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Transmission Line Conductor Asset Health Assessment with Non-Contact Monitoring Technology

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SUMMARY

Transmission line asset managers are facing increasing challenges associated with aging transmission lines and are tasked with the decisions on how to maintain and replace conductors currently in service. This decision-making process requires reliable long-term and up-to-date information on the state and condition of the conductors but currently, most asset managers lack such information. New remote sensing technology developed by LineVision is able to collect previously unavailable rich datasets of information on transmission line conductors. These datasets enabled the development of an Asset Health Module (AHM) which creates an asset digital twin, integrating both historical and real-time data from the target transmission line in order to compute its baseline Asset Health and detect changes over time. These inputs include high-temperature cycling, extreme sag and blowout forces, galloping events and their intensity, precipitation loads from icing, and other events the conductor experiences during its lifetime which will impact asset health. Without monitoring equipment many of these damaging events will go unnoticed unless they cause catastrophic failures which can be dangerous, cause forced service interruptions, and take months or years to repair. The Asset Health Module integrates engineering specifications such as the design information collected, as-built, and real-time field measurements obtained via a remote monitoring system. Based these inputs, an extensive proprietary model determines the operating conditions and the asset health of the transmission line conductor.

KEYWORDS

Transmission Line Monitoring, Transmission Line Asset Health, Asset Health, Conductor Assessment

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1 Introduction

As our transmission grid ages, operators are facing difficult challenges around how to best maintain and operate the existing grid assets. Operational and planning decisions about overhead transmission line conductors are an important part of overall transmission asset management process. The decision-making process requires well supported up-to-date information about the conductor’s current condition. Unfortunately, most transmission line asset managers do not have access to actual asset condition data for their work.

Currently, when the condition of a conductor is assessed, the results are mainly based on visual inspections carried out over large time intervals which can be up to several years. However, new technology can monitor the conductor’s physical and electrical properties and transmit that information to decision makers in near real-time to provide significant increases in situational awareness.

LineVision V3 monitoring equipment utilizes non-contact sensing technology to determine key conductor parameters for each individual phase monitored such as conductor sag, horizontal motion, conductor temperature, galloping, ice build-up, as well as anomalies using a combination of sensor types. The collected information can be further analyzed, and an Asset Health Model of the transmission line conductor has been developed. The model works by creating a “digital twin” of the span which is relatable to the overall stringing section.

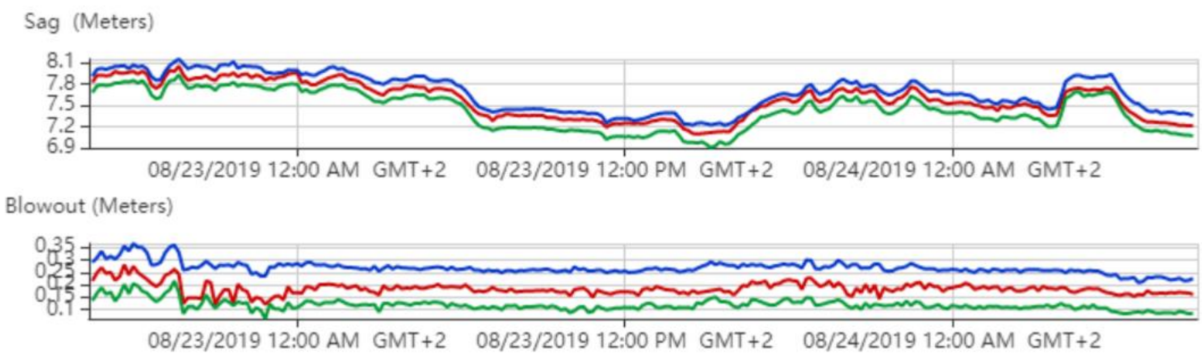

Fig. 1. Snapshot of two days of individual phase conductor motion data collected by a single LineVision V3 system

2 The Model

The model uses a mathematical representation of the conductor based on the field measurements called the “digital twin” (DT). This model incorporates the various conductor support, sag, temperature, position, and motion for the specific span. The model parameters can accommodate the condition changes of the conductor and forms the basis of further evaluation of conductor status.

The available mechanical properties and catenary position of the conductor are used to create a reference state that is corrected to a specific temperature. The reference state is then compared to the conductor’s behavior in real-time. A variety of factors can be observed which negatively impact the conductor asset health.

The major components that can be derived from the measurements are: Thermal aging, creep, precipitation overload, sag change, and galloping. The information and results computed by the Asset Health Model can be sent to the transmission operation control center, transmission line asset management department, and/or field operations.

3 Principles of the LineVision V3 System's Operation

The LineVision V3 system is a remote, non-conductor-contact transmission line monitoring system that is typically installed on the transmission line's supporting monopole or lattice structure. The sensors continuously monitor multiple aspects of the lines, both physically in space and electrically. The equipment uses a combination of patented EMF and optical sensors to measure the electrical properties of the line and the physical position of the conductors. This data is then used to calculate asset health parameters and dynamic and forecasted line ratings which are delivered to the transmission line owner via a secure data feed or private cloud interface.

4 Areas of the model

The developed Asset Health Model covers Thermal aging, Historical sag, Precipitation overload, Sag change, Galloping, and Operational Limit Recharacterization.

4.1 Thermal Aging

One of the most important variables which must be detected by a real time monitoring system is the temperature of the conductor. This is derived from the measured sag and the line calibration equation [1] of the monitored span as related to that span's specific geometry. Transmission lines are designed for a certain maximum operational temperature. Operating the line at a high temperature above 90 C can degrade the strength of the conductor and can lead to rapid deterioration of the conductor's health. There are several well-established thermal degradation models that provide an indication of the impact of high operational temperature events and their duration on the remaining strength of the conductor. The most widely accepted and used model was developed and published by J.T. Harvey [2], [3]. IEEE standard 1293 provides detailed information [4]. Other models are also available published by V. T. Morgan [5], [6], F. Jakl et al. [7] and Bhuiyan et al [8].

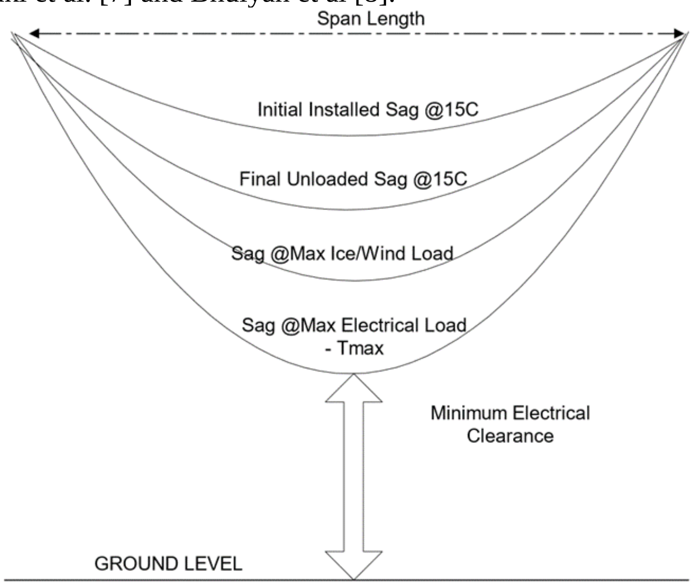

Fig. 2. Catenary change after installation where T-max is the maximum conductor temperature with conductor temperature, ice loads, wind loads and time after installation where T-max is the maximum conductor temperature. [9]

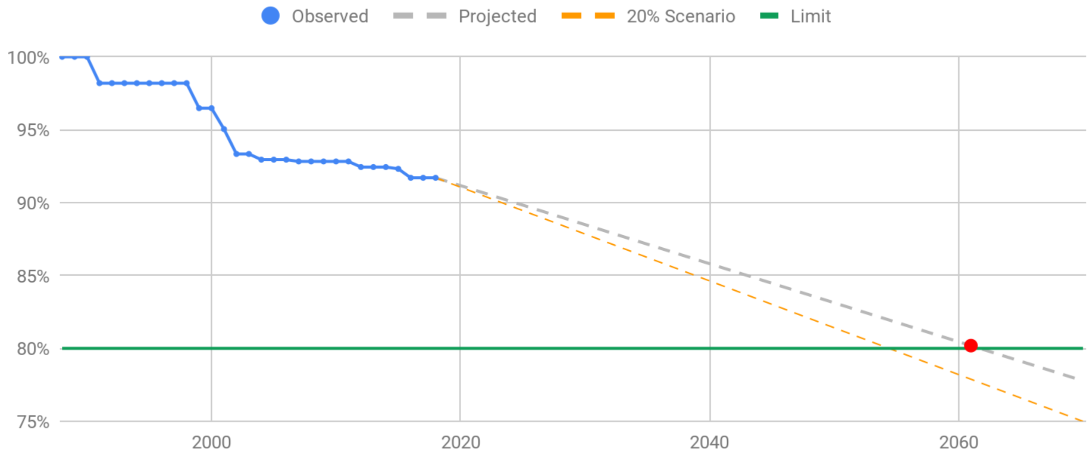

Fig. 3. Conductor loss of strength over its lifetime and end of life projection based on history.

From the sensor measurements, including the data sets that measure temperature cycle levels and durations (conductor exposure), the strength reduction can be estimated. More accurate models can be developed for the conductor using detailed temperature strength reduction in laboratory environments. Using the digital twin model, the remaining strength of the conductor is compared to the line's acceptable limit. This acceptable limit must be defined by the transmission line's design parameters.

When the conductor's historical records are evaluated over time, the annualized degradation rate can be determined. Assuming a constant rate of degradation and conductor loss of strength, the conductor's remaining useful life can be estimated. The "digital twin" of the conductor can be used for checking design, schedule replacement and making business justification on decisions regarding the conductors.

4.2 Historical Sag

For as long as monitoring equipment has been installed, it is able to provide historical records of the individual conductor sag and horizontal motion. These sag measurements along with the calculated deviation from the originally designed state and temperature can be used for computing the long-term elongation of the conductor (creep). These permanent plastic elongations can then be evaluated and compared to acceptable limits.

Historical records of the sag and the real time measured sag can be compared to the engineering designed acceptable criteria and the remaining life as a percentage of the initial design can be determined. When sag monitoring is carried out from the installation date of the conductor, the various conductor elongations can be directly computed.

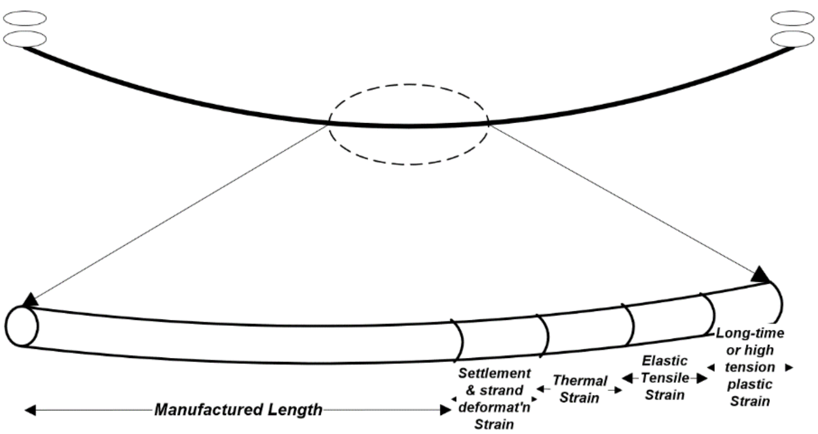

Fig. 4. Types of elongation in conductor. [10]

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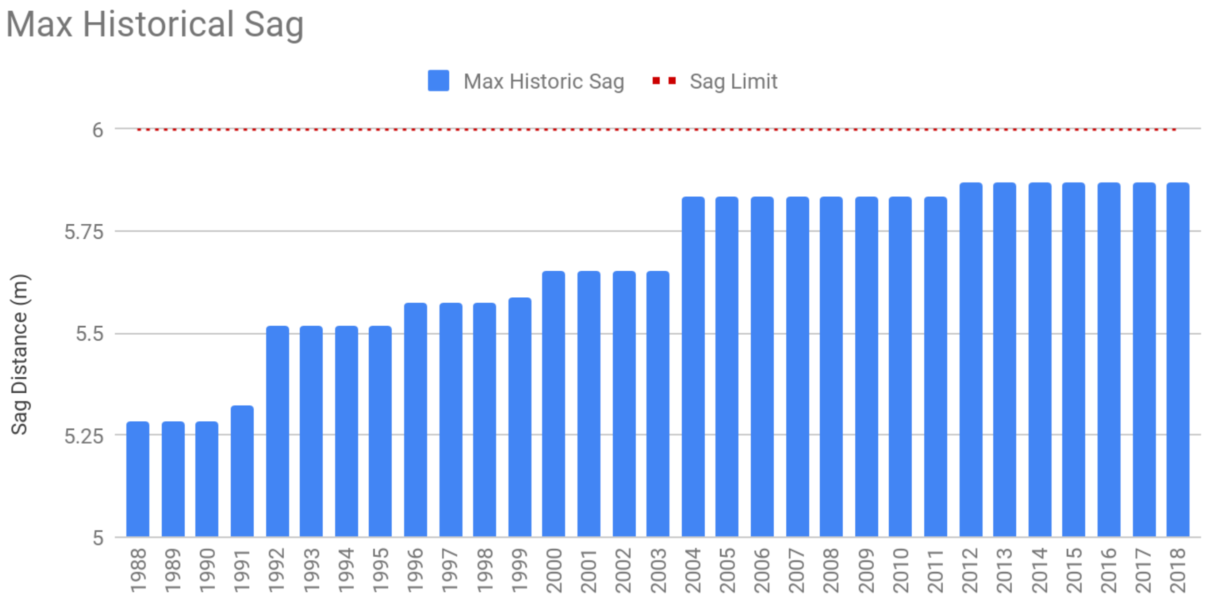

Fig. 5. Estimates of the historical maximum sags from high temperature events shown as an annual high water mark format.

4.3 Precipitation Overload

Over the lifespan of a conductor, it may be experience abnormal mechanical loading caused by various forms of precipitation such as snow loading, ice formation, or rime. In cloud icing, or freezing rains, ice build-up from falling snow can be one of the highest mechanical and structural loads that a transmission line experience.

LineVision equipment continuously monitors the conductor sag. When ice or snow build up occurs, it is usually progressive and gradual. The sensors can indicate that on-conductor precipitation build up is in progress and send an alert can to the transmission control center. This provides a valuable indicator to system operators that an event which can compromise system reliability is occurring. The alert may trigger intervention from the control center to implement de-icing protocols, or system operating orders to mitigate the precipitation event impact on the transmission line. For example, system operators may implement switching protocols to load the icing line with additional current, so that it heats up and the ice is melted off the conductor, preventing it from experiencing plastic deformation from the additional ice loading.

The digital twin model of the span can be used as a reference for evaluating how much ice or snow formation has occurred on the conductor at the current situation. From the sag and the original position of the conductor the unit weight of the precipitation accumulated on the conductor can be computed using catenary formulas. The input items are the physical and designed properties of the conductor and the sag position of the conductor. The output is the additional load form the precipitation acting on the line.

These sag measurements will also indicate any additional, operational and safety related issues from the increased sag under precipitation load. These can include potential flash over or conductor sagging excessively at certain critical locations where these excessive sags cannot be tolerated. Examples are long spans crossing roads, railways and waterways. Additionally, long crossings in commercial, industrial and residential areas where clearances need to be kept for safety reasons are of most concern. Based on the measurements during a snow or icing event, the transmission line asset management group as well as the transmission line design group can gain invaluable data on the local load conditions of the line. Moreover, the duration of the ice build-up and the rate of loading and unloading is also monitored in near real time.

After the icing or snow event is over, the sag of the conductor is again measured and taken in account as a part of the AHM system's continuous operation. By analyzing the sag measurements after the precipitation loading event and comparing them to the digital twin before the event, the plastic deformation of the conductor can be computed. The sag condition after the icing event can be also evaluated and decisions can be made if remedial actions are needed on the line or not due to excessive sag.

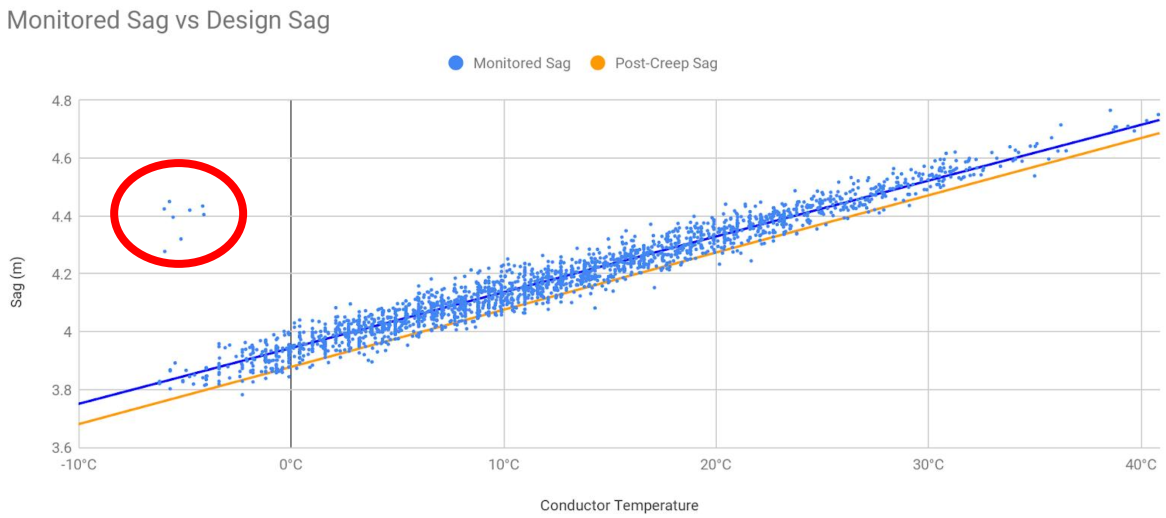

Fig. 6. Examples of excessive sag from icing on a transmission line.

4.4 Sag Change

LineVision equipment monitors in real time the conductor's position and relates this to its sag and horizontal motion. If a sudden change is detected which may be an indication of damage to either the conductor support (structure, cross arm, insulator, hardware etc.) or to the conductor itself, the asset health model can trigger an anomaly detection alert. For example, a tree falling on the line, a large branch of a tree blown into the line, a piece of tarp or other item blown by the wind into the conductor. Other security concerns can be detected. If one conductor were to suddenly start sagging lower due to a foreign intrusion, this change in position can be immediately detected. These changes can flag potential problems with the line's operating condition and trigger an alert to a utility that a site inspection is required to determine the severity of the issue. This type of transmission line monitoring equipment increases reliability and safety of the line.

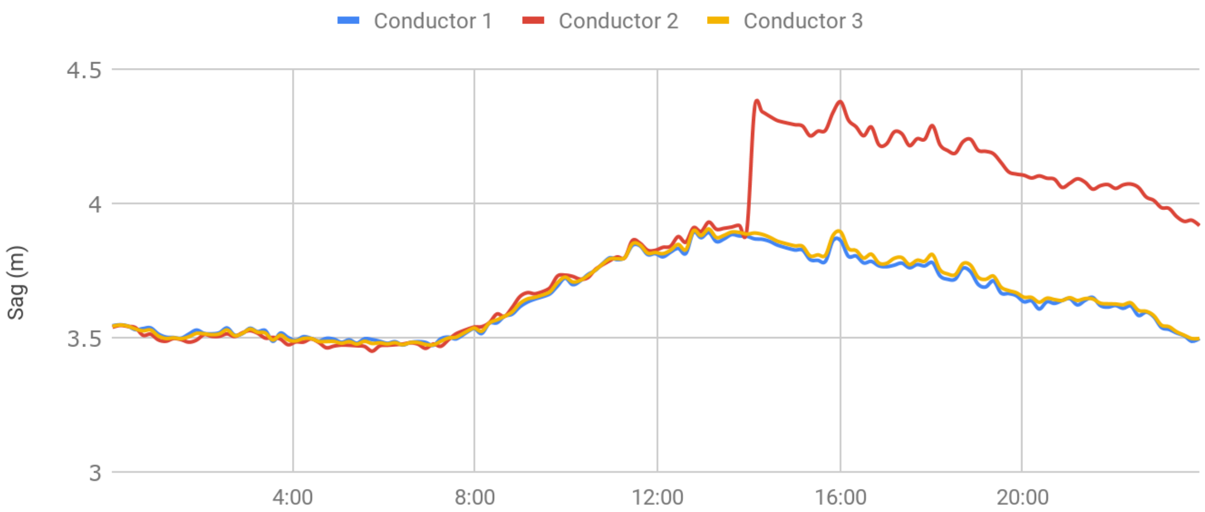

Fig. 7. Anomalous motion of one conductor phase on a transmission line.

4.5 Galloping

Conductor galloping is the high-amplitude, low-frequency oscillation of overhead power lines due to wind. The movement of the wires occurs most commonly in the vertical plane, although horizontal or rotational motion is also possible. Galloping can have significant influence on the conductor remaining life. Significantly larger axial forces caused by the conductor's motion and possible phase to phase touching causing flashover burns on the conductor surface can happen. LineVision equipment is able to monitor the conductor motion in real time which can provide operators with information that can indicate when dangerous conductor galloping is occurring and provide the conductor's minimum and maximum amplitude of galloping.

Once the conductor position measurement has been recorded, the conductor's modal frequency and amplitude determined. From the conductor motion's frequency and amplitude, structural and mechanical overload forces of the conductor and structure can be computed. The formulas are available in Ma et al. [12]. After the galloping event has occurred, the catenary position of the conductor is identified and compared to pre-galloping position of the Digital Twin. Any deviations are then identified which are evidence of possible plastic deformation or damage to the conductor support.

Galloping can cause permanent damage to bundled conductors creating a twisted permanent position of the bundle after the galloping is over. This twisted position also can be detected and flagged for further attention. Field services crews can be alerted and dispatched to site addressing potential damage to the line from galloping. After evaluating the potentially damaging events, asset managers are able to evaluate and justify required actions for the line's improvement such as redesign, phase-to-phase insulators or additional dampers.

Based on historical records of the conductor's position along with damage suffered from galloping as determined by the minimum and maximum amplitudes of the galloping, estimates can be generated for the remaining life of the conductor

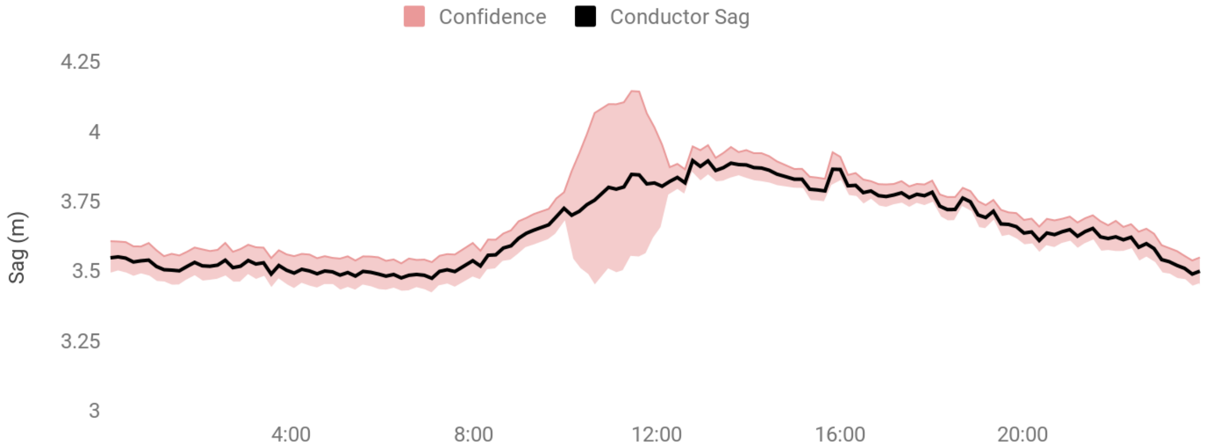

Fig. 8. Galloping indicated by an increasing range of observed conductor sag.

5 Operational Limit Recharacterization

After a conductor has experienced any of the previously mentioned damaging events, or over the course of its life, it will naturally experience a change in its operating conditions from the designed parameters. While the changes may be slow over time, or sudden after an icing event, there will be a permanent change in the conductor's sag/temperature curve. This will effectively create a new operating limit for the conductor so that a new maximum operating temperature will correspond to the safe operating sag limit.

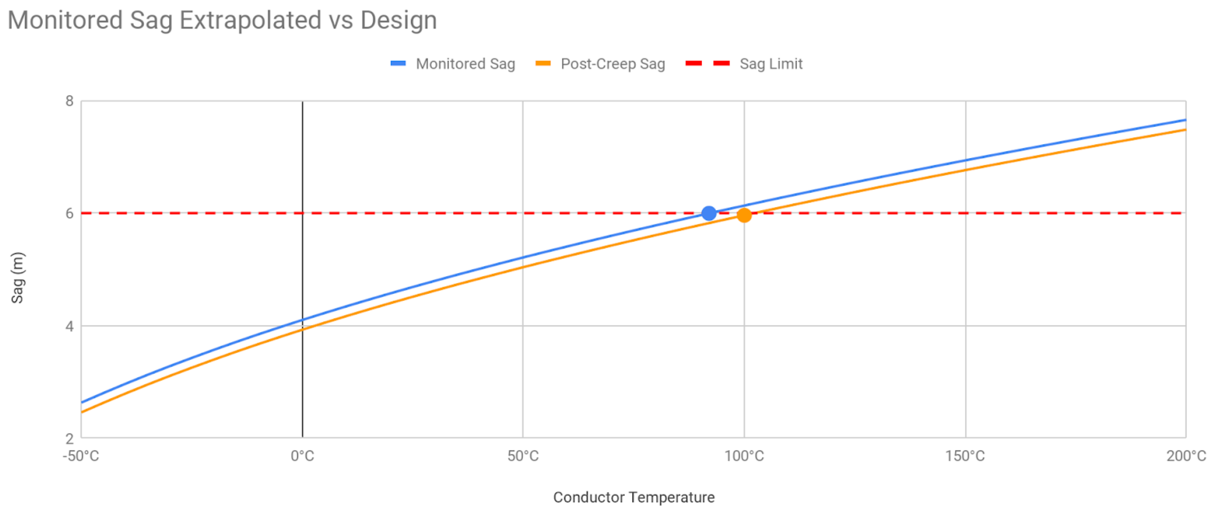

Fig. 9. Sag-Temperature Recharacterization Curve

6 Conclusions

A transmission line conductor Asset Health Module (AHM) has been developed which creates a digital twin, integrating both historical and real-time data from the target transmission line in order to compute its baseline Asset Health from LineVision system data. These outputs of the module analyzes high-temperature cycling, extreme sag and blowout forces, occurrences of galloping and their intensity, and precipitation loads from icing, and other anomalous events the conductor experiences during its lifetime.

Based on the various derived models, such as thermal aging, historical sag, sag under precipitation, and galloping, the plastic deformation and other permanent deformities that the conductor has experienced can be determined. These permanent deformations can be compared to the allowable and tolerable limits as defined by transmission engineers and a historical rate of wear and tear can established.

The remaining life of the conductor is estimated and continuously updated based upon new operating conditions. The information provided by the AHM can be used by utility engineers and asset managers to improve system reliability and make informed decisions on conductor maintenance and replacement.

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