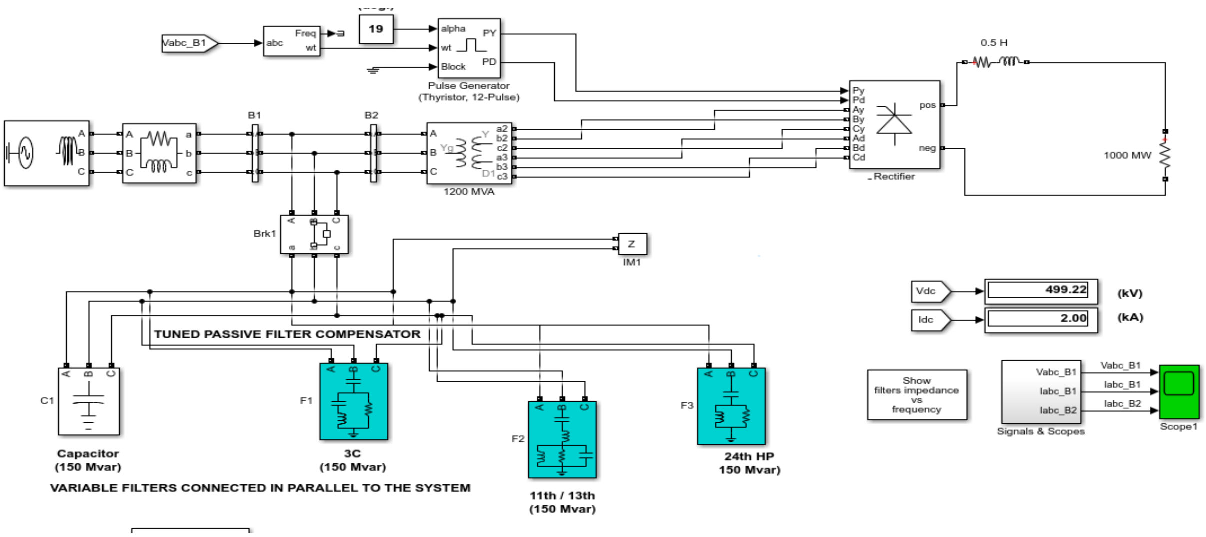


Figure 3: three phase power system model with harmonic passive filters

Table 2: Simulation parameters

Parameters	Values
Power system capacity	0.75 MVA
Transformer type	Three phase power distribution transformers
Load capacity	33/11KV
Inductance	0.5H
Total reactive power	600Mvar

5. RESULTS AND DISCUSSION

The section presented the performance of the passive filter developed and used for the optimization of power quality in the transformer system. The single tuned filter was developed with mitigate harmonic from frequency of 50 to 300Hz. The MVar of the filter is 49 and will mitigate 5th harmonics with a quality factor of 30. The Double tuned filter will mitigate 11th and 13th order harmonics with a quality factor of 16 and reactive power of 49Mvar. The High pass filter mitigate 24th order harmonic at quality factor of 10. The C-Type filter mitigates 3rd order harmonics with quality factor of 1.75. The results of the four filters were presented in the figure 4.

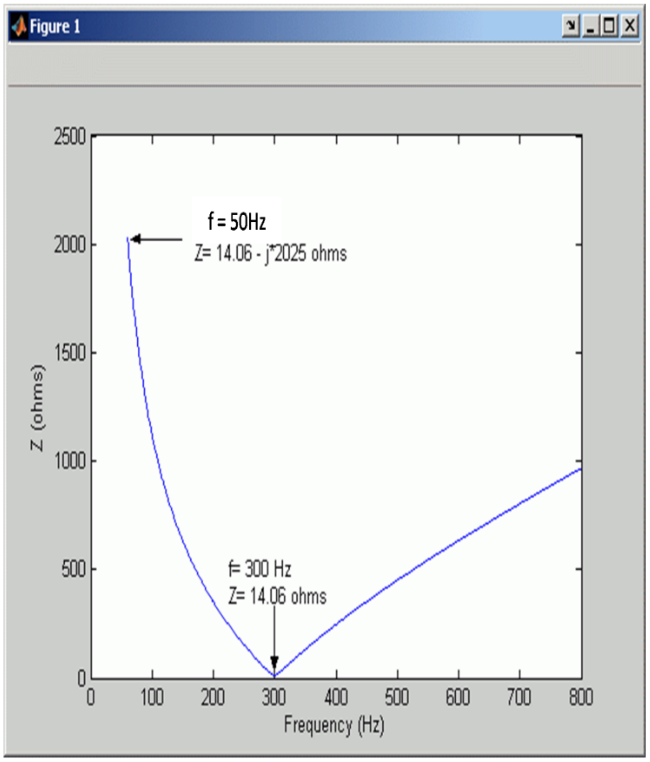


Figure 4: Single-Tuned, 315 kV, 49 Mvar, 5th Harmonic Filter; *Q* = 30

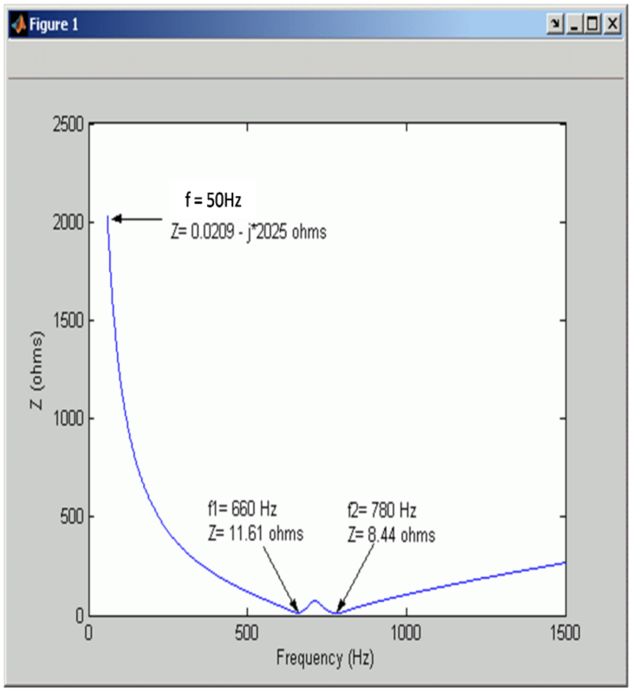


Figure 5: Double-Tuned, 315 kV, 49 Mvar, 11th and 13th Harmonics Filter; *Q* = 16

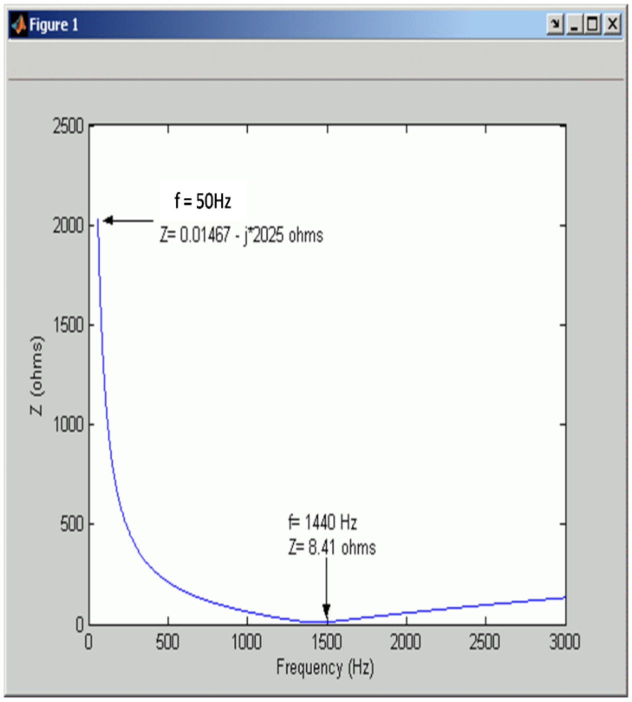


Figure 6: High-Pass, 315 kV, 49 Mvar, 24th Harmonic Filter; *Q* = 10

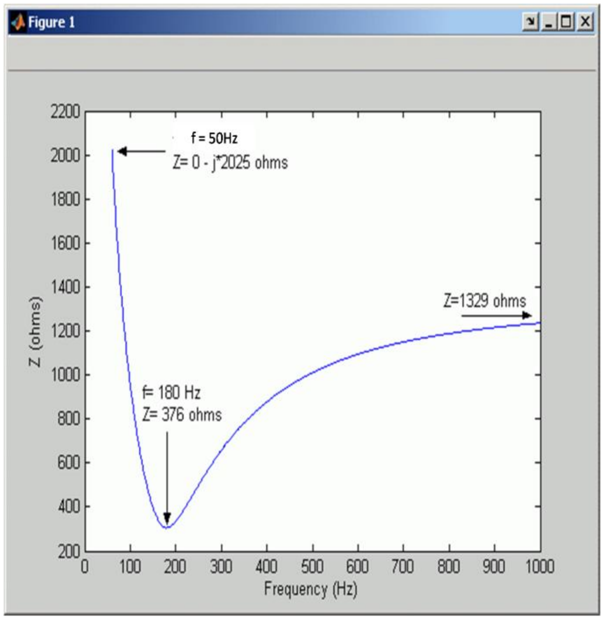
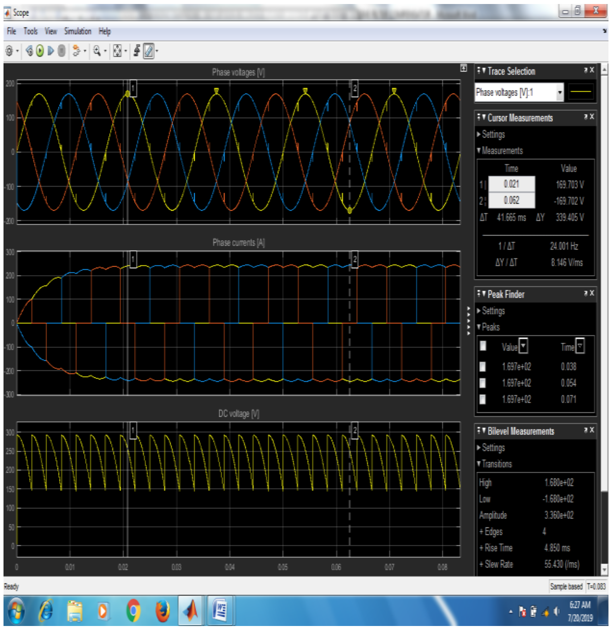


Figure 7: C-Type High-Pass, 315 kV, 49 Mvar, 3rd Harmonic Filter; *Q* = 1.75

5.1 Results of Filter Simulation with 33/11KV transformer on load

This section presented the filter performance when the simulated with the 33/11KV transformer system. The waveform of signal was presented in figure 8;



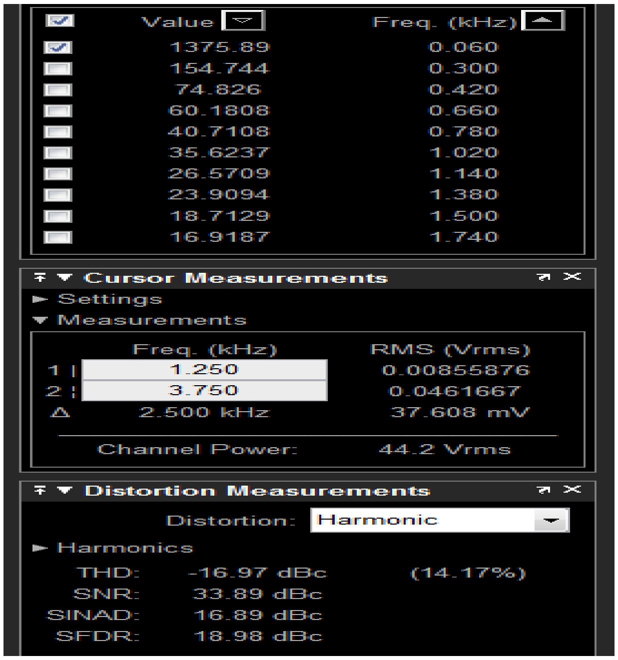
	Time		Value
1	0.021		169.703 V
2	0.062		-169.702 V
ΔT	41.665 ms	ΔY	339.405 V
	1 / ΔT		24.001 Hz
	ΔY / ΔT		8.146 V/ms

	Value	Time
☐	1.697e+02	0.038
☐	1.697e+02	0.054
☐	1.697e+02	0.071

High	1.680e+02
Low	-1.680e+02
Amplitude	3.360e+02
+ Edges	4
+ Rise Time	4.850 ms
+ Slew Rate	55.430 (/ms)

Figure 8: Three phase signal with harmonics

The figure 8 presented the performance of the simulated power distribution system, showing how the filter was used to mitigate harmonics on the waveforms. The filters were able to mitigate all others of harmonics from the transformer. The single tuned filter was used to mitigate the 5th order harmonics, the double tuned was used to mitigate the 11th and 13th order harmonics, the high pass filter was used to mitigate the 24th order harmonics and the C-Type filter was used to mitigate the 3rd order harmonics. Before the activation of the filter, the figure 9 was used to show the percentage harmonic on the Simulink transformer model which was equivalent as identified in the characterized.



☑	Value	Freq. (kHz)
☑	1375.89	0.060
☐	154.744	0.300
☐	74.826	0.420
☐	60.1808	0.660
☐	40.7108	0.780
☐	35.6237	1.020
☐	26.5709	1.140
☐	23.9094	1.380
☐	18.7129	1.500
☐	16.9187	1.740

	Freq. (kHz)	RMS (Vrms)
1	1.250	0.00855876
2	3.750	0.0461667
Δ	2.500 kHz	37.608 mV

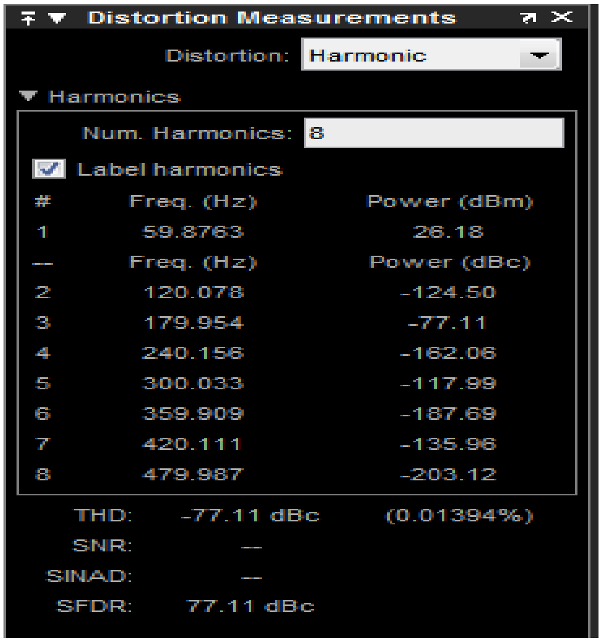
Channel Power: 44.2 Vrms

Distortion: Harmonic

THD: -16.97 dBc (14.17%)
SNR: 33.89 dBc
SINAD: 16.89 dBc
SFDR: 18.98 dBc

Figure 9: Result of harmonics without filter

The figure 9 showed that the simulated harmonics content on the distribution transformer without the filter activated is 14.17%. However, when the filter was activated in the simulation, the result of the harmonic percentage was presented in the figure 10;



Distortion: Harmonic

Num. Harmonics: 8

☑ Label harmonics

#	Freq. (Hz)	Power (dBm)
1	59.8763	26.18
—	Freq. (Hz)	Power (dBc)
2	120.078	-124.50
3	179.954	-77.11
4	240.156	-162.06
5	300.033	-117.99
6	359.909	-187.69
7	420.111	-135.96
8	479.987	-203.12

THD: -77.11 dBc (0.01394%)
SNR: —
SINAD: —
SFDR: 77.11 dBc

Figure 10: Result of harmonics with filters

To minimize the harmonic noise, a tuned filter designed using the RLC components was used which separates and channel the harmonic signal to low impedance, thus minimizing the harmonic to a negligible rate of 0.01394%. This proves the effectiveness of the intelligent filter.

6. CONCLUSION

This work has successfully discussed the several causes of harmonic in a distributive power system, it is however revealed that this harmonic effect is inevitable due to certain components that must be part of power system control and monitoring scheme. Capacitors on its part is used for power factor correction, however, it induced harmonic resonance too and hence, the RLC designed tuned filter connected to the power system in parallel is used for the elimination of harmonic to 0.01394% as opposed to the initial 14.17%.

7. REFERENCES

Alejandro O., and Gustavo A. (2019) “Instantaneous p-q theory for harmonic compensation via shunt active power filter” IEEE transactions on power electronics and power quality

Alejandro P., and Liliana C., Jose I., and German M. (2013) “Characterization of Harmonic Distortion on the Electric Network Caused By a Battery Charger for Electric Vehicles; Asian journal of empirical research applications.” page 1-4.

Anon (2005) “Performance of Harmonic Mitigation Alternatives”, Accessed on Gonen T. and Foote B. (2011) “Distribution System Planning using Mixed Integer Programming”. IEE Proceedings-Generation, Transmission and Distribution,128 (2): pp70-79.

Ashitha S., Dinari K., Kumar A., and Shruti V. (2017) “Reduction of Harmonics in Power Distribution Systems Using Hybrid Active Filter” International Journal of Advance Engineering and Research Development Volume 4, Issue 5.

Daniel F., Stefano N., Alessandro C., and Michael G. (1993) “Harmonic Reduction Methods for Electrical Generation: A Review”, IEEE recommended practices and requirements for harmonic control in electrical power systems, page1-112,

Geena S., and Kanchan J. (2016) “Harmonic Reduction using Shunt Active Power Filter” International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 5, Issue 6.

Jizhong Z. (2009) “Optimization of Power System Operation. IEEE Transactions on Power Systems”, vol.16, no.3, pp600-614.

Jonathan K., and Daniel J. (2017). “Economic and Electrical Benefit of Harmonic Reduction Methods in Commercial Facilities” PU00904002E dated 07/04.

Katiraei F., Abbey C., and Bahry R. (2006) “Analysis of voltage regulation problem for a 25-KV distribution network with distributed generation.” IEEE Power Engineering Society General Meeting, pages 18-22.

Sanjib K., Siddikur R., andRidown R. (2015) “Harmonic Analysis on LVDC Distribution System and Passive Filter Techniques for Harmonic Reduction”. 978-1-4673-9257-0/15/$31.00.