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Field validation of gap-type overhead conductor creep

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Abstract: Gap-type overhead conductor sag-tension calculations based on experimental conductor creep tests are based on stress-strain and metallurgical creep tests. Although for bi-metallic conductors, these tests are carried out for both the core and the full conductor, for gap-type overhead conductors the aluminum metallurgical creep is usually neglected and the full conductor metallurgical creep is not carried out. The purpose of the presented study is the validation of these calculation methods. For this purpose, field measurements have been obtained in a pilot line in operation. The gap-type conductor installation process has been measured and the conductor creep has been monitored during three years of line operation. In order to model relevant events such as the pre-sagging and sagging steps during the installation, and ice and wind events during the operation, a flexible sag-tension calculation method has been used. Besides, the widely used graphical sag-tension method has also been evaluated, obtaining similar results as the flexible method. The tension-decrease is used as the indicator of the creep. The calculated and measured tension-decrease values are close. Therefore, it is concluded that the sag-tension calculations based on experimental conductor creep tests are valid to represent the actual creep of the conductor in operation.

Keywords: Transmission line, gap-type overhead conductor, creep, sag-tension calculation, power system operation, power system expansion planning

1. Introduction

Power system operation and planning are constrained by the rating of system components. In the case of the overhead lines, there is a limitation in the maximum sag so that the distance between the conductor and ground is secure. The sag increases with the conductor thermal expansion and for this reason, the maximum allowable temperature is limited. Besides, the sag also grows due to the permanent deformation experienced by the conductor because of creep. Sag-tension calculation methods calculate the change on the conductor sag as a function of the conductor temperature and time [1]-[6].

Creep can be defined as the permanent deformation of conductors due to the metallurgical creep of the conductor material and the geometrical settlement of the conductor wires [7]-[10]. Metallurgical creep is a function of stress, temperature and time, and it is cumulative. Creep development rate decreases over time and accumulated creep. On the other hand, geometrical settlement depends only on stress. As the historical maximum stress of the conductor increases, a geometrical settlement of the conductor wires occurs and an increase of the conductor length is developed. Initially, the historical maximum stress value is the experienced in the installation process. In operation, if the stress in the event is higher than the historical maximum stress, the permanent deformation due to geometrical settlement increases its value due to events of wind or ice loads.

High Temperature Low Sag (HTLS) conductors are used for the uprating of overhead lines due to their lower coefficient of thermal expansion CTE and higher maximum allowable temperature values [11]-[13]. Among the different types of HTLS conductors, one of the most widely used is the gap-type conductor. The gap-type conductors are composed of steel core and aluminum outer strands [14]-[17]. The gap between the steel and the aluminum ensures aluminum layers remain slack during the conductor installation process.

The installation process is a key influence on the creep developed by the conductors. As the creep is cumulative, it is beneficial if some creep is permitted to occur during the installation process [10]. Pre-tensioning and over-tensioning in the installation are used to mitigate the creep developed during operation. Pre-tensioning means tensioning the conductor for a short period before the conductor is clamped. Over-tensioning means increasing the installation tension to compensate for the creep during operation.

Due to the limitations of the existing sag-tension methods to model the installation process of the gap-type conductors, the authors developed a method for the gap-type conductors and the conductor performance was analyzed from simulated results [18]-[20]. In order to validate the simulated results with actual measurements, this paper demonstrates the results obtained in a pilot line. A 119 mm^2 ACSR LA-145 conductor has been replaced by a 131 mm^2 GTACSR-150 gap-type conductor in a 30 kV distribution line. A 282.5 m length span has been monitored with conductor tension and temperature measuring systems. The conductor installation process has been measured and the operation of the line has been monitored during three years. Three years is a long period for the creep evaluation because most of the creep develops at the beginning of the installed conductors' lifetime.

The paper starts describing the installation process of gap-type conductors because it is important to understand the creep performance of the conductor. Then, creep calculation methods are discussed, and the need for a flexible calculation method is justified. In the next section, the steps for the creep calculation are defined from the measured tension and temperature values. These steps are applied with the flexible creep calculation method developed by the authors and creep results are obtained. Besides, the calculations are carried out with the widely used graphical method. The creep that an ACSR conductor would develop has also been calculated for comparative purposes. Next, the measured creep is quantified and the difference with the calculated values is analyzed. Finally, some conclusions are described.

2. Installation process of gap-type conductors

The installation process of gap-type conductors is particular. The objective is to leave slack the aluminum layer when the installation is completed [17]. As a result, the knee-point temperature of the conductor is the installation temperature and the conductor shows low sag performance above this temperature.

The first step in the installation is the stringing. Figure 1 shows the stringing process in the pilot line. The original ACSR conductor is removed and the new conductor is strung in the pulley blocks. The stringing tension should be low, below 70 % of the installation tension.

Fig. 1. Stringing the gap-type conductor

The first end-point of the conductor was clamped in a conventional way and a load cell that measures the tension was installed between the tower and the insulating string (Fig. 2). A temperature and current measurement sensor for high voltage lines (Arteche SMT) is used for measuring the conductor temperature (Fig. 3). The conductor surface temperature is measured.

The installation process of the second end-point is special, so that the aluminum is slack at the end of the installation process. The next step in the second end-point is the pre-sagging. Figure 4 shows the process of pulling the gap-type conductor by means of the aluminum gripping clamp. The pre-sagging tension value is 70 % of the installation tension. The conductor is cut and a portion of the aluminum layer is removed in the looser part of the conductor. In a conventional ACSR conductor, in the pre-sagging step, both the steel and aluminum share the tension, as there is no possibility of relative displacement. However, in the gap-type conductor, due to the gap between the steel and aluminum, the steel is slack and the tension is in the aluminum. This is relevant, as the geometrical settlement experienced by the aluminum in this step will reduce the geometrical settlement in wind or ice events.

Fig. 2. Load cell for measuring the conductor tension

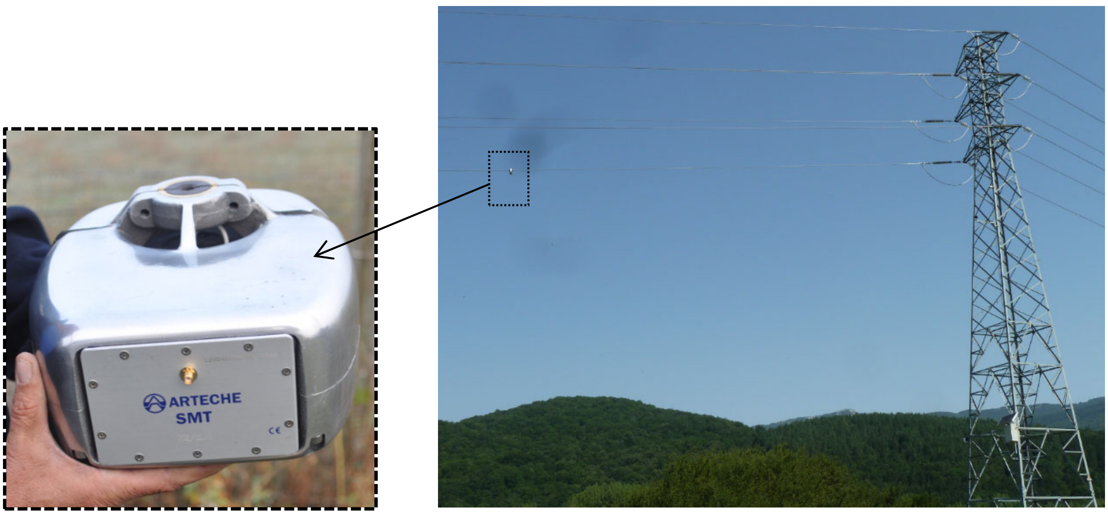

Fig. 3. Temperature and current measurement sensor

Fig. 4. Pre-sagging: pulling the new conductor by an aluminum gripping clamp

The conductor sagging is the final step. The steel core is tensioned by the steel gripping clamp, after inserting the steel clamp (Figure 5). Then, the aluminum gripping clamp is loosened. The aim of the sagging process is to obtain a certain tension or sag at ambient temperature as indicated by the sagging tables. For the gap-type conductors, a period of time where the conductor is at rest over the steel core with the aluminum loose is needed. This is to guarantee that the aluminum is slack when the clamp is compressed. While in a conventional bi-metallic ACSR conductor both the steel and aluminum share the tension in the sagging step, in the gap-type conductor all the tension is in the steel core. The creep experienced by the steel in this step is removed from the creep experienced during operation.

Fig. 5. Sagging the gap-type conductor

3. Creep calculation method for gap-type overhead conductors

The sag-tension calculation methods are classified according to the conductor elongation models: Linear Elongation (LE), Simplified Plastic Elongation (SPE), or Experimental Plastic Elongation (EPE) models [4]. The EPE models are based on experimental conductor tests. Two types of standard tests are carried out in order to characterize the creep performance of overhead conductors: the stress-strain test and the creep test. In the stress-strain test, the conductor stress is increased, maintained constant for one hour, and decreased, in several cycles. The stress-strain characterizes the geometrical settlement as a function of the conductor stress. In the creep test, the conductor is under a constant stress for 1000 hours at a constant temperature. In this test, the metallurgical creep development rate is characterized. The whole conductor and the conductor core are tested separately. The aim of the whole conductor test is to measure the aluminum performance. Removing the performance of the core from the whole conductor performance, the aluminum performance is calculated. This is carried out both for the stress-strain and the metallurgical creep test.

The creep does not depend on the conductor size. It depends on the stranding of the conductor and the material type of the wires. In [21], initial stress-strain curves and final stress-strain curves (including 10 year metallurgical creep) are given for different conductor stranding types: 6/1 ACSR, 24/7 ACSR, 26/7 ACSR, etc. Regarding the material type of the wires, for example, metallurgical creep tests for Aluminum Clad

Steel (ACS) cores result in higher strain values than tests carried out for galvanized steel core. This is due to the contribution of the aluminum in the ACS core. The GTACSR core installed in the pilot line consists of 7 Aluminum Clad Steel (ACS) wires. The core has been tested and the test results have been used for the calculations.

In the case of gap-type conductors, core-only creep tests are normally carried out assuming full conductor tension i.e. considering applied load of the un-tensioned aluminum layers. The whole conductor metallurgical creep test is not carried out because the aluminum metallurgical creep is neglected. This is acceptable because during operation the aluminum in the gap-type conductor is expected to be slack or with low tension. As a result, the aluminum metallurgical creep during the operation is expected to be low. This is not the case for conventional ACSR conductors where the aluminum shares the tension with the steel core. In fact, in conventional conductors the aluminum is the main responsible of both the geometrical settlement and metallurgical creep. This is because both the metallurgical creep and geometrical settlement of the aluminum are higher than the steel creep for similar stress and temperature conditions.

The graphical method is one of the most widely used EPE sag-tension methods [4]. This is the method implemented in some commercial software programs, such as PLS-CADD. There are two options for the final creep after ten years of operation. The first option is to consider a continuous metallurgical creep at ambient temperature during ten years. The second option is to consider the geometrical settlement related to a maximum tension condition due to ice or wind events. Both options are calculated and the highest value is taken. The steel core and the aluminum are modelled independently. The initial creep in the graphical method corresponds to the geometrical settlement related to the installation tension of the conductor. When the graphical method is applied to gap-type conductors, the installation tension is assumed to be in the steel while the aluminum is slack. Therefore, the geometrical settlement of the steel is calculated but the initial creep of the aluminum is assumed to be zero.

The graphical method is not able to reflect the geometrical settlement of the aluminum in the pre-sagging step nor the metallurgical creep of the steel while it is at rest in the sagging step. Besides, the creep is calculated only in two steps: initial (1 hour) and final (10 years). For this reason, the authors proposed a new sag-tension method [18]-[20]. This method increases the number of steps for the creep calculation. As many steps as required can be defined, the creep is calculated sequentially starting from the first step. In the case of the gap-type conductor, the initial steps are chosen to reflect the installation process described above. Besides, in the operation period of the line, the method is able to model ice or wind events that occur at a certain moment, as it takes into account the creep developed up to that moment.

A detailed description of the proposed method is given in [20]. The method is based on strain summation. Several steps are defined and the creep developed in each step is calculated considering the creep developed so far. Each step is defined by the conductor temperature, the load conditions (ice or wind), the duration and the initial tension. The first two magnitudes are assumed constant during the defined duration, whereas the tension variation is calculated as a function of creep. In each step, the metallurgical creep ε_{mc} and the creep due to geometrical settlement ε_{gs} developed both in the aluminum and the steel core are calculated separately. The metallurgical creep is calculated as a function of the stress σ, the conductor temperature θ and the duration t of the step. The metallurgical creep follows the law given in (1), where K, Φ, β and μ are constant coefficients [8]. The coefficient values are obtained from creep tests. The values of Φ and β have been obtained from tests carried out at different stress and temperature values in a steel core with higher size but same stranding. The creep does not depend on the conductor size but on the stranding and material type. The core in the pilot line is composed by 7 Aluminum Clad Steel (ACS) wires. A test of the pilot line conductor core has been carried out at constant temperature (20 ºC) and constant tension (20 % of the overall conductor rated breaking strength) for 1000 hours. The values of K and μ are estimated from this test and the previously obtained Φ and β values.

$$\varepsilon^{mc} = K \cdot e^{\Phi\theta} \cdot \sigma^{\beta} \cdot t^{\mu} \quad (1)$$

4. Definition of the steps for creep calculation

Each step for the calculation of the creep is defined by the conductor temperature, the conductor tension, the ice or wind overload and the duration of the step. The steps have been defined so that they represent the measured conductor performance both in the installation process and during the line lifetime.

4.1 Installation process

The monitored span was installed in October 2012. Figure 6 shows the evolution of the tension during the pre-sagging and the sagging process.

The conductor temperature and tension change over time. However, for the creep calculation, the temperature is assumed constant in each of the steps, assuming that the effect on creep of the temperature change during the duration of the step is low. Three steps are modeled for the installation process:

1) Pre-sagging: All the tension is assumed to be in the aluminum.
2) Sagging – At rest: All the tension is assumed to be in the steel core.
3) Sagging – Clamp compression: All the tension is assumed to be in the steel core

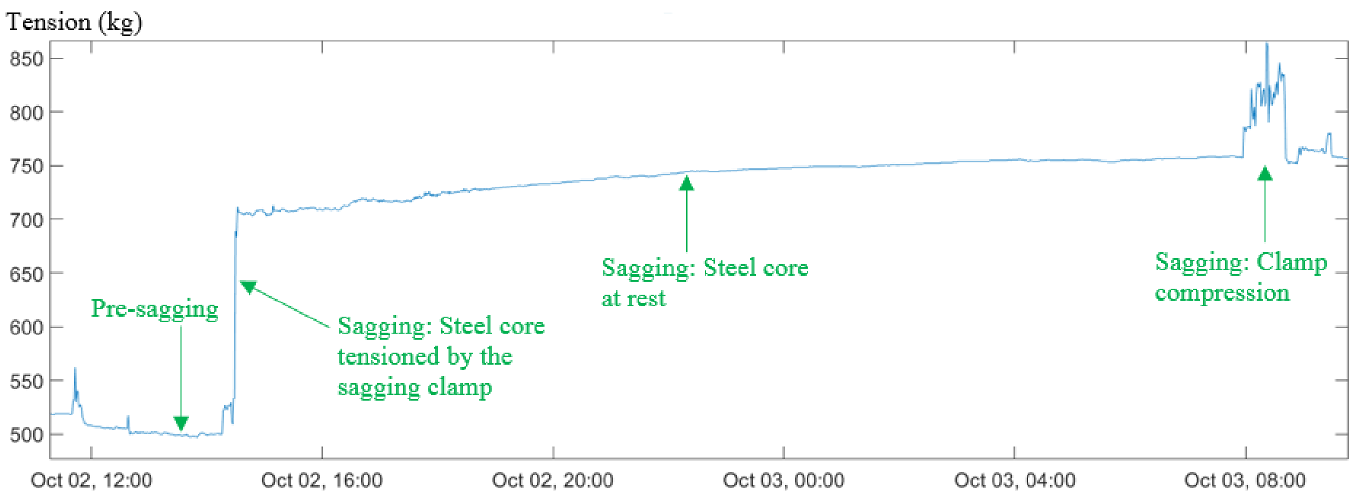

Fig. 6. Tension during pre-sagging (slack steel) and sagging (slack aluminum) processes

Table 1 shows the duration of each step and the average values of the tension and air temperature.

Table 1. Steps in the installation process

Step	Aluminum tension (kg)	Steel tension (kg)	Temperature (ºC)	Duration (h)	Wind/ice overload
Pre-sagging	510	0	14	2.5	No
Sagging – At rest	0	740	5	18	No
Sagging – Clamp compression	0	830	7	1	No

The tension when the installation is completed is 757 kg at 7 ºC. When the linemen are working to compress the clamp (Figure 5), the tension is 830 kg. When they finish the work and leave the conductor, the tension decreases to 757 kg. Therefore, the tension after the installation is completed is 757 kg, but the conductor has experienced 830 kg during the installation.

4.2 Operation period

Figure 7 shows the tension measured during the operation period. Some overloads due to ice (Figure 8) and wind (Figure 9) are observed. Table 2 shows the most relevant overloads. All tension values are around 1000 kg. This is equivalent to a 30 % increase in the conductor weight. The increase is not high and this means that the experienced loading events are not severe.

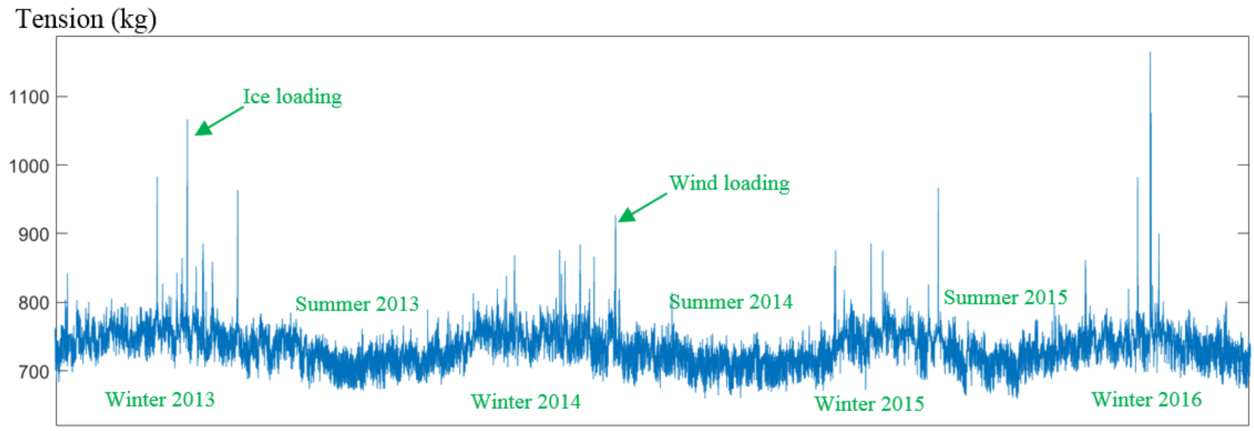

Fig. 7. Measured tension during the first 3 years of the line lifetime

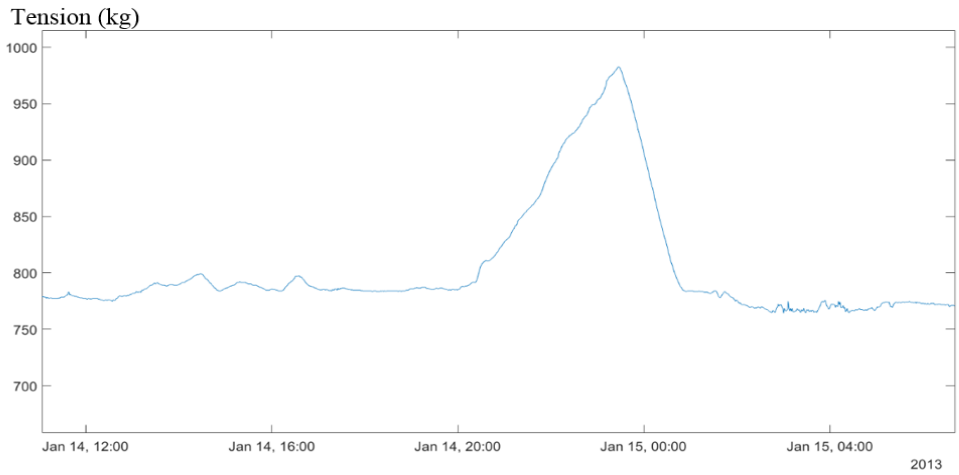

Fig. 8. Overload due to ice

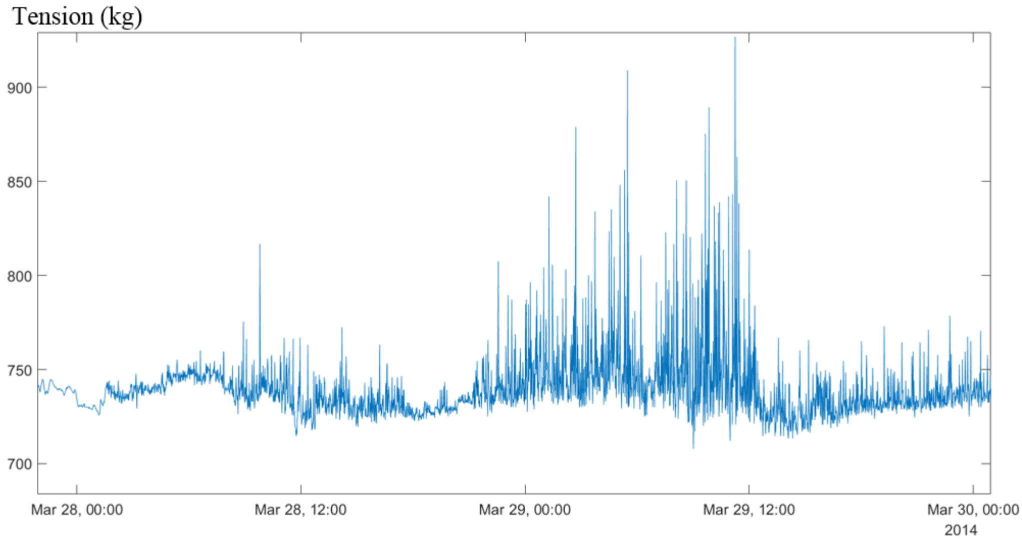

Fig. 9. Overload due to wind

Table 2. Ice and wind overloads

Date	Ice/Wind	Tension (kg)	Conductor Temperature (ºC)
14/01/2013	Ice	980	2
11/02/2013	Ice	1040	3
04/03/2013	Wind	980	11
06/04/2013	Ice	940	3
23/02/2014	Wind	940	11
09/03/2014	Wind	940	13
29/03/2014	Wind	990	14

27/11/2014	Wind	910	14
19/01/2015	Ice	900	3
23/03/2015	Ice	1000	3
26/12/2015	Wind	920	13
15/02/2016	Ice	1020	2
27/02/2016	Ice	1150	1

The conductor temperature and tension are continuously changing and affect the metallurgical creep. Figure 10 shows the histogram of the measured conductor temperature. For simplification of the creep calculation, the temperature is assumed to be constant during the operation. The average measured conductor temperature during the operation period is 13.5 ºC. Therefore, this value is taken for metallurgical creep calculation purpose. This is the same assumption as the graphical sag-tension method makes. In the case of ice events, the temperature is assumed to be the average value during the event, usually close to 0 ºC.

The average measured conductor temperature is lower than the maximum allowable conductor temperature, which is 105 ºC in the pilot line. Although the HTLS conductors are designed to support high temperature values, this does not mean that their normal operation is at high temperature. Usually, the high temperature operation is related to emergency situations. This pilot line is an example of low temperature operation of a HTLS conductor.

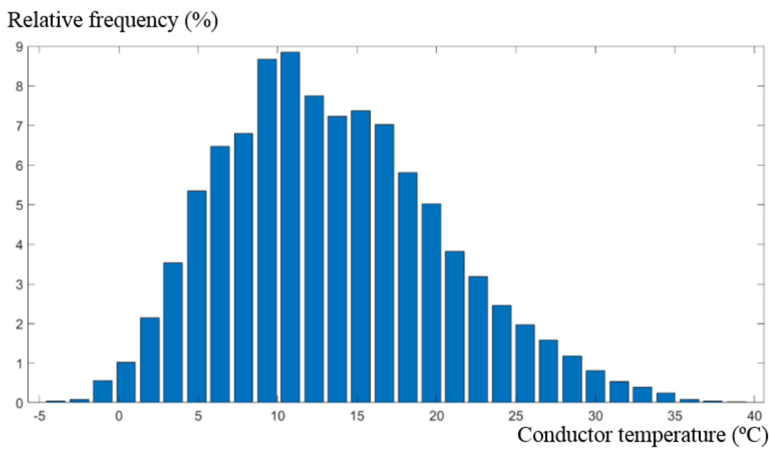

Fig. 10. Histogram of the conductor temperature

The tension value is only defined at the beginning of the first step of the operation period. As above mentioned, this value is 757 kg for the steel and 0 kg for the aluminum at 7 ºC. As creep develops, the tension value decreases. In every step, the tension value is recalculated according to the creep developed so far.

Therefore, the steps for modelling the operation period are a mixture of constant temperature steps and steps of wind or ice events. In the first step the temperature is 13.5 ºC and there is no ice or wind load. It starts when the installation is concluded and it finishes with the first ice event, the 14^{th} of January of 2013. The second event is the ice overload at 2 ºC and with one hour duration. The third step is a constant temperature period. The forth step is the ice event of the 11^{th} of February…

5. Creep calculation results

As it is mentioned above, in order to model the pre-sagging and sagging steps during the installation, and ice and wind events, a flexible sag-tension calculation method [20] is used.

The calculation starts quantifying the creep developed during the installation. The geometrical settlement is evaluated for both the steel core and the aluminum. However, the aluminum metallurgical creep is neglected and only the steel metallurgical creep is calculated. The steps defined in Table I are used for the calculation.

Table 3 shows the creep strain at the end of the installation process. The strain in the aluminum and core due to geometrical settlement, $\boldsymbol{\varepsilon_a^{gs}}$ and $\boldsymbol{\varepsilon_{core}^{gs}}$, and the strain in the core due to metallurgical creep, $\boldsymbol{\varepsilon_{core}^{mc}}$, are shown. In the pre-sagging step, the aluminum geometrical settlement develops. When the conductor is at rest, the steel core metallurgical creep develops. With the compression of the clamp, the final value of the steel geometrical settlement is defined. This is the strain that is removed from the creep that will be developed during the operation.

Table 3. Strain at the end of the installation process

Geometrical settlement		Metallurgical creep
ε_{a}^{gs} (p.u.)	ε_{core}^{gs} (p.u.)	ε_{core}^{mc} (p.u.)
$4.2604\cdot10^{-4}$	$1.3609\cdot10^{-4}$	$2.6854\cdot10^{-5}$

Once the creep developed in the installation process is defined, the creep during the operation period is calculated. Table 4 shows the tension values in some representative icing and wind events compared with the maximum tension values experienced in the installation process and given in Table 1. In all cases, both the aluminum and steel tension are lower than the maximum values experienced in the installation process. As a result, there is no increase in the strain due to the geometrical settlement. Obviously, the conductor could experience geometrical settlement in areas where heavy ice or wind loading is expected. Table 5 shows the creep strain at the end of the first icing event. Only the steel metallurgical creep experiences an increase. This happens for all the icing and wind events measured during the three years of line operation. Therefore, during the measured operation of the pilot line, only the steel metallurgical creep increases.

Table 4. Tension in some representative icing and wind events

	Installation process. Maximum tension (kg)	Icing event (14/01/2013) Tension (kg)	Wind event (04/03/2013) Tension (kg)	Icing event (27/02/2016) Tension (kg)
Steel	830	788	819	820
Aluminum	510	192	161	330

Table 5. Strain at the end of the first icing event

Geometrical settlement		Metallurgical creep
ε_{a}^{gs} (p.u.)	ε_{core}^{gs} (p.u.)	ε_{core}^{mc} (p.u.)
$4.2604\cdot10^{-4}$	$1.3609\cdot10^{-4}$	$9.4833\cdot10^{-5}$

Table 6 shows the tension-decrease and sag-increase according to the calculations. The calculations include both metallurgical creep and geometrical settlement. However, only the metallurgical creep increases the value as the considered ice and wind events are not heavy enough to increase the geometrical settlement. The results have been extrapolated up to 10 and 30 years of operation. The results reflect that creep development rate decreases over time. The tension-decrease in the first 3 years is the 70 % over the decrease in 30 years. This shows how most of the creep develops at the beginning of the line lifetime.

Table 6. Tension-decrease and sag-increase at 13.5 ºC since installation for the GTACSR conductor

Year	Tension-decrease since installation (kg)	Sag-increase since installation (m)
1	14	0.13
2	17	0.16
3	19	0.18
10	25	0.23
30	28	0.26

Apart from modeling the pilot line with the detailed sag-tension method, other two calculations have been carried out. Firstly, the creep has been evaluated using the widely used graphical method. Although the method is simpler than the detailed model developed by the authors, this is the method used by the utilities for line design. Therefore it is useful to show the differences obtained by the methods. Secondly, the creep that would develop an ACSR conductor is calculated, in order to show the creep difference between the gap-type GTACSR, where the aluminum metallurgical creep is neglected and the ACSR, where the creep is governed by the aluminum.

5.1 Creep calculation with the graphical method

The graphical method is based on experimental creep and strain-stress tests. Similarly, the method proposed by the authors is based on the same tests. Besides, both methods neglect the aluminum metallurgical creep. The main difference between the methods is the number of steps. The graphical method considers two steps: initial (installation) and final (10 years creep or maximum conductor tension loads under high wind and ice conditions). The method proposed by the authors is flexible in the number of steps.

The graphical method simplifies the installation and operation periods of the line. For example, instead of taking into account the temperature variation over time, the temperature is considered constant during 10 years. The installation process is also simplified as no aluminum geometrical settlement is assumed. As a result, the difference in the obtained results is related to the number of the considered steps.

The tension-decrease in 10 years at 13.5 ºC calculated by the method proposed by the authors is 25 kg (Table 6). Using the graphical method, the dominant factor is the steel metallurgical creep, i.e. the maximum conductor tension load effect is lower. The calculated tension-decrease is 26 kg. The results obtained with both methods are almost the same for 10 years. This is because both methods are based on the same tests and the same assumption of neglecting the aluminum metallurgical creep.

In order to follow the measured creep over time, a flexible method is needed. The graphical method does not give the creep in year 1, 2, 3… It cannot evaluate an ice overload in month 3, etc. Therefore, the method proposed by the authors is useful for relating the actual creep change over time and the calculation assumptions. However, for line design purposes, there is no need for such a detailed method as the simplified graphical method shows good agreement with the detailed flexible method.

5.2 Creep calculation for ACSR conductor

As mentioned above, in ACSR conductors the aluminum is the main responsible of both the geometrical settlement and metallurgical creep. Table 7 shows the tension-decrease and sag-increase of the same conductor working as an ACSR. For the calculations of the aluminum metallurgical creep, the public data of the ACSR Partridge conductor has been used [22]. This conductor is similar in size to the installed GTACSR conductor. As expected, the creep in the ACSR conductor (Table 7) is higher than in the GTACSR conductor (Table 6). In 30 years, the expected sag-increase is 0.26 m for the GTACSR conductor and 1.02 m for the ACSR conductor.

Table 7. Tension-decrease and sag-increase at 13.5 ºC since installation for an ACSR conductor

Year	Tension-decrease since installation (kg)	Sag-increase since installation (m)
1	54	0.56
2	61	0.63
3	65	0.68
10	79	0.84
30	93	1.02

6. Validation of the calculated creep with measurements

Based on the aforementioned on-site measurements, a comparison between the tension-decrease due to the calculated creep and the measured tension-decrease is carried out. An agreement between the results would validate the calculation procedure. There are some uncertainties in both the calculated and measured values that should be considered in the analysis.

With regard to the calculation, some simplifications have been considered. Firstly, the aluminum metallurgical creep is neglected. Besides, the aluminum compression in the knee-point [23-25] has been neglected in the calculation. The change of the value of the coefficient of thermal expansion (CTE) with temperature has been analyzed. Instead of an abrupt change of CTE, a progressive reduction of the CTE value with temperature has been detected. Although some aluminum compression is observed, it has not been taken into account in the calculations because the aluminum metallurgical creep is neglected. Some simplifications are also made when modelling the installation and operation steps. When defining the steps, a balance between the complexity related to a high number of steps and the relevance of the steps with respect to the creep has been found.

Regarding the measurements, the error depends on the accuracy of the measuring devices. Besides, the measured conductor temperature is local. The temperature may vary along the span especially due to wind variation. This may produce a distortion in the tension-temperature curve used for the creep evaluation. Anyway, the temperature variation in a single span is expected to be low. Another aspect to consider is the difference between the conductor surface and core temperature. At high temperature, the difference can be considerable.

Figure 11 shows the tension and temperature measurements. The graphs show dispersed values. In order to reduce the effect of the dispersion of individual measurements, groups with many measurements have been taken. Measurements taken in autumn (from October to December) have been chosen and the evolution of the tension between autumn 2012 and autumn 2015 has been analyzed. Figure 11 shows the measurements in autumn 2012 (blue dots), 2013 (red asterisks), 2014 (green crosses) and 2015 (light blue circles). In order to compute the decrease in tension, mean values of the tension as a function of the temperature have been calculated for each of the groups. Temperature values with low number of measurements have been removed from the analysis. Therefore, the tension average values have been calculated between 5 ºC and 25 ºC. Taking into account that the conductor was installed at 7 ºC, the aluminum is expected to be slack in most of the analyzed temperature range. The curves corresponding to the average tension values are shown in Figure 11: autumn 2012 (continuous line), 2013 (dashed line), 2014 (dotted line) and 2015 (dash-dotted line).

There is some uncertainty in the results because there is some fluctuation in the measurements. However, the results are reasonable because the tension decreases over time as expected. Besides, the creep development rate also decreases over time.

The measured tension-decrease is the difference between the average tension values in two periods of time: there is 7 kg of tension-decrease between the average tension in autumn 2012 and autumn 2013. Figure 12 shows the change over time of the calculated tension values at 13.5 ºC. The green dots show the tension values at the beginning of October. The horizontal red lines show the average tension between October and December. When the tension change rate is high, there is a considerable difference between the tension value at the beginning of October and the average value in autumn. The first value corresponding to autumn 2012 is much lower than the tension at the beginning of October. The difference between the average and instantaneous values is lower in the next autumns. There is an offset between the references (initial values) of the instantaneous calculated values and the average measured values.

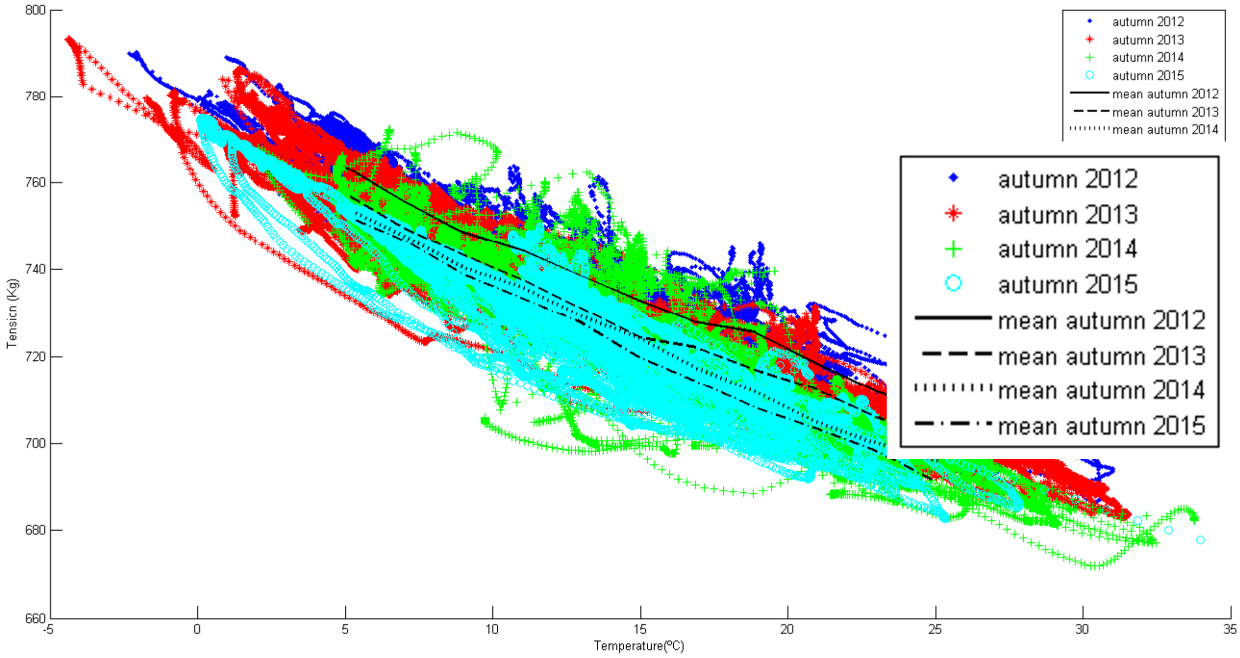

Fig. 11. Measured tension-temperature values 2012-2015

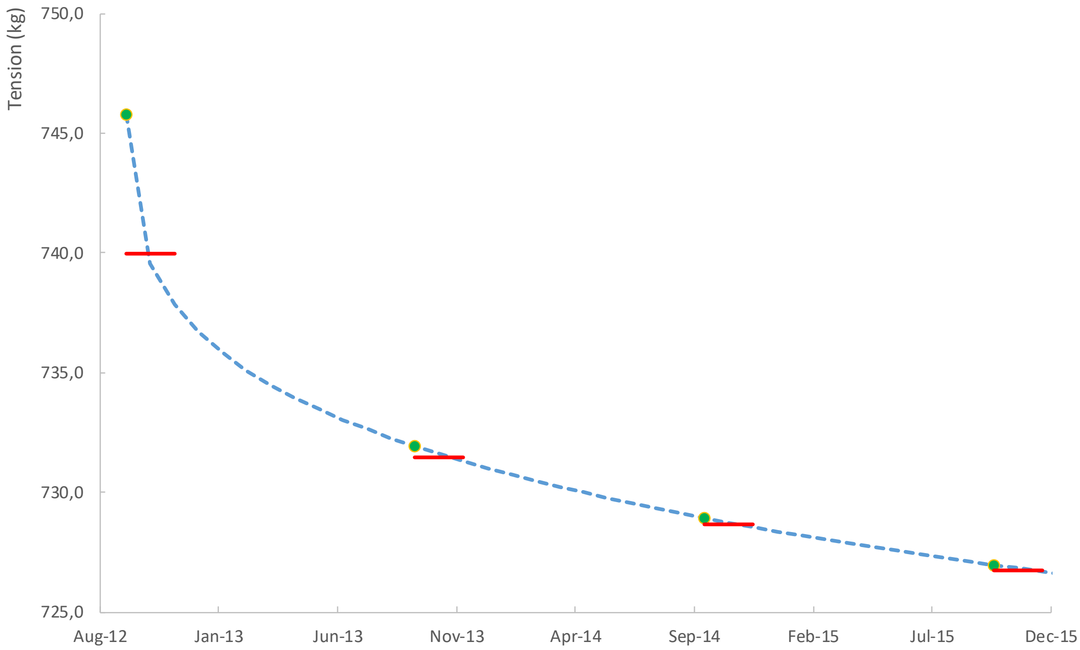

Fig. 12. Calculated tension at 13.5 ºC

Table 8 shows the tension-decrease calculated taking into account the average values of autumn together with the measured values. The reference average tension in autumn 2012 at 13.5 ºC is 740 kg (14.8 %

of the rated breaking strength). The average tension-decrease is 13 kg in 3 years (1.8 % of the initial 740 kg). Comparing the measured values and the calculated values, the values are very close. Therefore, although some uncertainties have been identified for both calculation and measured values, the agreement of the results suggest that the impact of the uncertainties is not important.

Table 8. Calculated and measured average autumn tension-decrease

Year	Calculated average autumn tension-decrease (kg)	Measured tension-decrease (kg)
1	8.5	6.6
2	11.3	10.4
3	13.2	12.7

7. Conclusions

A flexible sag-tension calculation method has been applied to follow the creep developed in a pilot line for three years of line operation. The measurements taken during the installation process and the operation period have been used to define several steps that have been used to calculate the conductor creep. The calculations show that there is no geometrical settlement development in the experienced ice and wind events, because the stress in aluminum and steel in these events is below the maximum value experienced during installation. This is because of the geometrical settlement developed independently by the steel and aluminum during the installation. Under different conditions, with severe ice and wind events, the conductor would experience geometrical settlement, but its value would be also mitigated by the geometrical settlement developed previously during the installation.

Although several steps have been applied by the flexible sag-tension calculation method, the number of steps that are usually used by conventional sag-tension calculation methods is lower. For this reason, the creep has also been evaluated for the widely used graphical method. The creep calculated by both methods in ten years is similar. In this case, the creep is governed by the metallurgical creep and the detailed modeling of the flexible sag-tension method does not make a great difference.

The applied calculation methods assume that there is no aluminum metallurgical creep. The conventional ACSR conductor creep is governed by the aluminum metallurgical creep but this is not the case of GTACSR conductors where the aluminum is slack or at low tension during line operation. The agreement between the calculated and measured values validate the assumption of neglecting the aluminum metallurgical creep.

The working conditions of the pilot line during the monitored three years has not been hard. The operation temperature has been low. This is because the line load was lower than planed and no emergency situation has occurred. Besides, the ice and wind events are not severe. For this reason, the conductor has not developed geometrical settlement. Although the calculation methods show good agreement with the measurements for this pilot line, further research should be done to analyze the creep with harder working conditions: at high conductor temperature operation and severe ice or wind loading conditions.

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