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DEVELOPMENT OF A GRAPHICAL USER INTERFACE FOR ASSIST THE TRANSMISSION LINES DESIGN

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Abstract. *Over the past decades there has been a huge increase in the need for electricity production, which itself is divided into the energy generation and transmission. Thus, due to this great demand needed, there was also the need for technological change in the design approach of electricity transmission lines face the great challenges of distance and environmental conditions with regard to the structural integrity of the transmission line. Transmission lines have peculiar characteristics and should be designed to perform under the action of random excitations, in which the wind action is the main agent, based on current technical standards NBR 5422 and NBR 6123.* Thus, possess tools to assist the user is of fundamental importance. Therefore, *this work will systematize the procedures of multicore cable transmission line project, according to the current technical standards, and develop a systematic computational analysis that will streamline project procedures. To do so, it has been developed a graphical user interface (GUI) in MATLAB, which all design criteria suggested by the current technical standards were implemented. This design tool allows the use of both technical standards combined to estimate the loads in which the transmission lines are subject*

Keywords: *Design Procedures, Transmission Lines, Graphical User Interface*

1. INTRODUCTION

The transmission line project begins with the mechanical design which all the forces acting on the constituent members are determined. The basic conditions for the transmission line project with maximum voltage, effective phase-phase value above 38 kV and not more than 800 kV, in order to ensure minimum levels of security and limit disturbances in nearby locations are set by the NBR 5422, published in 1985 by ABNT - Brazilian Technical Standards Association. The design of a transmission line (TL) involves an analysis sequence, where the interdependencies of electrical, mechanical and environmental parameters that affect the design are studied in order to obtain the operating performance with the lowest cost. Since there is no a tool that can simultaneously analyze all these interdependencies, most often the project is developed to dimensioning-alone each transmission line component. This work will systematize the procedures for multicore transmission line project, according to existing technical standards and develop a systematic computational analysis that will facilitate and accelerate the design procedures.

2. WIND AND TEMPERATURE EFFECTS ON CONDUCTOR CABLES ACCORDING TO THE STANDARDS NBR 5422 AND NBR 6123

2.1 The mathematical function of cable position.

The mathematical function that best represents the curve of a cable suspended between two points is a function known as the catenary. The calculation of the catenary is essential to determine the shortest distance between conductor cable and the ground. Moreover, the NBR 5422 stablish that the shortest distance must not be lower than 10 m, thus, if necessary, that distance must be increased. Power cables are suspended between two towers, forming the catenary, whereas the cable weight is modeled as a uniformly distributed load that accompanies the shape of the cable (so in the deformed condition) one comes to the equation of the catenary, as shown in Fig 1, where "A" and "B" are the transmission towers, "g" is the distributed load, "*A*" is distance between two towers, "X" and "Y" are the coordinates system, "Θ_A" is the slope angle of the line at the suspension point "A" of the tower and "*f*" is the sag. Depending on the environmental conditions and the behavior of the cables, the transmission line catenary changes significantly. According to the type of analysis performed, it is necessary to adopt different hypotheses for the mechanical calculations.

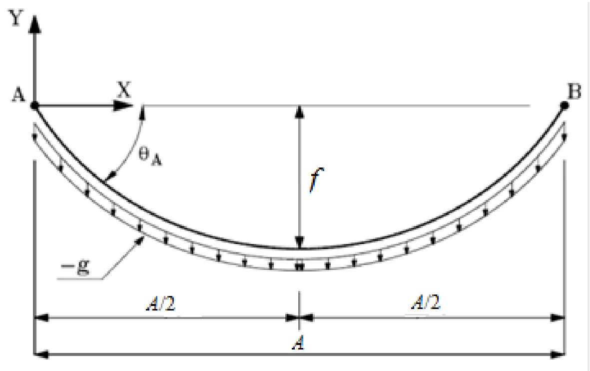

Figure 1. Distributed load on the cable represented by catenary function.

The distance between the ground and the lowest catenary height depends on the transmission line sag, which is defined as the vertical distance between a straight line connecting the two attachment points, namely the rope, and a straight line tangent to the curve. In the case of the cable attachment at the same height, this catenary is symmetrical relative to the central axis (mid-span) where the vertex is located, which is the site of highest sag. The sag depends on the cable weight per unit length (*p*), span length (*A*), temperature (t_0), and the tensile applied to the cable (T_0) when it is installed, and can be calculated assuming a parabola as the function that defines the axis of the cable or taking the form of a catenary, which would be the best approach. In practice, the use of the parabola instead of the catenary leads to small errors when the span is too small, as shown in Eq. (1) (Labegalini *et al*., 1992).

$$f = \frac{pA^2}{8T_0} \tag{1}$$

2.2 Wind Action Effect

The wind incident on the cables encounters a resistance which manifests itself in the form of pressure. This is proportional to wind speed squared, with its resultant force perpendicular to the longitudinal axis of the cables. This force is transferred by the cables to the structures that support them. It is considered that the wind acting perpendicular to the direction of the lines of the cable exerts a pressure (*q*), function of air density (ρ) and the design wind velocity (V_p), given by Eq. (2).

$$q = \frac{1}{2}\rho V_p^2 \tag{2}$$

The basic wind speed (V_0), function of the transmission line location, is multiplied by three parameters: topographic factor (S_1), terrain roughness factor (S_2) and statistical factor (S_3), for determining the characteristic wind velocity (*V*), as shown in Eq. (3). The topographical factor (S_1) takes in account the variations of the relief of the land and the increase of the wind speed in the presence of mounts and slopes, but it doesn't consider the reduction of the turbulence when the wind speed increase. The (S_2) factor considers the combined effect of the ground asperity, the variation of the wind speed with the height above ground and the dimensions of the construction or part of it in consideration. The NBR 6123/88 suggests that the land asperities should be divided in 5 categories. Regarding the dimensions, the constructions had been divided in 3 classes.

$$V = V_o S_1 S_2 S_3 \tag{3}$$

For the diameter (*d*) of the cables and the drag coefficient (*Ca*) the horizontal force resulting, the wind drag force perpendicular to the wires can be determined by Eq. (4).

$$F_a = C_a qd \tag{4}$$

This force is uniformly distributed along the conductor and applies horizontally, transversely to the longitudinal axis of the cables. In the case of the towers supports in the same heights, if only considered the cable own weight effect, the cable will describe a catenary in the horizontal plane (XY) as previously shown in Fig. 1. However, under the simultaneous action of the cable own weight and the wind force (Fig. 2a), the cable suffers an apparent increase in your weight, then operating in the shifted plan of the new catenary *f'*, as shown in Fig. 2b, where γ is the catenary shifted angle.

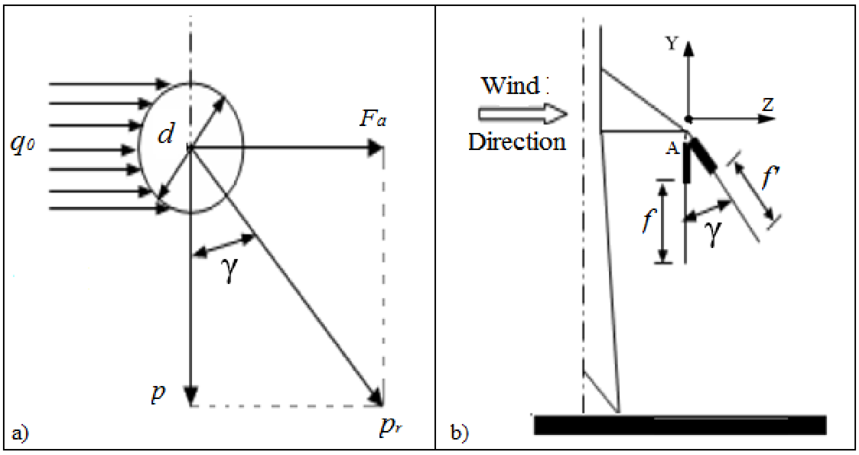

Figure 2. Wind pressure effect on the conductors of an overhead line
(Adapted from Labegalini *et al*., 1992).

Thus observing an apparent weight (p_r), which is calculated in Eq. (5).

$$p_r = \sqrt{F_a^2 + p^2} \tag{5}$$

This apparent increase in weight causes an increase in the cables tractions and the appearance of a transverse horizontal force in the support points, which the structure must absorb. The maximum deflection of the suspended cable in the new plan also increases (Labegalini *et al*., 1992).

2.3 Temperature variation effect

The temperature range also changes the cable tensile and its sag. The linear thermal expansion coefficients of the materials that the cables are made have significant values, causing considerable contractions and expansions under changes in temperature. Thus, there are variations in cable length, implying variations in the sag. On the other hand, the tensile is inversely proportional to the value of the sag. Hence its value will also vary with the conductor temperature variation, meaning that it will increase with decreasing temperature, and vice versa. The most appropriate way to calculate this variation is through so-called equation of state. These equations also enable to estimate the wind effect on the conductors with simultaneous variation of temperatures and wind forces (Labegalini *et al*., 1992).

Through these equations of state, new traction (T_{02}) values can be calculated when considering the effect of wind pressure and temperature. Knowing traction T_{01} of a transmission line at a predetermined temperature t_0, without the action of wind, the traction T_{02} subjected to another temperature t_1 can be found by the Eq. (6).

$$T_{02}^3 + T_{02}^2 \left[\frac{S \cdot E \cdot p^2 \cdot A^2}{24\, T_{01}^2} + S \cdot E \cdot \alpha \cdot (t_1 - t_0) - T_{01} \right] = \frac{S \cdot E \cdot p^2 \cdot A^2}{24} \tag{6}$$

Where:

A – Distance between two towers supports
E – Elasticity modulus
S – Cable cross section area
α – Thermal linear expansion coefficient

3. COMPUTATIONAL PROGRAMING

In this section, it is presented a computational program for the transmission line towers design according to the NBR 5422 and NBR 6123 standards. The platform used for the creation of the program was the Matlab, from a GUI tool to build graphical interfaces for interaction with the user or user through features such as windows, buttons, and menus.

To validate the computer program, the results obtained in Matlab from the user interface are compared to examples from the literature reviewed. The operation of the program is described based on a validation test produced to evaluate the efficiency and performance of the proposed algorithms in this work. Figure 3 illustrates the initial screen of program developed.

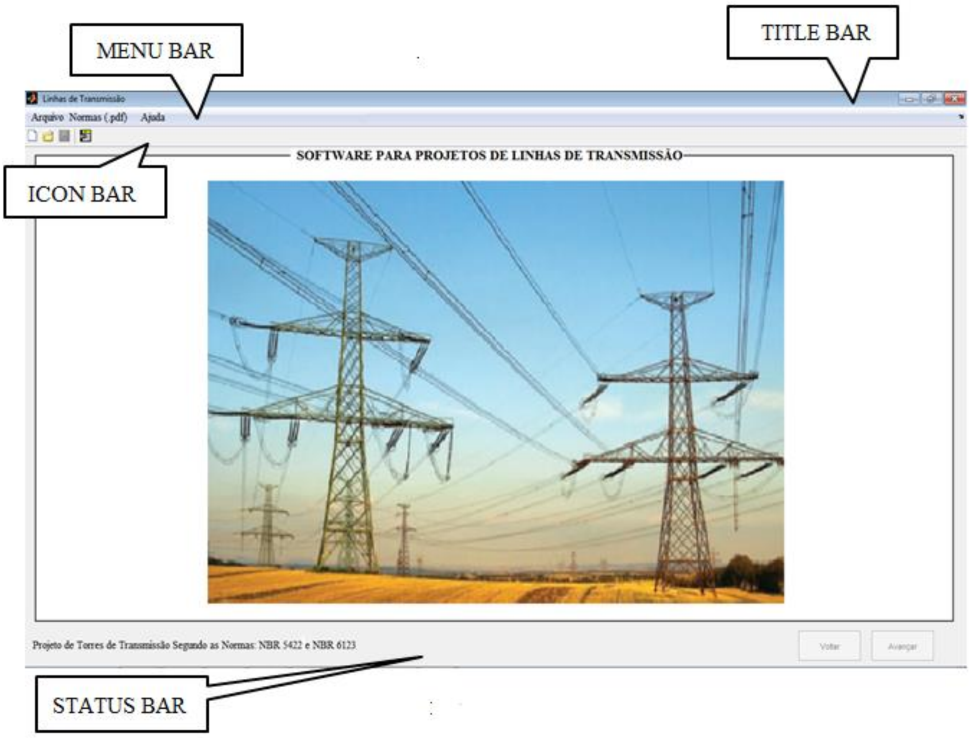

Figure 3. Program initial window

3.1 Case Studies

In order to prove the efficiency and accuracy of the program developed in Matlab, a case studied has been conducted using the same input data used by Bezerra (2010), in which evaluated a transmission line located in the southeast of Brazil. The developed program output results will then be compared with the results obtained in Bezerra's studies. The Table 1 summarizes the input data used for wind temperature and pressure variation hypothesis.

Table 1. Input data for wind loading calculation

Average environment temperature	23 ºC
Coincident temperature	14 ºC
Failure load	115.3 kN
Cable weight (p)	15.7 kN
Nominal wire diameter (d)	0.0296 m
Nominal cable cross section (S)	688.59 mm²
Initial expansion coefficient (α)	0.0000209 1/°C
Elasticity modulus (E)	6679 MPa

In SILHOUETTE TOWER window, shown in Fig. 4, are entering the project input data.

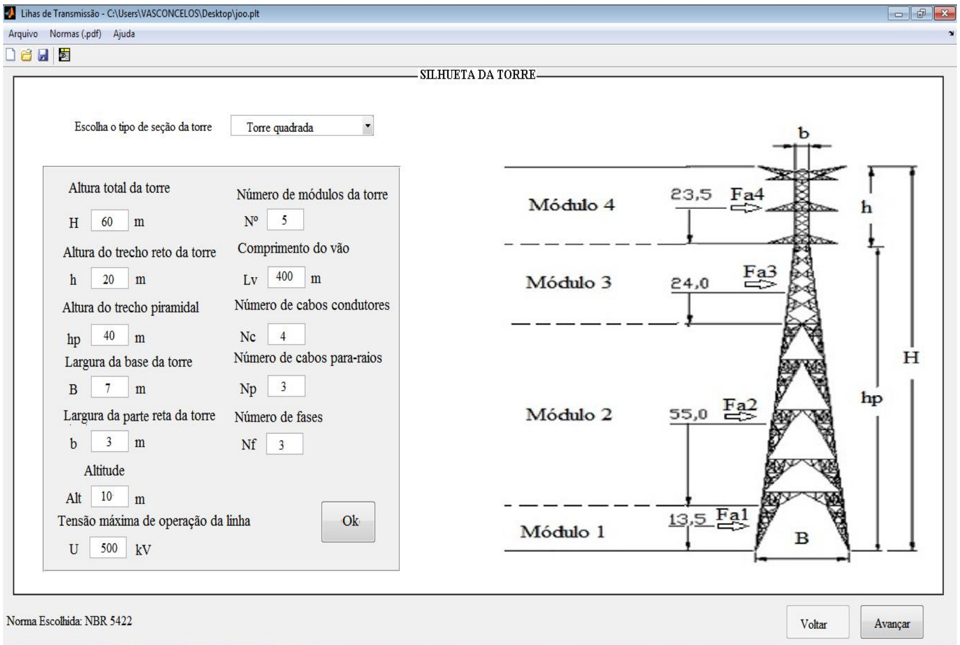

Figure 4. Silhouette tower window

After clicking NEXT, comes the window TEMPERATURES REQUIRED TO DESIGN-DIRECT METHOD. This window is of fundamental importance in this analysis, since the fundamental assumptions in mechanical calculation of the conductors depend on these temperatures. Thus, five given temperatures are: average, average maximum, coinciding, maximum and minimum temperatures. Their values must be inserted in this section, as shown in Fig. 5, according to the weather charts.

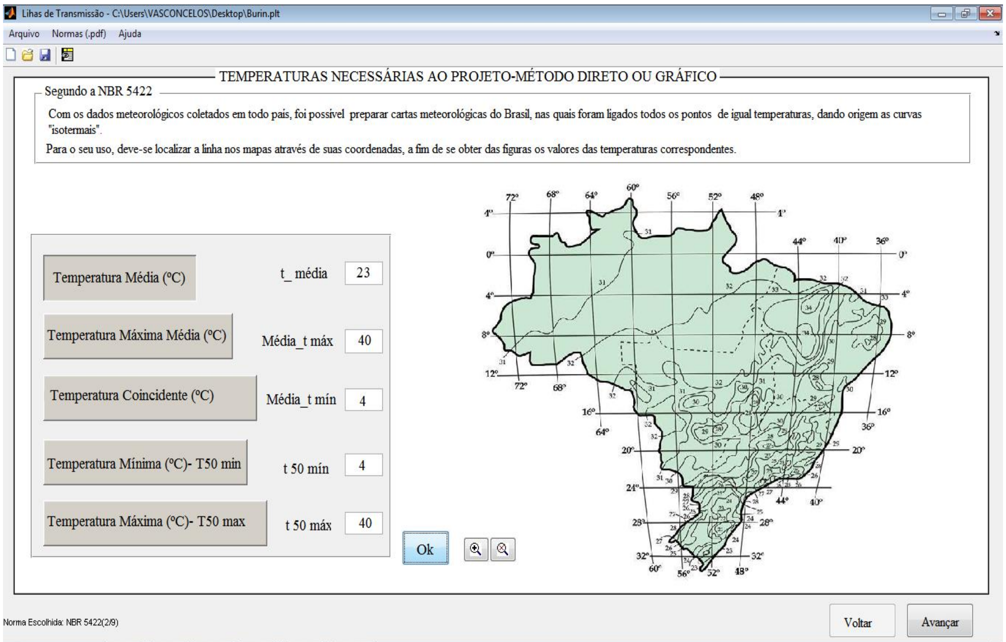

Figure 5. Temperatures required to design-direct method window

Following, comes the BASIC WIND SPEED window (Fig. 6). This speed is of extreme importance, as well as representing the first given information on the effect of wind on the conductors. From this information, it is possible to calculate the value of the design speed and consequently the dynamic pressure.

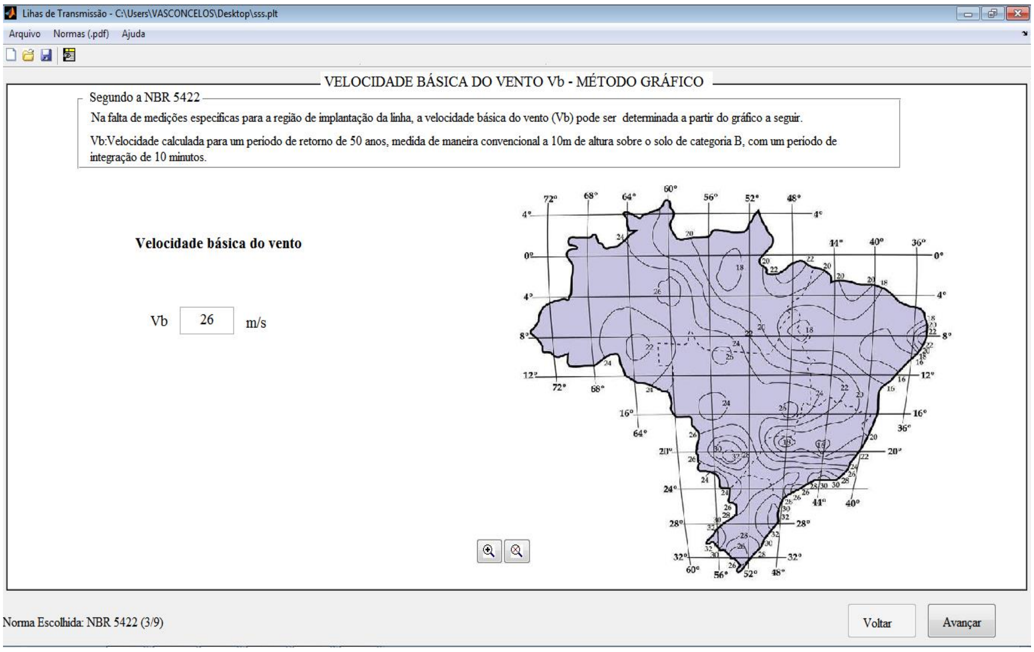

Figure 6. Basic wind speed window

The next window is called STATIC BEHAVIOR OF CONDUCTOR CABLES (Fig. 7). First, the span type (leveled span or unleveled span) must be chosen from the hypothesis of calculation for cables, where it is observed the temperature change and the wind effect hypothesis. Figure 7 represents the hypothesis of longer duration. This is used as an initial hypothesis for comparison with the other, in this case maximum load hypothesis. After completing the input data simply click the button labeled "OK" so that the program can do the calculations and present the output data. Next to the input parameters, the image produced by the program with the results is shown. This illustrates the shape of the cable and the towers positioning.

As the tension on conductor cable is used from its failure load, and according to the Tab. 1, the value found for failure load is 115.3 kN. Therefore, it is used T_0 as being equal to 20% of the failure load (according to recommendations of NBR 5422), then T_0 = 23.5 kN. Knowing the horizontal stress and the resulting weight per unit length, it is possible to calculate the mechanical stresses for all loading conditions.

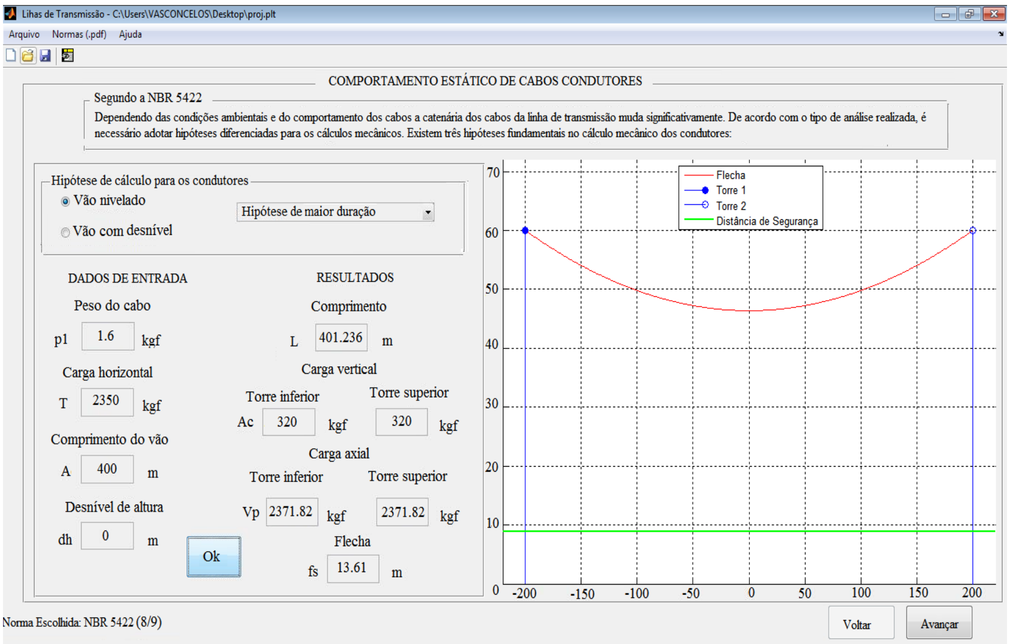

Figure 7. Static behavior of conductor cables

Figure 8 shows the leveled span condition, with the maximum load hypothesis selected.

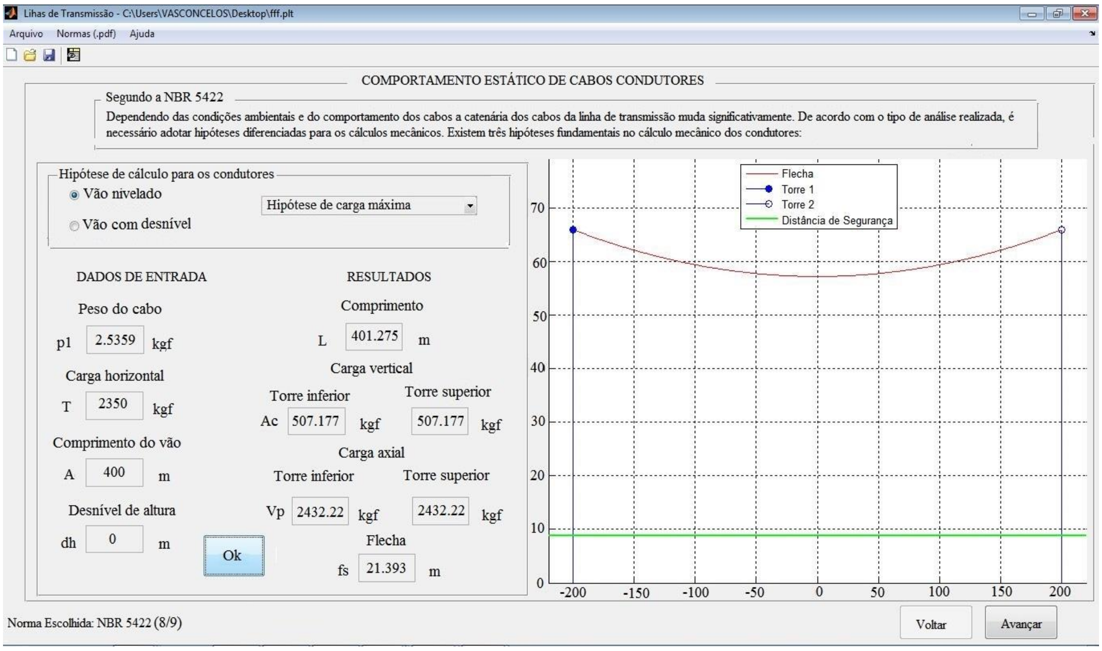

Figure 8. Maximum load hypothesis

4. RESULTS

According to the data calculated and verified in Fig. 7, the output data are presented in Tab. 2, which compares all the values found by the computer program developed with the results from Bezerra (2010), for the average temperature condition and no wind effect, known as EDS condition, and leveled span. To compare the values obtained by the program, with the bibliography, it was decided to calculate the error, so such comparisons were made from the calculation of errors in each of the applied cases.

Table 2. EDS condition and leveled span.

	Program developed	Bezerra (2010)	Error (%)
Length (m)	401.24	401.24	0
Horizontal force (kN)	23.05	23.05	0
Axial load - Lower tower (kN)	23.26	23.26	0
Axial load - Top tower (kN)	23.26	23.26	0
Sag (m)	13.62	13.64	0.002

Again, according to the data calculated and verified in Fig. 8, the output data are presented in Tab. 3, which compares all the values found by the computer program developed with the results from Bezerra (2010), for maximum load condition and leveled span.

Exactly as in Bezerra (2010), the maximum load in Tab. 2 was related to the lower support, whose value is equal 23.34494 kN, corresponding to 20.2% of the rupture tension. As for the safety specification, the maximum tension value on the cable should be between 20 and 23% of cable rupture tension, then the design example is suggested according to the specification.

Table 3. Maximum load condition and leveled span.

	Program developed	Bezerra (2010)	Error (%)
Length (m)	401.2754	403,0757	0.44
Horizontal force (kN)	23.31923	23.32267	0.014
Axial load - Lower tower (kN)	23.85193	23.86154	0.04
Axial load - Top tower (kN)	23.85193	23.86154	0.04
Sag (m)	21.393	21.5369	0.67

Comparing the sag values for each case, it is clear that when considering the hypothesis of longer duration compared to maximum load, there was an increase in the value of the sag, fact considered due to temperature variation that suffered the conductor cable, causing its expansion. This increase was expected, since it depends on temperature variation, coupled with this, there is the influence of the cable weight, as this increases due to wind pressure and, depending on how this is increased, the sag can increase significantly. Regarding the tension value, this also was increased, caused by the wind.

5. CONCLUSION

The Brazilian standard, most current, responsible for assisting engineers in the project is the NBR 5422 (1985). However, even this being the Brazilian standard in applicable at the time, it already has 25 years old and may contain approaches that are not currently applied. Thus, a review of this standard is being conducted by a working group composed by several companies, including: Furnas, Chesf, Eletronorte, Eletrosul, Cepel, among others. In addition to the NBR 5422, several other standards are essential for the collection of property data, as thermal and mechanical evaluation used to choose the most suitable cables and structures in each case.

The use of computational tools is essential for the design calculations of a transmission line due to the complexity of the calculation model and the large number of data necessary for the design of a transmission line, hence the importance of this work.

According to the data in Tab. 2 and Tab. 3, it is observed that the values obtained with the developed program are very close to those calculated by Bezerra (2010). It is noticed that the difference is practically zero, with no occurrence of errors greater than 1% in any of tension and sag values. This shows the efficiency of the program. It is also noticed that the geometric parameters affect the behavior of the conductor cables. In addition to these parameters, the metrological factors are of fundamental importance in the mechanical behavior for both cables and towers.

6. REFERENCES

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7. RESPONSIBILITY NOTICE

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