Original Research Article

Ambient Temperature Effects on a High Voltage Power Line

ABSTRACT

The temperature increase causes a heating of the line conductors which is at the origin of the tension drops and the losses joule increases in line which cause a dilation of the line conductors. In this paper, we investigate of the ambient temperature influence on some quantities of power lines, including line resistance, line voltage drops, joule losses, and line deflection. The interest of this study is to predict the impact of the temperature rise on the electrical network working in order to optimize the transit of the electrical energy which satisfied the thermic limits of the lines.

Keywords: Ambient temperature, effects, high voltage, power line

1. INTRODUCTION

The overhead power line is designed to carry electrical energy. It is sized according to the intensity of the current flowing through it. This current must satisfy the thermal limits of the conductor. Except for this constraint, line conductors are faced with another challenge, namely climatic phenomena such as sunshine, which moreover cause a rise in the temperature of the conductors. The temperature reached by conductors caused by strong sunshine must always obey the thermic limits of conductors, otherwise:

- the durability of the line would be compromised by early ageing of the conductors and sleeves;
- the safety of people and property would be jeopardized by the increase of line deflection;
- the increased conductor impedance and voltage drops would cause more drop in voltage and Joule losses.

This recurring phenomenon in sub-Saharan countries requires a study to propose a rational exploitation of electricity networks. Thus, it is one challenge to evaluate the rise in the temperature of the conductors carrying the electricity in order to optimize the admissible current intensity according to the ambient environment.

2. METHODOLOGY

2.1 Steady overhead line temperature

In this study, we will focus on an underground cable having a sheath made of several insulating layers shown in Figure 1 [Silec, 1939], which gives an illustration of a cable from the thermic point of view. From this representation, we will deduce the thermic situation of an overhead line whose conductors are bare and exposed to the open air.

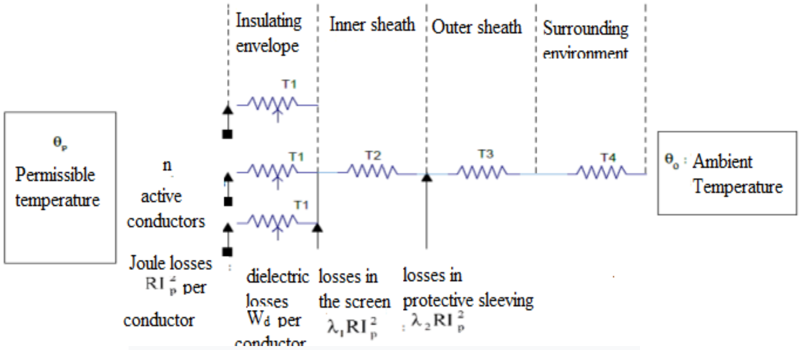

Fig. 1. Thermic representation of a cable

Ip: Intensity of permissible current in a conductor (A)
θp: permissible temperature on the core (°C)
θ_0: ambient temperature (°C)
R: resistance of a conductor at the permissible temperature (Ω / m)
Wd: dielectric losses in the conductor insulation (W / m)
T1: the conductor insulation thermic resistance (K.m / W)
T2: the inner sheath thermic resistance (K.m /W)
T3: the outer thermic resistance (K.m / W)
T4: the environment thermic resistance (K.m/W)
n: number of conductors actually traveled by the current
λ_1: losses ratio in the screen to losses joule in conductors
λ_2: losses ratio in armor to losses joule in conductors

Assuming that the dielectric losses are uniformly distributed in the insulator and can be considered as being applied in the insulation thermic resistances T1 shells on the one part, and the thermic resistances of the metallic coatings are negligible compared to those of the other elements of on the other hand, the rise in temperature θ_p-θ_0 and the current intensity Ip are related by the relation [1]:

$$\theta_p - \theta_0 = \left[\left(RI_p^2 + \frac{1}{2}W_d\right)T_1 + \begin{bmatrix} RI_p^2(1+\lambda_1) \\ +W_d \end{bmatrix} nT_2 + \begin{bmatrix} RI_p^2(1+\lambda_1+\lambda_2) \\ +W_d \end{bmatrix} n(T_3+T_4)\right]10^{-5} \qquad (1)$$

In the case of overhead lines, conductors are naked, in the open air. There is no armor or screen. In addition, the different layers of the underground cable are considered as air. Thus, the thermic resistances are the same and equal to the air thermic resistance T_a as well as the loss ratios. On the assumption that:

$T_a = T_1 = T_2 = T_3 = T_4$ and $\lambda_a = \lambda_1 = \lambda_2$

λ_a, being the losses ratio air to losses joules in the conductors.

Equation (1) then becomes:

$$\theta_p - \theta_0 = (5n\lambda_a + 3n + 1)T_a 10^{-5} RI_p^2 \times \left[1 + \frac{W_d}{RI_p^2}\frac{6n+1}{5n\lambda_a + 3n + 1}\right] \qquad (2)$$

By denoting, by α, the temperature coefficient, the conductors resistance R at the permissible temperature θ_p is given by: $R = R_0\left[1 + \alpha\left(\theta_p - \theta_0\right)\right]$.

Joule losses typically account for about 80% of losses in a high-voltage transmission system [2]. One sees immediately that $W_d \ll RI_p^2$, and that the term $\frac{W_d}{RI_p^2}\frac{6n+1}{5n\lambda_a+3n+1}$ is negligible compared to 1.

Under these conditions, equation (2) can be written:

$$\theta_p - \theta_0 = KRI_p^2 \tag{3}$$

où $K = (5n\lambda_a + 3n + 1)T_a 10^{-5}$

Since the rise in the conductor temperature θ is proportional to the amount of energy consumed by the Joule effect, the variation in the conductor temperature as a function of the current intensity I flowing through it is given by [3]:

$$\theta - \theta_0 = KR_\theta I^2 \tag{4}$$

where
$R_\theta = R_0[1 + \alpha(\theta - \theta_0)]$, denotes the conductor resistance to the temperature θ;
with relations (3) et (4) we obtain :

$$\frac{\theta - \theta_o}{\theta_p - \theta_o} = \frac{1 + \alpha(\theta - \theta_0)}{1 + \alpha(\theta_p - \theta_0)} \frac{I^2}{I_p^2} \tag{5}$$

The equation's resolution (5) makes it possible to determine the conductor temperature θ.

$$\theta = \theta_o + \frac{1}{\left(\alpha + \frac{1}{\theta_p - \theta_0}\right)\left(\frac{I_p}{I}\right)^2 - \alpha} \tag{6}$$

2.2 Correlations between ambient temperature and power line Resistance

The electrical conductor resistance expresses the difficulty that this material presents when the electrical current flows [4], [5].
It is established that at the frequency of 50 Hertz, the skin effect and proximity are considered negligible. Under these conditions, the electrical resistance in alternating current is practically equivalent to that in continuous current.
Given the temperature variation also causes that of a conductor length of by linear expansion effect, the electrical conductor resistance of length L to the temperature is:

$$R_\theta = \frac{\rho_\theta L_\theta}{S} \tag{7}$$

For a length conductor L, placed in an ambient temperature environment θ_o, the resistivity and the conductor's length are given by:

$$\begin{cases} \rho_\theta = \rho_o[1 + \alpha(\theta - \theta_o)] \\ L_\theta = L_o[1 + \lambda(\theta - \theta_o)] \end{cases} \tag{8}$$

λ , is the expansion linear coefficient ($\lambda = 23.10^{-6}$ $^oC^{-1}$ for the almelec [2].)
Taking into account (8), relation (7) is written:

$$R_\theta = R_o . K(\theta, \theta_o) \tag{9}$$

with $K(\theta, \theta_o) = [1 + \alpha(\theta - \theta_o)][1 + \lambda(\theta - \theta_o)]$ and $R_o = \frac{\rho_o L_o}{S}$

2.3 Correlations between ambient temperature and Voltage drops

The voltage drops per unit of length are calculated according to the classical formula:

$$\Delta U = \sqrt{3} Z I \quad (10)$$

where I is the current through the line and Z is the line impedance at the temperature line θ.

The approximate formula given in relation (11) shows that all the parameters defining the reactance have a practically negligible variation with temperature [4], [5]. The reactance can therefore be considered as a constant compared with the temperature and given by:

$$X_c = 2\pi f \left[K' + 0{,}2 \ln\left(\frac{2s}{d_c}\right)\right] \times 10^{-3} \quad (11)$$

where X_c is the conductor inductive reactance (Ω / km), f, the frequency (Hz), s, the space between the conductor axes (mm), d_c, the conductor diameter (mm) and K', the constant which depends on the conductors shape.

The voltage drop will be written:

$$\Delta U = \sqrt{3} I \sqrt{R_0^2 [K(\theta, \theta_o)]^2 + X_C^2} \quad (12)$$

2.4 Correlations between ambient temperature and electrical deflection line

By deflection is meaning the vertical distance between the line joining the two points of suspension and the conductor. In the case of the HV overhead lines, the average ranges are between 300 and 400 m.

The line deflection is given by the classical relation [6], [7]:

$$f_n = \frac{P^2}{8a} \quad (13)$$

where P is the conductor length over a range and a, a constant.

The increase in the temperature of the active conductors causing the linear dilation of these conductors, the line deflection line will consequently grow. The relation (13) becomes then:

$$\frac{f_n}{f_0} = [1 + \lambda(\theta - \theta_0)]^2 \quad (14)$$

$f_0 = \frac{P_0^2}{8a}$, being the deflection expression at ambient temperature θ_0.

3. RESULTS AND DISCUSSION

The Applications of our theoretical approach are made on the Ngo-Djiri power line in the Republic of Congo. Connecting the Ngo substation in the Plateaux Department and the Djiri station in Brazzaville. This line is in almelec with 500-mm2 of section, 208 km of length and a voltage of 220 kV.
The line resistance values R and its reactance X at the temperature of 20°C are respectively 13.3 Ω and 83.2 Ω. The Djiri substation has two transformers with a capacity of 45 MVA each one, for a total power of 90 MVA.
In this part, we present the results obtained on the correlation between the ambient temperature and the main parameters of this line, their analysis and discussion.

3.1 Effect of ambient temperature on conductors temperature

From the relation (6) and taking into account the maximum value of the current intensity to be transported on the Ngo-Djiri line, as well as the permissible temperature for the high-voltage lines (θp = 70 °C), we represent, in figure 2, the variation curve of the conductors temperature versus the ambient temperature. This curve shows that the temperature of conductors increases linearly with ambient temperature. We also interest to the difference between the temperature of conductors and ambient temperature. The figure 3 shows that it is negligible. One can note that, the maximum difference between the conductor’s temperature and that of the surrounding environment (Figure. 3) does not exceed 3 ° C

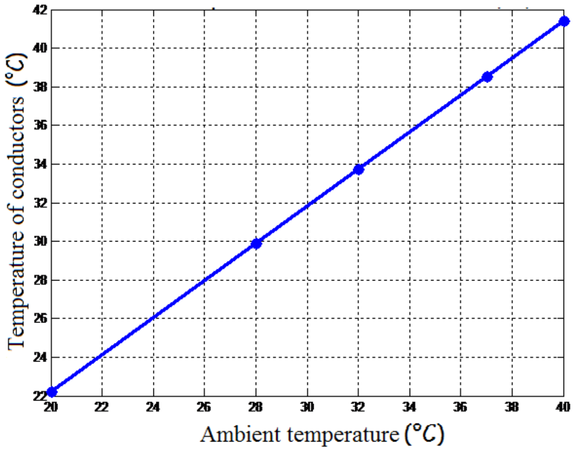

Fig. 2. Variation in the temperature of conductors

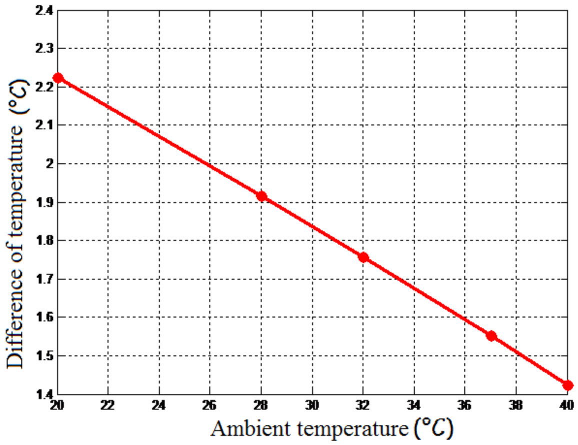

Fig. 3. Temperature difference

3.2 Effect of the line current on the on the conductors temperature

From relation (6) and fixing the ambient temperature value, we represented in Figure 5, the conductors temperature variation versus current intensity passing through the Ngo-Djiri line.

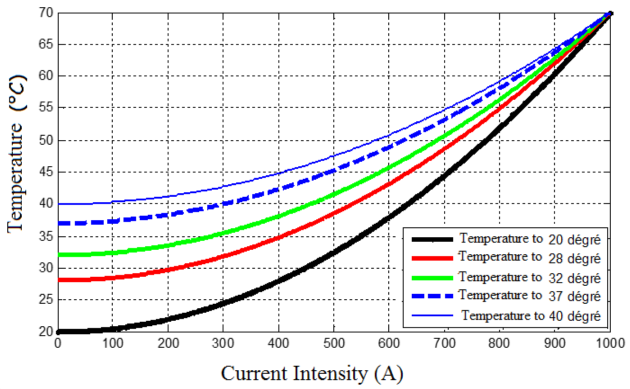

Fig. 4. Conductor temperature according to the current intensity

The Figure 4 shows that the conductors temperature of a power line increases exponentially with respect to the current intensity flowing on the line. In addition, the convergence of all the curves at different ambient temperature levels is only possible when the current flowing on the line reaches the admissible current value of 1000 A.

3.3 Effect of ambient temperature on electrical conductors resistance

To determine the ambient temperature effect on the electrical resistance of the line conductors, we calculated the conductors resistances R_θ from the relation (9) for different temperature values. The results are consigned in Table 1. The Figure 6 illustrates the variation of electrical conductors resistance as a function of the ambient temperature.

Table 1. Electrical resistance of conductors

Ambient temperature	**20 °C**	**28 °C**	**32 °C**	**37 °C**	**40 °C**
Ratio K	1.0090	1.0077	1.0070	1.0062	1.0057
Resistance (Ω)	13.417	13.829	14.0501	14.290	14.443

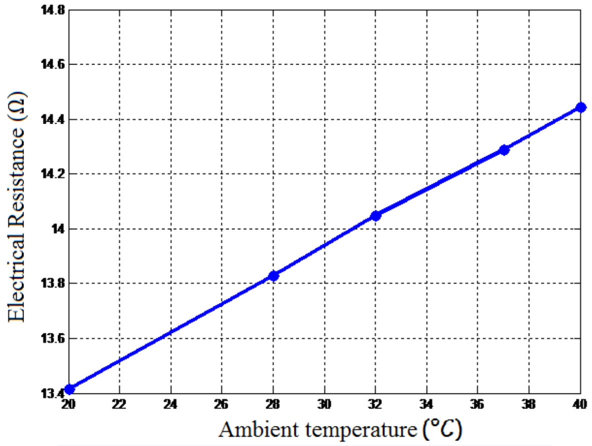

Fig. 5. Variation of electrical resistance

This figure 5 shows that the variation curve of the electrical resistance increases linearly with the ambient temperature, consequently, an increase in losses by Joule effect on the line. By analyzing the values of the ratio K presented in Table 1, K is almost equal to 1. We can thus conclude that in the case of the Ngo-Djiri line, the ambient temperature has minor effects on the conductors electrical resistance.

3.4 Effect of ambient temperature on deflection and drops voltages

In the assumption that the ration K is approximately equal to 1 for any ambient temperature lower or equal to 40°C, from the equations (12) and (14), we have evaluated the line deflection and drops voltages. The obtained results are shown in table 2. This allowed us to represent the curves of voltage drops and their deviation versus the ambient temperature as shown in figures 6, 7 and 8.

Table 2. Voltage drops on the Ngo-Djiri line at different temperature levels

Ambient temperature (^{o}C)	**20**	**28**	**32**	**37**	**40**
Resistance (Ω)	13.4170	13.8293	14.0501	14.2909	14.4438
Reactance (Ω)	83.2	83.2	83.2	83.2	83.2
$\Delta \mathbf{U}(\mathbf{kV})$	33.5653	33.5930	33.6100	33.6300	33.6350
Voltage difference (kV)	0	0.0277	0.0447	0.0647	0.0700
Ratio of the deflection $\mathbf{f_n/f_0}$	1.0001	1.00008	1.00008	1.00007	1.00006

The results in Table 2 show that the ratio of the deflection $\left(\frac{f_n}{f_0}\right)$ to any conductor temperature θ relative to that of the ambient environment varies very slightly as a function of the ambient temperature.

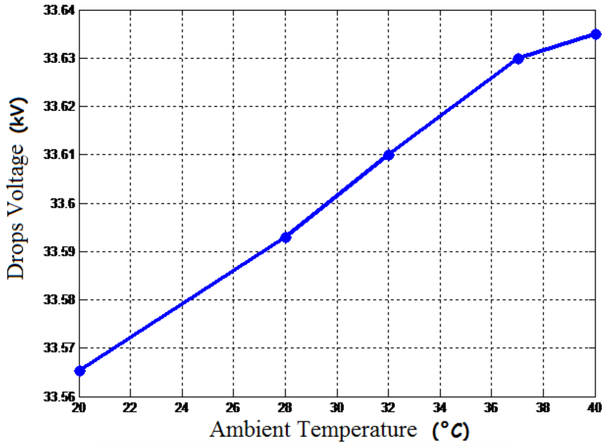

Fig. 6. Variation of voltage drops

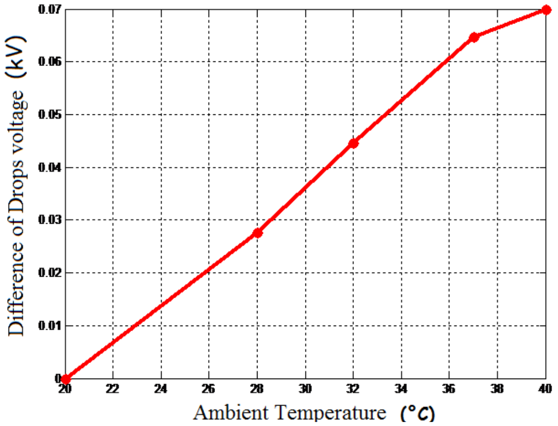

Fig. 7. Difference of drops voltages

The figure 6 shows that the ambient temperature causes a quasi-linear increase of the voltage drops on a power line. However, the figure 7 shows that, with the ambient temperature variation, the voltage drops deviations do not exceed 0.07 kV, which means 0.03% of the nominal voltage over the entire Ngo-Djiri line. This voltage drop level will not influence the operation of this line since in many literature of high voltage electrical networks, the allowable voltage variations are of the order of ± 5% of the nominal voltage. The figure 8 represents the voltage drops curves and their deviation. As one can see, these quantities are almost constant when the ambient temperature varies.

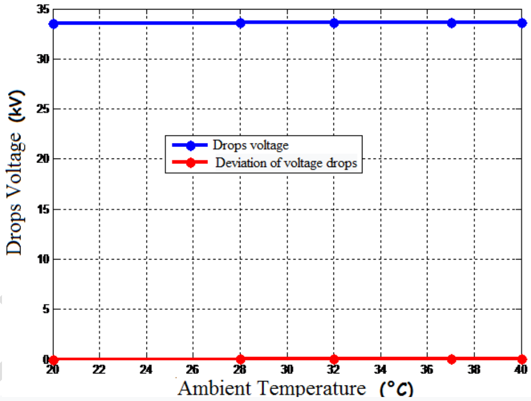

Fig. 8. Voltage drops and deviation of voltage drops

4. CONCLUSION

The study conducted in this work shows that the ambient temperature can have a considerable effect on certain parameters of a high voltage power line such as the conductors temperature and the conductors electrical resistance. However, the application to the Ngo-Djiri line shows that the effects of the ambient temperature on the electrical resistance are minor, therefore negligible on the deflection line and on the voltage drops.
It is therefore likely that in other environment, with lines of identical or non-identical characteristics that this influence is not negligible. The electrical networks operators are, for this purpose, invited to take into account the temperature of environment traversed by an electrical line in order to guarantee a stability in the management of the electrical networks.

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