

## Modelling Of Underground Cables for High Voltage Transmission

<sup>1</sup>, Omorogiuwa Eseosa , <sup>2</sup>, Obi Patrick. I

<sup>1</sup>, Department of Electrical/Electronic Engineering College of Engineering, University of Port Harcourt

<sup>2</sup>, Department of Electrical/Electronic Engineering Anambra State University, .Anambra

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### ABSTRACT

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*The high failure rates and economic implications of regularly maintaining Overhead lines has necessitated the need for using Underground Cable system. This paper covers the current carrying capacity of underground cables under three states namely, the steady, transient and short circuit states. Also covered is the reactive power generated in underground cables during operation.*

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### I INTRODUCTION

A Micro-hydro means a plant of small power, having about 100 kW. The Micro-hydro power plants represent lately, one of the ways out to clean energy generation, due to the following advantages: Require water sources of low flow and fall; Don't need big investments; Are environment friendly from the equipment point of view; Are very useful for isolated areas; Can autonomously function; Can be easily used by anybody. In this work, the design of a micro-hydro power plant with robust governor for improve system performance is considered. All over Nigeria, there are many rivers both large and small (hydropower potential sites) and around some of them little communities with no electricity because they are too isolated to be connected to the electricity grid (network). Nigeria has not being able to exploit her small rivers hydropower potential site because of the none availability of suitable hydro plant capable of utilizing low water head and flow from small rivers to generate power (Prof. O.O. Adewoye 2009), but has only partially succeeded in exploiting her large rivers hydropower potential sites, by building large scale hydroelectric power plant (e.g. Kainji hydropower plant, Jebba hydropower plant, Shiroro hydropower plant) to generate huge amounts of power from water stored behind massive dams. According to the international energy agency (IEA), large-scale hydroelectric plants currently supply 29% of Nigeria electricity supply. However, such kind of projects requires tremendous amounts of land for impoundment, relocation of people from the land and flood-control, and often they produce many environmental impacts despite their emission-free electricity production. One main problem of hydropower electricity is to keep the constant frequency value (the constant speed value) because these plants are affected by change in the regime of river. In a power system operation such as hydro electricity plants, system frequency varies depending on the difference between demand, therefore generated power load-frequency control is very important for supplying efficiently electrical power of good quality, as the consumers want continuous, stable, quality and reliable power at rated frequency and voltage. For a power system to be term reliable, constant frequency value must be provided against the varying load value. Hence this project aims to design a reliable hydroelectric power plant that is devoid of the problem associated with large scale hydro plant, and capable of utilizing the smaller rivers in Nigeria to generate electricity.

### II DESIGN OBJECTIVE

To design an hydroelectric power plant that does not require:-

- A large water reservoir or Dam
- Relocation of people from there land and need for flood control
- Connection to the power grid to supply electricity, (hence it can serve remotely located community.)
- To design an hydroelectric power plant capable of utilizing low water head and flow from small rivers to generate power
- To design an hydroelectric power plant capable of providing constant frequency value against the varying load value.

This design will help in providing guide for the construction of suitable hydroelectric plant capable of utilizing low water head and flow from small rivers to generate power, hence enabling the country to start exploiting her small hydro potential sites. The construction of hydroelectric power plant in the country that is truly

environment friendly is achieved via better power load-frequency control on hydroelectric power plant in the country and beyond.

### **III DESIGN METHODOLOGY:**

In this work, micro-hydro power plant, consisting of five elements: **water tank and valve, supply pipe, chain type hydro turbine, generator and controller** is considered. The work presents a systemic approach on Micro-hydro plant, starting with the achievement of block diagram with one control closed loops. Discussion /analysis, as well as modeling and simulation of the electro mechanical part (hydro turbine, generator) was considered. The results of this work prove the correctness of this design that could be used in practical applications. The design is limited to hydro electric power plant for use in run-of-river' scheme and only the electro-mechanical components of the plant (i.e. the turbine-generator) and the Controller (i.e. the governor)

### **IV LITERATURE REVIEW**

Hydropower is a renewable, non-polluting and environmentally benign source of energy. Hydropower is based on simple concepts. Moving water turns a turbine, the turbine spins a generator, and electricity is produced. Many other components may be in a system, but it all begins with the energy in the moving water. The use of water falling through a height has been utilized as a source of energy since a long time. (**Dilip Singh 2009**) It is perhaps the oldest renewable energy technique known to the mankind for mechanical energy conversion as well as electricity generation. In the ancient times waterwheels were used extensively, but it was only at the beginning of the 19th Century with the invention of the hydro turbines that the use of hydropower got popularized. Hydropower was the most common way of electricity generating in the early 20th century.

The first commercial use of hydroelectric power to produce electricity was a waterwheel on the Fox River in Wisconsin in 1882 that supplied power for lighting to two paper mills and a house. Within a matter of weeks of this installation, a power plant was also put into commercial service at Minneapolis. India has a century old history of hydropower and the beginning was from small hydro. The first hydro power plant was of 130 kW set up in Darjeeling during 1897, marked the development of hydropower in the country. Similarly, by 1924 Switzerland had nearly 7000 hydropower stations in use. Even today, Small hydro is the largest contributor of electricity from renewable energy sources, both at European and world level. With the advancement of technology, and increasing requirement of electricity, the thrust of electricity generation was shifted to large size hydro and thermal power stations. However, it is only during the last two decades that there is a renewed interest in the development of hydro power projects mainly due to its benefits particularly concerning environment and ability to produce power in remote areas. Small hydro projects are economically viable and have relatively short gestation period. The major constraints associated with large hydro projects are usually not encountered in small hydro projects. Renewed interest in the technology of small scale hydropower actually started in China which has more than 85,000 electricity producing, hydropower plants. Hydropower will continue to play important role throughout the 21st Century, in world electricity supply. Hydropower development does have some challenges besides the technical, economic and environmental advantages it shares above other power generation (fossil fuel based) technologies. At the beginning of the new Millennium hydropower provided almost 20% (2600 TWh/year) of the electricity world consumption (12900 TWh/year). It plays a major role in several countries. According to a study of hydropower resources in 175 countries, more than 150 have hydropower resources. For 65 of them, hydro produces more than 50% of electricity; for 24, more than 90% and 10 countries have almost all their electricity requirements met through hydropower. Hydroelectricity is the term referring to electricity generated by hydropower; the production of electrical power through the use of the gravitational force of falling or flowing water. It is the most widely used form of renewable energy. (**Wikipedia.com, 2011**)

Hydropower is energy from water sources such as the ocean, rivers and waterfalls. Water from the reservoir flows due to gravity to drive the turbine connected to a generator. Power generated is transmitted over power lines. Water turbine considered the energy of flowing or falling water into mechanical energy and drives a generator, which generates electrical power. A control mechanism to provide stable electrical power known as the governor delivers the power (**Bhatti, T.S., Bansal, R.C. and Kothari, D.P 2004**).

Hydropower converts the energy in flowing water into electricity. The quantity of electricity generated is determined by the volume of water flow and the height of "head" (the height from turbines in the power plant to the water surface) created by the dam. The greater the flow and head, the more electricity produced. A typical hydropower plant includes a dam, reservoir, penstocks (pipes), a powerhouse and an electrical power substation. The dam stores water and creates the head; penstocks carry water from the reservoir to turbines inside the

powerhouse; the water rotates the turbines, which drive generators that produce electricity (**Working Group on Prime Movers 1992**).

• **TYPES OF HYDRO POWER PLANT AND CLASSIFICATIONS**

(**Venkateswaran R. 2003**) Hydropower is classified as follow:

- Upto 100KW – Micro Hydro Power
- 101Kw to 2000Kw – Mini Hydro Power
- 2001Kw to 25000Kw – Small Hydro Power

**Classifications Based on Head**

- Ultra Low Head – Below 3 meters
- Low Head – Less than 40 meters
- Medium/High Head – Above 40 meter

(**Dilip Singh 2009**) Though different countries have different criteria to classify hydro power plants, a general classification of hydro power plants is as follows:

**Current Carrying Capacity Of Cables:** Ampacity in an underground cable system is the capacity of the installation to extract heat from the cable and dissipate it in the surrounding soil and environment. The maximum operating temperature of cables is a function of the damage the insulation can suffer as a result of high operating temperatures. There are three standardized ampacity ratings namely: steady state, transient (or emergency) state, and short circuit state. In computing the ampacity of cables, both numerical and analytical methods are used. The numerical approach is mainly based on finite differences of finite elements technique. The finite elements technique is better suited for cable Ampacity because of the round geometry of the cables. The two major international standards organizations, the IEEE and the IEC both adopt the analytical method as the basis for their standards. In an underground cable system, the main heat transfer mechanism is by conduction with the exception of the air in the conduit in the duct banks or buried duct installations. The different Ampacity ratings conditions are considered in the cause of the research.

• **STEADY STATE AMPACITY RATINGS**

The flow of current is usually accompanied by the production of heat. The heat sources in cable installations can be divided into two generic groups. They are the heat generated in conductors and the heat generated in insulators. The losses in the conductor element are by far the most significant losses and are caused by :a) Joule losses due to impressed current, circulating current or induced (eddy current) losses.b) Hysteresis losses in conductors which are also magnetic. The metallic components of an underground cable that produce heat are the core conductors, sheaths, concentric neutrals, Armours, Skid wires and pipes or ducts. The losses in these components are functions of the frequency f, and the temperature of operation and it is proportional to the square of the applied current. This dependence on frequency and temperature is included in an equivalent AC resistance to express Joule's law as

$$W = R_{ac}(f, t) I^2 \tag{1}$$

Where W represents heat loss through conductor,  $R_{ac}$  is the equivalent AC resistance ( $\Omega$ ), f is frequency (Hz), t is the time in seconds, I represents the current in amperes. Heat is also produced in the insulating material. This heat produced in the insulating layer is only important under certain high voltage conditions. The loss relationship is given by  $W_d = G_d V^2 = \epsilon C V^2 \tan(\delta)$  Where  $W_d$  represents heat loss through the insulation,  $G_d$  represents geometrical factor of dielectric used. C is the capacitance, V represents voltage applied,  $\epsilon \tan \delta$  is loss angle. The ampacity calculations under steady state condition is computed using the Neher-McGrath. This is based on a thermal – electrical analogy method due to Pashkis and baker (1942). The basic idea is to subdivide the study area into layers. Then one substitutes the heat sources for current sources, the thermal resistances for electrical resistances and thermal capacitance for electrical capacitance. It is worthy of note that capacitance has no part in steady state analysis between layers. Thus, the potential difference between the terminals of the circuits and the innermost current source represents the temperature rise of the core of the cable with respect to the ambient temperature. Therefore, the temperature of the cable's core is the ambient

temperature plus change in temperature. These details are represented below:

$$\theta_c - \theta_a = W_c(T_1 + T_2 + T_3) + W_d (\frac{1}{2} T_1 + T_3 + T_4) + W_s (T_3 + T_4) \tag{2}$$

$$\Delta \theta_c = W_c (T_1 + (1 + \epsilon) (T_3 + T_4)) + W_d (\frac{1}{2} T_1 + T_3 + T_4) \tag{3}$$

where  $\theta_c$  represents the Maximum operating Temperature  $^{\circ}K$

$\theta_a$  represents the Ambient temperature  $^{\circ}K$

$W_c$  represents the heat loss of conductor ( $I^2 R_{ac}$ )

$W_d$  represents the Dielectric losses W/m

$W_s$  represents the Sheath loss W/m

$T_1, T_3$  and  $T_4$  represents the thermal resistances of Insulation, Sheath and Oil ( $^{\circ}K m/W$ ) respectively

In order to derive an expression from which the Ampacity can be computed directly, the heat sources (electrical losses)  $W_s$  are expressed as a proportion of the conductor losses ( $W_c$ ). The conductor losses are computed using the ac resistance and the current. By substituting the following expressions, we have:  $W_s = \lambda_1 W_c$ ,  $W_c = R_{ac} I^2$ . Where  $\lambda_1$  is Sheath loss factor

For the purpose of simplicity

Let  $X = (T_1 + (1 + \lambda_1)(T_3 + T_4))$ ;  $Y = (\frac{1}{2} T_1 + T_3 + T_4)$ ,

$$W = W_d, R_{ac} = R_{ac} I = \sqrt{\frac{[\Delta\theta - WY]}{RX}} \quad (4)$$

From equation (4), we can compute the ampacity of an underground cable under steady state condition. Of paramount importance for cable rating is the accurate calculation of the thermal resistance  $T$ , the loss factor  $\lambda_1$  and the AC resistance  $R_{ac}$  of the cable core. The loss factors  $\lambda_1$  takes into account the eddy losses induced and the circulating currents, while  $R_{ac}$  considers the temperature dependency of the resistances.

### • CALCULATION OF THERMAL RESISTANCES

The Thermal Resistivity of the Insulation, the protective covering and the surrounding soil (serving and bedding) must be calculated accurately:

**Cable Insulation:** A careful look at the cross section of the cable, the internal layers have tubular geometries. Therefore the thermal resistance of the insulation  $T_1$  is given as

$$T_1 = \frac{g_1}{2\pi} \ln \left[ \frac{R_1}{r} \right] \pi \quad (5)$$

Where  $T_1$  = Thermal Resistance of the Insulation,  $g_1$  = Thermal resistivity of the Insulation = Radius of Sheath;  $r$  = Radius of conductor. For a multi core cable, the calculation of the thermal resistance is quite difficult due to its complex thermal field.

**b) Protective Covering:** The protective covering is also cylindrical in shape. It therefore follows that the thermal resistance will be similar to that of the insulation. The armour thickness is generally very small and can be neglected. Thus the thermal resistance of the protective covering is given as:

$$T_{(2,3)} = \frac{g_2}{2\pi} \ln \left[ \frac{R_1}{R_2} \right] \quad (6)$$

Where  $T_{(2,3)}$  = thermal Resistance of the protective covering,  $g_2$  = Thermal resistivity of the bedding and serving,  $R_1$  = Radius over the Sheath,  $R_2$  = external radius of the cable,

**c) Surrounding Soil:** The heat conducted through the cable is passed into the soil. For an underground cable with external radius  $R$ , buried a distance  $h$  metres below the ground surface in a soil of constant thermal resistivity  $T_4$  in  $^{\circ}C/watt$ . The thermal resistance of Soil is  $T_4$  and is given by

$$T_4 = \frac{g_3}{2\pi} \ln \left[ \frac{2h}{R_2} \right] \quad (7)$$

Where  $T_4$  = Thermal Resistance of the surrounding soil  $g_3$  = Thermal resistivity of soil in  $^{\circ}C/watt$ ,  $h$  = depth of cable in the ground,  $R_2$  = external radius of the cable. From the above equation, it is evident that the depth of laying of cable affects the Ampacity of an electric cable. Deeper laying means an increased thermal resistance of the soil (to the surface) hence the cable is de-rated.

### • CALCULATION OF LOSS FACTOR

Loss factor in equations 6 and 7 relates the losses that metallic layer such as Sheath, armour etc produce in proportion to the Cable core. These losses are due to induced (eddy's) current and circulating currents. The geometrical arrangements are diverse and some are quite complicated. The bonding used for the Sheaths plays a vital role in the current intensity that circulates in them. Thus the losses are very much dependent on the bonding type and the geometrical arrangement of the cables (flat or triangular). A cable has a capacitance between the core and the sheath. When a voltage is applied to an unloaded cable, a capacitive current (or charging current) flows. Since the resistivity of the insulation is not infinite, leakage current flows and a power loss occurs. With ac voltages, the phenomenon of dielectric absorption also contributes to the power loss. Thus, a cable acts as an imperfect capacitor and the total current, under loaded conditions, leads the voltage by an angle of  $(90 - \delta)$ . The angle  $\delta$  is termed the loss angle of the dielectric. The dielectric loss  $P_d$  is

$$P_d = VI \cos \phi = VI \sin \delta = \omega CV^2 \sin \delta$$

Where  $C$  = capacitance  $V$  = line to neutral voltage,  $\omega$  = angular velocity, frequency =  $2\pi f = 100\pi$

### • A.C RESISTANCE



The values of I is computed for various values of  $\theta$  using Matlab and the graph plotted. The output of the graph is shown in figure 1.0:

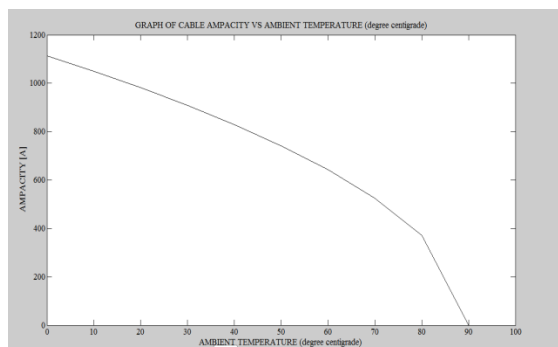


Fig1.0 Cable Ampacity vs Ambient Temperature for XLPE with aluminium conductor

**XLPE insulated cable with copper conductor:** For copper conductor, the relationship between the ampacity and the ambient temperature and its plot is shown in figure 2.0:

$$I = \sqrt{\frac{(90-\theta) - 0.0107}{0.000043788}}$$

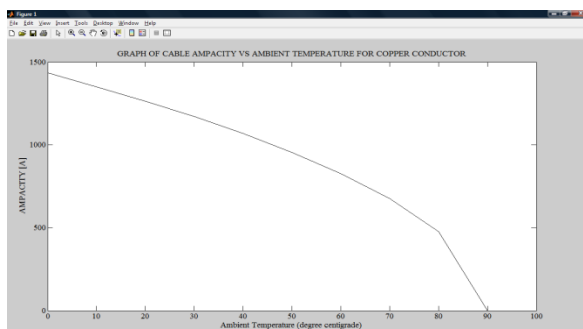
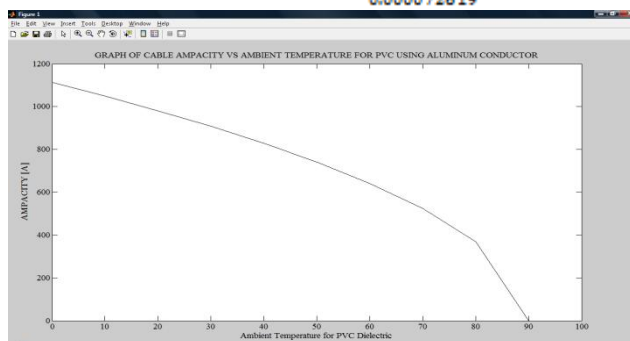


Fig 2.0 Graph of Ampacity vs Ambient temperature for XLPE insulated copper conductor cable

**For Polyvinyl Chloride Insulator: For Aluminium Conductor :** The relationship between the Ampacity and the Ambient temperature and its graph is shown below:

$$I = \sqrt{\frac{(90-\theta) - 0.0802}{0.000072619}}$$



Graph of Ampacity vs Ambient temperature for PVC with Aluminium conductor

**Copper conductor with PVC insulation:** The relationship and the graph are shown in figure 3.0

$$I = \sqrt{\frac{(90-\theta) - 0.0802}{0.000072619}}$$

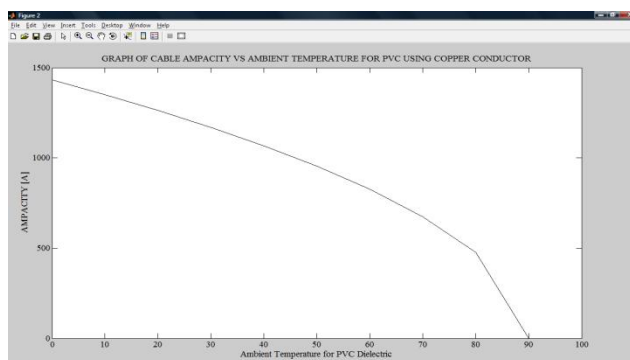


Fig 3.0 Graph of ampacity vs ambient temperature for PVC insulation with copper conductor

**Oil Impregnated Paper dielectric:** The relationship between the ampacity and ambient temperature for each of the two different types of conductor using paper dielectric is shown in figure 4.0

**Aluminium Conductor:** The relationship and the graph is shown below:

$$I = \sqrt{\frac{(90-\theta) - 0.0201}{0.000072619}}$$

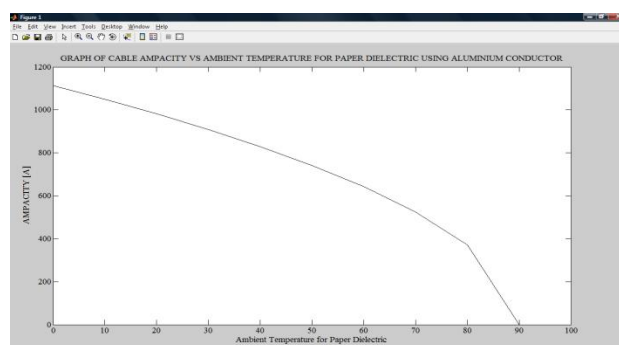


Fig 4.0 Graph of ampacity vs Ambient Temperature for Paper Dielectric using aluminium

**Copper Conductor:** The relationship and the graph for a paper insulated cable for ampacity against ambient temperature is shown in figure 5.0

$$I = \sqrt{\frac{(90-\theta) - 0.0201}{0.000072619}}$$

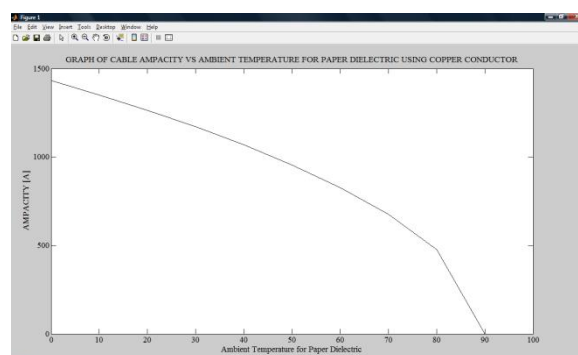


Fig 5.0 Graph of ampacity vs ambient temperature for paper insulated copper conductor cable

**Conductor Temperature :** As shown from the Ampacity calculations, the relationship between the Ampacity rating of underground cables and the Conductor temperature for Aluminium and Copper Conductors respectively are;

**Aluminium:**

$$I = \sqrt{\frac{(\theta - 20) - 0.0107}{0.000072619}}$$

where  $\theta$  = Conductor Temperature  
The values of I is plotted for various values of  $\theta$  and the graph showing this relationship is shown in figure 6.0

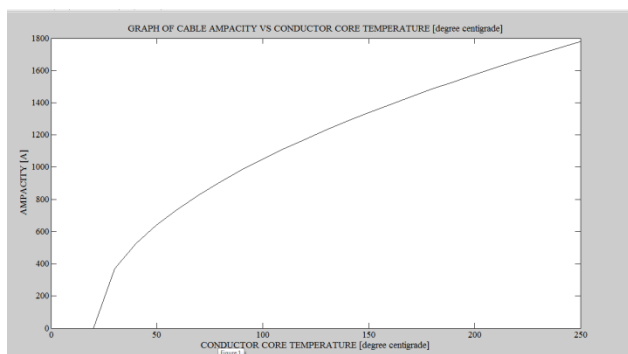


Fig 6.0 Graph of Cable Ampacity vs Core temperature with Aluminium conductor  
**For Copper Conductor:** The relationship and its graph is shown in figure 7.0

$$I = \sqrt{\frac{(t-20) - 0.0107}{0.000072619}}$$

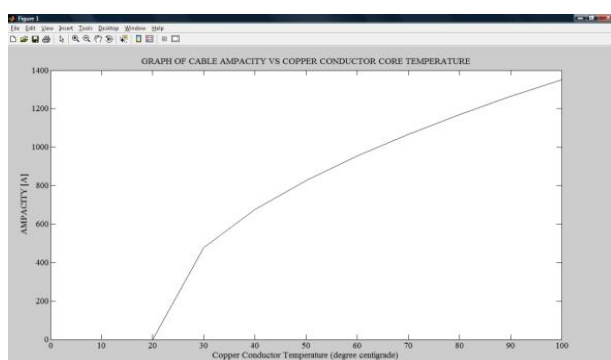


Fig 7.0 Graph of Ampacity vs copper conductor core temperature

**For Dielectric loss:** The effect of dielectric losses on Ampacity is studied for XLPE insulation with each of the two conductors i.e. aluminium and copper conductors. The relationship and the plot of Ampacity vs dielectric loss for each of the different dielectric is shown in figure 8.0 and 9.0 respectively

**FOR ALUMINIUM CONDUCTOR:**

$$I = \sqrt{\frac{70 - 4.4737X}{0.000072619}}$$

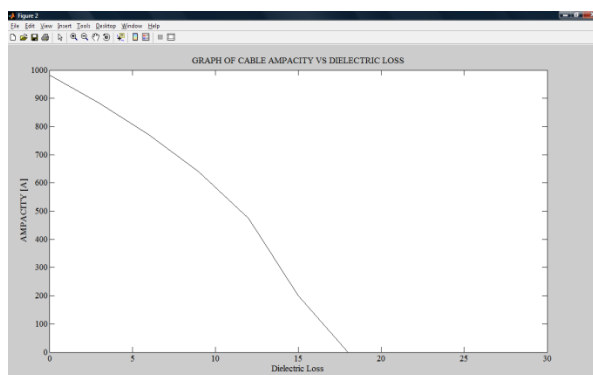


Fig 8.0 Graph of Ampacity vs Dielectric loss for Aluminium Conductor

**Copper Conductor:** The relationship and the graph of Ampacity vs. dielectric loss for a copper conductor XLPE insulated cable is shown below:

$$I = \sqrt{\frac{70 - 4.4737X}{0.000043788}}$$



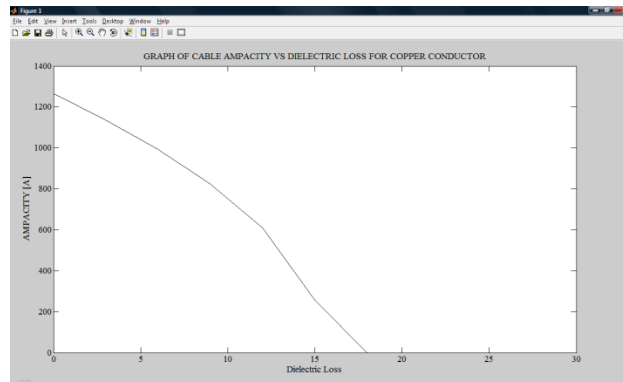


Fig 9.0 Graph of Ampacity vs Dielectric loss for copper conductor, XLPE insulated cable

- TRANSIENT STATE :** The insulators are weakened as a result of over voltage surges in transmission lines. This is majorly noticed when XLPE insulated cables are used for underground cabling. This eventually results in cable failure. However, in ensuring that this failure does not happen, the insulator breakdown as a result of temperature rise should therefore be computed in order to determine the over-voltage ratings of such cables. The rise in core temperature and time duration of over-current should be known to calculate the over-current rating and it depends on their thermal conditions.
- SHORT CIRCUIT RATING :** According to Jean-Pierre in Nexans publication (2004), Short circuit current in an electrical network are as a result of the accidental connection of one or more phase conductors, either together, or with the ground. There are two types of short circuit currents namely: **Symmetrical Short Circuits (3 phase short circuits)** where the currents in the three phases form a balanced system. These currents therefore only circulate in the conductor (cores) of the cable. **Zero Sequence Short Circuits** result from an unsymmetrical i.e. unbalanced current system. Zero sequence currents return via the ground and/ or by the conductors that are electrically parallel to the ground. These conductors are mainly ground conductors, metallic screens connected to the ground at the line termination or ground itself. Under short circuit conditions, the current flowing in the cable is many times the full load value of the current. Heat produced in the conductor is proportional to the square of the current. The safe value of limiting temperature is usually taken as 120°C. For a maximum continuous operating conductor temperature of 50°C and a permissible temperature rise of 20°C during Short Circuit, the approximate formula may be given as  $I_{SC} = \frac{KA}{\sqrt{t}}$  Where  $I_{SC}$  = Short Circuit rms value of the current, A = Cross-sectional Area of the conductor, t = Duration of Short Circuit (seconds), K = A constant (The value of the constant depends on the rise of temperature). If the amount of heat generated in a cable is equal to that dissipated, a thermal equilibrium is reached. For satisfactory operation of the cable, the operating temperature should be lesser than the permissible maximum temperature. In case the amount of heat generated is more than the dissipated, the cable temperature goes on rising till a

**thermal breakdown** occurs when the insulation is damaged. Thus there's a need for protection of underground cables against Transient Over-Voltages and Short Circuit current.

#### • EFFECTS OF SHORT-CIRCUIT CURRENTS ON EQUIPMENT

**Thermal effects :** Short-circuit currents flowing through conductors of various power system equipment create thermal effects due to heating and excess energy input over time as measured by  $I^2 T$ . Where  $I$  is short-circuit current magnitude and  $T$ , short-circuit current duration. The heat loss from conductors during is also very low. Generally, both ac and dc components of short-circuit current contribute to thermal heating of conductors.. During the making of high short-circuit currents by inadequately rated circuit-breakers, their contacts may weld together encouraged by a pre striking flashover arc and possibly contact popping.

- Mechanical Effects :** Short-circuit currents flowing through conductors of various power system equipment create electromagnetic forces and mechanical stresses on underground cables. The electromagnetic forces produced by short-circuit currents in three-core unarmored cables tend to repel the cores from each other and could burst the cable altogether leading to insulation damage if the cores are not adequately bound.

• **POWER GENERATED IN AN UNDERGROUND CABLE**

Reactive power is a concept used to describe the background energy movement arising in Alternating Current (AC) system due to production of electric and magnetic fields. These fields store energy which changes through each AC cycle. Reactive power flows can give rise to substantial voltage changes across the system thus it is necessary to maintain reactive power balances between the sources of generation and the point of demand on zonal basis. Underground cables, when operating at normal system voltage produce strong electric field and so generate reactive power. When current flows through a cable, it produces magnetic fields which absorb reactive power. The reactive power generated by electric field in underground cables is always greater than the reactive power absorbed by the magnetic field. Thus, the underground cable is a net generator of reactive power. Since the single core cable has an earthed metallic sheath, there is an electric field between the conductor core and the sheath. Let the charge on the surface of the conductor be  $q$  coulomb per metre length of cable. The electric flux density  $D_x$  at a radius  $x$  is

$$D_x = \frac{q}{2\pi x} \text{ C/m}^2 \tag{12}$$

The electric field intensity  $E_x$  at a radius  $x$  is  $E_x = D_x / \epsilon_r \epsilon_0 = q / 2\pi \epsilon_r \epsilon_0 x \text{ V/m}$  13.

Where  $\epsilon_r$  is the relative permittivity (dielectric constant) of the cable insulation and  $\epsilon_0 = 8.85 \times 10^{-12} \text{ F/m}$ . The potential difference between the core and the sheath is

$$V = \int_r^R E_x dx = (q / 2\pi \epsilon_r \epsilon_0) (\ln \frac{R}{r}) \text{ volts} \tag{14}$$

Capacitance between the conductor core and sheath is

$$C = \frac{q}{V} = (2\pi \epsilon_r \epsilon_0 / \ln \frac{R}{r}) \text{ F/m} \tag{15}$$

An underground cable has high capacitance which results in charging current and reactive power. If  $V$  is the line to line voltage, the charging current  $I_c$  is

$$I_c = 2\pi f CV / \sqrt{3} \tag{16}$$

This therefore implies that the 3-phase reactive power is  $\sqrt{3} VI_c$ . Applying equation 16

$$\begin{aligned} \text{Reactive power} &= \sqrt{3} VI_c = \sqrt{3} V (2\pi f CV / \sqrt{3}) [2\pi \epsilon_r \epsilon_0 / \ln \frac{R}{r}] \\ &= 4\pi^2 f V^2 \epsilon_r \epsilon_0 / [\ln (R/r)] \text{ vars/m} \end{aligned} \tag{17}$$

The flow of charging current causes heating of the cable. Therefore, the load current capability of the underground cable is decreased (i.e. derating occurs) if the temperature rise is not exceeded.

**VI RESULTS OF RESEARCH**

The Steady state Ampacity rating of an underground cable is derived and it is given as:  $I = \sqrt{\frac{\Delta T - T_c}{\theta}}$  Where

$$X = (T_1 + (1 + \theta_c \theta_a) (T_3 + T_4)) \quad Y = (1/2 T_1 + T_3 + T_4) \quad W = W_d, R = R_{ac}, \Delta T = T_c - T_a,$$

$T_c$  = Conductor temperature  $T_a$  = Ambient temperature. Due to the economic implications of underground cable failures, it is important to study the different parameters that directly or indirectly affect the Ampacity rating of an Underground Cable. The following results have therefore been deduced:

**Ambient Temperature:** The research shows that the ambient temperature is inversely proportional to the Ampacity rating of an Underground Cable in the steady state irrespective of the type of conductor (whether copper or Aluminium used). For all the graphs plotted, it is clear that irrespective of the type of insulation, the Ampacity of a copper conductor is always higher than that of an Aluminium conductor.

**Conductor Temperature:** The conductor core temperature is directly proportional to Ampacity of an underground cable. It can further be deduced that,

**Insulation Resistance.** The insulation resistance of a dielectric is inversely proportional to the Ampacity of an Underground Cable. This therefore means that the higher the Ampacity, the lesser the Insulation resistance.

**Cable Depth In Soil (for direct burial method):** The cable depth in soil is inversely proportional to the Ampacity rating of the Underground cable. The higher the depth value is, the lower the Ampacity of the cable.

**Transient State And Short Circuit State Condition:** In the event of a switching over-voltage (transient state) and a short circuit fault (short circuit condition) the insulator must be able to withstand the rapid temperature rise accompanied by these occurrences without the insulator degrading so as to eliminate that cause of underground cable failure

The reactive power generated in underground cables is accompanied by the flow of charging current which causes heating of the underground cable. The insulator should be able to withstand the amount of heat produced without degrading so as not to result in failure of the Underground Cable.

## VII CONCLUSION

The study of the behaviour of underground cables in the steady, transient and short circuit states gave so much insights into the behaviour of underground cables under these conditions. The knowledge of the main cause of Underground cable failure which is the failure of the dielectric or the insulating material due to excessive heating of the cable was covered. In order to reduce failure rates of underground cables, the design and construction of cables should be such that it operates within acceptable temperature limits during each of the steady, transient and short circuit conditions. Also the effect of the environment (which includes the surrounding soil where the cable is to be laid ). All the various aspects of this research should therefore be considered during the design of cables in order to get the desired output.

**VIII RECOMMENDATION:** Although the cost of installation of underground cable system is very high compared to the equivalent cost of installing an overhead transmission line system, the underground cable has a far higher reliability than the overhead line. The underground cable system also has a lesser failure rates and outages compared to the overhead line system. With the ever growing Nigerian population and the recent intention of the federal government of Nigeria to increase the primary transmission voltage from 330kV to 750 kV, the use of Underground cables for the transmission of this 750 kV will be a good and economical option. The use of 750kV in overhead line will pose too much risk to lives and properties as they are exposed to increased radiation. Most importantly, they are also at serious risk of electrocution if the air between the overhead line and the ground is ionized as a result of the extremely high voltage. Alternatively, with the Underground cable system, the failure rates are highly reduced thus far lower outages, they last longer than overhead transmission lines, underground cables can be passed through residential areas without posing any risk to the people and animals living in that area

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