Demonstration of Advanced Monitoring and Data Analytics of Power Transmission Lines

ORNL, LineVision, and Xcel Energy outfitted 3 transmission lines with advanced non-contact sensors (EMF and LiDAR) to monitor for 12 months and collect data from conductors to determine power market efficiencies gained from Dynamic Line Ratings (DLR) as well as planning efficiencies achieved from novel conductor health assessments.
PRINCIPAL INVESTIGATORS
Dr. Zhi Li, R&D Staff Member, Oak Ridge National Lab
Jonathan Marmillo, VP Product, LineVision Inc.
Kristine Engel, Applications Engineer, LineVision Inc.

WEBSITE
www.ornl.gov
www.linevisioninc.com
DOE PROGRAM OFFICE: OE – Transformer Resilience and Advanced Components (TRAC)

FUNDING OPPORTUNITY: AOP

LOCATIONS: Minnesota, Wisconsin, Colorado

PROJECT TERM: 01/01/2021 to 06/30/2022

PROJECT STATUS: Incomplete, Ongoing

AWARD AMOUNT (DOE CONTRIBUTION): $500,000

AWARDEE CONTRIBUTION (COST SHARE): $350,000 LineVision Subcontract
• ORNL, Xcel Energy, and LineVision have been engaged in a project to demonstrate Dynamic Line Ratings (DLR) and Conductor Asset Health assessments with non-contact sensor technology.

• Sensors were installed on lines in MN, WI, and CO.

• Average DLR exceeded static reference ratings by 9-33% in winter months and 26-36% in summer months at the monitored sites; Available on monitored lines over 85% of the time.

• The impact to Xcel Energy, and utilities in general, is more transmission capacity available today to integrate renewable energy via a cost-effective technology. Utilizing DLR will provide a significant increase in capacity and greater flexibility in operations,

• Ongoing analysis to evaluate the impacts of Dynamic Line Rating with power flow simulations on Xcel lines in MISO.

• Conductor Asset Health reports show that monitored conductors have not experienced significant annealing and not lost tensile strength, but identified sag discrepancies warranting investigation.
Innovation Update

Non-Contact LiDAR & EMF Sensor Technologies

Patented Technology:
> Electromagnetic Field (EMF) Power Flow Monitoring
> LiDAR Conductor Position Monitoring

Scanning LiDAR:
> Continuously measures conductor position
> Full catenary shape determined and conductor sag & blowout calculated

Simplified Installations
> No outages
> No live-line work

Industry Best Accuracy & Analytics
> Data on all conductor phases
> Any tower, any voltage, any conductor
> IEEE & CIGRE standards based
Real-time field verified information and alerts on conductor motion allows operators and risk managers to protect asset health, system reliability and public safety.

Output:
- Each phase conductor sag
- Each phase conductor blowout
- Line loading, current
- Icing & galloping alerts
- Anomalous motion alerts
- Local ambient weather conditions
LineRate

Increases the transfer capacity on existing transmission lines with Dynamic Line Ratings.

Output:
- Dynamic Line Rating
- Conductor temperature
- Forecasted line ratings, time-configurable
- Emergency ratings (STE, LTE, Load-Dump)

**FERC Order No. 881 Requires:**
- Transmission providers implement ambient adjusted ratings on the transmission lines over which they provide transmission service that are impacted by air temperatures.
- RTOs and ISOs are required to implement the systems and procedures necessary to allow electronically updated transmission line ratings least hourly.
- FERC will continue to explore the implementation of Dynamic Line Ratings in a new docket AD22-5-000.
LineHealth

Create a conductor digital twin and prioritize the repair and replacement of lines that are most critical based on the module’s estimation of remaining conductor life.

Inputs:
- Historical SCADA
- Historical weather data
- Engineering design information
- LineVision sensor measurements

Output:
- Thermal aging analysis and loss of tensile strength from annealing
- Projected conductor end of life
- Conductor elongation damage evaluation: designed vs actual sag
- Operating limit recharacterization
- Rated breaking strength evaluation
- Sag discrepancies
- Galloping & icing event analysis

High temperature events cause loss of
Projected end of life

Conductor Life Projection

High temperature events cause loss of
Projected end of life
## Dynamic Line Ratings - MN & WI

### DLR to Static Line Rating Comparison

<table>
<thead>
<tr>
<th>Line</th>
<th>Winter Static Rating</th>
<th>Average Winter Dynamic Rating</th>
<th>% Increase</th>
<th>Summer Static Rating</th>
<th>Average Summer Dynamic Rating</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>0817/3303 RPO-GMT</td>
<td>1460</td>
<td>1594</td>
<td>9.2%</td>
<td>1076</td>
<td>1451</td>
<td>34.8%</td>
</tr>
<tr>
<td>3101 ASK-ECL*</td>
<td>2000</td>
<td>3661</td>
<td>83.0% *</td>
<td>1994</td>
<td>3358</td>
<td>68.4% *</td>
</tr>
</tbody>
</table>

*Line 3101 ASK-ECL is clearance-limited by other spans along the line which are not monitored by LineVision.*
### Dynamic Line Ratings - CO

#### DLR-Static Rating Comparison

<table>
<thead>
<tr>
<th>Line</th>
<th>Winter Static Rating</th>
<th>Average Winter Dynamic Rating</th>
<th>% Increase</th>
<th>Summer Static Rating</th>
<th>Average Summer Dynamic Rating</th>
<th>% Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>7109 DANI-MSST</td>
<td>3257</td>
<td>4081</td>
<td>25.3%</td>
<td>2868</td>
<td>3715</td>
<td>29.5%</td>
</tr>
<tr>
<td>5115 DANI-SRDG</td>
<td>2086</td>
<td>2562</td>
<td>22.8%</td>
<td>1849</td>
<td>2338</td>
<td>26.4%</td>
</tr>
<tr>
<td>5113 DANI-MSST</td>
<td>2112</td>
<td>2798</td>
<td>32.5%</td>
<td>1860</td>
<td>2536</td>
<td>36.3%</td>
</tr>
<tr>
<td></td>
<td>Line 5113</td>
<td></td>
<td>Line 5115</td>
<td></td>
<td>Line 7109</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
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<td>-----------</td>
<td>----------</td>
<td>-----------</td>
<td>----------</td>
</tr>
<tr>
<td></td>
<td>Site 9b</td>
<td>Site 11b</td>
<td>Site 9b</td>
<td>Site 10</td>
<td>Site 10</td>
<td>Site 11b</td>
</tr>
<tr>
<td>Maximum Conductor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature Calculated</td>
<td>223 F</td>
<td>111 F</td>
<td>108 F</td>
<td>107 F</td>
<td>109 F</td>
<td>107 F</td>
</tr>
<tr>
<td>Strength Reduction</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>due to Thermal Annealing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sag Increase</td>
<td>0.0 ft</td>
<td>-0.5 ft</td>
<td>0.7 ft</td>
<td>-2.1 ft</td>
<td>0.2 ft</td>
<td>0.9 ft</td>
</tr>
<tr>
<td>Observed – Design</td>
<td>(0.0%)</td>
<td>(-0.4%)</td>
<td>(2.0%)</td>
<td>(-6.1%)</td>
<td>(0.4%)</td>
<td>(5.5%)</td>
</tr>
<tr>
<td>Revised Projected Max</td>
<td>212 F</td>
<td>212 F</td>
<td>212 F</td>
<td>184 F</td>
<td>207 F</td>
<td>188 F</td>
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<tr>
<td>Operating Temperature</td>
<td>(no change)</td>
<td>(no change)</td>
<td>(no change)</td>
<td></td>
<td>(no change)</td>
<td></td>
</tr>
</tbody>
</table>

**Asset Health Comparison – Colorado**

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Phase by Phase Sag Discrepancy Observed

Site 3 has a difference in absolute sags

Left Phase
-4.0 ft (-2.2%)

Middle Phase
-7.8 ft (-4.3%)

Right Phase
0 ft (0.0%)
Max Sag Exceeds the Designed Value

Greater than expected sag at Site 1a
Elevated Temperature Detected

Line 5113 conductor temperature has likely exceeded annealing

Annealing Temp
200 F (93 C)

Max Calculated Conductor Temp
223 F (106 C)
Xcel will take a multi-pronged approach to achieving its carbon commitments. Increased transmission capacity in the form of new transmission lines and optimization of existing lines will allow for increased renewable generation and dynamic use of existing assets.

- A National Renewable Energy Laboratory study found that to reach 80% renewable electricity in the United States, a 56%-105% increase in long-distance transmission capacity would be required[1]. Grid enhancing technologies can double the capacity on existing power lines right now.[2] New transmission is needed, but DLR can be strategically leveraged and make immediate impacts.

- In areas where moderate or strong winds are common, the use of a DLR monitoring system can increase the achieved power flow capacity of overhead conductors by 5-25% when compared to an SLR for 80-90% of the time (results vary across different lines and geographic regions)[3].

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Acronyms

DLR = Dynamic Line Rating
SLR = Static Line Rating
EMF = Electromagnetic Field
LiDAR = Light Detection and Ranging
MISO = Midcontinent Independent System Operator
THANK YOU
Field Data - Minnesota & Wisconsin

Line 0817/3303 RPO-RRK - DLR Heatmap
Field Data - Colorado

Line 7109 - DLR Heatmap

![Heatmap Image]
# Field Data - Minnesota & Wisconsin

<table>
<thead>
<tr>
<th></th>
<th>Line 0817/3303</th>
<th></th>
<th>Line 3101</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Site 1a</td>
<td>Site 1b</td>
<td>Site 2</td>
</tr>
<tr>
<td>Maximum Conductor</td>
<td>166°F</td>
<td>162°F</td>
<td>164°F</td>
</tr>
<tr>
<td>Temperature Calculated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strength Reduction</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>due to Thermal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annealing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sag Increase Observed</td>
<td>1.8 ft (2.8%)</td>
<td>-1.1 ft (-2.5%)</td>
<td>0.2 ft (1.3%)</td>
</tr>
<tr>
<td>- Design</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Revised Projected Max</td>
<td>149°F (no</td>
<td>198°F (no change)</td>
<td>185°F</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>change)</td>
<td>(from 198°F)</td>
<td>(no change)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>