OVERHEAD TRANSMISSION LINE MONITORING

Incubatenergy Labs 2020 Pilot Project Report

Startup

LineVision

Host

Tennessee Valley Authority (TVA)

Technology Solution

Utilities are constantly striving to maintain safe and reliable operation while increasing the performance and productivity of overhead transmission lines. Adhering to design limits for conductor temperature is essential to prevent annealing damage and loss of strength, and maintaining physical clearances from trees and structures is necessary for meeting safety and reliability objectives. Additionally, utilities must have a good understanding of remaining asset life, and they require methods and tools for optimizing asset utilization by balancing system risks with increased power flow and streamlined maintenance effort.

The LineVision pilot was aimed at demonstrating the types of data that can be provided by a novel transmission line monitoring system and to explore asset health and other potential use cases based on continuous access to information on thermal loading, line clearance, and other parameters. The LineVision V3 system integrates non-contact field sensors installed at both ends of a transmission span with weather model data, historical utility load information, modeling and analytics, and a display portal. Field instrumentation includes two self-powered components, an electric and magnetic field (EMF) sensor for continuous monitoring of electrical properties and a LiDAR scanner for precisely identifying conductor locations.

Challenge: Customer and Community Resilience

LineVision system as deployed in the field

Project Overview

This collaborative project was designed to conduct a proof-of-concept demonstration of the LineVision V3 system and to investigate the value proposition of a rigorous field trial, which for transmission line health monitoring technologies typically takes about 1 year to complete. The project approach included field testing of LineVision technology and a parallel data gathering effort by TVA and EPRI to support comparative analyses and follow-up investigations.

Based on discussions with LineVision representatives, TVA identified lines with different types of conductors, operating voltages, load profiles, bundling, and surrounding environments to identify demonstration sites for illuminating the strengths and weaknesses of the technology. One of the test lines was selected due to its connection to energy storage and because of routine heavy loading; traditionally, line monitoring systems tend to perform better under these conditions.

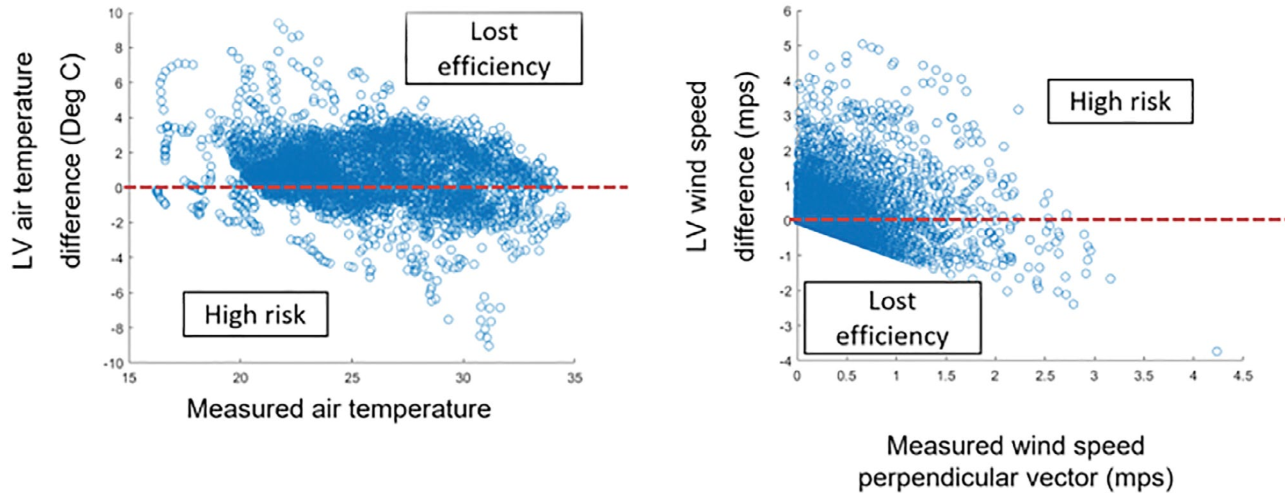
The LineVision and EPRI systems were installed by TVA line crews on towers at three sites in fewer than 2 days. One span was between dead ends at Raccoon Mountain, and two spans were at Chickamauga.

TVA collected line loads at multiple locations to compare against loads calculated by the LineVision V3 system. EPRI collected weather information to compare against the system's weather model data and calculated parameters such as wind cooling of conductors. Because known industry standards for conductor temperature and annealing are based on weather-related data, the accuracy of LineVision's modeled and calculated values has a clear and measurable effect on its results. Additionally, assessing the real-time accuracy of LineVision's weather model data provides insight into its historical annealing analyses.

Results & Learnings

After minor updates to the deployed instrumentation, both the LineVision and EPRI systems were able to collect and make data available in real time via web portals. The LineVision portal displayed measured values for line sag and blowout; calculated values for conductor temperature, line rating, line load, and effective wind speed; and model data for air temperature, rain rate, and solar intensity. The EPRI portal displayed weather and line rating information.

The LineVision system continuously analyzes the accuracy of the data from field sensors and, when necessary, reverts to using weather model data. In this study, the sensors were utilized approximately



Example of data comparisons from the Chickamauga 161kV line location

31% of the time. For the Chickamauga test site, air temperature and wind speed data are shown above. EPRI-measured data are plotted on the horizonal axis and LineVision model or calculated data on the vertical axis.

Air temperatures from the LineVision model showed general agreement but with some periods having differences approaching as much as 10°C (18°F). For periods when LineVision sensors were utilized, calculated effective wind speeds were typically within 2 m/s (6.5 ft/s) but occasionally exhibited greater variation from EPRI-measured data.

Accurate wind speed data are essential for estimating the effect of real-time conditions on annealing potential. Importantly, EPRI's ultrasonic anemometers measure wind speed at a point in space on a transmission tower, whereas the LineVision system's LiDAR sensor determines wind speed along the length of the span between two towers. While the spans involved in this pilot are relatively short and have consistent levels of wind sheltering by trees, differences in measurement strategy are an inherent source of variability.

The figure on the next page provides a comparative analysis of the line load data. Loads estimated by LineVision were within ±5% of TVA's measured loads about 75% of the time for Widows Creek, 64% for Raccoon Mountain, and 21% for Chickamauga. Some of the discrepancy can be attributed to methodology: the LineVision system provides instantaneous values, whereas TVA measured a 10-minute average.

A longer study period would increase the statistical significance of these comparative analyses, and different patterns may emerge with more data. Based on the analyses across the three test sites, the LineVision system appears to perform best when a line is isolated—the only circuit within the right-of-way. Performance appears to decline in scenarios with adjacent circuits such as in the case of the Chickamauga line, where underbuilt distribution is present.

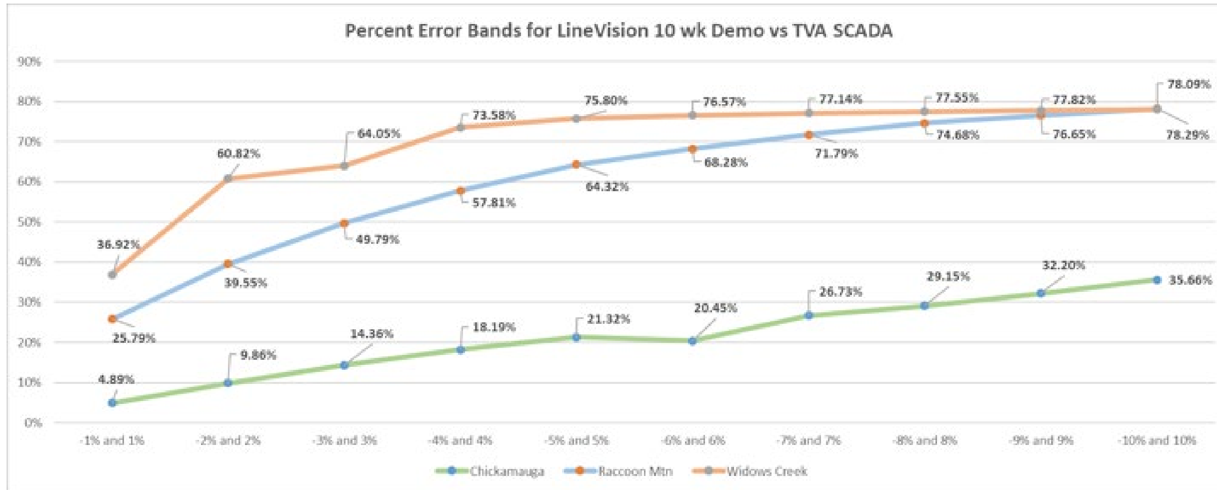
Methods were identified for improving the rigor of future assessments of the LineVision system. For example, sample testing can verify the remaining strength of conductors, and direct measurements can validate calculated conductor temperatures. Additional study also would help improve understanding of factors underlying the LineVision system's assessment of the effects of real-time and historical conditions on annealing. The system applies the same weather data to evaluate real-time conditions and assess historical annealing potential, but it is unknown if identical weather models are used. The system applies real-time loading estimates to calculate conductor temperatures and gain insight into conditions that may cause loss of life, whereas utility-provided line load data are used for historical assessment of annealing damage.

Implications & Next Steps

This 3-month field trial has helped TVA understand the potential of online transmission line monitoring and gain insight for better aligning technical capabilities with specific utility needs. Valuable information can be obtained from continuously monitoring and analyzing transmission line health parameters and physical clearances, but there are challenges in using this approach relative to existing methods.

Typically, utilities perform periodic LiDAR overflights on a rotating basis—for example, one-third of lines annually, thereby covering all lines within 3 years. This provides routine access to point-in-time information relating to line sag and sag-tension relationships for all spans. The LineVision system is designed to provide continuous monitoring on spans between dead-end structures. In this demonstration, the focus was on assessing health monitoring capabilities.

There is a high degree of commonality between measurements used to track annealing and to calculate ratings, as both rely on understanding the conductor temperature as it relates to design limits and, in fact, use the same IEEE-783 equations. Considering cost-benefit as compared to existing overflight practices, TVA sees a potentially stronger use case in the dynamic line rating capabilities of the LineVision system if the sensor accuracy can be demonstrated to be sufficient.



Data comparison of line loads based on percentage of data within an accuracy bin

TVA is interested in extending the field trial with an adjusted focus on dynamic line rating. To achieve this, additional monitoring of the conductors will need to be performed. Discussions with LineVision are ongoing to increase accuracy compared to that observed in the initial demonstration project. Potential improvements include obtaining line loads directly from utility SCADA and integrating local air temperature measurements within the LineVision system. Other utilities interested in evaluating applications are encouraged to reach out to the team involved in this pilot project.

Resources

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LineVision uses non-contact LiDAR sensing technology to aid in providing situational awareness of the health of transmission line assets. As utilities look for new technology for modernizing the grid, innovations that improve understanding of asset health conditions can help in ensuring system integrity. Working with LineVision has helped our engineers think of more innovative ways of using technology and solving problems.

Upon reviewing the project summary on the previous pages, LineVision expressed disagreement with certain aspects, as highlighted below.

LINEVISION RESPONSE TO EPRI-TVA ANALYSIS

Differences in measurement approach between EPRI and LineVision sensors

EPRI and LineVision both installed sensing equipment on transmission towers. However, these sensors measure and report different pieces of information and should not be misconstrued as generating comparable data. EPRI installed a weather station, and LineVision installed a non-contact LiDAR-based conductor monitoring system. EPRI's ultrasonic anemometer and thermometer represented localized weather conditions at a singular point in space. The LineVision system represented the net effective perpendicular wind speed along the entire stringing section of conductor.

As such, the two systems should not be assumed to exhibit a natural correlation. The anemometer's measured wind speed and direction are subject to localized effects. All spans in the conductor's stringing section act as a coupled thermo-mechanical system, and the LineVision effective perpendicular wind speed thus represents the net collective effect of all varying wind speeds impacting the various sections along the stringing section.

CIGRE Technical Bulletin 498 warns against the direct use of spot measurements: "It should also be noted that the [conductor] temperature changes along the span. The cooling effect of the wind will vary from place to place on the line. The measurement at one point is thus not a true representation of the temperature at other points on the line, thus is not representative of the sag and line rating."

LineVision sensor utilization percentage

The EPRI-TVA project summary incorrectly states that LineVision's sensor is utilized only 31% of the time. LineVision's sensor is utilized 100% of the time. It is used to collect conductor position, EMF values, and other information from which additional conductor properties are calculated. When adequate heat rise is present on the conductor as compared to ambient temperatures, the LineVision system has the appropriate confidence level to report the effective perpendicular wind speed and calculate the dynamic line rating.

When line loading is low and conductor temperature is near ambient, temperature-based monitoring systems of any variety cannot compute the apparent convective cooling rate, the effective perpendicular wind speed, or a dynamic line rating with acceptable certainty. Under these conditions, the LineVision system employs a secondary calculation using weather model data for wind speed to produce a dynamic line rating value. In this particular study, conductor heat rise was sufficient 31% of the time, largely due to relatively low line loading patterns.

LineVision line loading analysis

The EPRI-TVA project summary includes a comparison of the line loading values as reported by LineVision's EMF sensors and TVA's substation current transformers (CT). However, the analytical approach applied failed to consider multiple influential factors when performing a comparison:

- LineVision's load data were instantaneous measurement values, whereas TVA's load data were 10-minute averages.
- TVA's own CTs had inherent error and reported inaccurate values below 72 amps, but these data points were still used in the comparison.
- TVA had CTs at the origin and terminus substations for both the Chickamauga and Widows Creek lines. Those CTs exhibited error when comparing their reported values, but amperages should be constant along a closed circuit. TVA's average absolute errors (amps) were 20.4 and 12.4, respectively, while the LineVision readings showed average absolute errors (amps) of 26.6 and 13.2, respectively.
- EPRI used a simple percentage difference approach when comparing values for average absolute error (amps), but % average absolute error is a more appropriate approach to data science. The percent difference approach will yield misleadingly high percent errors when looking at smaller numbers; for example, comparing readings of 12 amps to 10 amps will yield an error of 20% while the absolute error is just 2 amps, a negligible amount when looking at transmission lines carrying hundreds or thousands of amps.

Line loading error assessment

To more appropriately perform the data analysis and resolve the problems mentioned in the previous section, LineVision took the following steps when creating comparisons of percent average absolute error and average absolute error:

1. Corrected any negative amperage values to 0 and zeroed out values below 72 amps as this inaccuracy is a known CT issue identified by TVA.
2. Updated formulas to omit periods of zero loading and null values, since a fraction cannot be evaluated with 0 in the denominator.
3. Updated the LineVision current values to conform to a pseudo-interval to match TVA's interval averaging data and LineVision's instantaneous readings.

This allowed for more accurate comparisons. As shown in the figure at right, results indicate a percent average absolute error of 2-6% and error rates consistent with those between TVA CTs on the same line.

Legend

LV = LineVision loading data

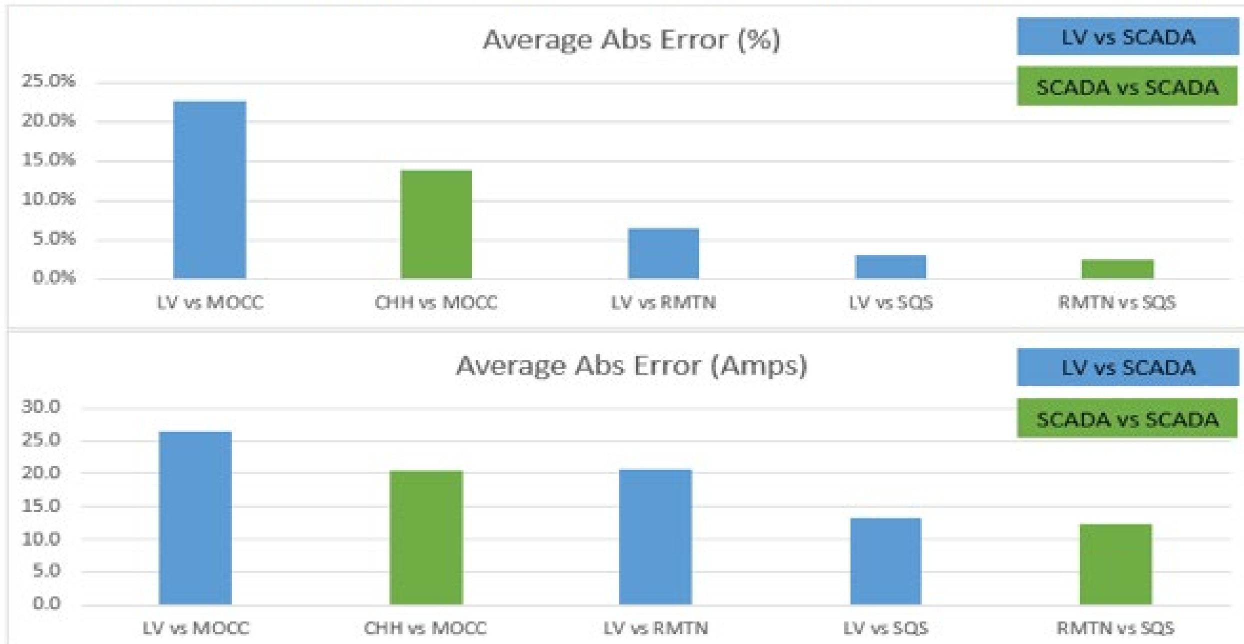
MOCC = Moccasin Substation CT loading data

CHH = Chickamauga Substation CT loading data

RMTN = Raccoon Mountain Substation CT loading data

SQS = Widows Creek Substation CT loading data

	Chickamauga		Raccoon	Widows Creek	
	LV vs MOCC	CHH vs MOCC	LV vs RMTN	LV vs SQS	RMTN vs SQS
% between -5% and 5%	24.0%	36.9%	68.5%	92.0%	97.7%
% Avg Abs Error	22.6%	13.8%	6.4%	3.1%	2.4%
Avg Abs Error (Amps)	26.6	20.4	20.8	13.2	12.4
% Avg Abs Error (>300 amps)	6.6%	6.3%	3.0%	2.1%	2.0%



LineVision assessment of line loading data errors

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March 2021

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