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IMPROVEMENT OF POWER QUALITY IN AN ELECTRICAL DISTRIBUTION NETWORK USING SELECTED SHUNT HARMONIC FILTERS

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ABSTRACT: This study examined the harmonic mitigation potential of five shunt power filters which are shunt passive filter (SPF), shunt active filter (SAF), hybrid shunt passive and shunt active filter (SASPF), fuzzy based shunt active filter (FLCSAF) and hybrid fuzzy based shunt active and shunt passive filter (FLCSASPF) in an industrial power network by considering the electrical distribution network layout of a typical beverage company (7-Up Bottling Company) in Ibadan, Nigeria. The network was modelled and simulated with and without the considered filters in MATLAB/Simulink environment. The voltage and current total harmonic distortions (V_{THD} and I_{THD}) before and after the application of filters were determined, analysed and compared. The simulation results showed that the network's voltage and current waveforms before filters' application were distorted with estimated V_{THD} and I_{THD} of 6.084 and 19.790%, respectively. The SPF, SAF, FLCSAF, SASPF and FLCSASPF use on the network minimized the V_{THD} from 6.084 to 0.780, 1.311, 1.289, 0.730 and 0.720%, respectively, while the I_{THD} was mitigated from 19.790 to 2.448, 4.163, 4.074, 2.240 and 2.227%, respectively. These results are indications that although all the five shunt filters considered have the capacity to mitigate harmonic distortion on the network considered, however, the performance of FLCSASPF is superior over other filters; producing the least V_{THD} and I_{THD}. This study established that appropriate use of fuzzy logic with hybrid configured shunt filters in an electrical distribution network is suitable for power quality enhancement.

Keywords: Electrical distribution network, Harmonic distortion, Non-linear loads, Power quality, Shunt filters, Industry

1. Introduction

The industrial and technological developments witnessed across the globe in recent times have increased the non-linear loads penetration in an electrical distribution network, a system that interfaces the consumers with the power grid. Widespread use of non-linear loads aids disruption of the optimum operating state of the power distribution networks due to harmonics generation resulting from their usage. This has, therefore, made harmonic mitigation in power systems a crucial power quality problem [1-6]. Some of the common non-linear loads that produce harmonics include computers, arc furnaces, high voltage direct current transmission, fluorescent lighting, adjustable speed drives among others.

Varieties of techniques have been deployed in literature to mitigate harmonic distortion in power system networks [7-11]. These include phase-shifting loads, harmonic filters and system reconfiguration. Among these techniques, harmonic filters have been reported to exhibit superior performance [12-15]. Harmonic filters are broadly categorised as active, passive or hybrid filters. Passive filters which act as frequency discriminators provide a path of low impedance for grounding harmonic components using passive elements such as resistor, inductor and capacitor and. Active filters on the other hand employ active components such as insulated-gate bipolar transistor to generate negative harmonics to cancel out the deleterious effects of harmonics injected into power networks by the non-linear loads [5]. These filters can compensate harmonics of several orders, hence, preventing the risk of network impedance-filter resonance. They equally adapt suitably to load fluctuations and changes in the power system network [4]. Hybrid harmonic filters combine the merits of both active and passive filters with respect to reliability, efficiency and price. The filters serve as a better approach for harmonic mitigation, overcoming the issues of physical limitations of passive filters and high cost involved with the use of high-capacity active power filters [16].

Aside classifications into active, passive and hybrid filters, harmonic filters are also categorized based on connection mode as series and shunt filters. While series filters are configured serially, shunt filters are parallel configured. Shunt harmonic filters (SHFs) are more commonly employed in power system applications because of their ability to create a path of low impedance for currents grounding on one or more harmonic frequencies [17]. More so, SHFs are more economical compared to series harmonic filters since the component parts are rated only for a portion of the system's voltage unlike the series filters whose component parts are rated for full system's current [18]. This requirement leads to a smaller size and lower cost for SHFs [17], [18]. Therefore, the goal of this study was to examine the effects of selected SHFs for improvement of power quality in an electrical distribution network.

2. Materials and Methods

2.1 Harmonics Estimation Indices

Total harmonic distortion of voltage and current, V_{THD} and I_{THD}, are key indices for power quality analysis [19, 20]. V_{THD} and I_{THD} provide respective measure of the total deviation or variation in voltage and current at harmonic frequencies in relation to fundamental frequency value. Mathematically, V_{THD} and I_{THD} are expressed by (1) and (2), respectively [19, 20]:

$$V_{THD} = \sqrt{\frac{\sum_{h=2}^{\infty} {V_h}^2}{{V_1}^2}} \times 100\% \tag{1}$$

$$I_{THD} = \sqrt{\frac{\sum_{h=2}^{\infty} {I_h}^2}{{I_1}^2}} \times 100\% \tag{2}$$

where V_1, V_h, I_1, and I_h are system fundamental voltage, voltage of harmonic component h, system fundamental current and current of harmonic component h respectively.

2.2. Design of Shunt Passive Harmonic Filter

2.2.1. Single Tuned Passive Filter

An inductor and a capacitor connected in series as shown in Fig. 1 constitute a single tuned passive filter (STPF). The reactor's intrinsic resistance, R, in Fig. 1 is usually deployed to prevent overheating of the filter. Any harmonic current will find a path of low impedance through the STPF if its frequency coincides with that of the filter [21]. The values of the components of the filter circuit are determined from (3) and (4) while (5) expresses the filter impedance:

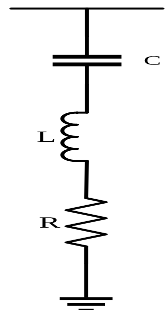

Fig. 1: Schematic diagram of a single tuned filter

$$C = \frac{Q}{2\pi f V^2} \quad (3)$$

$$L = \frac{1}{(2\pi f)^2 C} \quad (4)$$

$$Z = R + j\,(X_L - X_C) \quad (5)$$

where Q, V, f, C, L, X_C and X_L are filter reactive power at fundamental frequency, filter voltage level, fundamental frequency, filter capacitance, filter inductance, capacitive reactance and inductive reactance.
X_C and X_L are expressed by (6) and (7), respectively as:

$$X_C = \frac{1}{j\omega c} \quad (6)$$

$$X_L = j\omega L \quad (7)$$

where ω is the angular frequency given by (8) since X_C and X_L of a filter circuit are equal at resonant frequency.

$$\omega_n = \sqrt{\frac{L}{C}} \quad (8)$$

The tuning index of the filter, n, is given by (9):

$$n = {f_n}/{f} \quad (9)$$

where f_n is the filter' tuned frequency.
The resonant frequency, f_o, of a STPF circuit is expressed by (10) while the quality index, Q, which defines the tuning sharpness of a STPF has been determined elsewhere [13] and it is given by (11):

$$f_o = \frac{1}{2\pi\sqrt{LC}} \quad (10)$$

$$Q = \frac{X_0}{R} = \frac{\sqrt{L/C}}{R} \quad (11)$$

where X_0 is the leading (capacitive) or lagging (inductive) reactance at the tuned frequency.

2.2.2. Double Tuned Filter

Figure 2 depicts a double tuned filter (DTF) circuit consisting of a series coupling of a capacitor, C_1 and an inductor, L_1 serially connected and a capacitor, C_2 and an inductor, L_2 connected in parallel. The parallel STPF equivalent of a DTF in Fig. 2 is shown in Fig. 3. Values of filter's components in Fig. 2 are obtained from (12) and (13) [22]:

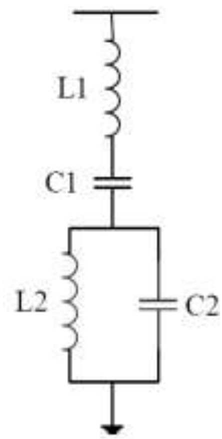

Fig. 2: DTF configuration

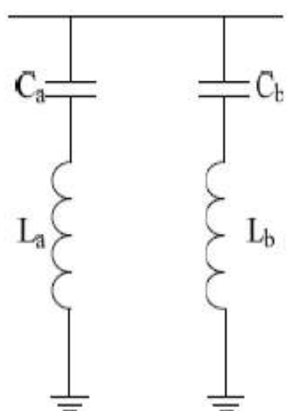

Fig. 3: Parallel STPF configuration

$$\omega_s = \frac{1}{\sqrt{L_1 C_1}} \tag{12}$$

$$\omega_p = \frac{1}{\sqrt{L_2 C_2}} \tag{13}$$

where ω_s and ω_p are series filter angular frequency and parallel filter angular frequency respectively.

The angular frequencies ω_a and ω_b of the parallel STPF circuit in Fig. 3 are given by (14) and (15), respectively [22]:

$$\omega_a = \frac{1}{\sqrt{L_a C_a}} \tag{14}$$

$$\omega_b = \frac{1}{\sqrt{L_b C_b}} \tag{15}$$

Since the DTF and parallel STPF of Figs. 2 and 3, respectively, are equivalent, (16) to (22) are obtained:

$$\omega_a \omega_b = \omega_s \omega_p \tag{16}$$

$$C_1 = C_a + C_b \tag{17}$$

$$L_1 = \frac{1}{C_a \omega_a^2 + C_b \omega_b^2} \tag{18}$$

$$\omega_s = \frac{1}{\sqrt{L_1 C_1}} \tag{19}$$

$$\omega_p = \frac{\omega_a \omega_b}{\omega_s} \tag{20}$$

$$L_2 = \frac{\left(1 - \frac{\omega_a^2}{\omega_s^2}\right)\left(1 - \frac{\omega_a^2}{\omega_p^2}\right)}{C_1 \omega_a^2} \tag{21}$$

$$C_2 = \frac{1}{L_2 \omega_p^2} \tag{22}$$

Hence, with the parameters L_1, C_1, L_2, C_2, L_a, C_a, L_b and C_b determined, the operation of DTF and parallel STPF circuits in Figs. 2 and 3 respectively can be fully defined.

2.3 Design of Shunt Active Filter

A SAF circuit applied on the basis of equivalent harmonic current injection to cancel out the impact of the original distorted current waveform is shown in Fig. 4. The rating of the filter's power converter employed for compensation requirements imposed by the load is determined from (23) [23]:

$$S_{SAF} = \frac{\sqrt{(sin\emptyset_1)^2 + THD^2}}{\sqrt{1 + THD^2}} S_{load} \tag{23}$$

where $\emptyset_1$ is the load power factor angle.

The filter's rating is, however, obtained from (24) if harmonic compensation only is required.

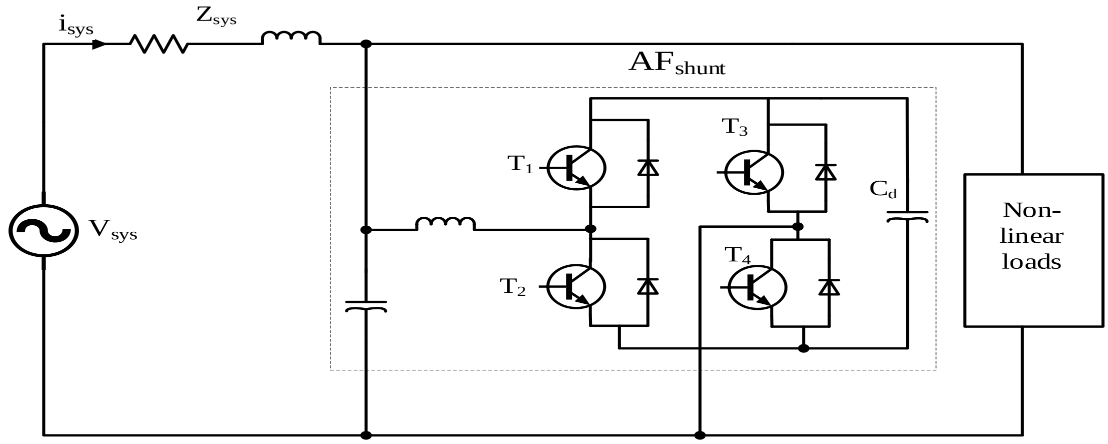

Fig. 4: Shunt configuration of a single-phase active filter [24]

$$S_{SAF} = \frac{THD}{\sqrt{1+THD^2}} S_{load} \quad (24)$$

where S_{load} is the load power rating.
The dc-link capacitor design is achieved by determining the generated active power by the power converter into the system based on (25) which modifies into (26):

$$P_{conv}(t) = P_s(t) - P_l(t) = \overline{P}_{conv} + \tilde{P}_{conv} \quad (25)$$

$$\bar{p}_{conv} = \frac{1}{2}(V_s I_l - V_s I_{l(1)} cos\emptyset_1) \quad (26)$$

where $\overline{P}_{conv}$, $\tilde{P}_{conv}$, V_s, I_l , $I_{l(1)}$ and $cos\emptyset_1$ are dc component of $P_{conv}(t)$, ac components of $P_{conv}(t)$, grid voltage, load current, fundamental load current and load power factor respectively. Hence, the energy stored in the dc-link capacitor is obtained from (27):

$$\frac{1}{2} c\Delta V_c{}^2 = (\overline{P}_{conv} - P_{loss})\Delta t \quad (27)$$

The ripple of the dc-link voltage is expressed by (28):

$$\Delta V_c = \sqrt{\left(\frac{\left(V_s I_l - V_s I_{l(1)} Cos\emptyset_1\right) - 2ploss}{c}\right)\Delta t} \quad (28)$$

Equation (28) expresses the dc link voltage's ripple as a function of the capacitor energy and based on this energy; the dc-link capacitor design is possible. The filter's inductor is designed via the same procedure.

2.4. Design of Hybrid Filter

A combination of passive and active filters results in a hybrid filter formation. All the harmonic currents in the system are confined to passive filter by an active filter which serves as the load's compensator. This, therefore, prevents the possibility of series and parallel resonance. The hybrid filters employed in this study were derived from the shunt passive and shunt active filters presented in previous subsections and these comprised SASPF, FLCSAF and FLCSASPF.

2.5. Fuzzy Logic

Two of the harmonic filters considered in this study were applied based on fuzzy logic. Fuzzy logic is one of the basic techniques for non-linear systems modeling and offers enormous capabilities for handling uncertainties to achieve the desired state [25]. The key stages involved in the fuzzy logic implementation for this study are:

(i) Fuzzification: This stage involves the classical data conversion into membership functions.
(ii) Inference process: This stage involves the fuzzy rules application to membership functions to produce the fuzzy outputs.
(iii) Defuzzification: This stage involves fuzzy outputs conversion into a single output value.

2.6. Test Network and Simulation Environment

This study considered the electrical distribution network layout of 7-Up Bottling Company as a test system. The 7-Up Bottling Company situated in Ibadan, Nigeria receives its power supply from a dedicated 33 kV feeder, stepped down through a 33 MVA power transformer to 11/0.415 kV. The Company has four 500 kVA generators as a back-up. One-line diagram of the diagram of the Company's distribution network is delineated in Fig. 5 with Table 1 showing the major load requirements. The network layout in Fig. 5 was modelled and simulated in MATLAB/Simulink environment. The Simulink model of the network is shown in Fig. 6.

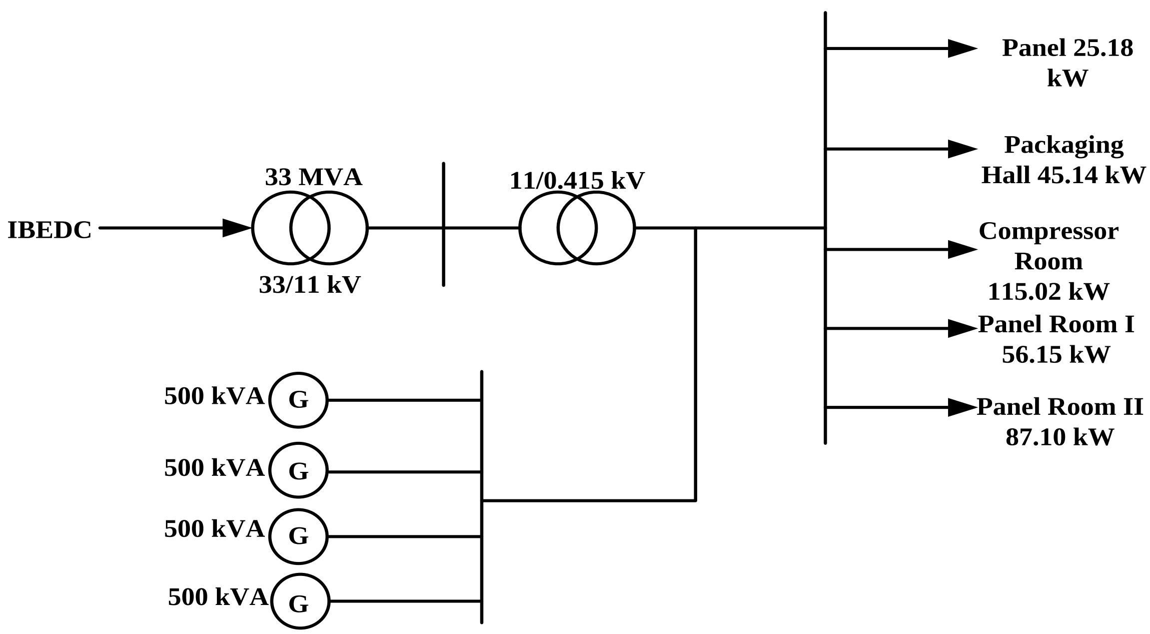

Fig. 5: One-line diagram of 7-Up Bottling Company electrical distribution network

Table 1: 7-Up Bottling Company major load requirements

Loads	S(kVA)	P(kW)	Q(kVAr)
Panel	30.70	25.18	18.43
Packaging Hall	56.03	45.14	33.61
Compressor Room	140.27	115.02	84.16
Panel Room I	68.48	56.15	41.09
Panel Room II	106.24	87.10	63.74

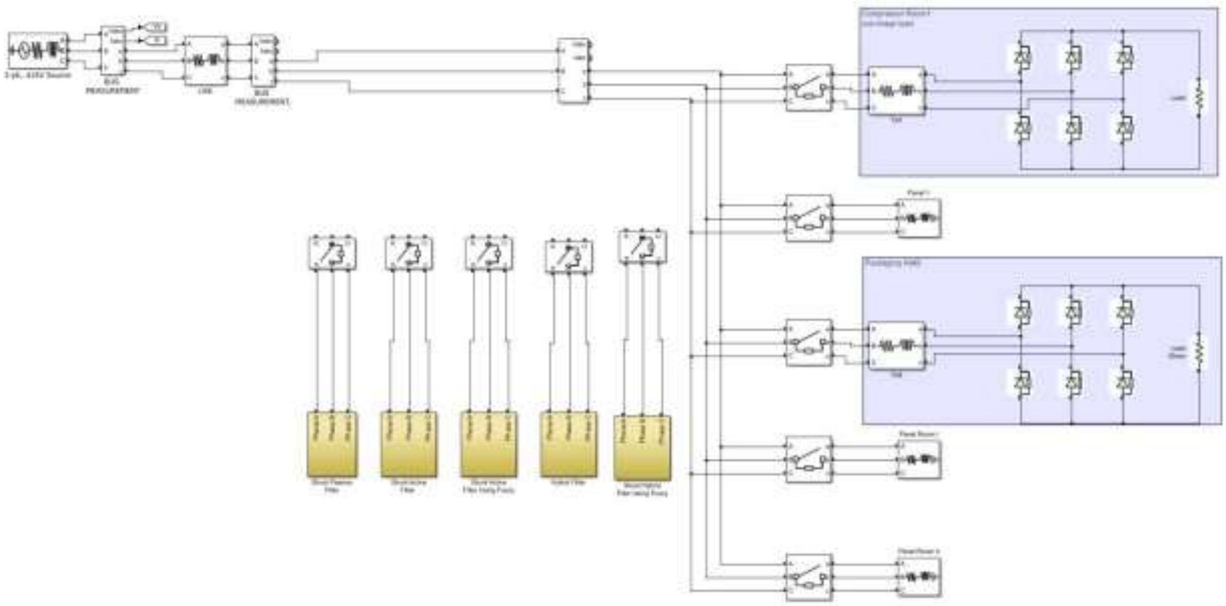

Fig. 6: Simulink model of 7-Up Bottling Company electrical distribution network

3. Results and Discussion

3.1. Results of 7-Up Bottling Company Electrical Distribution Network Simulation without Filter

Figures 7 to 10 present the obtained simulation results of the 7-Up Bottling Company distribution layout model in Figure 6 before the application of filters. The network's voltage and current signals are respectively depicted in Figs. 7 and 8 while the spectra of voltage and current harmonics are respectively shown in Figs. 9 and 10. Observing from Figs. 7 and 8, the voltage and current signals of the electrical distribution network of the bottling Company were found to be distorted, indicating the presence of harmonics. The V_{THD} and I_{THD} computed from Figs. 9 and 10 were 6.084 and 19.790 %, respectively. The V_{THD} and I_{THD} values recorded were above the voltage and current distortion limits of 5 and 16 %, respectively allowed on the distribution network [26-27].

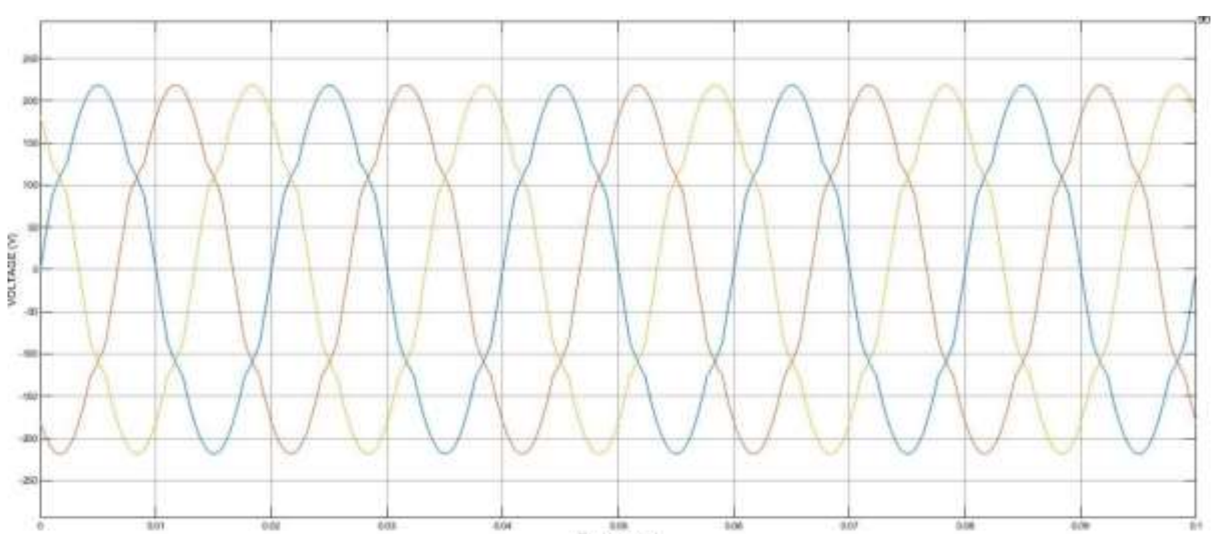

Fig. 7: The 7-Up Bottling Company distribution network voltage signal before filtering

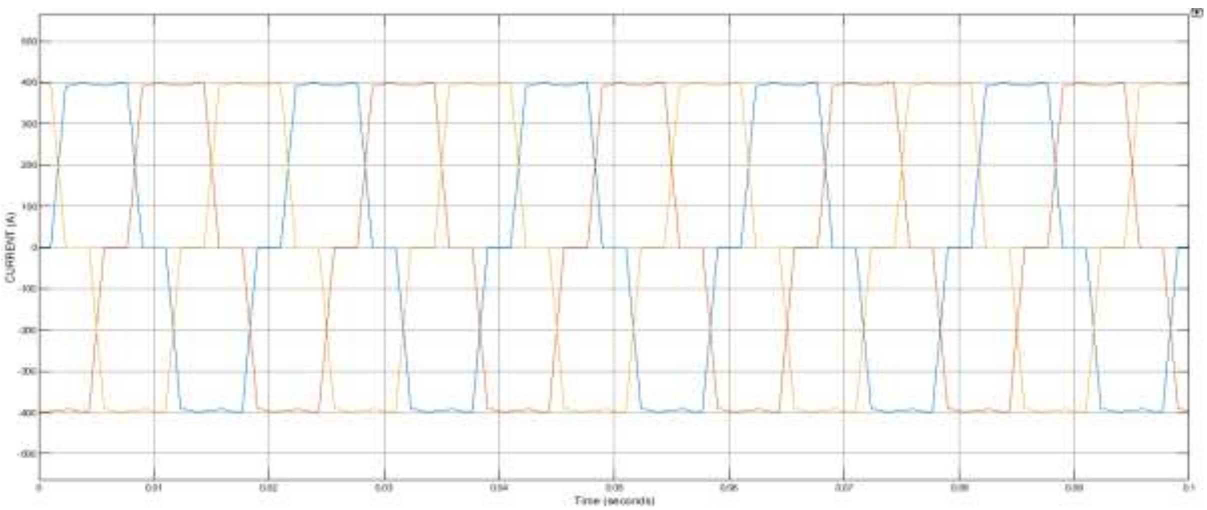

Fig. 8: The 7-Up Bottling Company distribution network current signal before filtering

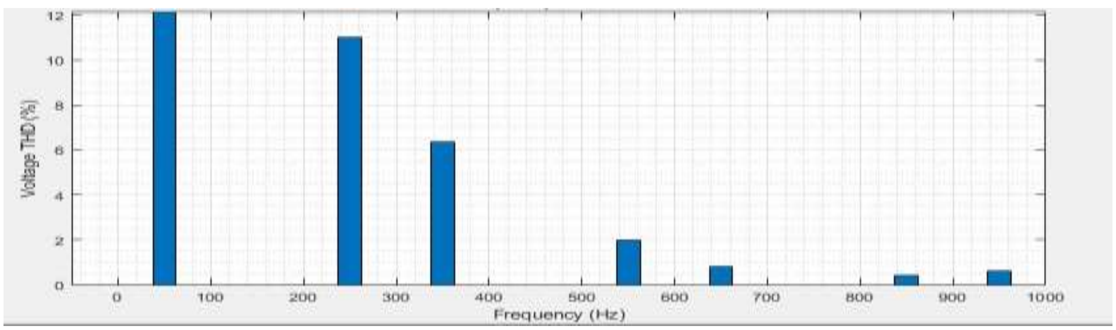

Fig. 9: Harmonic spectrum of 7-Up Bottling Company distribution network voltage before filtering

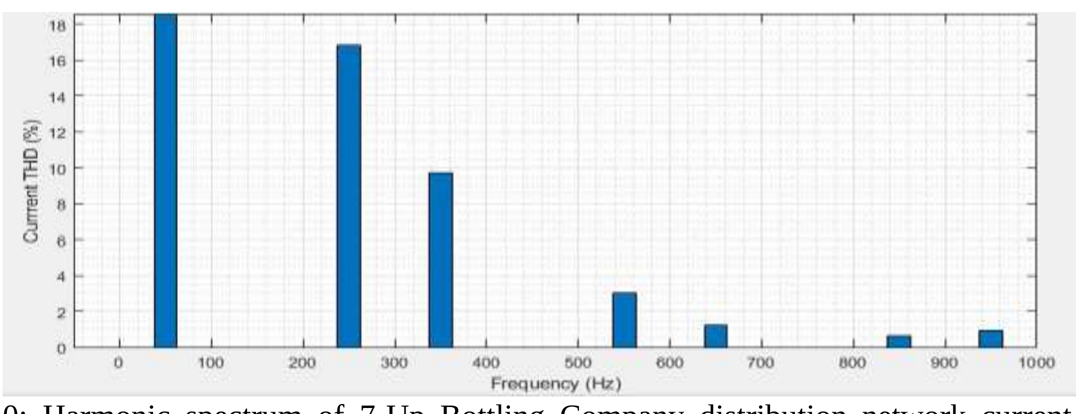

Fig. 10: Harmonic spectrum of 7-Up Bottling Company distribution network current before filtering

3.2. Simulation Results of Electrical Distribution Network of 7-Up Bottling Company with Filters

The results obtained when the 7-Up Bottling Company distribution network model of Fig. 6 was simulated with SPF, SAF, SASPF, FLCSAF and FLCSASPF are presented in Figs. 11 to 30.

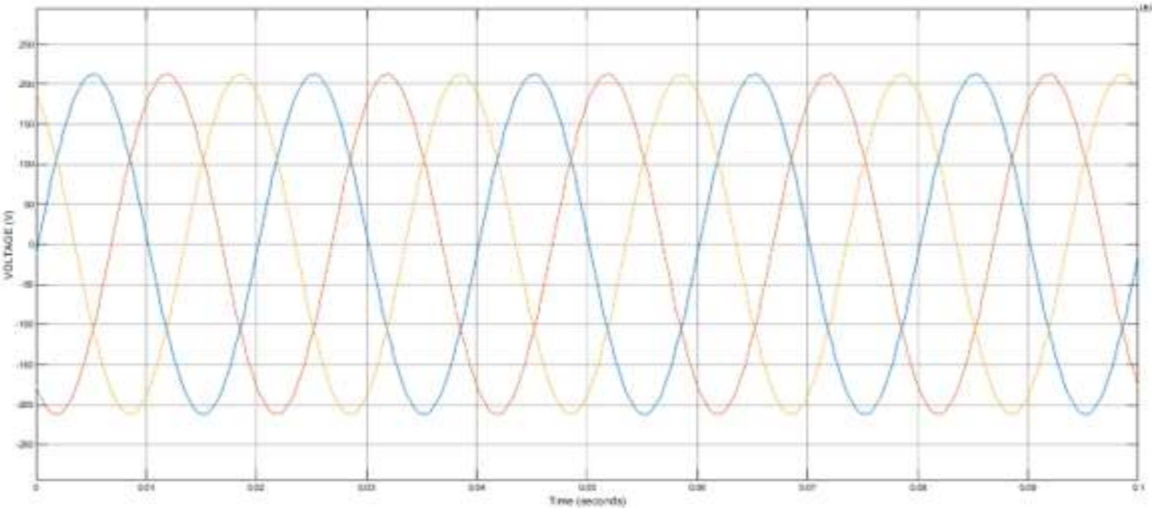

Fig. 11: The 7-Up Bottling Company distribution network voltage signal after SPF use

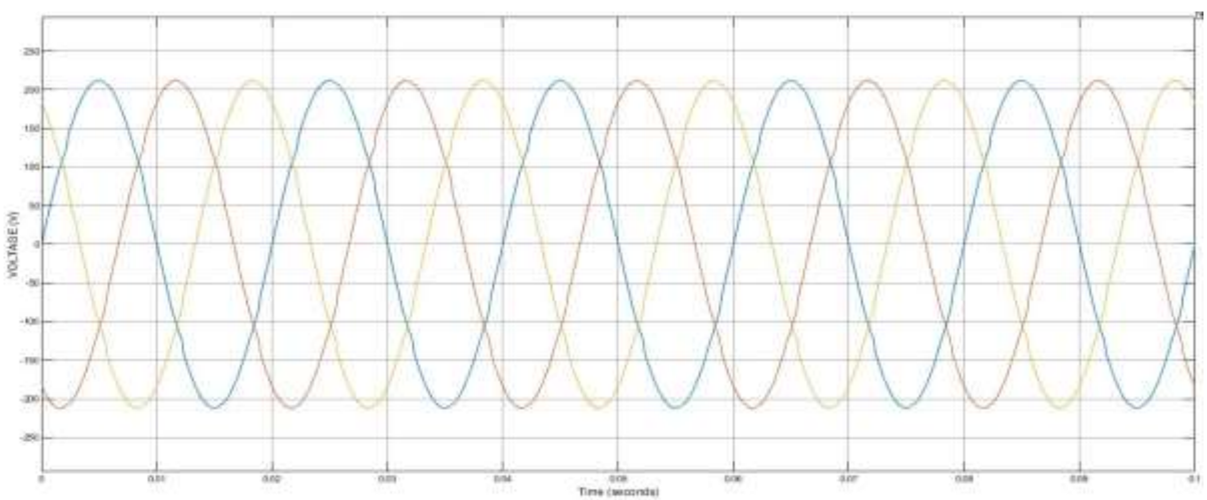

Fig. 12: The 7-Up Bottling Company distribution network voltage signal after SAF use

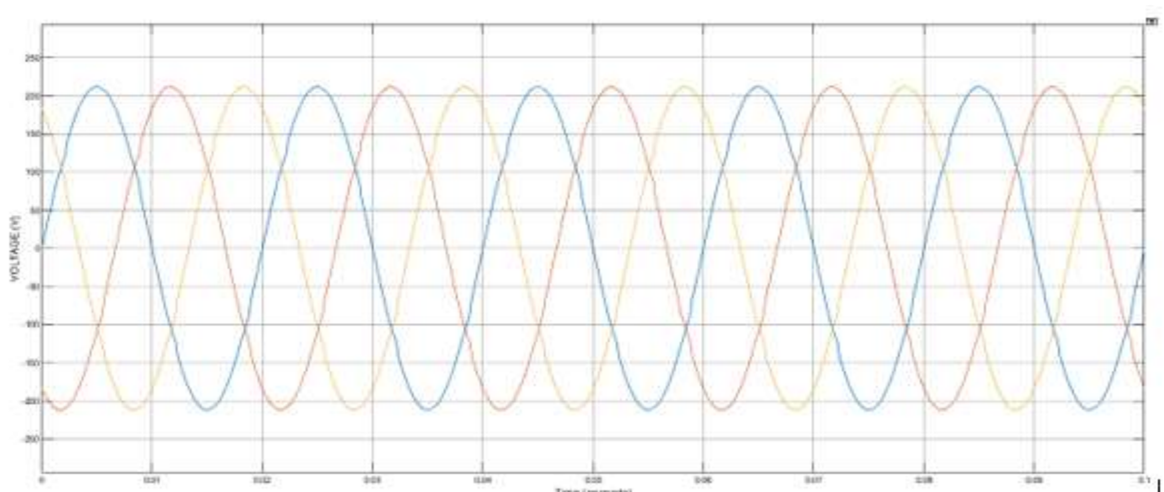

Fig. 13: The 7-Up Bottling Company distribution network voltage signal after FLCSAF use

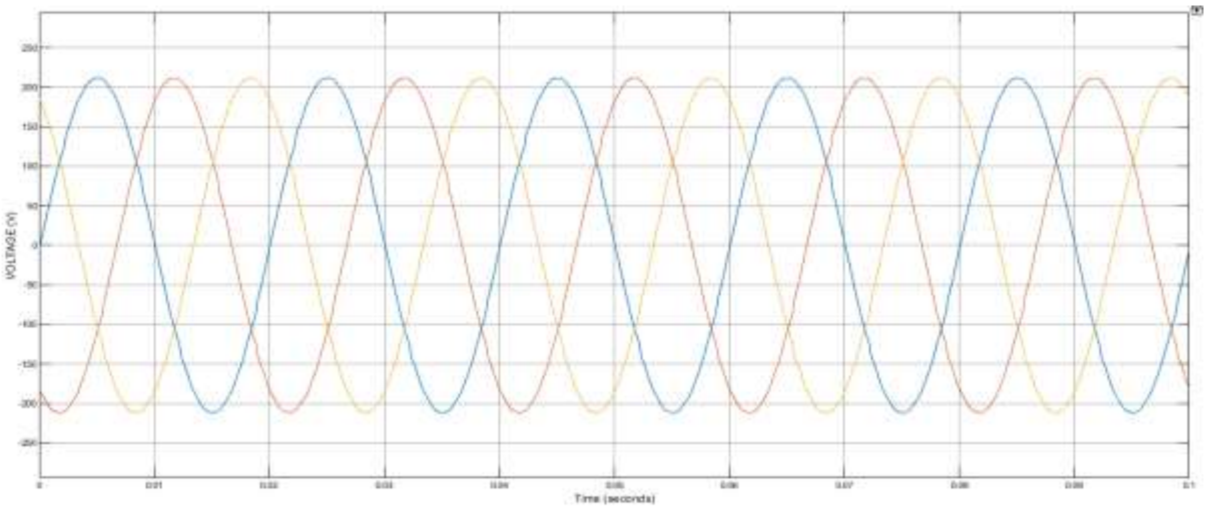

Fig. 14: The 7-Up Bottling Company distribution network voltage signal after SASPF use

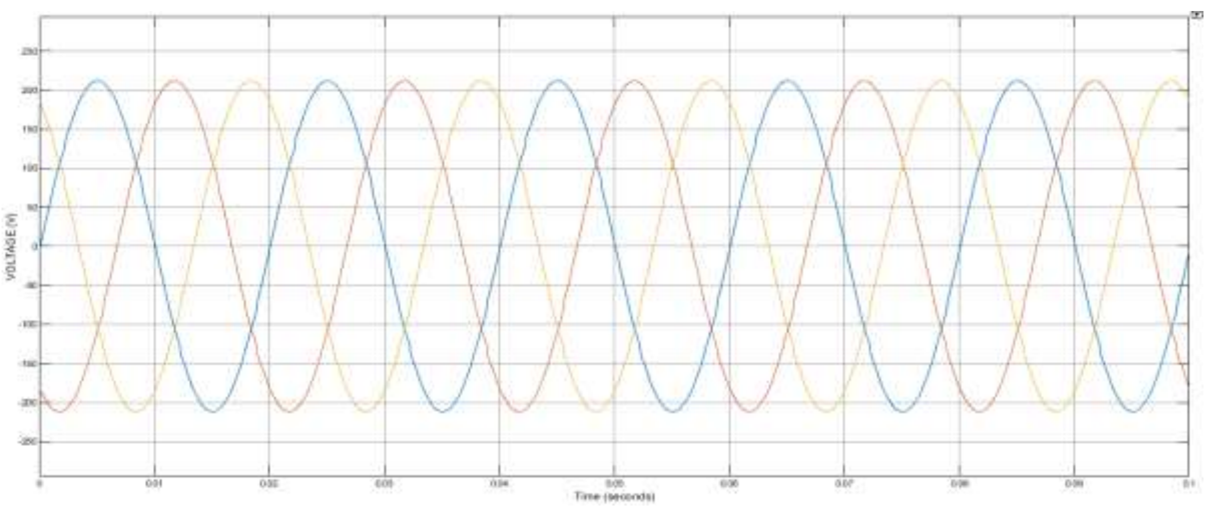

Fig. 15: The 7-Up Bottling Company distribution network voltage signal after FLCSASPF use

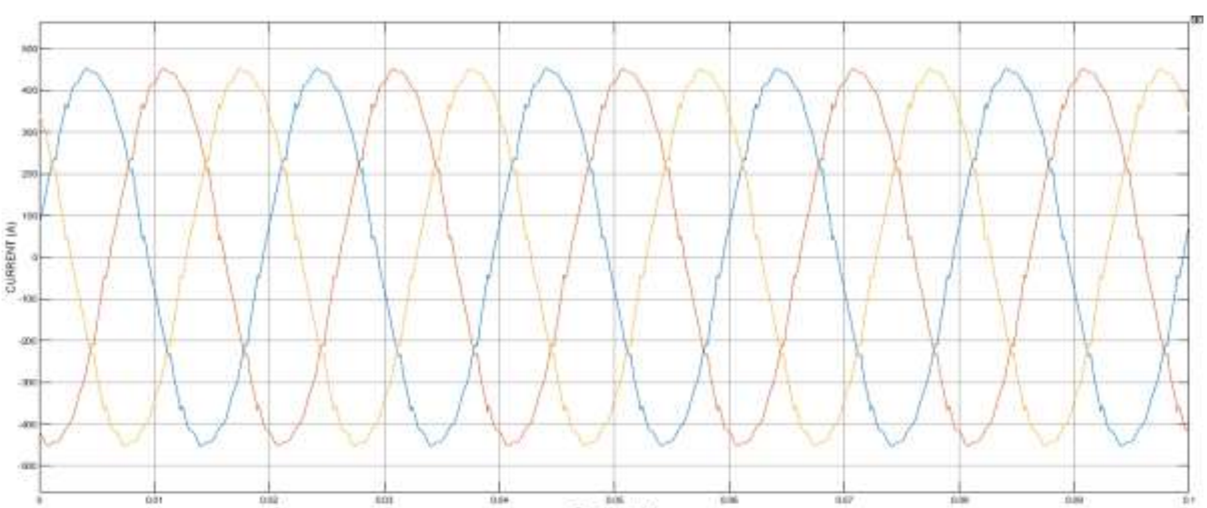

Fig. 16: The 7-Up Bottling Company distribution network current signal after SPF use

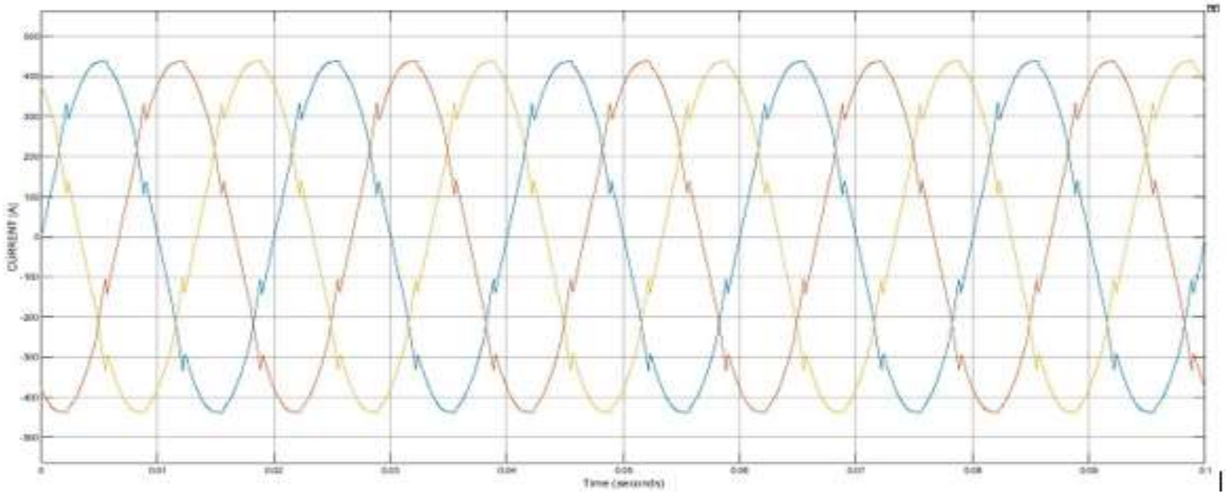

Fig. 17: The 7-Up Bottling Company distribution network current signal after SAF use

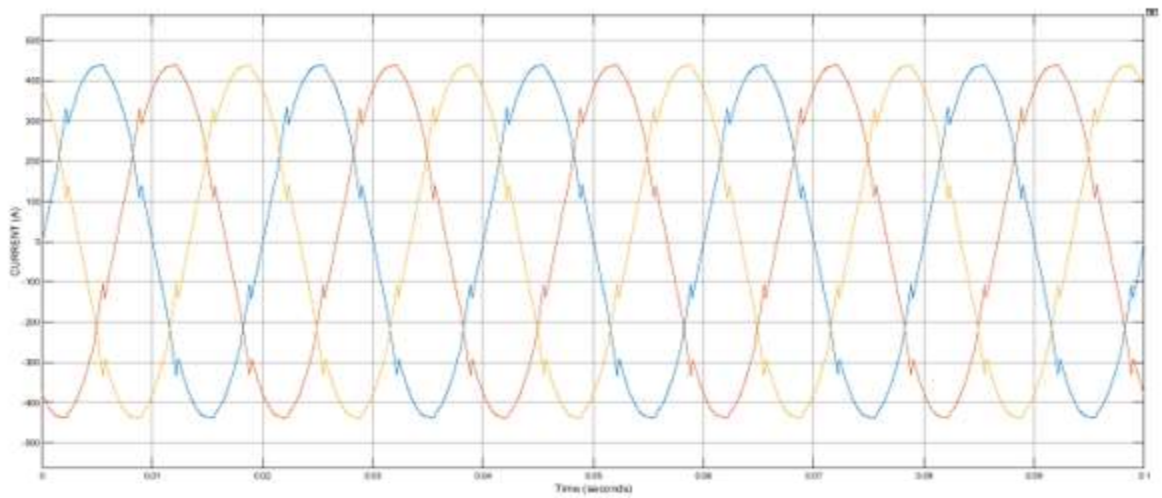

Fig. 18: The 7-Up Bottling Company distribution network current signal after FLCSAF

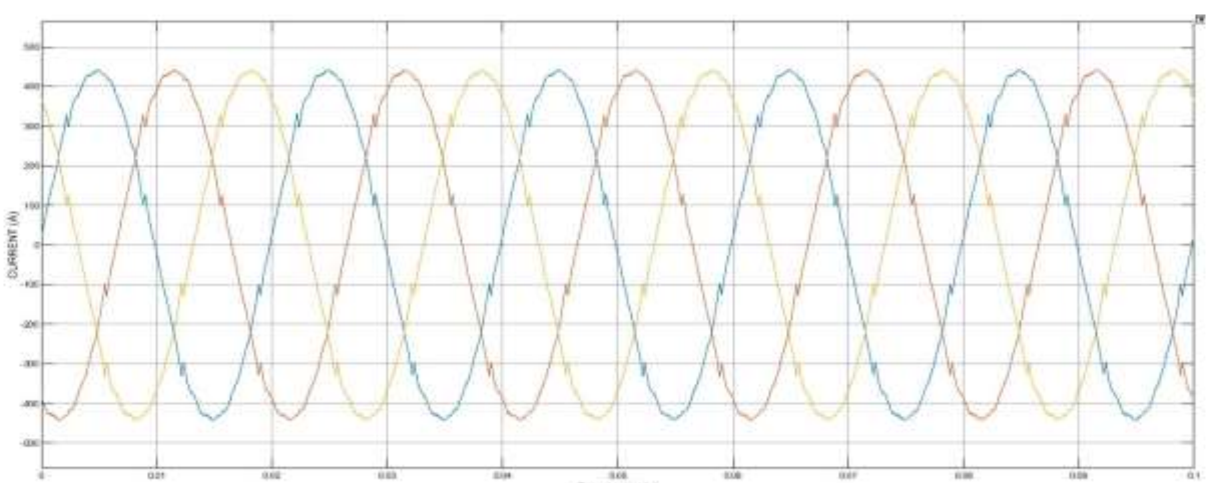

Fig. 19: The 7-Up Bottling Company distribution network current signal after SASPF use

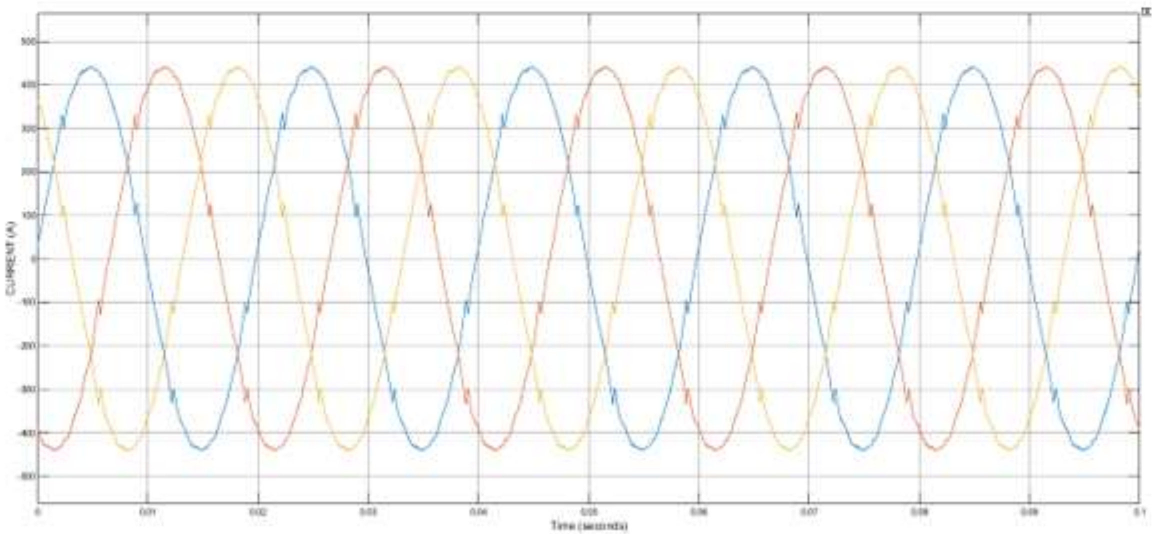

Fig. 20: The 7-Up Bottling Company distribution network current signal after FLCSASPF use

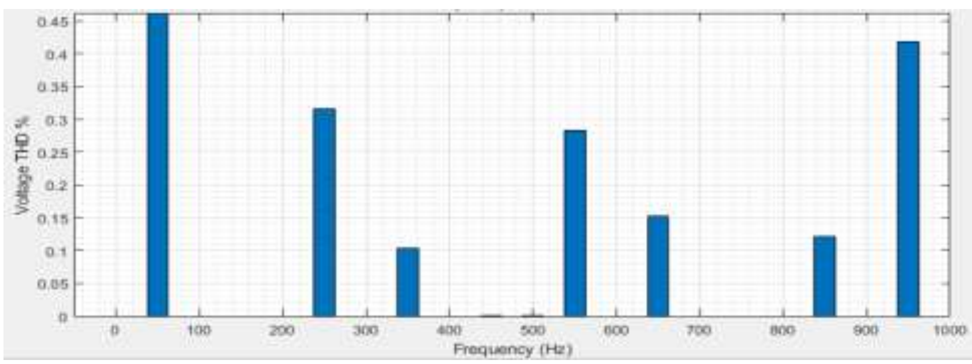

Fig. 21**:** Spectrum of voltage harmonics on 7-Up Bottling Company distribution network voltage after SPF use

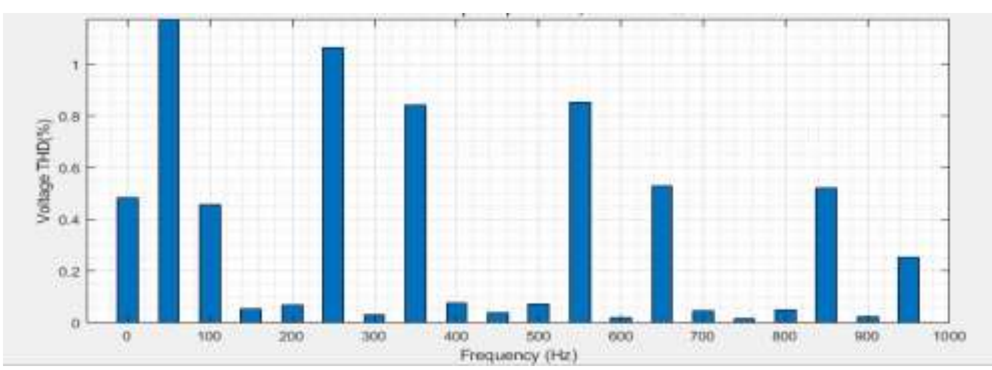

Fig. 22**:** Spectrum of voltage harmonics on 7-Up Bottling Company distribution network voltage after SAF use

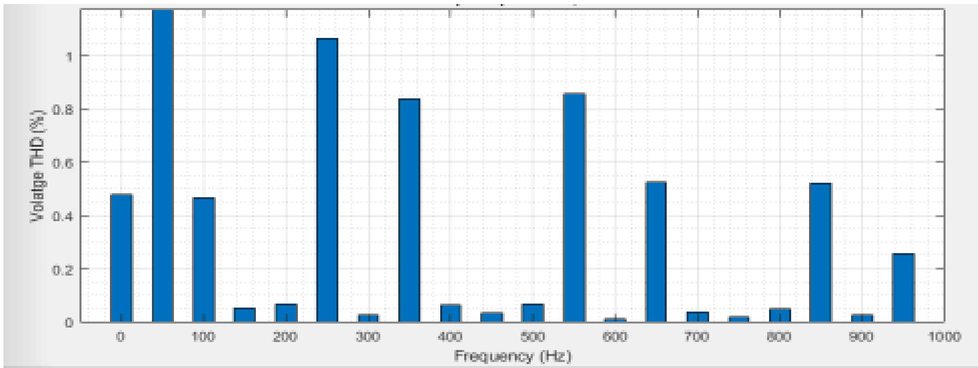

Fig. 23**:** Spectrum of voltage harmonics on 7-Up Bottling Company distribution network voltage after FLCSAF used

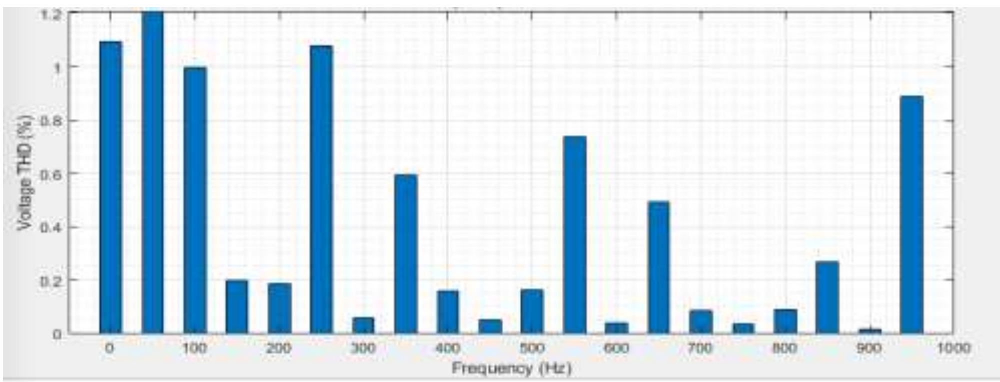

Fig. 24**:** Spectrum of voltage harmonics on 7-Up Bottling Company distribution network voltage after SASPF used

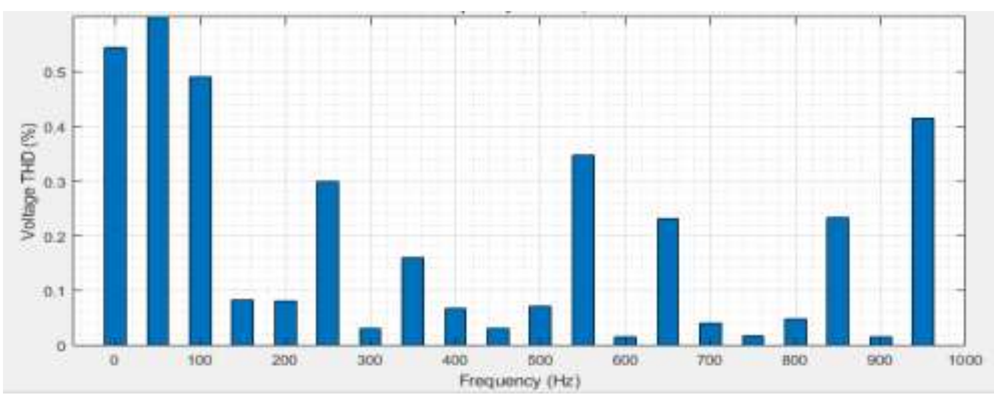

Fig. 25**:** Spectrum of voltage harmonics on 7-Up Bottling Company distribution network voltage after FLCSASPF used

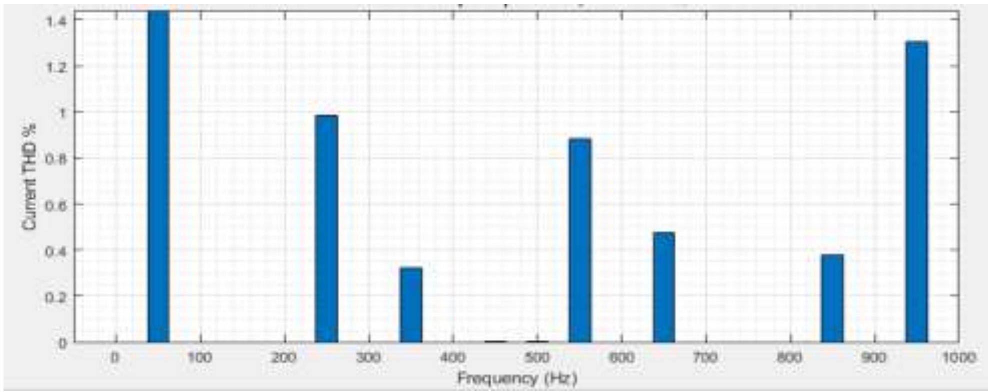

Fig. 26: Spectrum of voltage harmonics on 7-Up Bottling Company distribution network current after SPF used

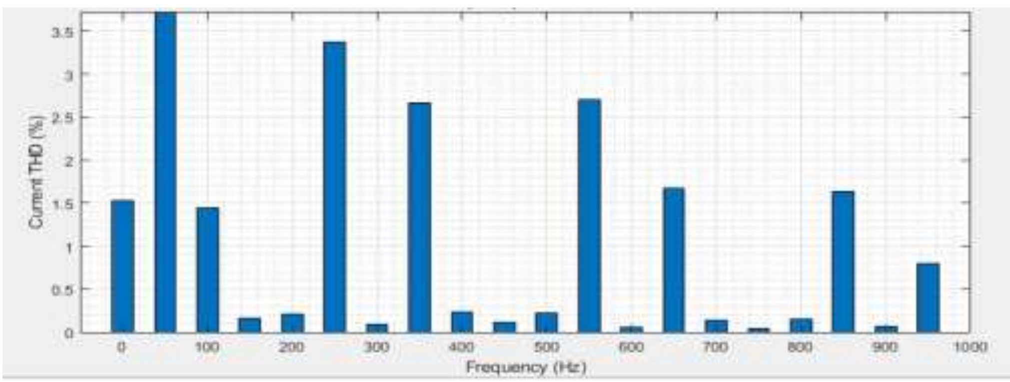

Fig. 27**:** Spectrum of voltage harmonics on 7-Up Bottling Company distribution network current after SAF used

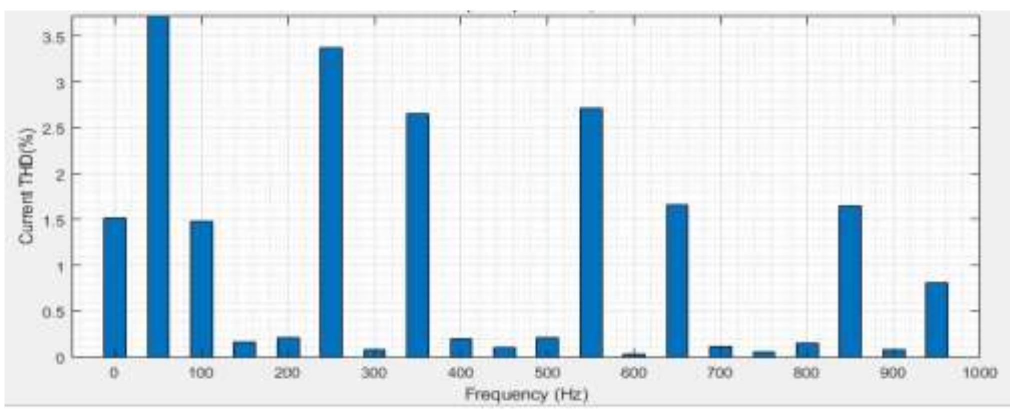

Fig. 28**:** Spectrum of voltage harmonics on 7-Up Bottling Company distribution network current after FLCSAF used

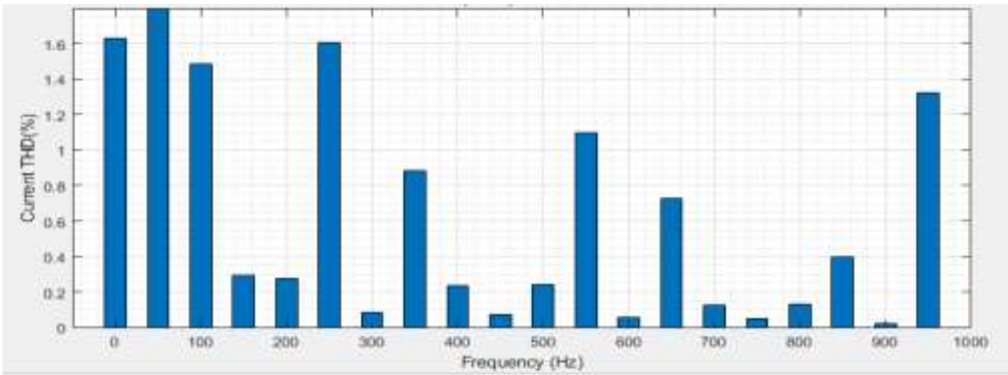

Fig. 29**:** Spectrum of voltage harmonics on 7-Up Bottling Company distribution network current after SASPF used

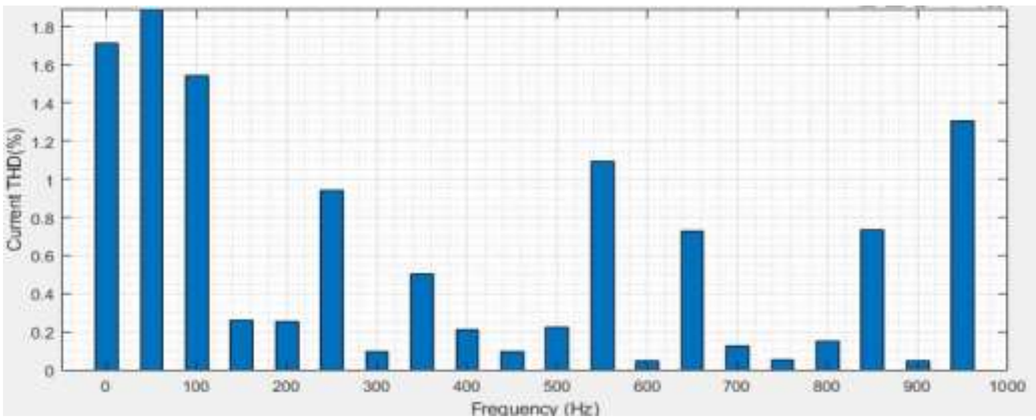

Fig. 30**:** Spectrum of voltage harmonics on 7-Up Bottling Company distribution network current after FLCSASPF used

Figures 11 to 15 show the voltage signals of the network with SPF, SAF, SASPF, FLCSAF and FLCSASPF respectively applied while the current signals with the five filters are presented in Figs. 16 to 20. Figures 21 to 25 on the other hand depict the harmonic spectra of the voltage with the application of SPF, SAF, SASPF, FLCSAF and FLCSASPF respectively whereas Figs. 26 to 30 delineate the current harmonic spectra of the network with the filter states.

The assessment of the voltage signals in Figs. 11 to 15 and current signals in Figs. 16 to 20 revealed that there was a substantial decrease in the level of harmonic distortion present in the electrical distribution network of 7-Up Bottling Company with SPF, SAF, SASPF, FLCSAF and FLCSASPF compared to Figs. 9 and 10 respectively when no filter was used. The estimated V_{THD} from Figs. 21 to 25 when SPF, SAF, SASPF, FLCSAF and FLCSASPF were applied on the network were 0.780, 1.311, 1.289, 0.730 and 0.720%, respectively, while I_{THD} evaluated from Figs. 16 to 20 with the five filter states were respectively 2.448, 4.163, 4.074, 2.240 and 2.227%. Consequently, the V_{THD} and I_{THD} values after the application of the considered filters on the network were now improved well-within the recommended voltage and current distortion limits of 5 and 16 %, respectively allowed on the distribution network.

The comparison of the filters' performance on the 7-Up Bottling Company electrical distribution network in terms of both V_{THD} and I_{THD} were presented in Figs. 31 and 32, respectively. From Figs. 31 and 32, the FLCSASPF was adjudged the best filtering technique for harmonic mitigation on the considered network since it exhibited superiority over other filters by producing the least V_{THD} and I_{THD} contents of 0.720 and 2.227 % , respectively.

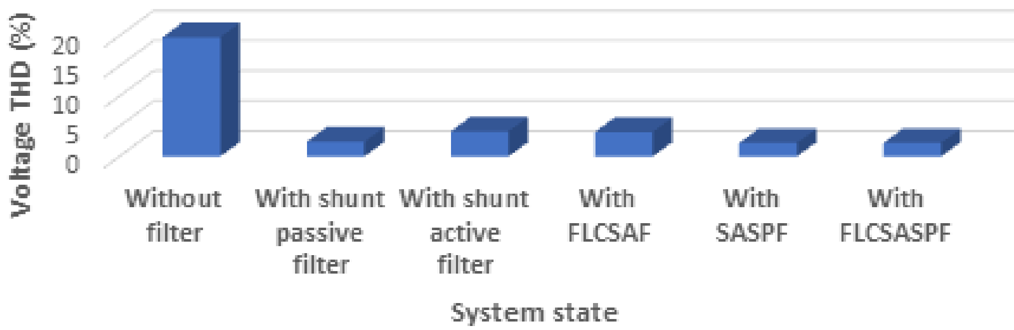

Fig. 31: Filters' performance comparison for voltage harmonic distortion mitigation on 7-Up Bottling Company distribution network

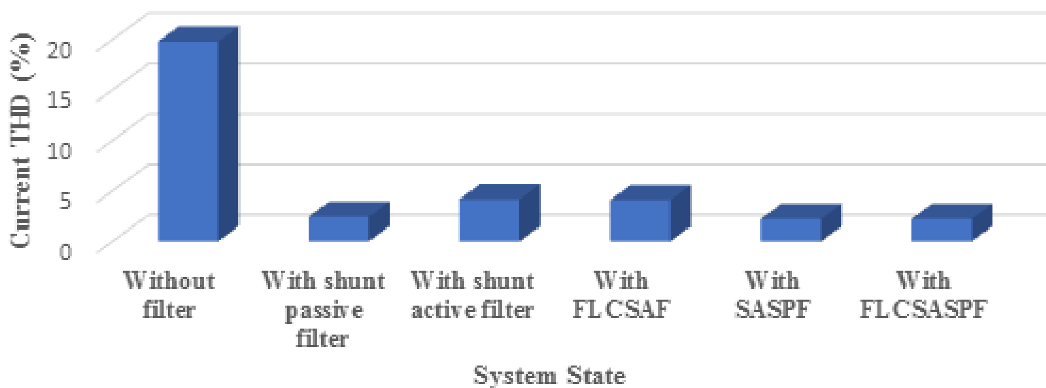

Fig. 32: Filters' performance comparison for current harmonic distortion mitigation on 7-Up Bottling Company distribution network

4. Conclusion

This study assessed the harmonic distortion mitigation capabilities of five shunt power filters which are SPF, SAF, SASPF, FLCSAF and FLCSASPF on an industrial electrical distribution network of a typical bottling company, 7-Up Industry Plc. The study observed a high penetration level of harmonic distortions on the modelled network without any filter being applied. Application of the five shunt filters on the network was found to be effective for harmonic mitigation. However, FLCSASPF exhibited superior performance over other filters by producing the least voltage and current total harmonic distortions. Hence, this study established that hybrid shunt active and passive filters with integration of fuzzy logic control has a great potential in mitigating harmonic distortion in an electrical distribution network.

References

[1] Yogita, H. and Shaikh, F.I. (2013). Harmonic Reduction System Using Active Filters. *International Journal of Electronics Communication, Instrumentation Engineering Research and Development*, 3(3): 45-52.

[2] Baggini, A. (2008). Handbook of Power Quality. John Wesley and Sons Ltd Sussex England.

[3] Sankaran, C. (2002). Power Quality. CRC Press London.

[4] Mikkili, S. and Panda, A.K. (2016). Power Quality Issues-Current Harmonics. Taylor and Francis Group, Boca Raton.

[5] Kiran, C.N., Dash, S.S., and Latha, S.P. (2011). A Few Aspects of Power Quality Improvement Using Short Active Power Filter. *International Journal of Scientific and Engineering Research*, 2(5): 23-31.

[6] Das, J.C. (2002). Power System Harmonics-Short Circuit Load Flow and Harmonics. Merker Derker, New York.

[7] Jafrodi, S.T., Ghanbari, M., Mahmoudian, M., Najafi, A., Rodrigues, E.M.A. and Pouresmaeli, E. (2020). A Novel Control Strategy to Active power Filter with Load Voltage Support Considering Current Harmonic Compensation. *Applied Sciences*, 10(5): 1664-1675.

[8] Yuehui, C., Zhao H., Zhenfeng, D., Pengwu, F., Guandong, Z., and Longfu, L. (2019). A Four Winding Inductive Filtering Transformer to Enhance Power Quality in a High-Voltage Distribution Network Supplying Nonlinear Loads. *Energies*, 12(10): 2021-2031.

[9] Ghulbet, S.M., Hinga, P.K., Nderu, J.N. 2017. An Investigation on Harmonic Problems for N-1 Contingency in Industrial Distribution and its Mitigation Using Fuzzy Controlled Hybrid Filter. *International Journal of Applied Engineering Research,* 12(20): 10284-10297.

[10] Afonso, J.L., Couto, C. and Martins, J.S. 2000. Active Filters with Control Based on the P-Q Theory. *IEEE Industrial Electronics Society Newsletter,* 47(3): 5-10.

[11] Zobaa, A.F. (2006). Practical Solutions for Harmonics Problems Produced in Distribution Networks. *Journal of Electrical Systems*, 2(1): 13-28.

[12] Neelima, K., Aditya, S.A., Kshthija, B.K., Goutam, K., Chandra, H.G. (2020). Mitigation of Harmonics in Power Transmission Network Using Filters. *International Journal of Recent Technology and Engineering*, 9(1): 1283-1288.

[13] Das, J.C. (2018). Harmonic Generation Effects Propagation and Control. CRC Press.

[14] Adejumobi, I.A., Adebisi, O.I. and Amatu, J.E. (2017). Harmonics Mitigation on Industrial Loads using Series and Parallel Resonant Filters. *Nigerian Journal of Technology*, 36(2): 611-620.

[15] Shihong, W., Gang, D., Jun, W., Xiaohui, L., Zhixia, Z., and Fengli, J. (2012). Harmonics Control Based on Fuzzy Logic. *Elsevier International Conference on Applied Physics and Industrial Engineering*, 24: 1292-1297.

[16] Naderi, Y., Hosseini, S.H., Zadeh, S.G., Mohammadi-Ivatloo, B., Vasquez, J.C. and Guerrero, J.M. (2018). An Overview of Power Quality Enhancement Techniques Applied to Distributed Generation in Electrical Distribution Networks. *Renewable and Sustainable Energy Reviews*, 93: 201-214.

[17] Kumar, R.S., Raj, I.G.C., Saravanan, S., Leninpugalhanthi, P. and Pandiyan, P. (2021). Impact of Power Quality Issues in Residential Systems. *In Power Quality in Modern Power Systems'', Academic Press*, 163-191.

[18] Halpin, S.M. and Card, A. (2011). Power Quality. *In Power Electronics Handbook, Butterworth-Heinemann*, 1179-1192.

[19] Adebisi, O.I., Ogundele, O.J., Adedokun, J.L., and Ladeinde, O.O. (2021). Power Quality Enhancement in an Electricity Distribution Network Using Active Power Filters. *Proceedings of the 3rd International Conference of the College of Engineering, Federal University of Agriculture, Abeokuta, Nigeria,* May 24-26, Abeokuta, Nigeria, 370 – 383.

[20] Adebisi, O.I., Adejumobi, I.A., Jokojeje, R.A. and Adekoya, O.D. (2017). Assessing the Performance of Harmonic Filters for Power Quality Improvement on Industrial Load: 7-Up Industry Plc Power Network as a Case Study. *ABUAD Journal of Engineering Research and Development,* 1(1): 32-48.

[21] De La Rosa, F. (2006). Harmonics and Power Systems. CRC Press Taylor and Francis, Boca Raton

[22] Abood, S.B., and Abdul-Wahhab, T.M. (2021). Investigation of Harmonic Reduction Using Passive Filters in a Distribution Network in Basra City. *IOP Conference Series: Materials Science and Engineering*, 1067(1): 012124.

[23] Brahim, B., Chellali, B., Dehini, B., Ferdi, B. (2020). Optimization of Shunt Active Power Filter System Fuzzy Logic Controller Based on Ant Colony Algorithm. *Journal of Theoretical and Applied Information Technology*, 14(1): 117-125.

[24] Masoum, M.A.S. and Fuchs, E. (2015). Power Quality in Power Systems and Electrical Machines. Elsevier Academic Press, U.K.

[25] Eremia, M., Liu, C.C. and Edris, A.A. (2016): Advanced Solutions in Power Systems: HVDC, FACTS, and Artificial Intelligence. Wiley-IEEE Press.

[26] Nair, M.S. and Sankar, D. (2015). A Review of Hybrid Filter Topologies for Power Quality Compensation. *International Research Journal of Engineering and Technology*, 2(4): 613-621.

[27] Sabin, D., Norwalk, M., Kittredge, K. and Johnston, S. (2022). IEEE Power Quality Standard. *20th IEEE International Conference on Harmonics & Quality of Power*, May 29-June 1, Naples, Italy, 1-6.