

DESIGN AGAINST THE VULNERABILITY OF OVERHEAD TRANSMISSION LINE CAUSED BY GALLOPING

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ABSTRACT

Transmission Lines often face severe ice or wind loads which may damage them and affect power system reliability. Even when the best design criteria are met, there are continues risks of extensive damage to overhead lines when extreme wind or ice storms exceed the designing criteria. One of weather related phenomena is galloping. The galloping phenomenon has been difficult to study due to his random nature. Moreover, utilities should not ignore effects of global warming and changes of climatic loads which may happen. In this paper, the minimum distance required between conductors of new 400kV transmission line Tirana - Podgorica, is calculated using Davison's method. The conductor loops during galloping are calculated in different conditions. The results show that in the standard conditions design, the galloping ellipses do not touch each other. Meantime, the 10% changes of the standard conditions causes the contact between the galloping ellipses, either between the phases or between phases and grounded wires. The minimum distance between conductors and ground wires is suggested. In these spans it is noticed the phenomenon of non – elastic extension (elongation) of metal conductor, due to the fatigue as result of the long – term mechanical strain of the metal conductor.

KEYWORDS: *Transmission Line, Galloping, Minimum Distance, Elliptical Region, Power System.*

I. INTRODUCTION

The today modern society is increasingly dependent on a reliable electricity supply. At the same time, the power system will be subject of major changes in the coming years, raising questions such as: How do the climatic changes affect the power system vulnerability?

Overhead transmission lines, due to the nature of their exposed constructional characteristics, are subject to loads imposed by the environmental conditions such are wind, ice, snow, earthquakes and flooding. The effects of these loads produce detectable forces in the line components that can affect their ability to withstand the operating conditions. Three different categories of wind induced conductor motion are recognized, being differentiated by their frequency, amplitudes and effects on conductors, interfaces and supports [1]. Conductor gallop is a form of wind effect characterized by vertical low frequency and high amplitude conductor motion. It is usually caused by relatively strong and steady winds on asymmetrically iced conductors [1]. Galloping increase loads in a conductor and especially the vertical forces at the supports ends [2]. Accumulation of snow and ice on conductors affect them in a twofold way. It increases the wires tensile forces due to the added weight, and additionally changes their aerodynamic characteristics by changing the shape of the surface exposed to the wind, with the effects related to those described previously.

The transmission lines are designed to withstand galloping. However, if the energized conductor gets close enough to any grounded part such as the tower steel, the grounded sky wire, or another energized conductor, a short circuit fault occurs momentarily until protection devices, such are relays and circuit breakers, interrupt the current flow of the short circuit. This is what causes lights flickering intermittently [3,4].

The Overhead Transmission Lines (OHL) often face severe ice or wind loads which may damage line sections and affect power supply to customers. Even when the best design criteria are met, there is always a risk of extensive damage to overhead lines when extreme wind or ice storms exceed the designing criteria. Utility Companies should not ignore the effects of global warming and the substantial climatic changes which might happen. During the years galloping has been difficult to study due to the random nature of phenomena.

In this paper the analysis of the new 400kV interconnection line Tirana – Podgorica if it meets the security condition at present and in future is studied.

The study is focus in the design evaluation of Tirana – Podgorica line (OHL) from the point of view of not to be unlocked during galloping. Two longest spans of the line are studied. The first line span of the double circuit line, 637m long, and the second longest span of the line, 944m long, with one circuit towers, which is used for the crossing of Vau Dejes Lake. The study analyses the galloping condition due to the phenomenon of metal conductor non elastic extension (elongation), as result of the long term mechanical strain of the metal conductor fatigue.

The real data modeling of the 400 kV Tirana –Podgorica line was used [5].The tower modeling was done as electric line with constant distribution parameters. The towers are modeled according to their geometric scheme and types, as well as their respective longitudinal profile. The spans are modeled according to the real placement and hanging of the conductor and of the OPGW.

II. THE GALLOPING OF CONDUCTORS

The galloping phenomenon of the conductors happens mainly in flat surfaces affected by the wind and where the layer thickness of the snow and ice are great. In such circumstances transverse conductor section is cover by a layer of ice and snow, t , and it change shape from circular into noncircular, Figure 1. When the wind blows transversely with the noncircular section, it causes its immediate setting up.

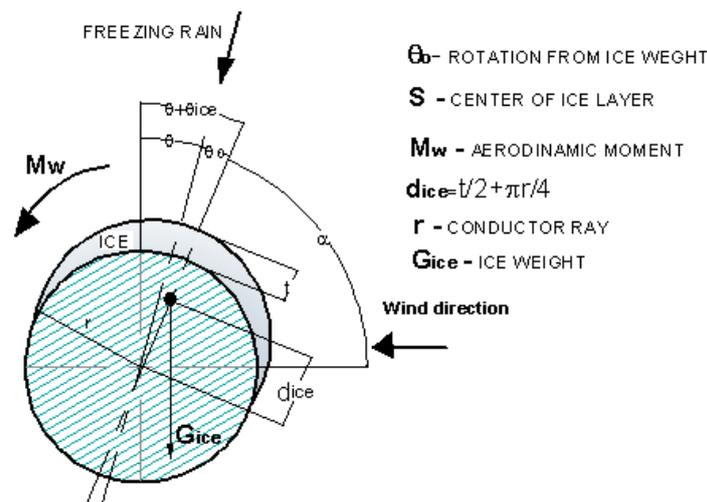


Figure 1. The forces in a cover section conductor

Galloping is an oscillation of single or bundled conductors due to wind action on an ice or wet snow accretion on the conductors, although there are recorded instances of non-ice galloping arising from the conductor profile presented to the wind.

Conductor movement are characterized by amplitudes that may approach or exceed the conductor sag (possibly >10m) and depending on the amplitudes and number of loops, frequencies up to 3 Hz. Galloping can occur when freezing rain collects on transmission towers and conductors, trees, and any other objects. Then icicles and odd-shaped ice can form on the conductor that is called ice accretion.

When wind pushes on those icicles and conductors, this causes uplift on the iced-up conductor and a consequent galloping, or jumping, motion happens. Power lines can sway in high winds, but it is the

combination of wind and ice that causes them to gallop more forcefully, Figure 1. So, six millimeters of ice and a steady wind of at least 30 kilometers per hour perpendicular to the transmission line are ideal conditions to create galloping. During galloping the conductor oscillate inside the ellipses, Figure 2, and one of the control criteria is that the phase ellipses do not touch each other. Potential dangers include ice dislodging and flying off the lines or power lines breaking loose. In all cases, during the galloping the conductors do not approach to other conductors of the transmission lines or to the towers.

The weight of snow and ice, wind may cause the following failures:

- Structural failure of overhead lines tower due to exceed of tower load from designed parameters
- Failure due to falling trees over the line conductors
- Failure due to conductors “galloping”
- Reduction of the clearance distances between live parts and grounded tower structures
- Super-cooled rain causes rapid build-up of ice causing line conductor stress exceed designed values
- Line Transmission faults
- Ice creations over glass insulators can reduce considerably the leakage path “Creepage distances”

Previous studies have revealed that there is a need for new knowledge for monitoring and managing transmission lines vulnerability [6]. This paper discusses the climate affect vulnerability of the power system.

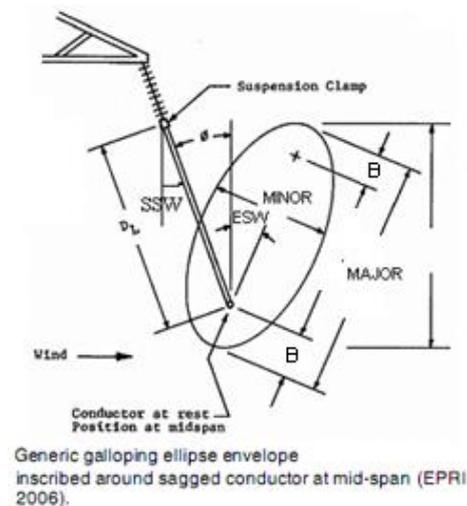


Figure 2. The phase ellipse

III. THE STUDY OF CONDUCTORS GALLOPING

In the following we will study the conductors galloping of 637m long span of the double circuit line. The construction of the galloping ellipses has been made according to the recommendations of Bulletin REA1724E-200, for the thickness of ice 12.7mm, with wind pressure 95.8Pascal (wind speed 12.4m/s), measured in 10m high from ground level.

The flexion angle of the isolators, found by the arctangent of the force according to the horizontal axes with the vertical one, is applied at the end of the isolator.

$$\theta_{Iz} = \tan^{-1} \frac{F_{Xiz}}{F_{Ziz}} \quad (1)$$

F_{Xiz} – is the total horizontal force that the wind pressure with a wind speed of 12.4m/s applies to the conductor covered with 12.7mm of ice in unit length per meter multiplied by the total wind span being studied

F_{Ziz} – is the total vertical force calculated by the weight of the conductor covered with ice, multiplied with the gravitational span (the longitude between the two lowest point of the conductor curve in the respective regime with ice at 0°C temperature). This is the real weight applied at the end of the insulator.

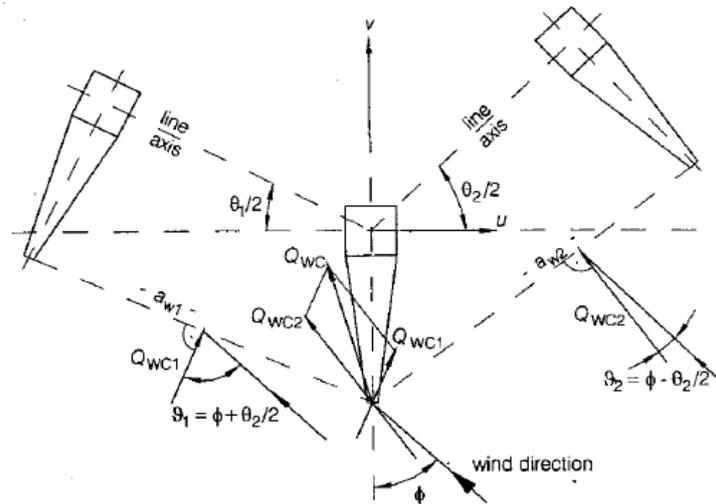


Figure 3: The wind blowing on conductor in angle towers

It is also defined the angle that the curve of the conductor in the span takes:

$$SSW = \tan^{-1} \frac{F_x}{F_z} \tag{2}$$

In this case the angle that the conductor takes is only the ratio F_x/F_z for unit (kg/m) without calculating the longitude of the horizontal span or vertical one.

2.1 The calculation of forces in conductors under galloping

According the type of the ground under the span based on EN 50341-1 and IEC 60826 standards, is identified the ground category as B category [7, 8]. So, we can calculate:

- The speed of the wind in height 40m is:

$$V_{Z-40m} = \frac{V_{Z-10m}}{K_j} \cdot \left(\frac{Z}{10}\right)^\alpha = \frac{12.4}{1} \left(\frac{40}{10}\right)^{0.16} = 15 \text{ m/s}$$

- The transversely force of the wind on the conductor is:

$$Q_{WC} = \frac{1}{2} \rho V^2 \cdot G_L \cdot G_q \cdot C_c \cdot d \cdot a_w \cdot \cos^2 \gamma =$$

$$= 0.613 \cdot 15^2 \cdot 1.625 \cdot 0.771 \cdot 1 \cdot \frac{30.6 + 2 \cdot 12.7}{100} = 0.971 \left[\frac{\text{kg}}{\text{m}} \right]$$

G_L – correcting coefficient according to the longitude of the span equal to:

$$G_L = 1.3 - 0.082 \cdot \ln a_w = 0.771$$

G_q – the coefficient of the reply effect of the wind for the conductors hanged in the space

equal to: $G_q = [1 + 2.28 / (\ln Z / Z_0)]^2 = 1.625$

C_C - The coefficient defined by the shape of the object stuck by the wind, for the conductors is 1.

a_w - The span of the wind.

γ -atacangle of wind (in this case 90°).

d – conductor diameter 30.6m (ASCR)

The weight of the conductor with ice (ACSR) is:

$$W_{TOT} = W_{ice} + W_{cond} = 1.558 + 1.8529 = 3.4143 \left[\frac{kg}{m} \right]$$

- The angel of the insulator of the go-between tower No168 is:

$$\theta_{IZ} = \tan^{-1} \frac{F_{Xiz}}{F_{Ziz}} = \tan^{-1} \frac{511.23}{1219.92} = 12.4^\circ$$

- Angle of the curve of the conductor takes in the span is:

$$SSW = \tan^{-1} \frac{F_X}{F_Z} = \tan^{-1} \frac{0.971}{3.4113} = 15.9^\circ$$

The tension of the tightening clutching of the conductor (29909N) for EDS(Every Day Stress on 15°C) is taken from the hanging tables according to the documentation delivered to Transmission System Operator by the implementation contractual working company.

- The dimension of the galloping ellipses are calculated as follow:

$$a = \sqrt{\left(\frac{L}{2}\right)^2 + S_i^2} = \sqrt{\left(\frac{637}{2}\right)^2 + 31.77_i^2} = 320.1[m]$$

- The big diameter is:

$$M = 0.3048 + \sqrt{\frac{3 \cdot 321 \cdot 1 \cdot \left(637 + \frac{8 \cdot 31.77^2}{3 \cdot 637} - 2 \cdot 320 \cdot 1\right)}{8}} = 11.4[m]$$

$$B = 0.2 \cdot M = 2.28[m]$$

- The small diameter is:

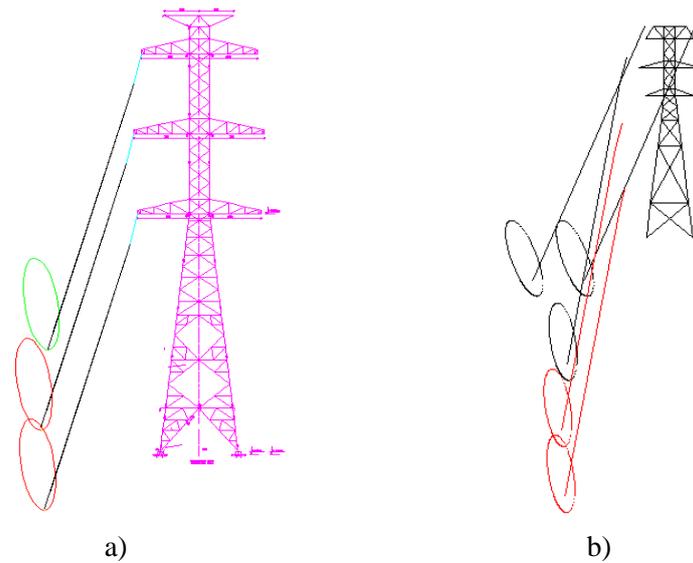
$$D = 1.104 \cdot \sqrt{M - 03048} = 3.68[m]$$

We can observe that in the case of the first longest span of the double circuit (637m),the galloping ellipses do not intersect each other.

The same procedure was applied for the second span 944m long crossing Vau Dejes Lake of the 400kV Tirana – Podgorica line. The calculation of galloping ellipses is repeated for different climatic parameters. The line was designed of parameters: the speed wind $V=31[m/s]$ and the ice thickness 8.869 [mm].The combined regime includes the wind speed $V_e=0.7V_{max}=12.4[m/s]$ and the weight of ice load thickness is calculated reversely looking at the foreseen additional ice loading $(Kg/m) = 1 \cdot 0.18\sqrt{D} = 1 \cdot 0.18\sqrt{30.6} = 0.9957[Kg/m]$, that corresponds to 8.869mm of ice thickness.

According to Albanian normative KTP 18 the wind speed in the combined regime is taken 50 % of V_{max} , while for this span it is taken 10% less equal to $0.4 V_{max}$.

In Figure 4 are represented the galloping ellipses designed with AutoCAD and the PLS CADD software. In this case the ellipses intersect each other.



a) Drawn With AutoCAD

b) Drawn automatically by PLS-CADD software

Figure 4 Galloping ellipses on the power line in the span 638 [m] long

The same estimation and check was made for the longest span of the overhead power Line Tirana-Podgorica at the 944m span over the Vau Dejes Lake. The galloping ellipses which intersect have been shown below:

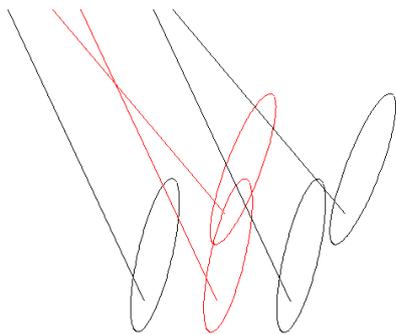


Figure 5 Drawn automatically by PLS-CADD software the 944m over Vau Dejes Lake

The conclusion: the ellipses path of the conductors intersects each other as the effect of the galloping. It happens because the conductor oscillation of the middle phase is limited compared with insulators of the other phases, as the result of two insulators of “V” shape placement.

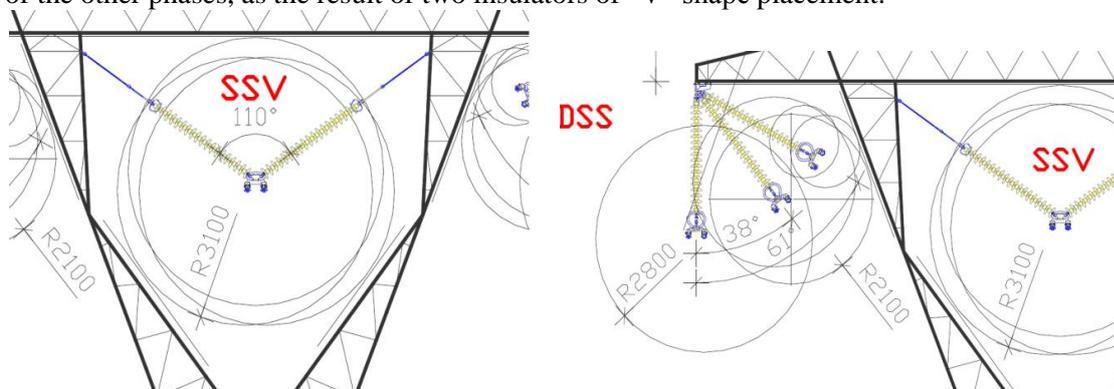


Figure 6: Showing the connection of the middle phase to the tower structure with V Shaped insulators to the tower structure with suspension insulators.

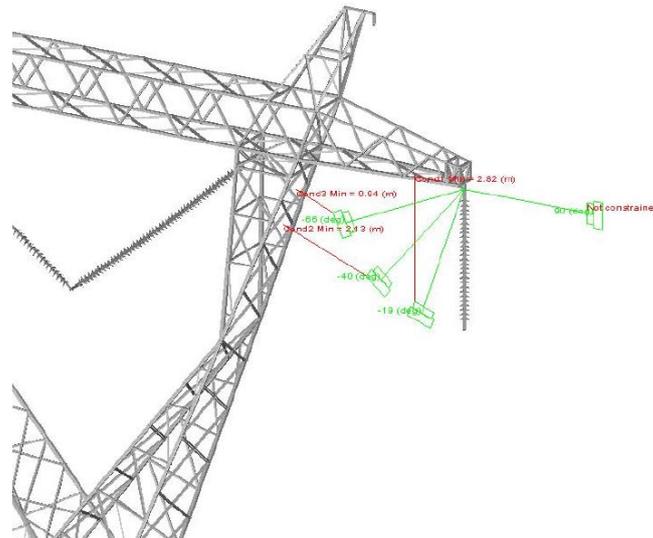


Figure 7:3D view of tower structure showing insulators setting

IV. THE STUDY OF THE NON-ELASTIC ELONGATION OF THE CONDUCTOR BECAUSE OF THE MECHANICAL STRAIN APPLIED FOR LONG TIME

The effect of the non-elastic elongation of the metal conductor as the result of its fatigue is a well-known phenomenon which is taken into consideration when calculating the hanging of the conductors.

The relative elongation curves (stress strain creep curves) of the conductor in percentage versus the mechanical strain applied on it ends is represented in Figure 8 [9]. Two curves of the relative elongation of the conductor with and without mechanical fatigue are given in the Figure 8.

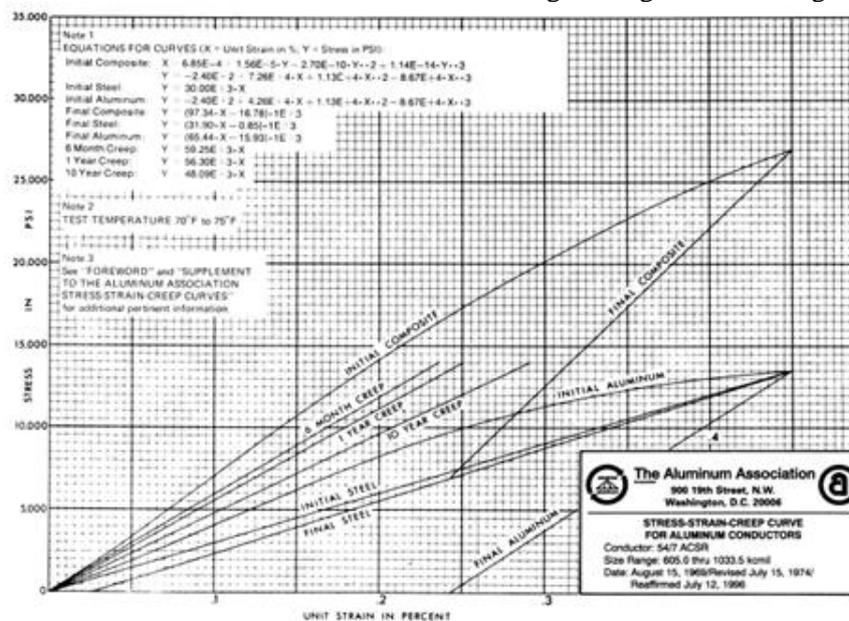


Figure 8. The curve of relative elongation of conductor 490/65 depending of the mechanical strain exercised on it in different periods of time.

The fatigued curve has a lower slope. It shows that for smaller strains we have a bigger relative elongation. It corresponds to the regime when new conductor is installed in the tower and is the subject of mechanical forces stress for the period of time, during that its relative elongation has occurred. After this period of time, the changes in the conductor length are becoming smaller. The

same results are obtained by using the mathematic equations that calculate the relative elongation of the conductor on installation, subject of the fatigue.

In the case of Tirana –Podgorica transmission line, a couple of the conductor where under mechanical strain conditions equal to the strain that is applied on the conductor normal condition installation, for a period of one year time. The test was made within a period of the time from August 13, 2002 to April 16, 2003. In the Table 1 are presented the results of elongation of conductor calculated by mathematic equation and compared with measured values during the test period.

Table 1 The elongation of conductor

Type of conductor	Strain of conductor	Swell Algorithm	Elongation of conductor $\mu\text{m}/\text{m}$		
			10 years	30 years	50 years
ACSR 490/65mm ²	EDS 20.86% $\sigma_{eds} = 51.24$	$180 \cdot t^{0.11}$	629	710	751
ACSR 490/65mm ²	EDS 20.77% $\sigma_{eds} = 49.76$	$80 \cdot t^{0.08}$	199	217	226

The conductor parameters, subject of the mechanical fatigue, are compared before and after experiment. From the data represented in Table 1 we can find that the initial elongation of the conductor in first ten years is much bigger than that occurs after this period, due to mechanical fatigue. The elongation of conductor compare to the value of ten year is 6.4% in the period from 10 to 30 years and is only 3.2% in the period from 30 to 50 years.

To take into account the initial elongation of the conductor, during the processes of transmission line construction, the sag of the conductor is set for a temperature shift of about 10°C [empiric methods standard EN50341]. The engineering staff of Implementation Company has suggested the same approaching method.

According to the documentation of implementation company “AS-Build” of the transmission line, during the installation, the conductor OPGW must be installed with deviation related of 15°C of displacement of the model for the fatigue of the metal for long term, Figure 9. We may use the relative elongation coefficients from the graphic 5, and later we can input the coefficients of the relative elongation according to the respective periods, for the aluminum and for the steel in the window fields of figure 10.

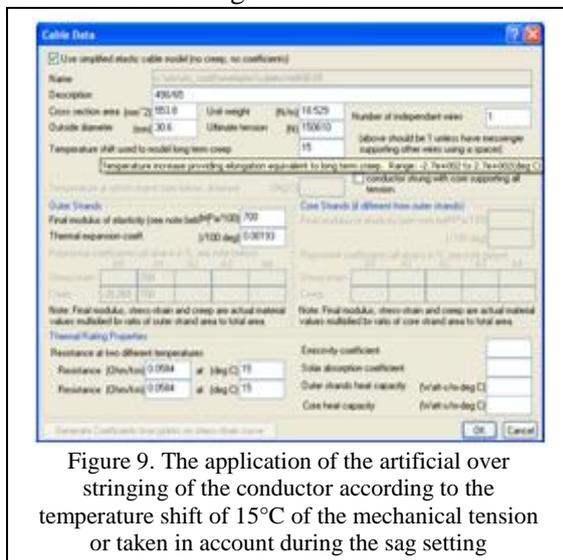


Figure 9. The application of the artificial over stringing of the conductor according to the temperature shift of 15°C of the mechanical tension or taken in account during the sag setting

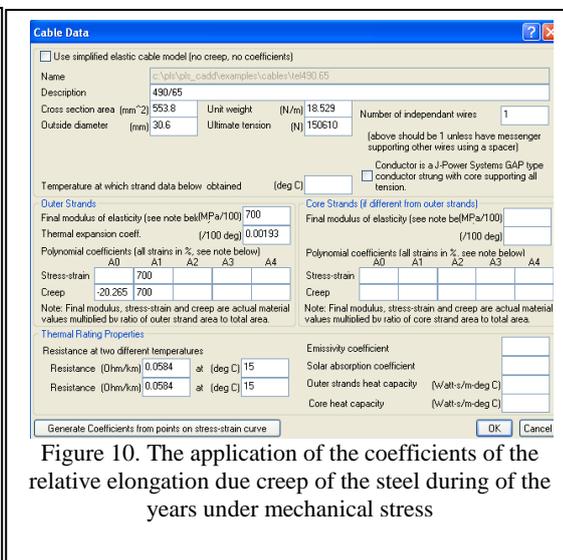


Figure 10. The application of the coefficients of the relative elongation due creep of the steel during of the years under mechanical stress

After calculated the span through PLS Cad software, we have checked if it meets the criteria of galloping for both initial conditions and after the fatigue of the metal happened. The ellipses of galloping for the both conditions are given in Figure 11.



Figure 11.The ellipses of galloping before and after fatigue.

We can see that the ellipses path of the conductors intersecting each other as a result of the conductor fatigue. This happens because of the conductor elongation, so the distance in the middle conductor phase is limited.

V. CONCLUSIONS

The change of the tightening tension between the ground wire and the conductor can negatively influence the galloping phenomenon, if we are too near the galloping critical zone.

The weight of the ground and conductor wire is different from each other. The fatigue of the conductor with metal that contains aluminum with very weak mechanical properties is different from the steel ground wires. After a long period of time more than 30 years, one of line span could not be immune towards the galloping phenomenon.

This extension is more evident in line which stands for a long time in ice weight regime over the years. This phenomenon mainly appears in two phases, first it is very evident in the first week after the conductor installation in the tower and second it is relative extension values changes less in percentage after the first ten years. This can also be evident from the conductor fatigue curve gradient. This gradient at the initial regime when the conductor is not “fatigued” has smaller value than in the relative extension curve, after the metals fatigue has already changed the relative extension. This means that the relative non elastic elongation due to conductor creep is more evident, it changes with smaller values afterwards.

In this paper we have calculated the minimum distance required between conductors of new 400kV transmission line Tirana - Podgorica, using Davison’s methods. The conductor loops during galloping are calculated in different conditions. The results show that the structure is designed that ellipses do not intersect each other in the normal conditions. The 10% changes from the normal conditions can lead to contact between either phase to phase wires or phase to overhead ground wires. The minimum distance between conductors and ground wires is suggested.

The mechanical extension that occurs in the conductor depends on the conditions of which it is subject. That is why often two curves are calculated, one of the relative non-elastic extension, when the conductor is a subject of normal mechanical strain and the other when it is subject of heavy mechanical strain loaded like ice.

The over stringing with a temperature shift is not a method approved by application design rules of EN50-341Standard; it is an empiric method that must be avoided and must not be used in construction lines of relative importance.

This procedure has been introduced in order to minimize the cost and delays during the conductor installation in order to avoid waiting the initial creep age of the conductor. This construction design approach needs to be updating based on latest knowledge required.

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