ARID ZONE JOURNAL OF ENGINEERING, TECHNOLOGY & ENVIRONMENT
AZOJETE March 2020. Vol. 16(1):120-136
Published by the Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
Print ISSN: 1596-2490, Electronic ISSN: 2545-5818
www.azojete.com.ng

ORIGINAL RESEARCH ARTICLE

THE CHALLENGES AND PANACEAS TO POWER DISTRIBUTION LOSSES IN NIGERIA

O. O. Mohammed[1*], A. O. Otuoze[1], S. Salisu[2], A. E. Abioye[3], A. M. Usman[1] and R. A. Alao[1]

([1]Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin, Kwara State, Nigeria
[2]Department of Electrical Engineering, Ahmadu Bello University, Zaria, Nigeria
[3]Department of Electrical and Electronic Engineering, Akanu Ibiam Federal Polytechnic, Unwana, Ebonyi State, Nigeria)
**Corresponding author's email address: reacholaabdul@gmail.com; mohammed.oo@unilorin.edu.ng*

ARTICLE INFORMATION

Submitted 21 March, 2019
Revised 17 July, 2019
Accepted 15 August, 2019

Keywords:
Nigeria power system
distribution system
technical losses
non-technical losses.

ABSTRACT

Energy losses in the distribution network and its subsystems have been issues of great concerns in Nigeria's power sector. For decades, several studies have been conducted on the challenges facing the power sector in Nigeria with most focus directed on the distribution subsystems. The major challenge in the distribution system is the high energy losses which are detrimental to the techno-economic benefits of the power systems. However, details of the distribution system challenges and the probable solutions have not been efficiently presented. In this study, some of these challenges are presented and the potential solutions are proposed. The features of the Nigeria distribution network, the technical and non-technical sources of losses as well as the identified challenges are presented before discussing the potential solutions. The panaceas so provided were from the understanding of some published works and other related materials as well as the in-depth understanding of the authors. This article can serve as a guide for the utilities and stakeholders in the power sector for efficient management operations and improved customer service delivery.

1.0 Introduction

Electric power system is one of the most important infrastructure for socio-economic development of any nation (Salisu et al., 2019). For years, there have been historical structural challenges affecting the overall generating capacity efficiency (Adoghe et al., 2009) resulting to several power crisis. Large investments have been made in both generation and distribution systems, however, remarkable improvement in the availability and quality of power delivery are yet to be achieved. Electricity demand in Nigeria is increasing daily without a corresponding increase in power generation or expansion of the transmission capacity to meet the increasing demand. Most of the power distribution network are abjectly maintained and the poor state of the electricity supply is continuously threatening the socio-economic activities of the country (Dada, 2014). Nigeria has an inexhaustible supply of natural resources with substantial reserves of oil and gas, and has one of the lowest net electricity generation per capita rates in the world (Team, 2015). Several articles have been written on power generation improvements, and other sources of inexhaustible energy generation have been proposed. However, details about the challenges facing the distribution systems have not been efficiently presented in the literature. Distribution subsystem is considered as the weakest part of the entire power system because while the transmission losses only account for about 17%, distribution losses are approximately 50% (Bhatti et al., 2015).

In this paper, the features and challenges of distribution networks based on the Nigeria scenarios are explored with emphasis on the technical and non-technical losses. Irregularities being perpetrated by the distribution companies are also assessed and recommended solutions proffered. The features and challenges of Nigeria's distribution networks in view of some previous studies are outlined. An overview of the distribution system's losses is presented, and the irregularities observed among the operators of the distribution systems are summarized. Some of the panaceas towards efficient management of the distribution system are given and the conclusions drawn from the study are highlighted.

2. Features and Challenges of the Distribution Network

Traditional power distribution systems are generally modeled in a radial form with the advantage of unidirectional power flow for easy control. However, there are limitations to the efficiency and reliability improvement in a radial distribution system (Short, 2014). The distribution system, via the distribution substations to the consumers, was initially developed to be relatively passive (DOE, 2015). Generally, distribution systems deliver electricity via distribution feeders and radial lines with control equipment operated through timed set points. This scheme is enough to provide consumers with basic service delivery at reasonable costs. Nonetheless, it cannot cope with the current needs for greater resilience, effective power quality control, and customers' participation (DOE, 2015). Moreover, the integration of renewable energy generations causes bidirectional power flow (Kim etal., 2013). The aged distribution systems had no consideration for renewable integration when it was designed. Therefore, connecting renewable energy generations to the distribution system may lead to various interconnection problems including over voltage, harmonics, rise in fault currents, fault coordination and is landing problems (Kim et al., 2013).

In most locations in Nigeria, the distribution network, the voltage profile as well as the billing systems are very poor (Vincent and Yusuf, 2014), contributing to a great loss to the utilities. This is due to several challenges which include; low-quality distribution lines, inadequate and weak network coverage, overloading of transformers and inferior feeder pillars, inaccurate system of billing, illegal practices by employees and poor customer relations, power thefts, inadequate logistic facilities, and obsolete communication equipment, inadequate skilled staff and lack of regular training, and inefficient maintenance schemes (Amuta et al., 2018; Otuoze et al., 2019).

Lack of proper and prompt maintenance of the existing distribution schemes is identified as the major cause for most of the challenges. Figure 1 depicts the sample of distribution lines that are not properly maintained. The characteristics of the current distribution systems in Nigeria are highlighted below (Aliyu et al., 2013; Kim et al., 2013).

Distribution systems are dominated by radial network: Due to the radial structure of the system, fault at any location in the system would disrupt the electricity supply to the entire area thereby making the system unreliable and tedious to maintain.

Challenges in voltage regulation: The voltage of sub-transmission and distribution need to be maintained within certain reference values. However, during the peak hours, due to the enormous power flows via the link, remarkable voltage dip beyond the reference limits may occur. In contrast during the off-peak hours, the shunt capacitors employed for voltage compensation remain connected to the system and thereby causing voltage rise.

Inadequate system facilities: As the demands on the system continue to increase, there is no commensurable increase in the system facilities. Therefore, the distribution system becomes heavily loaded and consequently causing tripping in the system as well as high losses and possibly, eventual systems' collapse.

Shortage in transformer supplies: The distribution systems in most parts of the country do not have adequate transformers, therefore overloading the existing ones, which subsequently leads to voltage drop, high losses and systems' unreliability.

Improper energy accountability: This is due to huge commercial and collection losses.

Lack of proper maintenance and existence of obsolete equipment: This accounts for high technical losses on the distribution networks.

Figure 1: Sample of a distribution line that are not properly maintained

To address some of the problems, the distribution system was privatised. In line with the privatisation programme, the Nigerian distribution networks were unbundled into 11 regional grids and were sold to foreign and local investors with a minor stake being maintained by the government. These distribution companies differ in terms of network size, geographical location and number of customers. Based on an agreement with the Bureau of Public Enterprises (BPE), the energy capacity allocated to each of the company differs, which in reality depends on the ability of the company to accept the capacity offered (Team, 2015) from the primarily defined customer size, geographical location, expected load demand and other related factors.

During the privatisation of these companies, some losses were considered in the transaction, however, after the completion of the process, the companies later realised the losses were greater than the envisaged values. The 2014 estimated losses are depicted in Figure 2, and the grid energy allocation percentage to the 11 distribution companies is as shown in Table 1 (Team, 2015). It can be observed from Figure 2 that the percentage of technical losses (12%) is far less than the non-technical losses. The greatest problem facing the distribution companies is the level of non-technical losses which include commercial losses (unbilled used energy), and collection losses (unpaid billed energy). These losses are associated with electricity theft and fraud, a huge amount of losses are incurred through electricity theft which is consequently preventing further investment plans for the utilities (Otuoze et al., 2017; Sharma et al., 2016). Unpaid billed energy, unbilled used energy, billing irregularities, defective meters, conventional meter manipulations, corruption of the employees (misappropriation of funds, illegal procurement, sales of distribution equipment, meter bypass and more) and other associated fraudulent activities (Otuoze et al., 2017). These losses have made some of the companies to reduce the amount of energy allocated to them in order to reduce their losses as can be seen in Table 1 (Team, 2015), the energy allocations are not proportional to the number of customers.

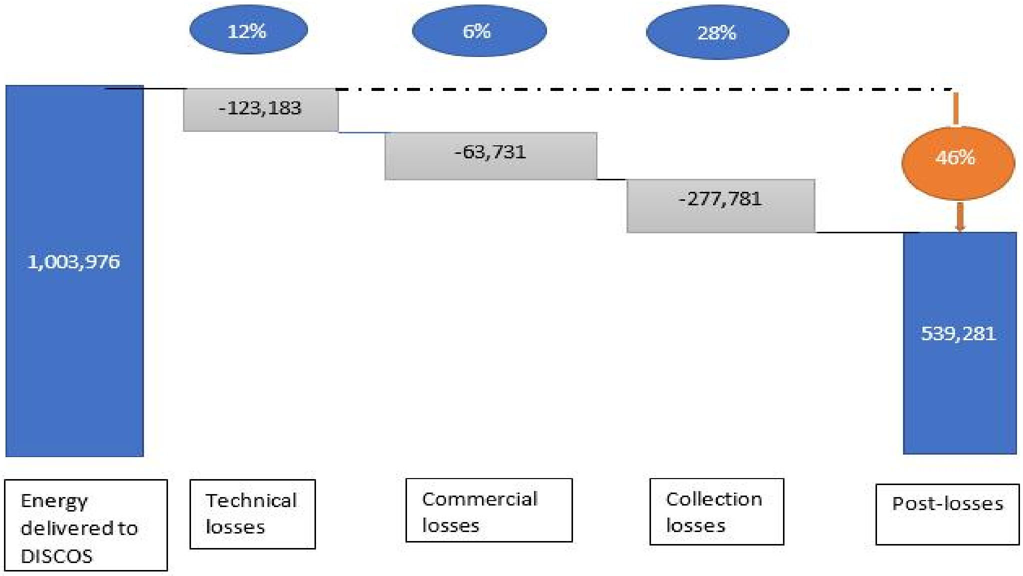


Figure 2: Annual estimated energy losses in 2014, due to technical, commercial and collection losses (MWh).

Table 1: The distribution companies with their allocated grid energy in 2014.

Area	Number of customers (*1000)	Distribution network (KM)	Allocation of grid energy (%)	Average allocation of grid energy (%)
Abuja	755	107,254	12	15
Benin	1,187	104,702	15	14
Eko	581	8,093	13	13
Enugu	819	25,078	9	12
Ibadan	1,750	24,355	8	10
Ikeja	1,128	12,466	10	9
Jos	466	12,227	8	8
Kaduna	459	26,653	7	7
Kano	598	21,041	6	5
Port Harcourt	557	17,989	8	5
Yola	345	6,505	4	2

It can be observed that the energy allocations are not proportional to the number of customers as expected. This is solely due to the inability of some of the companies to accept the energy offered to them in an attempt to minimize their losses due to estimated unbilled used energy and unpaid billed energy. However, the major losses are due to commercial and collection losses, attributed to the crude system of billing and vulnerability of the distribution systems to power theft. There is a paradigm shift in most parts of the world, to the deployment of advanced distribution systems' equipment which is robust and resilient to most of the distribution systems' challenges thereby making the distribution losses reside within an acceptable limit. Most of the developing nations, especially in Sub-Saharan Africa, are still battling with several challenges in their power sector and Nigeria is not an exception.

Several studies have been conducted on the challenges facing power sector in Nigeria, however, most of these articles focus on the generation-based problems. Akpojedje et al. (2016) reviewed the challenges in the transmission system and the rural electrification schemes. The work proposed an improvement in the transmission network and the rural electrification. Similarly, Emodi and Yusuf (2015) studied the obstacles militating against the development of electricity access in Nigeria while highlighting feasible solutions as Komolafe and Udofia (2020) examined the sources of electrical losses in the Nigerian power scheme. Patrick et al. (2013) studied the feasibility of smart grid deployment in the Nigerian power 330 KV system to reduce the high active and reactive transmission losses. Aniefiok et al. (2013) and Vincent and Yusuf (2014) also explored the feasibilities of smart technology deployment in the Nigeria's power scheme with considerations of renewable energy inclusion. However, the prerequisite for smart grid deployment is a stable electricity supply for the effective functioning of the smart system. Although, the authors proposed the basic requirement for the smart grid deployment, those requirements need concerted efforts to be put in place otherwise the deployment of the smart grid would be a mirage. Some of the challenges of smart grid deployments related to most developing nations have been highlighted by Otuoze et al. (2017). Reliability assessment of electric power utility was investigated by Popoola et al. (2011) using questionnaire distributed to customers in South-west geopolitical zone of Nigeria. The results were analysed using statistical tools to investigate the interruption costs incurred by customers. Some recommendations were highlighted to mitigate the effects of interruption costs on customers. Osueke and Ezeh (2011) assessed the Nigeria power sector, comparing generation and demand, energy supply projection, energy efficiency and conservation. Some suggestions were proposed to balance the wide gap between demand and supply which include analyses carried out with considerations of many factors including demand factor, duration of supplies, electricity needs, development, expansion and effective integration of alternative energy sources, smart metering to encourage high demand response with respect to energy savings (Abam et al., 2014; Oluwasuji et al., 2020).

An overview of the current energy challenges in Nigeria and the difficulty of the issues involved was presented by Aliyu et al. (2013). The country's generation potential as at 2010 was analysed, and 20 years expansion plans by government were also presented. The simulation results of the electricity generation system including the environmental impact of siting a nuclear power in one of the potential sites were also presented and analysed. The impact of fossil fuels on the environment was presented and other sources of energy were suggested based on the vision 2020 plans (Abam et al., 2014; Oyedepo, 2014). A study by Oseni (2011) analysed the overall performance of the Nigeria power sector and presented some policy guidelines for achieving a world standard power market and sustainable development. Usman et al. (2015) examined the country's energy sources and the power sector reform adopted by the government. The paper outlined some recommendations based on the reform implemented by other countries with similar resources to Nigeria which yielded remarkable results. In another study, Dada (2014) presented the benefits and challenges of deployment of smart microgrids in Nigeria's electricity delivery scheme. The article gives an overview of the current state of electricity supply in the country. It states the advantages of the deployment of smart microgrids in the country's power supply system.

Distribution systems serve as the host for distributed generation and the microgrid. The challenges associated with distribution systems need to be addressed for effective deployment of smart microgrids. From the literature survey, it can be concluded that most of the existing articles focus on the power generation sector, demand and supply gap, deployment of smart grid systems, and renewable energy integration. However, all these aforementioned sectors cannot have a meaningful impact without addressing the challenges associated with distribution systems. Therefore, this article gives details on the technical and non-technical problems regarding distribution systems in Nigeria. It highlights problems and feasible solutions.

3. Power system distribution losses

Distribution systems represent a very important position in the power system structure as it serves as the main point of connection among the transmission network, distributed storage, distributed generation, the consumers and the metering points for consumption (Patrick et al., 2013). However, the challenges of the distribution systems are majorly associated with energy losses. Generally, total energy losses are being calculated using energy balances, the losses equal to total energy delivered to distribution substations and feeders minus total energy consumed (metered and billed) by customers (Khodr et al., 2002). The total losses consist of technical losses (TL) and non-technical losses (NTL). These losses need to be estimated separately. Conventionally, TLs are estimated based on the line parameters (Agüero, 2012) particularly by computing the active power losses at peak load demand scenarios (using computational techniques or existing load data), then applying a loss factor to evaluate mean power losses and consequently multiplying the mean power losses by time (in hours) to get monthly or annual energy losses (Agüero, 2012). The NTL are obtained by subtracting the calculated TL from the total losses. The computational complexity of these estimations relies on the technique employed for calculating the power losses at peak load demand and loss factors, and the features of the distribution system's components incorporated in the analysis (Khodr et al., 2002). Moreover, when computing loss factors, a comparative study on the entire system’s losses is required because the influence of the NTL needs to be incorporated especially if the latter is high. Furthermore, low-voltage secondary systems’ losses are sometimes not incorporated in this calculation or inappropriate values are used in the calculation. This practices lead to inaccuracies of the calculated results, especially for systems with long secondary lines and a large number of customers (Agüero, 2012; DOE, 2015). Subject to the level of accuracy required, the aforementioned practices may be employed in some modern systems such as those of the North American distribution systems (Khodr et al., 2002). Similarly, detail modelling of distribution transformers is necessary even though computational techniques are employed for the estimation of losses at peak load, the transformer modelling must include load and no-load losses to avoid degradation in the accuracy of losses estimation (Agüero, 2012). Figure 3 summarizes the various sources of losses associated with distribution systems. The following subsections describe the various losses in distribution systems.

Corresponding author’s e-mail address: reacholaabdul@gmail.com; mohammed.oo@unilorin.edu.ng

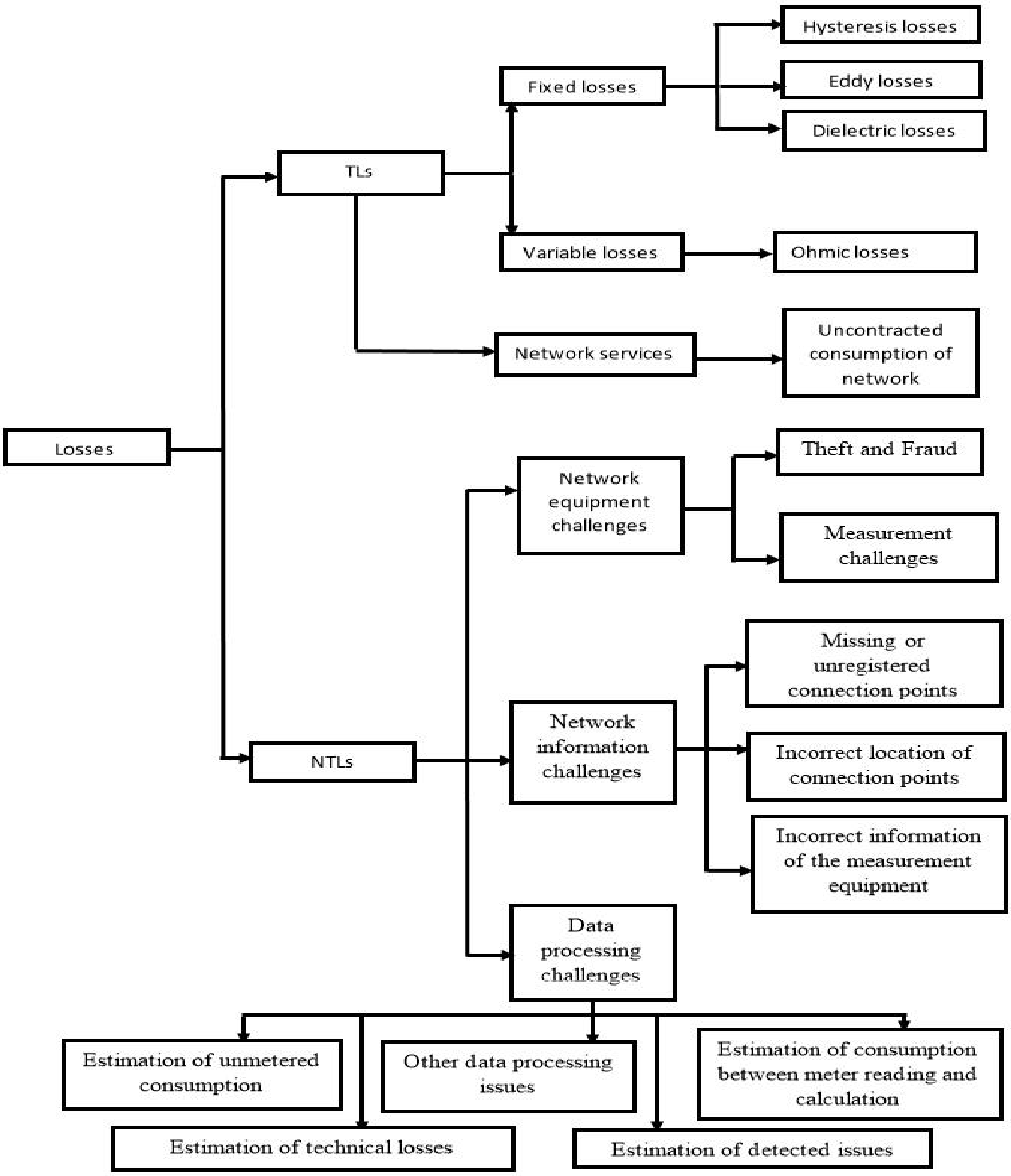


Figure 3. Summary of the entire sources of losses in the distribution system of Nigeria

3.1 Technical losses

TLs are natural occurrence as they comprise of energy dissipation in system components such as lines, transformers, connections, measuring devices and other associated equipment that transport energy to and from customers (Antmann, 2009). They are also referred to as physical losses since the energy is being transformed to heat and noise while distributing electricity. This energy dissipation incurs costs on the customers and as well as causing carbon emission (Quezada et al., 2006). The level of TL is associated with the physical features of distribution network components used. They rely on the design and quality of the entire power grid, line reactance, voltage and the transformation levels and the length of the lines used. They also relate to the level of investment in the distribution components (there is a trade-off between initial costs of investment and the operational costs). TL also relate to effective planning and quality of distribution networks design (Agüero, 2012). TL can be grouped into three kinds of losses as can be seen in Figure 3. These include variable losses (associated with load), fixed losses (dissociated with load) and network services (uncontracted consumptions of the network components).

Variable losses are losses associated with heat dissipation in all conductors in the system due to their internal resistance which causes them to dissipate heat when carrying electric current (Aten and Ferris, 2009). Due to the variation of these losses with respect to the current flowing in the conductors, they are termed variable losses. These losses vary in proportion to the square of the electric current and are usually called Ohmic or copper or resistive losses. Generally, variable losses take the larger percentage of the total TL, up to two-thirds or three-quarters of the overall value. Basically, there are two measures to reduce these losses: either to reduce power flows or to lower the resistance of the flowing paths (Shirmohammadi and Hong, 1989). Reducing the network equipment utilization (upgrading the network equipment) can reduce both current and resistance. However, upgrading network capacity requires huge investments. Hence, there is a compromise between capital investments and costs of losses. It has been suggested that the optimal average utilization rate on a distribution network taken into consideration, the cost of losses in its planning and design could reduce losses to about 30% (Aten and Ferris, 2009).

Fixed losses are losses due to energy dissipation in network equipment and components when energized (Aten and Ferris, 2009). These losses are not variable, they are not associated with the current flow in the system and hence, with or without power supply to the customers, these losses are incurred once the system components are energized. They are associated with the losses in the transformers (hysteresis and eddy current losses). Other sources of these losses are leakage current due to poor insulations, and losses due to corona effects. Fixed losses solely depend on the system's voltage; they are mainly fixed since the system voltage is comparatively stable when the system equipment is energized. Increasing the efficiency of the system components will reduce the fixed losses.

Network services are related to uncontracted consumption i.e. the power consumed by the measuring devices such as meters, information systems which are installed within the system. They can be electromechanical, electronics or general ICT equipment.

Generally, technical losses depend on the network characteristics and mode of operation (Emodi and Yusuf, 2015). These losses cannot be eliminated but can be reduced by using efficient and proper planning and maintenance schemes.

3.2 Non-technical losses

NTL, also known as commercial and collection losses, are non-natural losses associated with the amount of non-billed electricity and billed electricity that is not paid for (Agha and Alfaoury, 2016; Sharma et al., 2016) or even paid but not properly remitted. The non-billed electricity occurs due to either error in the metering or billing systems or as a result of illegitimate behaviour of customers (Agha and Alfaoury, 2016; Bandim et al., 2003). Illegitimate acts such as energy used by fraudulent consumers can be described as institutional theft, corruption and/or organized crime (Bandim et al., 2003). The costs associated with NTL are covered by the participation of utilities and/or legitimate consumers paying bills (Antmann, 2009). In NTL, some of the energy delivered via the distribution system to the consumers cannot be measured or appropriately accounted for. Since they cannot be directly charged by the suppliers or distribution companies, they are sometimes referred to as black losses (Agha and Alfaoury, 2016; Antmann, 2009). NTL are predominantly associated with unknown, unassigned, and incorrect energy flows. They constitute the amount of energy delivered but could not be accounted for. It is however very important to note that NTL may result from each of the following scenarios: energy accounted for but not billed, or energy billed but the bills are not paid or energy used, billed and paid for, but not remitted appropriately (Otuoze et al., 2019). Fraudulent consumers are not easily determined except by electricity theft detection techniques which always come with its underlying shortcomings. These shortcoming always arise as no known energy theft detection technique performs 100% efficiently, hence, making it difficult to determine who and how much of energy is fraudulently consumed (Bandim et al., 2003). Although, with the application of artificial intelligence and machine learning using the energy consumption data, many research outputs are yielding positive results regarding the determination of fraudulent customers (Ahmad et al., 2018; Messinis and Hatziargyriou, 2018).

NTLs are caused by activities that are external to the power system (Chauhan, 2015). The energy loss is not directly associated with energy transportation and dissociated with the physical-technical features of the system network (Antmann, 2009; Bastos et al., 2009). They can be viewed as unknown customer loads, when an unknown load is connected to the network, the actual losses increase while the losses envisaged by the utilities remain the same. This increase losses will appear on the utilities' account and the costs will be distributed to the customers as network charges (Chauhan and Rajvanshi, 2013). Several scenarios result in NTLs. All lie on the utility for the ineffective and inefficient management operation of the network. NTLs are generally associated with customer management process (Chauhan, 2015) and can be categorized as follows: Network equipment challenges, Network information challenges, and Energy data processing challenges.

NTL are often faced with various challenges which could be due to consumer behaviours, the sophistication of the metering devices, failure of any component or connection point of the network topologies and faults on the lines, information processing errors, estimated billings and other ill-fated social actions aimed at evading appropriate electricity bill payments. These challenges are discussed under network equipment, network information and information processing in the next subsections.

3.3 Network equipment challenges

These are associated with theft and fraud, and measurement errors.

Theft and fraud: these are caused by illegitimate interference with the network equipment. There are various techniques used to illegally connect to the network (Antmann, 2009). The larger part of the NTLs are associated with theft and fraud (Chauhan, 2015). Theft and fraud are the major challenges faced by the power industries, and it requires the efforts of all stakeholders to find a lasting solution to this problem. Theft can be referred to as any illegal connection to the use of electricity asides the points where metering systems are positioned by the suppliers. It can occur where an illegitimate connection to the system is made or an unauthorized reconnection after disconnection by the supplier due to high debt incurred by the customer. It can also occur where there is an incomplete connection. Fraud can take many shapes, ranging from manipulation of customer's meter, so that the meter can record lower amount of used electricity or it can also come in the form of meter bypass, where some of the customer's loads are connected directly without being recorded by the meter.

Challenges of measuring systems: errors from measuring devices, such as the metering system, are also categorized under NTLs. These losses are the difference between the amount of electricity delivered via the meter and the amount recorded by the meter or read from the meter (Chauhan and Rajvanshi, 2013; Chauhan, 2015; Depuru et al., 2011). The causes of these losses are as follow; uncertainty associated with the measuring system, permanent error in the meter reading, faulty measuring system, inappropriate configuration or installation of measuring systems, and complete breakdown of measuring systems. All these can occur as a result of lack of maintenance, lightning, ageing equipment or other related issue which could cause loss of unaccounted amount of energy, thereby causing an increase in NTLs (Chauhan, 2015; Doorduin et al., 2004).

3.4 Network information challenges

In this scenario, electricity is delivered and consumed but the energy is not accurately measured due to errors in the distribution database. These inaccuracies or errors in consumption data fall under NTL and are as a result of the following (Agha and Alfaoury, 2016; Bastos et al., 2009); unregistered or missing connection points, inappropriate location of connection points, and wrong information from the measuring equipment.

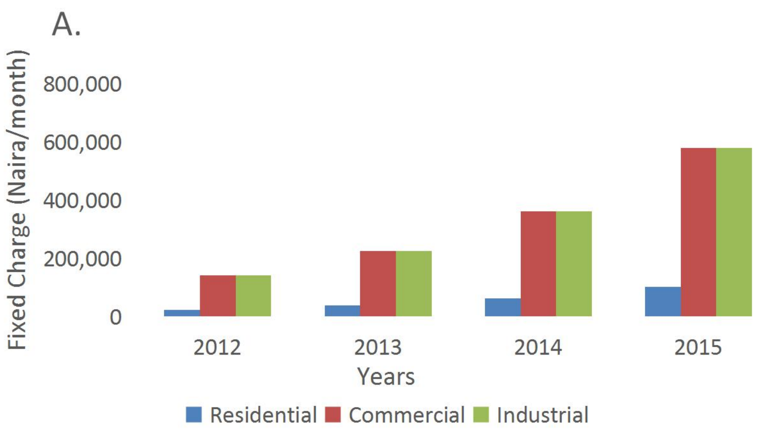
3.5 Problems associated with data processing

During energy data processing for the evaluation of energy losses, inaccuracies may occur and this is associated with the error in the evaluation of energy produced or consumed. These errors are also incorporated in NTL and are as a result of the following (Agüero, 2012; Angelos et al., 2011; Antmann, 2009); evaluation of the consumption that are not metered, estimation of the calculation consumption and the readings from the meter, TL estimation, estimation of some detected challenges, and other energy data processing. The following section presents some of the irregularities associated with Nigerian distribution companies.

3.6 Irregularities on the part of distribution companies

The operation and maintenance of the distribution equipment are parts of the responsibilities of the employees at the distribution offices all over the country. However, most of these employees are not equipped with the skill to perform these jobs. They work with obsolete logistics' facilities, tools and safety equipment, and operation vehicles (Dada, 2014). Therefore, customers usually sought the means of solving most of the electrical faults at their end. There is no prior notification or warning to the customers in an event of faults or outages that occur at the distribution level and in most cases, it takes ages before the problems are solved. There is also lack of effective planning and management at the distribution level, no reliable real-time data about the condition of the distribution systems, and no effective coordination and automation controls to prevent system failures which can subsequently lead to cascading collapse (Okafor and Ezeh, 2010). Transformers are perpetually subjected to overloading thereby causing tripping and frequent breakdown due to the absence of coordinated control and information exchange to register the status of all the distribution transformers in order to take decisive measures (Oseni, 2011).

In spite of this erratic power supply, there is a continuous rise in electricity tariff. The average electricity tariff between 2012 and 2015, for the three categories of customers (residential, commercial and industrial), charged by Kaduna DISCO, Ikeja DISCO and Port Harcourt DISCO are as shown in Figures 4, 5 and 6, respectively (NERC, 2016). The A and B parts of Figures 4, 5 and 6 are for fixed and energy charges, respectively. This average annual tariff increase is the same for other DISCO across the country. The inaccuracy associated with this tariff system is a serious challenge due to the insufficient and obsolete metering system at the customers' premises. Additionally, the fraudulent activities of the system cannot be over emphasised, for example, a fixed tariff is forced on customers without electricity meters, irrespective of whether electricity is supplied or not. In most cases, those having meters are faced with challenges of overestimated billings. Defective meter readings due to a fault, extortion from distribution employees, illegal connections and disconnections (NEWS, 2013; Sambo et al., 2012) are additional irregularities contributing to either the losses being incurred by the DISCO or making some customers pay higher than their normal billings.



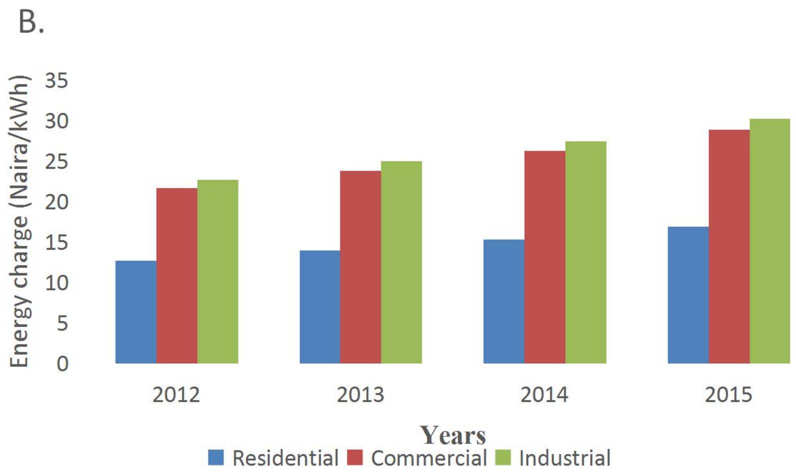


Figure 4: Average electricity tariff for the three categories of customers by Kaduna DISCO (a) fixed charge and (a) energy charge.

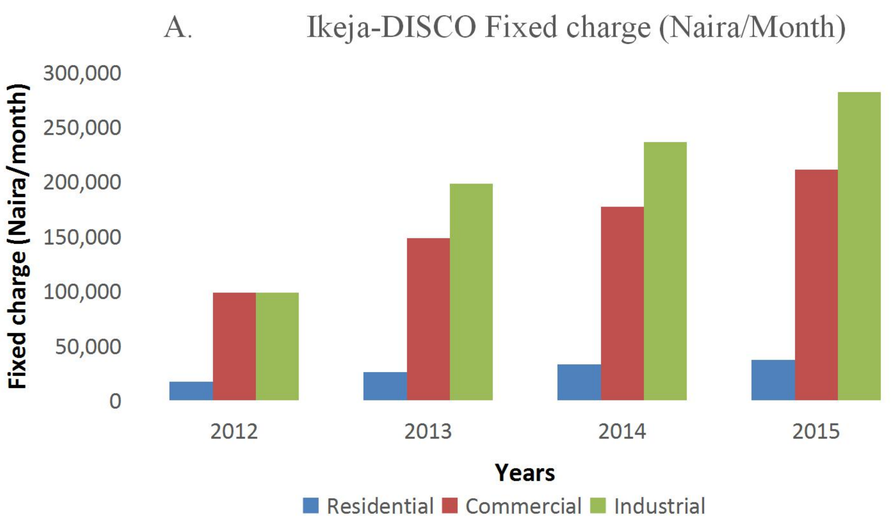


Figure 5: Average electricity tariff for the three categories of customers by Ikeja DISCO (A) fixed charge and (B) energy charge.

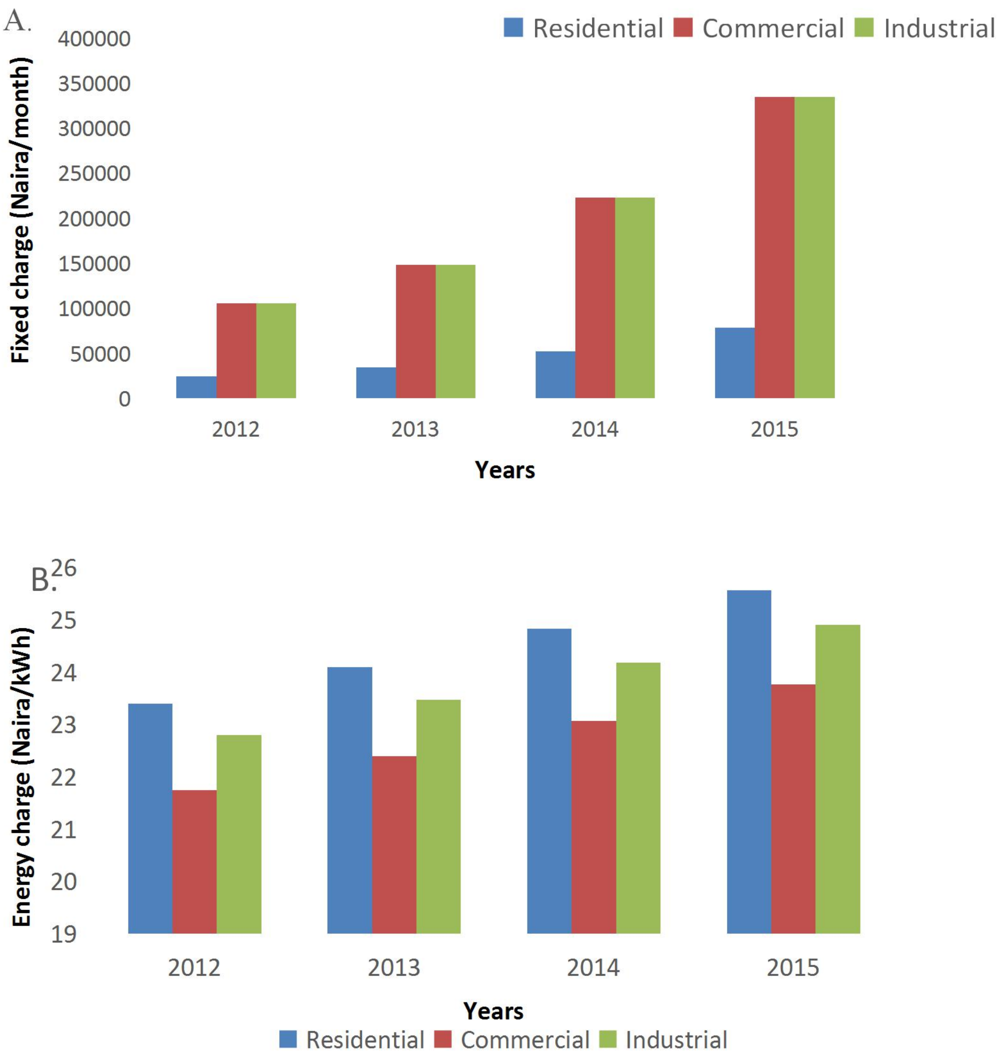


Figure 6: Average electricity tariff for the three categories of customers by Port Harcourt DISCO (A) fixed charge and (B) energy charge.

Corresponding author's e-mail address: reacholaabdul@gmail.com; mohammed.oo@unilorin.edu.ng

4. Panaceas to the existing distribution systems challenges

Few articles (Bollen et al., 2008; De Martini, 2014; Hallberg, 2013; Howard, 2014; Wiedman and Beach, 2013) have discussed the distribution system challenges and solutions. However, more concerted efforts are required to promote distribution system innovation and planning to cope with the "smart grid" paradigms. A planned, effective and smart distribution network is key to cope up with the ever-increasing demand for domestic, commercial and industrial loads. The upgrading of the existing distribution system can be achieved by adopting the following measures.

Automation of the entire substation and distribution systems for a reduction in power losses and efficient power delivery.

Deployment of tamper-proof smart metering systems to reduce NTL remarkably.

Analysis of the financial implications of tamper-proof metering systems should be carried out to study the feasibility of its deployment.

Upgrading of the primary feeders from a radial to a loop configuration needs to be considered in order to efficiently accommodate distributed generations.

Increasing the use of distributed energy resources in the distribution system.

Establishment of state of art communication framework for information interchange between substation and central distribution management system.

Creation of information exchange between the customers and distribution system operators for efficient operation of the distribution system.

A proper framework for interaction between customers, distribution system operators and the market operators.

Adoption of conservative policies and tariff reduction benefits which will encourage customer participation in demand-side management.

Distribution system interfaces directly with the public, hence, there is need to put in place sufficient network coverage and provision of quality supply with effective marketing and customer delivery of service.

5. Conclusion

This paper presented some of the challenges facing Nigeria's power distribution subsector. Detailed power distribution losses and types of losses associated with the distribution system, technical and non-technical losses, are presented. The features of the Nigeria distribution system are highlighted along with the associated challenges. The irregularities by the distribution system operators are also emphasized. Finally, the paper proposed solutions to improve the distribution system to meet up with the state-of-the-art distribution equipment such as tamper-proof smart metering system and communication framework for effective service delivery and efficient system operations. This paper can serve as an important guide for the distribution system operators and power system engineers in the power distribution system subsector. It is hoped that the country will step up and sustain efforts to transform the grid to an intelligent grid. Further studies must carry out empirical studies involving data obtained from the operators and consumers to help match a desired balance in the operations of the distribution systems. Cost-benefit analysis of smart meter deployment to help in enhanced monitoring and accountability must be carried out to properly advise the government on ways forward.

Corresponding author's e-mail address: reacholaabdul@gmail.com; mohammed.oo@unilorin.edu.ng

References

Abam, FI., Nwankwojike, BN., Ohunakin, OS. and Ojomu, SA. 2014. Energy resource structure and on-going sustainable development policy in Nigeria: a review. International Journal of Energy and Environmental Engineering, 5(2-3): 102.

Adoghe, A., Odigwe, I. and Igbinovia, S. 2009. Power sector reforms-effects on electric power supply reliability and stability in Nigeria. International Journal of Electrical and Power Engineering, 3(1): 36-42.

Agha, A. and Alfaoury, A. 2016. Commercial losses in Jordanian electrical system (case study). Proceedings of the 13th International Multi-Conference on Systems, Signals and Devices (SSD) held between 21-24 March, 2016 in Leipzig, Germany., 189-193.

Agüero, JR. 2012. Improving the efficiency of power distribution systems through technical and non-technical losses reduction. Proceedings of PES T&D 2012 held between 7-10 May 2012 in Orlando, FL, USA., 1-8.

Ahmad, T., Chen, H., Wang, J. and Guo, Y. 2018. Review of various modeling techniques for the detection of electricity theft in smart grid environment. Renewable and Sustainable Energy Reviews, 82: 2916-2933.

Aliyu, AS., Ramli, AT. and Saleh, MA. 2013. Nigeria electricity crisis: power generation capacity expansion and environmental ramifications. Energy, 61: 354-367.

Amuta, E., Wara, S., Agbetuyi, AF. and Matthew, S. 2018. Smart Grid Technology Potentials in Nigeria: an Overview. International Journal of Applied Engineering Research, 13(2): 1191-1200.

Angelos, EWS., Saavedra, OR., Cortés, OAC. and de Souza, AN. 2011. Detection and identification of abnormalities in customer consumptions in power distribution systems. IEEE Transactions on Power Delivery, 26(4): 2436-2442.

Aniefiok, E., Igweonu, I., Eguzo, C. and Robert, B. 2013. Integrating smart grid model in Nigeria power network. International Journal of Advances in Engineering & Technology, 6(4): 1760.

Antmann, P. 2009. Reducing technical and non-technical losses in the power sector. Available at https://openknowledge.worldbank.org/bitstream/handle/10986/20786/926390WP0Box3800in0the0power0sector.pdf?sequence=1. Accessed [Online] on 13th October 2018.

Aten, M. and Ferris, R. 2009. Analysis of distribution losses and life cycle CO2 emissions. Proceedings of the 20th International Conference on Electricity Distribution (CIRED 2009) held between 8-11 June 2009 in Prague, Czech Republic., 15-23.

Bandim, C., Alves, J., Pinto, A., Souza, F., Loureiro, M., Magalhaes, C. and Galvez-Durand, F. 2003. Identification of energy theft and tampered meters using a central observer meter: a mathematical approach. Proceedings of the 2003 IEEE PES Transmission and Distribution Conference and Exposition (IEEE Cat. No. 03CH37495) held between 7-12 Sept. 2003 in Dallas, TX, USA, USA., 163-168.

Bastos, P., Souza, BA. and Ferreira, N. 2009. Diagnosis of nontechnical energy losses using Bayesian Networks. Proceedings of the 20th International Conference and Exhibition on Electricity Distribution held between 8-11 June 2009 in Prague, Czech Republic., paper 0566.

Bhatti, SS., Lodhi, M., ul Haq, S., Gardezi, S., Javaid, M., Raza, M. and Lodhi, M. 2015. Electric power transmission and distribution losses overview and minimization in Pakistan. International Journal of Scientific and Engineering Research, 6(4): 1108-1112.

Bollen, M., Yang, Y. and Hassan, F. 2008. Integration of distributed generation in the power system-a power quality approach. Proceedings of the 13th International Conference on Harmonics and Quality of Power, 2008. ICHQP 2008 held between 28 Sept.-1 Oct. 2008 in Wollongong, NSW, Australia., 1-8.

Chauhan, A., and Rajvanshi, S. 2013. Non-technical losses in power system: a review. Proceedings of the 2013 International Conference on Power, Energy and Control (ICPEC) held between 6-8 Feb. 2013 in Sri Rangalatchum Dindigul, India., 558-561.

Chauhan, AA. 2015. Non-technical losses in power system and monitoring of electricity theft over low-tension poles. Proceedings of the 2015 Second International Conference on Advances in Computing and Communication Engineering held between 1-2 May 2015 in Dehradun, India., 280-284.

Dada, JO. 2014. Towards understanding the benefits and challenges of Smart/Micro-Grid for electricity supply system in Nigeria. Renewable and Sustainable Energy Reviews, 38: 1003-1014.

De Martini, P. 2014. More than smart: A framework to make the distribution grid more open, efficient and resilient. Available at https://authors.library.caltech.edu/48575/. Accessed [Online] on 25th January 2018.

Depuru, SSSR., Wang, L. and Devabhaktuni, V. 2011. Electricity theft: Overview, issues, prevention and a smart meter based approach to control theft. Energy Policy, 39(2): 1007-1015.

DOE, U. 2015. Enabling modernization of the electric power system. Quadrennial technology review, 22. Available at https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter3.pdf. Accessed [Online] on the 6th June 2018.

Doorduin, W., Mouton, HDT., Herman, R. and Beukes, H. 2004. Feasibility study of electricity theft detection using mobile remote check meters. Proceedings of the 7th Africon Conference (IEEE Cat. No. 04CH37590) held between 15-17 Sept. 2004 in Gaborone, Botswana., 373-376.

Emodi, NV. and Yusuf, SD. 2015. Improving electricity access in Nigeria: obstacles and the way forward. International Journal of Energy Economics and Policy, 5(1): 335-351.

Hallberg, P. 2013. Active distribution system management a key tool for the smooth integration of distributed generation. Eurelectric TF Active System Management, Union of the Electricity Industry - EURELECTRIC, Brissel, Belgium, pp. 53.

Howard, MW. 2014. VII. The Integrated Grid: Realizing the Full Value of Central and Distributed Energy Resources. The ICER Chronicle Edition 2, July 2014, 1: 32.

Khodr, H., Molea, J., Garcia, I., Hidalgo, C., Paiva, P., Yusta, J. and Urdaneta, AJ. 2002. Standard levels of energy losses in primary distribution circuits for SCADA application. IEEE Transactions on Power Systems, 17(3): 615-620.

Kim, JC., Cho, SM. and Shin, HS. 2013. Advanced power distribution system configuration for smart grid. IEEE Transactions on Smart Grid, 4(1): 353-358.

Komolafe, O. and Udofia, K. 2020. Review of electrical energy losses in Nigeria. Nigerian Journal of Technology, 39(1): 246-254.

Messinis, GM. and Hatziargyriou, ND. 2018. Review of non-technical loss detection methods. Electric Power Systems Research, 158: 250-266.

NERC. 2016. Retail tariff for respective DISCOs. Available at https://nerc.gov.ng/index. php/library/documents/Tariff-Charges--and--Market-Rules/Retail-Tariff-for-respective-DISCOs/. Accessed [Online] on 4th November 2018.

NEWS, P. 2013. On PHCN's Fraudulent Tariff Regime. Available from https://www.pmnewsnigeria.com /2013/06/19/on-phcns-fraudulent-tariff-regime/.

Okafor, E. and Ezeh, G. 2010. Outages in Nigeria electric power system: A review. Journal of Economics and Engineering, 1: 65-69.

Oluwasuji, OI., Malik, O., Zhang, J. and Ramchurn, SD. 2020. Solving the fair electric load shedding problem in developing countries. Autonomous Agents and Multi-Agent Systems, 34(1): 12.

Oseni, MO. 2011. An analysis of the power sector performance in Nigeria. Renewable and Sustainable Energy Reviews, 15(9): 4765-4774.

Osueke, C. and Ezeh, C. 2011. Assessment of Nigeria power sub-sector and electricity generation projections. International Journal of Scientific and Engineering Research, 2(11): 1-7.

Otuoze, A., Usman, A., Mohammed, O. and Jimoh, A. 2017. A review of smart grids deployment issues in developing countries. Arid Zone Journal of Engineering, Technology and Environment, 13(6): 858-867.

Otuoze, AO., Mustafa, MW., Ibrahim, O., Salisu, S., Mohammed, OO., Oloyede, AA. and Gaya, ZS. 2019. Threats and Challenges of Smart Grids Deployments-A Developing Nations' Perspective. ELEKTRIKA-Journal of Electrical Engineering, 18(2): 33-43.

Otuoze, AO., Mustafa, MW., Mohammed, OO., Saeed, MS., Surajudeen-Bakinde, NT. and Salisu, S. 2019. Electricity theft detection by sources of threats for smart city planning. IET Smart Cities, 1(2): 52-60.

Oyedepo, SO. 2014. Towards achieving energy for sustainable development in Nigeria. Renewable and Sustainable Energy Reviews, 34: 255-272.

Patrick, O., Tolulolope, O. and Sunny, O. 2013. Smart grid technology and its possible applications to the Nigeria 330 kV Power System. Smart Grid and Renewable Energy, 4(05): 391.

Popoola, JJ., Ponnle, AA. and Ale, TO. 2011. Reliability worth assessment of electric power utility in Nigeria: residential customer survey results. Assumptin University Journal of Technology, 1: 217-224.

Quezada, VM., Abbad, JR. and Roman, TGS. 2006. Assessment of energy distribution losses for increasing penetration of distributed generation. IEEE Transactions on Power Systems, 21(2): 533-540.

Salisu, S., Wazir, MM., Olatunji, MO., Mamunu, M. and Touqeer, JA. 2019. Techno-economic feasibility analysis of an off-grid hybrid energy system for rural electrification in Nigeria. International Journal of Renewable Energy Research (IJRER), 9(1): 261-270.

Sambo, AS., Garba, B., Zarma, IH. and Gaji, MM. 2012. Electricity generation and the present challenges in the Nigerian power sector. Journal of Energy and Power Engineering, 6(7): 1050.

Sharma, T., Pandey, K., Punia, D. and Rao, J. 2016. Of pilferers and poachers: Combating electricity theft in India. Energy Research and Social Science, 11: 40-52.

Corresponding author's e-mail address: reacholaabdul@gmail.com; mohammed.oo@unilorin.edu.ng

Shirmohammadi, D. and Hong, HW. 1989. Reconfiguration of electric distribution networks for resistive line losses reduction. IEEE Transactions on Power Delivery, 4(2): 1492-1498.

Short, TA. 2014. Electric Power Distribution Handbook: CRC press, New York.

Team, AP. 2015. Nigeria power baseline report. Office of the Vice President, Federal Government of Nigeria in conjunction with Power Africa, Abuja, Nigeria.

Usman, ZG., Abbasoglu, S., Ersoy, NT. and Fahrioglu, M. 2015. Transforming the Nigerian power sector for sustainable development. Energy Policy, 87: 429-437.

Vincent, EN. and Yusuf, SD. 2014. Integrating renewable energy and smart grid technology into the Nigerian electricity grid system. Smart Grid and Renewable Energy, 5(09): 220.

Wiedman, J. and Beach, T. 2013. Distributed generation policy: encouraging generation on both sides of the meter. The Electricity Journal, 26(8): 88-108.

Corresponding author's e-mail address: reacholaabdul@gmail.com; mohammed.oo@unilorin.edu.ng