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# Modeling of the Electric Power of the Kakobola-Kikwit High Voltage Line in the DR Congo

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***Abstract***— *In this article, we discuss the modeling of the electric powers of the high voltage line. This article describes the approach of a modeling of the parameters of the electric power transmission network. It is above all to make a certain number of simplifying assumptions which condition both the complexity and the domain of validity of the model. The main assumptions used in the modeling are the following: the steady state behavior assuming that the network is fully balanced and linear. This modelling already allows to predetermine, for a given generation plan and load level, what will be the load of each high voltage line in normal operation. What will be the voltage plan of the electrical network. The mathematical model of a high voltage line must be adapted to the problem at hand and will be different depending on whether or not there is a current in the ground and on the speed of the phenomenon.*

***Keywords***— *Electrical power, High Voltage Line, Kakobola-Kikwit, DR Congo.*

## I. INTRODUCTION

World energy consumption is increasing by about 2% per year while we are faced with a reduction of fossil energy resources and a major risk for the future of our planet with climate change. The era of abundant and extremely cheap energy is behind us. Energy will therefore become a scarcer and more expensive commodity.

Of all the forms of energy, electrical energy is the most noble and easiest to implement. This is why the proportion of electrical energy in the total energy consumed is constantly increasing. The management of electrical energy, which is imperative to be concerned with, is one of the components of a total energy control. The recent development of computerized means and programmable automatisms brings very powerful solutions which make it possible to apprehend the control of this energy [A B].

However, the human and material investments allocated to transport far exceed the investments devoted to the production sector. We know that electrical energy is transported over conductors such as overhead lines and underground cables. Despite their apparent simplicity, these conductors hide important properties that greatly influence the transmission of electrical energy.

The modeling of a power line is done by the triplet (R, L, C). The mathematical model of overhead lines for lengths at system frequency can be represented as a π diagram as shown here. An overhead line of any length that operates in a sinusoidal symmetrical regime is represented by an equivalent physical model in π. The model is composed of the physical elements such as, the longitudinal effective impedance (Zl), compound the line resistance (Rl) and the line reactance (Xl).

In this paper, we model the electrical powers of the high-voltage line Kakobola-Kikwit in DR Congo. Based on the equations of the physical model, the electrical model and the equations of the electrical power losses.

## II. MODEL OF ELECTRIC POWER EQUATIONS

### *II.1 Model of a High Voltage Line*

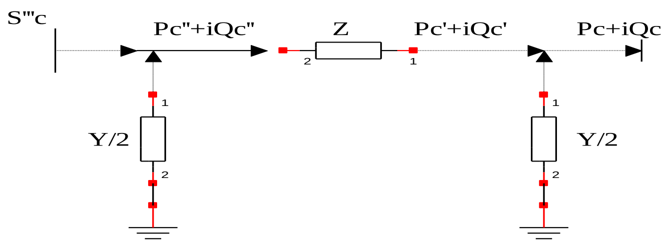


Figure 1 : Model of a line

#### *II.1.1 Active power at beginning of line*

$$\Delta P_l = 3R_l I^2 = 3R_l(I_a^2 + I_r^2) \quad (1)$$

$$P_c'' = \sqrt{3}U_1 I_1 \cos\varphi_1 \quad (2)$$

$$Q_c'' = \sqrt{3}U_1 I_1 \sin\varphi_1 \quad (3)$$

$$I_a = \frac{P_c''}{\sqrt{3}U_1} \quad (4)$$

$$I_r = \frac{Q_c''}{\sqrt{3}U_1} \quad (5)$$

$$\Delta P_l = R_l\frac{P_c''^2}{U_1^2} + R_l\frac{Q_c''^2}{U_1^2} = R_l\frac{S_c''^2}{U_1^2} \quad (6)$$

#### *II.1.2. Active power at the end of the line*

$$\Delta P_l = 3R_l I^2 = 3R_l(I_a^2 + I_r^2) \quad (7)$$

$$P_c' = \sqrt{3}U_1 I_1 \cos\varphi_1 \quad (8)$$

$$Q_c' = \sqrt{3}U_1 I_1 \sin\varphi_1 \quad (9)$$

$$I_a = \frac{P_c'}{\sqrt{3}U_1} \quad (10)$$

$$I_r = \frac{Q_c'}{\sqrt{3}U_1} \quad (11)$$

Hence, we have:

$$\Delta\overline{P}_{L2} = R_{L2}\left(\frac{S_4}{U}\right)^2 \qquad (12)$$

*II.1.3. By analogy the reactive power*

$$\Delta Q_l = X_l\frac{P_c''^2}{U_1^2} + X_l\frac{Q_c''^2}{U_1^2} = X_l\frac{S_c''^2}{U_1^2} \qquad (13)$$

$$\Delta P_l = R_l\frac{P_c'^2}{U_1^2} + R_l\frac{Q_c'^2}{U_1^2} = R_l\frac{S_c'^2}{U_1^2} \qquad (14)$$

*II.1.4. Power equations at the line input*

The formulas for apparent power (S1), active power (P1) and reactive power (Q1) at the line source can be represented geometrically by the power triangle. The equation of the active, reactive and apparent power can be found as follows:

$$P_1 = \sqrt{3}\,U_1.I_1.\cos\varphi_1 \qquad (15)$$

$$Q_1 = \sqrt{3}\,U_1.I_1.\sin\varphi_1 \qquad (16)$$

$$\overline{S_1} = \sqrt{3}\,\overline{U_1}.\overline{I_1^*} = P_1 + jQ_1 \qquad (17)$$

*II.1.5. Power equations at the load terminals*

The active, reactive and apparent power equation at the load terminals can be determined as follows:

$$P_2 = \sqrt{3}\,U_2.I_2.\cos\varphi_2 \qquad (18)$$

$$Q_1 = \sqrt{3}\,U_2.I_2.\sin\varphi_2 \qquad (19)$$

$$\overline{S_2} = \sqrt{3}\,\overline{U_2}.\overline{I_2^*} = P_2 + jQ_2 \qquad (20)$$

*II.2 Power loss equations*

*II.2.1. Losses in the high voltage line*

The equation of active power, reactive power consumed, reactive power supplied by the voltage and reactive power supplied in the line can be determined as follows:

$$\Delta P = 3RI^2 \qquad (21)$$

$$Q = 3L\omega I^2 = 3X_l I^2 \qquad (22)$$

$$Q_c = \frac{1}{c\omega}3C\omega V^2 = C\omega U^2 \qquad (23)$$

$$Q_c = Q_{c1} + Q_{c2} = \frac{Y}{2}U_1^2 + \frac{Y}{2}U_2^2 = \frac{C\omega}{2}(U_1^2 + U_2^2) \qquad (24)$$

The reactive power losses on the line can be obtained by the following equations:

$$\Delta Q = L\omega I^2 - \frac{C\omega}{2}(V_1^2 + V_2^2) \qquad (25)$$

$$\Delta Q = 3X_l I^2 - \frac{C\omega}{2}(U_1^2 + U_2^2) \qquad (26)$$

*II.2.2. Transit power*

Newton Raphson's method, we consider that the active power quantities P_i and reactive Q_i are known while the unknowns are the modulus V_i and the phase φ_i of the voltage. We initialize the parameters by choosing an approximate value of the voltages and phases at each node**:**

$$V_1^0, V_2^0, \dots, V_n^0 \;\; et \;\; \varphi_1^0, \varphi_2^0, \dots, \varphi_n^0 \qquad (27)$$

From which we can calculate the active and reactive powers drawn at each node :

$$P_1^0, P_2^0, \dots, P_k^0, \dots P_n^0 \; et Q_1^0, Q_2^0, \dots, Q_k^0, \dots Q_n^0 \qquad (28)$$

From the equations at the nodes 6), we calculate the power deviation at the nodes:

$$\Delta P_i^0 = P_i^d - P_i^0 \qquad (29)$$

$$\Delta Q_i^0 = Q_i^d - Q_i^0 \qquad (30)$$

These expressions can be written in the following matrix form :

$$\begin{bmatrix}\Delta P_i^0\\ \Delta Q_i^0\end{bmatrix} = \begin{bmatrix}P_i^d\\ Q_i^d\end{bmatrix} - \begin{bmatrix}P_i^0\\ Q_i^0\end{bmatrix} \qquad (31)$$

Where $P_i^d$ and $Q_i^d$ are the active and reactive powers given at node i, they are fixed. We compute the norm of the error vectors $\Delta P_i$ and $\Delta Q_i$ such that:

$$\|\Delta P_i\| = \mathrm{Max}|\Delta P_i| \qquad (32)$$

$$\|\Delta Q_i\| = \mathrm{Max}|\Delta Q_i| \qquad (33)$$

The determination of the corrections to be made on the initial values is done by introducing the values:

$$V_i^1 = V_i^0 + \Delta V_i^0 \qquad (34)$$

$$\varphi_i^1 = \varphi_i^0 + \Delta\varphi_i^0 \qquad (35)$$

The computation of $\Delta V_i^0$ and $\Delta V_i^0$ is such that the errors $\Delta P_i^1$ and $\Delta Q_i^1$are zero. Expanding to order 1 the functions $P_i^d$ and $Q_i^d$ ; we have:

$$P_i^d = P_i^0 + \Delta P_i^1 \qquad (2.36)$$

Where :

$$\Delta P_i^1 = \sum_{k=1}^{n}\frac{\partial P_i}{\partial V_k}\Delta V_k + \sum_{k=1}^{n}\frac{\partial P_i}{\partial \varphi_k}\Delta\varphi_k \qquad (37)$$

$$P_i^0 = P_i(V_1^0, V_2^0, \dots, V_k^0, \dots, V_n^0;\; \varphi_1^0, \varphi_2^0, \dots, \varphi_k^0, \dots, \varphi_n^0) \qquad (38)$$

De même, on a pour la puissance réactive :

$$Q_i^d = Q_i^0 + \Delta Q_i^1 \qquad (39)$$

Where :

$$\Delta Q_i^1 = \sum_{k=1}^{n}\frac{\partial Q_i}{\partial V_k}\Delta V_k + \sum_{k=1}^{n}\frac{\partial Q_i}{\partial \varphi_k}\Delta\varphi_k \qquad (40)$$

$$Q_i^0 = Q_i(V_1^0, V_2^0, \dots, V_k^0, \dots, V_n^0;\; \varphi_1^0, \varphi_2^0, \dots, \varphi_k^0, \dots, \varphi_n^0) \qquad (41)$$

II.2. 3 Reactive power generated by the line

A line is a reactive power generator; in HV the line generates 13.5 MVAR and in EHV generates 27 MVAR. The power generated on the line is divided in half on each side of the line and is obtained by the following formula:

$$q_{ij} = \frac{k_q.d_{ij}}{U_{1-2}} \qquad (42)$$

*II.2.4. Power loss in the high voltage line*

An electric line produces active and reactive power losses. Considering a line A-B of electric power transmission, knowing that the apparent power to be transmitted, the nominal voltage and its linear characteristics of the section are known; the losses of active, reactive and apparent power are defined as follows :

$$\Delta P = \left(\frac{S}{U}\right)^2 x\, R \qquad (43)$$

$$\Delta Q = \left(\frac{S}{U}\right)^2 x\, X \qquad (44)$$

$$\Delta S = \Delta P + j\Delta Q \qquad (45)$$

## III. RESULTS

*III.1 Power generated*

*III.1.1 Power generated by Kakobola-Kikwit Boulevard*

The reactive power generated by Kakobola-Kikwit Boulevard as a function of line voltage is shown in Fig. 1.

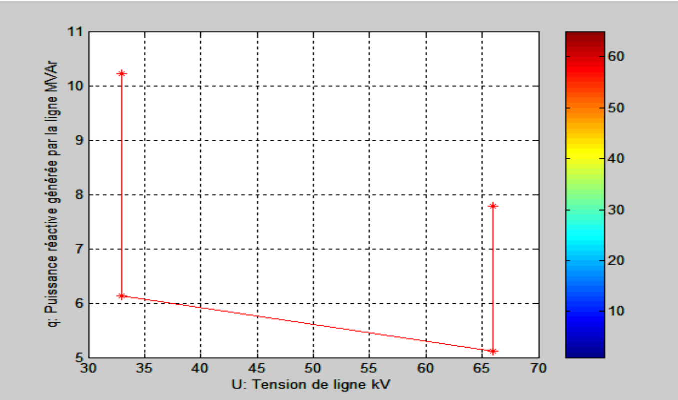


Figure 1: Reactive power generated per boulevard as a function of voltage

Reactive power generated by the Kakobola-Kikwit high voltage line varies from 5.113 MVAr to 10.227 MVAr. This power varies for the simple reason that; the voltage injected on the line varies from one point to another.

*III.1.2. Reactive power generated by Kakobola-Kikwit Boulevard as a function of line length*

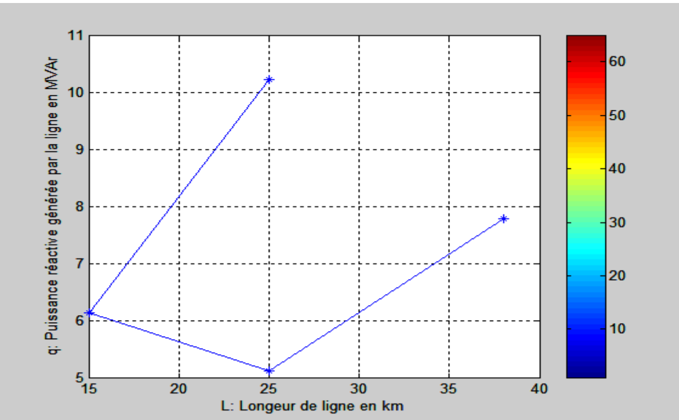


Figure 2. Reactive power generated per boulevard as a function of length

The reactive power generated by the Kakobola-Kikwit high voltage line also varies with the distance of each section. This power varies in the range of 10.227 MVAr to 5.113 MVAr as shown in Figure 2.

*III.1.3 . Reactive power generated per boulevard as a function of voltage and length*

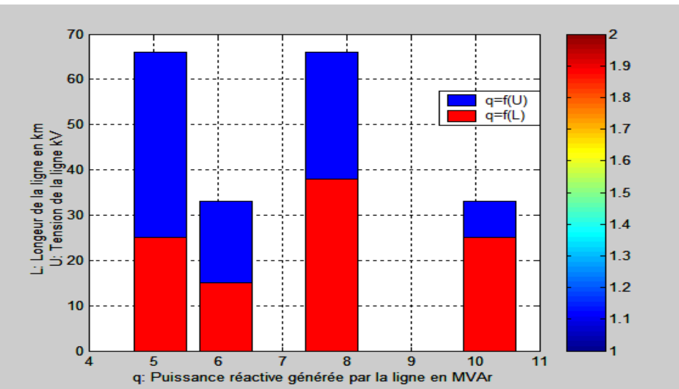


Figure 3. Reactive power generated as a function of voltage and length

There are two possibilities to obtain the power generated by the high voltage line; voltage dependent and distance dependent. In both cases, the reactive power generated by the Kakobola-Kikwit high voltage line varies from 5.113 MVAr to 10.227 MVAr.

*III.2. Evolution methods of three powers on the Kakobola-Kikwit section*

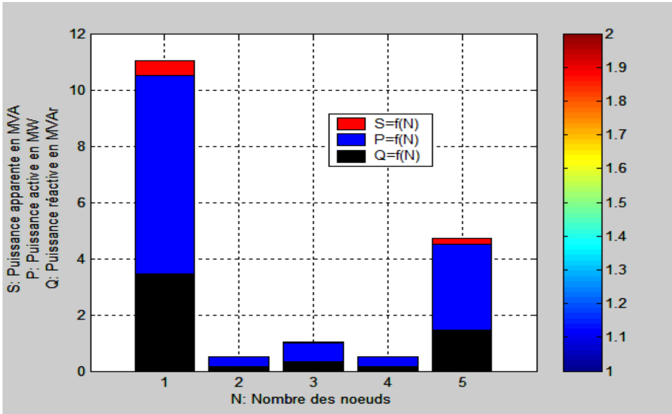


Figure 4. Evolution of three powers on the Kakobola-Kikwit section

The red bar describes the apparent power trend, which varies in the range 0.52631579 MVA to 11.0526316 MVA. The black bar describes the reactive power which varies in the range of 0.16434206 MVAr to 3.45118316 MVAr. The blue bar describes the reactive power trend that varies in the range of 0.52631579 MVA to 11.0526316 MVA. The blue bar describes the active power trend which varies in the range of 0,5 MW to 10,5 MW

*III.3. Power losses in Kakobola-Kikwit Boulevard*

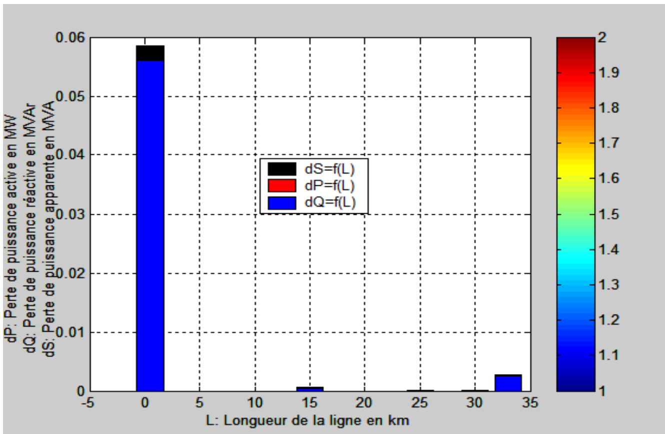


Figure 5. Simulation of power losses

The black bar describes the apparent power loss which varies in the range of 0.00268889 MVA to 0.05855807 MVA. The blue bar describes the reactive power loss which varies in the range of 0.00257549 MVAr to 0.05608846 MVAr. The red bar describes the active power loss which varies in the range of 0.00077265 MW to 0.016 MW.

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## IV. CONCLUSION

This article consisted in the modeling of the electric powers of the high voltage line kakobola-kikwit in DR Congo. Based on the equations of the physical model, the electrical model and the equations of the electrical power losses, we find that the apparent power varies linearly as a function of the unit powers of each node, by a rate of increase of 4.5%. While, the reactive power varies linearly as a function of the tangent-phi of each node, whose rates of increase of 4.6%. So the active power of the line, also varies linearly as a function of cosine-phi of each node. This power varies by a rate of increase of 4.7%. The active power losses vary by a rate of increase of 4.37%. While the reactive power losses vary by a rate of increase of 4.4%. In order, the apparent power losses vary by a rate of increase of 3.4%.

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