Scientific Research Publishing

Modern Mechanical Engineering, 2022, 12, 1-26
https://www.scirp.org/journal/mme
ISSN Online: 2164-0181
ISSN Print: 2164-0165

Reducing Greenhouse Gas Emissions through Improving the Life Span of Wooden Power Electric Poles of *Eucalyptus saligna*

Joseph Voufo[1,2*], Zakari Yaou[2,3], Florent Biyeme[1,2], Rolland Djomi[1,2], Richard Dadji Metangmo[1,4], Théodore Tchotang[1,2]

[1]National Advanced School of Engineering of Yaoundé (NASEY), Yaoundé, Cameroon
[2]Laboratory of Civil and Mechanical Engineering, Yaoundé, Cameroon
[3]Higher Technical Teacher Training College of Ebolowa, Ebolowa, Cameroon
[4]Department of Industrial and Mechanical Engineering, Yaoundé, Cameroon
Email: *joseph.voufo@univ-yaounde1.cm

How to cite this paper: Voufo, J., Yaou, Z., Biyeme, F., Djomi, R., Metangmo, R.D. and Tchotang, T. (2022) Reducing Greenhouse Gas Emissions through Improving the Life Span of Wooden Power Electric Poles of *Eucalyptus saligna*. *Modern Mechanical Engineering*, **12**, 1-26.
https://doi.org/10.4236/mme.2022.121001

Received: December 28, 2021
Accepted: February 25, 2022
Published: February 28, 2022

Abstract

The present work deals with reducing greenhouse gas emissions through improving the life span of wooden power electric poles of *Eucalyptus saligna*. Indeed, in Sub-Saharan African countries, Cameroon in particular, most of the power line networks are made of wooden supports and according to the Cameroon energy distribution company, wooden poles represent 32% of the causes of death linked to the state of the network. The company's 2019 annual report indicates that 40,000 wooden poles were in critical condition and should be replaced. A significant number of mechanical failures affecting these supports have been observed. For example, on the HVA/LV power line "D17 Nkoabang" in Yaoundé in Cameroon, less than three years old, 10 (ten) cases of poles falling and/or breaking, due to their mechanical loading, were observed over a period of fewer than nine months, causing an average service stoppage for more than 11 hours and affecting an average of 3280 customers. These incidents lead to questions about how the supports are dimensioned and what load capacities they are designed to support. The aim of this work is, therefore, to suggest a method of dimensioning wooden poles hence reducing greenhouse gas emissions due to the deforestation by reducing the number of wooden poles at risk to be replaced on Cameroon's electricity distribution network. And more specifically, to reduce the number of mechanical failures affecting the wooden supports observed by analyzing the current wooden supports with their loads and to make proposals for improving the actual dimensioning methods. From the study carried out, it appears that 449 out of 845 supports, *i.e.*, 53% needed to be replaced or monitored because they support the nominal forces ranging from 85% to 150% of their admissible limit and proposals have been made to improve their dimensioning.

Keywords

Electrical Power Line, Dimensioning Wooden Pole, Efforts on Pole, Pole's Height, Method of Loading, Overload Coefficients

1. Introduction

The public and industrial electricity power supply requires efficient production equipment and reliable transmission and distribution networks. In Sub-Saharan Africa, the transmission and distribution networks are mostly constituted of "overhead power lines", which are assemblies of conductor cables held by steel, concrete or wooden supports.

In Cameroon, in particular, a great number of mechanical failures affecting the electric line supports are still observed, causing financial losses, risks to the people's safety and goods, electrical power distribution/supply services interruptions, and increased deforestation. According to the Cameroon energy distribution company, wooden poles account for 32% of causes of death linked to the condition of the grid. The company's 2019 annual report indicates that 40,000 wooden poles were in critical condition and should be replaced [1]. A significant number of mechanical failures affecting these supports have been observed. For example, over a period of fewer than nine months, 10 cases of poles' failures or breakings under the effect of their mechanical loading have been reported on the D17 Nkoabang power line in Yaoundé Cameroon, in electrical power line networks which are less than three years old. It should be noted that these incidents caused an average downtime of more than 11 hours 41 minutes to more than 3280 customers on average [2]. This early replacement of these wooden poles increases deforestation, and therefore, increases greenhouse gas emissions. This state of affairs questions the validity of the dimensioning initially done for those wooden poles, and their ability to support loads. What are the current loads of the supports? How to dimension the wooden power line supports to be more reliable, more sustainable and how to reduce greenhouse gas emissions due to the deforestation? This work attempts to answer these questions. The first section is devoted to the constituent elements and characteristics of power lines, and presents the methods and formulas used to dimension wooden poles. The second section presents the results obtained after applying these methods on the D17 Nkoabang power line supports, and the third section determines the loading state of the differrent columns and proposes dimensioning complements in order to make the line supports more reliable and more sustainable.

2. Material

2.1. Elements of an Electric Power Line

The elements of an electric transmission line are conductors, line's supports and the line's accessories.

2.1.1. The Conductor

The conductor is the piece of hardware through which circulates the electric current. Here, its sizing is essentially to choose/determine: its material, its section area and its structure. This structure reveals how the different strands of conductor have been assembled together, in a smooth or twisted pack, to favour either mechanical resistance or heat dissipation [3]. The most commonly used materials for electrical conductors are copper, aluminium, and alloys produced from one of them. The material met in this study is almelec, and the conductors have the twisted structure. Some useful features of almelec conductors are recorded in Table 1.

2.1.2. The Line Accessories

After the conductor, follow the line accessories. Among these accessories, we find:

- Insulators (in the form of a seat): these are insulating elements making the connection between the conductors and the supports. They play role both in mechanical (for fixing the conductor to the support, maintaining a suitable tension) and in electrical (for providing insulation between the conductor and the support). Their choice is made essentially according to the level of voltage carried by the conductor. Insulators are used for currents medium and high voltage;
- Suspension and fixing elements (clamps, cross members, uprights, rods, fasteners, plates, fittings…). They are essential to link the conductor to its support;
- Some supports are fitted with anti-cascade devices, to protect the line in case of incident;
- According to the type of conductor, its length, and the wind speed, vibration absorbers may be required on some lines.

2.1.3. The Line Support

It is the hardware element that carries and suspends the conductors at the required height, in order to ensure people and environment safety. It must be able to withstand the applied loads/efforts on it in a sustainable way, without breaking

Table 1. Characteristics of the most common almelec conductors [4] [5] [6].

Section Area (mm^2)	Diameter (mm)	Breaking Limit Load (N)	Linear Mass (kg/m)	Density (kg/m^3)	Young Modulus (MPa)	Linear Expansion Coefficient ($^\circ C^{-1}$)
34.36	7.50	11,170	0.094			
54.55	9.45	17,730	0.149	2700	60,000	23×10^{-6}
93.27	12.5	29,950	0.257			

or significant deformation. Line supports are usually poles, porticos or towers, made of wood, concrete or steel. In this case study, the supports are wooden poles from *Eucalyptus saligna* wood, which present an advantageous compromise between mechanical characteristics, mass, regrowth period, availability and cost.

2.2. Applied Loads on the Eucalyptus Wooden Poles

2.2.1. Shape and Properties of the Eucalyptus Wooden Poles

The available Eucalyptus wood posts are approximately circular in cross-section, and the trunks are smoothly scrolled, with a shape close to that of a cylinder or a low-angle cone trunk. The sizes to be determined for a pole are its cross-section (or its diameter or its circumference), and its height. The latter is broken down into four parts, as shown in **Figure 1** below.

The head height h_{head} is the pole's height above the point where the lowest conductor is fixed on the pole. The beam f represents the maximum difference of height between the point where the conductor is fixed on the pole and the lowest point of the suspended conductor. The ground clearance H_{ground} represents the minimum distance to maintain between the ground and the lowest point of the suspended conductor, for security reasons. The *implanted height* h_{im} is the height of the pole to be buried in the ground, so as to ensure stability.

For further sizing computations, it is necessary to define the anchorage height H_a (distance between ground and the point where the conductor is linked to the pole) and the height above ground H_r (the pole's height measured from the ground level).

The type of wood used is that of the Eucalyptus, whose mechanical characteristics are noted in **Table 2**.

Eucalyptus wood poles are divided into 7 classes (A, B, C, D, E, F and G). They are classified according to their diameters (measured at the poles base and at the poles head), circumferences, average volume, average weight or admissible load [10]. Regardless, the poles are also declined into 3 categories (see **Figure 2**),

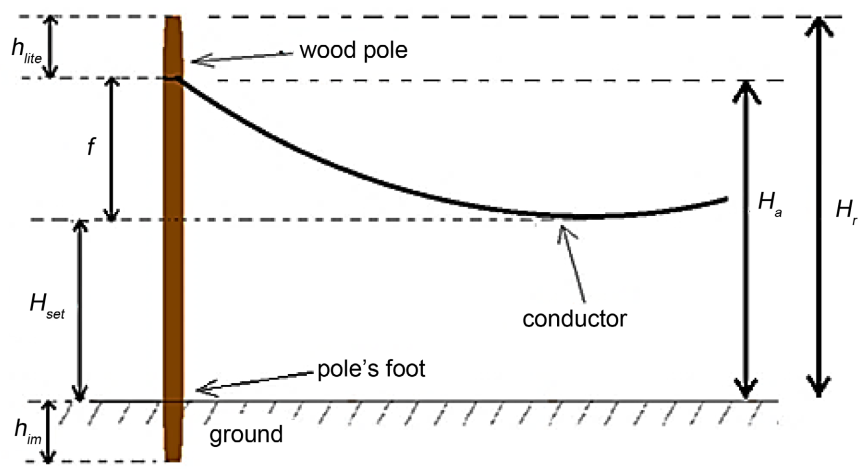

Figure 1. Characteristic heights of a pole.

(a) (b) (c)

Figure 2. Types of poles according to the assembly mode.

Table 2. Mechanical characteristics of Eucalyptus wood poles [7] [8] [9].

Data	Average value at 25% humidity
Breaking limit compression stress	49,500,000 N/m^2
Breaking limit bending stress	55,000,000 N/m^2
Elastic limit (in compression)	29,300,000 N/m^2
Young modulus	10,000,000,000 N/m^2

according to their assembly mode: (a) simple poles, (b) twin poles and (c) strutted poles.

Hence, the sizing to be done for a pole will result in choosing a class, a height and a mode of assembly.

2.2.2. Applied Efforts on the Pole

The wooden pole in service undergoes efforts divided into three (3), according to their direction.

- Vertical effort is made of the conductor's and line accessories weight (**Figure 3**).

Conductors weight on one side and the side other of the pole. It doesn't represent the entire weight of the conductors, but only the portion effectively supported by the considered pole.

In the further work, only the resulting force (V) will be considered.

- Longitudinal effort is the result of the conductors' tensile strength (**Figure 4**).

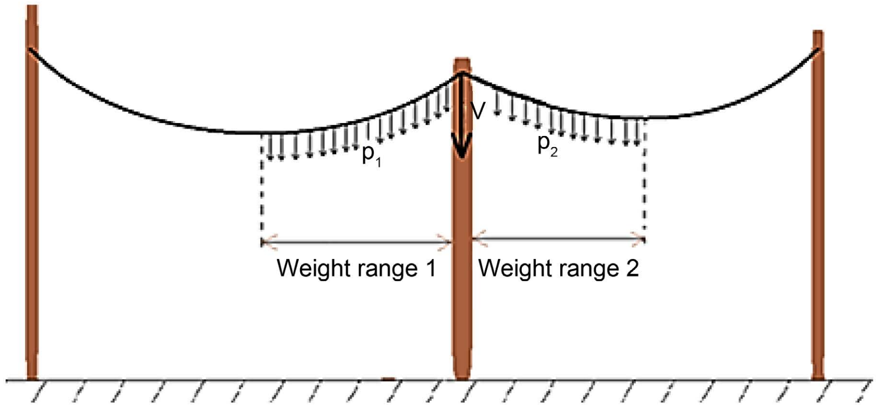

Figure 3. Vertical effort on the pole.

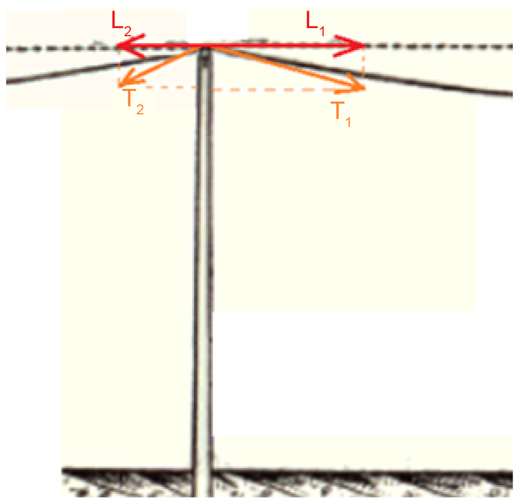

Figure 4. Longitudinal effort on the pole.

The contact action of the conductor on the pole (Ti) has two components: the vertical is nothing else than the conductor's weight, and the horizontal component (Li) is the tensile strength of the conductor. This is the one counted as longitudinal effort.

In the further work, only (L) will be considered as the resultant of the tensile strengths of the different conductors linked to the pole.

- Transverse effort is due to the action of wind, both on the pole and on the carried conductors (**Figure 5**).

Wind actions on the conductor (t1) and on the pole itself (t2).

In the further work, only (T) will be considered as the resulting transverse effort applied on top of the pole. This will produce the same effect (bending moment) as the two previous extended forces.

- The balance of the applied efforts on the pole is represented on **Figure 6**.

The forces are used according to the chosen limits of the dimensioning. The permanent effort is used for dimensioning the pole with regards to its elastic limit. It takes into account the loads that the pole must support at all times, and is determined assuming the minimum wind and the minimum tensile strength of

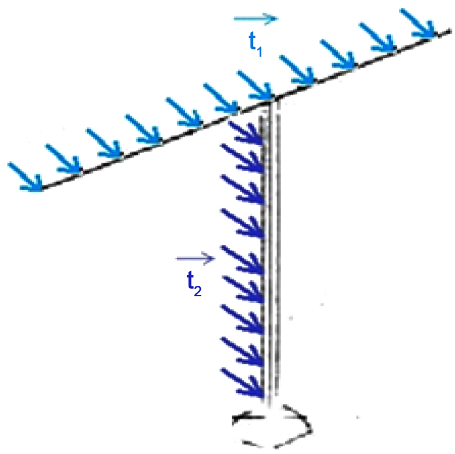

Figure 5. Vertical effort on the pole.

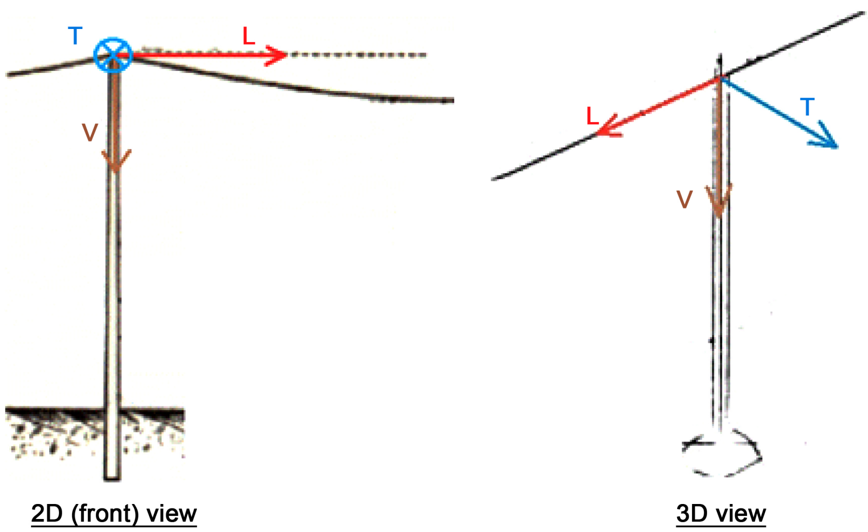

Figure 6. Balance of the applied efforts on the pole.

the conductors.

The nominal effort is used for dimensioning the pole with regards to its breaking limits. A value is determined for each of the possible climatic conditions in the area, and the maximum value is used for dimensioning.

3. Methods

The methodology used for dimensioning wooden poles is the synthesis of four calculation approaches below:

1) The one established by the French "the French Electricity Transmission Network (RTE)" [11];

2) The one promulgated by the Belgium "the General Regulation on Electrical Installations (RGIE) of Belgium" [12];

3) The one adopted for the calculation of the American electricity network [13];

4) The one in force in Cameroon [4].

This approach is articulated around eight main steps: the choice of the conductor and accessories, the evaluation/balance sheet of the loads and efforts directly sustain by the conductor, the verification of the conductor to vibrations, the calculation of the (minimum) height of the support, the efforts (and the moments) which will apply to the support, the choice of the support and the choice of the embedding. Since we are working on an existing network, our work will consist of collecting data on those elements, to evaluate the loads and stresses on the conductors of the line, and to calculate the forces applied to the poles and compare these forces with the nominal forces.

3.1. Efforts on the Conductor

To dimension a pole, it is necessary to take into account the conductor's deflection and the forces that the conductor transfers to the pole.

3.1.1. La the Arrow

A conductor suspended between two posts takes the form of a chain with the equation:

$$y = a \cdot ch\left(x/a\right) \quad [14]$$

and its deflection given by:

$$f = p \cdot d^2 / 8T \quad [15]\ [16] \tag{1}$$

With *f*: conductor's beam (m), *p*: conductor's linear weight ($N \cdot m^{-1}$), *T*: conductor's horizontal tensile strength (N), and *d*: distance between the two poles (m).

3.1.2. Mechanical Tension

The mechanical stress of the conductor is affected by the weather conditions. To take this into account, the following equation of state is to be used:

$$\frac{p^2 \cdot d^2}{24T^2} - \frac{T}{E \cdot S} - \alpha \cdot \theta = \text{constant} \quad [17]\ [18] \tag{2}$$

With *p*: conductor's linear weight ($N \cdot m^{-1}$), *T* conductor's horizontal tensile strength (N), *d*: distance between the two poles (m), *E*: conductor's Young modulus (MPa), *S*: conductor's section area (mm^2), α: conductor's linear expansion coefficient ($^\circ C^{-1}$) and θ: temperature ($^\circ$C).

In practice, the state Equation (2) is used to determine the value of the mechanical tensile strength T in the conductor in different climatic conditions, and Equation (1) then gives the beam.

3.2. The Various Efforts Applied on the Pole by Conductor

These efforts are vertical effort, longitudinal effort and transverse effort.

3.2.1. Vertical Effort

The vertical effort corresponds to the amount of the conductors' weight effectively supported by the pole. It is worth:

$$p = \rho \cdot S \cdot I_p \cdot g \quad (3)$$

With p: conductor's weight (N), ρ: conductor's density (kg·m^{-3}), S: conductor's section area (mm^2), I_p: weight rang of conductor (m) and g: gravity (N·kg^{-1}).

3.2.2. Longitudinal Effort

The longitudinal effort is the result of mechanical tensile strength of the conductors linked to the pole.

$$F = \frac{1}{2} k \cdot \rho_a \cdot v^2 \cdot C_x \cdot D \cdot l_v \ \ [19] \quad (4)$$

With F: wind action on conductor (N), k: dispersive coefficient (no unit), ρ_a: wind density (kg·m^{-3}), v: win speed (m·s^{-1}), C_x: aerodynamic coefficient (no unit), D: conductor's diameter (m) and l_p: weight rang of conductor (m).

The term given by $\frac{1}{2} k \cdot \rho_a \cdot v^2$ is called wind dynamic pressure, and often noted q_{dyn}.

3.3. Wood Pole Computation

In general, the support is similar to a vertical beam embedded at its lower end and subjected, in addition to the effect of its own weight, to two other types of stress:

- A compression force, due to the weight of the conductors on either side of the support;
- A bending stress, resulting from the action of the wind on the support itself or on the conductors, and possibly from the asymmetry of the conductors.

3.3.1. The Pole's Height

The total height of a support is the sum of: the installation height h_{im}, the ground clearance H_{ground}, the maximum conductor's beam f, and the head height h_{head} [4]. (**Figure 7**).

It is given by the formula:

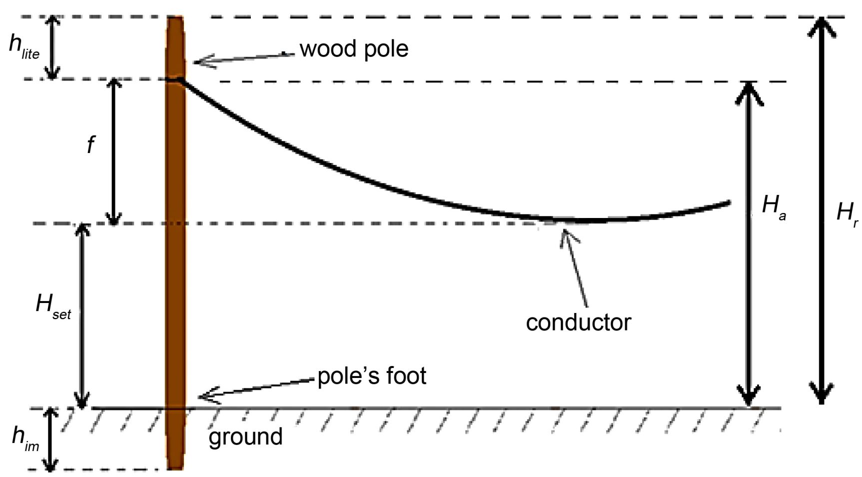

Figure 7. Characteristic heights of a pole.

$$h_{im} = 0.1H_{ground} + 0.5 \tag{5}$$

With H: pole height (m), h_{im}: implanted height (m), H_{ground}: ground clearance (m), f: conductor's beam (m) and h_{head}: pole's head height (m).

Head height depends on the armament of the pole, and is usually between 0 and 0.5 m for the highest placed conductors. Ground clearance is settled by an inter-ministerial order, and depends on the area [20]. *Implanted height* approximately worth:

$$h_{im} = 0.1H_{ground} + 0.5 \quad (\text{in meters}) \tag{6}$$

Conductor's beam is determined by Equation (1) previously given; here, it is its maximum value.

3.3.2. The Stress on the Pole

The various efforts are calculated individually, and then combined according to the principle of the resulting moment [12].

1) Longitudinal effort

The moment of the longitudinal effort, calculated regarding the pole's foot, is given by:

$$M\_1 = T.H\_\propto \tag{7}$$

With M_1: momentum of the longitudinal effort (N·m), T: conductor's horizontal tensile strength (N) and H_a: anchorage height of the conductor (m)

And $H_a = H - h_{im} - h_{head}$ (in meters) (8)

2) Transverse effort

The transverse effort is made up of the wind action, both on the pole itself and on the conductors. The related moments are calculated using formulas:

$$M_{t1} = 0.5C_{Xp} \cdot q_{dyn} \cdot D' \cdot H_r^2 \quad [12] \tag{9}$$

With M_{t1}: momentum of the wind action on the pole (N·m), C_{xp}: pole's aerodynamic coefficient (no unit), q_{dyn}: wind dynamic pressure (N·m^{-2}), D': pole average diameter (m) and H_r: height above ground (m).

$$M_{t2} = F \cdot H_a \tag{10}$$

With M_{ta}: momentum of the wind on the conductor (N·m), F: wind action on the conductor (N) and H_a: anchorage height of the conductor (m).

Transverse effort is then given by:

$$F_{transversal} = \left(M_{t1} + M_{t2}\right)/H_r \tag{11}$$

On another hand, the combined resulting moment worth:

$$M = M_l + M_{t1} + M_{t2} \tag{12}$$

The resulting head effort applied to the pole is then given by [4]:

$$F_{tete} = M/H_r \tag{13}$$

This effort, and the height previously determined, is the basis on which the convenient pole is chosen among the common poles listed in the catalogue (see **Appendix 1**).

For the wood poles of the line that have a particular function, it is preferable to check that the permanent effort remains under the value causing plastic deformation. This value is given by the pole's catalogue [10].

3.3.3. Stresses and Deformations

The aim here is to determine the stresses and strains and to check that they remain below the permissible limit values [11]. We have used the "ideal model with the characteristics of the minor fiber" [12] [21]. It will be the model of a vertical straight cylindrical beam, whose diameter is either the head diameter of the pole or the foot diameter, whichever is the most unfavorable, and whose mechanical characteristics will be taken equal to those of the least resistant fibers found in Saligna eucalyptus trunks.

1) Bending stress

The bending of the pole is due to horizontal loads.

The bending moment M_f at the embedment has the following components:

$$\left(H_r - h_{head}\right)\cdot F + 0.5\cdot q_l\cdot H_r^2 \text{ et } \left(H_r - h_{tete}\right)\cdot T \quad [22] \tag{14}$$

The resulting maximum stress is then determined:

$$\sigma_f = \frac{M}{I_G}\cdot D_p \tag{15}$$

With σ_f: maximum flexion stress, M: resulting bending moment (N·m), I_G: quadratic moment of the seciton (m^4) and D_p: pole's diameter (m).

This stress must be less than the maximum permissible value (breaking limit for supports in alignment, and elastic limit for the others). Otherwise, a column with a larger diameter is chosen, which will have a greater quadratic moment and a reduced stress.

2) Horizontal beam

Given the horizontal loading of the posts, this maximum deflection has two components, which can be found from the deformation equation:

$$\frac{u''}{\left(1+u'^2\right)^{3/2}} = \frac{M}{E_b\cdot I_G} \quad [23] \tag{16}$$

With u pole's beam (m), M: resulting bending moment (N·m), I_G: quadratic moment of the seciton (m^4) and D_p: pole's diameter (m).

To check that it is less than 5% of H_r (the dot is times Hr). If not, a pole with a larger diameter is chosen, which will have an enlarged quadratic moment of the section and a reduced deflection.

3) Buckling

Here the values are calculated to ensure that the pole does not buckle too much under vertical loading. These are on the one hand the pole's *twinge* λ and on the other hand the buckling critical load N_c.

Let us recall the formulas of the critical buckling load.

$$N_c = \frac{\pi^2\cdot E_b\cdot I_G}{4\cdot H_r^2} \quad [21] \tag{17}$$

With λ: pole's twinge (no unit), λ_{lim}: pole's limit twinge (no unit), N_c buckling critical load (N), I_G: quadratic moment of the section (m^4), E_b eucalyptus young module (Pa), H_r: height above the ground, (m), S_p pole's section area (m_2) and R_e pole's stress limit (Pa).

And critical constraint:

$$\sigma_c = \frac{\pi^2 \cdot E_b \cdot I_G}{4 \cdot S \cdot H_r^2} = \frac{\pi^2 \cdot E}{\lambda^2} \quad [24] \tag{18}$$

We determine:

- the limit twinge of Euler of our material, which is around 180:

$$\lambda_{lim} = \pi \cdot \frac{E}{R} \quad [21] \tag{19}$$

- the current twinge of our pole is:

$$\lambda = 2 \cdot H_r \cdot \sqrt{\frac{S}{I_G}} \quad [21] \tag{20}$$

Then, two situations are conceivable.

➢ If $\lambda \geq \lambda_{lim}$, Euler's considerations apply, and it must be verified that:

$$\frac{u''}{\left(1+u'^2\right)^{3/2}} = \frac{M}{E_b \cdot I_G}$$

P: conductor's linear weight ($N \cdot m^{-1}$).

(3 is the buckling safety coefficient used in this hypothesis).

If $\lambda_{lim} > \lambda \geq 20$, Rankine's empirical considerations apply, and it is a question of verifying that:

$$p \leq \frac{\pi^2 \cdot E \cdot S}{2 \cdot \left(\lambda_{lim}^2 + \lambda^2\right)} \quad [21] \tag{21}$$

If $20 \geq \lambda$, there is safety to buckling, and it is a question of checking that

$$p \leq \frac{2}{3} \cdot R_e \cdot S \tag{22}$$

In any case, if buckling safety is not guaranteed, a pole with a larger diameter should be chosen.

4. Results

4.1. Data of Nkoabang D17 Line

The voltage at the start of the line is set at 15 kV, and transformers are installed at the points where it is necessary to lower the voltage. The line is divided into 76 laying cantons. A canton is a continuous portion of the line, at the ends of which anti-cascade devices are fitted. The poles placed at the ends of a canton are therefore dimensioned to support the entire canton in the event of an incident.

The poles are divided into 4 categories, according to their position and function on the line. The stop poles are at the ends of the line. Corner poles are those where the line deviates by more than 10˚. This deviation is the angle measured between the direction of the conductor arriving at the poles and the direction of the conductor leaving the post on the other side. The anchor poles are at the ends of the installation cantons. The other poles, which are neither at particular points nor have a particular function, are called alignment or suspension poles.

The data of the power line are summarized in **Table 3** below.

For conductors, an inter-ministerial decree gives the values of the different ground clearances according to the type of pole [20] (see **Appendix 2**).

The dimensioning calculation is carried out for each installation canton. Within the same canton, the mechanical tension of the conductors is constant, and the conductors have the same characteristics (except in the case of derivation).

4.2. Application to the First Pole of the First Canton

A pole of the first canton is selected for this application. The data collected on the field are recorded in **Table 4** below, and explicit calculations follow.

4.2.1. Computation of the Pole's Height

In addition to the scope of data, we must take into consideration: ground clearance, linear weight and minimum mechanical tensile strength of the conductor, at 75˚C [3].

The computation using formula (1) then gives the beam $f \approx 1.08\ \text{m}$.

The attachment methods and the minimum distances to keep between the

Table 3. Characteristics of the D17 Nkoabang power line.

Data	Value
Initial voltage level (MV)	15 kV
Total line length (derivations included)	27.93 km
Number of anchorage poles	80
Number of angle poles	203
Number of suspensions	562
Total number of poles	845, among which 396 on derivations
Number of cantons	76

Table 4. Data concerning the first pole of the first canton.

Pole	Function	Conductors	Weight ranges (m)	Wind ranges (m)	Ranges (m)
Twin D12	Stop	3xalm54 3xalm93	8.1 8.1	8.1 8.1	16.1 16.1

NB: The writing "3xalm54" indicates the presence of three conductors (three-phased line), made of almelec, with a section area of 54 mm^2. The same logic is extended to similar designations.

conductors and the way they are linked to this pole impose a minimum value for the head height $h_{head} \approx 0.8$ m.

Therefore, the pole's height can be extracted from Equation (5): $H \approx 11.75$ m.

Appendix 2 gives the ground clearance equal to 8.2 m and Equation (5) then gives the height of the pole: $H \approx 11.75$ m. This calculation confirms that a 12 m height is correct for this pole.

4.2.2. Computation of the Vertical Effort

In addition to previous data (**Table 4**), the conductor's density (**Table 1**) is to be considered. Formula (3) gives the weight of the conductors effectively supported by the pole: $P \approx 95$ N.

The mass of the various line accessories supported by this pole (isolators, fasteners, armament) is evaluated to 37 kg, which implies an additional load of 362.4 N.

The vertical effort is the direct sum of these two loads, giving $F_{vertical} \approx 475.4$ N.

The total mass of the various accessories supported by the pole (insulators, fixing elements, reinforcement) is evaluated using the data in **Appendix 3** is 37 kg, resulting in an additional load of 362.4 N.

The vertical force is the sum of these two loads, *i.e.*, $F_{vertical} \approx 475.4$ N.

4.2.3. Computation of the Transverse Effort

In addition to previous data, must be considered: aerodynamic coefficients for the conductors and the pole [2], conductor's diameter [2], wind dynamic pressure in the retained climate hypothesis [3], pole's average diameter [3], anchorage height and height above ground. The data are recorded in **Table 5** below, for this pole.

Formulas (4), (9), (10) and (11) enable to find $F_{transversal} \approx 4614.1$ N.

4.2.4. Computation of the Longitudinal Effort

In addition to previous data, it is needed to know: Young modulus and linear expansion coefficient for the conductor (**Table 6**), tensile strength imposed at the implementation of the conductors [3], linear masses, and section areas.

A computer-based resolution from the state Equation (2) provides the maximum expectable tensile strength in the conductor, in the hypothesis of considered climate. The longitudinal effort is then deducted as the resultant of these tensile strength: $F_{longitunal} \approx 12921$ N.

Table 5. Additional data for the computation of the transverse effort.

q_{dyn}	Poteau	C_{Xp}	D_p (m)	Conductor	C_X	D (mm)	H_a (m)	H_r (m)
960 Pa	Twin D12	0.126	0.21	Alm54 Alm93	1.2 1.45	9.45 12.50	10.05 9.3	10.3

Table 6. Additional data for the computation of the transverse effort.

Conductor	Linear mass (kg/m)	Section area (mm^2)	Implanted tensile strength (N)
Alm54	0.149	54.55	940
Alm93	0.258	93.30	1620

4.2.5. Computation of the Resulting Effort in Head of the Pole

Considering the previous given data and found results, this effort can be computed from formulas (7), (12) and (13). For this pole, we find $F_{head} \approx 12930\ \text{N}$.

4.2.6. Computation of the Pole's Maximum Bending Stress

The resulting bending moment applied on the pole and its average diameter are known already. Formula (15) provides the value of the maximum bending stress in the pole $\sigma_f \approx 7.324 \times 10^7\ \text{Pa}$.

4.3. Application on the First Laying Canton

The data collected in the field that have to be taken into account for the calculation. They are compiled in **Appendix 4**.

Using these data, we determined the spans for the laying canton and the spans for each pole. These spans are given in **Appendix 5**.

4.3.1. Calculation of Pole Force of the First Canton

By applying the same method of calculating forces applied to the first pole of the first canton, and other the poles of canton, the values of the vertical, transverse, longitudinal and nominal forces applied are determined.

Table 7 summarizes the results of these calculations and the nominal allowable stress for each pole.

4.3.2. Forces Calculation of the Column of Particular Function

Poles with particular function in this canton are Pole's Order 1 (stop pole), Pole's Order 5 (deviation pole) and Pole's Order 11 (anchorage pole). For these poles with a special function, it must also be checked that they do not acquire any noticeable plastic deformation. For this checking, the permanent forces have to be calculated (Table 8).

4.4. Assessment of the Entire Line

Similar calculations were applied to all columns in all cantons line for vertical, transverse, longitudinal and permanent loads. These calculations were used to establish the loading status of the poles of the entire line.

5. Discussions

5.1. First Pole of the First Canton

5.1.1. Height Verification

The height found for this first pole is: $H \approx 11.75\ \text{m}$ Calculations confirm that a

Table 7. Applied forces on pole of the first canton and nominal admissible force.

Pole's Order	Vertical Effort (N)	Transverse Effort (N)	Longitudinal Effort (N)	Resulting Top Nominal Effort (N)	Resulting Top Nominal Effort (N)	Eligible pole's Top Nominal Effort (N)
1	D12 strutted	460	465	12,921	12,930	**7350**
2	D12 strutted	1047	1435	8866	8982	**7350**
3	11 concrete	249	787	0	787	**3250**
4	E12 simple	752	2150	1950	2903	**3250**
5	C12 strutted	1558	1944	3616	4106	4800
6	D12 strutted	762	1617	1300	2075	**7350**
7	D12 simple	644	1040	0	1040	**2450**
8	D12 simple	779	1520	1300	2001	**2450**
9	D12 simple	891	1861	0	1861	**2450**
10	D12 simple	859	1845	2100	2796	**2450**
11	D13 strutted	759	1369	5900	6057	**7050**

Green color => the pole suitably withstands the efforts. Yellow color => the pole withstands the efforts, but is close to its limits. Red color => the pole is loaded over its eligible limits.

height of 12 m is well indicated for this pole.

5.1.2. Verification of Nominal Effort at Nominal Allowable Forces

The resulting nominal effort is $F_{tete} \approx 12930\text{ N}$.

This value is compared with the eligible nominal efforts listed in the pole's catalogue. The lowest pole found capable of supporting this effort is the *strutted D*12.

5.1.3. Checking in Relation to Bending

The maximum bending stress is $\sigma_f \approx 7.324\times10^7\text{ Pa}$ The limit value for this pole (given in Table 2) is 5.5 × 10^7 Pa.

This result leads the need to select a pole with higher bending strength. The closest suitable pole is D12, which is strutted.

5.1.4. Findings

The pole in place here (type D12 twin) is no longer suitable for the forces to which it is subjected, in particular the nominal force at the head of the pole and the bending stress. It must be replaced by a D12 type pole that is strutted.

5.2. First Canton of Installation

5.2.1. Checking the Efforts in Head

By comparing the head stress of each pole with its nominal allowable stress, we find that: three poles from the first canton (Pole's Order 1, 2 and 10), are 27.27% of the poles must be replaced, three other poles (Pole's Order. 4, 5 and 8), are

27.27% of the poles need to be monitored as their head forces are close to their nominal allowable forces five poles are 45.45% of the poles hold the forces perfectly.

5.2.2. Checking the Yield Strength of Poles with Special Functions

By comparing the permanent stress of each pole with its permissible permanent stress from Table 8, we can see that the permanent stress of Pole's Order 1 is above its yield strength, while that of Pole's Order 5 is slightly below its yield strength.

5.2.3. Conclusion

Out the 11 poles in the first canton, three poles (27.27%) need to be replaced. Three other poles (27.27%) are considered sensitive, but can still be retained. The types of replacement posts are shown in Table 9.

5.3. Overall Assessment of the Entire Line

Based on the calculations results of the stress and strain obtained on the 845 poles of the line, we have established the loading status of the posts of the entire line. This state is summarized in Table 10 below.

Table 8. Permanent efforts for the poles with particular function in the first canton.

Pole's Order	Effort V (N)	Effort T (N)	Effort L (N)	Permanent Effort (N)	Eligible Permanent Effort (N)
1	460	254	8502	8506	**3650**
5	1558	994	2524	2713	**2800**
11	759	685	4094	4151	**3550**

Table 9. Poles to be replaced on the first canton.

Pole's number	Function	Current poles	To be replace by
1	Departure	D12 twinned	D12 strutted
2	Angle	D12 twinned	E12 twinned
10	Derivation	D12 simple	E12 simple

Table 10. Loading status of the supports according to their function on the whole line.

Type de support	Stop/ Anchorage poles	Deviation poles	Suspension poles	Total number of poles
Poles to be replaced	26	76	67	169
Poles loaded near limit	32	71	177	280
Pole suitably withstanding the efforts	22	56	318	396

We evaluated the percentages of poles to be replaced along this line. Figure 8 shows these percentages by support loading condition.

It emerges from this assessment that almost 53% of the poles need to be replaced or monitored, with 20% of the poles to be replaced automatically.

Out the 20% of poles to be replaced, 45% are corner poles, 40% are alignment poles and 15% are anchor or stop poles (Figure 9).

6. Analysis of the Causes of Poles Overloads and Proposal of Remedial Solutions

The high percentage of supports to be replaced on the network with less than three years of operation led us to carry out an in-depth analysis of the D17 Nkoabang line. This analysis revealed that many poles were overloaded by additional elements during their operation (see Picture 1). Among these elements, we can mention.

- Added Conductors by ENEO to meet the electricity needs of populations, establishments or industries newly established in the area;

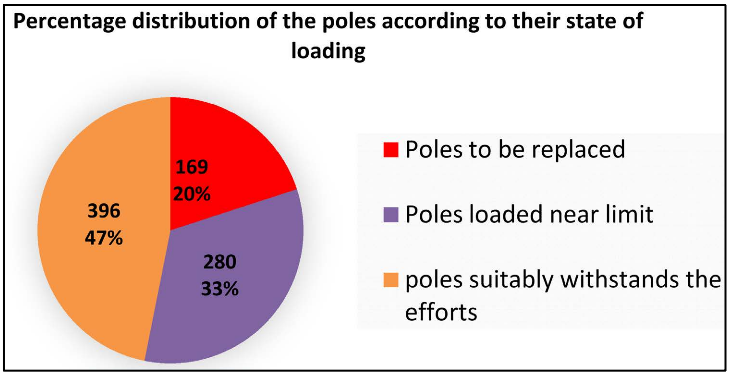

Figure 8. Percentage distribution of posts according to their state of loading.

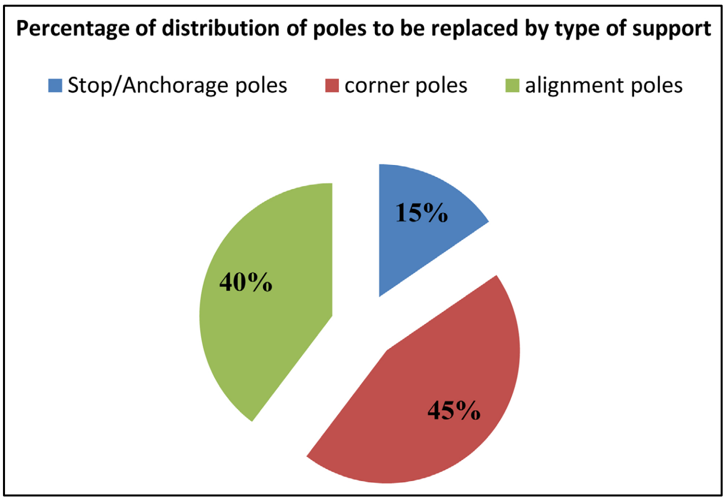

Figure 9. Percentage distribution of poles to be replaced per type of support.

Picture 1. State of the supports of line (TEG picture).

- TV cable distribution conductors;
- banners and posters;
- Unrecognised conductors added by third parties for the purpose of fraudulent supply of electricity from the ENEO network;
- Lampposts.

6.1. Determination of the Expected Overload Coefficients of the Supports

We carried out an evaluation of the loads initially planned on the supports during the installation of the line (loads used for the initial dimensioning of the poles by ENEO) and the actual loads carried by each of the supports after three years of operation. For these two loads, we determined the vertical, longitudinal and transverse components. These components allowed us to evaluate the resulting loads on each support. The results recorded in Table 11 illustrate these overloads on a few critical supports.

We have determined the overload coefficients for the different forces that stress the pole by making the ratios of the different forces. We have:

$$k_{overload} = \frac{\text{actual effort on the 3 years of usage}}{\text{planned effort during initial sizing}} \tag{23}$$

The average overload coefficients by direction of effort are summarized in Table 12.

6.2. Propositions

In front of the difficulty of preventing these overloads, which are mainly caused by acts of incivility, we propose that these overloads be included in the initial dimensioning of the poles from now. Therefore, these overload coefficients can be considered as second safety coefficients for future dimensioning of power line

Table 11. Etude comparative de charges sur les poteaux les plus surchargés.

Poles	Originally planned loading	Corresponding efforts (N)	Actual loading	Actual efforts (N)
Twin C12	3xalm54 3xalm93	Vertical: 810 Longitudinal: 1300 Transverse: 870 Resulting: 1762	3xalm54 3xalm93 2xalm34 3xalm93 3xalm34	Vertical: 1615 Longitudinal: 1480 Transverse: 1215 Resulting: 2505
simple D12	3xalm54	Vertical: 380 Longitudinal: 0 Transverse: 510 Resulting: 636	3xalm54 3xalm93 2xalm34 Other ca-bles	Vertical: 812 Longitudinal: 235 Transverse: 875 Resulting: 1217
simple D11	3xalm93 3xalm34	Vertical: 640 Longitudinal: 0 Transverse: 710 Resulting: 956	3xalm93 3xalm93 3xalm34 3xalm34 Lampposts	Vertical: 1523 Longitudinal: 498 Transverse: 1354 Resulting: 2098
simple C11	3xalm93 3xalm34	Vertical: 640 Longitudinal: 0 Transverse: 735 Resulting: 975	3xalm93 3xalm93 3xalm34 3xalm34 Other ca-bles	Vertical: 1025 Longitudinal: 546 Transverse: 1049 Resulting: 1565
Twin D12	3xalm54 3xalm93 3xalm34	Vertical: 1020 Longitudinal: 3200 Transverse: 1040 Resulting: 3516	3xalm54 3xalm93 3xalm34 3x3xalm34 Other ca-bles	Vertical: 1210 Longitudinal: 3048 Transverse: 3840 Resulting: 5050
Twin C12	3xalm54 3xalm93	Vertical: 810 Longitudinal: 1840 Transverse: 1156 Resulting: 2320	3xalm54 3xalm93 3x3xalm93 3x1xalm34	Vertical: 1575 Longitudinal: 2140 Transverse: 3475 Resulting: 4375
simple D12	3xalm54	Vertical: 380 Longitudinal: 0 Transverse: 915 Resulting: 991	3xalm54 3xalm54 3x3xalm34 Other ca-bles	Vertical: 789 Longitudinal: 1010 Transverse: 1355 Resulting: 1866

Table 12. Overload coefficients (empirical determination).

Effort type	Overloading coefficient
Vertical	2.38
Longitudinal	1.17
Transverse	3.70
Resulting	2.20

poles in the region. For this reason, for:

- ✓ The calculation of the nominal and permanent resultant stress, an additional coefficient of 2.2 will be applied to the stress;
- ✓ Buckling verification, and in particular the calculation of the critical buckling load, an additional coefficient of 2.38 will be applied to the stress;
- ✓ The verification at bending, an additional coefficient of 3.7 will be applied.

7. Conclusions

After analyzing the current line supports, we found the load of each pole, and compared these current forces to the nominal forces of the poles. The results of this comparison show that:

169 of the 845 poles in the line (20%) must be replaced because they either support nominal forces ranging from 113% to 150% of the admissible limit, or they are stressed beyond the limits in bending or buckling.

Another 280 posts (33%) must be monitored as they are almost at their limit (85% - 98% of the permissible limit).

Regarding the overloads of the poles, we carried out an evaluation of the loads initially foreseen on the supports during the installation of the line (loads used for the initial dimensioning of the poles by ENEO) and the actual loads carried by each of the supports after three years of the operation. We then determined the two load cases on each pole, evaluated the resulting loads on each support in both cases and calculated the overload coefficient by reporting the different loads. From these calculations, it appears that the average overload coefficients by direction of force are: 2.38 for the vertical force, 1.17 for the longitudinal force and 3.70 for the transverse force. The resulting force has an overload coefficient of 2.20.

Face to the difficulties of preventing overloading poles extending the life span of the pole, hence reducing the emission of greenhouse gases by reducing the number of eucalyptus trees to be cut, we propose these overload coefficients which are considered as second safety coefficients for future dimensioning of power line poles in the region and, in addition, the effects of different modes of loading each individual pole should be checked. To this end, for the calculation of:

- ✓ The nominal and the permanent resultant force, an additional coefficient of 2.20 will be applied to the force;
- ✓ The critical buckling load (buckling check), an additional coefficient of 2.38 will be applied to the stress;

- ✓ The maximum resultant stress (verification at bending), an additional coefficient of 3.70 will be applied to the stress.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] ENEO (2019) ENEO 2019 Annual Report. ENEO, Cameroon. http://eneocameroon.cm/pdf/Rapport_Annuel_Eneo2019.pdf

[2] Dadji, T.R. (2020) Sizing of Power Lines' Supports: Case of the Line D17 Nkoabang of ENEO Network. Dissertation, Yaoundé I National Advanced School of Engineering, Yaoundé, 107 p.

[3] Gaezl, J. (1954) Annual Report of the Geological Survey. Directorate of Mines and Geology, Ministry of Mines and Energy, Yaounde, 135 p.

[4] AES-Sonel (2007) Construction Standard for HTA and LV Overhead Lines on Wooden Poles in Rigid Technology. Networks Direction, AES-Sonel, Cameroon, 144 p.

[5] Chanal, A. and Levêque J.-P. (2008) Overhead Lines: Equipment—Guard Conductors and Cables. Engineering Techniques, Edition Techniques d'Ingenieur, Marseille, 10 p.

[6] Chakira Cable Tunisia (2020) Domestic Low Voltage Cables, Industrial in Distribution. http://www.chakira-cables.com/fr/catalogue.php?id_cable=44&cat=5

[7] Gérard, J., Kouassi, A.E., Daigremont, C., Détienne, P., Fouquet, D. and Vernay, M. (1998) Synthèse sur les caractéristiques technologiques de référence des principaux bois commerciaux africains. The French Agricultural Research Centre for International Development, Paris, 189 p.

[8] Gerhards, C.C. (1965) Physical and Mechanical Properties of Saligna Eucalyptus, U.S. Department of Agriculture, Washington DC, 16 p.

[9] French Agricultural Research Centre for International Development (CIRAD) (1965) Essais de poteaux d'Eucalyptus provenant du Cameroun. http://agritrop.cirad.fr/363961/

[10] AES-Sonel (2009) Spécification techniques pour l'élaboration des poteaux bois. DRES/SDD/DNGT, 28 p.

[11] Réseau de Transport d'Electricité (2000) Cahier de charges général—Lignes aériennes HTB—Ouvrages neufs, 164 p

[12] Houet, O. (1998) Sizing of a Three-Phased Junction. Engineer Dissertation, University of Liège, Belgium, 142 p.

[13] Ditrinou, E. (2003) Modélisation du comportement mécanique des supports de lignes électriques en béton de sable armé et précontraint pour le Réseau d'Electrification Rurale du Sénégal. Universite Cheikh Anta Diop, Thiès, 105 p.

[14] Hatibovic, A. (2014) Derivation of Equations for Conductor and Sag Curves of an Overhead Line Based on a Given Catenary Constant. *Electrical Engineering and Computer Science*, **58**, 23-27. https://doi.org/10.3311/PPee.6993

[15] Douglass, D.A. and Thrash, F.R. (2007) Sag and Tension of Conductor. In: Grigsby, L.L., Ed., *Electric Power Generation, Transmission, and Distribution*: *The Electric Power Engineering Handbook*, 2nd Edition, CRC Press, Boca Raton, 176 p.

[16] Hatibovic, A. (2012) Integral Calculus Usage for Conductor Length Determination on the Basis of Known Maximal Sag of a Parabola. *Periodica Polytechnica Electrical Engineering and Computer Science*, **56**, 35-41. https://doi.org/10.3311/PPee.7076

[17] Anusandhan, S. and Abebe, Y.M. (2015) Overhead Transmission Line Sag, Tension and Length Calculation using Affine Arithmetic. 2015 *IEEE Power*, *Communication and Information Technology Conference* (*PCITC*), Bhubaneswar, 15-17 October 2015, 211-216. https://doi.org/10.1109/PCITC.2015.7438162

[18] Hlalele, T.S. and Du, S. (2013) Real Time Monitoring of High Voltage Transmission Line Conductor Sag: The State-of-the-Art. *International Journal of Engineering and Advanced Technology*, **3**, 297-302.

[19] Chanal, A. (2008) Lignes aériennes, Dimensionnent, Technique de l'Ingénieur, D4421, 2008.

[20] Ministry of Water and Energy Resources (2006) Arrêté interministériel fixant la garde au sol des poteaux pour le réseau de distribution d'énergie électrique en vigueur au Cameroon. Ministry of Water and Energy Resources.

[21] Itterbeek, R. (2017) Chapter 8. Resistance of Material—Buckling. In: *Cahier des Charges General Lignes Aériennes HTB—Ouvrages Neufs* (*CCG—LA Ouvrages Neufs*), RTE, Paris, 80-98.

[22] Réseau de Transport d'Electricité (2000) Cahier de charges général—Lignes aériennes HTB—Ouvrages neufs, 164 p.

[23] Makhlouf, O. and Mansour, N. (2019) Etude de flambement des structures métalliques. Mémoire de master, Université Mouloud Mammeri de Tizi-Ouzon, Tizi Ouzou, 70 p.

[24] Benaissa, A. and Khadraoui, M. (2017) Flambement des barres comprimées et comprimées fléchies-effet de déformation initial et l'excentricité du chargement. Mémoire de master, Université de Tlemcen, Algérie, 87 p.

Appendix 1: Nominal Forces at the Head of the Wooden Poles

1) Simples poles

Nominal efforts F (DaN)

Classe	Head of the wooden poles	8	9	10	11	12	13	14	15
A	Nominal effort	100	100						
	Permanent deformation								
B	Nominal effort	140	140						
	Permanent deformation	35	35						
C	Nominal effort	190	190	175	165	160	150		
	Permanent deformation	45	45	45	45	45	45		
D	Nominal effort	255	255	255	250	245	235	230	
	Permanent deformation	75	75	75	75	75	75	75	
E	Nominal effort		325	325	325	325	325	320	320
	Permanent deformation		110	110	110	110	110	110	110
F	Nominal effort		390	390	385	380	380	380	375
	Permanent deformation		150	150	150	150	150	150	150
G	Nominal effort			550	550	550	550	550	550
	Permanent deformation			200	200	200	200	200	200

2) Twin poles

Nominal efforts F (DaN)

Classe	Head of the wooden poles	8	9	10	11	12	13	14	15
A	Nominal effort	300	300						
	Permanent deformation								
B	Nominal effort	420	420						
	Permanent deformation	205	195						
C	Nominal effort	570	570	525	495	480	450		
	Permanent deformation	250	240	260	250	240	210		
D	Nominal effort	900	900	840	750	735	705	690	
	Permanent deformation	480	450	435	380	365	355	350	
E	Nominal effort		1035	1035	1035	1020	1005	960	960
	Permanent deformation		570	550	540	525	510	500	485
F	Nominal effort		1170	1170	1155	1140	1140	1140	1125
	Permanent deformation		610	600	590	580	570	565	560
G	Nominal effort			1500	1500	1500	1500	1500	1500
	Permanent deformation			750	750	750	750	750	750

3) Strutted poles

Nominal efforts F (DaN)

Classe	Head of the wooden	8	9	10	11	12	13	14	15
A	Nominal effort	900	780						
	Permanent deformation	600	520						
B	Nominal effort	1110	950						
	Permanent deformation	740	640						
C	Nominal effort	1620	1450	1260	1075	930	900		
	Permanent deformation	1080	970	840	720	620	600		
D	Nominal effort	2600	2250	1955	1760	1525	1300	1200	
	Permanent deformation	1735	1500	1320	1180	1050	900	810	
E	Nominal effort		2800	2720	2560	2300	2150	2005	1860
	Permanent deformation		1870	1820	1710	1540	1440	1340	1250
F	Nominal effort		3250	3020	2900	2700	2540	2400	2215
	Permanent deformation		2170	2050	1950	1800	1700	1600	1500
G	Nominal effort			3800	3700	3600	3600	3600	3500
	Permanent deformation			2600	2500	2400	2400	2400	2400

Appendix 2: Ground Guards in Force in Cameroon [20]

Zone	Ground clearance of MV	Ground clearance of LV
Ordinary ground (pavements, fields, …)	6.2 m	4 m
Road crossing	8.2 m	6 m
Railway crossing	Max (7.21 m; train height +2.9 m)	
Crossing of navigable watercourses T	8.2 m Above the high waters	8 m Above the high waters
Crossing of non-navigable watercourses	3 m (high waters) 6 m (low water level)	

Appendix 3: Masses of Line Accessories [2]

Element	Masses	Element	Masses
Single pole	2 kg	Armement tablecloth	20 kg
Isolator 1 plate	4 kg	Tablecloth vault	16 kg
Isolator 2 plates	5 kg	Flag/Triangle	30 kg
Isolator 3 plates	6 kg	Anchoring/stop	40 kg
Grounding	7 kg	Transformer	25 kg

Appendix 4: Data from the First Paving Canton

MV (Medium Voltage), LV (Low Voltage).

Appendix 5: Load-Bearing Capacity Values of the First Installation Canton

Rang	Downward reach (m)	Declination	Conductors	Weight reach (m)	Windward reach (m)
1	50.9 50.9 50.9	−5.1	3xalm54 1xalm34 3xalm34	46.9	47.0 47.0 47.0
2	53.0 53.0 53.0	−1.8	3xalm54 3xalm93 1xalm34	52.0 50.1	52.0 52.0 52.0
3	67.1 67.1 67.1	−6.9	3xalm54 3xalm93 1xalm34	60.4 60.4	60.1 60.1 60.1
4	9.9 88.1 38.8	−1.8	3xalm54 3xalm93 1xalm34	38.7 77.7	38.5 77.6 53.0
5	38.3	0	3xalm54	24.1	24.1
6	49.7	0	3xalm54 1xalm34	44.0	44.0
7	49.9 49.9 49.9	−11.3	3xalm54 3xalm93 2xalm34	50.8 70.0	49.8 69.0
8	28.9 28.9 28.9	−13.8	3xalm54 3xalm93 2xalm34 3xalm93	42.0 42.0	39.4 39.4 39.4
9	47.5 33.4	0	3xalm54 3xalm93 2xalm34	39.9 32.8	38.2 31.2
10	15.6	0	3xalm93 3xalm93 3xalm34	24.5	24.5
11	40.1 40.1	0	3xalm54 3xalm93 3xalm34	45.2 29.3	43.8 27.9