

Harmonic Mitigation on a 33kV Distribution Line using Passive Filters

L.M. Adesina

Department of Inspection and Quality Assurance
Eko Electricity Distribution Plc (EKEDP)
Lagos – Nigeria

(Corresponding author) lambe.adesina@ekedc.com; lmamaj@yahoo.com; Mobile: 08023091620

O.A. Fakolujo

Department of Electrical/Electronic Engineering
University of Ibadan
Ibadan – Nigeria
ao.fakolujo@ui.edu.ng; olaosebikanfakolujo@gmail.com

ABSTRACT

The use of modern power electronic devices in circuits has made ‘power quality’ an increasingly important factor in the planning of both transmission and distribution systems. These devices are nonlinear loads such as office equipment like Central Processing Units (CPU), Plotters etc and most electronic home appliances such as TV, Video players, etc., that generate distorted harmonic currents and voltages, which get injected into the power system and leads to ineffective operation of the system. Harmonic mitigation scheme is therefore imperative in the design and planning of power system network. Consequently, this paper presents the control of harmonics in a 33kV Distribution line by using passive filters – a case of RLC and LC filters in both single and cascaded configurations were examined in order to study the net effects of their application in a distribution line. It involves the use of the distribution line (case study) results obtained from previous studies on power flow and harmonic analysis of the overall network that contains the distribution line of case study. These results serve as source data for this research. Only a distribution line of the network was used as a test case. The harmonic mitigation analysis was carried out using MATLAB/Simulink platform. The simulation results of mitigation harmonics are presented. Conclusions and necessary recommendations for future research are also discussed.

Keywords: Power quality, Harmonic mitigation, Passive filters, RLC filter, Passive LC filter, 33kV Distribution link

African Journal of Computing & ICT Reference Format:

L.M. Adesina & O.A. Fakolujo (2015): Harmonic Mitigation on a 33kV Distribution Line using Passive Filters.
Afr J. of Comp & ICTs. Vol 8, No. 3. Pp 89-100.

1. INTRODUCTION

In recent time, electrical power engineers, power utility companies and electric power end users have become a lot more concerned about power quality. The increasing number of nonlinear loads produces harmonic currents in transmission and distribution feeders and thus, distorts voltage waveforms [1]. A power quality problem exists if a variation in voltage, current or frequency results in a failure of customer's equipment [2]. To ensure a better operation of a power system, it is imperative to get rid of the system harmonics. For this purpose, filters are often required. Both passive and active filters can be used to reduce harmonic currents. While passive filters provide low impedance paths to absorb harmonic currents, active filters give countervail harmonic components to purify load currents [3-5]. However, passive filters are usually a better choice for customers considering cost. The capacitors of passive filters also provide reactive power compensation to improve power factor.

Very often, harmonic mitigations are achieved by applying power flow and harmonic analysis results to model network formulation for harmonic mitigation analysis. Consequently, the results of the previous researches on power flow and harmonic analysis of a 33kV Distribution network were used as the source data for this mitigation research. To avoid cumbersomeness in presentation, the results obtained on only one of the distribution lines were used as the case study.

In this paper, the harmonic mitigation on a 33kV line using passive filters is studied. Consideration for various filters of the type or form, Single RLC, Cascaded RLC, Single LC and Cascaded LC on a formulated model distribution line came to play. The mitigated harmonic results for each case are displayed and discussed. The various harmonic minimization methods using filters are highlighted in subsequent sections of this paper.

2. HARMONIC MINIMIZATION METHODS

Majority of large power (typically three-phase) electrical nonlinear equipment often requires mitigation equipment in order to attenuate the harmonic currents and associated voltage distortion to within necessary limits as stipulated by IEEE Standards 519-1992. Depending on the type of solution desired, the mitigation may be supplied as an integral part of nonlinear equipment (e.g., an AC line reactor or a line harmonic filter for AC PWM drive) or as a discrete item of mitigation equipment (e.g., an active or passive filter connected to a switchboard) [2]. There are many ways to reduce harmonics, ranging from variable frequency drive designs to the addition of auxiliary equipment. Few of the most prevailing methods used today to reduce harmonics include (but not limited to) the use of:

1. Isolation Transformers
2. Reactors
3. Passive (or Line) Harmonic Filters
4. Low Pass Filter
5. Phase Shifting Transformers
6. Active Power Filters
7. Power Factor Corrections

A number of researchers devoted their studies to filtering out the harmonic currents in a power system. Heydt and Grady [3] used a simple filter configuration of connecting a single branch of series RLC (or single tuned filter) connected to the Busbar system.

2.1 Passive Harmonic Filters for Harmonic Mitigation

Passive filters are combination of inductance, capacitance and resistance elements configured and tuned to reduce the impact of harmonics in the power systems [4]. Passive harmonic filter techniques are among the oldest and perhaps the most widely used techniques for filtering power line harmonics. Besides the harmonics reduction, passive filters can be used for the optimization of apparent power in a power network [5]. The classical solution for reducing current harmonic distortion is to connect a shunt LC-series filter nearby the harmonic source in order to drain the current harmonics generated by the load, trying to keep the main source current sinusoidal [6]. Passive harmonic filters are also known as harmonic trap filters and are used to eliminate or control more dominant lower order harmonics specifically 3rd, 5th, 7th, 9th, 11th, 13th and 15th and are the more severe examples of triplet harmonics that produce bigger problems to engineers because they possess more distortion in voltage [7]. Passive Harmonic Filter is comprised of a passive L-C circuit (and also frequently resistor R for damping) which is tuned to a specific harmonic frequency which needs to be mitigated (for example, 5th, 7th, etc).

Their operation relies on the “resonance phenomenon” which occurs due to variations in frequency in inductors and capacitors. The series tuned filters are used to compensate the dominant harmonics of the supply current. The cost of the passive filter is very low and it is easy to tune the particular frequency [8]. This filter acts as zero impedance at the tuning frequency that absorbs the harmonics. Passive filters are usually connected in parallel with nonlinear load(s) and are “tuned” to offer very low impedance to the harmonic frequency to be mitigated. In practical application, above the 13th harmonic, their performance is poor, and therefore, they are rarely applied on higher-order harmonics [8]. Passive filters are made of passive elements like resistors, capacitors and inductors.

Passive filters have a value-added function of achieving power-factor correction of inductive loads. This function brings an advantage to passive filters in many cases, but not in all cases [9]. However, the disadvantages of passive filter implementations to filter out the current harmonics include possibility of resonances with the source Impedance, Supply impedance dependent system performance and fixed compensation [10]. They are considered best suited for three phase four wire network [5]. Various kinds of passive filter techniques are given below [5]:

1. Series passive filters
2. Shunt passive filters
3. Low pass filters or line LC trap filters and
4. Phase Shifting Transformers

2.1.1 Series Passive Filters

Series passive filters are usually placed in series with the supply and the load. Series passive filters are considered good for single phase applications and specially suited to mitigate the third harmonics [5]. They do not produce resonance and offer high impedance to the frequencies they are tuned to. These filters must be designed such that they can carry full load current [5].

2.1.2 Shunt Passive Filters

Shunt Passive filters are also designed using passive elements and they offer good results for filtering out odd harmonics especially the 3rd, 5th and 7th harmonics. They provide low impedance to the frequencies they are tuned for. Since they are connected in shunt, they are therefore, designed to carry only harmonic currents [5]. Their nature of being in shunt makes them loads to the supply side and can carry 30-50% load current if they are feeding a set of electric drives [5]. Economic aspects reveal that shunt filters are always more economical than the series filters due to the fact that they need to be designed only for the harmonic currents. Therefore they need comparatively smaller sizes of L and C, thereby reducing the cost. Furthermore, they are not designed with respect to the rated voltage, thus making the components less costly than it is for series filters. However, these types of filters can create resonant conditions in the circuit.

2.2 Design of Passive Filters

The most common type of shunt filters used in harmonic mitigation is the Single Tuned Filter (STF), which is either a low pass or band pass filter [10]. This type of filter is the simplest to design and the least expensive to implement [11]. The basic principle of operating a passive filter is that at the tuned frequency, the filter will offer low impedance to current through which harmonic currents tends to divert in the system [12]. Secondly, passive filters come with the property of reactive power compensation. A very simple arrangement of single tuned filter is shown in fig 1, which also gives the connection arrangement used in the design of single tuned filter [13]:

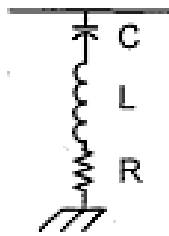


Figure 1: Single Tuned Filter [14]

It can easily be seen in fig.1 that single tuned filters are the simple series connection R-L-C component and LC components. The equation of resonant frequency for a single tuned frequency is given by [15]:

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (1)$$

where,

f_0 = Frequency at resonance in Hertz

L = Inductance of filter in Henry

C = Capacitance of filter in Farads

Another important term, which is necessary to consider, is the design of the filter Quality factor. The term "Quality factor" is the ratio of the reactance at resonant condition to the resistance of the circuit as follows [15]:

$$Q_f = \frac{(X_L \text{ or } X_C)}{R} \quad (2)$$

Where,

Q_f = Quality factor (for a normal distribution system, typical value of Q_f varies between 15 and 80)

R = Resistance of the filter in Ohms

In a Single Tuned Filter, the inductive and capacitive reactance at the tuned frequency is given by [16]:

$$Z = R + j\omega L + \frac{1}{j\omega C} \quad (3)$$

where,

ω = Angular frequency ($2\pi f$) of power system

R = Resistance of filter branch

C = Capacitance of filter branch

L = Inductance of filter branch

If h is the ratio between the fundamental and harmonic frequencies, then the value of capacitance and inductance can be obtained using the following equations that relate the harmonic and electronic component of filters [15]:

$$X_{Lh} = h \times 2\pi f \quad (4a)$$

$$X_{Ch} = \frac{1}{h \times 2\pi f} \quad (4b)$$

Again, at the tuning of the filter, the impedance value of the filter must be low; for which purpose, if we inspect the simple circuit of filter and find that the only way to minimize the impedance of the filter is to make both of the reactance cancel out, this can be made possible through the resonant condition viz:

$$X_{Lh} = X_{Ch} \quad (5)$$

Now, when we put the value of X_{Ch} and X_{Lh} in equation (6), another relationship between harmonic and passive components which is important for filter design, will be achieved:

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

Again, if X_0 is the reactance of the capacitor, or filter reactor at its tuning frequency,

$$X_0 = \omega_n L = \frac{1}{C\omega_n} = \sqrt{\frac{L}{C}} \quad (7)$$

but,

$$Q = \frac{X_0}{R} = \frac{\sqrt{L/C}}{R} \quad (8)$$

The pass band is bounded by frequencies at which [16]:

$$|Z_f| = \sqrt{2}R \quad (9)$$

$$f = \frac{\omega - \omega_n}{\omega_n} \quad (10)$$

The sharpness of tuning is dependent on R as well as X_0 and reducing these can reduce the impedance of the filter at resonant frequency.

Note that, at parallel resonance, the equation of a resonant frequency for a single tuned frequency is given as:

$$f_{o(\text{parallel load})} = \frac{1}{2\pi\sqrt{(L_s+L)/C}} \quad (11)$$

$f_{o(\text{parallel load})}$ = Frequency at resonance for networks involving nonlinear loads in Hertz

L_s = Inductance present in the network (source inductance)
before connection of filter in Henry

L = Inductance of filter in Henry

C = Capacitance of filter in Farads

In this condition, the total source impedance will be so much and have an impact such that the resonant condition of the system will be just before the tuning frequency, usually about 3 – 6% of its desired value [17]. Also, when there are multiple harmonic filters connected in the system, the resonance of the filter circuit will be affected for all the harmonic filters.

3. MODELLING OF ALAGBON – FOWLER DISTRIBUTION LINE FOR HARMONIC MITIGATION

A 33kV distribution network of Island Business District, Eko Electricity Distribution Plc, from which one of the 33kV Distribution lines (line between Alagbon and Fowler Busbars) was selected for the study, and is shown in fig. 2 below. A power flow and harmonic analysis researches for scenario hours of feeder restoration had been previously carried out on the line and some of the results obtained from these analyses serve as the source data for this research work.

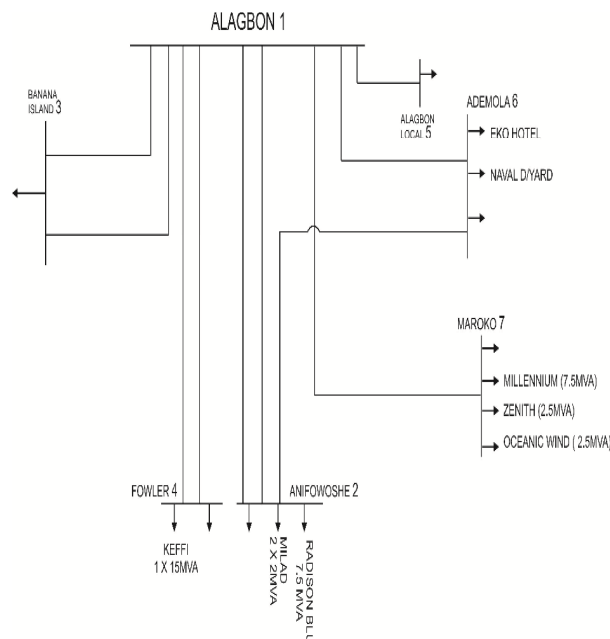


Fig 2: 33kV Network of Islands Business Unit, EKEDP

Generally, transmission or distribution lines are modelled using any of these networks: π - network, T - network and π & T networks, depending on the distance of the line. Since the distribution route length of Alagbon (ALG) – Fowler (FOW) D/L is 3.00km, a π distribution line modelling approach was adopted using the MATLAB/Simulink environment.

Fig. 3 shows the model of the initial setup of ALG – FOW Distribution line of case study, before the process of mitigation was initiated. Also, π -modelled diagram or circuit was considered suitable for the display of harmonics flowing between two buses. The circuit comprises of the source, which is the input, and the output electrical parameters such as resistance, reactance, and susceptance. It also has two oscilloscopes placed at Fowler (FOW) and Alagbon (ALG) Busbars to measure the input and output voltage variation due to harmonic flow on the line. A reactor is connected for power control, while a current source is included to act as non-linear loads which generate harmonics.

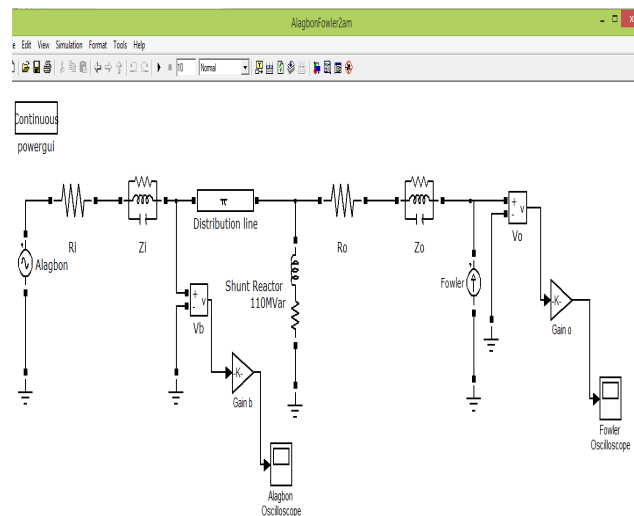


Figure 3: Model of the Initial setup of the ALG – FOW Distribution Line

The Amplitude of source voltage at the sending end (Alagbon Bus) of ALG – FOW Distribution line is 33kV. When the simulation is done, the 4 harmonics generated on the line are shown in the Impedance/Frequency characteristic graph in fig. 5. To start with, an RLC filter is inserted at Alagbon end of the line as shown in fig. 4:

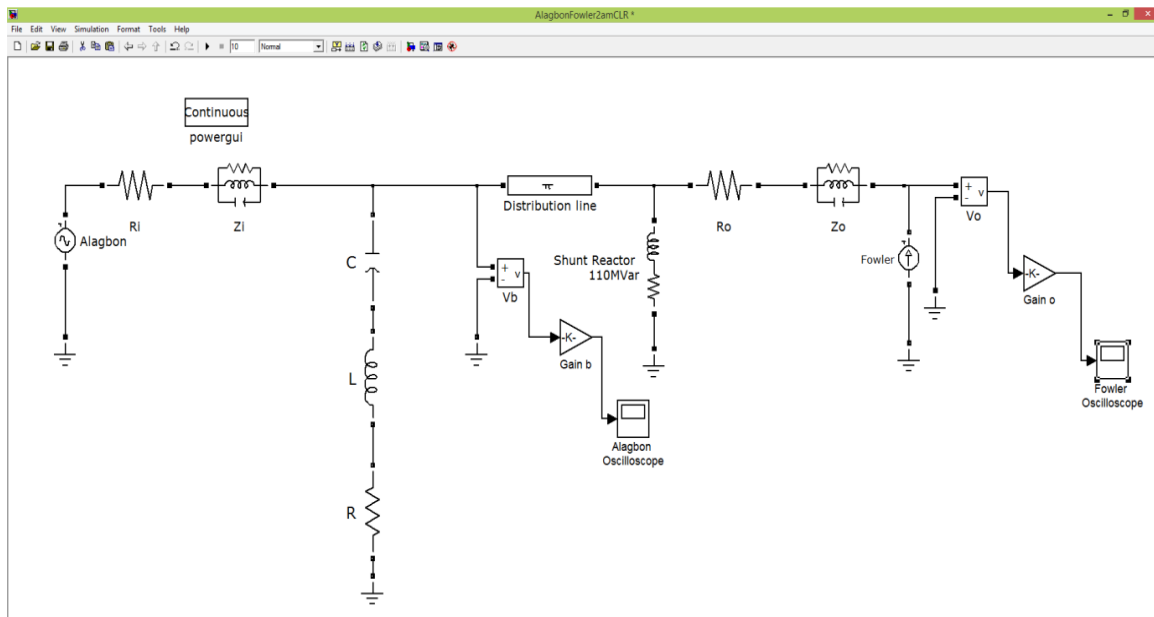


Figure 4a: Model showing the Introduction of an RLC Filter into the Existing ALG - FOW Distribution Line

The values of electronic components; Resistance ($R = 1\Omega$), Inductance ($L = 1\text{ mH}$), and Capacitance ($C = 150\mu\text{F}$) are MATLAB/Simulink default values, while the component values used in fig. 4 above were obtained using passive filter design equations illustrated in equations (1) to (10). MATLAB simulations were carried out for an RLC filter implemented within ALG – FOW Distribution line as shown in fig 4. The other configurations of filters introduced to the model include: 2 RLC filters in cascade; an LC filter and two LC filters in cascade. These configurations are illustrated in figures 4b to 4d.

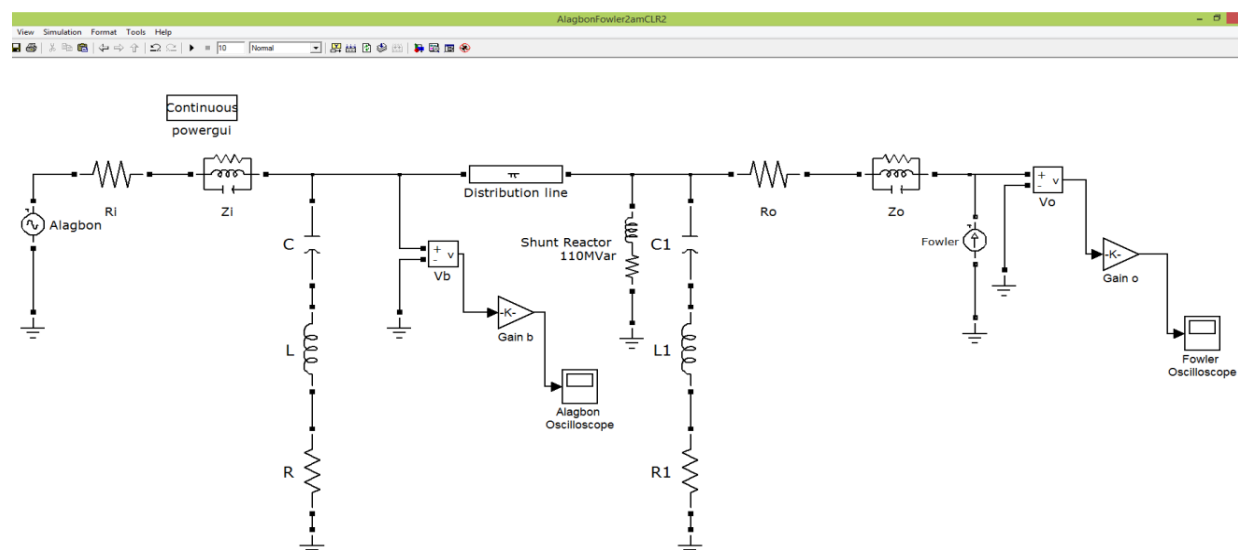


Figure 4b: Model showing the Introduction of two RLC Filters in Cascade into the Existing ALG - FOW Distribution Line

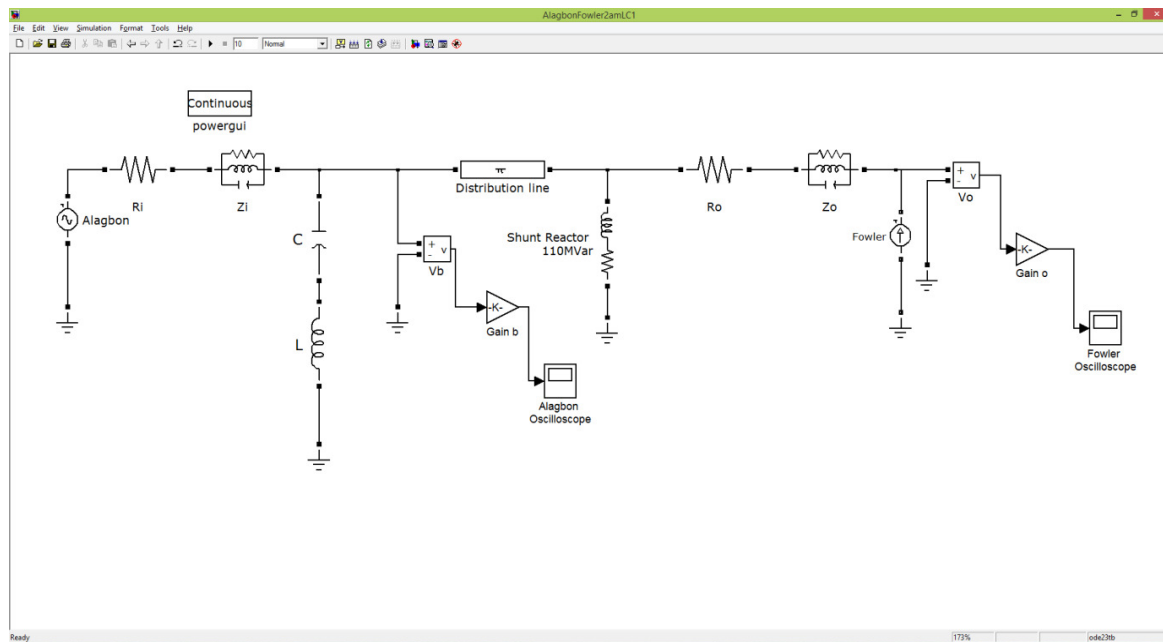


Figure 4c: Model Showing the Introduction of a Passive LC Filter into the Existing ALG - FOW Distribution Line

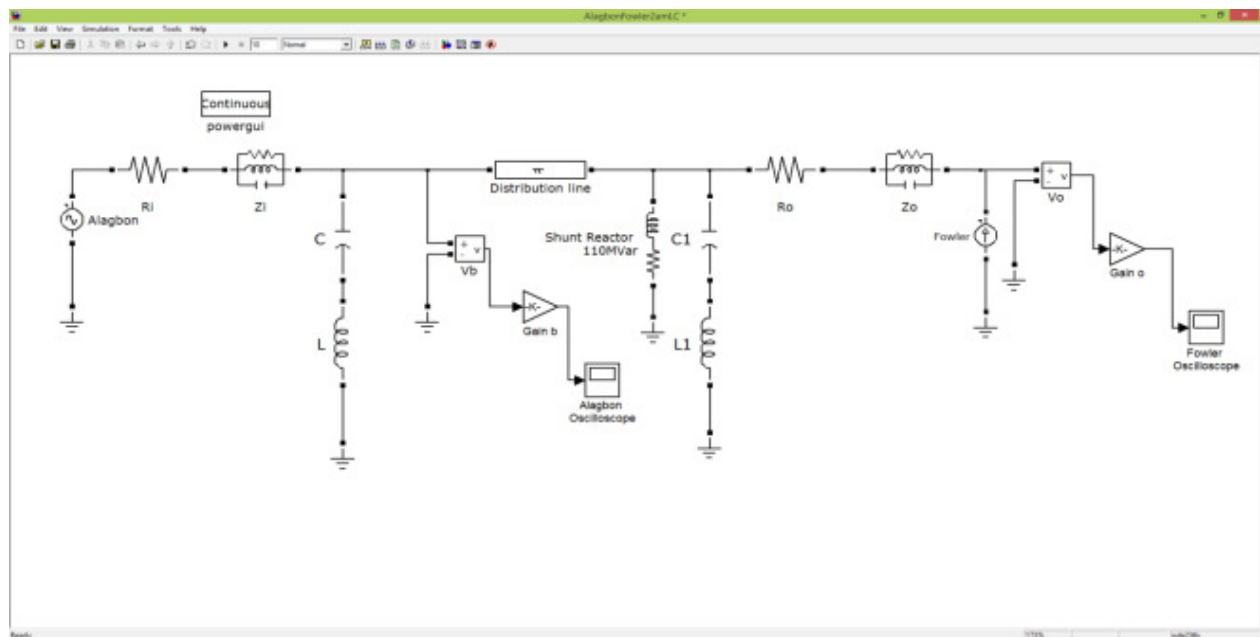


Figure 4d: Model Showing the Implementation of two Passive LC Filters in Cascade on ALG- FOW Distribution Line

4. MITIGATION RESULTS AND DISCUSSION

Fig. 5 below shows the harmonics generated on the ALG – FOW Distribution Line before mitigation. It can be seen that 4 harmonics were generated on the line namely: 2nd, 6th, 15th and 24th harmonics at impedance levels of $10^{1.985}\Omega$, $10^{2.508}\Omega$, $10^{2.268}\Omega$, and $10^{2.198}\Omega$ respectively, for a range of frequencies between 0-1500Hz.

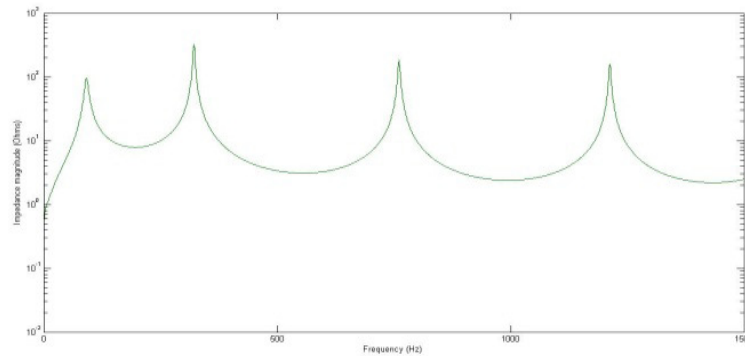


Figure 5: Harmonics of the ALG – FOW Distribution Line Upon implementation of the RLC filter, the harmonics generated on the line were visibly reduced from 4 to 3 as shown in the impedance magnitude/frequency graph fig. 6a:

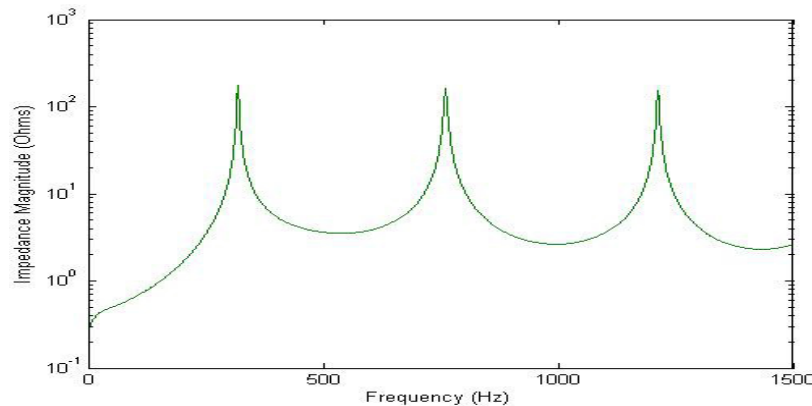


Figure 6a: Mitigation Result on Application of an RLC Filter to ALG - FOW Distribution Line

The value of output voltage after the simulation using an RLC filter in the line (i.e. voltage at FOW end of the line) is about 32.99kV as shown in fig. 6b below:

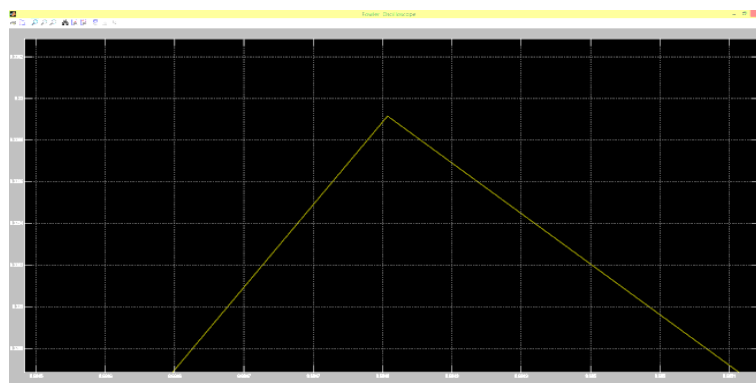


Figure 6b: Output Voltage at FOW Bus after applying RLC filter

The peak impedance magnitude from the harmonic result shown in fig 6a is about $10^{2.24}\Omega$ as clearly shown in fig. 6c below:

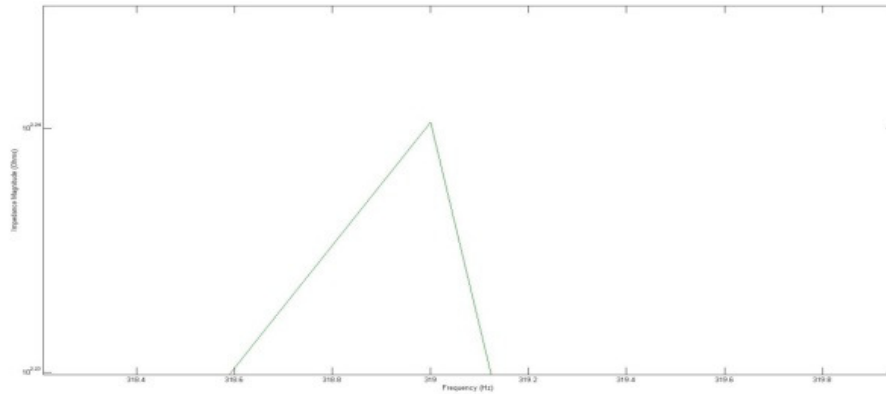


Figure 6c: New Impedance Magnitude / Frequency Characteristic of Reduced Harmonic on ALG - FOW Line

The percentage reduction in magnitude of harmonic impedance (% HR) from the initial impedance magnitude of $10^{2.508}\Omega$ to that value after applying an RLC filter is illustrated as follows:

$$\% HR = \frac{10^{2.508} - 10^{2.24}}{10^{2.508}} \times 100\% = 46.05\%$$

When two RLC filters were applied in cascade as shown in fig. 4b, simulation shows that the number of harmonics still remains 3 as shown in fig. 7a and the impedance magnitude/frequency characteristic plot shown in fig. 7b. However, the peak impedance magnitude of the harmonics further reduced from $10^{2.24}\Omega$ (shown in fig. 6c) to $10^{0.585}\Omega$ as shown in fig 7b

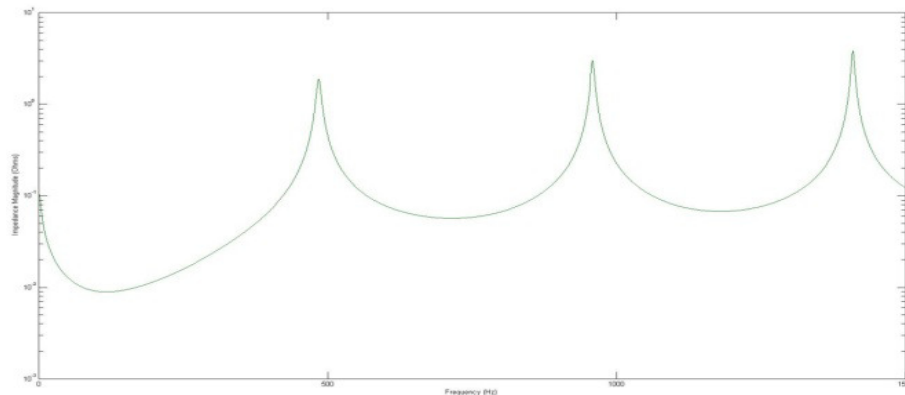


Figure 7a: Mitigation Result on Application of two RLC Filters in Cascade to ALG - FOW Line

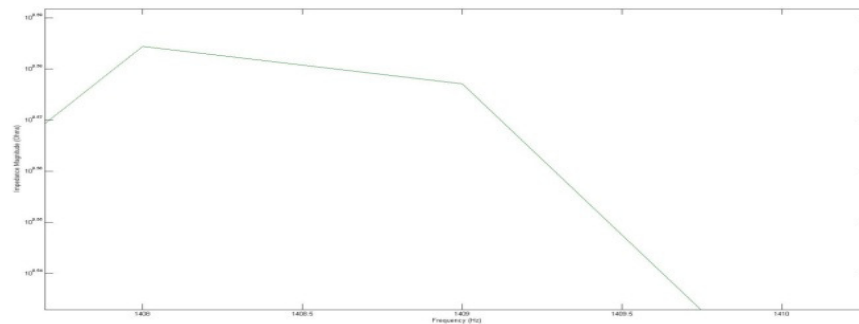


Figure 7b: New Impedance Magnitude / Frequency Characteristic of Reduced Harmonic on ALG - FOW Line after Applying two RLC Filters in Cascade

However, the value of output voltage at FOW Bus with the implementation of 2 RLC filters in cascade is about 73.80V as shown in fig. 7c:

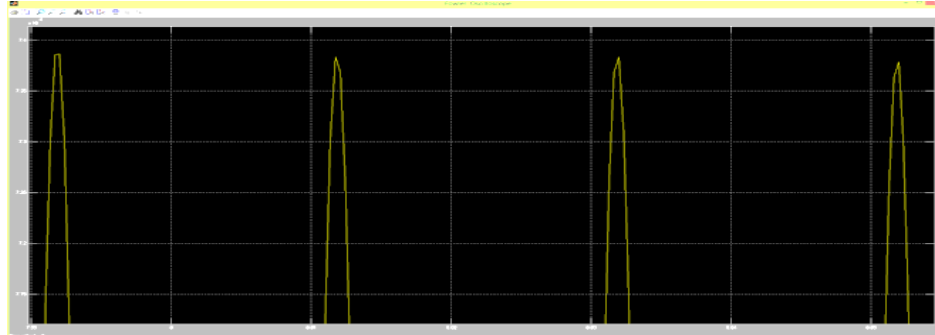


Figure 7c: Result showing the Output Bus Voltage at FOW with the implementation of 2 RLC Filters in Cascade

The total percentage reduction in harmonic impedance in this case, from the initial peak value of $10^{2.508} \Omega$ to the new value of $10^{0.585} \Omega$ is,

$$\% HR = \frac{10^{2.508} - 10^{0.585}}{10^{2.508}} \times 100\% = 98.81\%$$

Furthermore, with the application of an LC filter in ALG – FOW line as shown in fig. 4c. The results obtained are shown in figures 8a and 8b, which illustrate the harmonic pattern and harmonic impedance characteristics respectively:

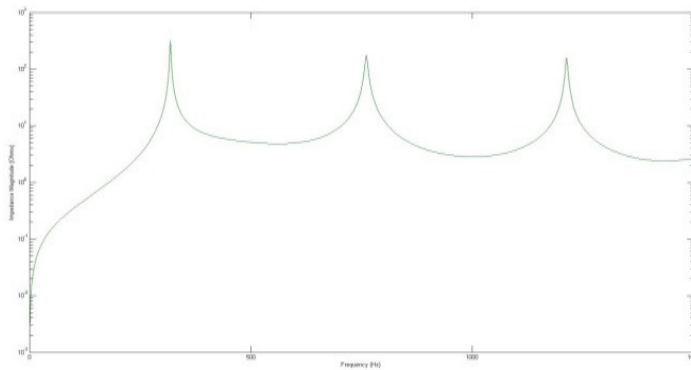


Figure 8a: Mitigation Result after Applying an LC Filter on ALG - FOW Line

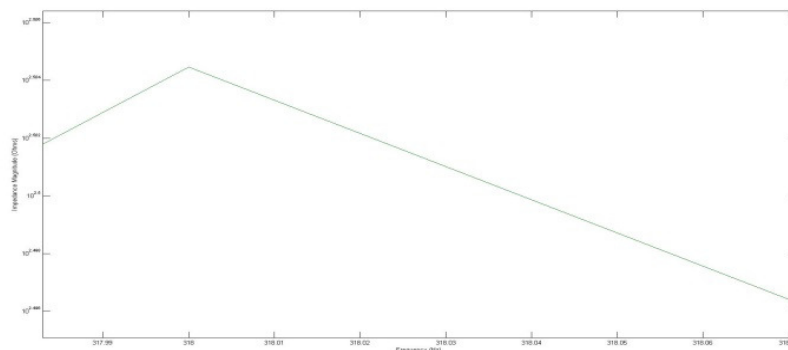


Figure 8b: Plot of Impedance / Frequency Characteristic of Reduced Harmonics on ALG - FOW Line with application of an LC Filter

The value of output Bus voltage at FOW Bus with the implementation of a passive LC filter is about 870V as shown in fig. 8c.

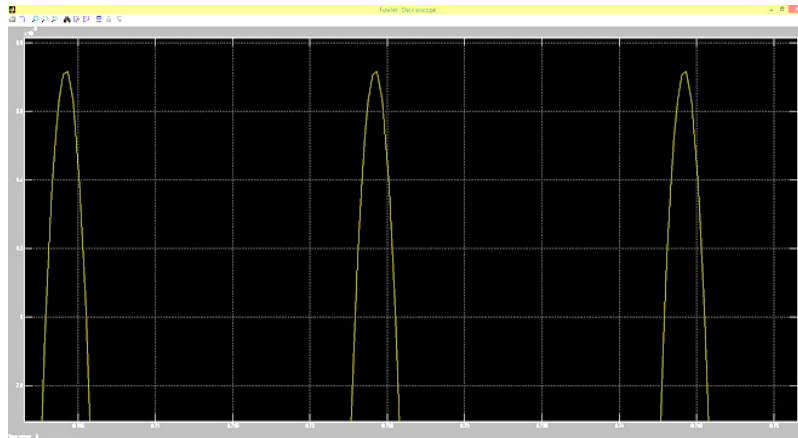


Figure 8c: Result showing the Output Bus Voltage at FOW with the application of an LC Filter

However, with 2 LC filters in cascade on ALG - FOW D/L as shown in fig. 4d below, simulation results obtained are also shown in figures 9a and 9b. Only one harmonic is eliminated. The output voltage in this case is 6.80V and this is shown in fig 9c.

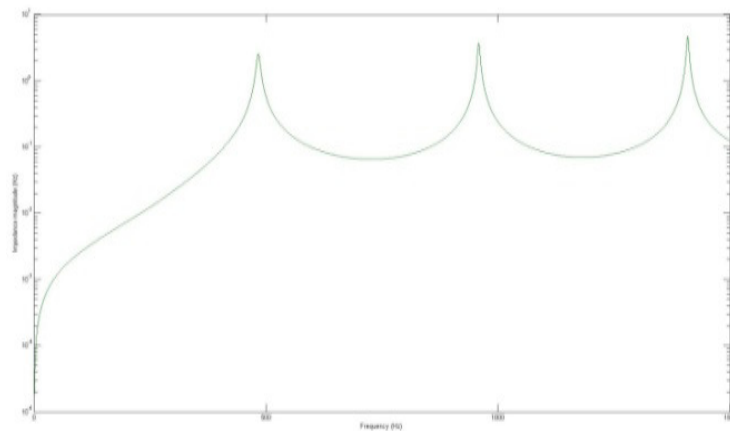


Figure 9a: Impedance / Frequency Characteristic of Reduced Harmonics on ALG – FOW Line with 2 LC Filters in Cascade

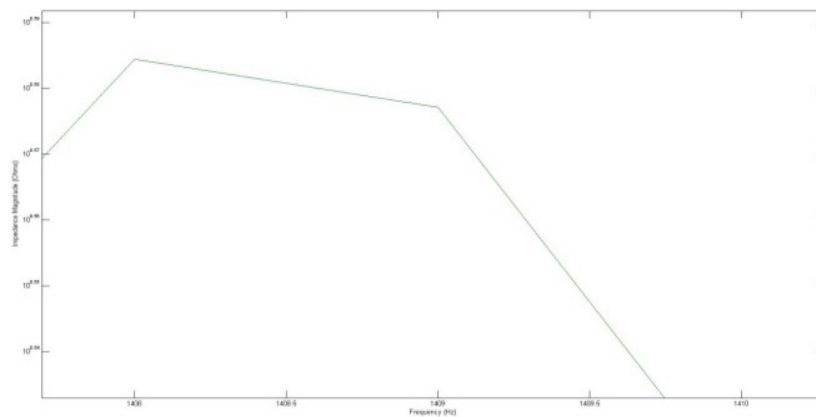


Figure 9b: Impedance / Frequency Characteristic of Reduced Harmonics on ALG – FOW Line with application of 2 LC Filters in Cascade

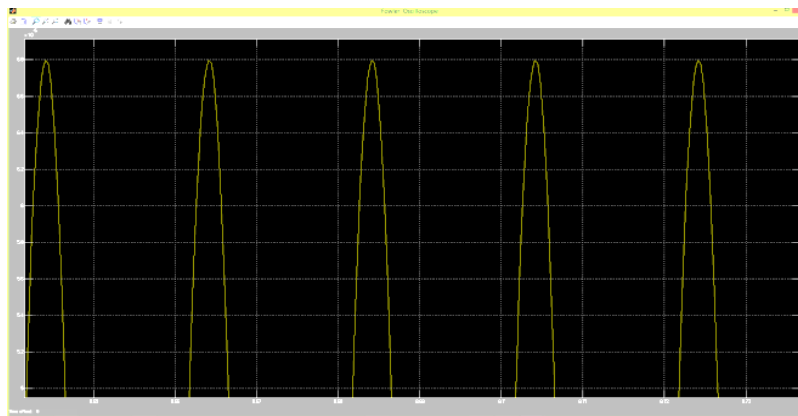


Figure 9c: Result showing the Output Bus Voltage at FOW with the application of 2 LC Filters in Cascade

Generally, the Impedance /Frequency Characteristic plots show that the number of harmonics on ALG – FOW D/L reduced from 4 to 3 in all the cases for which the 4 configurations of filters were implemented. The only visible variations were observed in their peak harmonic impedance values and the output voltage at the receiving end (FOW) Bus. The value of percentage reduction in harmonic impedance magnitude when single RLC and LC filters were implemented on the line model were estimated to be approximately the same value of 46.05%.

The value for the cases where 2 RLC and 2 LC filters were separately implemented in cascade configurations, was estimated to be about 98.81%. This value is approximately 100% and therefore, implies that using these configurations on a 33kV D/L has a net suppressive effect on the impedance magnitude of harmonics generated when the D/L is in service. However, when the single RLC filters was introduced on the line, the voltage at the receiving end Bus at FOW was 32.99kV as shown in fig. 6b. with the addition of a second RLC filter on the D/L, the value of voltage at FOW Bus plummeted very significantly to 73.80V.

By changing the filter configuration on the D/L to a single passive LC filter, the voltage on FOW Bus was raised to 870V; whereas, with the addition of a second passive LC filter, the voltage drop across FOW Bus was observed to be about 6.80V as earlier mentioned.

5. CONCLUSION

It can therefore be inferred from the simulation results that although the overall harmonic level (or number of harmonics present) on the D/L gave the same result upon filter implementation, increasing the number of RLC or passive LC filters on a D/L would result in a reduction in the value of impedance magnitude of the harmonics on a D/L. However, this would result in an undesirable reduction in the output voltage at the tail-end of the line. It is also worthy of note that based on the results of the simulation, the RLC filter is preferable to the LC filter of the same configuration, for the purpose of harmonic control on a 33kV distribution line with harmonic-generation tendencies, as the RLC filters give higher output voltages.

It is therefore, highly recommended that in future studies related to this research work, a voltage boost converter can be introduced in the power system to resolve this undesirable effect of voltage drop. It should be noted also that the poor output voltage results were never a surprise as literature has it that passive filter approach to harmonic mitigation is often recommended for three phase four wire networks [5] (usually low voltage). Consequently, active filters may be applied to the same distribution line and then observe the difference in harmonic mitigation level, compared to passive filter applications.

6. CONTRIBUTIONS TO KNOWLEDGE

Research on previous work done on harmonic mitigation reveals that passive filter approach to harmonic mitigation was mostly applied to low voltage distribution networks, i.e. 3-phase-4-wire networks. This research, however, has successfully presented passive filter approach to harmonic mitigation on a high voltage network (i.e. a 33kV distribution network).

REFERENCES

- [1] Dugan, R.C., McGranaghan, M.F. and Beaty, H.W. *Electric Power Systems Quality*, McGraw Hill Company, 1996.
- [2] Siemens, *Harmonics in Power Systems - Causes, Effects and Control*, Siemens Industry Inc., Georgia, 2013.
- [3] Heydt, G.T. and Grady, W.M. "Distributed Rectifier Loads in Electric Power Systems" *IEEE Transactions on Power Apparatus and Systems*, PAS 109 no.9, September 1984, pp. 2452-2459.
- [4] Parthasarathy, S. and Jeyasri, E. "Harmonic Distortion Evaluation and Reduction in radial Distribution System", *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 3, 2014, pp. 113-117. eISSN: 2319-8753 / pISSN: 2347-6710.
- [5] Sher, A. H., Addoweesh, E. K. and Khan, Y. "Harmonics Generation, Propagation and Purging Techniques in Non-Linear Loads", *Department of Electrical Engineering*, King Saud University. Riyadh : INTECH, 2013, pp. 3-18.
- [6] Deckmann, S.M., et al. *Capacitive Compensation in Distribution Grid with Non-Linear Voltage Type Loads*. 2005. 8th Brazilian Power Electronics Conference - COPEB. pp. 399-403.
- [7] Dugan, E.C., et al. *Electrical Power Systems Quality*, McGraw-Hill, 2002.
- [8] Sriranjani, R. and Jayalalitha, S., "Comparison of Passive and Active Hybrid filter in Front-end System", *International Journal of Communication Engineering Applications*, IJCEA, 2012, Vol. 03, pp. 503-506.
- [9] Akagi, H. "Modern Active Filters and Traditional Passive Filters. Bulletin of the Polish Academy of Sciences Technical Sciences", Vol. 54, no. 3, 2006, pp. 255-269.
- [10] Bukka, S., et al., "Performance Analysis of Three Phase Shunt Hybrid Active Power Filter" *IJRET, International Journal of Research in Engineering and Technology*, Vol. 03, 2014, pp. 256-263. eISSN: 2319-1163 / pISSN: 2321-7308.
- [11] Diwan, S., Inamdar, H.P. and Vaidya, A.P. "Simulation Studies of Shunt Passive Harmonic Filters: Six Pulse Rectifier Load Power Factor Improvement and Harmonic Control" *International Journal on Electrical and Power Engineering*, ACEE, 2011, Vol. 02, pp. 1-6.
- [12] Diwan, S., Indamar, H. and Vaidaya, A. *Simulation Studies of Shunt Passive Harmonic Filters: Six Pulse Rectifier Load – Power Factor Improvement and Harmonic Control*, 2010, *Proceedings of International Conference on Advances in Electrical & Electronics*, pp. 205-211.
- [13] Brown, R. *Lecture notes: Harmonic analysis*. Department of Mathematics, University of Kentucky, Lexington. 2001.
- [14] Singh, B., Al-Haddad, K. and Chandra, A. "A Review of Active Filters for Power Quality Improvement. 6, 1999, *IEEE Transactions on Industrial Electronics*", Vol. 46, pp. 960-971.
- [15] Artega, J.M., Payan, B.M. and Mitchell, C.I., "Power Factor Correction and Harmonic Mitigation", *IEEE Industry Applications Conference*, Vol. 5, October 2000, pp. 3127-3134.
- [16] Srivastava, K.K., Shakil, S. and Pandey, A.V., "Harmonics and Its Mitigation Technique by Passive Shunt Filter", *International Journal of Soft Computing and Engineering*, Vol. 2, 2013, pp. 325-331. ISSN: 2231-2301.
- [17] Das, J. *Passive Filter Potentialities and Limitations* *IEEE Transactions on Industry Applications*, Vol. 40, 2004,
- [18] Maswood, A.I. and Haque, M.H. "Harmonics, Sources, Effects and Mitigation Techniques", *Second International Conference on Electrical and Computer Engineering*, ICECE, 2002, pp. 26-28.