Prediction of Overhead Sag Using Cigre Elastic and Plastic Analytical Models and their Validation by Experimental Measurement on Overhead Line

Donal Patel[1], Dr. Vishal Singh[2], Dr. Mitesh Shah[3] and Dr. Gurpreet Grewal[4]

1 Student, Department of mechanical engineering, ADIT, Anand, Gujarat, India

2 Head and Professor, Department of mechanical engineering, ADIT, Anand, Gujarat, India

3 Professor, Department of mechanical engineering, ADIT, Anand, Gujarat, India

4 Deputy Director and Head, M.I.M.D, Electrical Research and Development Association, Vadodara, Gujarat, India

ABSTRACT

Over 80% of existing overhead transmission lines have been strung using Aluminum Steel Reinforced (ACSR) type conductors, which are used for voltage ratings upto 1200 kV. An important parameter characterizing the overhead lines is the conductor sag as it determines the safe electrical clearances mandated as per various codes & specifications. Therefore, it is important that accurate models for prediction of sag of overhead conductors be available as a function of conductor temperature. In light of this, CIGRE has developed two linear and one non-linear models for predicting the conductor sag. The two linear models include the "Linear Elastic (LE)" and the "Simplified Plastic Elongation (SPE)" models. In both these models, the elastic modulus and coefficient of thermal elongation are computed for the complete conductor using appropriate methodologies and values of individual elastic modulus and coefficient of thermal expansion of steel core and surrounding Aluminium are not considered separately. In the third "Experimental Plastic Elongation (EPE)" model, the behavior of the steel core and Aluminium sheath are modeled separately by actual experimental measurements (for computing the elastic moduli) and computation (for coefficient of thermal expansion). Further, in this model the stress strain behavior is represented by a polynomial type equation. The central objective of the present work is to undertake experimental measurements of conductor sag as a function of temperature of an actual overhead line in the state of Gujarat and validation of the measurements with "linear elastic" and "linear plastic" sag prediction models of CIGRE.

Keyword: *Sag, Temperature, Tension, elastic elongation model, simplified plastic elongation model*

INTRODUCTION

According to survey in 2003 over 80% of the transmission lines are built up from the aluminium conductorsteel reinforced (ACSR). Over all aluminium conductor, Aluminium alloy conductors ACSR conductor have high structural strength so it can bare high amount of electrical as well as mechanical load at the support. Dependency of overall cost of the transmission line is of requirement of tower erection and for that main consideration is sag and tension induced in the conductor so that thetransmission tower can sustain the mechanical as well as electrical load safely. Apart from that there must be some clearance so that there is no harmful effects due to heavy electromagnetic field of conductors to the surrounding. That minimum safe clearance is standardizes by the Indian Standard IS-5613. The sag-tension performance of a line section is the sag tension performance of a system composed by conductors, suspension structures and strain structures. The influence of the error of the span length value and the influence of the structure movement have been analyzed[1] and it shows that the conductor sag is mainly dependent on conductor temperature, ice and wind load on the conductor, tension in the conductor.Two hypothesis have been put forward to explain the knee point shift aluminium strand compressive forces and effects of conductor manufacturing processes. The results of the proposed study will improve the understanding of the effects conductor stranding on the sag behaviour of ACSR lines[2].parametric study is conducted for steady state surface temperature, thermal time constant, change of emissivity, absorptivity, conductor material, temperature along the radius for various ACSR and HTLS conductors. They have also done experimental study and obtain the result. They have studies and compare the performance of different types of HTLS and ACSR conductors[3].Today new lines are based on HTLS conductor is builded up more than ACSR conductor due to its high current carrying capacity. Weather parameters like temperature, ambient temperature, wind speed, solar radiation for the southern Sweden overhead line and the internal relations between the measured parameters. The result shows that the sag versus line temperature is approximately linear within the measured temperature range. So the real time monitoring system gives adequate knowledge of the line position to ensure safety distance. He has created model for the line temperature as a function of current, ambient temperature and wind speed and providing relationship between parameters that affects the temperature and sag of overhead lines by highlighting difference between two overhead lines named OL9 and ZL8[4].

In this study sag tension calculation by the cigre models. Two models are there for the calculating the sag namely elastic elongation models and simplifies plastic elongation model. in the elastic elongation model conductor is behaves like a spring so as the temperature is increases the sag is increasing and as the temperature us decreases the sag in the conductor is decreases and for that composite co efficient of thermal expansion and the composite modulus of elasticity is calculated from this model and in the simplifies plastic elongation modelthe value of creep consideration is justified and the calculation of sag and tension is carried out from the known temperature of the on line conductor which is carrying electrical load. The measurement is carried out near Karamsad and the calculated the sag and tension value is validating by the experimental sag on the transmission between tower no 12 and 13. Sag and tension are calculated as a function of temperature.

1 CIGRE Analytical Models

At the time of installation, the conductor sag or tension is measured with the conductor unloaded at a known temperature. Sag and tension typically change as: (a) the conductor weight increases due to ice and wind loading; (b) the conductor temperature changes due to changes in air temperature, solar heating and electrical current; and (c) as the conductor’s aluminium layers elongate plastically over time or with design ice and wind loading.

In order to calculate the sag and tension under various loading, temperature, and time conditions, one must be able to model the change in conductor length due to each factor. Once the various conductor elongation models are known, then the tension can be found at which the total conductor length, L, of loaded conductor equals the sum of the original length (unloaded length) and any plastic, thermal and elastic changes in length due to changes in tension, time, loading, and temperature. Conductor elongates elastically, plastically or thermally [5]. So according to that the conductor models is specified as the line carries the current the variation in the Conductor length due to temperature is considered in the both models.

1.1Linear Elastic (LE) model

Overhead conductors are modeled as linear springs with a single elastic modulus and a single coefficient of thermal elongation. An effective elastic modulus and effective coefficient of thermal elongation must be calculated for non-homogeneous conductors (e.g. ACSR). Typical values of modulus and CTE are used. With the increase in the current, solar heating temperature of the conductor will increases again the cooling through change in atmospheric conditions conductor is behaving like elastic and regain its original sag in the conductor and follows hooks law hence it is called elastic.

1.1.1 Linear elastic strain

Approximately 80% of bare overhead stranded conductors used in power lines are ACSR With a non-homogeneous stranded conductor such as ACSR, the equation for elastic behavior is more complex than with all aluminum conductors. The composite stiffness (elastic modulus) depends not only on the modulus of each component but also on their relative cross-sectional areas. This section discusses how the composite conductor modulus can be calculated.

if the component modulus and area is known. Even though the equations in the following refer to A1/S1A conductor, the concept applies equally well to non-homogeneous conductors constructed from other materials.

The total tension H_{as}, in the non-homogeneous conductor is the sum of the tensions in the outer layers H_a and the core H_s.

$$H_{as} = H_a + H_s$$

The strains of the aluminium and steel components must be equal since the two components are bound together at the ends of the conductor:

$$\epsilon_{as} = \epsilon_a = \epsilon_{as}$$

Given the link between stress and strain in each component as shown in equations , the composite elastic modulus, $E_{AS}$of the non-homogeneous conductor can be derived by combining the preceding equations:

$$\epsilon_{as} = H_{as} \times \frac{A_{as}}{E_{as}} = \frac{H_a}{A_a E_a} = \frac{H_s}{A_s E_s}$$

The component tensions are then found by rearranging equations:

$$H_a = H_{as} \times \frac{E_a A_a}{E_{as} A_{as}}$$

And

$$H_s = H_{as} \times \frac{E_s A_s}{E_{as} A_{as}}$$

Finally, in terms of the modulus of the components, the composite linear modulus is :

$$E_{as} = E_a \times (\frac{A_a}{A_{as}}) + E_s \times (\frac{A_s}{A_{as}})$$

The two terms on the right hand side of this equation are sometimes referred to as the “virtual modulus” of the outer layers and the core, respectively. Note that a stress-strain plot for ACSR showing the component modulus multiplied by the area fraction can be simply added to find the total modulus.

1.1.2Linear Thermal Strain

For non-homogeneous stranded conductors such as ACSR, the composite conductor’s rate of linear thermal expansion is less than that of all aluminium conductors because the steel core wires elongate at half the rate of the aluminium layers. The composite coefficient of linear thermal expansion of a non-homogenous conductor such as may be calculated from the following equation

$$\propto_a \times \frac{E_a A_a}{E_{as} A_{as}} + \propto_s \times \frac{E_s A_s}{E_{as} A_{as}}$$

The linear thermal elongation coefficient of aluminium is twice that of steel. Therefore, as the temperature of an conductor increases, while the entire conductor elongates according to the composite coefficient of linear thermal expansion shown above, there is also a transfer of tension from the aluminium strands into the steel strands.

1.2Simplified Elastic Elongation (SPE) model

Overhead conductors are modeled as linear springs. Plastic conductor elongation is calculated by adding a typical permanent change in length (usually expressed as an equivalent temperature change). The amount of plastic elongation is based on experience rather than on laboratory tests or design loads. Normally, the conductor coefficient of thermal elongation and elastic modulus are single valued but for non-homogeneous conductors such as ACSR, the different tensions in the aluminum layers and steel core can be calculated for the typical plastic elongation but the variation with design loading cannot[6]. For high conductor temperatures, a typical knee-point temperature can be calculated but any dependence on conductor type, design load, and span length cannot. The excessively high initial loaded tensions that result from ignoring the initial non-linear behavior of the aluminium layers are usually reduced by experienced engineers or used as an additional safety margin in structure design.

1.2.1 Creep consideration

- Based on a large number of laboratory creep tests on the zebra conductor at different tensions and temperatures, Bradbury and Harvey and Larson[7] have suggested the use of the following three predictor equations which correlate tension, temperature, time and creep strain
- $\varepsilon = K\, T^{ß} e^{\varphi t} t'^{(\Upsilon / T\delta)}$
- T = tension in conductor, kg
- t' = time h
- α = coefficient of thermal expansion, / ° C
- $K, \delta, \Upsilon, ß, \varphi$ = creep constants
- t = temperature °C

Equivalent change in temperature due to every day stresses that exerted on the conductor till date is found out with help of above equation. Temperature shift of 26 °C is calculated from this equation and the conductor stringing data is calculated.

2 Experimental Procedure

Measurement is carried out near Karamsad on the Karamsad Mogar 2 line between the tower no 12 and 14. The measurement is carried out the elevation difference method. For fixing the elevation of the lower point of the suspension tower from where the conductor is being supported and fixed is done with the help of the Total station theodolite which can measure up to 1 second. It is one the most versatile instrument used for the surveying purpose and the center point between the two tower is fixed it up from where the conductor sag is maximum and the clearance criteria from that point is being calculated. Having known the distance from the midpoint to tower and the distance from the midpoint which is manually set up where the theodolite is being kept and the variation in the conductor sag is measured in both winter and summer.

2.1 Instruments used for the experiment

Figure 2.1 Total Station Theodolite

Figure 2.2 Vernier Theodolite

Above both instrument is used for the elevation measurement and from the difference of that sag is calculated. Temperature of the conductor is measured with the help of Thermal imager.

3 Result and analysis

3.1 Experimental model

Conductor used for the 220 kV Karamsad Mogar 2 line is zebra. Which conductor containing inside the steel strands and covered bt aluminium strands. Thermal elongation of aluminium is twice as the steel. As according to the IEC 1597 steel and aluminium modulus of elasticity are 190 GPa and 55 GPa. Other specification and conductor detail are given below.

Table 3.1 Specification of Zebra conductor (GETCO karaamsad-220kv transmission line)

Sr, no.	Description	Dimension
1	No. of strands (Al/St)	54/7
2	Nominal diameter	3.18 mm
3	Overall conductor diameter	28.6 mm
4	Cross section area	484.5 mm^2
5	Weight	1.621 kg/m
6	Ultimate tensile strength	130.30 kN

Experimentation is done on the transmission line Karamsad-Mogar 2, between the tower number 12 and 13. date 11th February and 5thapril.

Table 3.2Hourly ambient Temperature data

	Ambient Temperature(°C)		Wind velocity(m/s)	
Time	Winter	Summer	Winter	Summer
10:00	24	30	1.65	2.77
11:00	26	32	2	2.5
2:00	29	35	2.75	1.94
13:00	30	37	1.8	1.66

14:00	29	40	2.5	2.77
15:00	30	41	2.5	3.6
16:00	28	41	3	4.1
17:00	28	38	0.8	4.7
18:00	25	36	0.8	5

Governing equations from the appendix the values of calculated sag and tension at given conductor temperature and experimentally sag is measured with Vernier theodolite. Measurement are taken at every hour of the day and the variation of sag and tension with respect to temperature is measured.

Table 3.3 Temperature of surface of conductor and sag value

Sr.no	Time	Temperature of conductor (°C)		Experimental Sag (m)	
		Winter	Summer	Winter	Summer
1	10:00	27.3	29.42	7.35	7.82
2	11:00	28.6	32.18	7.43	7.88
3	12:00	30.5	39.4	7.56	8.36
4	13:00	30.8	37.1	7.57	8.22
5	14:00	29.6	40.32	7.50	8.44
6	15:00	32.5	42.39	7.71	8.48
7	16:00	31.3	43.82	7.63	8.52
8	17:00	33.9	38.17	7.75	8.28
9	18:00	35.9	35.32	8.01	7.93

Table 3.4 Electrical parameters from GETCO Karamsad Sub Station

Sr. no	Time	Load (MVA)		Current (Amp)	
		Winter	Summer	Winter	Summer
1	10:00	60	61.	164.40	153
2	11:00	61.2	66	160.40	166.20
3	12:00	66	67.2	163.80	167.40
4	13:00	66	63.6	145.80	156
5	14:00	58.8	67.2	156.00	166.20
6	15:00	63.6	66	156.60	165.07
7	16:00	62.6	67	149.40	167.40

8	17:00	64.6	60	148.40	152.40
9	18:00	65.2	57.60	156.20	145.2

3.2 Validation model

For the validation of the sag tension calculation these experimental data is compare with the Kalpataru power transmission ltd. The data collected for the line 220 KV having same conductor specification and span length.

Temperature	Tension	Sag
24	3079	7.254
26	3045	7.335
28	3012	7.415
30	2980	7.495
32	2948	7.567
34	2917	7.657
36	2887	7.736
38	2857	7.817
40	2829	7.895
42	2801	7.974
44	2773	8.054
46	2746	8.133
48	2720	8.211
50	2695	8.287
55	2633	8.482
58	2598	8.597
60	2575	8.673
65	2520	8.863
70	2468	9.049

3.3 Analysis

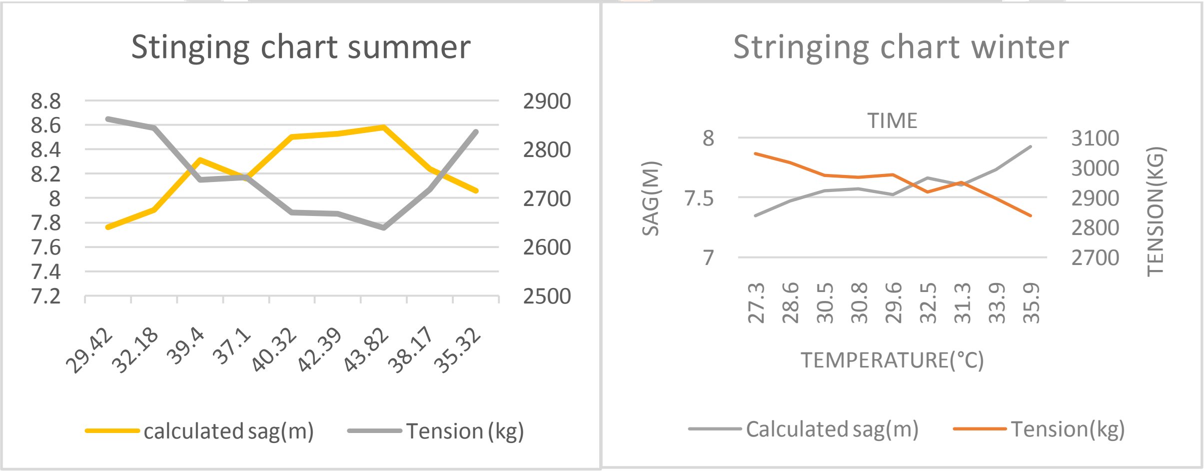

Figure 3.1 Stringing chart for summer and winter

4 Conclusion

- Dependency of sag is mainly on the conductor temperature and the variation on the load on the conductor.

- Prediction of overhead sag is justified well by the simplified plastic elongation model.
- While designing the transmission line creep should be the factor.
- With the variation the temperature of surface conductor 8.6 °C there is change in the sag in the conductor is 0.66 m.
- With variation of ambient temperature of 7 °C variation in the sag is 0.66 m. at the same variation of sag electrical load varies in the conductor is 14.4 MVA which is equivalent to 36 amp
- Duration of 32 years there is 17.22 % change in the conductor sag considering creep in to account there is error in the measurement is 2.07 %.
- Major factor affecting the variation in temperature is the conductor temperature which is changing
- Due to higher temperature in the summer there is higher sag in the summer by 0.5 m.

5 References

[1]Bedialauneta M.T., Fernandez E., Albizu I., Mazon A. J. and Sagastabeitia K.J., Factors that Affect the Sag-Tension Model of an Overhead Conductor, Department of Electrical Engineering ,University of the Basque Country UPV/EHU

[2] Sibilant G.C., Davidson I.E.,Stephen R.G. and Douglass D.A., 2016 “introduction to ACSR conductor sag at high temperature” CIGRE-IEC Colloquium 21, rue d’Artois, F-75008 May 9-11, 2016

[3]Reddy Subba B. and Chatterjee Diptendu, 2016, Analysis of high temperature low sag conductors used for high voltage transmission, Advanced in Energy Research, India Energy Energy Procedia 90(2016) 179-218

[4]Liu. Fang and Findlay Raymond D., 2008, Investigation of mechanical properties of single layer ACSR based on an Integrated Model, Electric Power Systems Research 78 (2008) 209–216

[5]Elisabeth lingerberth, The overhead line sag dependence on weather parameters and line current, UPTEC W1101, Examensarbete 30 hp, December 20111

[6]Harvey John R. and Larson Robert E.,1970, “Use of elevated-temperature creep data in sag- tension calculations”, IEEE transactions on power apparatus and systems vol.pas-89, no.3

[7]D. Douglass and M. Gaudry, WG B2.12,“ Sag-Tension Calculation Methods for Overhead Lines”, Task Force B2.12.3

[8]Douglass D., Gaudry M. and Hoffmann S.,2016, Sag-Tension Calculation Methods for Overhead Lines, Task Force B2.12.3

[9]Loudon D., Douglass D.A., Stephen R.G. and Sibilant G.C., 2017, Calculation accuracy of high-temperature sag for ACSR in existing lines, Cigre Science & Engineering • N°7 February

[10]Nigol J.S and Barrett (1981), Characteristics of ACSR conductors at high temperatures and stresses, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-100, No. 2

[11]IEEE guide for determining the effects of high temperature operation on conductors, IEEE standard 1283^{TM} 2004