U6CAU Proceedings Volume 1, Number 1, 23 - 32, September 2019 *Maiden Edition*
on Harnessing African Potentials for Sustainable Development, Calabar, Nigeria **ISSN 1596-1273**

TRANSFORMER PARAMETERS MONITORING FOR DISTRIBUTION NETWORK OPERATION

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ABSTRACT
Distribution transformers (DT) are the most important and costly components among the equipment required in distribution transformer substations. For the stability of electricity supply, more attention is deserved on monitoring of DT operational parameters such as frequency, active power, reactive power, power factor, etc. Distribution transformers are often failed probably as a result of cellulose deterioration, overloading, poor insulation, poor dielectric strength of the oil, old age etc. Experience shows that utility companies in Nigeria are insensitive to the monitoring of these DT's operational parameters which results in sudden breakdown or persistence outages of the feeder. The utility company may be affected with an approximate reduction in monthly revenue collection compared to previous ones. Thus, it becomes necessary to carry out DT operational parameters' monitoring for all transformers in the circuit. Planning engineers might have several methods of solving this problem and the approach varies from one country to the others due to variation in operational styles. However, this paper presents a case study of 300kVA, 11/0.415kV Transformer for Parameters monitoring in Distribution Network Operation using Power Quality and Energy Analyser (PQEA) equipment (Fluke 435 Series II). The pre-set network operational parameters recorded or measured were downloaded via personal computer after the experiments. The experimental results and their graphical analyses by excel application are presented. Recommendations for the utility's operations and maintenance engineers on the field for compliance are presented. The results obtained show that this approach is a reliable way of monitoring DT parameters for the operational planning of distribution networks.
Keywords: Insulation, Cellulose, Outages, Experiment, Distribution Transformer

INTRODUCTION

A transformer is a power system component that enables alternating current power to be transformed with high efficiency from one voltage level to another at the same frequency (Abdur *et al*, 2018; Fink and Beaty 2000). By electromagnetic induction, an alternating current of one voltage is transformed to another voltage, without change of frequency (Uwaifo, 1994; Theraja, 2005).

The physical basis of a transformer is mutual induction between two circuits linked by a common magnetic flux. This simply means it consists of two inductive coils that are electrically separated but magnetically linked through a path of low reluctance. Connecting any of these coils to a source of AC supply sets up alternating flux in the Lamination core most of which is linked with the second coil in which it produces mutually - induced emf according to Faraday's laws of Electromagnetic Induction as shown in equation (1) (Bengtsson, 1996; Lai *et al*., 2017; Li *et al*., 2019; Ravishankar *et al*., 2016; Yiwei *et al*., 2019).

$$E = M\,x\frac{di}{dt} \qquad (1)$$

If the second coil is closed, a current flow in it. This shows that electric energy is transferred magnetically from the first coil to the second coil. Thus, the first coil is called primary winding while the second coil is called secondary winding. Depending on the number of turns on each winding, a transformer could be either a step-up or step-down transformer.

Step-up transformer has more turns on the secondary coil than on the primary coil and therefore the voltage induced in the secondary coil is larger than the primary coil voltage. If the number of turns on the primary coil, $N_{P,}$ and the number of turns on the secondary coil, $N_{S,}$

then the respective voltages are V_P and V_S. Therefore, the relationship between these parameters is defined as shown in equation (2) (Abdur *et al.*, 2018; Uwaifo, 1994; Theraja, 2005; Fink and Beaty, 2000; Edan, 2013),

$$\frac{\mathbf{Ns}}{\mathbf{Np}} = \frac{\mathbf{Vs}}{\mathbf{Vp}} \qquad (2)$$

A step-down transformer has more turns on the primary coil than on the secondary coil and therefore the voltage induced in the secondary coil is smaller than the primary coil voltage. Thus, the same equation (2) also holds for a step-up transformer.

Transformers are widely used in electrical power systems. Transformers used in generation and transmission networks are referred to as power transformers. This category of transformers usually ranges from 30MVA and above and they of high voltages. On the other hand, transformers used in distribution networks range from 2.5MVA to 25MVA.

In this regard, 15 MVA and 25MVA transformers are in most cases used in the power utility distribution injection substations. Transformers between the range of 25kVA and 2.5MVA are often installed as public transformers or dedicated transformers for industries/large customers. In Nigeria for example, these transformer's ratings are available on the field as 25, 50, 100, 200, 315, 500, 750, 1000 and 2000 kVA for 11kV distribution transformers and 100, 200, 315, 500, 1000, 2000 and 2500 kVA for 33kV distribution transformers.

In practice, Nigeria, it has been very difficult to effectively monitor each transformer parameter in the distribution network operation of most utility companies, perhaps because there are often too many distribution transformers on a feeder. The percentage loading of these DTs remains the only parameter used to measure their performance in the circuit. This accounts for the reasons why in most cases large numbers of transformers are lost in the circuit. Therefore, the objective of this paper is to determine other DT parameters that are exceptionally useful in monitoring the performance of DTs in distribution network operation.

This is achievable using modern equipment such as Power Quality and Energy Analyser equipment (Fluke 435 Series II) for an experimental arrangement with a DT that is on – load. The PQEA equipment is connected to the low voltage side of the DT while necessary calibrations are carried out on the equipment as part of the requirements for the experiment.

The experimental setup i.e DT low voltage side and PQEA equipment connections are left for a specified period so that readings at a pre-set interval such as 5 or 10 minutes etc are accumulated and stored. The results of the set parameters are later downloaded using a personal computer for analysis using excel application.

Three Phase Transformer Connections

There are various methods available for transforming 3 phase voltages to higher or lower 3 phase voltages (Theraja, 2005; Fink and Beaty, 2000). The most common connections are star-star, delta-delta, star-delta, delta-star, open-delta (or V/V connection) and Scott connection (or T -T connection) (Theraja, 2005).

Typical distribution network uses delta-star connections for both step-up and step-down purposes. When used as a step-up transformer, the high-tension winding is Y connected; when used for step-down purposes, the low-tension winding is usually Y connected in order to provide a grounded neutral for secondary transmission or primary distribution (Fink and Beaty, 2000).

The three-phase supply system is found to be quite balanced in both magnitude and displacement at the generation and transmission level, which is not so at the distribution end (Edan, 2013). Voltage unbalance, which is a common and global phenomenon, is found to be very prominent in deteriorating the operations and performance of electrical apparatus most especially in distribution transformers. This paper is analyzing the operation of three-phase distribution

transformers with unbalanced voltage conditions.

Numerical details study of distribution transformers substation with primary delta connection and secondary star connection with solidly grounded neutral would be presented in this paper.

Power And Power Factor In Distribution Transformer

The power factor of an AC electrical power system is defined as the ratio of the real power flowing to the load to the apparent power in the circuit (Sandesh, *et al.*, 2012). It is a measure of electrical efficiency and is given by the ratio of active power consumed by the load to apparent power delivered to the load (Allah, 2014). In an ac circuit, there is generally a phase difference between voltage and current. The term cosϕ is known as power factor of the circuit and represented as shown in Equation 3 (Khanchi and Grag, 2013, Adesina, 2016, Theraja, 2005):

$$\boldsymbol{Cos\phi = \frac{S}{\{1.73\ (IV)\}}} \qquad (3)$$

Where,
S = Apparent power of the transformer in VA.
I = Current flowing in the circuit.
V= Line voltage of the transformer.

Equation (3) can also be re-written as shown in Equation (4) (Adesina, 2016)

$$\boldsymbol{Power\ factor = \frac{\{kilowatt(Real\ power)\}}{\{kilovoltampere(Reactive\ Power)\}}} \qquad (4)$$

Since, kW = kVA$Cos\phi$ and kVAR = kVASineϕ.

Therefore, the Pythagoras relation of these parameters is as shown in Equation (5).

$$\boldsymbol{kVA = [(KW^2) + (KVAR^2)]^{0.5}} \qquad (5)$$

Where,
kVA = Apparent power in kilovolt amperes
kW = Active power in kilowatts
kVAR = Reactive power in kilovolt amperes reactive

power factor varies with load and it has a value from 0 to 1. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a nonlinear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power.

In an electric power system, a load with a low power factor draws more current than a load with a high-power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor (Rashid, 2001).

Power factor improvement leads to a big reduction of apparent power drawn from the ac source which in turn saves energy and minimizes the transmission losses. It generally employs means that control reactive power in power system network (Sandesh *et al.*, 2012). Different systems are available to produce reactive energy and improve the power factor (Al- Naseem and Adi, 2003).

The process is usually denoted by reactive power compensation which is a productive technology employed for improving power systems performance. In recent years, the demand for controllable reactive power source has gone up mainly for efficient and reliable operation of ac electric power system. VAR compensators should be controlled to provide rapid and continuous reactive power supports during static and dynamic power system operating conditions (Sandesh, *et al*., 2012). Power quality problem can occur as a non-standard voltage, current and frequency. The power quality has serious economic implications for customers, utilities and electrical equipment manufacturers.

Distribution Transformer Performance Analysis

It involves searching for overloaded distribution transformers (DTs) or troublesome DT substations in power utility company's networks. The most critically overloaded DTs are then selected, and their sites visited for Distribution transformer and Equipment (Fluke 435 series II Power Quality and Energy Analyser)'s connections as an experiment.

A 300 kVA, 11/0.415kV distribution transformer substation was selected and used as

the case study. At the DT substation, the connection of the Fluke with an on-line transformer on load at the secondary terminals was carried out. Necessary calibrations were carried out which includes, selection of Parameters to be determined i.e Rms Voltage (Single phase and 3 Phases), Current, Frequency, Active Power, Apparent Power, Reactive Power and Power Factor. The Calibration of Fluke Machine to record parameter values at an interval of 10 minutes was also done. After all the connections, the power analyzer was left for a duration analysis time (T) of one hour while the data capturing time interval was chosen to be 10 minutes. When the T setting is completed, the Power Quality and Energy Analyser (PQEA) equipment will be disconnected and brought to the office for further work. The results recorded by this PQEA equipment are presented in the next section. The flowchart in Fig.. 1a and b describe the procedural details.

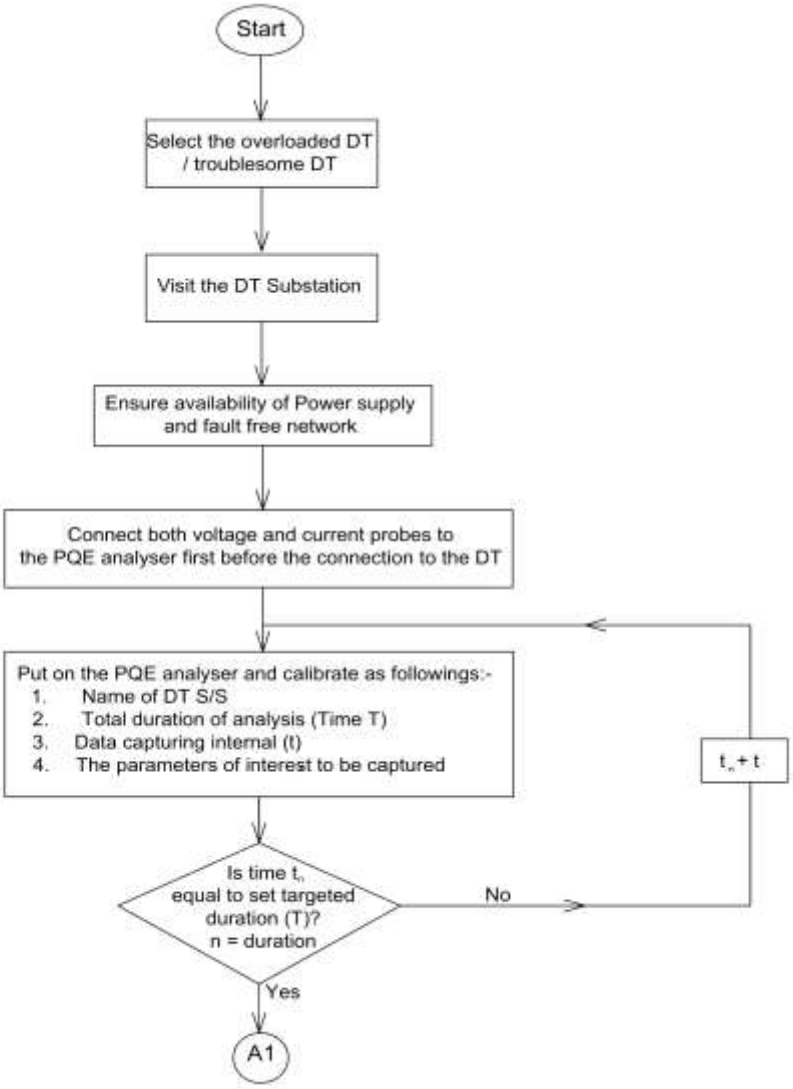


Fig. 1a: Flow Process of typical DT power analysis using power Quality and Energy Analyser Equipment

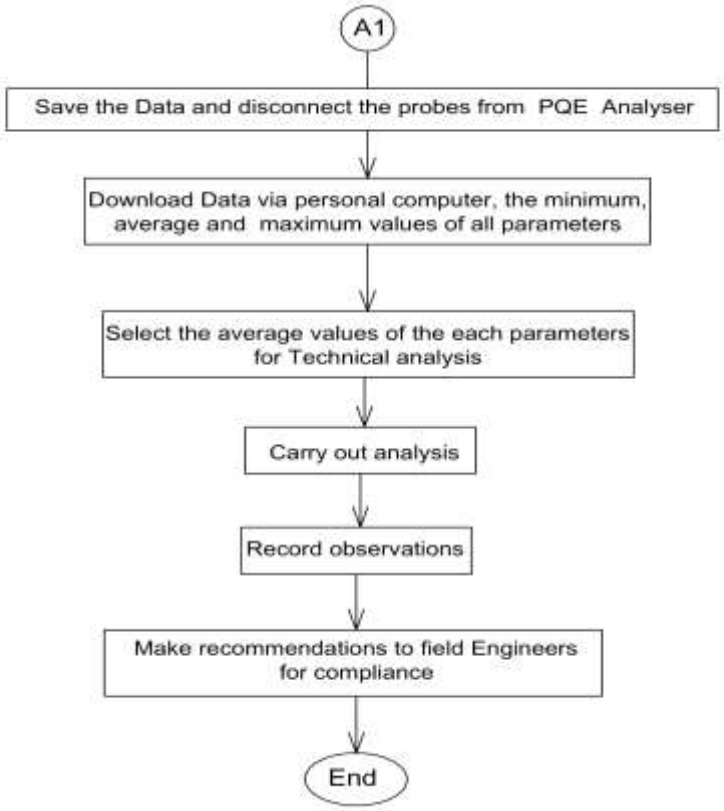


Fig. 1b: Continuation of Flow Process of typical DT power analysis using power Quality and Energy Analyser Equipment

DISCUSSION

The results recorded by the PQEA equipment are downloaded using a personal computer. Graphical analysis of all the parameters were also carried out using excel application and the results obtained are shown in Fig. 2 to 9.

Fig. 2 shows that on this DT Substation, the phase to neutral voltage recorded ranges from 221.28V to 223.84V which falls below the conventional value of 230V according to Nigerian Standard and Specification. The phase to phase rms voltage also recorded ranges from 382.34V to 387.62V which falls below the convectional value of 400V according to standard, this can be seen in Fig. 3. As presented in Fig. 4, there is a load imbalance observed at this DT substation, necessitating a high record of neutral current.

Observation of the plot in Fig. 5 shows that the load on this transformer can be said to be unbalanced because the 3 phases are hot having the same values or values that are relatively closed. The frequency is measured to be between 50.449 to 50.606Hz, hence the operation is considered stable. However, ± 2% of 50Hz frequency is allowed by the standard in power system operation.

From Fig. 6, 7 and 8, the peak active power, apparent power and reactive power are 252.0 kW at 10:53:04 am, 259.92 kVA at 10:53:04 am and 66.62 kVAr at 10:53:04 am respectively. While the average power drawn from the DT at that hour of the day are 204.84 kW, 244.53 kVA, 63.86 kVAr for active power, apparent power and reactive power respectively. This implies that the percentage of reactive power to active power in this network is 31.18% which violated the allowable value of 5%

by the Institute of Electrical and Electronics Engineers (IEEE) regulation.

Fig. 9 shows that the Lines Power factor is satisfactorily within the minimum value of 0.96 and a maximum value of 0.97 across the three phases. While the network power factor ranges from 0.95 to 0.97 and the overall average network power factor was estimated to 0.97.

Considering the average apparent power value of 259.92 kVA loading of the distribution transformer with its 300kVA rated capacity, it implies the percentage loading of the DT as that time was 86.64%. However, it is important to note that the readings were taken at the off-peak load period of the DT substation, but the loads on it have a greater value of reactive power. It is expected that the reactive power presence would be higher at peak load period with an appreciable consequence of power factor value reduction.

The following recommendations are thus presented to operation Engineers for Compliance: The load in-balance observed at this DT substation necessitated high records of neutral current as shown in Fig. 4; it becomes necessary for the operation Engineers to comb the network and approximately balance the load in all the phases.

Theoretically, the 3 phase's loads should be equal which results in zero Neutral currents. In practice, this is difficult to achieve. Hence there exist a minimum Neutral current that guarantees an approximate balance of 3phases.

The average PF of the DT substations is 0.96 as shown in Fig. 9. Whenever the PF falls below 0.85, the installation of an appropriate size of capacitor bank would be required for the correction of PF to desire specification (0.9 to 0.95). Also, the use of standard equipment and materials in the substation is desirable and the proper earthing of substation equipment very necessary. The DT substation must be cleaned and free from the water-log.

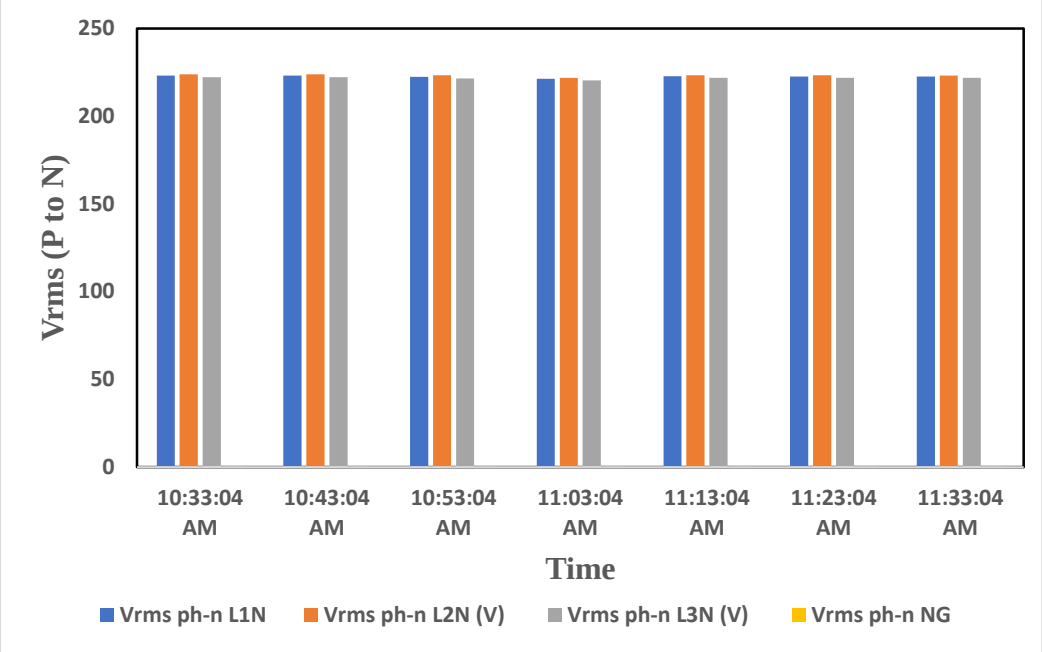


Fig. 2: Variation of Vrms (Phase to Neutral) with Time

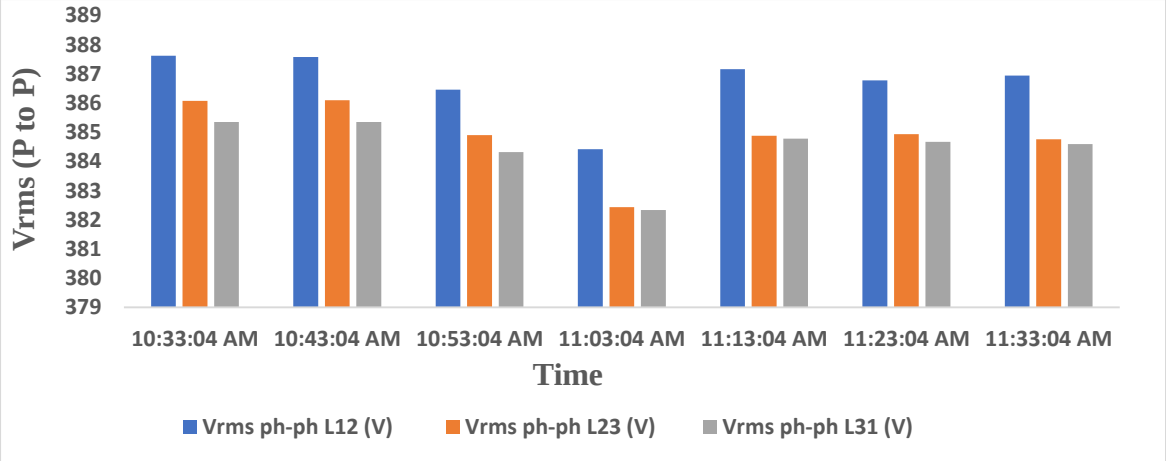


Fig. 3: Variation of Vrms (Phase to Phase) with Time

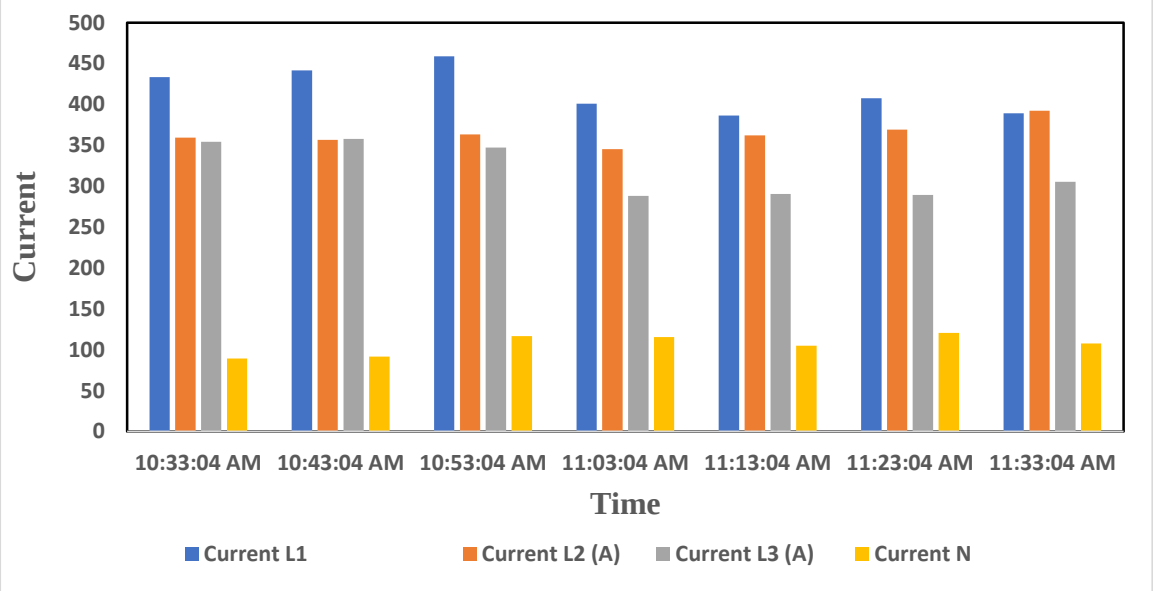


Fig. 4: Variation of Current with Time

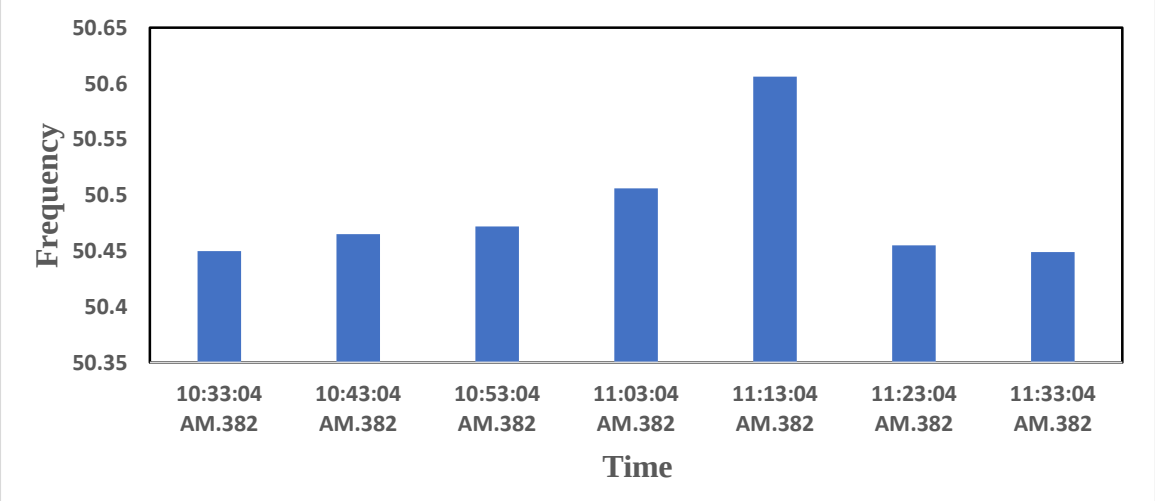


Fig. 5: Variation of Frequency with Time

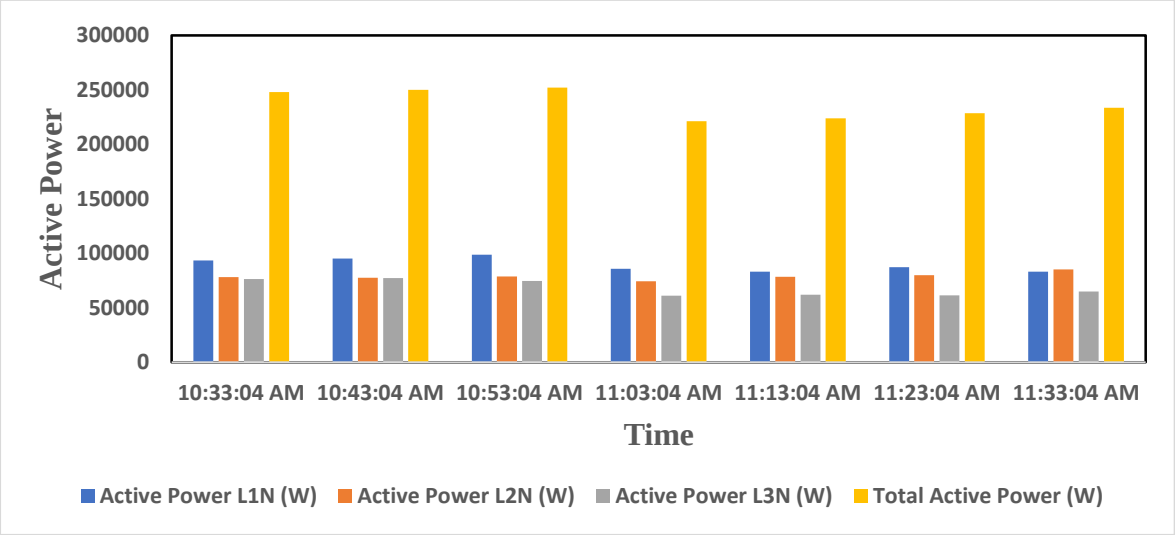


Fig. 6: Variation of Active Power with Time

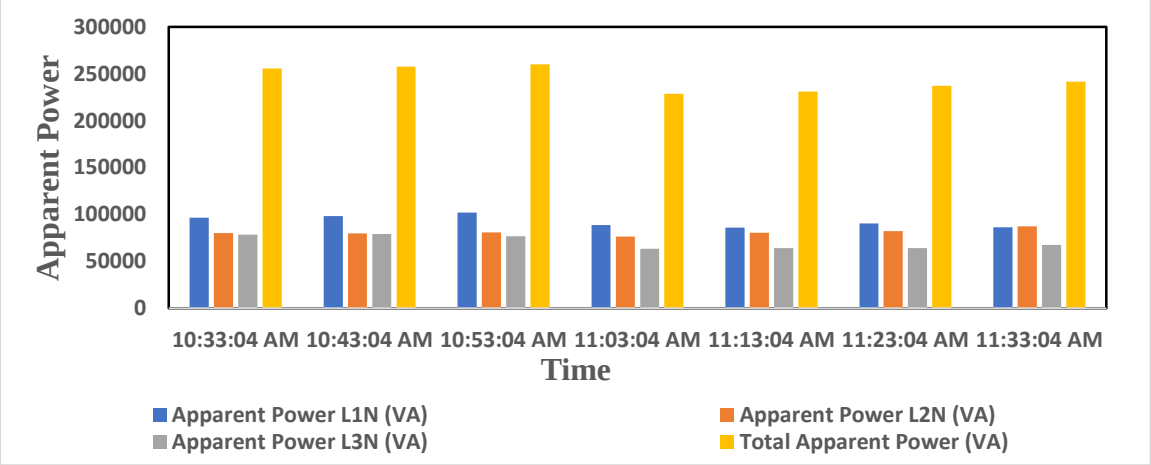


Fig. 7: Variation of Apparent Power with Time

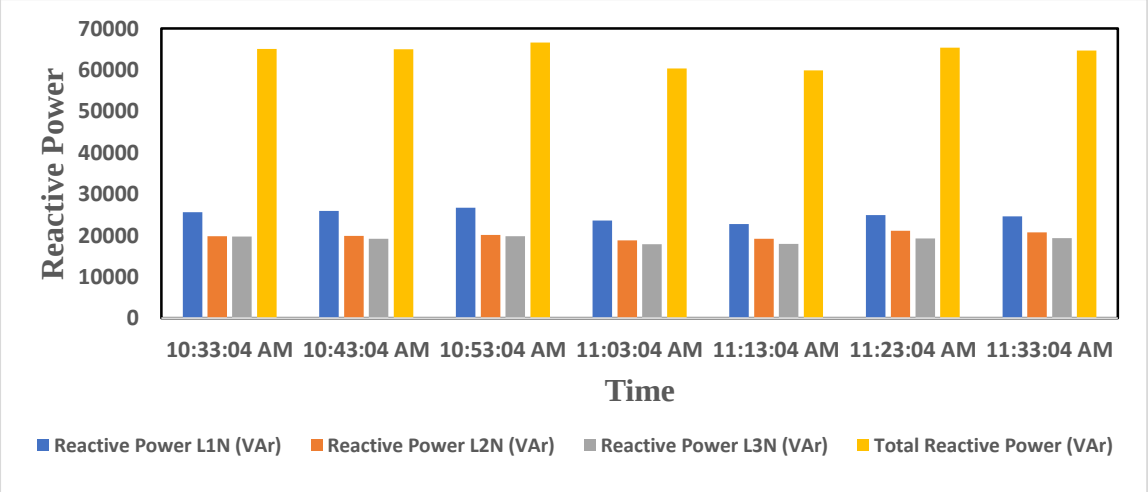


Fig. 8: Variation of Reactive Power with Time

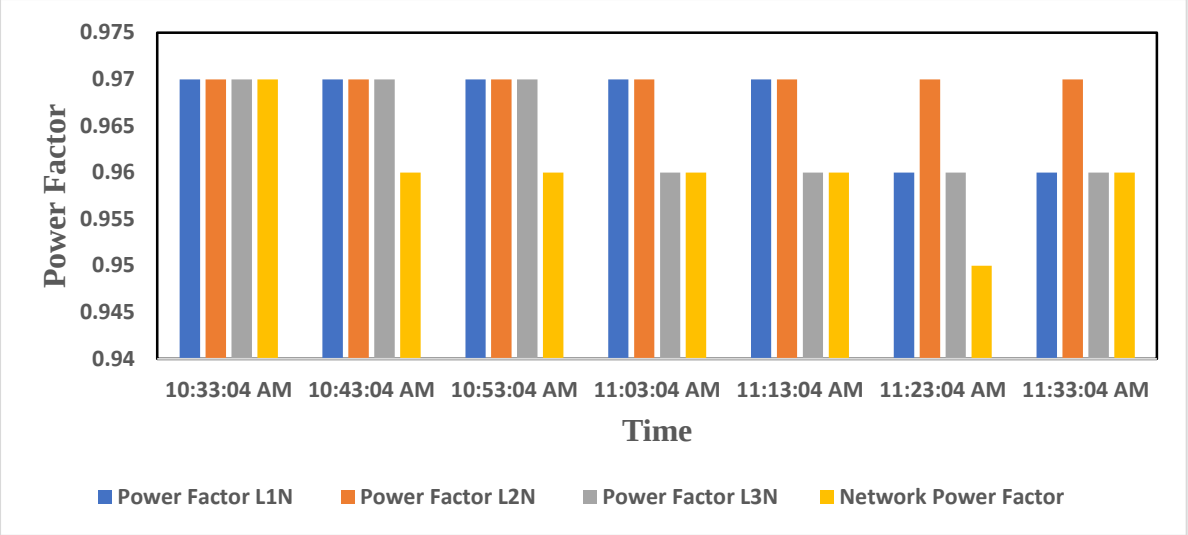


Fig. 9: Variation of Power Factor with Time

CONCLUSION

Distribution Transformer as major equipment in electric power utility companies deserves to be regularly monitored for its performance to ascertain continuous electricity supply to utility customers and enhance improved revenue collection. The paper has presented a monitoring strategy for the Parameters of a DT for Distribution operation planning by considering a case study of 300kVA, 11/0.415kV distribution transformer substation. These Distribution Transformer parameters were investigated when the DT is on-load. The results of DT parameters such as voltage, current, frequency, active power and power factor are quite satisfactory, while the overall investigation results show that the percentage of reactive power to active power in this network is 31.18% which violated the allowable value of 5% by IEEE regulation. Also, the apparent power of 259.92 kVA loading of the Distribution transformer compared to its 300kVA rated capacity suggest the percentage loading of the DT as the time of investigation was 86.64%, meaning the DT is in good loading condition. In general, this approach has generated a set of reliable operational parameters for the case study distribution transformer. Necessary recommendations required for the DT substation's higher operational efficiency are presented to utility's operations and maintenance engineers for compliance.

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Cite as: **L. M. Adesina and O. Ogunbiyi (2019). Transformer parameters monitoring for distribution network operation. In: Asuquo, Francis E. (Editor) on *Harnessing African Potentials for Sustainable Development, Calabar, Nigeria, September 2019;* UNICAL Press & GIS Publishers. *U6CAU Proceedings (Maiden Edition) Volume 1, Number 1, 23 – 32*.**