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(Research Article)

Improving real-time power quality using ANFIS-controlled hybrid active filter for THD reduction

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Abstract

The major issue that impedes the successful transmission of electricity via low voltage systems has been the constant occurrence of harmonic distortion especially in the current, voltage and frequency signals. These distortions are generally as a result of operations of the non-linear loads that introduce signals that degrades the power quality. Additionally, electronic devices, generators, transformers and motors also generate distortions that resonates to increase system instability, voltage profile abnormality and increase in power flow congestions. To improve on the power quality of a real time network, this paper utilized a hybrid of active filter and adaptive neuro fuzzy inference system (ANFIS) control for the mitigation of the harmonic distortions in voltage, current and frequency signals in a 33 kV network located in the southern region of Nigeria. The network was modeled in MATLAB/Simulink with the active filter introduced afterwards. The outcome from the active filter was used as input data in the configuration of the ANFIS model. from the results generated, it was observed that in bus 6, The total harmonic distortion (THD) value without filter, with active filter and with the hybrid of active filter and ANFIS controller for voltage signal were 8.6042%, 4.732% and 1.1831% respectively. For current signal, it was 11.8467%, 5.331% and 1.3327% respectively while for frequency signal, THD was 7.1115%, 3.9113% and 0.9778% respectively. Hence, the implementation of hybrid active filter with ANFIS proved to be the best in improving the power quality via harmonic distortion reduction than the standalone active filter.

Keywords: Power Quality Improvement; Harmonic Distortion Mitigation; Power System Network; Active Filter; ANFIS Controller; Current Signal; Voltage Signal; Frequency Signal

1. Introduction

The power distribution in the power system network is a critical and final phase of the power system design because this stage entails ensuring that electricity is distributed to the final consumers. There has been technological enhancement in design of power load equipment to ease the livelihoods of individuals, industries and commercial users but with the enhancements, comes an issue to the power distribution systems. Most of the electronics utilized were classified as non-linear loads. These non-linear loads generate signals that impedes the successful transmission and distribution of electricity to the final consumers.

Distortion of harmonics in the power distribution network impedes the improvement of power quality especially in the distribution network. The total harmonic distortion (THD) can be described as the indices utilized for measuring the rate of harmonic distortion in voltage, current and frequency signals and can be utilized for quantifying the number of distortions as a result of the presence of non-linear loads. The major essence of the application of the filters is primarily, to attenuate or mitigate the impact of the non-linear loads to the power system distribution and transmission network. The two major traditionally existing filters were passive filter and active filter and can be effectively implemented in

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power system for attenuating voltage, current and frequency signals. Improvement of power quality is essential as every economy across the globe have ties to power system network. Hence, a down time in the supply of electricity would practically result to the economic instability as it would stall industrial and commercial activities.

2. Literature Review

The process for the level of harmonic distortion in power system network as proposed by Braide, (2022) involves the following;

- Acquisition of the power system line diagram and the necessary power system parameters from the power station and central control.
- Modeling of the power system in any power system simulation application such as PSAT, ETAP, NEPLAN and other power applications.
- Simulation of the model and generation of the current, voltage, frequency and other signal harmonics.
- Determination of the total harmonic distortion (THD) using the models relating to each of the signals.

The general THD model utilized for the determination of the level of harmonics distorted was shown in equation 1 (Islam *et al*, 2024).

$$THD_N = \sqrt{\sum_{i=1}^{n} N_i^2} \tag{1}$$

Where N represents the signal parameters (voltage current, frequency and other power system signals, i represents each bus network and n representing the number of buses in the power system network. For the direct distortion monitoring in current and voltage signals, Lin & Zheng, (2018) suggested the route of non-sinusoidal models for the voltage and current as shown in equations 1 and 2 respectively.

$$V_t = V_L + V_H \tag{2}$$

$$I_t = I_L + I_H \tag{3}$$

where V_L, V_H, I_L and I_H represents the fundamental voltage signals and current signals components respectively where;

$$V_L = \sqrt{2V_1 \sin(\omega t - \alpha_1)} \tag{4}$$

$$V_H = \sqrt{2} \sum V_h \sin(\omega th - \alpha_h) \tag{5}$$

$$I_L = \sqrt{2I_1 \sin(\omega t - \beta_L)} \quad (4)$$

$$I_H = \sqrt{2} \sum I_h \sin(\omega th - \beta_h) \quad (5)$$

where V_1, I_2, V_h and I_h represents the rms values of the harmonic current and voltage components respectively, α_1, α_h, β_L and β_h represents the phase changes of the fundamental voltage and current harmonics. The research has shown the utilization of conventional filter device for the mitigation of harmonic distortion. the filters were active filter and passive filter. The active is most preferably used for a low voltage distribution and transmission system while the passive filter is largely implemented in the high voltage system (Karekar, 2018).
The model for the low pass active filter (which was the type of active filter utilized in the paper) is shown in equation 6.

$$Y(s) = \frac{k}{1+\left(\frac{s}{wc}\right)} \tag{6}$$

where Y(s) represents the transfer function clean output signal in laplace domain, k represents the pass band gain and wc represents the cutoff frequency.

Various studies have been done on the reduction of harmonic distortion with active filter (Adesina *et al*, 2025; Anuar *et al*, 2025; Biswas *et al*, 2017; Alasali *et al*, 2022; Gaiceanu *et al*, 2025; Ifeanyi *et al*, 2025; Mahmoud *et al*, 2020; Nehete *et al*, 2013; Ogundele *et al*, 2025). Despite the outcome of the research, the prospect of the implementation of an artificial intelligent system as a boost/hybrid to the conventional filter has not been tested. The only hybrid filter design carried out was done by Njor and Abdullah (2024) and it was on utilizing hybrid of active and passive filter for harmonic distortion mitigation.

The power quality improvement commenced by ensuring a smooth operation in the generation stations. The study carried out by Abunike *et al*, (2021) on a switched reluctance motor (SRM) of a conventional generator showed that power quality of power system network is improved when the torque ripples is dynamically low. The transient stability of the power system network constitutes to reduction in occurrence of distortion in harmonics. Nkan *et al* (2019a), applied FACTS in the improvement of transient stability. Hence, improvement of transient stability in power system network results to the improvement of power system quality and furthermore, the steady state and dynamic improvement of the power system parameters (especially voltage stability and power flows parameters such as voltage profile, active and reactive flows and line losses) cumulates to the improvement of the power quality in the power system network (Nkan *et al*, 2019b; Nkan *et al*, 2019c). The improvement of the power flows and power loss reduction is essential for improvement of the available transfer capability (ATC) of the power system network (Natala *et al*, 2023). The ATC is a vital parameter in the process of power quality improvement. The integration of renewable energy sources is essential for the improvement of power quality as it can be directly linked to distribution networks for direct electricity reception by the end users (Nkan *et al*, 2025). However, renewable sources like solar PV are one of the causes of increase in harmonics in the power system distribution networks because, the inverters utilize pulse width modulation (PWM) switching which is a non-linear process which results to distortion in current and frequency signal harmonics (Du *et al*, 2013)

This paper centered on the improvement of the power quality of a real time 33kV power system network in the south-southern Nigerian using a hybrid of active filter and an ANFIS model controller. The ANFIS model was designed with the input data being the output of the filter and the target data being a clean signal of THD less than 1%. The ANFIS model was designed to learn the signal to enable a clean signal output better than the output signal from standalone active filter.

3. Material and methods

3.1. Design Procedure

The procedure utilized in the actualization of THD improvement in power system network is shown in the flow diagram presented in Figure 1.

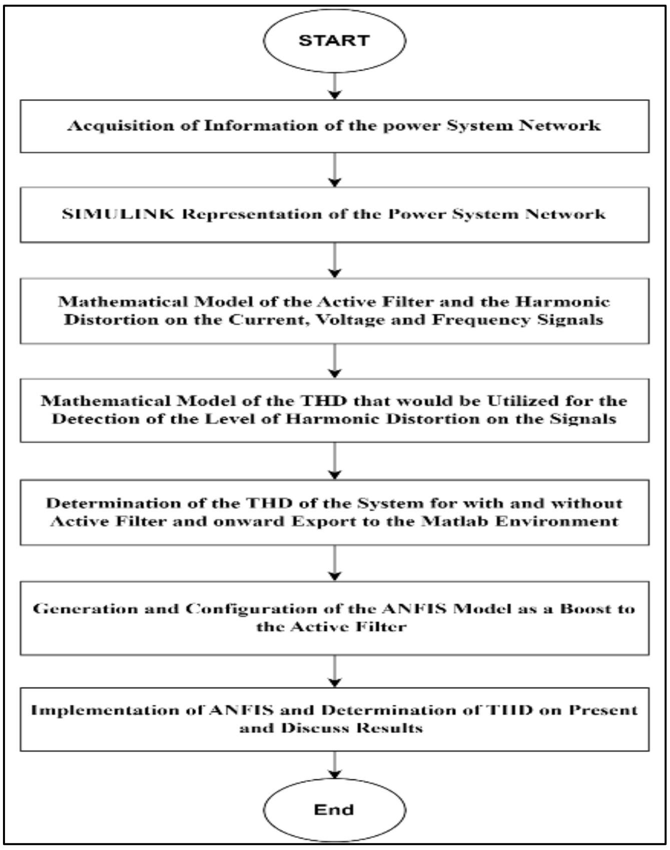

Figure 1 Flow Diagram of the Method

Data Acquisition: The data utilized is a 33 kV Nigerian network mainly in the Akwa-Ibom state southern region. The line diagram of the network is shown in Figure 2.

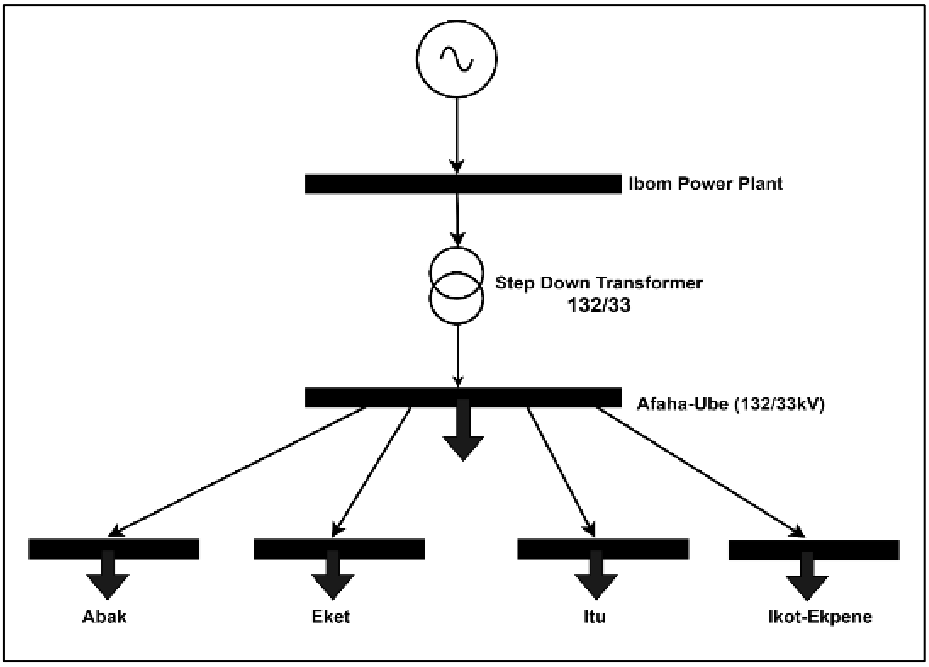

Figure 2 Power System Line Diagram

The Ibom power plant from the diagram presented in Figure 2 supplies a 132kV transmission power to the Afaha-Ube which steps it down to 33 kV and supplies to Abak, Eket, Itu and Ikot-ekpene.

The bus data for the network is shown in table 1.

Table 1 Bus Data

Bus number	Bus location	Voltage rating (pu)
1	Ibom	1
2	Afaha-Ube	1
3	Abak	1
4	Eket	1
5	Itu	1
6	Ikot-Ekpene	1

The line information of the power system network is shown in table 2.

Table 2 Line Data of the Power System

Line number	From bus	To bus	Distance (kM)
1	1	2	73
2	2	3	17.5
3	2	4	48.92
4	2	5	33.22
5	2	6	21.33

The line and bus data were utilized in the generation of the SIMULINK model.

3.2. Modeling of the Power System Network in SIMULINK

The procedure for the modeling of the power system in SIMULINK was presented in the flow diagram shown in Figure 3.

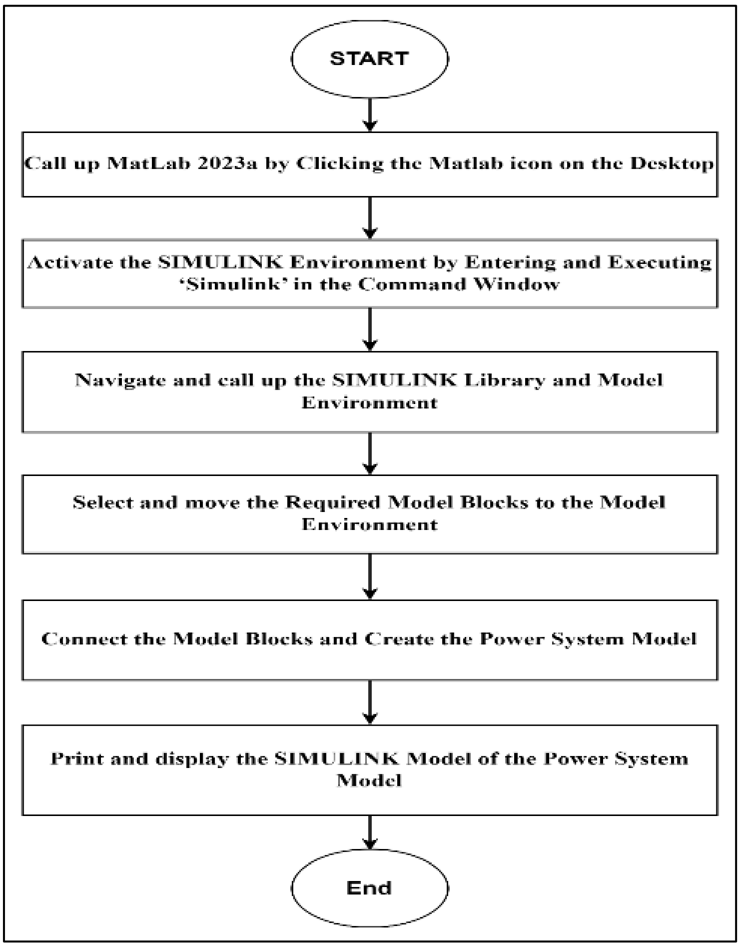

Figure 3 Procedure for the Modeling of the Power System Network in SIMULINK

The Simulink model was activated by entering the command 'Simulink' in the MATLAB's command window. From the library environment, new model environment was opened where the power system network was modeled. The SIMULINK environment with the power system model is shown in Figure 4.

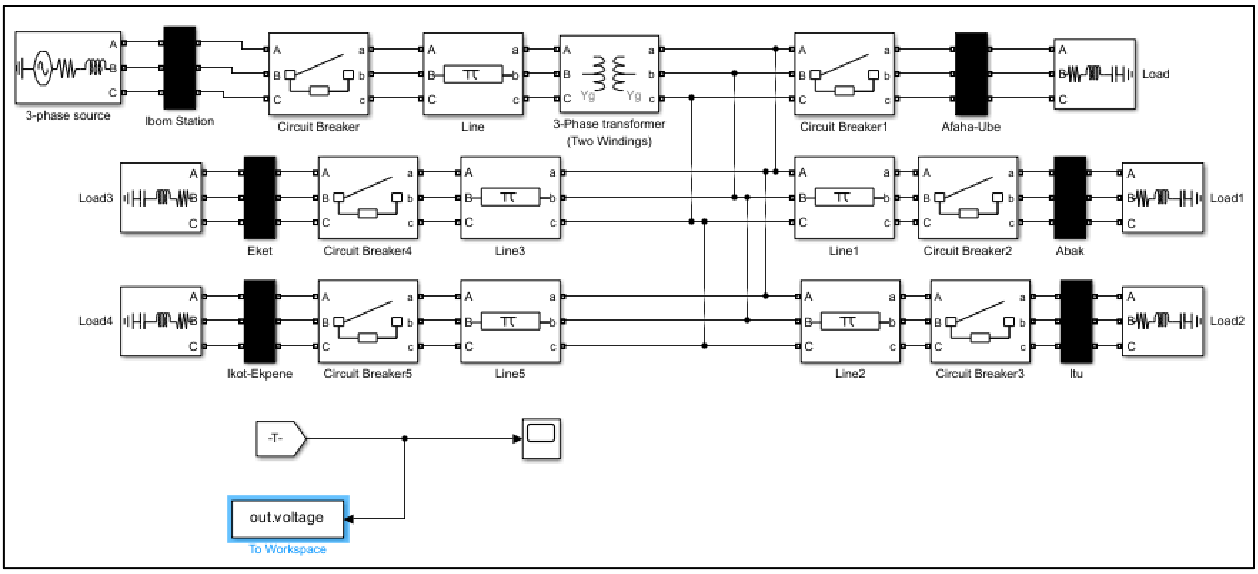

Figure 4 Simulink Model of the Power System Network

The type of active filter utilized was a second order low pass filter with the equation shown in equation 1.

$$E(s) = \frac{E_0}{1+[C_1(R_1+R_2)+(1-E_0)R_1C_2]s+R_1R_2C_2C_2s^2} \quad (7)$$

where E(s) represents the transfer function of the gain output, C represents the capacitor of the filter, R represents the resistance of the filter and s is for the transfer function variable.

Due to its flexibility, the second order filter type was a unity gain filter implying;

$$E_o = 1 \quad (8)$$

Hence, equation 7 becomes;

$$E(s) = \frac{1}{1+[C_1(R_1+R_2)]s+R_1R_2C_2C_2s^2} \quad (9)$$

The implementation of the active filter to the power system model was shown in Figure 5.

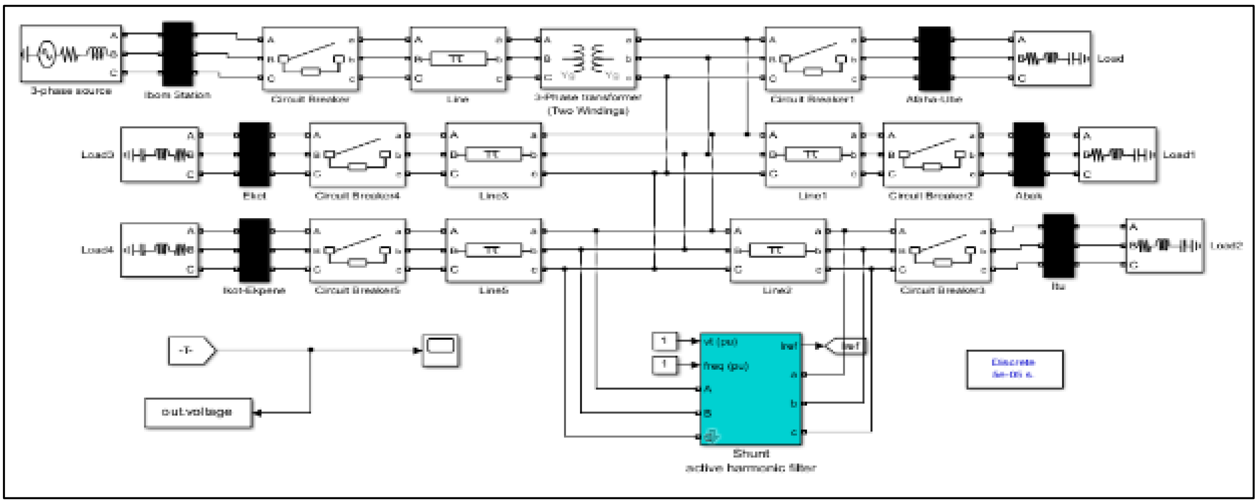

Figure 5 Implementation of the Active Filter on the Power System Network

The essence of utilizing the active filter is to minimize the total harmonic distortion (THD) of the power system network. The equation for the THD for voltage, current and frequency signals are presented in equation (10-12)

$$THD_{Voltage} = \sqrt{V_1^2 + V_2^2 + \cdots + V_n^2} \quad (10)$$

$$THD_{current} = \sqrt{I_1^2 + I_2^2 + \cdots + I_n^2} \quad (11)$$

$$THD_{frequency} = \sqrt{f_1^2 + f_2^2 + \cdots + f_n^2} \quad (12)$$

where V represents the voltage signal for each of the buses, I represents the current signal for each of the buses and n represents the number of buses in the power system network and f represents the frequency for each of the stations. The THD block is attached to the Simulink model before the scope block for the determination of the current and voltage THDs.

3.3. Configuring ANFIS as a boost to Active filter

The essence of introducing ANFIS model to the power system network was to act as a boost to the active filter in reducing the harmonic distortion in the power system network. The steps utilized for the configuration of ANFIS is done and shown in the flow diagram in Figure 6.

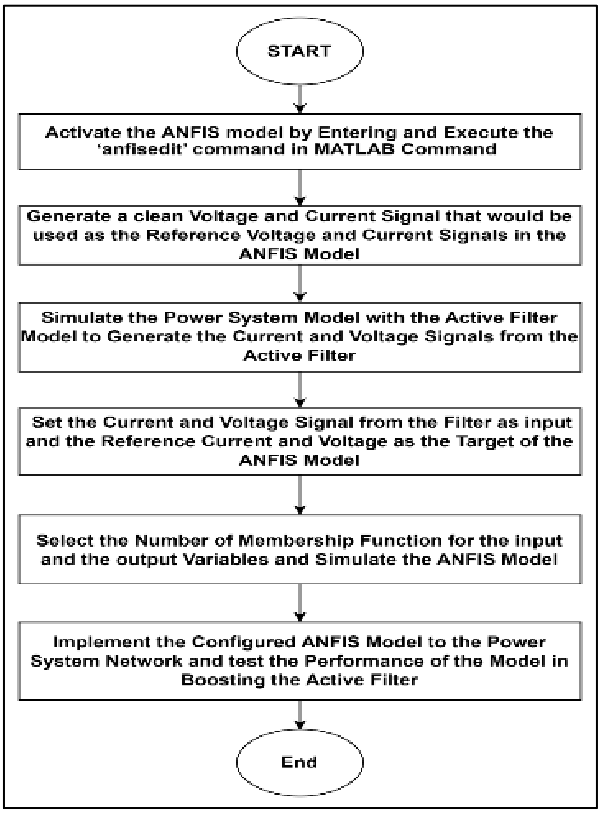

Figure 6 Flow Diagram of the ANFIS Modeling Process

The type of the membership function selected is the triangular membership function and the number of membership functions selected for each variable is four and the epochs selected is 5. The inference rules utilized is the Sugeno inference rules. The outcome of the performance of the active filter and ANFIS are presented in the result section of the research.

ANFIS is used as a boost to the active filter by ensuring that the signals from the active filter are sent directly to the ANFIS model as the input. The target is to ensure that ANFIS model outputs a clean signal through a Sugeno learning process. Hence, the target variable are current and voltage signals with THD values of less than and equal to 1.0%.

4. Simulation results and discussion

4.1. Performance Evaluation

The performances of the active filter alone and active filter with the boost (ANFIS control) for voltage signal are shown in Figure 7.

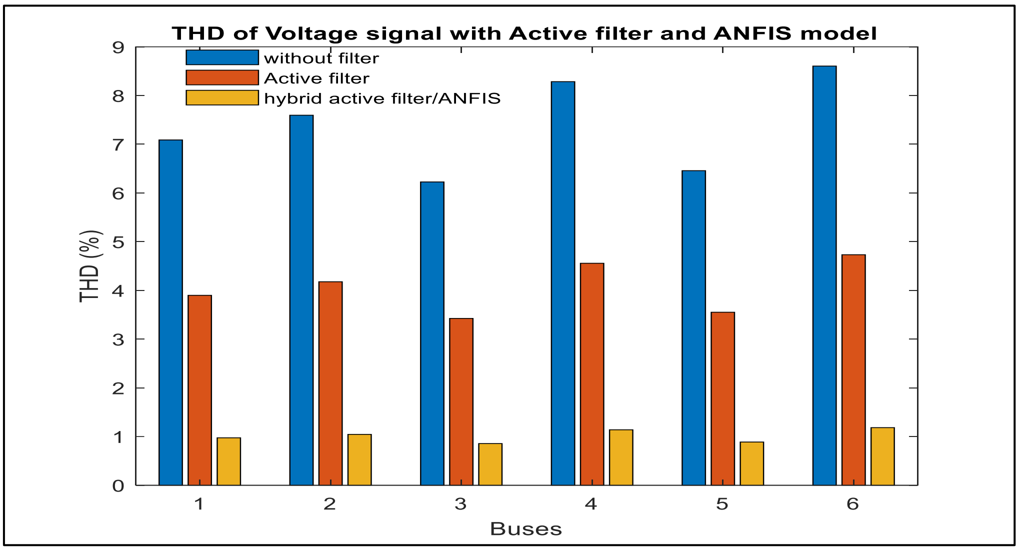

Figure 7 Performance of the Filters in THD Mitigation for all the Buses for Voltage Signal

Figure 7 shows the comparative analysis of the impact of active filter and a hybrid of active filter and ANFIS model on the voltage signal of the power system network. From the outcome presented, it is seen that all the bus stations had voltage THD less than 5% which was less than the THD threshold. The impact of the harmonic distortion without filter is more on bus with THD value of 8.6042% (bus 6). The introduction of active filter reduced the THD to 4.732%, whereas, the implementation of hybrid of active filter and ANFIS model reduce the THD to 1.1831%. The impacts on other buses are also seen with the introduction of the active filter and the hybrid filter

The outcome of the THD of the current signals for each bus with a hybrid of active filter and ANFIS model is shown in Figure 8.

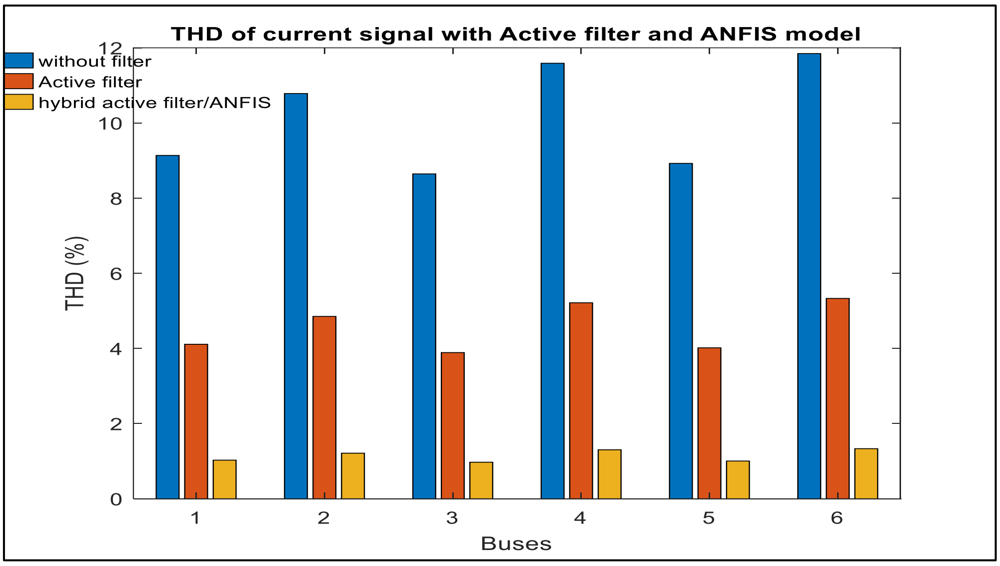

Figure 8 Current Signal Distortion Improvement with a Hybrid of Active Filter and ANFIS Model

Figure 8 shows the comparative analysis of the impact of active filter and a hybrid of active filter and ANFIS model on the current signal of the power system network. From the outcome presented, it is seen that all the bus stations had current THD less than 5% which was less than the THD threshold. The impact of the harmonic distortion on the current signal was more on bus 6 with THD value of 11.8467%. The introduction of active filter reduces the THD to 5.331% and the introduction of the hybrid filter further mitigated the impact to 1.3327%

The outcome of the THD of the frequency signals for each bus with a hybrid of active filter and ANFIS model is shown in Figure 9.

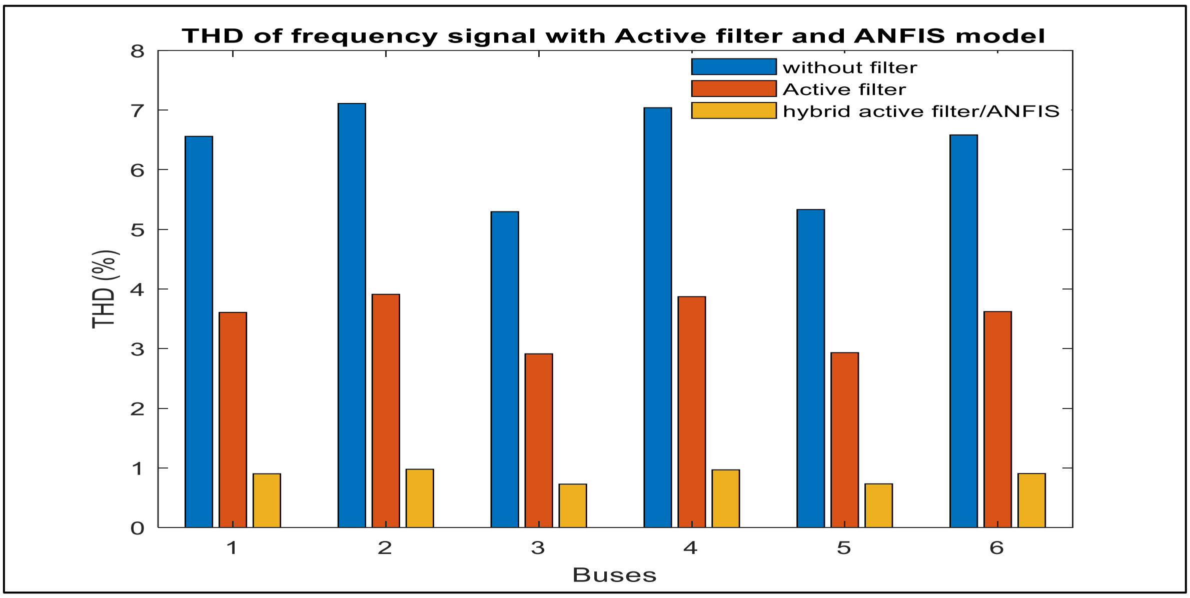

Figure 9 Frequency Signal Distortion Improvement with a Hybrid of Active Filter and ANFIS Model

Figure 9 shows the comparative analysis of the impact of active filter and a hybrid of active filter and ANFIS model on the frequency signal of the power system network. From the outcome presented, it is seen that all the bus stations had voltage THD less than 5% which is less than the THD threshold. The impact of the harmonic distortion on the frequency is more on bus 2 with THD value of 7.1115%, the introduction of active filter mitigated the impact to 3.9113% while the implementation of the hybrid system mitigated the impact to 0.9778%.

5. Conclusion

In the paper, standalone active filter and active filter with ANFIS boost were utilized for the mitigation of THD in a real time 33 kV network located in Nigeria. The ANFIS model was designed to utilize the active filter output signals as its input with a cleaned signal utilized as the target so as to adequately learn the power system. From the results generated, it was seen that the system without filters had as high as 12% average distortion for the buses considered which was attributed to the presence of non-linear loads. When the filters were implemented, the voltage signal had THD of 1.1831% for bus 6 (which was the highest in all the buses), current signal had THD of 1.3327% for bus 6 and frequency signal had 0.9887% for bus 2. It was found that the hybrid of active filter and ANFIS controller was more suitable for the purpose of mitigating the THD than the stand-alone active filter. Future works will see the implementation of other intelligent systems as controls to the active filter to compare with the outcomes generated in this paper.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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