Evaluation of technical power losses of the Nigerian 330kV network

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Abstract

In recent times, electric power demand has increased drastically due to increase in population and industrialization that need electrical energy unfortunately, electricity is not always used in large demand in the same location it is being generated. Once cables are used to transmit the generated electricity either through underground or overhead system method, this transmission does not take place without encountering losses, either technically or Non-technically. Different methods like Depezo loss formula, loss factor, use of system parameters for evaluating the system losses, the differential power loss and power flow methods, B-losses coefficient, which expresses the transmission losses as a function of outputs of all generation are explained in this paper on how they can be used to solve this technical losses. Measures to be taken to make sure that transmission losses can be reduced to minimum, were also explained.

Keywords ; Technical loss, Depezo, Power System, Transmission System

Introduction

Electricity generated from the power station, needs to be transmitted to the end users, through transmission and distribution lines. This transmitted energy is not without losses, but the capacity to transmit at minimal losses is what this report entails to x-tray. Basically, losses in electrical power system can be identified as those losses caused by internal factors known as Technical losses and those cause by external factors are called non-technical losses. Due to the size of the area the power system serves, the majority of the power systems are dedicated to power transmission (Anumaka, 2012). Generally, system losses increase the operating cost of electric utilities and consequently result in high cost of electricity. Therefore, reduction of system losses is of paramount importance because of its financial, economic and socio-economic values to the utility company, customers and the Nigeria. However, low losses in transmission system could be achieved by installing generating stations near the load centers

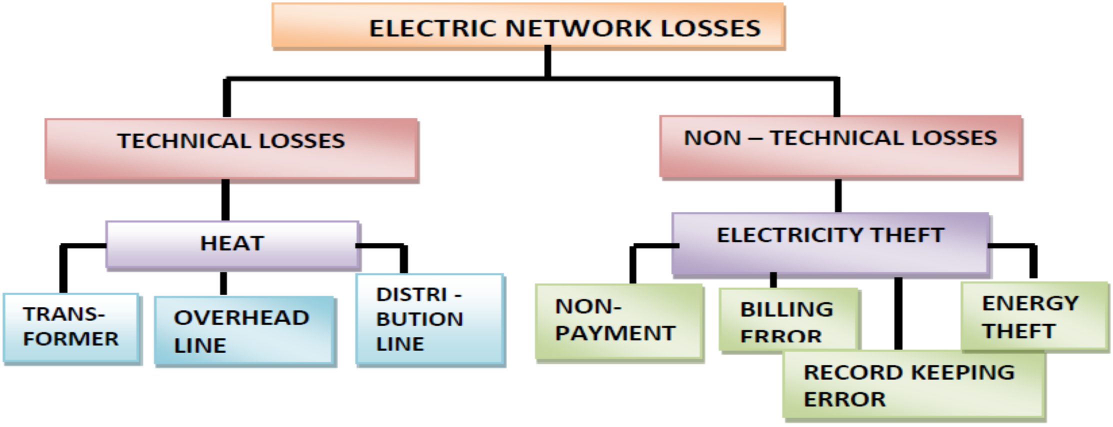

Figure 1: Classification of Losses

Technical losses are due to current flowing in the electrical network. It generates the following types of losses:

(i) Copper losses: These are due to I^2R losses that are inherent in all conductors because of their finite resistance. This is sometimes called conductor loss or conductor heating loss and is simply a real power loss.

(ii) Dielectric losses: These are losses due to the heating effect on the dielectric material between conductors.

(iii) Induction and radiation losses: These are produced by the electromagnetic fields surrounding conductors.

However, they can be calculated based on the natural properties of components of power system (Inderjeet, *et al.,* 2013): resistance, reactance capacitance, voltage, current, and power. They are calculated as a way to specify which components will be added to the system, in order to reduce losses and improve voltage levels. Accuracy in calculation of technical losses is of peculiar importance because for the calculation of non-technical losses, the difference method is used and this is what the technical losses computation failed to take into account.

Non-technical losses, on the other hand, are caused by actions external to the power system, or are caused by loads and conditions that the technical losses computation failed to take into account. Non-technical losses are more difficult to measure because these losses are often unaccounted for by the system operators and thus have no records (Navani, *et al.,* 2003). The most probable causes of non-technical losses are electricity theft, non-payment of bill by customers, errors in technical losses computation and errors in accounting and record keeping that distort technical information.

Analysis of Technical Losses in Power System

Technical losses in electrical system can be determined in different ways. Electric technical losses occur as current flows through resistive materials and the magnetizing energy in the lines transformers and motors. However, the losses incurred in resistance materials can be reduced by adopting the following means (Lukman *et al.,* 2002)

a. Reducing the current

b. Reducing the resistance and the impedance

c. Minimizing voltages.

Generally, technical losses can be evaluated or computed using several formula considering the pattern of generation and loads (Cory, 2008) by means of any of the following methods considered for related technical losses analysis:

Computation Of I^2R In Transmission Line

Consider the circuit model of a simple three-phase radial transmission line between two points of generating /source and receiving/load to be trivial (ideal conductor) as illustrated in the one-line diagram of Figure 2. The three-phase line loss is given as

$$P_{Loss} = P_L = 3I^2R$$

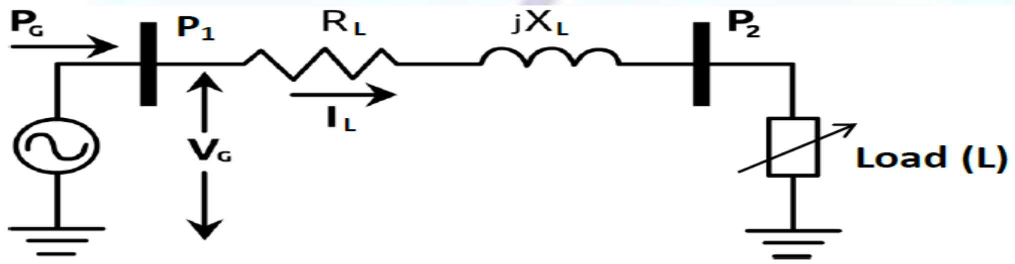

Figure 2.: One-line diagram with one source and one load

It can be deduced from Figure 2. that I^2R line loss are inherent in all conductors because of the finite resistance of conductors. The current I is obtained as

$$|I| = \frac{P_G}{\sqrt{3}V_G\cos\theta_G} \qquad 1$$

Where P_G is the generated power (load power and losses) , V_G is the magnitude of the generated voltage (line-to-line) and $Cos\ \Phi_G$ is the generator power factor leading.

Combining equations 2. and 3, we have

$$P_L = \frac{R}{|V_G|^2 \cos^2 \emptyset_G} (P_G^2) \qquad 2.$$

Assuming fixed generator voltage and power factor, the losses can be written as

$$P_L = BP_G^2 \text{ where } B = \frac{R}{|V_G|^2 \cos^2 \emptyset_G} \qquad 3$$

Where B = the loss coefficient

Evaluation of Line losses using B-Loss Coefficient

In a large interconnected network where power is transmitted over a long distances with a low local density area, losses are a major factor. These losses are thus approximated as a second order function of generation. If a second power generation is present to supply the load as shown in Figure 3, the transmission losses can be expressed as a function of the two plant loadings represented by

$$P_L = P_1^2 B_{11} + 2P_1 P_2 B_{12} + P_2^2 B_{22} \qquad .4$$

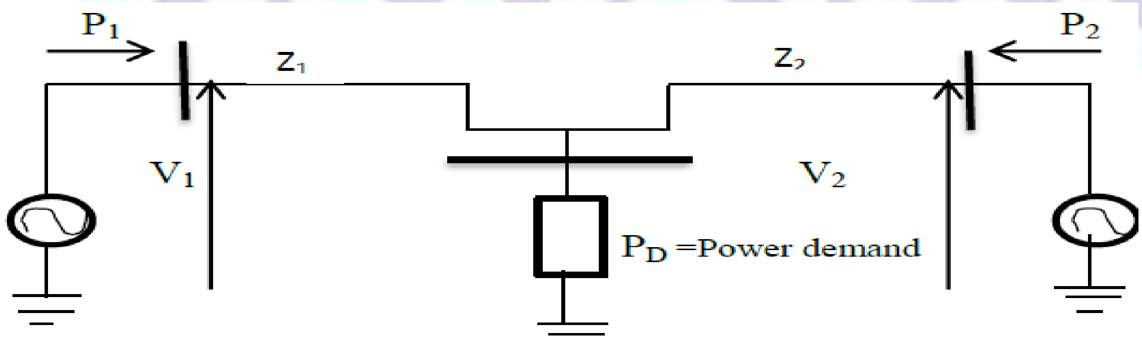

Figure 3: Radial system with one additional generation

Transmission losses become a major factor to be considered when electric energy is transmitted over long distances or in the case of relatively low load density, over a vast area. The active power losses may amount to 20 to 30 % of total generation at a frequency of 50Hz in some situations.

In industrial systems, the losses are made up of complex combination of fixed (core and corona) and variable (I^2 dependent) losses. That is

$$P_L = B_0 + B_1 P_G^2 \quad (5)$$

Where

B_0 represents fixed loss, B_1 represents variable loss , P_G is the generated power

It should be noted that the calculation of B-loss coefficients is more complex in large industrial systems.

Differential Loss Method of Loss Evaluation

Power loss can also be expressed as the difference between the transmitted power and received power:

$$P_{loss} = P_{Sent} - P_{Received} = (P_S - P_R) \quad (6)$$

The relationship between the power sent, power received and associated losses in the transmission network is illustrated in Figure 4 (Lukeman, 2002)

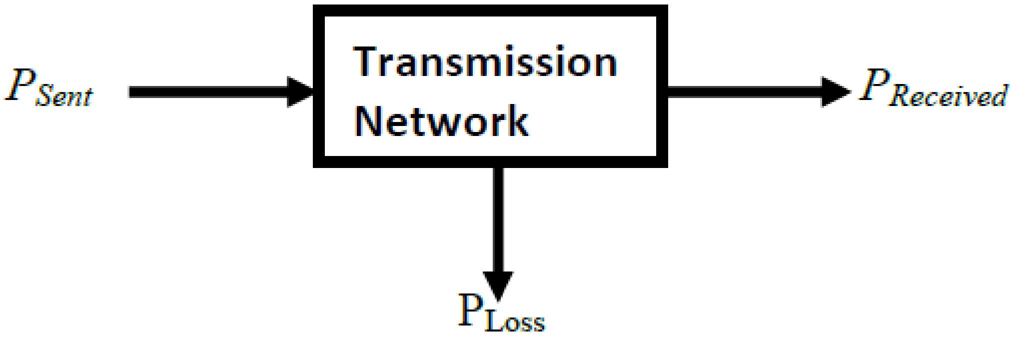

Figure 4: The relationship between power sent and power received.

1. **Efficiency Of Transmission Line**

Technical losses can also be calculated from the efficiency of transmission line where the efficiency η of a transmission line is defined as

$$\eta = \frac{\text{Power received}}{\text{Power sent}} = \frac{P_R}{P_S} \quad (7)$$

$$\eta = \frac{\text{Power supplied} - \text{Power loss in the line}}{\text{Power sent}} = \frac{P_R - P_L}{P_S} \quad 8$$

$$\eta = 1 - \frac{P_L}{P_S}$$

therefore, efficiency $\boldsymbol{\eta}$ of a transmission line can also be defined as

$$\eta = \frac{P_R}{P_S} = \frac{P_R}{P_S + P_L} \quad 9$$

where

P_L is the power loss in the line

P_R is the power received

P_S is the power sent (Kimbak, 1971).

Dopezo Transmission Loss Method

In (Dopazo, *et al.,* 1967), the authors derived an exact formula for calculating transmission losses by making use of the bus powers and the system parameters

Let S_i be the total injected bus power at bus i

This is equal to the generated power minus the load at bus i.

The summation of all such powers over all the buses gives the total losses of the system as

$$P_L + jQ_L = \sum_{i=1}^{n} S_i = \sum_{i=1}^{n} V_i I_i^* = V_{bus}^T I_{bus}^* \quad 10$$

Here, and are the real and reactive power losses of the system respectively. V_{bus} and I_{bus} are respectively the column vectors of voltages and currents of all the buses.

Thus , $V_{bus} = Z_{bus} I_{bus}$

Where Z_{bus} is the bus impedance matrix of the transmission network and is given by

$$Z_{bus} = R + jX = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{13} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ r_{31} & r_{32} & \cdots & r_{nn} \end{bmatrix} + j \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{13} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ x_{31} & x_{32} & \cdots & x_{nn} \end{bmatrix} \quad 11$$

For economic reasons, the conductor size should be considered. The most economic conductor size can be calculated considered by application of Kelvin's law. The current in the feeder is at the maximum value only at certain times. At all other times the current is less than the maximum current and it is necessary to use a factor to account for this fact.

Loss factor is defined in (Depazo *et al.,* 1967) as $\text{Loss factor} = \frac{\text{Average power loss}}{\text{power loss at peak load}}$

The actual power loss is $\text{Loss} = 3\,(I_{max})^2\,R\,(\text{loss factor})$

If the load is constant throughout, the loss factor is one. In actual practice the load varies with time of the day. If the actual load curve is known, the loss factor can be calculated. An approximate value of factor can be found from the following equation (Depazo *et al.,* 1967)

$$\text{Loss factor} = (0.3 \times \text{Load factor}) + (0.7)\,(\text{Load factor})^2$$

Where the load factor is the ratio of average load to peak load.

line flow computation

The figure below shows a line connecting i and j buses, we assume the normal π representation of transmission line current flowing from bus i towards bus j

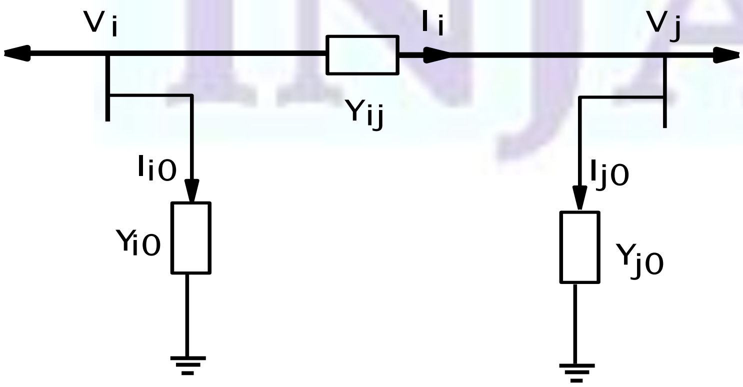

Figure 5 Transmission line model for calculating line losses

$I_{ij} = I_i + I_{io} = Y_{ij}\,(V_i + V_j) + Y_{io}\,V_i$ 12

Similarly, applying the same KCL at bus j for Iij which is considered positive in the direction j→i, this line current is given as $I_{ji} = -I_j + I_{jo} = Y_{ij}\,(V_j - V_j) + Y_{jo}\,V_j$ 13

$S_{ij} = V_i\, I_{ij}^*$ 14

$S_{ji} = V_j\, I_{ji}^*$ 15

$SL_{ij} = S_{ij} + S_{ji}$ 16

These equations are the mathematical model requirement for simulating load flow and line losses using Newton raphson method

Transmission System Parameters

When current flows in a transmission line, the characteristics exhibited are explained in terms of magnetic and electric field interaction. The phenomenon that results from field interactions is represented by circuit elements or parameters. A transmission line consists of four parameters which directly affect its ability to transfer power efficiently. (Depazo *et al.,* 1967). These elements are combined to form an equivalent circuit representation of the transmission line which can be used to determine some of the transmission losses.

Shunt Conductance

The parameter associated with the dielectric losses that occur is represented as a shunt conductance. Conductance from line to line or a line to ground accounts for losses which occur due to the leakage current at the cable insulation and the insulators between overhead lines. The conductance of the line is affected by many unpredictable factors, such as atmospheric pressure, and is not uniformly distributed along the line. The influence of these factors does not allow for accurate measurements of conductance values. Fortunately, the leakage in the overhead lines is negligible, even in detailed transient analysis. This fact allows this parameter to be completely neglected.

Resistance

The primary source of losses incurred in a transmission system is in the resistance of the conductors. For a certain section of a line, the power dissipated in the form of useless head as the current attempts to overcome the ohmic resistance of the line, and is directly proportional to the square of the rms current traveling through the line (I^2R) (Gupta, 2008) . In dc (Mehta R et al 2004) resistance of conductor is given by

$$R = \frac{pl}{a} \qquad 17$$

Where p = resistivity of the conductor 'Ω – m,

1 = length in meter

a = cross sectional area in m^2

Change in temperature also affects the line resistance for small changes in temperature, the resistance increases linearly with temperature and resistance at a temperature t is given as

$R_t = R_0(l+a_0t$

Where R_t = resistance at t^oC

R_0= resistance at ^oC

a_0 = temperature coefficient of resistance ^oC the temperature increase between two intermediate temperature is

$$\frac{R_2}{R_1} = \frac{1 + at_2}{1 + at_1} \quad 18$$

Where: R_l = 1st resistance

R_2 = 2nd resistance a= temperature coefficient

T_l = 1s'temperature

T_2 = 2nd temperature

the temperature difference can be found using

$$\frac{R_2}{R_1} = \frac{{}^{1}/{a_0} + t_2}{{}^{1}/{a_0} + t_1}$$

$$R_2 = R_l \frac{T + t_2}{T + t_1} \quad 19$$

T and a_0 = constant temperature that depends on the material.

It directly follows that the losses due to the line resistance can be substantially lowered by raising the transmission voltage level, but there is a limit at which the cost of the transformers and insulators will exceed the savings (Westing, 1982).

The efficiency of a transmission line is defined as

$$\eta = \frac{P_R}{P_S} = \frac{P_R}{P_R + P_{Loss}} \quad 20$$

Where P_R is the load power and P_L is the net sum of the power lost in the transmission

As the transmission dissipates power in the form of heat energy, the resistance value of the line change. The line resistance will vary, subject to maximum and minimum constraints, in a linear fashion. If we let R be the resistance at some temperature, T_1 and R_2 be the resistance at time T_2, then,

$$R_2 = R_1 \left\{\frac{235 + T_2}{235 + T_1}\right\} \qquad 21$$

If T_1 and T_2 are given in degrees Centigrade (Anumaka, 2012)

Capacitance

The capacitance of a transmission line comes about due to the interaction between the electric fields from conductor to conductor and from conductor to ground. The alternating voltages transmitted on the conductor causes the charge present at any point along the line to increase and decrease with the instantaneous changes in the voltages between conductors or the conductors and ground. This flow of charge is known as charging current and is present even when the transmission line is terminated by an open circuit.

Inductance

When the alternating currents present in a transmission system they are accompanied by alternating magnetic fields the lines offered of the magnetic fields are concentric circles having their center's at the centre of the conductor and are arranged in planes perpendicular to the conductors. The interaction of these magnetic fields between conductors in relative proximity creates flux linkage. These changing magnetic fields induce voltages in parallel conductors which are equal to the time rate of change of the flux linkages of the line

Due to the relative positioning of the lines, the mutual coupling will cause voltages to be induced. The induced voltage will add vectorally with the line voltages and cause the phases to become unbalanced. When a three phase set is unbalanced the lines do not equally share the current. it is easy to see that the losses in one line will increase significantly more than the reduction of losses in the other lines. These suggest that a simple way to minimize the total I^2R losses is to maintain a balanced set of voltages.

Reasons for High Technical Losses in Transmission

Following are some of the factors that influence system losses

i. Circulating current: In modern highly interconnected networks, failure to maintain a flat voltage profile across networks will result in the flow of circulating currents. It is therefore important for a power system to maintain stringent voltage limits to minimize losses.

ii. Phase balancing: This is of significance when dealing with heavily loaded lines, the objective is to balance the phase load, so that the maximum deviation from the average is below 10%.

iii. Power factor: At unity power factor the current is minimum and any reactive component will cause an increase in current with a resultant increase in real power losses. For large inductive loads losses due to volt ampere reactive (VAR) become significant and demand side compensation become necessary (i.e. by installation of shunt capacitors). Furthermore as a result of increase in current in the system the voltage drop due to line resistance is greater than it would be at unity- power factor.

iv. Voltage regulation: Since line losses increase with the square of load current either maintaining and or increasing the normal operating voltage of the system, can reduce both maximum demand and energy losses.

Measures For Reducing Technical Losses

i. Identification of the weakest areas in the distribution system and strengthening/improving them so as to draw the maximum benefits of the limited Resources

ii. Reducing the length of LT lines by relocation of distribution sub stations/installations of additional distribution transformers (DTs).

iii. Installation of lower capacity distribution transformers at each consumer premises instead of cluster formation and substitution of DTs with those have lowered no load losses such as amorphous core transformers.

iv. Installation of shunt capacitors for improvement of power factor.

v. Mapping of complete primary and secondary distribution system clearly depicting the various parameters such as conductor size line lengths etc.

Conclusion

The Nigerian 330kv transmission network is associated with various problems, the systems is characterized by high voltage drops and power losses associated with long and fragile network making it vulnerable to failure and poor performance . Different methods can be used to compute the value of technical losses dissipated in the electrical power system depending on the situation and purpose. Although the power flow method is frequently used for determining the power loss. So, the B-loss coefficient and Depazo, I^2R methods can be used to obtain dependable results.

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