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*Original Article*

# Analysis of Harmonics in Goma Power Distribution System

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**ABSTRACT**
Non-linear load is the major element in a network to rise harmonics due to its characteristics. Harmonics are creating a lot of problems and disturbing the electrical network such as malfunction of electrical devices, efficiency reduction as well as reduction of the effective lifetime of electrical devices. This paper proposes a study of harmonics and analysis of filter to be implemented in order to remove higher-order harmonics and total harmonic distortion of current in the electric power systems of Goma that can be a key for proper connection to a smart grid for any network and to move to it in Goma network. Simulation results in Matlab/Simulink are presented and compared for the distorted IEEE-519 - 15kV without filtering and with a passive filter as well as an active filter.
**Keywords:** power quality, harmonics, smart grid, active filters, passive filter, network.

## INTRODUCTION

Actually, several studies are oriented in how to move from conventional electrical grid to a smart grid. However, many requirements are necessary to get a smart grid which presents a lot of advantages and facility; among which is power quality. Power quality is one of the most important characteristics found in a smart grid that include harmonics, flicker, reactive power balance, voltage imbalance, transients and interruption also considered as issues. Due to these issues, harmonics play a major role in the PQ. Many factors are at the origin of harmonics in a network. The use of non-linear loads in industry and domestic application such as variable electrical drives, computers, furnaces, electronic ballast, industrial process controls, UPS systems, medical equipment, public light. have led to the flow of load currents encompassing odd harmonics, which are integral multiples of the fundamental frequency[1], resulting in distortion in the shape of the current consumption curve. At power plants, the generated electricity has an almost sinusoidal shape of the voltage curve. Consequently, the shape of the voltage curve is distorted in the transmission and distribution of electric energy over electrical networks of different voltage levels[2]. Current harmonics in distribution networks cause several problems, the main being increased neutral current in four-wire systems, overload and over the temperature of system components, extra losses, mechanical oscillations in motors, insulation failures, unpredictable behavior of protection systems, interference with communication systems, etc.[3]. To eliminate harmonics in a network, filters are used. There are analog filters composed with passive and active filters included FIR and IIR; where the passive is constructed by a proper arrangement of inductors and capacitors and the active one is composed of power semiconductor switches, inductors, and capacitors. The distribution network in Goma is facing the same problem of harmonics and power quality in general. Its installed power reach to 50MVA which is apportioned to $7(seven)$ distribution lines HTA/BT with a supply voltage of $15KV$ or $6.6KV$ presented in the table 1 below.

**Relevant conflicts of interest/financial disclosures**: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

**Table 1: installed power of Goma's distribution network[4]**

| | **Centre feeder** | **South feeder** | **North feeder** | **Route Sake feeder** | **Monusco feeder** | **Sotraki feeder** | **Total [KVA]** |
|---|---|---|---|---|---|---|---|
| Installed Power [KVA] | 7, 875 | 12 900 | 3 970 | 16 575 | 630 | 8 050 | 50 000 |
| Supply voltage [KV] | 15 | 15 | 15 | 15 | 15 | 6.6 | |

However, the power supply does not reach the above value of installed power due to a shortage of production. The power suppled in Goma various between $5\ and\ 10\ MW$ [5]. This network is also suffering with a lot of losses, an important part of those losses is created by harmonics. The *table 2* and *figure1* below described the losses of each feeder, where we find active and reactive losses.

**Table 2: Active and reactive losses in Goma's network[6]**

| | Centre feeder | South feeder | North feeder | Route Sake feeder | Sotraki feeder | **Total** |
|---|---|---|---|---|---|---|
| Active losses [KW] | 219.6 | 179.8 | 22.15 | 558.8 | 267.34 | 1,247.69 |
| Reactive losses [KVar] | 257.5 | 210.9 | 25.97 | 888.2 | 318.02 | 1,700.59 |

This paper proposes to compare according to the results obtained, performances, advantages and even disadvantages of using different filters to make a choice which one is better to be used to remove harmonics of course by reducing power losses in this network with a major aim to give it a way to start moving in a smart grid and to improve the grid efficiency.

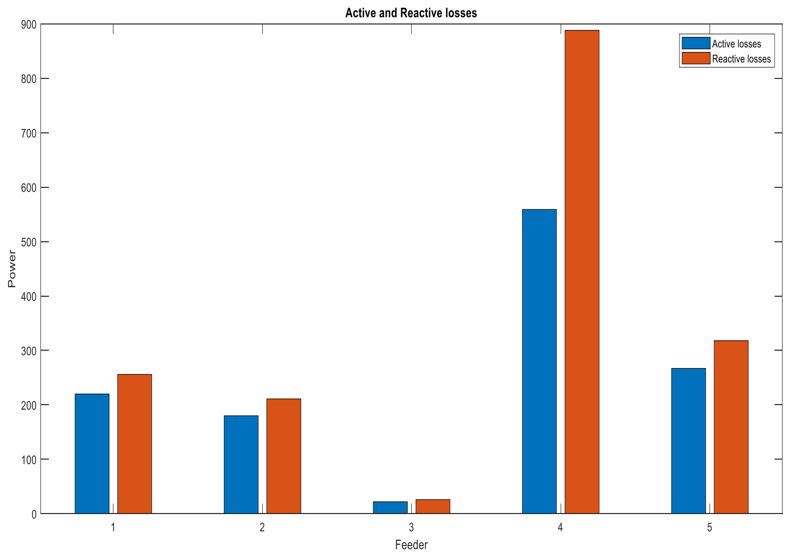


**Figure 1: Active and reactive losses**

## I. Smart grid

Many definitions related to the term smart grid can be found. According to [7]define a smart grid as an electricity network that can intelligently integrate the actions of all users connected to it generators, consumers and those that do both in order to efficiently deliver sustainable, economic and secure electricity supplies. A smart grid is characterized by a lot of factors [7] namely first flexibility (enable active participation by consumers), secondly accessibility (accommodate all generation and storage options), thirdly reliability (enable new products, services, and markets), fourthly economic (provide power quality for the digital economy), interactive (provide an appropriate information regarding the status of the system). A smart grid has many benefits [8] which can be **technical** (Energy efficiency improvement, Grid reliability improvement, Quality of supply, Improved connection and access of the grid), **environment**

(Reduction in carbon emissions, Climate change), **electricity market.**

## II. Harmonics and its risks

A harmonic is multiple wavelengths produced by another wavelength, which has an amplitude and frequency. It is characterized by factors called total harmonic distortion (*THD*), that are calculated regarding voltage and current respectively by the equation (1) and (2):

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_f} \times 100\% \quad (1)$$

$$THD_U = \frac{\sqrt{\sum_{n=2}^{\infty} U_h^2}}{U_f} \times 100\% \quad (2)$$

Where $I_f$ and $U_f$ are respectively fundamental values of current and voltage. $I_h and\, U_h$ represent the component of current and voltage with harmonic order *h*. To characterize the number of harmonic currents in relation to the nominal line current the distortion factor *TDDi* (*total demand distortion*) is used. The line current *I*L is the maximum current throughout 15- or 30-minute intervals or the nominal current of the point of common coupling (PCC)[9]

$$TDD_i = \frac{\sqrt{\sum_{h=2}^{40} (I_h)^2}}{I_L} \quad (3)$$

In practice [9] there can be harmonics of very high order (up to 200th), but usually, harmonics are measured up to the 25th or 50th order. Harmonics higher than this are very low (less than 0.1%). According to international standards as [10],[11] the necessary compatibility between distribution networks, consumers and electrical products and give limits for harmonic currents and voltages. It should be noted that none of these standards is so far in a way compulsory requirement in DRC special in Goma. Referring to the IEEE 519 [12],[13], the total harmonic distortion factor has to be *THDu* 5 % and the limit value for each individual harmonic voltage is 3% shown in *table 3* and so *the table 4* below shows for current harmonic.

**Table 3: Voltage distortion limits [13]**

| Bus voltage $V$ at PCC | Individual harmonic (%) | Total harmonic distortion THD (%) |
|---|---|---|
| $V \leq 1.0$ kV | 5.0 | 8.0 |
| 1 kV < $V \leq$ 69 kV | 3.0 | 5.0 |
| 69 kV < $V \leq$ 161 kV | 1.5 | 2.5 |
| 161 kV < $V$ | 1.0 | 1.5[a] |

**Table 4: Current distortion limits for systems rated 120 V through 69 kV [13]**

| Maximum harmonic current distortion in percent of $I_L$ | | | | | | |
|---|---|---|---|---|---|---|
| Individual harmonic order (odd harmonics)[a, b] | | | | | | |
| $I_{SC}/I_L$ | $3 \leq h < 11$ | $11 \leq h < 17$ | $17 \leq h < 23$ | $23 \leq h < 35$ | $35 \leq h \leq 50$ | TDD |
| < 20[c] | 4.0 | 2.0 | 1.5 | 0.6 | 0.3 | 5.0 |
| 20 < 50 | 7.0 | 3.5 | 2.5 | 1.0 | 0.5 | 8.0 |
| 50 < 100 | 10.0 | 4.5 | 4.0 | 1.5 | 0.7 | 12.0 |
| 100 < 1000 | 12.0 | 5.5 | 5.0 | 2.0 | 1.0 | 15.0 |
| > 1000 | 15.0 | 7.0 | 6.0 | 2.5 | 1.4 | 20.0 |

Where, $I_{SC}$ is maximum short circuit current at the point of common connection (PCC) and $I_L$ maxim the um current drawn by the installation (fundamental) at PCC. Harmonics have different impacts in a network, such impact can be either instants effects (energy losses, disturbance of low current lines, inadvertent tripping and installation shutdowns, vibrations, and noises) or effect in long term due to overheating (heating, aging, consequences on the neutral conductor).

## III. Characterization of nonlinear load

A load supplied by a voltage source of equation (4),

$$v(t) = V.\sin(\omega t) \quad (4)$$

It absorbs a current $i(t)$ of a form:

$$i(t) = I_1\sqrt{2}\sin(\omega t - \varphi_1) + \sum_{n=2}^{\infty} I_n\sqrt{2}\sin(n\omega - \varphi_n) \quad (5)$$

Its power expressions are:

$$S = V * I \quad (6)$$

$$P = VI_1\cos\varphi_1 \quad (7)$$

$$Q = V\,I_1\sin\varphi_1 \quad (8)$$

Normally the apparent power should be generated by the fundamental current $I_1$ from the equation (5) which will create (9), due to the presence of harmonics in the grid the one used is (6) and we are seeing that the effects of harmonics in a network because (6) is greater than (9).

$$S_1 = V\,I_1 = \sqrt{P^2 + Q^2} \quad (9)$$

where $P$ and Q represent the real and reactive power measured

at the network side, respectively.

Thus, there is a distortion power expressed by the equation (10) below:

$$D = \sqrt{S^2 - (P^2 + Q^2)} = \sqrt{S^2 - S_1^2} \quad (10)$$

This power (10) above leads to those impacts of harmonics in a network described previously in this paper. Figure 2 below shown that for non-linear load the current it is not pure sine as it could comparatively with its voltage supply.

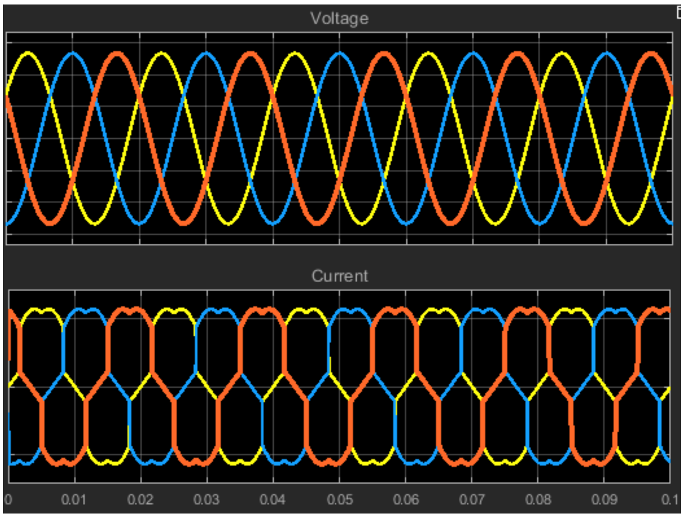


**Figure 2: Signal characteristic of a non-linear load**

## IV. Filters

### 1. Passive filter

The term passive filter is used for filters that are realized using only passive, or lossless, circuit elements, i.e., inductors, capacitors, transformers, gyrators, and resistors, which cannot increase the signal energy. Most of these circuit elements have corresponding passive implementations. Passive filters are generally utilized to eliminate 5th and 7th harmonics which have higher amplitudes. The functionality of these filters is dependent on the system impedance.[14]

### 2. Active filter

Active power filters (APFs) are solutions used for compensation of harmonic currents from nonlinear loads. The considered active filter is a parallel filter of medium power, which works on low voltage level in the supply network of industrial plant, where a significant number of frequency converters are connected.[15]

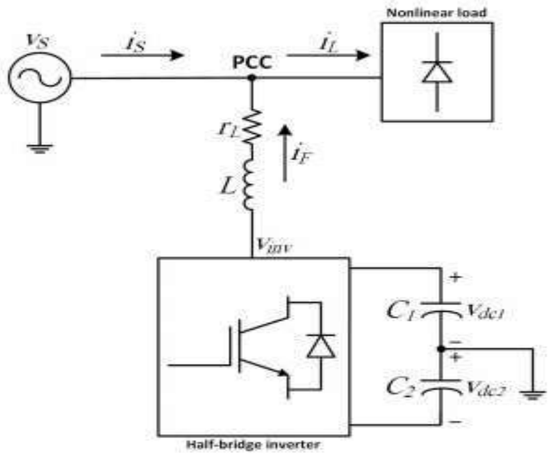


**Figure 3: Single-phase shunts active power filter.**

The filter is connected in parallel to the network in the substation to a common bus on the secondary side of the transformer. The filter is connected in parallel to the network in the substation to a common bus on the secondary side of the transformer. It monitors current in each phase and processes the data of current sensors from the power network using a fast-digital signal processor. The filter regulates the state of the network so that it actively injects into the network interfering signals of opposite polarity. There are several possibilities of the use of parallel active filters. They differ both in the placement of the filter into the structure and in the used control algorithm. The two basic functions of filters are harmonic currents filtering and compensation of reactive current[16]. The maximum value of the injected current is given by the formula:

$$I_{filter} = \sqrt{I_h^2 + I_Q^2} \tag{11}$$

where *Ih* is harmonic current and *IQ* is reactive current. Active filter in the compensation mode of reactive power can provide a very fast, precise and continuous compensation Injected reactive current of the filter is given by the formula:

$$I_{filter} = \sqrt{I_Q^2} \tag{12}$$

## 3. Hybrid filters configurations

Hybrid filters are comprised of active and passive filters. The main aim of utilizing such filters is the reduction of active filters power which leads to the decrement of these filters' cost. Covering the disadvantages of passive and active filters, hybrid filters effectively eliminate harmonics and compensate reactively power. Regarding different passive and active filters connection in a hybrid filter, various configurations of hybrid filters is possible[14] *figure 3* below shows one of the configurations.

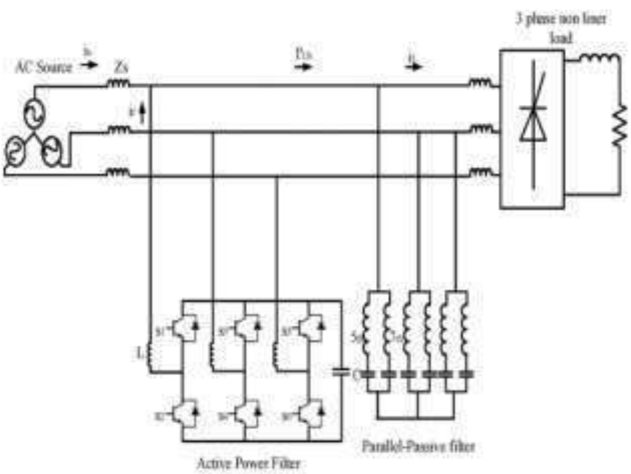


**Figure 4: Parallel connection of passive and active filter and load[14]**

## V. Simulation results and discussion

Goma's network is composed of five feeders as shown in *figure5*. It is been noticed that in this network the current has a high total harmonic distortion and each feeder is suffering from the same problem, therefore the *table2* shows the power losses in the network. The aim of this paper was to see if in that loss there is a part from harmonics and table 5 as well as figures as figure 6,7,8,9,10 show it.

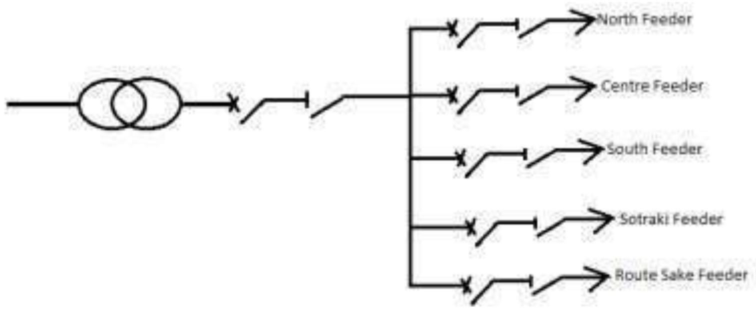


**Figure 5: Structure scheme of Goma network**

To get our result we used Matlab/Simulink for simulation where the data in table 1 were used in order to get the losses which are in table 2. Figure 6 above shows the different blocs used for our simulation.

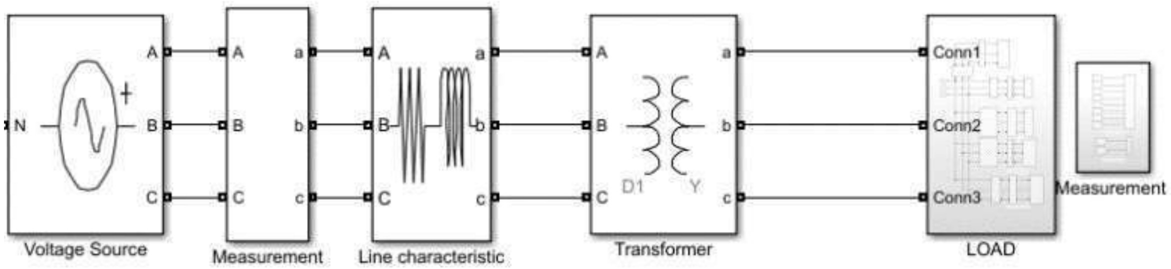


**Figure 6: Simulation scheme**

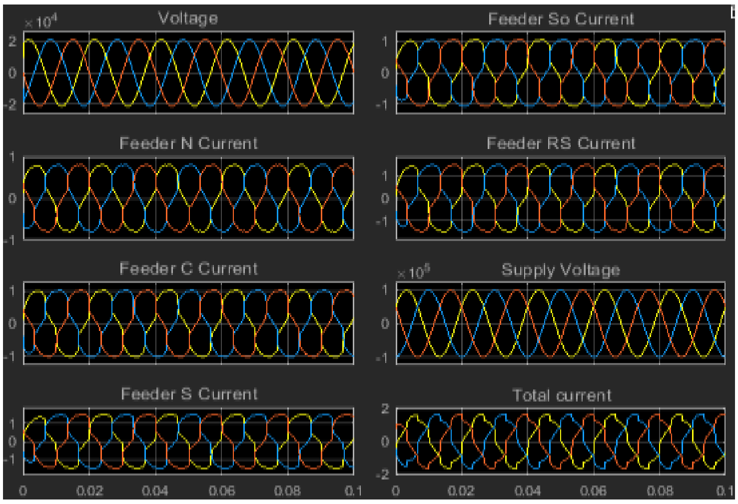


**Figure 7: Waveform of the currents and voltages for each feeder**

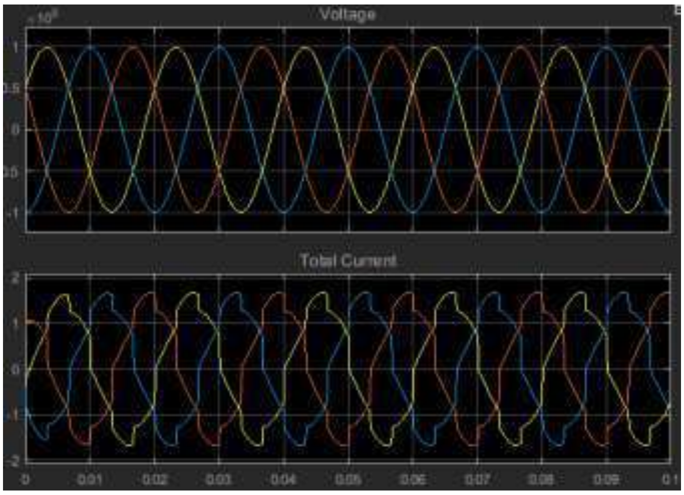


**Figure 8: Waveform of Supply voltage and current at the network side**

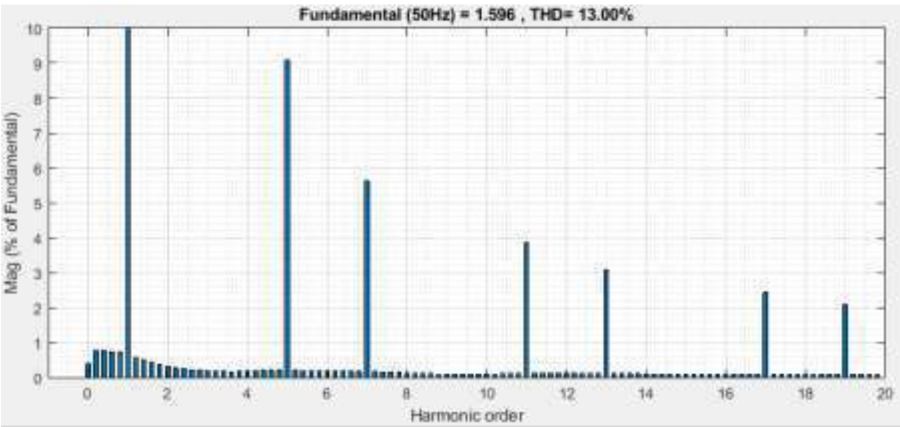


**Figure 9: harmonic order and THD at the network side**

**Table 5: Percent of harmonics relative to the fundamental frequency**

| Order Harmonic | North Feeder | South Feeder | Centre Feeder | Route Feeder | Sotraki Feeder | Grid |
|---|---|---|---|---|---|---|
| 5 | 9.3 | 11.7 | 10.52 | 11.64 | 10.78 | 9.09 |
| 7 | 5.24 | 7.51 | 6.23 | 7.28 | 6.53 | 5.62 |
| 11 | 3.84 | 5.06 | 4.41 | 4.94 | 4.56 | 3.87 |
| 13 | 2.92 | 4.09 | 3.44 | 3.98 | 3.59 | 3.07 |
| 17 | 2.41 | 3.02 | 2.77 | 3.14 | 2.88 | 2.43 |
| $THD_I$% | 12.21 | 17.58 | 14.95 | 17.06 | 15.54 | 13.00 |

According to IEEE-519 standard as shown in the table 4, the results found in the table 9 above as well as in the figures 7,8,9,10 and 11 are not understandable, which show the presence of harmonics in the network which have also an economic impact.

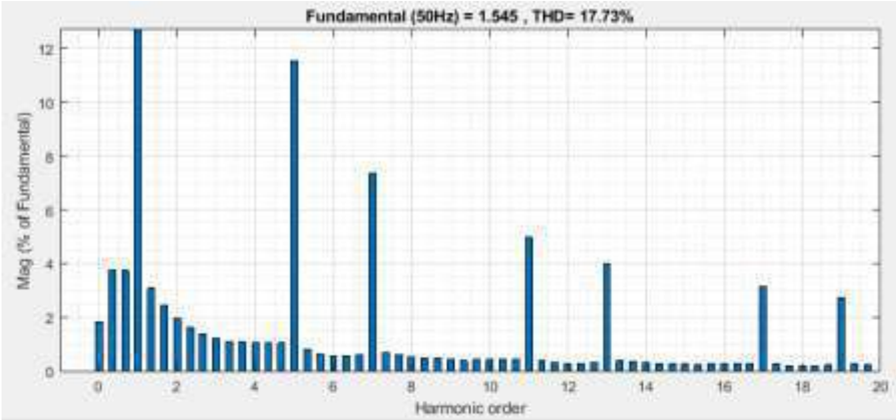


**Figure 10: harmonics order at South Feeder**

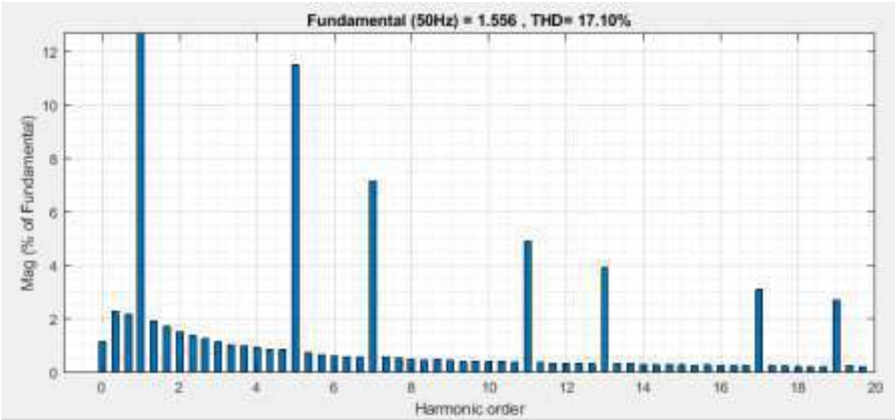


**Figure 11: harmonics order for Route Sake feeder**

In order to reduce the network harmonics and to reach the standard IEEE-519 harmonics prosed, we have use filters which will play two roles, firstly compensation of reactive power and lastly to eliminate the order harmonics as well as to reduce the total harmonic distortion. The table 6 and figure 12,13,14,15,16 show the current waveform after filtering.

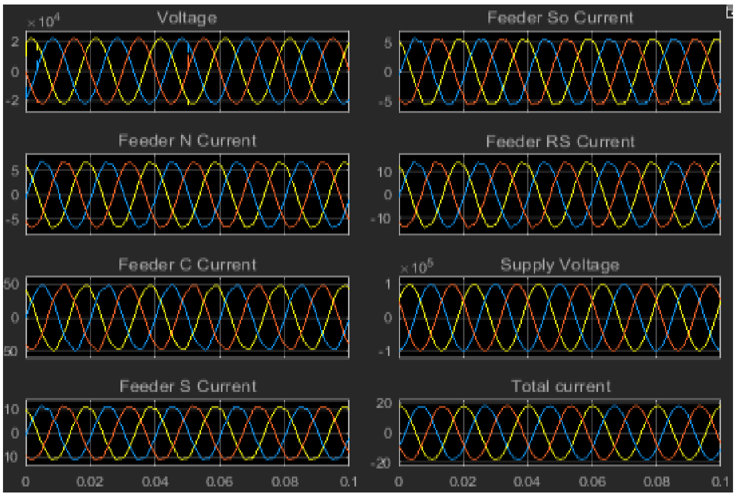


**Figure 12: Waveform of currents and voltages after filtering for each feeder**

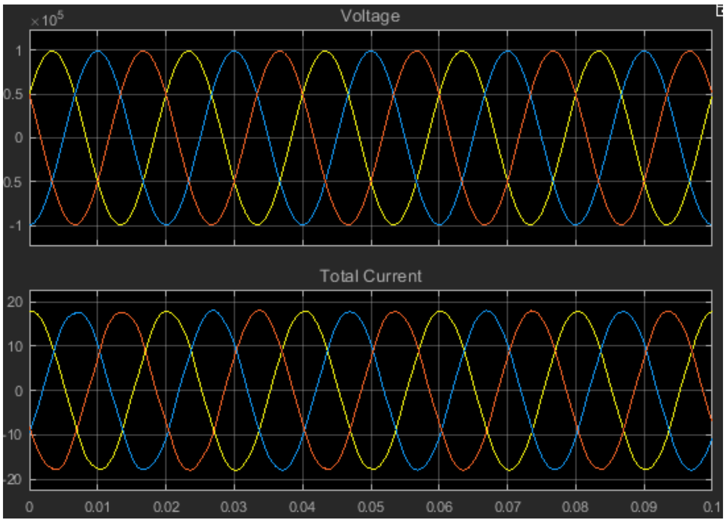


**Figure 13: Waveform of supply voltage and current after filtering at the network side**

**Table 6: Percent of harmonics relative to fundamental frequency after filtering**

| Order Harmonic | North Feeder | South Feeder | Centre Feeder | Route Feeder | Sotrak Feeder | Grid |
|---|---|---|---|---|---|---|
| 5 | 0.64 | 1.17 | 2.30 | 0.83 | 1.62 | 0.88 |
| 7 | 1.53 | 2.06 | 0.79 | 1.83 | 2.20 | 0.43 |
| 11 | 0.29 | 0.15 | 0.08 | 0.14 | 0.27 | 0.02 |
| 13 | 0.09 | 0.08 | 0.05 | 0.08 | 0.10 | 0.01 |
| 17 | 0.02 | 0.10 | 0.02 | 0.02 | 0.22 | 0.05 |
| $THD_I$% | 1.8 | 2.58 | 2.59 | 2.17 | 2.98 | 1.25 |

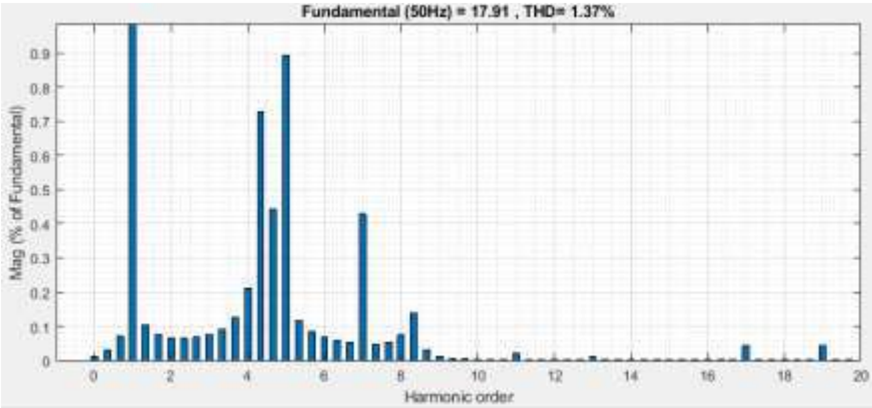


**Figure 14: harmonics order and THD of the network after filtering**

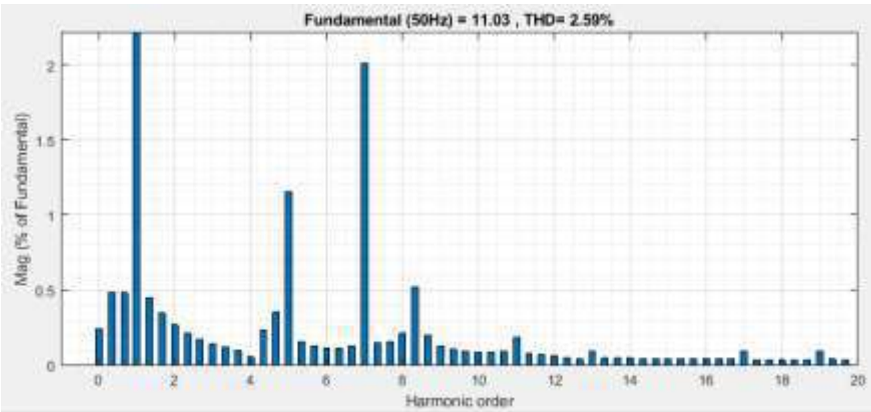


**Figure 15: harmonics order and THD for South feeder after filtering**

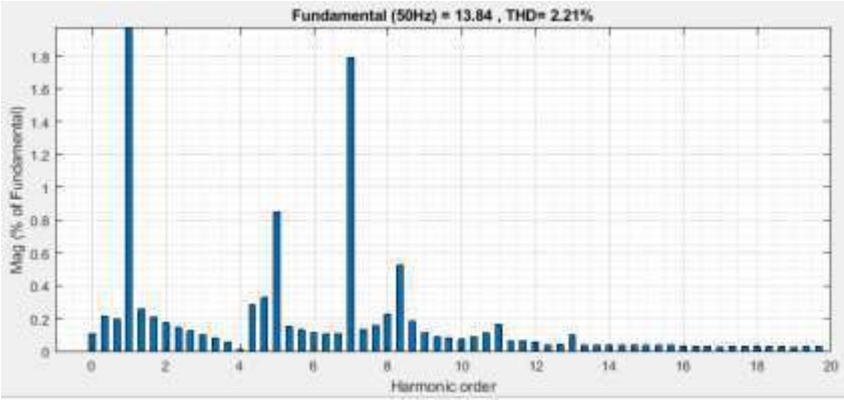


**Figure 16: harmonics order for Route Sake and THD after filtering**

Passive filter, as well as active filter, have been used to get the results. For both, it is possible to find the same THD and order harmonics but the issue lies in the size. For passive filter, it required a big size of capacitors as well as capacitor reactive power to reduce the THD and eliminate order harmonics especially the non-odd multiple of the fundamental frequency as it is shown in figure 17. Based on how active filter works and comparatively to passive filter size used, the size of the active filter was very small to get the same results. Therefore, we are suggesting to implement the active filter so that it can be used to remove dynamically order harmonic and THD which are also dynamic due to the load in a network.

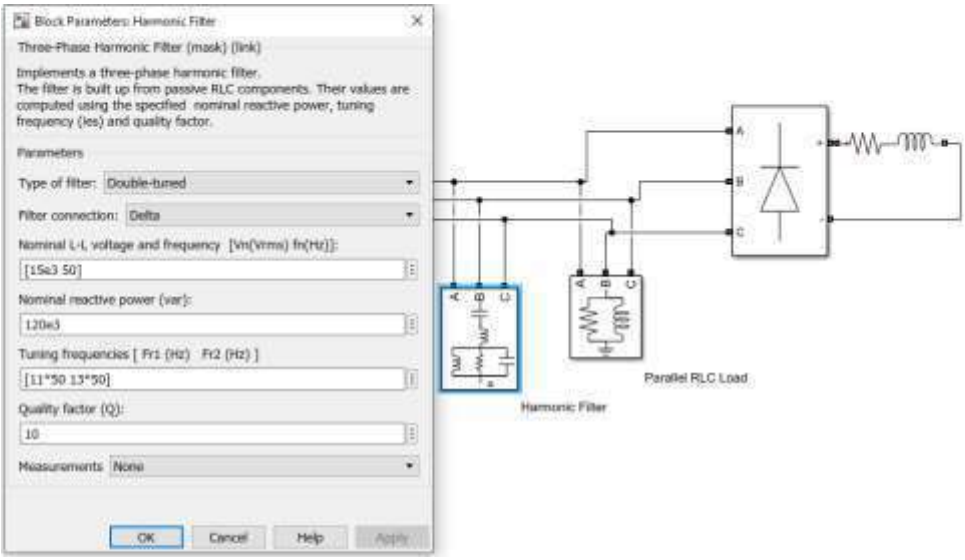


**Figure 17: Parameter harmonic passive filter**

## CONCLUSION

This paper studied the harmonics order and total harmonic distortion in the network of Goma and analysed the filters which implemented have been made and the results are presented in this paper. It is shown that the high harmonics order for each feeder were 5,7,11,13,17 and 19$^{th}$ where other order harmonics were inconsiderable according to their percent harmonics while the THDs was 13% for the network side before filtering and 1.25% after using filters, 12.21% for North feeder which has been reduced to 1.8% after filtering, 17.58% for south feeder due to its number of supply transformers and loads was reduced to 2.58%, from 14.95% to 2.59% for centre feeder, 17.06% for Route sake caused by number of supply transformers and its distance as well as its loads and 15.54% to 2.98% for Sotraki feeder after filtering. These results were found by using both filters namely, passive filter and active filter. However, by using the passive filter it had required a big size of the capacitor and remain static while harmonics are dynamic followed the various of the current load but by using active it had required an average size of the capacitor.

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