MINIMIZING HARMONICS IN 11KV POWER DISTRIBUTION TRANSFORMER SYSTEM USING SHUNT ACTIVE FILTER

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Abstract: **This work presents the minimization of harmonics in 11KV power distribution transformer system using shunt active filter. The aim was to reduce to the lowest percentage the level of harmonic voltage in the Djamija 11kV feeder transformer characterized from the data collected at the Enugu Electricity Distribution Company (EEDC)using k-factor technique which read harmonic percentage of 5.37%. This was reduced by developing a shunt filter using RLC elements and implemented on the 11kV feeder using Matlab. The result showed that harmonic was reduced from 5.37% to 0.085% which according to the Nigerian Electricity regulation Commission (NERC) is within the acceptable tolerance value for harmonics in power system.**

Keywords: **Harmonic, Filter, 11kV Transformer, Shunt Element, Fourier Frequency Analyzer.**

I. INTRODUCTION

Power quality issues are becoming a major concern of today's power system engineers. Harmonic distortion plays a significant role in deteriorating power quality. Harmonic distortion in electric power system is increasingly growing due to the widespread use of nonlinear loads [1]. Large considerations of these nonlinear loads have the potential to raise harmonic voltage and current in an electrical power system to unacceptable high level that can adversely affect the system (Moreau et al., [2].

[3]Classifies harmonics into three, which are the positive sequence harmonics, negative-sequence harmonics and zero-sequence harmonics. The harmonic components have large current magnitudes. Positive sequence harmonics are current harmonics components, negative sequence harmonic are usually experienced in phase lines which as a result increases the total system harmonics, and the zero sequence harmonics flows through the neutral wire and causes overheating on the wire ([4]; [5] and [9]; [6]).Huge loss in terms of time and money has made power quality problems a major anxiety for modern industries with non-linear loads in electrical power system. [7]revealed that with the penetration increase of dynamic loads nature, the power factor degradations of the loads, reduction in the efficiency of transmission network and maximization of the transmission line losses among other factors are all expected, and as a result, the harmonic distortion of the power system distributive network rises significantly. Various researchers discussed in ([8]; [9] and ; [2]) have all contributed to solve the challenges of power system harmonics. [10], proposed a technique for the reduction of these harmonic distortions using passive power filters, but despite the success they achieved harmonics is still a present challenge in power system. The passive power filter is not adaptive to the dynamic changes in non linear loads and hence a control technique to minimize these harmonic distortions is of vital importance for power system operational optimization and quality of service.

II. PREVIOUS RELATED WORK

AUTHOR	TITLE	TECHNIQUE	WORK DONE	RESEARCH GAP/LIMITATION
[12]	Minimizing harmonic distortion in power system with optimal design of hybrid active power filter using differential evolution	Hybrid active power filter (HAPF)	The study used differential evolution approach to develop a HAPF. The solution was used to mitigate both current and voltage harmonic	11KV distribution transformer was not considered
[9]	Total harmonic distortion education for power quality improvement	3-phase active shunt harmonic filter	The work reveals that distortions are caused as a result of the applications of power electronics and hence increases losses in the form of heat dissipation and also harmonics	11KV distribution transformer was not considered
[13]	Characterization of harmonic distortion on the electric network caused by a battery charger for electric vehicles	Schumacher SE-4225 battery	The work revealed that battery charger induced harmonics on load flow for electric vehicles and hence used Schumacher battery solution to solve the problem	11KV distribution transformer was not considered
[14]	A dynamic characterization of power system harmonics using Markov chains.	Probabilistic approach	The work presents a probabilistic approach to the characterization of dynamic properties of harmonics in power systems The study identified the dynamic properties of harmonics in power system via characterization and then used the Markov model to develop a stochastic components to mitigate the harmonics	11KV distribution transformer was not considered
[15]	Harmonic distortion in power systems	Qualitative analysis	The research work is concerned with the sources of distortions (loads) and its propagation in power system.	The works revealed that harmonic is the major causes of low power quality when supplied.

III. METHODS AND SYSTEM DESIGN

The system development methods are: the case study of 11KV transformer empirical study and analysis via characterization, harmonic analysis, and development of the shunt active harmonic filter system. These methods were achieved by using mathematical models to develop the 11KV feeder transformer, develop the model of the total harmonics in the transformer and then the modelling of the shunt active harmonic filter.

Empirical study of the Djamija 11KV Feeder System

For this research, data of the Djamija 11KV transformer located at trans-ekulu, Enugu Nigeria was collected from the Enugu Electricity Distribution Company (EEDC) using load flow analysis and K-factor technique (Alejandro et al., 2016) for harmonic analysis and it was observed that the total harmonic content on the feeder is 5.37% which according to the IEEE and Nigeria Electricity Regulatory Commission (NERC) standards is not good and need to be minimized. To solve this problem, the model of the transformer was developed and improved with shunt active harmonic filter.

Model of the 11KV Distributive System

This section presented the equivalent 11KV primary distribution system transformer model using the relationship between the bus and voltage profiles identified using the sending (k) and receiving (j) (primary and secondary) sides and then modelled as shown;

So for the side k,

$I_{kj} = \left[|V_k| < \delta_k - \frac{|V_j|<\delta_j}{t<\theta}\right]$y(1)

For side j,$I_{jk} = \frac{I_{kj}}{t<\theta}$ (2)

The corresponding power flows for the two ends of the power transformer are $S_{jk} = V_{jk} I^*_{jk}, S_{kj} = V_{kj} I^*_{kj}$.

Total Harmonic Model

The total harmonic voltage distortion is defined considering the harmonic current, voltage and root mean square value and the order of harmonic in the system

$THD_V = \left[\sqrt{\frac{\sum_{h=2}^{\infty} V_h^2}{V1}}\right]$ (3)

Where V_h is the harmonic voltage at harmonic frequency hf in RMS; V_1 is the rated fundamental voltage in RMS, and h is the harmonic order. H=1 corresponds to the fundamental frequency. Similarly to determine the total harmonic current in the system, the same equation 3 is adopted and substituted voltage with current as shown in equation 4;

$THD_I = \left[\sqrt{\frac{\sum_{h=2}^{\infty} I_h^2}{V1}}\right]$ (4)

Where I_h is the harmonic current at harmonic frequency h_f in RMS and I_1 is the rated fundamental current in RMS; Now that the total current and voltage harmonics are determined in the existing system using equation 3 and 4, the RMS voltage and current can now be expressed in terms of THD

$V_{RMS} = \sqrt{\sum_{h=1}^{\infty} V_h^2}$ (5)

$I_{RMS} = \sqrt{\sum_{h=1}^{\infty} I_h^2}$(6)

MODELLING OF THE SHUNT ACTIVE HARMONIC FILTER

To develop the model of the filter the shunt RLC elements are combined with the phasor frequency to form the shunt active filter as shown below;

Power in the Shunt Resistance

Real (or active) power dissipated in a shunt resistor is determined by considering the total harmonic current and voltage as related using the RMS equation 3 and equation 4 to define the model in equation 7:

$P = \frac{1}{2}\sum_{h=1} V_h I_h = \frac{1}{2}\sum_{h=1} I_h^2 R_h = \frac{1}{2}\sum_{h=1}(V_h^2 / R_h)$ (7)

Where $R_h$is the resistance at the hth harmonic.

Power in the Shunt Inductance

Power in pure Inductance is determined as;

$Q_L = \frac{1}{2}\sum_{h=1} V_h I_h = \sum_{h=1} V_{h(RMS)} I_{h(RMS)}$ (8)

Where

$V_1 = j2\pi f_1 L I_1; V_h = j2\pi f_h L I_h; f_1 = \text{fundamental frequency}$

Thus

$\frac{V_h}{V} = h \times \frac{I_h}{I_1}$ (9)

$Q_{L(pu)} = \sum_{h=1} h \times I_{h(pu)}^2 = \sum_{h=1}(\frac{V_{h(pu)}^2}{h})$ (10)

Power in Shunt Capacitance

Power in pure capacitance is determined as;

$$Q_C = -\frac{1}{2}\sum_{h=1} V_h I_h = -\sum_{h=1} V_{h(RMS)} I_{h(RMS)} \quad (11)$$

Here negative sign indicates that the reactive power is delivered to the load

$$V_1 = \frac{I_1}{j2\pi f_1 C} \quad (12)$$

$$V_{h1} = \frac{I_1}{j2\pi h f_1 C} \quad (13)$$

$$\frac{V_1}{V_h} = \frac{I_h}{hI_1} \quad (14)$$

$$Q_{C(pu)} = \sum_{h=1} h \times V_{h(pu)}^2 = \sum_{h=1}\left(\frac{I_{h(pu)}^2}{h}\right) \quad (15)$$

Now combining equation 7, 10 and 15 produce the corresponding Shunt RLC models (Y) as in equation 16 for the shunt filter;

$$Y = \frac{-LC\omega^2 + j\left(\frac{L}{R}\right)\omega + 1}{jL\omega}; \quad \omega = 2\pi f. \quad (16)$$

IV. IMPLEMENTATION OF THE SIMULATION MODEL

This section discusses the implementation of the mathematical transfer functions of the power system with the related parameters defined by the various models in the previous section of this work. The model will be implemented using the power system toolbox, optimization toolbox, mathematical models and simulink as shown in figure 2;

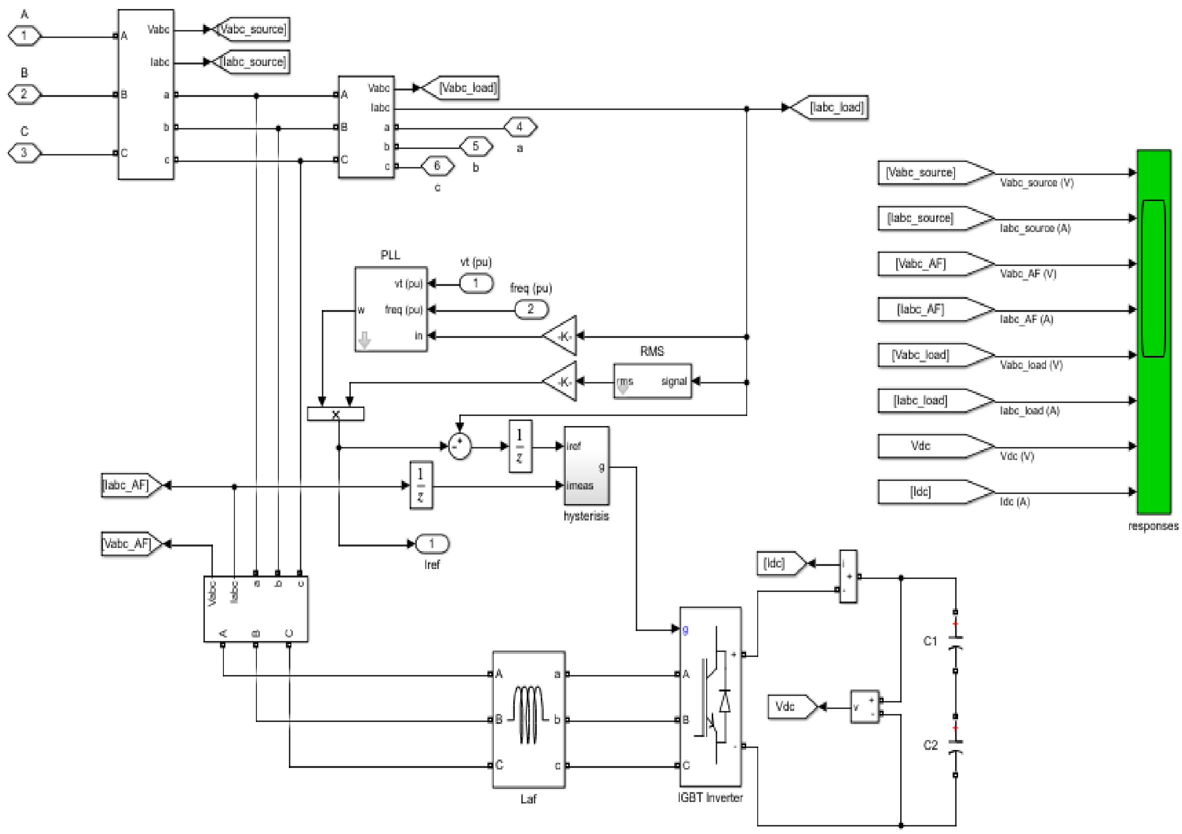

Figure 1: The transfer function of the shunt filter

The figure 1 presented the transfer function of the shunt active harmonic filter developed to mitigate harmonic on the 11KV transformer. The filter was deployed with the transfer with simulink as shown in figure 3;

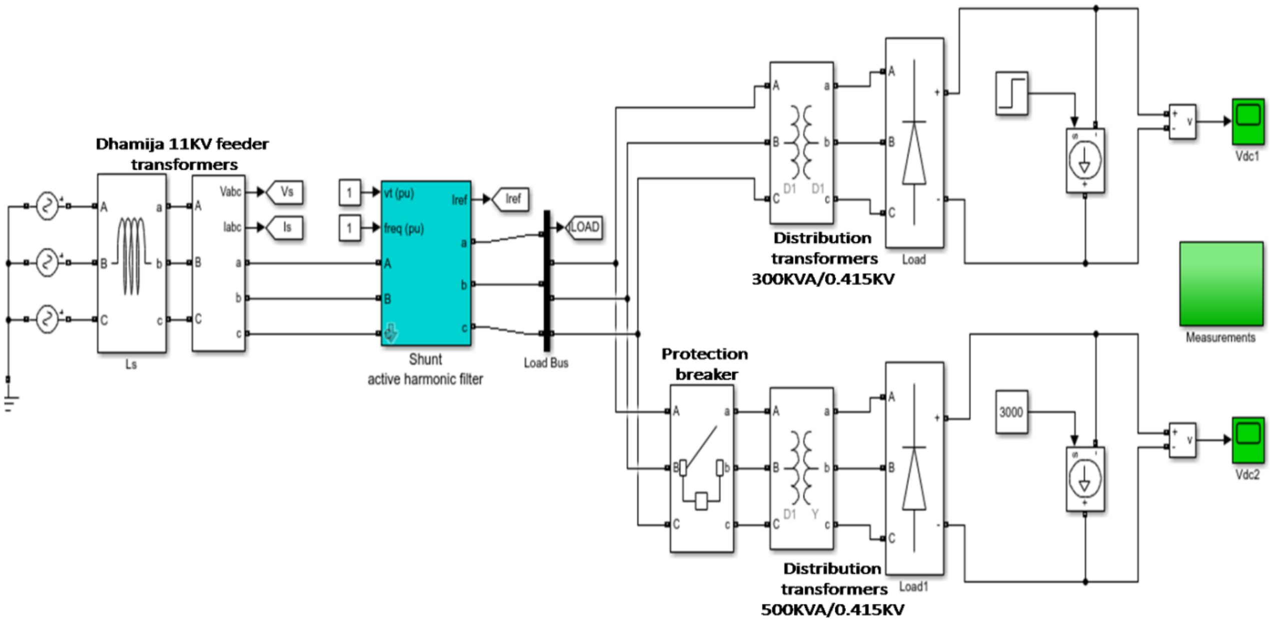

Figure 2: The model of the three phase system with shunt active harmonic filter

Figure 2 shows the implementation of the shunt active harmonic filter developed on the transformer for mitigation of harmonics.

Parameters	**Values**
Dhamija feeder rating	11kV
Number of Buses	2
Transformer type	Three-phase power transformer
Load capacity	7.5MVA
Inductance	0.5H
Total reactive power	600Mvar
Frequency	50Hz
Number of cycles	2
Capacitance	20 X 10^6uf
Maximum frequency	4000Hz
Start time	0.06s
Base value	1.0
Resistance	2000MΩ
Window style	FFT window or signal
DC components	4.849e + 04
Samples per cycle	614
Sampling time	3.25521e-05s
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V. RESULTS AND DISCUSSIONS

The section will analyze the performance of the feeder system using the simulation settings in table 1; these results were achieved from the simulation of the models implemented in figure 3 and presented with the performance of the voltage performance as shown in the figure 3

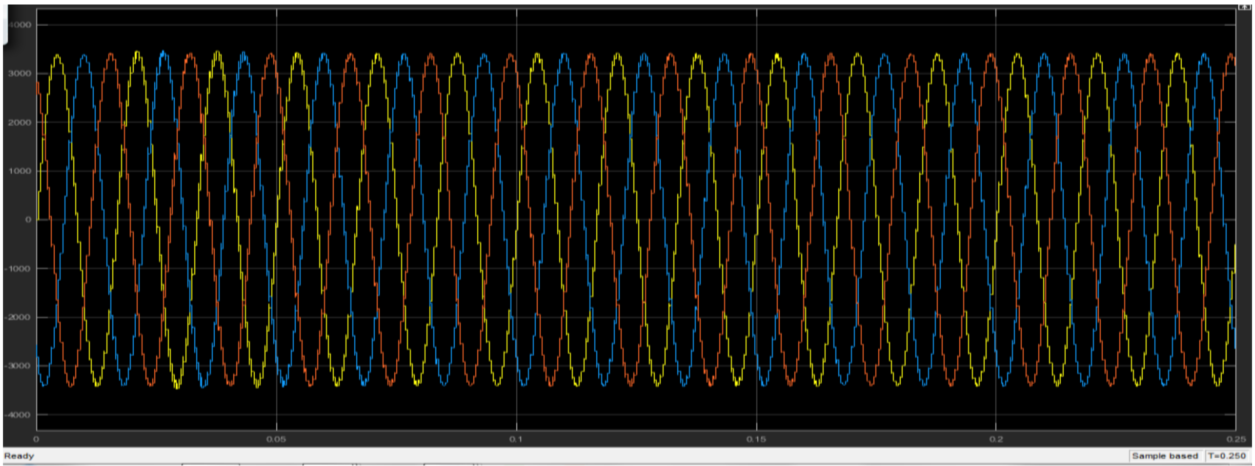

Figure 3: Phase voltage from the 11KV feeder

The result in figure 4 presents the voltage performance of the 11KV feeder, and it was observed that the voltage signal flows in a nonlinear sinusoidal form due to harmonic from the load. From the result, it could be observed that the voltage signal modelled with the root means square model in equation 5of the transformer was presented. To measure the filter performance, the fourier filter analyzer was used as shown in figure 5;

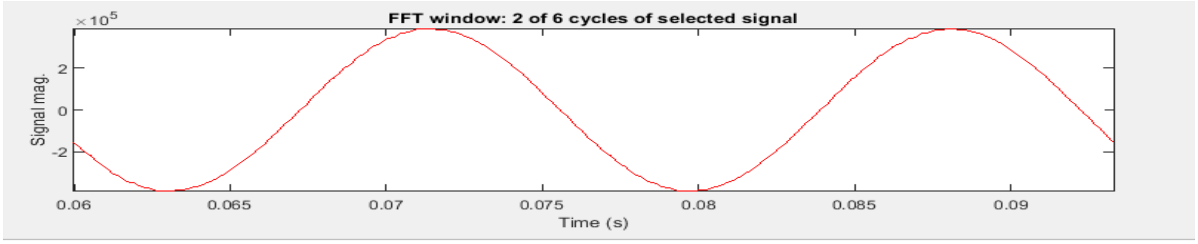

Figure 4: Filter response to harmonic voltage

The result in the figure 4 shows the filter response to the harmonic voltage using a sigma function of the root mean square voltage magnitude and the filter model developed with the shunt RLC elements respectively in equation 16. From this analysis the total harmonic was reduced from 5.37% which was recorded in the characterized 11KV feeder to 0.085% as shown in the figure 5 below;

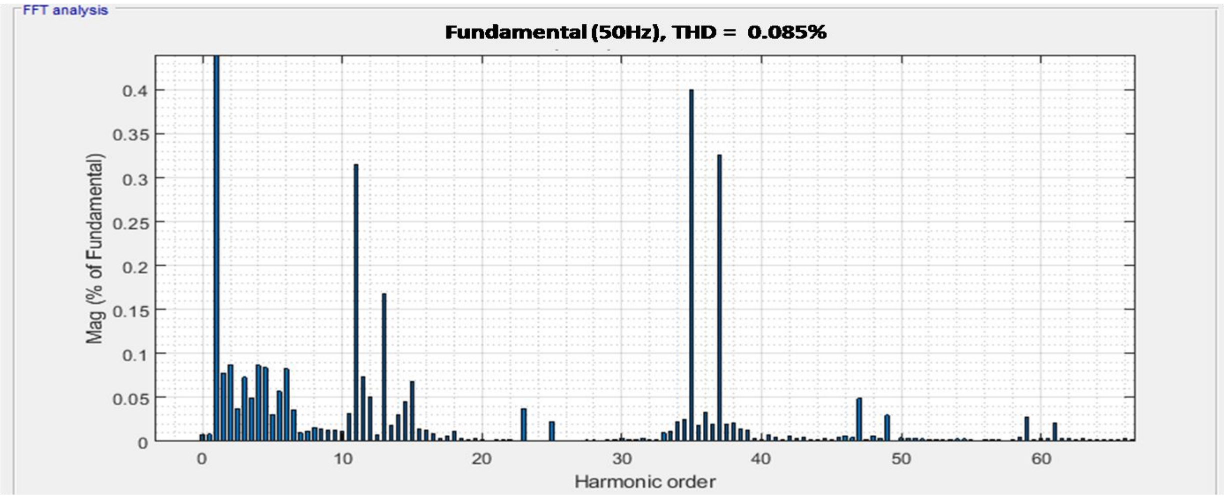

Figure 5: Shunt filter response on voltage harmonic

From the result presented in the figure 5, it was observed that the total harmonic voltage identified is 0.085%. This work has successfully showed that the use of shunt active filter is able to mitigate harmonic in 11KV distribution system to 0.085% which according to the NERC standard for quality of power supply is very good.

VI. CONCLUSION

This work has successfully improved the performance of the Djamija 11KV feeder transformer by mitigating the voltage harmonic response from 5.37% to 0.085%. This was done by developing a shunt active harmonic filter using RLC elements and then deploying on the transformer to mitigate harmonic and improve the power supplied to the load.

Innovation/ Contribution to knowledge

i. Shunt active filter was developed for Dhamija 11kv distribution feeder

ii. Harmonic was minimized to a lowest value of 0.085% in Dhamija 11kV feeder

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