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Parametric Modeling Of Undervoltage And Its Impact On Nigerian Electric Power Distribution Network: A Case Study

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***Abstract*—This paper presents the parametric modeling of undervoltage and its impact on Nigerian electric power distribution network. The issue of undervoltage in Nigeria power distribution network has been a recurrent decimal in the power sector, which have serious effects on the electricity supplied to homes appliances; and it has resulted to incessant fire outbreak in offices and residential buildings. The present state of the electric power distribution network was x-rayed to critically review and identify the causes, impact and resultant effects of undervoltage on the system. From the survey carried out, it was revealed that there were high voltage fluctuation, voltage dip, voltage drop, power losses and undervoltage in the system. The paper then further proposes the ways to improve the undervoltage in the power distribution network of Nigeria.**

Keywords—Parametric, Modeling, Undervoltage, Causes, Remedies, Power Distribution Network.

1. INTRODUCTION

The electricity supply in Nigeria has been epileptic for the past decades, before the power reform was embarked upon by the Nigeria government which aimed at improving the total megawatts of electricity generated, transmitted and distributed to Nigerians [1]. Despite this reform, the Nigeria power system is still been characterised with inadequate and inefficient power supply, voltage drops, undervoltages and high power losses especially in the distribution network. The power system of Nigeria have evolved over decades and their primary emphasis has been on providing a reliable and economical power supply to their customers [1]. The Nigerian economic growth has been badly affected by the epileptic and unreliable power supply.

Furthermore, the development of any country is largely hinged on the availability of undisturbed and regulated power supply [2]. Hence, the availability of electricity and it stability has been the most powerful tool of introducing economic development and social change throughout the world [3]. The economic development of any nation depends on the reliability and voltage stability of electricity supply in it. In other words, reliability of power supply and voltage stability (regulated) are keys factors for economical drive or boom.

The Nigerian power system is sub-divided into generation managed by Gencos; transmission managed by Transcos and distribution managed by Discos. The distribution company of Nigeria (Discos) comprises of different companies managing different sections of the distribution network.

The Benin Electricity Distribution Company (BEDC) controls four states, comprising two states in the Nigeria South-South (Edo and Delta) and two states in the South-West of Nigeria (Ondo and Ekiti). These areas are fully controlled and managed by the BEDC.

The Nigerian electric power distribution network is faced with enormous challenges and its is characterised with epileptic supply, haphazard connections, under/over sized cables, lengthy distribution lines, over-loading, load shedding, undervoltage etc.

Recently, the issues of overvoltage has been dealt with in detail due to the damage it causes on home appliances and

buildings when fire outbreak occurs as a result of overvoltage [4]. This has make researchers to proffer solution by producing different electrical power rating fuse for different purposes to avoid a recurrent decimal of fire outbreak and damage to electrical appliances and also, various electrical power surge circuit breakers protectors and stabilizers are also designed to curtailed this overvoltage in electrical power network [4]. But the issues of undervoltage and its impact has been worked on; though has not been properly dealt with that much or in-depthly. This undervoltage and its impact has become a recurrent decimal in Nigeria electric power distribution network. Consequently, the issue of undervoltage characteristics, causes, resultant effect and remedies are exhaustively considered in this article.

1.1 CAUSES OF UNDERVOLTAGE IN ELECTRIC POWER DISTRIBUTION NETWORK

Voltage irregularities is one of the greatest problem bedeviling electrical power system; especially the distribution network. In fact, about 95% of the problems revealed in electrical networks stem from voltage problems [5]. According to Hershey [5], "Technically speaking, over/undervoltage condition is reached when the voltage exceeds/lags the nominal voltage by 10% for more than one (1) minute".

The following discuss some common causes of undervoltage in power distribution network:

i. **Lengthy Distribution Lines:** One of the major sources of losses in the distribution system is the power lines which connect the substation to the load [6]. Distribution lines in Nigerian electric power system has been characterised with haphazard connections and extended over a long distances to feed load scattered over large areas. The 11kV and 415volts lines in rural areas are practically extended over long distances and the primary and secondary distribution lines in rural areas are largely radially laid over long distance [7]. Actually, all real power that are lost in the distribution system is due to copper losses [6]. From equation one (1) below:

$$R = \rho L/A_s \quad (1)$$

A long line will have a higher resistance, resulting to larger losses, since the longer the line, the larger the resistance.

ii. Transformer Siting: The siting of distribution transformers is requisite for even distribution of load in the distribution network. In most cases, distribution transformers are not located centrally with respect to consumers load. When the distribution transformer is not properly sited at the centre of the load to be powered, it can creates uneven supplies of voltages or distribution of voltages to the load. This causes low voltage at the farthest end of the distribution network. In Nigeria today, even when the distribution transformer is properly sited; load expansions and haphazard (Unregulated) connections of load to the distribution transformers have caused the unevenness of voltage distribution at the distribution level which has led to serious undervoltage in Nigeria power distribution system. Any planned action has not been taken to guide against this ugly menace.

iii. Inadequate or Inappropriate Sizing of Distribution Line Conductors: Conductor sizing for distribution line is a critical issue today in Nigeria power distribution network due to the haphazard connections and unregulated load expansion. The Nigerian technicians, craftsmen and electrians have not employ their expertise when connecting loads to the distribution network. All manner of cables are being used for connections; both under and over sized have been used to connect load to the distribution network without considering the effects on the system. The size of the distribution conductors should be selected on the basis of KVA x KM capacity of standard conductor for required voltage regulation. However, rural loads are usually scattered and generally fed by radial feeders [7].

iv. Transformer Sizing and Selection: Transformer sizing and selection is an important aspect of distribution system. Transformers, along with other power distribution apparatus, remain a fundamental components in electrical power system, especially for commercial buildings [8]. The electrical size of the distribution transformer load is rated in KVA. And a general approach to determine distribution transformer capacity and selection of proper rating for the design application is to be obtained by the calculated designed load from the respective electrical scheduled and add 20% spare capacity for future load growth [8]. The selection of distribution transformer start with the KVA rating required to supply the loads connected or needed in the electrical system and also, the type of load supplied: Linear and Nonlinear load [8]. For the nonlinear load, the K-rated distribution transformer should be selected combined with harmonic filters or chokes for harmonics mitigation while in the linear load, the distribution transformer with lower core losses should be selected [8]. In absence of the above mentioned, high losses and low power factor occurs hence, undervoltage is experienced in the distribution network.

v. Low Power Factor of Primary and Secondary Distribution System: In most of the low tension

(LT) distribution circuits, low power factor is experienced in Nigeria power system. Normally, the power factor of most LT distribution circuits ranges from 0.65 to 0.75 [7]. This low power factor is caused by non-linear loads in the system. A low power factor contributes towards high distribution losses [7]. According to Akpojedje, Onogbotsere and Egedi-idu [9], "The overall power factor of a system is likely below 0.7 lagging, unless corrective measures are taken to improve it". Hence, the operation of power system (distribution) at low power factor is highly uneconomical to electric power consumers as well as the suppliers (utility companies) [9]. For a given load, if the power factor is low, the current drawn-in is high and the losses is proportional to the square of the current will be more [7]. Consequently, high losses in the distribution system has resulted to undervoltage experienced today.

vi. **Bad Workmanship:** Bad workmanship greatly contributes significantly towards increasing distribution losses [7]. Inexperienced technicians and craftsmen have contributed greatly to the undervoltage experienced by Nigerian power distribution network today. Due to bad or shoddy work carried out by inexperienced electrians has led to high losses in the system and the haphazard connections witnessed has also contributed to undervoltage occurring today in the distribution network.

vii. **Feeder Load Balancing and Phase Current:** Load balancing on the three phase circuits of the distribution power transformer is the easiest way of loss minimization in the power distribution network. Feeder phase balancing also tends to balance voltage drop among phases giving three phase customers less voltage unbalance [7]. Feeders are usually considered "balanced" when phase current magnitudes are within 10 [7]. Similarly, balancing load among distribution feeders will also lower losses assuming similar conductor resistance [7]. But the distribution network today is characterized with unbalanced load and phase current. Consequently, losses are experienced in the network.

viii. **Distribution Transformer Switching:** One of the method of reducing fixed losses is by switching off distribution transformers in the periods of low demand [7]. If two distribution transformers of a certain size are required at a substation during peak periods, only one might be required during time of low demand so that the other transformer might be switched off in order to reduce fixed losses [7]. But during the distribution transformer switching losses occur due to flashover between the switch contacts.

ix. **Hot Spots:** Due to inexperienced electrians in the distribution system, shoddy jobs are carried out. Bad workmanship has caused weak joints and poor terminals in the distribution network. Hence, high losses in the system. Wherever a mechanically weak joint and poor termination are made, high resistance point is formed. Thus, the joint or termination will undergo a progressive failure due to heat created in the point. High resistance creates localized heating and since heating increases oxidation and creep, the connection becomes less tight, and further heating occurs until the contact tends to glow [4]. As resistance of aluminum and copper increases with respect to temperature, a higher voltage drop is realized at that point [4].

x. **Poor Joints and Terminations:** Poor joints and terminations are one of the contributing factors of high voltage drops on the feeders [4]. Poor joints and terminations are resulted from loose contact between the two conductors which are joined together [4]. Because of inexperienced technicians in the system, bad or shoddy jobs are the order of the day, where loose joints and poor or bad terminations are carried out by inexperienced technicians in the distribution network. This bad workmanship has led to increase in resistance and consequently, voltage drop and losses at the weak points.

Table 1: Causes of Undervoltage in Nigeria Power Distribution Network at Glance

S/No.	Causes of Under Voltage
1	Lengthy Distribution Lines
2	Transformer Siting
3	Inadequate or Inappropriate Sizing of Conductors of Distribution Lines
4	Transformer Sizing and Selection
5	Low Power Factor
6	Bad or Inexperienced workmanship
7	Neutral Failure
8	Feeder Load Balancing and Phase Current
9	Distribution Transformer Switching
10	Unbalance Three Phase Load
11	Drop of J & P Fuse
12	Haphazard Connections of Service Cables
13	Bad Cable Jointing
14	Overloading of Distribution Transformer
15	Hot Spots

1.2 MATERIALS AND METHODS

The parametric modeling of undervoltage in electric power distribution network focused on the total voltage drops in the distribution network and the time the drop stays. Also, it looks at the effects of undervoltage on electrical home

appliances in residential houses and offices. Literature review of undervoltage were considered and various causes were highlighted. Data were obtained by administering questionnaires to both consumers in the distribution network and technical power staff assigned to the area. Physical measurements of voltages in the distribution network were also carried out in Esan North East Local Government Area, Edo State, Nigeria. Undervoltage were examined in both residential and point load areas using voltmeters. The results were analysed graphically using MatLab2015 and Microsoft software.

1.3 PARAMETRIC MODELING OF UNDERVOLTGE IN DISTRIBUTION LINES

Distribution networks are low voltage systems which supplies the consumers the required voltage with minimum variation of a regulated percentage of ±6% of the voltage up-to 650V [3] at the farthest end under peak condition and normal system of operation. Often time, the significant portion of the power that utility generates is lost in the distribution processes. These losses occur in numerous or various small components in the distribution system, such as transformers, hot spots, improper or poor joints and terminals, and distribution lines etc.

Hence, high voltage losses may lead to undervoltage in the system. Undervoltage is a voltage drop of 10% or more that stays continuously for one minute or more [5]. Undervoltage can be caused by various voltage drops. The losses in transmission and distribution lines represent a significant proportion of power loss in both developed and developing countries. According to Anumaka [10], "The Nigerian electricity grid has a large proportion of transmission and distribution losses - whopping 40%".

The effect of line resistance is to cause voltage drop and power loss in the line and also, the effect of line inductance is to cause voltage drop as well.

Therefore, the parametric modeling of undervoltage (U_v) is an inclusive models of voltage drops and power losses in the distribution lines caused by the resistance and the inductance of the line. Since the secondary distribution voltage is low, the effect of the line capacitance is negligible and its parametric modeling will be neglected in this research work.

In parametric modeling of undervoltage, key parameters are to be considered such as line resistance (R), line inductance (L_h), current flow (I), line length (L), surface area of conductors (A_s), specific resistance or resistivity (ρ), time (t) and power loss (P_L). Parametric modeling, the various voltage drops and power losses that caused undervoltage in the distribution network are modeled as follows:

a) Voltage drop due to the distribution line resistance

$$V = IR$$

Where $R = \rho L/A_s$ from equation 1.

Then, $V_{d1} = \rho LI/A_s$ (2)

b) Voltage drop due to the inductance of the distribution line

$$V_{d2} = 2\pi f L_h I \quad (3)$$

c) Voltage drop due to the heat energy dissipated in the distribution line as a result of the line resistance [power loss (P_L)]

$$P_L = I^2R$$

Then, $V_{d3} = P_{L/}I$ (4)

The total voltage drop (V_D) in the distribution line is therefore obtained by summation of equation 2, 3 and 4,

since undervoltage (U_v) is voltage drop of 10% or more that stays continuously for one minute or more[5].

Then, when modeling undervoltage time is of essence, the parametric modeled of undervoltage (U_v) is:

$$U_v = \sum(\rho LI/A_s + 2\pi f L_h I + PL/I)t \quad (5)$$

1.4 RESULTS ANALYSIS AND DISCUSSIONS

The data obtained are analysed graphically with discussions as follows:

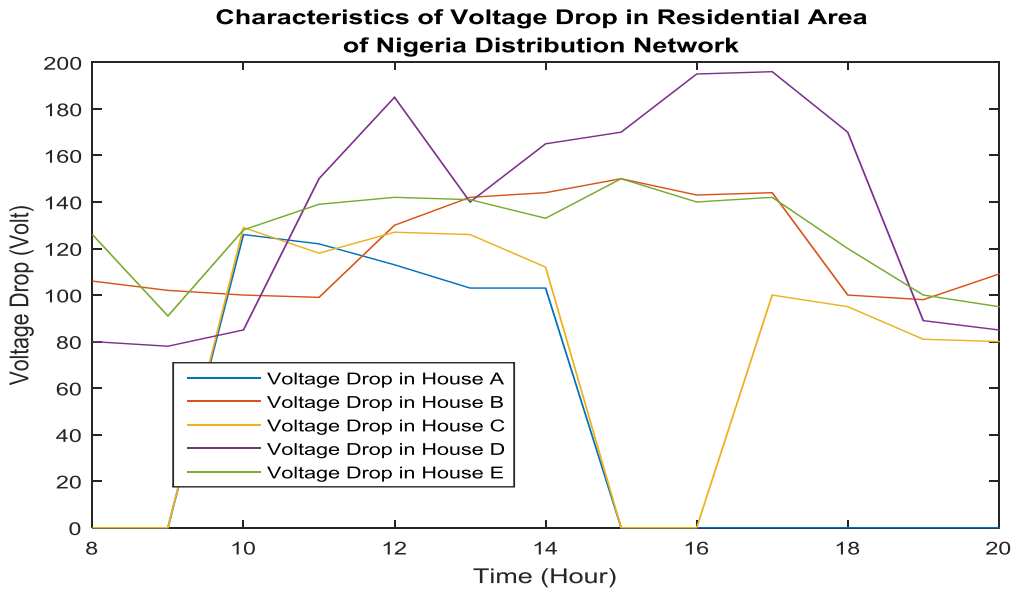

Figure 1: Voltage Drop (Volt) in Residential Area against Time (Hour)

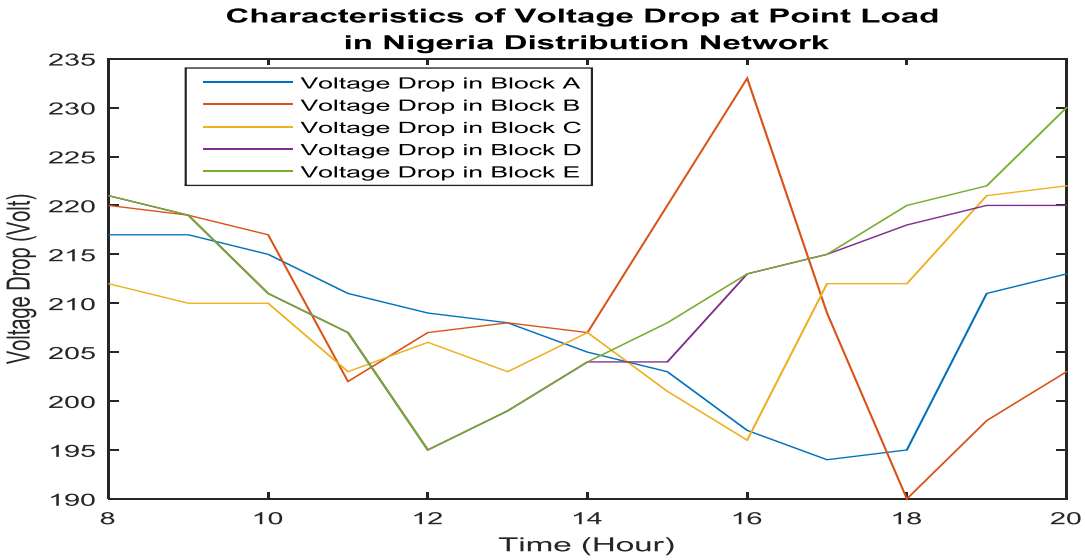

Figure 2: Voltage Drop (Volt) at Point Load Area against Time (Hour)

Figure 1 above shows the values of voltage drops occurrences in various residential houses of Nigeria electric power distribution network in Egbele community, Uromi, Edo State. It was observed that the residential areas of the distribution network has different degrees of voltage drop in the distribution network.

Considering House A, between 8 to 9 and 14 to 20 hours of the day, there was power interruption but when power suppy was restored, the voltage was characterised with high voltage drops which led to undervoltage in the system. Also, there were high voltage fluctuation and voltage dip in the network as seen from the Figure 1 above. Similarly, House B, C, D and E showing same chacteristics as House A.

It was seen that the voltages have serious voltage violation of the allowable or statutory limit of ±6% of voltage variation or fluctuation of low voltage system in Nigeria power sector.

This ugly menace of high voltage drop in the Nigeria distribution network is worrisome, and the poor voltage characteristics of the distribution network was due to the various factors highlighted in section 1.1 of this research work. According to [11], "Distribution network is considered as the weakest link in the entire power system, since the distribution losses is approximately 50%". This distribution losses are visible in Nigeria distribution network due to excessive voltage drop, undervoltage and unregulated voltage fluctuation at consumers point in the Nigeria power distribution network.

The residential areas considered, the supplied voltages ranges between 78 to 195V, while point load areas considered have voltage ranging between 194 to 233V.

Figure 2 shows the values of voltage occurrences at point load of the distribution network in Block A, B, C, D and E of the point load considered.

The point load areas shows meaningful of reliable electricity supply but the voltage was characterised with high voltage drop, undervoltage and unregulated voltage fluctuation similar to the residential areas of the network. The voltage supplied ranges between 194 to 233V as earlier mentioned.

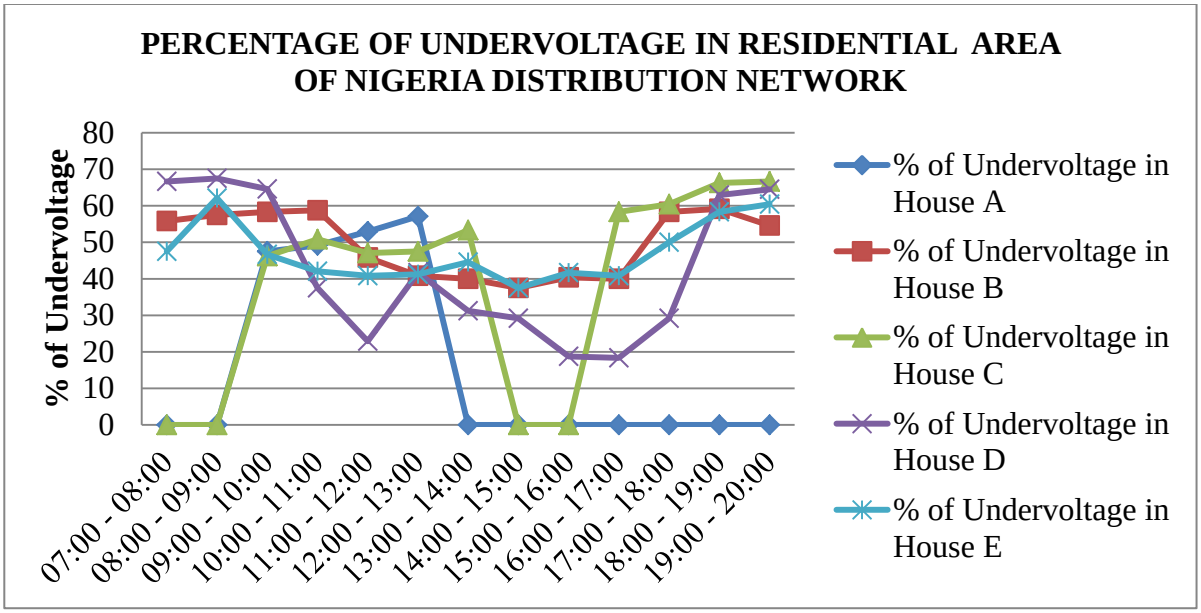

Figure 3: Percentage of Under Voltage (Volt) in Residential Area against Time (Hour)

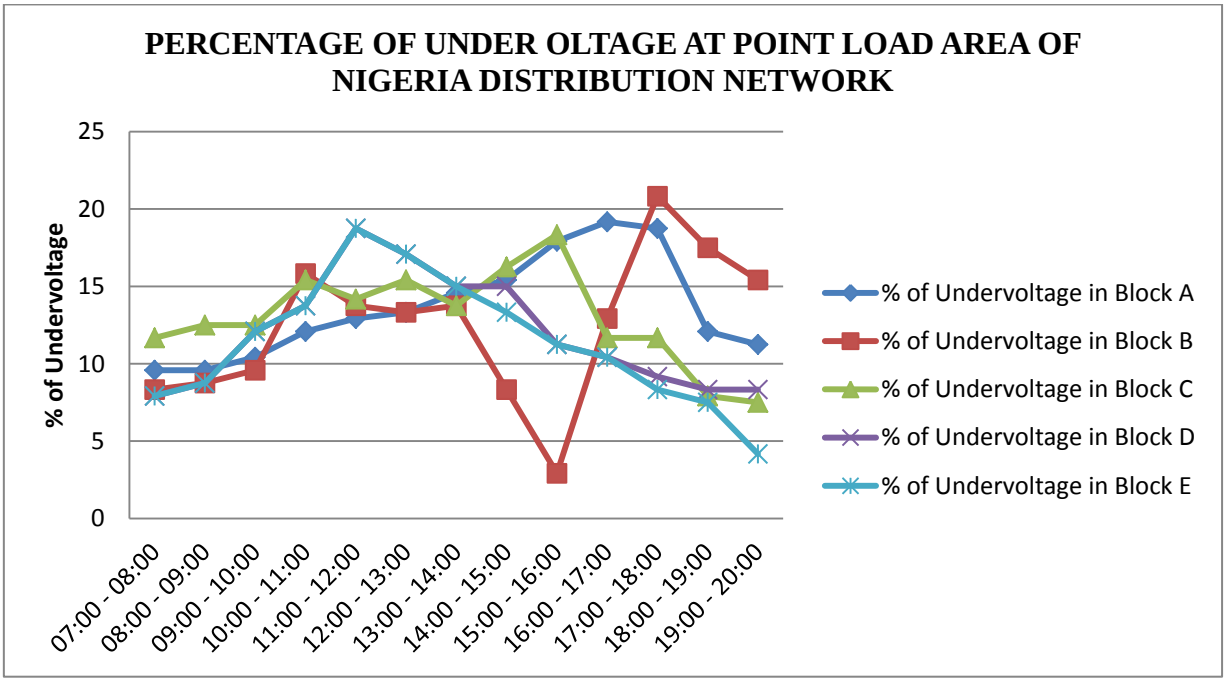

Figure 4: Percentage of Under Voltage (Volt) at Point Load Area against Time (Hour)

Losses are inherent in the distribution of electricity and cannot be totally eliminated but can be minimized or reduce to the barest minimum [12]. Losses in the distribution network are both technical and non-technical. The technical losses are due to energy dissipated in the conductors, distribution lines, transformers and magnetic losses in transformers [12]. The technical losses are normally 22.5% and they directly depend on the network characteristics and mode of operation [12]. While the non-technical losses include equipment vandalization, metering errors,

inadequate/inaccuracies of meter reading, inaccurate customer billig, power theft etc. Hence, undervoltage is as a result of losses in the distribution lines, voltage drop and excessive voltage fluctuation in the network.

According to [5], undervoltage is a voltage drop of 10% or more that stays continuously for one minute. Hence, Figure 3 and 4 show the percentage of undervoltage in residential areas and point load of Nigeria distribution network respectively.

It was observed that the voltage drop of both residential and point load areas increased beyond 10% in most cases and stays above one minute according to [5]. Hence, undervoltage was predominant in the Nigeria distribution network. The undervoltage ranges between 22.92 to 67.50% and 10.42 to 20.82% for both residential and point load areas respectively.

1.5 WAYS OF IMPROVING UNDERVOLTAGE IN NIGERIA DISTRIBUTION NETWORK

Undervoltage is a serious issue in Nigeria distribution network today, little or no attention has been given to undervoltage in the system. Therefore, the followings suggest ways on how to minimize under voltage in the distribution network.

i. **Load Transfer:** The feeders loads should be checked routinely for overload or undervoltage existence. When a feeder is observed to be overloaded or undervoltage exist, the feeder load transfer method is suitable at that point. load transfer can provide a fast long term and generally low-cost solution to overload and undervoltage problems [12]. Typically, load transfer also returns significant loss reduction in the system [12].
   In some cases, load transfer may cause the displacement of recloser or a load break switch [12]. Consequently, the protection of the corresponding feeder should be revised or adapted to the new network configuration [12].

ii. **Load Unbalanced Corrections:** A four-wire wye (Y) feeder connection, unequal currents causes zero sequence current, which returns to the source via both the neutral line and by the earth [12]. This current rises and causes increase in voltage drop in heavier loaded phase, overload conductors, increase in losses and increase in negative-sequence voltage [12]. Therefore, correcting the unbalanced load should be considered importantly. Balancing and rebalancing of loads requires transferring of loads from phases with highest loads to phases with lesser loads [12]. Performing load transfer maximize loss reduction and voltage improvement [12].

iii. **Feeder Reactive Compensation:** The application of reactive compensation to the network is another suitable method of reducing losses and improving line voltage. Capacitor bank should be installed on the network feeders to boost the line voltage and reduce losses in the system.

iv. **Line Conductor Replacement:** The replacement of wear-out line conductor is apposite to optimising the line losses. Overloaded conductor appear when the current in a conductor exceeds the conductor's allowable limit [12]. This situation may lead to excessive overheating or damage to the conductors when backing up other feeders or during cold-load pick-up [12]. In this case, damaged conductors should be replaced.

v. **Installation of Voltage Regulators:** Voltage regulators should be installed in the lines where voltage drops are high and also, undervoltage line in the distribution network. Voltage regulators provide a greater gain in voltage than the other solutions, and they allow undervoltage problems to be corrected over an extended period in the future [12].

1.6 CONCLUSION

Undervoltage is voltage drop that stays for one minute or more continuously. For proper functioning and operation of equipment, the required power and voltage must be supplied. Incorrect power or voltage supply reduces the life span of the equipment, decreases reliability, increases utility cost, inefficient operation of machines, wasteful power usage, fire outbreak occurrences and as well as equipment damage [4]. Undervoltage is an impairment to efficient and reliable power distribution in Nigeria power sector. The consumers have suffered undervoltage in the distribution network and also, the utility company has neglected the consumers to wallow in this predicament.

Undervoltage in the system has reduced the efficiency of home appliances and this has led to burnt of appliances in various homes and offices. This research work has thoroughly dealt with undervoltage in Nigeria power distribution network and proposes ways to ameliorate the situation in the distribution network.

References

[1] Akpojedje, F. O., Okakwu, I. K., Onogbotsere, M.E and Egedi-idu, S.O., "Reliability Estimation of injection Substations Based on Outages Scheduling in Nigeria Power System", Journal of the Nigerian Association of Mathematical Physics, Vol. 28, No. 2, November 2014. Pg. 405 - 414.

[2] Akinlola, A.P., "Performance of Domestic AC Voltage Stabilizers in Meeting Low Voltage Problem in Nigeria: A Case of 12 Different Brands", International Journal of

Engineering and Technology, Volume 5, No. 6, June, 2015. Pg. 358 - 367.

[3] Gupta, J.B., "A Course in Power Systems', Published by Sanjeev Kumar Kataria for S.K. Kataria & Sons, July 14, 2005. Part II, Pg. 1

[4] Osahenvemwen, O.A., and Omorogiuwa, O., "Parametric Modeling of Voltage Drop in Power Distribution Networks", International Journal of Technical Research and Applications, Volume 3, Issue 3, May - June 2015. Pg. 356 - 359.

[5] Hershey Energy Systems, "Power Quality and the Hershey System", hersheyenergy.com/PowerQualityandtheHersheySystem.pdf, Retrieved 17th October, 2016. Time: 5:35pm.

[6] Heydt, G.T., "Losses in Electric Power Systems", School of Electrical engineering, Purdue University, west Lafayette, December 1992.

[7] Total losses in Power Distribution and Transmission Lines, electrical-engineering-portal.com/total....., Accessed on the 15th October, 2016. Time: 8:08pm.

[8] Raph Baeza, "Selecting, Sizing Transformers for Commercial Buildings", https://www.csemag.com/single-article/selecting-sizing-transformers-for-commercial-buildings/4efa064775c5e26f27bfce4foa61378e.html, accessed on the 27th October, 2016. Time: 00:45am

[9] Akpojedje, F.O., Onogbotsere, M.E and Egedi-idu, S.O., "Impact of Power Factor Correction on Energy Saving in Nigeria Power System: A Case Study", Journal of the Nigeria Association of Mathematical Physics, Vol. 25, November 2013. Pg. 385 - 394.

[10] Anumaka, M.C., "Analysis of Technical Losses in Electrical Power System (Nigerian 330kV Network as a Case Study)", IJRRAS 12(2), August 2012. www.arpapress.com/Volumes?Vol12issue2/IJRRAS_12_2_20.pdf

[11] Sultan Zafar "Power Distribution & Transmission Lines Losses in Pakistan", Published on the 29th August, 2015. https:www.linkedin.com/.../power_ ...., Accessed on the 21th November, 2016. Time: 8:20pm.

[12] Jean-Pierre Laflamme and George Simard, "Six Steps to Improve Distribution Voltage Quality", T & D World Magazine, 1st March, 2014. Accessed on the 21th November, 2016. Time: 7:53pm.