ELECTRIC ENERGY LOSSES IN TRANSMISSION AND DISTRIBUTION NETWORK: AN OVERVIEW

Abstract

This paper presents an overview of a typical electric energy transport system network. It examines the losses experienced in the transmission and distribution network and suggest practical measures to be taken by stakeholders (Government and Utility owners) to minimize these losses.

Key words: Transmission, Distribution, Grid, Corona, Transformer, Substation, Reactance, Power Cable, Back emf, Losses, Load Centres.

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1.0 Introduction.

Electrical power or energy is generated and transported after transformation to transmission voltage via a transmission network to various distribution substations in different communities which substations either distribute the transported energy to various load centers around its domicile communities or re-transport same to nearby communities for on-ward distribution. Very long and over-aged transmission and distribution lines, unequal phase loading, inadequate reactive compensation and energy theft and not using appropriate conductors on the lines contributed to the high-energy losses in the network (Anyaka et al, 2014). With the growing population and industrialization which has created a high need for electrical energy, the losses can be imagined to be very high. From the fore-going it can be noted that, electricity is not always used in the same place where it is produced meaning long distance transmission lines and distribution systems are required. Transmitting electricity over a long distance via network involves energy loss. So with the growing demand comes the need to minimize the energy loss.

Transmission and distribution of electrical energy require cables and power transformer which create three types of energy loss;

1. The joule heating effect (loss) where energy is lost as heat in the conductor (e.g copper wire)
2. Magnetic (core) losses where electric energy is dissipated in a magnetic field

3. The dielectric effect (loss) where energy is absorbed in the insulating material.

The joule effect in a transmission cables accounts for losses of about 2.5% while the losses in transformer ranges between 1% and 2% depending on the type and rating of the transformer (Alumna et al, 2014).

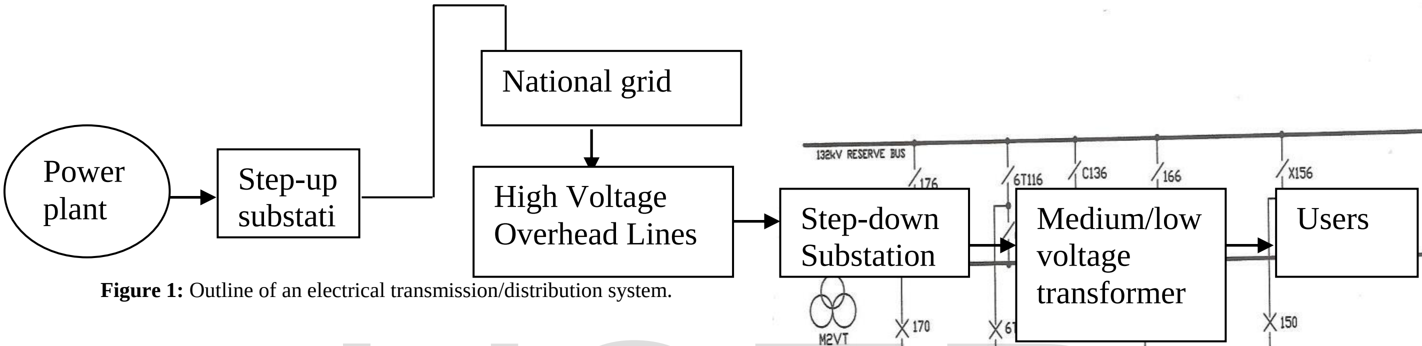

Figure 1: Outline of an electrical transmission/distribution system.

Note that only the main elements are on the schematic diagram since control gear and switchgear do not create significant losses.

A power plant produces electrical energy in a medium of certain amount of energy which this is elevated to a high voltage of 330kv by a step-up substation and connected to the national grid, electrical power is then transmitted through long distance via high-tension power lines and the higher the voltage the more power can be transmitted.

A step-down substation converts the high voltage back down to medium voltage of 132kv and 33kv and electrical power can then be transported by medium voltage lines overhead lines/cables. Most of the users are fed from the low voltage side of 33kv and 11kv lines and bigger factories fed most on 33kv lines.

The length of cables between a power plant and a step-up substation is short since they are usually installed in the same place so the energy losses therefore are quite low. The situation is not the same between the step-down substation and users, as they are at several kilometres apart. Hence several medium and low voltage poles and cables have to be erected.

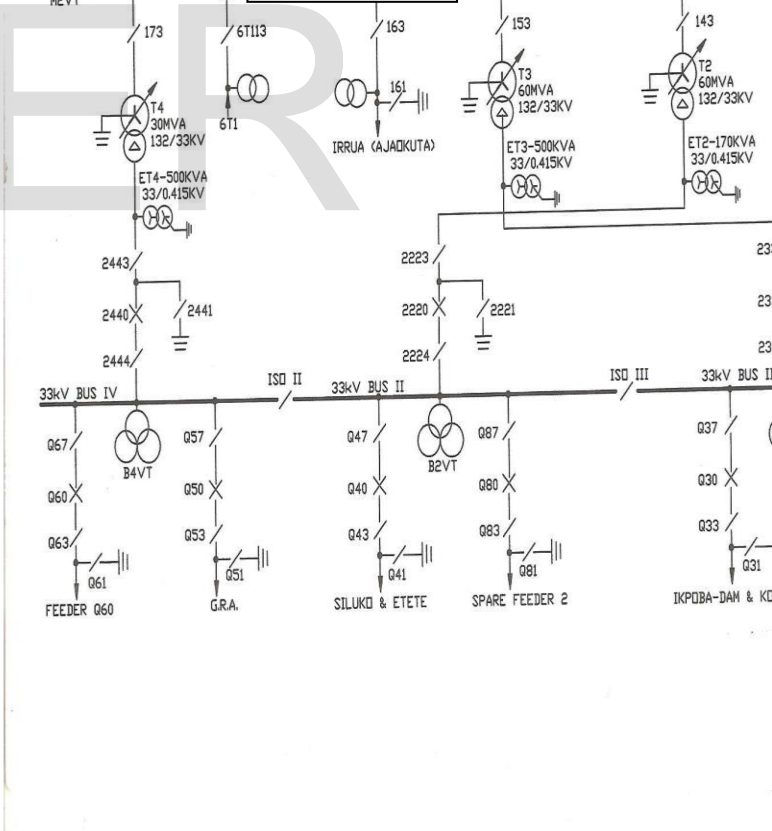

Figure 2: Single line diagram of 132kv/33kv. Benin t/s station

2.0 CORONA:

This is another important area of losses where transmission line operates at high voltage to produce electric field strengths of sufficient intensity to ionize the air near the phase conductors (Dabbagh and Arzani, 2008). This effect is called **Corona** which produces losses over the entire length of the transmission line network.

The corona effect is detectably audible with a buzzing and hissing sound and usually as a faint bluish aura surrounding the conductors. The critical field intensity $\sum_o$ at which this ionization begins for dry air is

$$\sum_{o} = 30Sm\left(1+ \frac{0.3}{\sqrt{\$}}\right) \text{ Kv/Cm}$$

\$ = relation air density 3.92b/T

B = atmospheric pressure in CmHg

T = absolute temperature in Kevin

M = stranding factor (O‹M‹L)

R = conductor radius in CM

The effective disruptive critical voltage to neutral is given by the relation v_c

V_c Mg \$rlogh $D/_r$ kv/phase

=2.3Mg \$r log10 $D/_r$ Kv/phase

Where

Mo= Irregularity factor which take into account the surface condition of the conductor

D= Distance between conductor in Cm

R= Radius of the conductors in Cm

g= Breakdown strength or disruptive gradient of air

G =Air density factor

2.1 The irregularity factor "Mo" depends on the shape of cross section of the wire and the state of its surface. Its value is unity for an absolutely smooth wire of one strand of circular section and less than unity for wires roughened due to weathering as shown below

IRREGULARITY FACTOR

Polished wire ------------------------------- 1.0

Weathered wire ----------------------------- 0.93 to 0.98

7 strand cables concentrically --------------- 0.83 to 0.87

Cables with more than 7-stands------------- 0.80 to 0.85

Using bundled conductor per phase tends to produce a large effective phase radius and therefore reduces the electric field intensity level in the conductor vicinity.

2.2 Corona has three undesirable features

1. Audible noise
2. Power losses
3. Radio and Television interference (i.e interference with neighbouring communication circuits)

2.2.1 Audible noise

Audible noise due to Corona may be divided into two components 120Hz hum and random noise sizzling sound both are in decibels

2.2.2 Power losses

Corona effects are undesirable because it constitutes power loss; the power loss is small, about 5 KW/KM for 330kv, 3 conductors per phase bundle. However, a corona loss increases dramatically when the line encounters precipitation in any form with frost creating the worst situation. Losses can run as high as 30kw/km with an average of about 2.4kw/km expected for line design.

2.2.3 Radio & T.V Frequency Interference

Radio and TV frequency interference is also a problem occurring essentially over a frequency range from 0.2 to 4m center around $f_o = 0.8$mHz. Precipitation increases Radio/TV interference at high humidity. As conductor age, radio/TV frequency interference level tends to decreases. Audible noise, power loss and radio frequency interference due to Corona are three main factors that must be considered when evaluating line design. (B.L and A.k. Theraja, 5th edition)

3.0 POWER TRANSFORMERS

One of the greatest advantages obtained from the used of alternating current {ac} is the fact that it may be transform from one voltage level to another without the aid of a rotating machine. There is a scope for improvement in the efficiency of power transformers and real economic benefits to be gained. Although all power transformers have a very high-efficiency -the largest are probably the most efficient machines devised by man. The losses from transformers can be enormous especially with increasing numbers of installations.

A recent survey on copper transformer revealed that distribution transformer losses represent 23% of the network losses (Oke and Bamigbola 2013).

By the time electric energy is received at the consumer’s premises at 415v three-phase or 240v single phase, most electrical energy has been through at least five transformations in voltage level. These transformers are energized 24hours per day, for almost twelve months of the year and are therefore consuming losses almost all of the year. It has been estimated that some five percent of all electricity generated is dissipated in iron losses in electrical equipments. (Sohan2012)

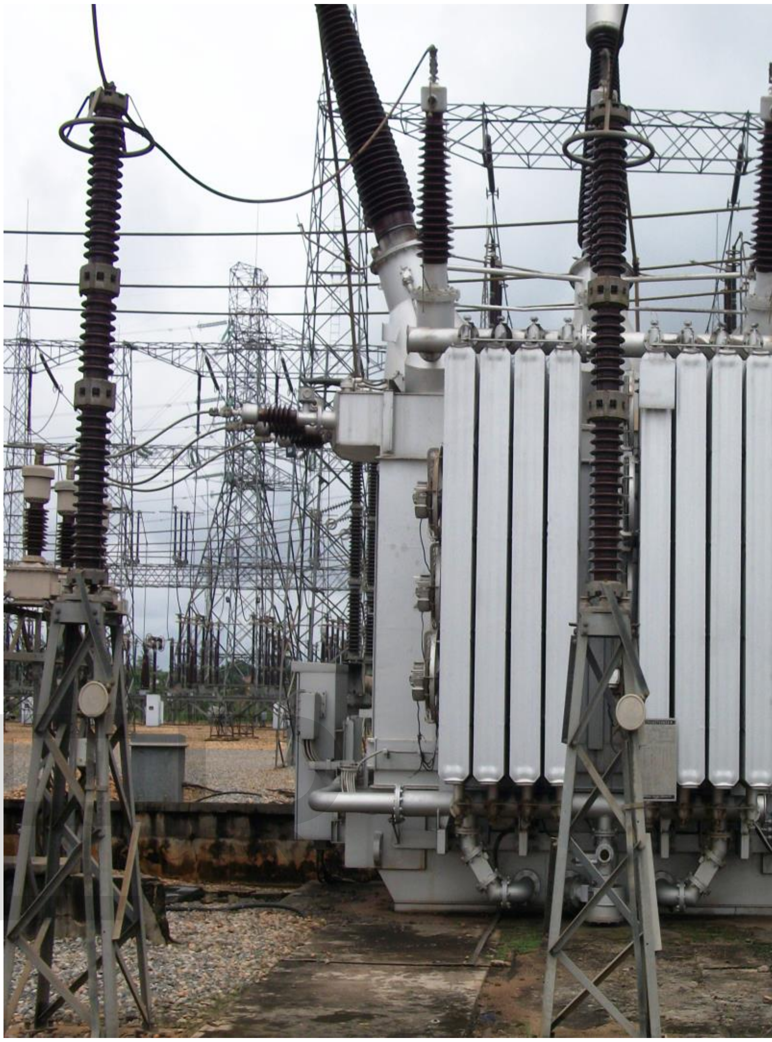

Figure 3 : 330kv / 132kv Power transformer

3.1 Types of transformers

Transformers are broadly grouped into two main categories, dry type and liquid filled transformer.

3.2 Dry type transformer

Dry type’s transformers are closed by natural forced circulation of air or inert gas through or around the transformer enclosure. Dry type transformers are further subdivided into ventilated, sealed, or encapsulated types depending upon the construction of the transformer. Dry type transformers are extensively used in industrial power distribution.

Figure 4: 60MVA 132KV / 33KV Power Transformer

3.3 LIQUID FILLED TRANSFORMERS

Liquid filled transformers are closed natural or forced circulation of a liquid coolant through the winding of the transformer. This liquid also serves as a dielectric to provide superior voltage with standard characteristics. The most commonly used liquid in a transformer is a mineral oil known as **Transformer oil** that has a continuous operating temperature of 105^{o}c, a flash point of 150^{0}c and fire point of 180^{0}c. a good grade transformer oil has a breakdown strength of 86.6 kv/cm (220kv/in) that is far higher than the breakdown strength of air which 9.84kv/cm (25kv/in) at atmospheric pressure (Sohan, 2012). Silicone fluid is used as an alternative to mineral oil. The breakdown strength of silicone liquid is over 118 kv/cm (300kv/in) and it has a flash point filled transformer arc classified as less flammable. The high dielectric strengths aid superior thermal conductivities of liquid coolants make them ideally suited for largely high voltage power transformer that are used in modern power generation and distribution

4.0 The Nature of Transformer Losses

A power transformer normally consists of a pair of winding, primary and secondary, linked by a magnetic circuit or core. When an alternating voltage is applied to one of these windings, generally by definition the primary, a current will flow which set up an alternating flux in the core. This alternating flux linking both windings, induces an electro-motive force (emf) in each of them. In the primary winding this is called the "back-emf" and, if the transformer were perfect, it would oppose the primary applied voltage to the extent that no current would flow. In reality the current which flows is the transformer magnetizing current. In the secondary winding the induced emf is the secondary open-circuit voltage. If a load is connected to the secondary winding which permits the flow of secondary current, then this current creates a demagnetizing flow thus destroying the balance between primary applied voltage and back-emf, so that an increased primary current is drawn from the supply (B.L Theraja, 5th edition). Equilibrium is once more established when this additional primary current creates ampere-turns balance with those of the secondary. Since there is no difference between the voltage induce in a single turn whether it is part of or either the primary or the secondary winding. The total voltage induce in each of the winding must be proportional to the number of turns. The relationship is established as $E_1/E_2=N_1/N_2$ and,

in view of the need for ampere-turns balance $I_1/N_2=I_2/N_1$

Where the $E_1 = N_1$ and $E_2 = N_2$

E_2, I_2 and N_2 are the induced voltage, the current and number of turns respectively. (vin callout & David)

4.1 Transformer Losses Fall into Three Categories

1. No-load loss, or iron loss
2. load- loss, or copper loss
3. stray-loss, which is largely load related

For some larger transformer there are also losses absorbed by fans and pumps providing forced cooling known as friction and windage losses.

4.1.1 No-Load Losses

Iron loss arises within the laminated steel core of the transformer and is due to the energy consumed in hysteresis and eddy-current within the material as it is taken through its alternating cycles of magnetization. An iron loss has been regarded by electrical engineers as the major area for improvement in transformer efficiency. Efficient operation of a power transformer requires the greatest possible flux linkage between primary and secondary winding and, for the best use of the core material this require that the core be operated at as higher flux density as possible whilst avoiding approaching to closely to magnetic saturation. Losses in iron increases as flux density are increased.

4.1.2 Load Losses

Load loss, or copper loss, has tended to receive less attention than iron loss in the pursuit of energy efficient in transformers. One reasons is because the magnitude of loss various in accordance with the square of the load. Copper loss arises mainly as a result of the resistance of the transformer winding, that is, it is the I^2R loss produced by the flow of the load current within the windings. There is however a significant additional component which is the eddy-current loss. Winding eddy-currents are produced as a result of the alternating leakage flux cutting the winding and these flow within the conductors at right angles to the load current path. For a particular winding the eddy-current losses are a fixed proportion of the load losses.

4.1.3 Stray Losses

So-called stray losses are those which occur in leads and tanks and other structural calculation techniques using finite elephant analysis, the magnitude of stray losses was usually determined empirically.

Computer programmed have not only removed the uncertainly from this aspect of design but have made possible improvements in the designs themselves by enabling designers to calculate and compare losses for differing arrangement as well as enabling the placing of suitable flow shield in critical area. Stray loss, which is load dependent, has thus been reduced from perhaps 10% of the load losses to around half this value. (Targosz and Topalis, 2007)

5.0 POWER CABLES

While the installation and use of much energy-efficient equipment is being well considered and auctioned, the energy losses in undersized power cable are frequently ignored. Those carrying high current sustain more heating and therefore endure more energy loss because of its joule effect with the increase in heat resulting from current flowing through the conductor. If cables are installed with a conductor size that is the minimum allowed to avoid overheating, energy losses can be very significant. Mandatory regulations specify minimum conductor sizes for thermal safety but are not intended to be the most economical if energy losses throughout the life of the power cable are taken into consideration for overhead lines for long distance transmission cable, which deliver energy from step up/ step-down substation to the user.

Electricity distribution companies (e.g. BEDC, EEDC, DEDC e.t.c) try to limit energy losses in overhead transmission and distribution lines to its lowest minnimum. This suggests that there is still room to improve its efficiency and reduce losses on our network.

Figure 7: Twin line 330kv runing from National Grid/ Delta 1

5.1 REQUIREMENT FOR A GOOD CABLE.

The underground system employs insulated cables which may be single, double or triple-core etc. A good distribution system whether overhead or underground should fulfill the following requirements;

a) The voltage at the consumer's premises must be maintained within +4% or +6% of the declared voltage, the actual voltage depending on the type of load at distribution.

b) The loss of power in the system itself should be small percentage (about 10%) of the power transmitted (voltage drop).

c) The transmission cost should not be unduly excessive.

d) The maximum current passing through the conductor should be limited to such a value as not to over-heat the conductor or injure its insulation.

e) The insulation resistance of the whole system should be very high so that there is no unduly leakage or danger to human life.

5.2 IEE REGULATIONS ON POWER CABLES.

Recommended procedures for choice of cable size are frequently followed without a full understanding of the implications. IEE regulation 19, now BS 7671 (equivalent to IEC 364 and European standard HD 384) can be used to ascertain the minimum permissible safe conductor size, these ensure that, when used at rated current flow, the cable does not over heat dangerously. For example a cable of 16mm^2 section can be rated at 109 amps and run at 90% but over a 100metre run would drop over 30volts and waste nearly 3.5kw energy. This would cost over =N5x3500w=N17, 500 if the electricity is bought at N5.00 per unit. (Oke and Bamigbola 2013)

CONCLUSION

From the above proceedings it can be observed that, majority of the losses or bulks of the losses are on the line and at a particular period of the year where losses are high due to corona effect as the wind which carried the rain blows. The loading in the various stations are fairly normal or in other words the transformer are not over loaded as such although over loading is not the only factor responsible for transformer losses.

We hope that with recent pronouncement of government on steps to curb vandalization and effect processes to replace overloaded transformers, reinforce the lines and expands network and have a good maintenance culture in terms of replacing all improvised and weak conductors, transmission lines will be given urgent attention in the cost of power losses along this line at an alarming rate, if time is taken to quantify the value the effort required to forecast the most economical size of conductor is small in comparison with that which has to be made to select a conductor size to comply with the requirements of the IEE Wiring Regulations. On the other hand the reduction in electricity bills, because of the reduction in wasted energy, incurred over the whole life of the project can be quite significant. The practice of using increased conductor sizes to provide a good standard of voltage regulation at equipment terminals, thereby contributing towards the efficient performance of equipment, is synonymous with economical conductor selection and reduced running costs. Conversely, to risk inferior

Performance from equipment by using the smallest permissible size of

Cable is wasteful and leads to unnecessarily high running costs.

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