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Mitigating Harmonics Impact for Efficient Electricity Distribution in Owerri-Urban using Matlab/Simulink

Abstract: **-** Electricity distribution grid in Nigeria is designed to operate at voltage levels of either 33 kV or 11kV and frequency of 50Hz but its performance is usually threatened by myriads of disturbances mainly at the point consumption. This disturbance is defined as disruption of the waveform's integrity, frequency, or magnitude, which clearly signifies a power quality glitch. This paper focuses on assessing the efficacy of filter in mitigating the impact of harmonics in power distribution network with emphasis on 11kV Owerri-urban distribution grid. To investigate the effect of harmonic in the system, a simulation of the distribution network is performed in two scenarios, one without filter and the other with inclusion of filter and implemented using Simulink software. The outcome revealed that percentage of total harmonic distortion in current and voltage were 17.56 %, 3.385% before addition of filters and 3.352%, 1.771% respectively, after harmonic filter was incorporated in the design. It is deduced that a well designed filter averts injection of harmonic current and voltage into the network in line with IEEE 519 -1992 specification.

Keywords: Harmonics Filter, Voltage Swell, Dips, Voltage Flicker, Matlab

I. INTRODUCTION

The socio-economic growth of any nation relies majorly on its ability to produce reliable electricity and efficiently distribute it to the point of consumption. Despite the abundance of resources in Nigeria, the power industry is performing below expectations. This deteriorating state of the electricity sector has become an issue of utmost concern over the last two decades. This cause is only attributed to obsolete infrastructure or gas supply constraints rather than power quality glitches due to the exponential rise in the application of electronic appliances [1]. A scheme or device that performs adequately in its electromagnetic environment devoid of distortion is referred to as power quality. IEEE explained it as "establishing guidelines for electrical equipment's powering and grounding[2],[3]. The principal effects quality include voltage dips, swell, transients, voltage flicker or fluctuation, and equipment breakdown, which results in the introduction of a significant amount of harmonics

This paper focuses on mitigating the impact of harmonic disturbance in Owerri's urban electricity grid. Harmonics is a component frequency of the signal, an integral multiple of the elementary frequency [4]. The concept of Harmonics is one of the foremost problems in the electrical industry, which manifests in a number of challenges in the distribution network, such as heat generation, interference, and loss of data [5]. It can also cause voltage imbalance and instability, resulting in a power outage or system collapse. Figure 1.0 shows the fundamental harmonic frequency waveforms. It contains fundamental, harmonic, and distorted signals [6].

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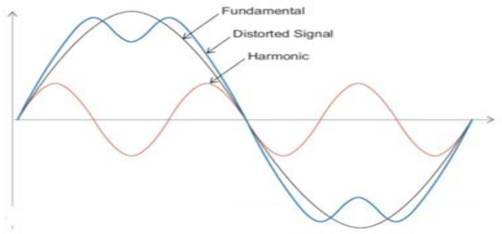


Fig. 1.0: Fundamental Harmonic frequency

II. ACRONYMS AND CONSTANTS USED THROUGHOUT THE PAPER IS STATED BELOW.

THD_V	= Total harmonic distortion voltage
THD_I	= Total harmonic distortion current
F	= Fundamental frequency
a_0	= DC component
a_n,b_n	= components of the series
n	= order of harmonic
ω	=angular Frequency
V_i	= rated voltage of the elementary frequency in root mean square
H	= harmonic order
V_h	= harmonic voltage
I_i	= rated current at the fundamental frequency
I_h	= harmonic current
R	= Resistor
L	= Inductor
C	= Capacitor

III. CLASSIFICATION OF LOAD SOURCES

In a power system, two distinct load sources exist are listed below:- i. Linear load: The current drawn by this kind of load is proportional to the voltage provided. For the duration of the alternating period, its impedance remains constant. There are four types of linear loads: inductive (transformers, motors), capacitive (e.g., capacitors), and resistive (electric heaters, incandescent light bulbs [6]. The schematic diagram of linear load that contains a capacitor and resistor is shown in Figure 2a, while Figure 2b illustrates the resistive and capacitive waveform

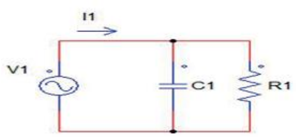


Figure 2a:

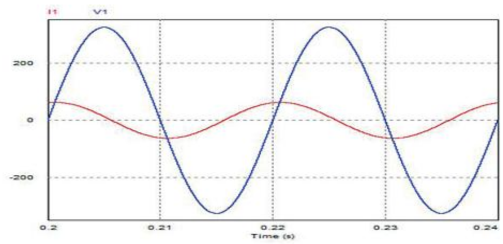


Figure 2b:

ii. Nonlinear load: Nonlinear load operates against Ohm's law. It changes its impedance with instantaneous applied voltage. Harmonic disturbances are usually caused by nonlinear load sources like large computers, inverters, welding machines, MRI scanners, SCADA systems, and variable frequency drives [6]. Figures 3a and 3b contain the schematic diagram and waveform of a nonlinear load of 6-pulse rectifier. It covers various types, including single-phase and three-phase rectifier blocks and both half-wave and full-wave diode-based applications. Moreover, the corresponding waveform characteristics for each configuration have also been studied extensively.

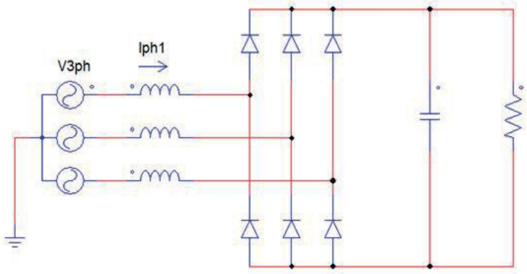


Figure 3a: circuit diagram of a rectifier with 6-pulse

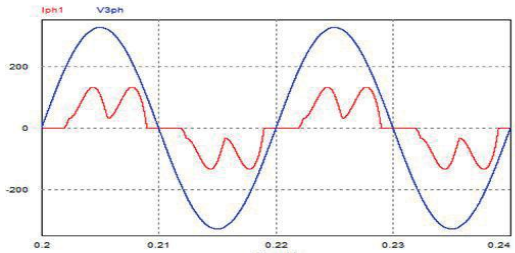


Figure 3b: Waveform of 6-pulse rectifier

3.1 Harmonic Filter

Several methods are adopted to lessen the effect of harmonics in the power system. Integrating filters is the most affordable and straightforward countermeasure for averting or sieving out harmonic frequencies from the network [7]. It is built up from passive RLC components, as shown in Figure 4.0. Harmonics are reduced by creating a tuned filter for the most prevalent harmonic order [8], [9]. Figure 4.0 shows the schematic diagram of a double-tuned Filter (DTF). It performs the task of minimizing two levels of harmonic distortion at the same time [10].

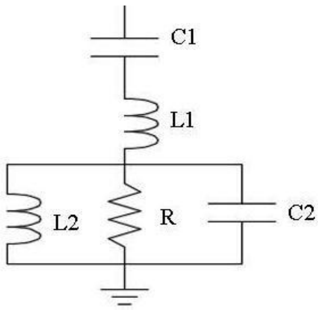
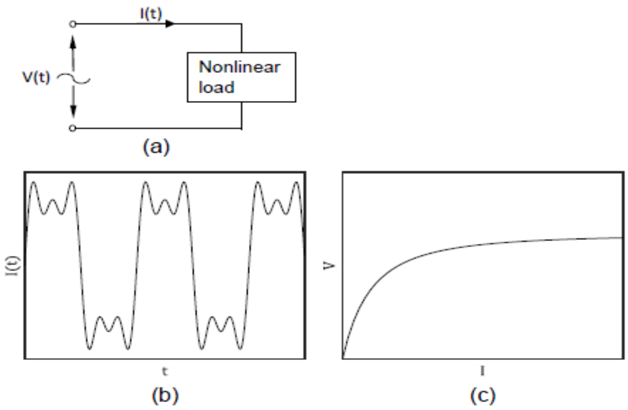


Figure 4.0: Schematic diagram doubled turned passive filter

IV. Mathematical Analysis of Harmonic Distortion

It explains the occurrence of a harmonic disturbance in electrical systems due to nonlinear gadgets, as highlighted in section 2.0 (ii). The model diagram of nonlinear nonlinear and associated waveform and line curve of voltage against the current are displayed in Figures 5a,b, and c, respectively [11].



Mathematical derivation of harmonic distortion can be achieved with fourier series transformation because of its periodic characteristic.

$$x(t) = a_0 + \sum_{n=1}^{\infty} [a_n \cos(n\omega t) + b_n \sin(n\omega t)] \quad (1)$$

$$\omega = 2\pi f$$

a_o, a_n and b_n are computed as follows

$$a_0 = \frac{1}{2\pi} \int_{-\pi}^{\pi} f(x)\, \omega t\, d\omega t \quad (2)$$

$$a_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(x)\, \omega t \cos(n\omega t) d\omega t \quad (3)$$

$$b_n = \frac{1}{\pi} \int_{-\pi}^{\pi} f(x)\, \omega t \sin(n\omega t) d\omega t \quad (4)$$

Recall that fourier series contains only odd harmonics when the waveforms' positive and negative half cycles exhibit similar properties.

4.1 Total Harmonic Distortion (THD)

The commonest applied parameter for assessing the quality of electric power is known as total harmonic distortion[11]. Its voltage factor can be expressed as follows:-

$$THD_v = \frac{\sqrt{\sum_{h=2}^{\infty} {V_h}^2}}{V_i} \quad (5)$$

Likewise, current distortion factor is expressed in equation 6:-

$$THD_i = \frac{\sqrt{\sum_{h=2}^{\infty} {I_h}^2}}{I_i} \quad (6)$$

V. Simulation Results and Discussion

The online diagram of the Owerri injection substation is designed in a Simulink environment. The software is a MATLAB-based graphical user interface tool with a set of customized block libraries that could be extended for particular purposes in system design, modeling, and simulation [12], [13]. The substation is located at Egbu Road by ABC transport company Owerri Imo State and is fed via a 33kV distribution line from the 132kV transmission substation Egbu work center. It is stepped down with a 2x15 MVA transformer into 11kV feeders: GRA, Naze, new Owerri, and Owerri Urban. This research is focused on the Owerri Urban feeder, which covers the following axes: Douglas Road, Roycee, Amaigbo Street, Umezuruike, Asumpta Avenue, Tetlow Road, Ogugba Street, etc. The network contains over eighty (80) distribution transformers of various capacities ranging from 50kVA to 500kVA, both public and private. The simulation is based on two different cases, without the inclusion of a filter and with the incorporation of a filter [14], [15]. The Simulink models are shown in Figures 6.0 and 7.0, respectively.

Case i. Simulation without filter

The model was initially simulated to ascertain the total harmonic current and voltage without including a harmonic filter device, illustrated in Figure 6.0. THDi and THDv percentage values are 17.56% and 3.385%, respectively, without including a filter device**.**

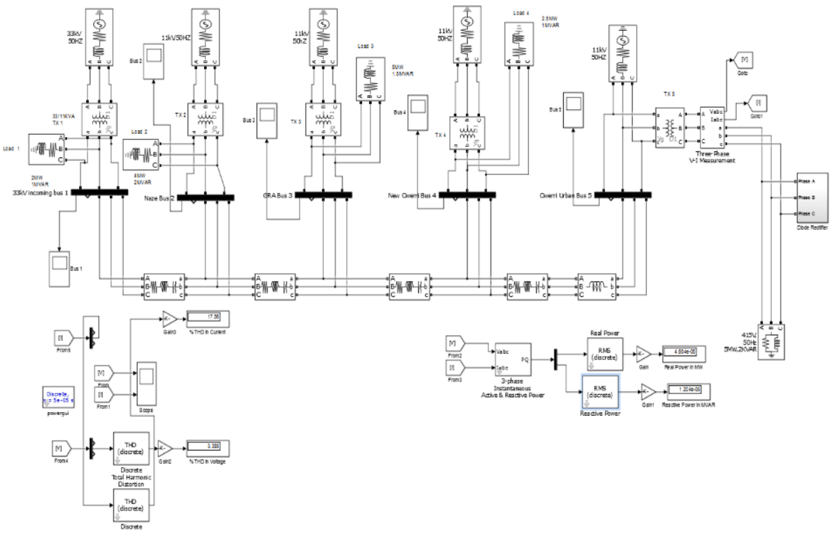


Figure 6.0: Simulink model of 11kV Owerri Urban distribution network without filter

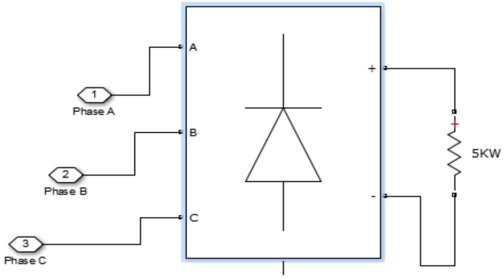


Figure 6.1 Schematic diagram bridge rectifier

Figure 6.1 displays schematic diagram of bridge rectifier were every switch device is wired in parallel to a series of RC snubber circuits.

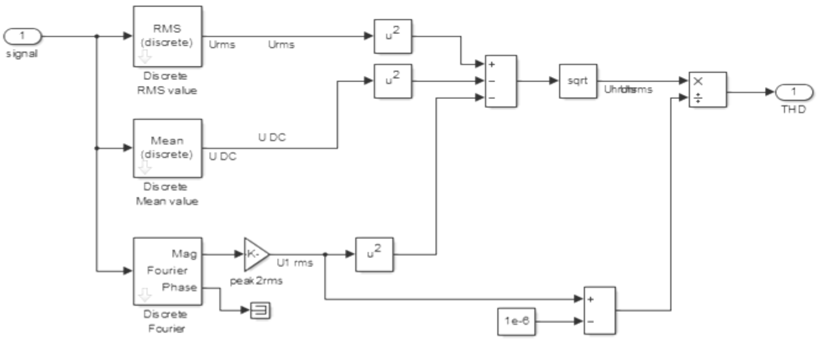


Figure 6.2 Discrete total harmonic distortion

Case ii. Simulation with the inclusion of filter

The network was again simulated to determine the total harmonic current and voltage with the incorporation of a harmonic filter device, as illustrated in Figure 7.0. As filter devices were included, the percentage values of THDi and THDv reduced drastically to 3.352% and 1.771%, respectively.

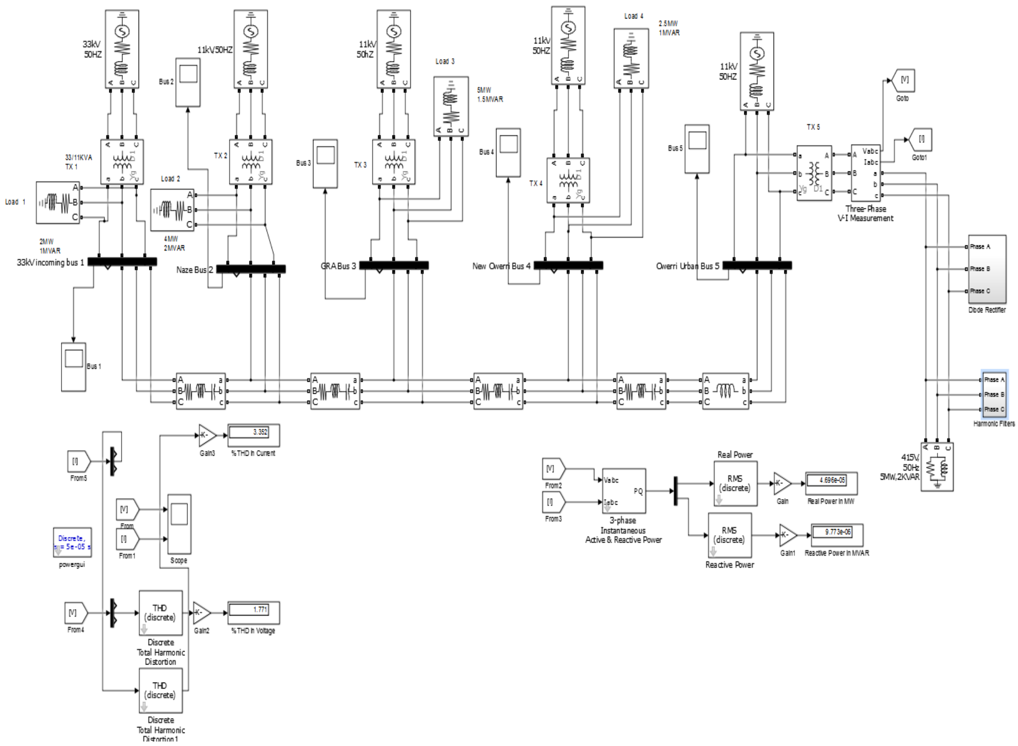


Figure 7.0: Simulink model of 11kV Owerri Urban distribution network filter

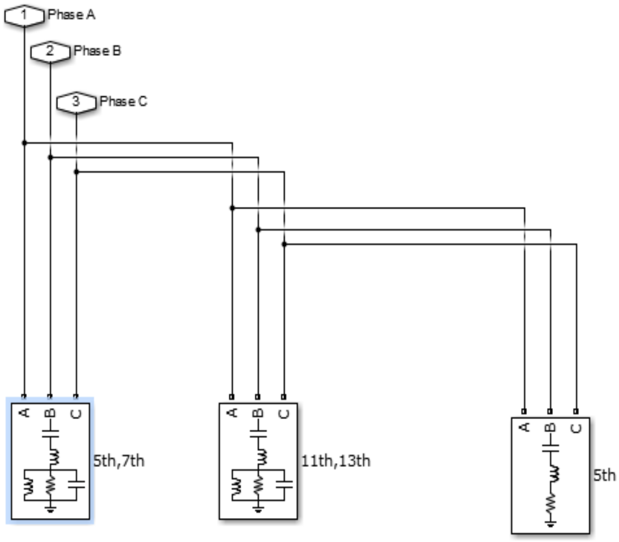


Figure 7.1: Sub-system of 3-phase harmonic filter

The sub-system of 3- phase harmonic filter is displayed in figure 7.1. It comprises of passive components of RLC.

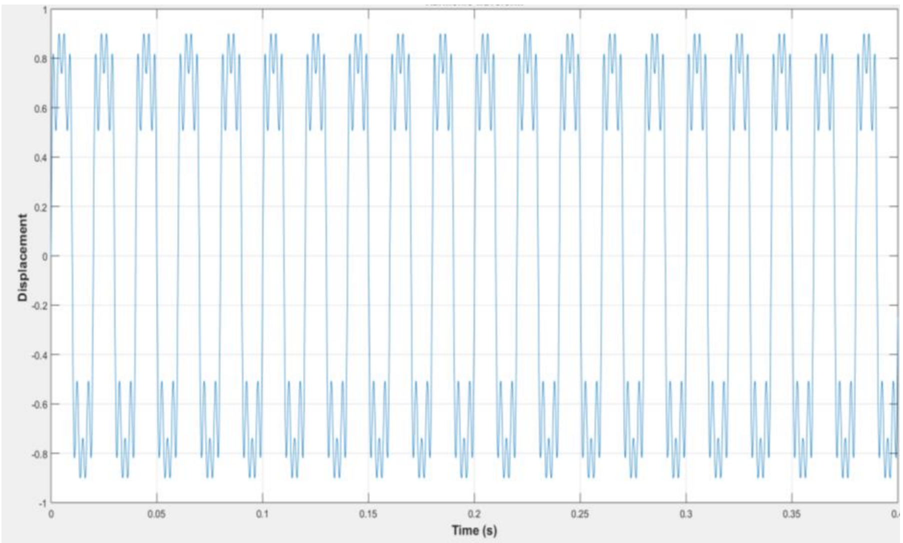


Figure 8: Waveform of harmonic filter in 11kV distribution grid

The waveform of the harmonic filter is shown in Figure 8.0. From the waveform, it is obvious the signal is not purely sinusoidal but somewhat distorted as a result of the harmonics available in the system signal

VI. CONCLUSION

The design and simulation of the 11kV Owerri-urban electricity distribution network was carried out using Simulink software. The essence of the simulation is to investigate the efficacy of filters in mitigating the impact of a harmonics system. The model was initially simulated without a filter and including a filter. The results showed that the percentage of THDi and THDv before and after the inclusion of the filter were 17.56 %, 3.385%, 3.352%, and 1.771%, respectively. It was inferred that a well-designed filter averts the injection of harmonic disturbance into the network, and the results fall within the stipulated IEEE 519 -1992 standard.

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