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Technical Losses across Distribution Networks in Nigeria and Mitigative Measures: A Review

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Abstract: *The different distribution companies (DisCOs) in Nigeria constantly battle with the issue of technical losses on their respective distribution networks. And this is one factor that heavily affects their revenue. Though, technical losses are inevitable because they cannot be totally eliminated but can be rather reduced. This paper identifies lengthy distribution lines, worn-out equipment, insufficient size of conductors of distribution lines, no growth provision of system, unequal load distribution of the three phases of low tension lines, low voltage, overloading of distribution lines, load factor effect, low power factor, abnormal operating conditions, transformer sizing and selection, location of distribution transformers, feeder length, poor workmanship, use of overrated distribution transformers, efficiency of equipment and lack of proper maintenance as some of the root causes of technical losses. In addition, practicable solutions are provided on ways the identified technical losses can be curbed on the networks of the distribution companies if implemented. The focus of this survey is to present the prevalent factors that induce technical losses on the DisCOs networks and the measures that can be taken to limit the occurrence of this class of losses. This assessment will aid industry experts, potential investors and other investigators in taking appropriate decisions on projects within this field.*

Keywords: *Distribution Companies, Technical Losses, Distribution Networks, Nigeria, Root Causes*

1. INTRODUCTION

The electrical network that runs throughout Nigeria is one of the most extensive interconnections of an evolving system in Africa to date. Losses are always present, regardless of how the system is designed. Electric power losses refer to wasted energy caused by internal or external sources, as well as energy diffused across the system. They include losses caused by theft, weather conditions, resistance, errors in computations, losses obtained between supply sources and load centres (or customers), and so on. Loss reduction and measurement are critical in all human endeavours. It can help a power system run more efficiently. Necessary steps are needed in order to limit and reduce losses. Accordingly, this will result in efficient and effective operation of the system. Thus, current electricity transmission and generation infrastructure can be utilized efficiently without the need to construct new facilities and save cost of losses at the same time. Essentially, losses in electrical power system can be described as those losses induced by external elements (non-technical losses) and those induced by internal elements (technical losses). The electricity grid of Nigeria has a huge magnitude of distribution and transmission losses. This is ascribed to non-technical as well as technical losses. In general, the cost of operating electric utilities increases as a result of system losses and this leads to high electricity cost. Hence, minimization of system losses is of great significance due to its socio-economic, economic and financial values to the utility firms, energy consumers and the country in general [1].

In most parts of the globe, the primal electrical power network operated consists of three essential divisions as follows: generation, transmission, and distribution. The distribution division of the network is in direct contact with the end-users of electricity as it steps down and dispenses energy at the needed voltage level to them. In 2013, eleven DisCOs (Abuja, Benin, Eko, Enugu, Ibadan, Ikeja, Jos, Kaduna, Kano, Port Harcourt and Yola) emerged from the privatization of the distribution and generation arms of the Nigerian power system. Expectations from the sector was high with the privatization but the aftermath was not the case, as the sector is still considerably beset with a lot of problems such as erratic power outages, unavailability of prepaid meters, exorbitant energy bills, deteriorated power quality, expansion issues, huge technical losses and so on. Since high technical losses directly affect income generation, electricity rates, and growth capabilities, they seem to be the worst of all the plagues. As well, notwithstanding the crucially of electric power to any nation’s development, electricity generation in Nigeria is insufficient - less than thirty per cent of national demand. On the other hand, more than fifty per cent of the energy generated are usually reported lost in the distribution network.

Prompt action is thus needed, as well as in-depth comprehension of the root causes of losses in Nigeria's power system [2, 3].

In all electric power networks, losses cannot be entirely removed and are inevitable. They have continued to be one of the greatest hurdles that confronts electric power system operations with significant impact on the efficiency and revenue inflow of each power system component. Even in highly developed countries, all the energy generated are usually not available for use by consumers; some are lost during transmission and distribution [2, 3].

Consumers bear bulk of the heat from increased losses in distribution networks as they will pay more for their energy consumption while on the other hand these losses hinder DisCOs from meeting their monetary obligations to their suppliers, employees and banks that might have lend them money. Thus, there is need to examine technical losses (this is captured in section 2) and ways of mitigating against the losses (this is in section 4). Some of the root causes of technical losses will be identified and analyzed in section 3, and conclusion of the study is presented in section 5. And it is expected that valuable insights will be attained in the process.

2. TECHNICAL LOSSES

Some studies have been carried out with respect to dampening of technical losses in electricity networks. Odiase & Agbonaye [4] were able to achieve technical losses minimization within a network by improving the power factor. Mufutau et al [5] carried out technical losses evaluation of eight feeders within a DisCO and found out that a particular feeder had the highest amount of the said losses due to the feeder span and unauthorized connection by energy consumers and suggested creation of new substation and routine maintenance as a means of curbing the losses. Anumaka [1] presented various mathematical approaches to determining technical losses while Audu et al [6] and Uchechukwu & Ephraim [7] both utilized specific approaches for technical losses estimation. Obi et al [8] carried out financial assessment of technical losses in south-East part of Nigeria and thereafter suggested that capacitor banks be installed in substations for improved profit realization. Amadi et al [9] and Egwaile et al [10] both looked at the cost effects of technical losses in the distribution networks of various DisCOs and suggested corresponding mitigative measures. Furthermore, Anyanor et al [11] presented mitigation of technical losses in transmission networks. The reviewed works presented only specific solutions to technical losses tailored only for specific situations but in this study, the various causes of technical losses will be harmonized and presented as well as practicable solutions will be proposed.

Technical losses are losses that results from energy dispersed in conductors, equipment utilized for distribution line, transmission line, sub-transmission line and magnetic losses in transformers. They are generally 22.5 per cent, and depend on the network features and the style of operation. The secondary and primary distribution lines are where bulk of the losses occurs in a typical power system. Whereas transmission and sub-transmission lines make for about 30 per cent of the total losses only [12]. They are known also as 'Physical losses' as they denote energy transformed to noise and heat while distributing electricity and thus, gets lost physically. This energy discharge leads to carbon emissions and costs end-users of electricity money. This loss type is induced due to the physical features of electrical equipment utilized in distribution networks. They rely on the electrical grid's design, power line length, transformation levels, and voltage. Furthermore, they relate to long-term signals (a tradeoff between investment costs and operational expenditure) and investment in equipment (transformers, lines). They are also associated with the design and efficient planning of distribution networks [13]. The following are the sub-divisions of technical losses [12, 13]:

i. Fixed losses
ii. Variable losses
iii. Network services (uncontracted network devices usage)

2.1 Fixed/Permanent Losses

Fixed losses, or no-load losses, do not fluctuate with current. Fixed losses account for approximately one-third to one-fourth of technical losses on distribution networks [12]. Implying, some electrical energy is dispelled by equipment like transformers, conductors, and network components since they are connected to the network and powered. Losses abound by virtue of the system being electrically energized whether or not power gets to the end-users. They take the shape of noise and heat, and are not dependent on the amount of electrical energy delivered by the network [13]. Fixed losses result largely from transformers energization (even though transformers also cause variable losses). They take place in the core of transformers and are thus known as core losses or iron losses. Core losses have the following sub-classes:

i. Hysteresis losses occur when the magnetic sign of the steel in transformer cores reverses during each alternating current cycle. This induces the material to pulse (producing a humming noise) and heat up [13]. As current travels in both directions, the core demagnetizes and magnetizes, causing hysteresis loss. Magnetic flux heightens as the magnetizing force increases but the former does not diminish at the same pace as the later. Meaning that the flux density will continue to be positive when the magnetizing force is zero. Magnetic force must be employed in the opposite path from the positive for flux density to be zero. Figure 1 depicts the relationship between flux density (B) and magnetic force (H). The size of the hysteresis loop depicts the energy needed to perform a complete cycle of de-magnetizing and magnetizing, as well as the energy lost during this process [14]. By monitoring a ferromagnetic material's magnetic flux while varying the magnetizing force, the loop is created. A ferromagnetic material that has been fully demagnetized or has not been magnetized before will follow the dashed line as H increases. The line shows that when additional current (H positive) is supplied, the component's magnetic field (B positive) becomes stronger.

Since practically the entire magnetic areas are at point "a," there won't be much of an increase in magnetic flux from further increases in the magnetizing force. The substance has reached the point of magnetic saturation. Point "a" will become point "b" on the curve when H is decreased to zero. It is now clear that the material contains some magnetic flux even in the case of zero magnetizing force. This point on the graph, referred to as the point of retentivity, shows how much remanence, or residual magnetism, is present in the substance. The curve changes as the magnetizing force is reversed, shifting to point "c (coercivity - the material's net flux is zero because enough domains have been flipped by the reversed magnetizing force)," where the flux is zero. As the magnetizing force is increased in the negative direction, the material will again become magnetically saturated, but in the other direction (point "d"). Point "e" is where the curve ends when H is reduced to zero. It will retain the same amount of magnetism as it did in the opposite way. Restoring H to its initial positive value will cause B to go back to zero. Observe that the curve did not go back to the graph's start point because of a force that moved point "f" to saturation point again; here, the loop will be finished [15].

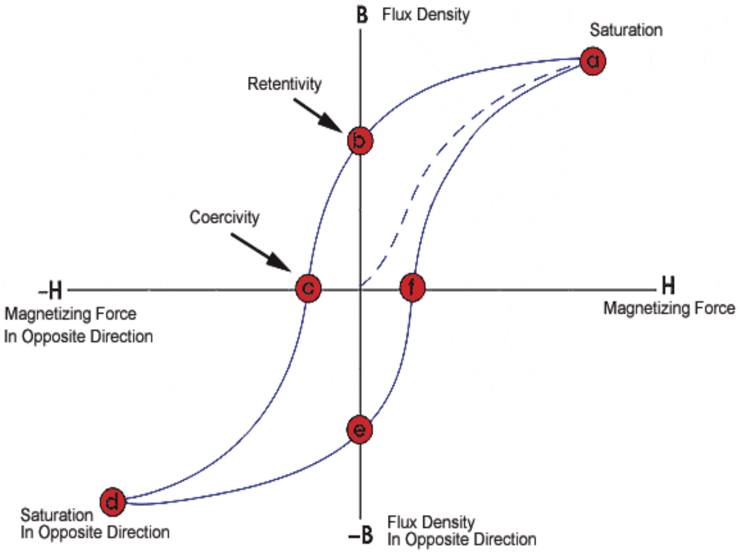

Figure 1: A hysteresis loop illustrating the link between H and B [14]

ii. Eddy current losses are losses caused by the movement of induced currents in conducting elements other than copper windings, like the steel core of a transformer [13]. When a magnetic substance is subjected to an alternating magnetic field, it generates an electromotive force (EMF). This is in conformity with Faraday's law of electromagnetic induction. EMFs distribute current within the substance's body because the magnetic material is a conducting material. These revolving currents are known as eddy currents. They are induced when the conductor encounters a varying magnetic field [16].

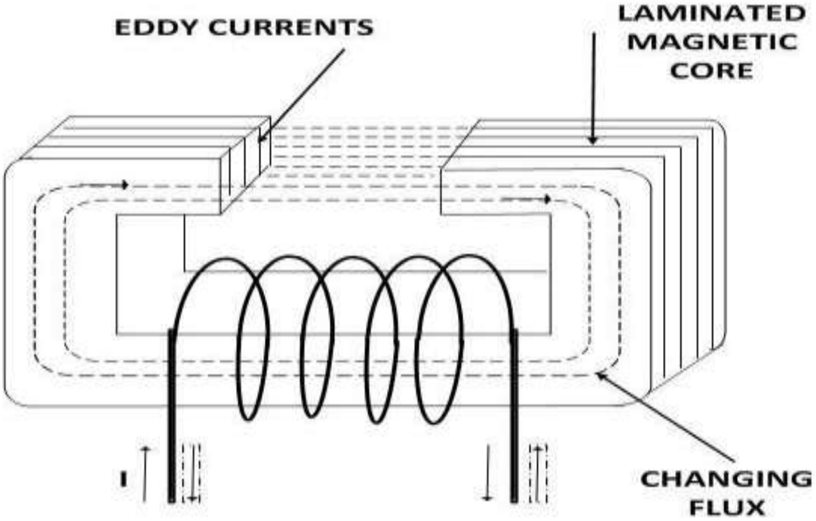

Figure 2: Sectional view of a typical magnetic core [16]

This current causes I^2R loss known also as eddy current loss. Where R is the resistance of the eddy current path and I represent the current value. The magnitude of I will be pretty enormous as well. Losses will be substantial if the core is comprised of solid iron with a bigger cross-sectional area [16]. In addition to transformer inefficiencies, electrical insulation in network devices is a source of fixed losses. Flaws in electrical insulation causes minute currents to flow round them in cables, lines, transformers, and other network devices. Fixed losses of these type are known as leakage current losses or dielectric losses [13].

2.2 Variable Losses

These are equal to the second power of current and vary with the amount of electricity delivered. As a result, losses heighten by over one percent for every 1 percent rise in current. They make for approximately $\frac{2}{3}$ to $\frac{3}{4}$ of all technical losses on distribution networks. All conductors have an intrinsic resistance that makes them to heat-up during the flow of current, and can be coils in transformers, copper or aluminium wires in overhead lines or cables, or fuses, switchgear, or metering devices. This loss type is known also as resistive or joule or copper or ohmic losses. Transmission networks have fewer losses than distribution networks because they require less current at higher voltages to convey the same quantity of electric power. This is due to the fluctuating nature of variable losses, which fluctuate as power flows fall and increase. Also, they can be influenced by factors like power quality, power factor, and the effect of network imbalance, which determine the amount of currents passing through conductors [12, 13].

Furthermore, they depend on the conductor's cross-section and length, as they change proportionally to resistance. Resistance diminishes as a conductor's cross-sectional area grows. As a result, variable losses have a limited influence on greater cable sizes. Similarly, in transformers, the cross-sectional domain and materials utilized determine variable losses. Weakened conductors and insufficient connections between network devices are additionally a contributor of this loss type, since they can induce the appearance of hot spots as a result of an increase in equivalent resistance [13].

2.3 Network Services

Aside from variable and constant losses, other networked equipment may use energy. Only the consumptions that cannot be covered by a contract are included here. Network control and measurement devices put on meters or along electric lines in energy customers' facilities, whether electronic or mechanical, are instances of uncontracted utilization [13].

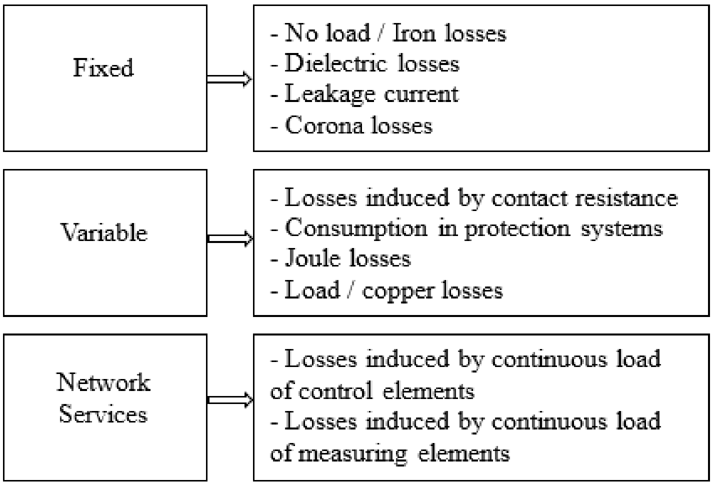

Figure 3: Overview of types of technical losses [13]

3. FACTORS INFLUENCING TECHNICAL LOSSES IN DISTRIBUTION SYSTEMS

In this section, the various factors influencing the prevalence of technical losses in the distribution subsection of Nigeria's power system are discussed. But it is worth noting that the most of the technical losses in Nigeria power system comes from the distribution end.

3.1 Lengthy Distribution Lines (Low Voltage Lines)

The distribution networks (secondary and primary lines) of the eleven distribution companies are very protracted and highly interconnected. This is because their coverage areas are broad comprising of wholly industrial areas, wholly residential areas and a combination of both. Some of these areas are highly urbanized while some are equally very remote areas. The protracted nature of the networks leads to high I^2R losses in the lines as a result of high line resistance [17].

3.2 Worn-out Equipment

This cannot be over-emphasized. It is very evident that most of the equipment currently being utilized are old (most have exceeded their useful life) and leads to losses on their continued utilization. In some locations, this is observed from the incessant faults/unavailability of supply due to erratic equipment failures.

3.3 Lack of Proper Maintenance

Most of the distribution networks are left for long periods of time without proper checks. In occasions when these checks are carried out, most are not done properly. This could be as a result of limited manpower. One can find a particular team covering a vast area, so most times, on fault occurrence, residences as well as commercial outlets are left for days without supply until same team clears the fault.

3.4 Efficiency of Equipment

When equipment is utilized beyond their stipulated life span, the efficiency of such equipment will naturally decline and this will lead to losses on the network.

3.5 No Growth Provision of System

New residences and commercial outlets spring up every day. Thus, these new additions greatly impact the already overloaded network. Thus, on exceeding the threshold number that equipment is designed to serve. Such could lead to losses as the affected equipment, being inanimate will strive to execute its function.

3.6 Location of Distribution Transformers

Most of the distribution transformers are not situated centrally with regards to consumers [12]. Meaning, consumers farthest from the transformers obtain low voltages. This leads to losses on the line.

3.7 Feeder Length

When the lengths of distribution feeders are protracted, this leads to losses. This is so because long lines have high voltage drops being due to the fact that distribution lines have higher current.

3.8 Inadequate Size of Conductors

Most of the distribution networks of the 11 DisCOs are made up of a mixture of bare aluminium conductors of varying sizes. Some are of the recommended standard size while others are largely off the recommended size. Thus, when these are energized, losses abound.

3.9 Low Power Factor

The power factor in majority of distribution networks typically falls between 65 percent and 75 percent. One element that leads to large distribution losses is a low power factor. If the power factor is poor for a given load, a high current drawn will result in losses that are proportionate to the square of the current [12].

3.10 Poor Workmanship

When a work is poorly or badly done, the end result of such may lead to a fault condition or other serious issues. And this leads to losses on the network.

3.11 Low Voltage

Devices especially induction motors when supplied with low voltage results in higher currents being drawn and this leads to higher losses. Some areas in the networks of the DisCOs are plagued with this issue owing to the factor that either the distribution transformer feeding such location(s) are overloaded or not centrally placed leading to low voltage supply to the end-users.

3.12 Load Factor Effect

End-user consumption of energy usually fluctuate all day round. For instance, commercial outlets load usually peak early in the afternoon while that of residential consumers peak in the evening [17]. Thus, these variations contribute to losses on the DisCOs networks.

3.13 Selection and Sizing of Transformer

Transformers have their inherent losses (no-load losses and load losses) [12] and their size as well as selection have their varying effects.

3.14 Unequal Load Distribution of the Three Phases of Low-Tension Lines

This is very much evident across the networks of the utility firms. And the most affected consumers in this category are the residential energy users. For instance, in an area or community, one can easily find this factor in effect. In the evening hours, on such affected environs, houses on the left-hand side can be seen with normal voltage levels while the opposite will be observed for houses on the right-hand side and vice versa. This shows that the loads on the houses are not balanced across the corresponding phases of the lines. A phase could be under-loaded, the other overloaded and the remaining one normally loaded.

3.15 Abnormal Operating Conditions

Occurrence of fault conditions are inevitable on distribution networks and generally leads to losses.

3.16 Overloading of Distribution Lines

This factor is equally prevalent in the distribution networks. New outlets spring up daily and these outlets are hooked up to the existing networks that are most times already overloaded.

4. PRACTICABLE FRAMEWORKS FOR TECHNICAL LOSSES MINIMIZATION

For technical losses minimization in distribution networks to be attained. The following solutions are proposed:

i. Worn-out equipment should be replaced.
ii. Constant and routine network maintenance should be done. This will go a very long way in identifying equipment that needs to be replaced.
iii. Transformers should be right-sized. Between eighty to hundred per cent of maximum capacity, transformers operate most efficiently. Underloaded transformers suffer from frequent core losses, rendering them inefficient. For transformers that are regularly overloaded, it may be more efficient and safer to install bigger transformers or rebalance the load so that the transformers are under capacity. On the other hand, it might be possible to install smaller transformers suitable for the load or shut down certain transformers strategically for occasions when some transformers are regularly underloaded. Therefore, a careful examination is required to ascertain when it will make financial sense to downsize, upsize or shut off a transformer [18].
iv. Voltage optimization: The total resistive loss in a system can be decreased. This can be achieved by minimizing the flow of current in parts of the network through the re-adjustment of the voltage levels in the network [18].
v. Utilization of capacitor banks for increasing reactive load: Reactive load is needed to magnetize an object like the core of a transformer while real load performs work. These two (real and reactive load) are components of apparent load. Thus, by adjusting or installing capacitor banks, reactive load percentage on the system can be lessened, and this minimizes real power losses [18].
vi. Feeder re-configuration: Feeder reconfiguration is the process of changing the topological structure of distribution feeders by altering the closed or open status of the ties and sectionalizing switches. During feeder re-configuration, loads on less heavily laden feeders can be raised by moving loads from severely loaded feeders to less loaded feeders. This leads to reduction in the overall system power losses, improves the voltage profile along the feeders and lastly, enables the load levels on different feeders to be altered [19].
vii. Reinforcement of feeder: About sixty to eighty per cent of total feeder losses are induced by the first few main sections (normally 3-5) of the feeder according to studies on various distribution feeders. This is primarily because the conductor size that was utilized when the feeders were first erected is no longer optimal with reference to current total load increase. The entire cost is the aggregate of the variable cost of energy losses in the conductor as a result of power flow and the fixed cost of investment of the line. The current carrying capacity of a feeder limits the inclusion of a new load on the feeder. To cater for extra load on a feeder, reinforcement of the feeder comes to play when the existing feeder gets overloaded. This method is ideal only for short term planning measures [19].
viii. Construction of new substation: Various potential solutions are usually studied whenever a new substation is to be built and connected to an existing network. These solutions might include various viable locations and several connection schemes of the intended substation while the primary connection system is defined by a limited number of possibilities. The location as well as the number of potential sites of newly constructed lines defines the cost of their operation and construction. Additional factors like environment considerations, land ownership and topology usually influence the final decision to be taken. Furthermore, the optimum site for a substation is defined as that location where losses will be minimal and cost of construction minimum. These include cost of operating the system and both investments in 33kV and 11kV voltage systems [19].

5. CONCLUSION

It is worth noting that technical losses are unavoidable in electrical power systems. Data from technical losses assessment are useful in planning grids and calculating energy losses. The knowledge from this study will enable electrical power distribution networks to be adequately planned, built and routed in a way that will reduce the adverse effects caused by technical losses. It will enable existing power infrastructures facing similar challenges to be improved upon. As well, it will reduce the burden on end users of electricity as power distribution companies in a bid to recover cost lost due to technical losses will no longer incorporate such on consumers' electricity bills. The factors influencing technical losses and practicable solutions to technical losses reduction presented in this study are not exhaustive. Thus, future studies can build on it.

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