Sag-Tension Calculations:
Refinements and Enhancements Made by Pondera

by:
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Abstract
Sag-tension programs have traditionally calculated the conductor's sag-tension characteristics using the ALCOA graphic method. By refining the input used in this equation, and augmenting these results with other definable variables and selectable parameters, Pondera has created a more comprehensive tool for the design and operation of transmission lines. This paper discusses the modifications and enhancements related to the input data, and explains how these changes improve transmission line planning capabilities. Calculation methods are also provided.

1.0 Introduction
The ALCOA graphic method traditionally has been used to calculate sag-tension. Using this methodology, conventional programs calculate the conductor's sag-tension characteristics without reference to the characteristic's influence on other components of a transmission line. Pondera has refined the stress-strain coefficients used as input by the ALCOA method. In addition to this sag-tension data, the program inputs consider conductor composition, stress-strain properties, adjustment for temperature and creep, the annealing factor, and tolerances. These factors enable the program to calculate regular sags and tensions of ruling spans, in addition to providing users with access to new output on structural loads, actual spans, inclined spans, regularly occurring loads, rarely occurring loads, low point and sighted sags, and uplift tensions.

2.0 Input Refinements
To predict the performance of installed conductors, the Pondera program requires two types of input: conductor parameters and conductor variables. Conductor parameters are properties affiliated with a particular conductor type. Conductor variables refer to external factors that act with the conductor's parameters and influence the performance of the conductor in field application.

2.1 Conductor Parameters
The Pondera system provides a user-selectable window of commonly-used conductors, including conductors made of two components (e.g. ACSR), homogeneous conductors (e.g. AAC), and fictitious two-component conductors made from a material "equivalent" to a single component conductor. Unlike traditional sag-tension programs that rely on a database to define properties for the selected conductor, these values are calculated by an auxiliary program. Developed by Pondera, this program works with the sag-tension program. The calculated properties associated with the selected conductor are used in analysis calculations and include:

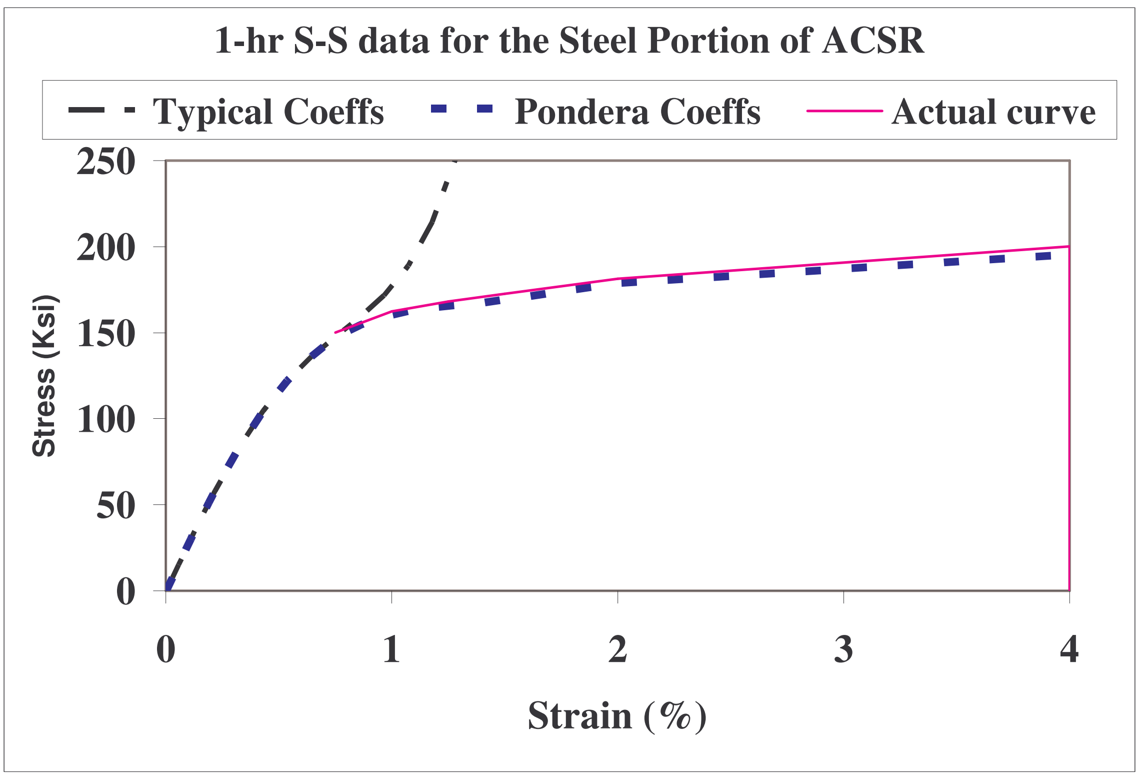
- Stress distribution between the outer and inner components (useful to evaluate Aeolian vibration performance).

- Conductor tension at higher temperatures, which is carried entirely by the inner component resulting in smaller sags. This feature can be turned on or off at the discretion of the user.

As new conductors are requied, the auxiliary program requires minimal input: conductor type, stranding, and size (e.g. ACSR, 26/7, and MCM). Using this data, the program calculates the required properties. These calculated values can be reviewed, modified, and stored for use by the sag-tension program. Coefficients for new conductors are also calculated using known coefficients originating from third parties, such as The Aluminum Association and ALCOA, and standard or conventional stress-strain-creep (S-S-C) charts. This feature makes it faster and simpler to analyze new conductors.

2.1.1. Stress-Strain Properties

Traditionally, stress-strain (S-S) properties used in the ALCOA method have been defined through polynomials of the third and four orders, namely four or five coefficients for each component. While these polynomials are accurate and satisfactory, they result in errors at higher conductor strains.



Graph 1: Comparison stress-strain values.

For example, Graph 1 illustrates the typical performance of the steel core of an ACSR conductor. Its predicted behavior, as determined by traditionally-used polynomials, is also charted. Next, it's stress-strain characteristics are plotted based on Pondera's enhanced sag-tension program. As the graph illustrates, Pondera's proprietary program exactly maps to the laboratory-tested cable performance. These more accurate stress-strain values are calculated by the Pondera program using either coefficients from third parties, standard laboratory test data, or published cable information.

2.2 Conductor Variables

2.2.1 Ruling Spans & Actual Spans

Sag-tension programs universally provide sags and tensions only for specified ruling spans, without reference to actual spans. Pondera's new sag-tension program clearly highlights the distinction between a ruling span and the actual span range that can be encountered within each ruling span. It also enables the design engineer to define the difference in elevation between the anchor points of any actual span.

Usually, instead of making the necessary calculations for the actual span, transmission line designers have simply substituted the ruling span sag and tension data for the actual span sag and tension data. This substitution introduces unnecessary errors, inefficiencies, and/or increased costs in the line design. Additionally, the actual spans are rarely, if ever, level spans as implied in the ruling span calculations.

These calculations are fully integrated into the main program and do not require reruns or other manual calculations.

2.2.2 Stringing Table

The standard program output shows the stringing sags for a number of actual spans ranging between the minimum and maximum expected actual spans within each ruling span. The design engineer has the option of specifying the required number of intermediate actual spans and can request the stringing data for special actual and inclined spans. This feature can be turned on or off.

2.2.3 Regularly& Rarely Occurring Loads

The program distinguishes between regularly and rarely occurring load cases. This allows design engineers to evaluate designs for typical weather conditions, as well as assess rarely occurring loads to ensure that the structure load capacities are not exceeded in extreme circumstances.

Regularly occurring loads are those that a line may experience as soon as it is energized, such as unloaded 18°C to 100°C (0^o to 212^o F) and NESC heavy/medium/light loads. The final sags and tensions are calculated after occurrence of these loads.

Rarely occurring loads allow for line evaluation in unusual conditions, which the line may infrequently, or perhaps never, experience during its economic lifetime. However, the ability to evaluate rarely occurring loads is essential for preventing catastrophic events without unnecessarily increasing the number of structures throughout the line. The user has the option to designate these loads as rare and the program will then:

- calculate the conductor tensions and structure loads corresponding to such loads
- provide final sags resulting only from the regular loads

- warn the line designer that resagging may be required if and where these loads occur

2.2.4 Tolerances

The actual performance of a transmission line is dependent in part on the ability of the design program to consider installation tolerances. In the past, these tolerances were often predefined. When installation conditions were expected to vary from these tolerances, designers had to manually adjust output or process the output through an alternative program to obtain a more accurate representation of field performance, or elect to accept the inaccuracy.

In the Pondera program, design engineers can define tolerances that are used by the program to determine sags, tensions, temperatures, and arc lengths. This has eliminated the manual or supplemental calculations and further enhanced modeling accuracy.

2.2.5 Annealing Factor

Historically, the impact conductor annealing has on line designs has been calculated based on a limited number of data points, which are extrapolated to predict performance at elevated temperatures. Pondera's program uses the available conductor data and a propriety algorithm to more accurately account for the annealing factor.

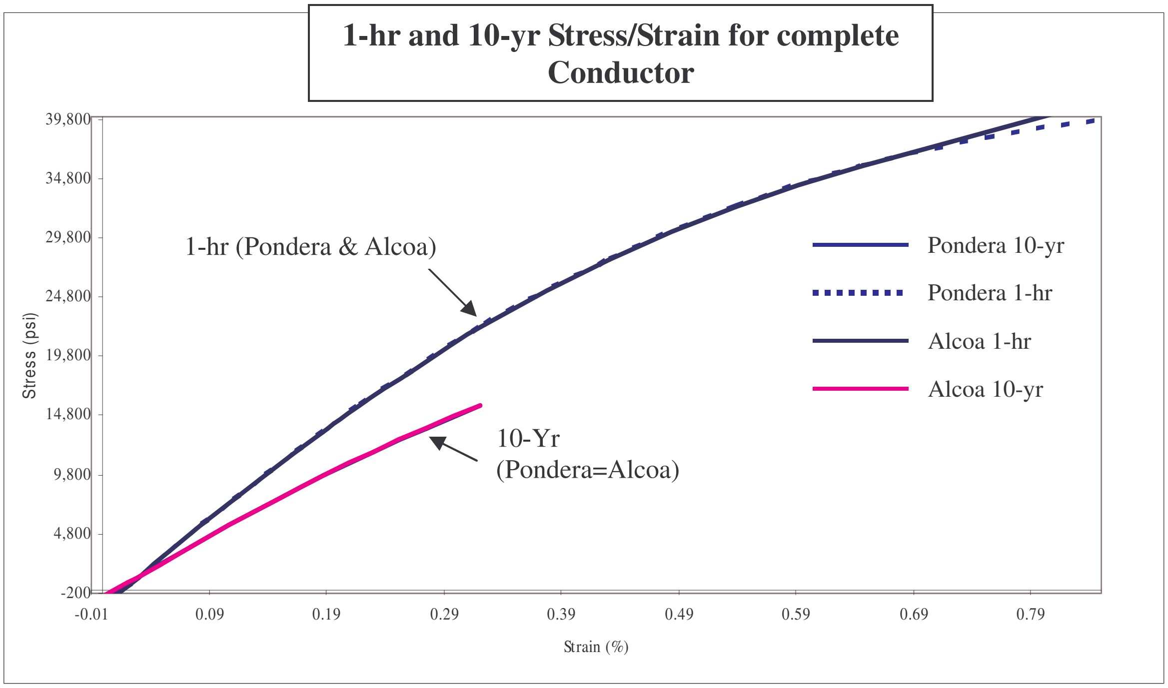
The accuracy of this data facilitates the creation of lines designed to operate at elevated temperatures for extended periods of time and determines the impact temperatures (and the annealing factor) will have on ground clearances after occurrence of operation under emergency conditions.

3.0 Refined Outputs

Through the use of more accurate input parameters and variables, refinements in output provide designers with enhanced information about creep, tension, inclined spans and low point sags, adjustments for temperature and creep, and unstressed conductor length. This output provides designers with the information needed to assess the cost and performance of line designs.

3.1 Creep

In addition to providing sag-tension information for the standard ten year creep, Pondera's new program also can determine creep after any number of years of operation (refer to Graph 2). The time period can be specified by the design engineer by changing one input parameter. This is a unique feature as it does not require new creep tests or any modification in the conductor data base. Again software packages are available to translate coefficients from third parties and creep information from standard laboratory tests or from published information.



Graph 2: Comparison data predicted by ALCOA process and Pondera calculations for one hour and 10 years.

3.2 Tension

Traditional programs provide only the conductor tensions and leave the calculation of the structure loads to the design engineer. The new program provides the vertical, transverse, and longitudinal components of the tensions at the upper and lower points of support for specified actual spans, initial, and final conditions. In particular, the vertical load at the lower point of support indicates whether or not the structure is under uplift conditions.

By recognizing that the conductor tensions are different at various locations throughout a catenary, the program applies the specified tension limits to the maximum T-tension in each ruling span, while evaluating the conductor S-S-C properties from the average P-tension in each ruling span. The program provides two options for calculating the P-tension:

- Conventional: Average between the tension at the low point of the catenary, H-tension, and T-tension. This calculation is inappropriate to use in up-lift conditions, where the low point is imaginary (outside the catenary).
- Accurate: Average between the tensions along the catenary at a number of equally spaced intervals.

3.3 Inclined Spans & Low Point Sags

Traditional sag-tension programs are for level ruling spans, where low point sags, sighted sags, and mid-span sags are one and the same. In the real world, spans are characterized by differences in elevation between the two points of support. Pondera's new program recognizes this, and provides the low point sags and the sighted sags for each span (the mid-span sags are almost identical to the sighted sags, even for inclined spans). For inclined spans, the program provides a warning if there are uplift conditions and provides the sags at the low point of the catenary as well as the sighted sags. Under uplift conditions, the low point sags become imaginary and only the sighted sags have significance.

3.4 Conductor Unit Weight Adjustment for Temperature & Creep

Traditional sag-tension programs use the fabricated conductor unit weight for their calculations. Pondera's new program adjusts the unit weight as a function of the temperature and creep. This feature can be turned on or off at the discretion of the design engineer.

3.5 Unstressed Conductor Length

When line installations require spans across water, deep ravines, or other special construction conditions, the Pondera program provides information to simplify installation. As part of the standard output, the software has the ability to calculate cutting length of an unstressed conductor at a specified cutting temperature to meet installation requirements for each ruling span.

4.0 Calculations

Contact Pondera Engineers (info@ponderaengineers.com) to obtain calculations used to derive some of the values discussed in this paper.

5.0 Conclusion

Since the introduction of the ALCOA method, little work has been done to improve sag-tension calculations, while the method has proven useful for transmission line design.

Pondera's work has enhanced the ALCOA method, providing designers with a tool for today's design environment. These enhancements have been achieved by refining program inputs related to the conductor's parameters and variables: stress-strain, ruling spans, actual spans, stringing table, regularly and rarely occurring loads, tolerances, and the annealing factor. As a result of refinements in these areas, the Pondera program uses data that more accurately represents the characteristics of the conductor over its installed life. These characteristics are reflected in the program's output with respect to creep, tension, inclined spans, low point sags, conductor weight adjustments, and unstressed conductor lengths. This output is essential for optimizing the design and operation of transmission lines.

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