ISSN Online: 2756-3898, ISSN Print: 2714-500X https://doi.org/10.47514/phyaccess.2022.2.1.005

Investigation on the Effect of Imbalance and Non-Linear Load on 11kV Pama Feeder

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Received 04-04-2022
Accepted for publication 13-05-2022
Published 18-05-2022

Abstract

In this research the effect of imbalance and nonlinear load on power quality was investigated via the electronic method with the aid of a Fluke 435 power quality analyser and the results obtained compared with IEEE standards. The study was carried out on 11 kV Pama feeder Kaduna state, Nigeria, which is comprised of Nassarawa, Boro1, Pama 1, Pama 2, and Pama 4 substation. The analyzed result shows an average value of 230 and 1327 times voltage dips and swells, 11.74 % harmonics current, 2.33 % harmonic voltage, 5.96% imbalance voltage and 25% imbalance current respectively. When compared with the IEEE standard limits of 5 % and 2 % harmonic current and voltage, 10 % and 5 % imbalance current and voltage, it could be seen that these results imply the presence of harmonics within the system which are fundamentally due to imbalance and non-linear load, triggering operating complications on the distribution system. These complications include load disruptions, over current, over voltage, heating, leading to forceful outage, increased power losses, faster ageing of insulations, unstable power supply, burnt cables, sockets and connectors, thus reducing capacity and ultimately resulting in premature failure of transformer.

Keywords: Non-linear Loads; Harmonics; Power Quality; Voltage Dips and Swells; 11 kV Pama Feeder

I. Introduction

The recent surge in the number of electrical equipment that produce harmonics over the last few decades has posed severe problems for electrical networks and power quality. Electrical distributions systems are being designed to operate on the frequency with linear load which obey ohm's law. Due to modern technological advancement, most electronic devices generate a signal that brings about changes in the impedance to the applied voltage. Non-linear loads are the main causes of harmonic currents and voltages in electrical distribution systems, and most appliances including power electronic switches operate as non-linear loads [1]. Due to the non-linear V–I characteristics of these devices, they tend to introduce power quality problems in the electric power distribution system, and contrastingly, they are also sensitive to power quality level [2].

The measure of power quality depends upon the needs of the equipment that are being connected to the supply. If the equipment connected with the supply operates correctly and reliably within the specified variable, then the supply is a good quality. On the other hand, if the equipment introduces distortions to the system that could affect the frequency, current/ voltage and lead to power losses, then the power quality is poor [3].

The most common power quality problems in industrial distribution systems are the voltage disturbances, which mainly encompasses the voltage sags, swells, harmonics, transients, unbalances, and flickers. These disturbances can cause the malfunction of voltage-sensitive loads in factories and buildings [4]. The proper measurements and analysis of the distribution system and implementation of the evolving methods and techniques to improve the condition of the supply system are some of the developing areas of present-day electrical engineering [5-6].

Since non-linear loads cannot be dispensed off due to many economic advantages [7], energy conservation, and increase in production; therefore, it is important to study the behaviour of these non-linear loads to find out proper mitigation techniques for power quality improvements on $11kV$ Power supply networks such as the Pama feeder in order to reduce the harmonic pollution of the supply system.

A. *Study Area*

The study area was located at Chikun Local Government area (LGA) of Kaduna state, Nigeria, at latitude $10°45'29.4''\ N$ and longitude $7°46'9.2''\ E$. The map of the study area is depicted in Fig. 1.

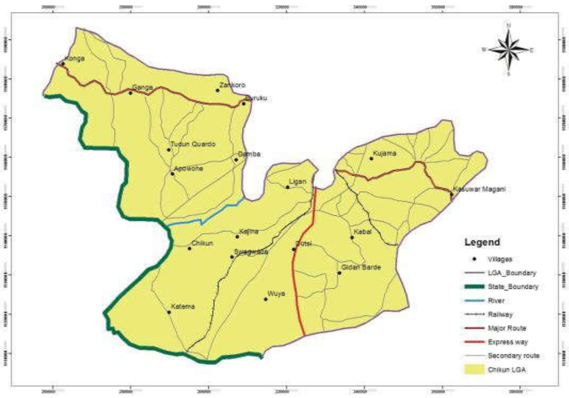


Fig. 1 Map of Chikun LGA of Kaduna state [7].

II. MATERIALS AND METHOD

A. *Materials*

Materials used for the research include a Clamp meter, Power quality analyser *Fluke* 435, standard safety wears or personal protective equipment (PPE) (Fire resistant clothing, Safety glasses or full face shields, Safety helmets, Rubber electrical gloves).

B. *Methods*

In this research, electronic method was used as the measurement technique. Measurements were carried out using a special instrument called 'power quality analyzer.

The power quality analyzer was used to investigate the effect of imbalance and non-linear load on the $11kV$ Pama feeder for the period of three days. A line diagram of the 11 kV Pama feeder which comprised of Pama 1, Pama 2, Pama 4, Nasarawa and Boro 1 substation respectively, is depicted in Fig. 2, while Fig. 3 shows the Installed Fluke 435 Series II power quality analyzer at one of the load points.

First, it was established that the Analyzer was calibrated and tested in accordance with standard EN61010-1 2nd edition (2001). Secondly, the points of installations were identified, followed by isolation of the study area, then safety requirements were put in place. Next, the analyzer was installed after which the analysis were carried out. Finally, the analyzer was uninstalled, and a representation of the logged data downloaded.

The observation period for each recorded value was 1 hour, thereafter imbalance load, total harmonics distortion (THDs) results were generated with load assessment carried out using the clamp meter. In addition, the data obtained from the load assessment were used to calculate the imbalance current and percentage load on $11kV$ Pama feeder using (1), (3), and (4).

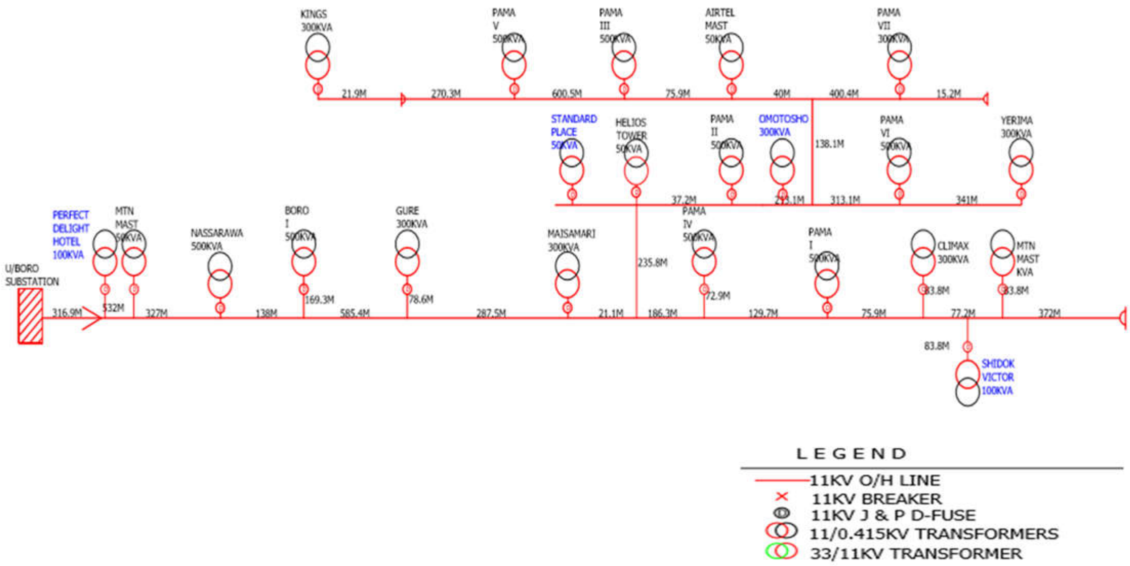
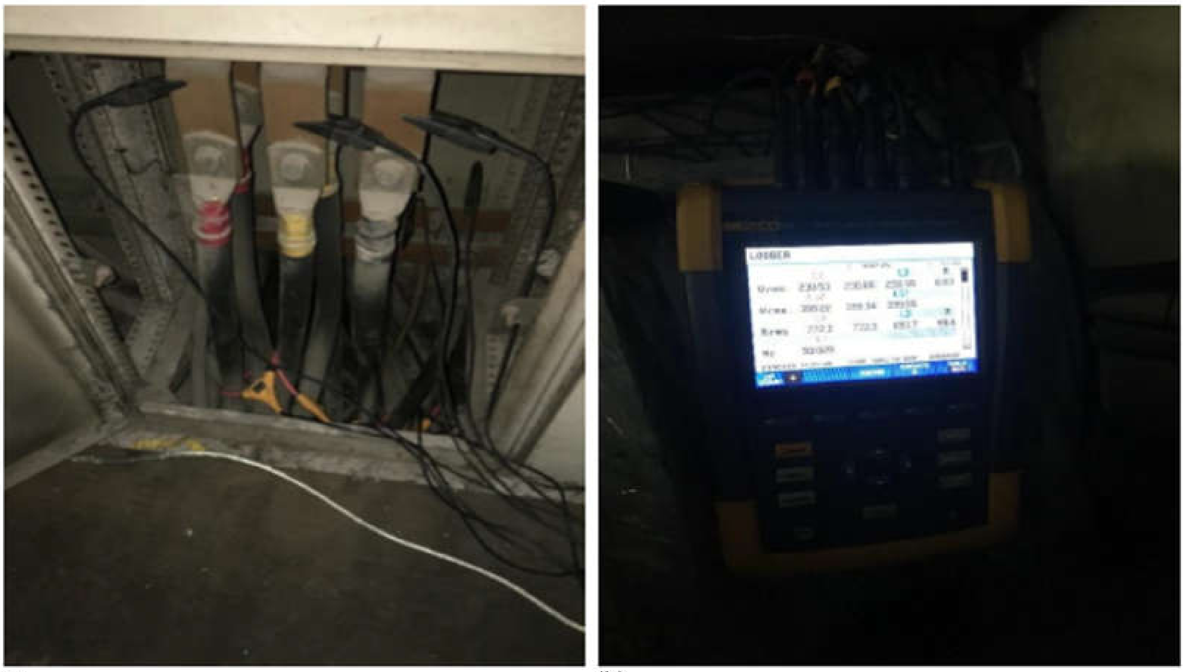


Fig. 2 Line Diagram of 11 kV Pama Feeder [7].



(a) (b)

Fig. 3 (a) Installation of Fluke 435 Series II power quality (b) Measurements from installed Fluke 435 Series II power quality analyser at one of the load points [7].

The percentage imbalance current was calculated using,

$$IC\,\% = \frac{MC - AC}{AC} \times 100\% \tag{1}$$

Where, IC is the Imbalance current, MC is the maximum current and AC the average current (Average current is defined as the sum of red phase current, yellow phase and blue phase divide by three).

Mathematically,

$$AC = \frac{A+B+C}{3} \tag{2}$$

Where A = red phase current, B = yellow phase current and C = blue phase current.

While the secondary current was also calculated using:

$$I = \frac{P}{\sqrt{3}V} \tag{3}$$

Where, I is the secondary current, P is the power rating and V is the secondary voltage.

The percentage load is calculated using:

$$Pl = \frac{AC}{I} \text{ X } 100\% \tag{4}$$

Where, I is the secondary current, AC is the average current and Pl is the percentage load [7].

III. RESULTS AND DISCUSSION

Results obtained include results for voltage dips and swells, current and voltage harmonic distortions and imbalance voltage and current for Nasarawa, Pama 1, Pama 2, and Pama 4 substation of the $11kV$ Pama feeder. The analyzed result from Table I showed that the voltage dip and swell has an average value of 230 times and 1327 respectively. The voltage drops during the dip, and rises during a swell. The dip begins when the voltage on one or more phases drops below the dip threshold and ends when all phases are equal to or above the dip threshold plus hysteresis. The trigger conditions for dips and swells are the threshold and hysteresis. The dips and swells are characterized by duration, magnitude, and time of occurrence. Also, during an interruption the voltage sinks well below its nominal value. The interruption begins when the voltage on all phases are below threshold and ends when one phase is equal to or above the interruption threshold plus hysteresis; the reference voltage is $350\,V$ and the threshold voltage is $125\,V$.

Equally, average values of 11.74 % and 2.33 % harmonic current and harmonic voltage were recorded. These values are well below the limits as could be seen in Table I. However, they still indicate some elements of non-linearity within the loads. Similarly, an average value of 5.96 % was achieved for the imbalance voltage. An imbalance voltage exceeding 5 % which is considered high in this case, could lead to a 'braking' effect in the distribution system, thus causing overheating leading to a life reduction of the system [8].

The results depicted in Table I shows that the disturbance is mainly generated from the loads.

Table I Current and voltage harmonic distortion, imbalance voltage and voltage dips and swell

SS	PF (IEC limit-0.93)	VHD % (IEEE limit 5%)	CHD % (IEEE limit 15%)	VI % (IEEE limit 5%)	VD and VS
Nasarawa	0.52	4.2	40	5.8	16 times voltage dips and 2 swells
Boro 1	0.69	1.4	4.5	7.2	186 times voltage dips and 1214 swells
Pama 1	0.59	2.8	5.2	4.8	115 times voltage dips and 3218 swells
Pama 2	0.61	1.75	4.2	8.8	832 times voltage dips and 52 swells
Pama 4	0.59	1.5	4.8	3.2	0 time voltage dip and 2148 swells
Average	0.60	2.33	11.74	5.96	230 times voltage dips and 1327 swells

SS = Sub Station; PF = Power Factor; Voltage Harmonic Distortion; CHD = Current Harmonic Distortion; VI = Voltage Imbalance; VD = Voltage Dips; VS = Voltage Swells

The imbalance current and percentage load were calculated using (1), (2) and (3) based on data acquired on the field using the clamp meter.

The result obtained (see Table II) shows that Nasarawa, Pama 1, Pama 2, and Pama 4 substation of the 11kV Pama feeder are overloaded (see Fig. 4). These results also illustrates that the system is imbalanced since the loads are not equal and identical in all the phases within the substations. The following phases are seen to be over loaded; Nasarawa substation red phase, Boro 1 substation blue phase, Pama 1 substation yellow phase, Pama 2 substation red phase and Pama 4 substation red phase. An imbalance current of more than 10 % is consider as high for the distribution system [8]. The imbalance current (see Fig. 5) represents higher level of imbalance within the systems.

Table II Load assessment results, imbalance current and percentage load

Substation	Red phase (*A*)	Yellow phase (*A*)	Blue phase (*A*)	Neutral current (*A*)	Average Value (*A*)	Load (%)	Imbalance Current (%)	Power rating (*kVA*)	Current secondary (*A*)
Nasarawa	740	512	589	321	614	88	21	500	696
Boro 1	396	438	461	011	431	62	7	500	696
Pama 1	344	714	451	311	503	72	42	500	696
Pama 2	619	604	338	293	528	75	19	500	696
Pama 4	412	318	183	162	304	73	35	300	417
Average							25		

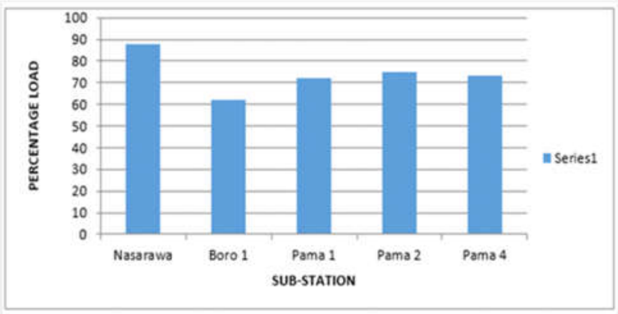


Fig. 4 Percentage load for Nasarawa, Boro 1, Pama 1, Pama 2 and Pama4 substation.

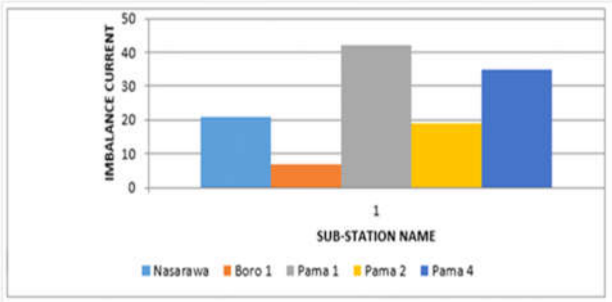


Fig. 5 Imbalance current for Nasarawa, Boro1, Pama1, Pama 2 and Pama 4 substation.

IV. Conclusion

This paper presents an investigation on the effect of imbalance and non-linear load on $11kV$ Pama feeder comprising of Pama 1, Pama 4, Pama 2, Nasarawa and Boro 1 substations within Chikun Local Government area of Kaduna state, Nigeria. Measurements were carried out using the Fluke 435 power quality analyzer, and results obtained include voltage dips and swells, current and voltage harmonic distortions and imbalance voltage and current. The analyzed result shows an average value of 230 and 1327 times voltage dips and swells, 11.74 % and 2.33 % harmonics current and voltage, 5.96% and 25% imbalance voltage and current respectively. When compared with the IEEE standard limits of 10 % and 5 % harmonic current and voltage, 10 % and 5 % imbalance current and voltage, it could be seen that these results confirmed the presence of harmonics within the system which are primarily due to imbalance and non-linear load, triggering operating snags on the distribution system, thus affecting power quality. As a consequence of the results obtained, it is recommended that the assessment of imbalance and non-linear load on the $11kV$ Pama feeder should be carried out regularly, while mitigation techniques such as fixing poor or nonexistent grounding on individual equipment or the facility as a whole, moving a few loads between branch circuits or adding extra circuits to help isolate the sensitive equipment from what is causing the harmonic distortion should be implemented.

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