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Thermal Rating of Nigerian Made Bare Overhead Aluminium Conductors

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Abstract

The increase in demand for electrical energy is growing while the available overhead aluminium cables which are the means for distribution of electrical energy are losing quality due to increase in the temperature of the ambient resulting from use and global warming. To meet the growing demand for electrical energy, the thermal ratings of existing overhead cables must be calculated for the purpose of making improved ones that can withstand the prevailing weather conditions. Increasing the current density, under the existing ambient condition of increased temperature due to global warming, has increased the lines' temperature beyond operating limits and therefore sagging, reduction in tensile strength, breaking of lines and violation of ground clearance are the attendant consequences. In this study, thermal ratings of overhead aluminium cables were estimated using the steady-state heat balance. The results reveal the need for quality improvement in overhead aluminium cable for satisfactory distribution of electrical energy in Nigeria.

Keywords**:** ground clearance, conductor temperature, aluminium cables.

1.0 Introduction

Temperature is a factor that affects many characteristics of conductors, such as thermal expansion, tensile strength and conductivity. Therefore, variation in temperature due to the changing weather system must be considered in the determination of aluminium cable thermal ratings [1, 2]. Regardless of climatic conditions, overhead aluminium cables are expected to deliver power with maximum efficiency. The continuous current carrying capacity of overhead aluminium cables must be determined for varying weather and designated maximum allowable temperature. This maximum allowable temperature is specified so as to limit the reduction of conductor tensile strength over the life of the cable and to prevent conductor sag due to thermal elongation from violating ground clearance [3]. When the heat supplied to the conductor is balanced by the heat dissipated, the thermal condition of the conductor is defined as steady state. In determining steady-state ratings, a continuous current is calculated that would yield the maximum allowable conductor temperature for prevailing weather conditions and conductor parameters. Conductor temperature is a function of the heat produced due to current flowing through the conductor, the thermal properties of the conductor and the ambient conditions. This is raised primarily through heat input from ohmic losses and partially from solar radiation. Ohmic losses are a function of conductor resistance and current while solar radiation input is dependent on the conductor's absorptivity. The conductor temperature is also affected by the cooling caused by heat loss through ambient convection and conductor radiation. Convection, the major source of heat loss, is a function of the air temperature, wind speed and direction. Conductor radiation, having a lesser effect on conductor temperature, is affected by air temperature and the conductor's emissivity. The reduction in tensile strength is caused by prolong exposure to a high temperature which degenerates conductor material. Reduction of tensile strength is irreversible and also cumulative; when the conductor temperature has been high, tensile strength is lost. When the conductor cools down, tensile strength does not increase again and when the conductor temperature becomes high the next time, tensile strength reduction continues from the already reduced value that was caused by earlier exposures to high temperatures. When this happen over a period of time, the conductor will be necking at some point under the influence of strong wind and storm.

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1.1 Steady–State Heat Balance

In steady state, heat input to the bare overhead conductor from solar radiation and ohmic losses balances the heat lost by convection and radiation cooling. For a unit length of bare overhead conductor, the steady-state heat balance equation is [4, 5, 6]

$$I = \sqrt{\frac{q_c + q_r - q_s}{R(T_c)}} \tag{1}$$

where q_c is convection heat loss

q_r is radiated heat loss

q_s is heat gain from sun

$R(T_c)$ is 60 Hz ac resistance of conductor at operating temperature T_c.

1.2 Solar Heat Gain

Solar heating raises the conductor temperature ambient air temperature and the solar heat gain equation is given by [4, 8]

$$q_s = \alpha Q \sin(\theta) A \tag{2}$$

1.3 Natural Convection Heat Loss

The major heat loss of an overhead conductor occurs through convection. The natural convection heat loss is due to rising air and is calculated by [4]

$$q_c = 0.283 \rho_f^{0.5} D^{0.75} \left(T_c - T_a\right)^{1.25} \tag{3}$$

1.4 Radiated Heat Loss

The radiated heat loss is the heat lost from the conductor by radiation and is given as [4]

$$q_r = 0.138 D\varepsilon \left[\left(\frac{T_c + 273}{100} \right)^4 - \left(\frac{T_a + 273}{100} \right)^4 \right] \tag{4}$$

1.5 Conductor Ohmic Loss:

The 60 *Hz* ac resistance of a bare, stranded conductor varies with frequency, conductivity, average current density, and temperature. To determine thermal ratings at temperature for which no resistance values are listed, the resistance at the desired temperature is calculated using the following linear equation [7]

$$R(T_c) = \left[\frac{R(T_H) - R(T_L)}{T_H - T_L} \right] \left(T_c - T_L\right) + R(T_L) \tag{5}$$

2.0 Methodology

In this study, conductor thermal ratings were calculated based on the heat balance method. The heat loss due to convection and radiation equals heat gain due to Ohmic losses and solar heating. This study made use of equations (1) to (5) to calculate the conductor thermal rating. The actual conductor dimensions were obtained from cable manufacturing company and an ambient air temperature of 39°C was used. An average value of the absorptivity of 0.5 was used. Likewise a value of 0.5 was used for emissivity. Values of the normal solar heat flux Q, solar altitude H_c, air density ρ_f and azimuth of the sun, Z_c were determined based on the regression equations and coefficients in [4]. The value of azimuth of power lines, Z_l, is assumed to be 0° or 180° for North-South lines and 90° or 270° for East–West lines [8].

3.0 Discussion of Results

Table 1 shows the current values for varying temperatures and cable diameters while Figure 1 shows the rise in current due to increase in temperature. At conductor temperature of 75°C, the conductors for distribution of electrical energy (35, 50, and 70 mm) are already carrying current in the range of 206.29 and 272.24 A. These values are still in the neighborhood of 200 A which is the optimum value. Increasing the current densities bring about an increase in temperature. The maximum allowable operating limit for these cables is 100^{o}C. Beyond this value, the conductor material degenerates gradually and thermal elongation sets in. The common consequences are violation of ground clearance and breaking of conductors.

The conductor for high tension (100 and 150 mm) can still withstand 100^{o}C. The rise in current is more pronounced at 120^{o}C as shows in the sharp bend of the curves in figure 1. Beyond 120^{o}C, the conductors experience sagging and sometimes contact between some of the conductors.

Table 1: Current values at varying temperatures and cable diameters

Temp.	35mm	50mm	70mm	100mm	150mm
60	114.36	130.16	147.01	167.17	193.35
70	175.82	202.29	231.02	266.07	312.65
75	206.29	237.29	272.24	314.32	370.43
80	237.97	274.81	314.98	364.26	430.12
90	308.54	357.00	409.96	475.09	562.37
100	396.63	459.49	528.30	613.05	726.83
110	520.08	603.06	694.00	806.13	956.84
120	730.06	847.19	975.66	1134.20	1347.49
130	1322.86	1536.10	1770.16	2059.21	2448.38

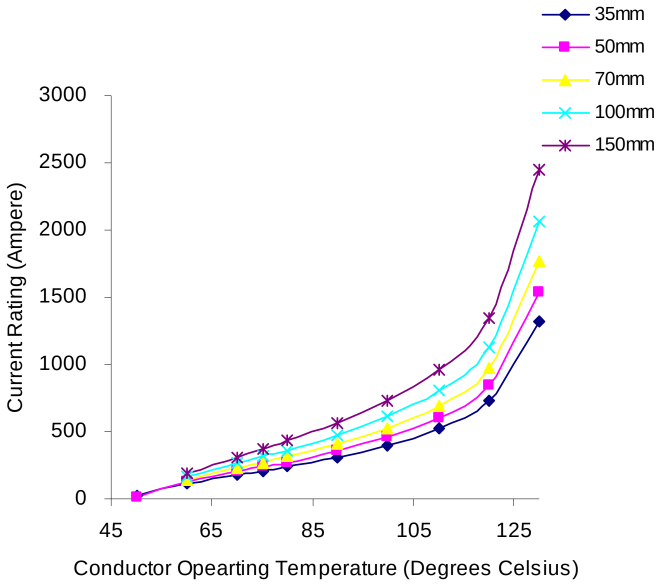

Fig. 1 Thermal Rating

4.0 Conclusion

In Nigeria, increasing the current density is usually the method of increasing the growing demand for electrical energy. This study reveals that it leads to increase in the conductor temperature and the attendant problems put the lives of the public at risk. The solution is an improvement in the quality of overhead cables produced locally.

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