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Subsoil Temperature and Underground Cable Distribution in Port Harcourt City

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Abstract: The present overhead network for Port-Harcourt city does no only present a shabby appearance and unreliable distribution system but unfit for the present demand in terms of bulk power transfer and telecommunication interference. Underground distribution network is primarily a matter of heat transfer from cable core where the heat is generated, through the cable insulation to the surrounding medium and finally is discharged from the surrounding medium. This study therefore presents the subsoil temperature at various periods of the year and at depth of 20, 50, 80 and 100 cm. Ten locations were chosen in Port Harcourt City, and in each location the soil temperature was taken at the given depths within the months of March, September and November. These months represent different seasons of the year. The effective discharge of heat to the surrounding environment is due to the condition of the soil (moisture content, grain size etc.,). Therefore, soil resistivity test was also conducted. These results were analysed and the variation of temperature within the year at various depths were known. This will enable designers to calculate proper rating of underground cable laid at different depths.

Key words: Dielectric losses, effective resistance, heat flow, isothermal lines, soil temperature, thermal resistance

INTRODUCTION

Port Harcourt city, due to its strategic position in land and sea has become one of the fastest growing cities in Nigeria and the most industrialized in the southern part of the country. Due to this advantaged position, this urban city is becoming congested and expanding rapidly, therefore public safety is necessary in terms of power distribution. Recently, there were cases of death reported as a result of falling high tension lines on public areas. It is therefore necessary to take advantages of the merits of underground system distribution in Port Harcourt City.

The ambient temperature of Port Harcourt City is 27ºC during the rainy season and 37ºC during the dry and harmanttan seasons. Due to global warming the temperature is becoming higher. The ground temperature is even higher than the ambient temperature due to the heat absorbed and therefore requires the knowledge of soil temperature for reliable underground system distribution. The various thermal conductivities of the media must be ascertained, if it is laid directly on the soil, the soil conditions must be favourable for heat transfer (Pabla, 2006; Gupta, 2007). Therefore the study was necessary to enable designers and planners to have the working data for underground cable distribution in Port Harcourt City.

Within the cable three sources of heat was identified, the Copper losses (I^2R), Dielectric losses, losses in sheath and armoring.

The I^2R losses are copper losses or resistance losses in the conductor. The ambient temperature (Gupta, 2007; Chard and de la, 1976) given in standard tables is about 20ºC. If a cable is operated at 70ºC (assumed), there will be a temperature rise. The final resistance could be found from the relationship as follows:

$$R_E = R_0 (1 + \alpha t) = R_o (1 + 0.004 \times 50) = 1.2 R_o$$

Where α is the co-efficient of expansion, t is the temperature difference and R_o is the resistance at 20ºC.

The energy losses occurring in the dielectric of cables are due to leakage and dielectric hysteresis. The former loss is due to passing of current by conduction through the resistance of dielectric and is independent of the supply frequency and therefore occurs with dc and a.c voltages.

The leakage current is proportional to the applied voltage and therefore the loss is proportional to the square of the applied voltage. With alternating voltage, there is a further loss of energy usually known as hysteresis loss and this loss under operating condition is usually very much higher than the leakage loss (Thapar *et al*., 1985). Apparently, part of the energy is consumed in reversing the stresses in the solid dielectric and this appears as heat. At normal operating stresses the dielectric stresses is proportional to the square of the electrostatic stresses, that is, to the square of the applied voltage.

The dielectric loss is VI Cosθ, which is VI sinδ, therefore dielectric loss per phase is:

$$V^2WC\delta \text{ Watts}$$

Since δ is very small

This shows that dielectric loss is proportional to the square of the voltage and therefore dielectric loss is much more pronounced in higher voltage consideration (Geri, 1999; Chard and de la, 1976).

The approximate formula for eddy loss for unbounded cables is given by Gupta (2007) as:

$$\text{Sheath loss} = = I^2\left[\frac{78\omega^2}{R_s}\left(\frac{r}{d}\right)^2 x10^{-7}\right] \text{ watts/phase} \quad (1)$$

Where I is the current per conductor, r is the mean radius of the sheath, d is the inter-axial spacing of conductors, R_s is the sheath resistant in ohms. If f = 50Hz, then $78\omega^2$ x 10^{-7} = 0.00977:

$$\text{Sheath loss} = \frac{0.00977^2}{R_S}\left(\frac{r}{d}\right)^2 \quad (2)$$

The actual current flowing along the sheath depends amongst other things on the magnitude and frequency of the current in the conductor, the arrangement and spacing of the cables, the sheath resistance and upon the conditions that the sheath is bounded or unbounded. In 3 core cables the effect is negligible while for single core cable it is of great importance.

The factors that determine the effective a.c resistance R_{ef} of each conductor of a cable are the d.c resistance (R_{dc}), skin effect, proximity effect, sheath losses and Amour losses (Araujo *et al*., 1979; Husok, 1981).

Thermal characteristics and current rating of cables: Determination of maximum current carrying capacity of cable is very necessary. The current carrying capacity of cable can be determined by the following factors:

- The Maximum permissible temperature at which the insulation surrounding the conductor can operate.
- The method of heat dissipation through the cable
- The insulation condition and the ambient temperature

The temperature of cable rises when the heat generated is greater than the heat dissipated. In conductor, heat is dissipated through the insulation, metal sheath, cable bedding and serving and finally to the ground if laid underground or into air. The thermal heat flow can be represented by Iso thermal lines as in Fig. 1.

Heat flow is analogous to the flow of electricity in a medium (cable)

- The current corresponds to Heat flow in watts.
- Potential difference corresponds to temperature difference in ºC
- The ohmic resistance corresponds to thermal resistance in thermal ohms

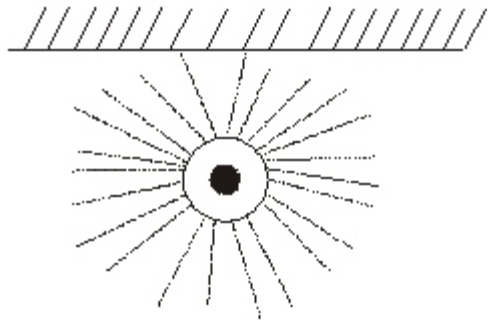

Fig. 1: Heat flow from the ground (Isothermal lines of heat flow)

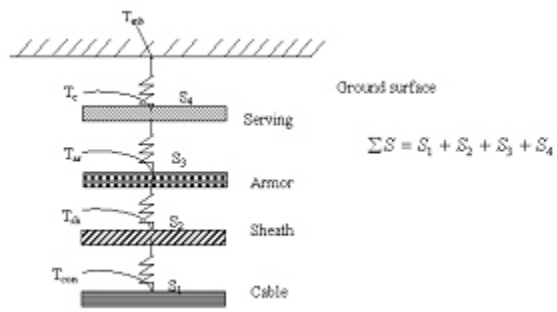

Fig. 2: Transfer and dissipation of heat

The thermal form of ohms law gives the amount of heat transferred across the layer whose opposite faces have a temperature difference:

$$\textit{Heat flow in watts} = \frac{\textit{Temperature Difference}}{\textit{Thermal resistance (thermal ohms)}}.$$

A thermal ohm is that thermal resistance which needs a temperature difference of 1ºC across it to cause a heat flow of 1 watt. Thus thermal ohms have a unit of ºC –m / watts. If the Heat flow is H and the temperature difference is ΔT and the total thermal resistance is $\sum S_t$:

$$\text{Heat flow H} = \frac{\Delta T}{\sum S_t} \quad (3)$$

Since H is heat generated by the current I flowing through n cores of resistance R_c, then H ∝ 1^2n R_c

That is , $\Delta T = I^2\, nR_g \sum S_t$

$$I = \sqrt{\frac{\Delta T}{nR_g \sum S_t}} \quad (4)$$

The thermal resistance of cable can be represented as shown in Fig. 2. Similar to electrical system, thermal resistance is directly proportional to length *l* in direction of transmission and is inversely proportional to the cross-sectional area A that is, $R_o = \frac{\rho_o l}{A}$.

The thermal resistance for a single core cable having core diameter d and inner diameter of sheath D is:

$$R = \frac{\rho_o}{2\pi} in\, D/d \qquad (5)$$

If the cable is 3core belted type, the thermal resistance will be approximately one- third of that of single core, but since the heat flow is no longer radial it is subject to a geometric factor G_m which depends on the geometry of the cable cross-section, thus:

$$R_3 = \frac{\rho_o}{6\pi}(G_m)$$

Simon (Gupta, 2007) suggested an empirical relationship based on his experimental work, which gives fairly accurate result as:

$$R_3 = \frac{\rho_o}{6\pi}\left(0.85 + \frac{0.2t}{T}\right)\log_e\left[1 + 2\left(\frac{T+t}{d}\right)\left(4.15 - \frac{1.1t}{T}\right)\right] \qquad (6)$$

Thermal Resistance of ground in which the cable is buried depends on the nature of soil, the depth of the soil, the salt and the water content of the soil. If the soil is considered homogeneous the thermal resistance of ground is taken as:

$$G_g = \frac{\rho_0}{2\pi}\log_e \frac{2l}{R} \text{ Thermal ohm-m/watts} \qquad (7)$$

Where, *l* is distance of ground surface to the cable laid underground. For cable installed in air, the thermal resistances of S_a is determined to be:

$$S_o = \frac{1}{\pi d(X_e + X_r)} \qquad (8)$$

where;
X_e = Heat transfer Co-efficient for convection W/cm ^{2o}C
Xr = Heat transfer Co-efficient for radiation W/cm ^{2o}C
d = Over all diameter of cable in cm.

When the thermal resistance of cable is known, it is possible to calculate the value of current I which will raise the conductor temperature to its maximum permissible value. This is the cable rating under the specified condition and under continuous loading or loading sufficient to prolong to enable steady thermal condition to be attained.

The power losses in n cores for each core having a resistance of R ohms per meter length is given by nI^2 R watts per meter length, where I is the current per core in ampere. If the sheath loss is times the conductor power losses. Neglecting armor losses, the total losses become $(1+\lambda)\, nI^2R$. If $S_p + S_g$ are thermal resistances of protective covering and ground (soil) respectively, while θ_a is the ambient temperature, then we have:

$$nI^2R.S_d + (1+\lambda)\ nI^2R\,(S_p + S_g) = \theta_m + \theta_a$$

$$I = \sqrt{\frac{\theta_m\ \theta_a}{nR\left[S_d + (1+\lambda)(S_p + S_g)\right]}} \text{ ampere} \qquad (9)$$

Where; S_d is thermal resistance of dielectric,

MATERIALS AND METHODS

The test was carried out in Port Harcourt city of Nigeria within the month of January 2009 to March 2010. Ten locations were chosen according to different activities in the area. These include industrial areas, government residential areas, and some public areas. In each location the temperature and the resistivity of the soil was measured at the depth of 20, 50, 80 and 100 cm. The purpose of the soil resistivity measurement was to determine the seasonal variation of the soil and the permanent moisture levels.

The Wenner technique was used for earth resistivity testing. This technique uses four equally spaced, short electrodes deployed in a single line. The outer electrode C_1 and C_2 are the current electrodes and the inner electrodes P_1 and P_2 were the potential electrodes. The four-point measurement (Wenner method) is shown in Fig. 3.

All electrodes are spaced at equal distances of 3 m and the measurements were taken at 20, 50, 80 and 100 cm. The ratio of the measured potential to the calculated current for a given spacing is given as apparent resistivity, that is, the resisitivity of the soil is proportional to V/I

The soil temperature was taken at the depth of 20, 50, 80 and 100 cm. These readings were taken during the months of March, September and November. The temperature and resistivity values were tabulated in Table 1.

$$\rho = 2\pi DR \text{ when } b << D$$

where;
ρ = Soil resistivity in ohm – m
D = Distance between two successive electrode
b = Dept of buried electrodes
R = The value of V/I in ohms

Table 1: Average values of temperature and resistivity

Depth cm	Resistivity			Temperature		
	March	Septh.	Nov.	March,	Septh.	Nov
20	611	100	402	45	29	41
50	397	79	220	42	28	39
80	209	58	100	36	27	32
100	104	40	55	28	23	26

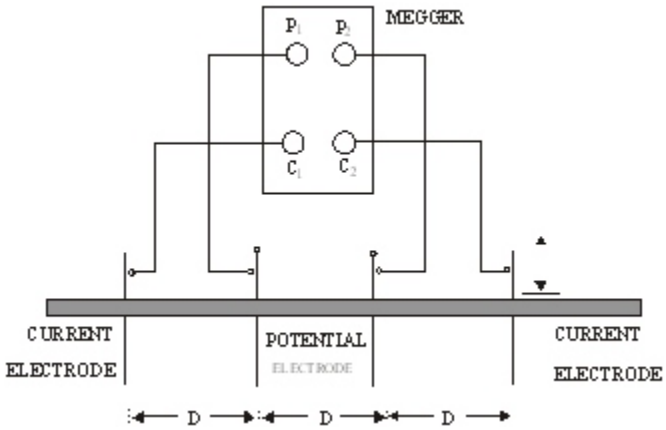

Fig. 3: Wenner method of soil resistivity measurement

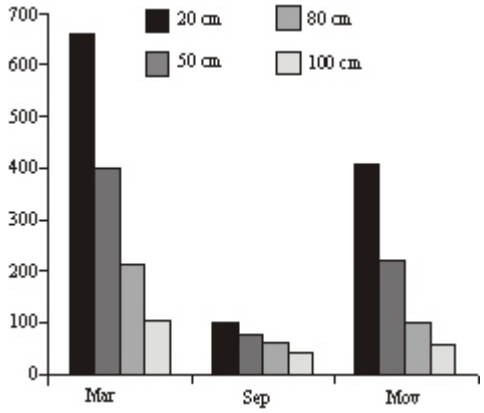

Fig. 4: Graph of resistivity values for various months

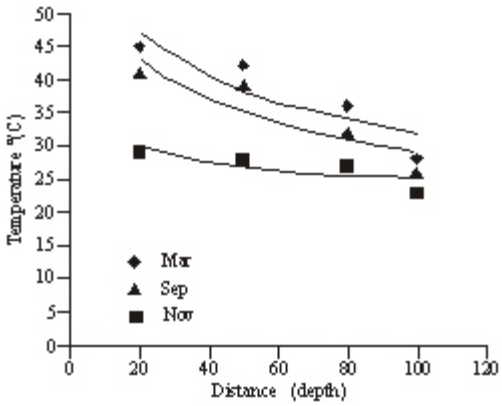

Fig. 5: Temperature variation with depth for the given months of the year

RESULTS AND DISCUSSION

The temperature variations and resistivity values taken at different sites for the same depth were in close range therefore the average resistivity and temperature were worked out for all the measured level and were used for analysis. The values are presented in Table 1.

The various temperature and resistivity values were represented graphically in Fig. 4 and 5, respectively.

From the reading, the temperature decreases as the depth increases. The effect of temperature was pronounced within the depths of 20 to 50 cm especially during the dry and harmathan seasons. The ambient temperature was about 32 to 35ºC but the constant heating of the ground, that is the air in the void trapped within the soil particles causes the heat to rise thereby causing the soil temperature to rise higher than the ambient temperature. From the higher temperatures recorded at 20 cm depth for GRA Phase II, Trans Amadi and Woji areas, it was observed that these sites that the soil water do not dry up completely due to depression or uneven planes, the temperature increase was not only as a result of the air in the pores of the soil, but as evaporation takes place the latent heat that enables the drying up of the soil water cause the rise of temperature due to this extra heat (Ala *et al.*, 2009; Mousa, 1994). Thus the temperature in these areas at the time of measurement was higher.

In such areas the subsoil (20 cm) resistivity is lower than other areas of the same depth. This could be attributed to some moisture present in the soil (Sakamoto, 2001; Sakamoto and Sekiguchi, 2001).

Within the period of April to September the rainy seasons dominates and the soil temperature was lower than the ambient temperature. Due to the water acceptance potentials of the soil the resistivity was lower.

CONCLUSION

The main distribution cable within the city is usually 11 and 33 kv. These cables are laid at average depth of 0.9 to 1.2 m either directly on ground or drawn in ducts. At that depth the seasonal temperature may not affect the cables laid, therefore allow good heat dissipation to the ground. The soil resistivity is moderately low at that depth, therefore may also affect the thermal resistivity of the soil (low thermal soil resistivity).

The low and medium voltage cables whose average depth is from 0.6 to 0.75 m may be affected by the period of November to the peak of the dry and harmathan seasons (March). The normal ambient temperature of cable is taken as 20ºC. At the depth between 0.6 and 0.75 m the average temperature is about 33 to 36ºC if the operating temperature of cable is taken to be 70ºC, then he difference in temperature may be 34 to 37ºC which will affect the heat dissipation rate.

It is therefore necessary that the proper rating factors must be taken into consideration in the distribution of cable design. Since in the rainy season the soil condition and temperature variations are moderate, such rating factors when properly applied may give the necessary safety and security needed for the system.

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