Grid Enhancing Technologies

Babak Enayati, PhD, PE
Principle Strategic Advisor, Ampacimon
Director of Engineering, New Leaf Energy
Email: babak.Enayati@ampacimon.com, benayati@newleafenergy.com
Building capabilities within our transmission networks will help enable the energy transition and advance smarter asset management.

The **Intelligent Transmission Network** is key to deploying innovations that will enable utilities to manage its network smarter utilizing real-time data to make better decisions and lower the cost to serve. Deploying new technologies is also essential to enabling the clean energy future. Such technologies as dynamic line ratings, power flow control devices, energy storage, and digital substations will allow utilities to operate networks and change settings that optimize the flow of variable renewable generation, while intelligent smart design will enable us to build quicker and realize capex efficiencies.

**Technologies we are currently deploying:**

<table>
<thead>
<tr>
<th>Real-time Intelligence</th>
<th>New Tools</th>
<th>Renewable Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Substations</td>
<td>Asset Health Tech (AI/ML/UAS/Robotics)</td>
<td>Energy Storage</td>
</tr>
<tr>
<td>Online Monitoring</td>
<td>Intelligent Design</td>
<td>Power Flow Control</td>
</tr>
</tbody>
</table>

- As we address asset condition issues and build new substations, we are deploying those stations to be Digital Substations with Online Monitoring.
- These stations will allow for quicker deployment and provide insight into our assets to make better asset decisions.
- Flow power more efficiently despite sudden changes due to variable generation and dynamic loads.
- We have deployed dynamic line and transformer rating technologies to demonstrate the utilization of greater line and transformer capacity.
- We are testing new innovations in Machine Learning and Robotics. Every year, we must inspect thousands of circuit miles to look for defects. We walk and fly our lines looking for these faults.
- We are testing robots that will crawl the line conductor evaluating the integrity of the conductor, while also testing Machine Learning to scan through millions of helicopter and unmanned aerial vehicles images to look for faults. Over time, the data will give us predictive data to forecast asset conditions.
- Using our new asset management systems (VOLT Enablement) this data will be utilize to better forecast O&M spend and reliability risks.
- Intelligent Design will allow us to speed and reduce the time to engineer our network utilizing 3D and 4D design capabilities.
- Our networks will need to deliver much higher amounts of variable generation in the future.
- We are deploying technologies such as energy storage and Power Flow Control devices. These technologies allow to increase the capacity of our networks and deferring the need for new lines.
- Essentially mitigating the need to obtain new rights of way, and enabling connection of renewables to the network at a lower cost to interconnect.
FERC Order 881

The Industry Challenge
Improve accuracy of transmission line ratings, increase overall transmission network efficiency, and lower costs by applying Ambient Adjusted Ratings

FERC Order 881 - Timeline
- Released December 2021
- Compliance filings due July 2022
- Implementation for heavily constrained lines Jan 2023
- Jan 2024
- Jan 2025
- Full Compliance Required by July 2025

FERC Order 881 - Scope
- All transmission lines impacted by air temperature

FERC Order 881 - Requirements
- Forecasted hourly ratings for the next 10 days based on ambient temperature impacting transmission line
- Ratings updated every hour
- Account for Day Vs. Night Solar Radiation
- Unique Emergency Ratings
- Operational range of +/- 10°F above or below historic static rating temperatures
- Compliant with IEEE-738 line ratings standard
- Maintain all information within a database
# Project Management Milestone

## FERC Example for AAR Project Management Milestones

### Initial set-up and ongoing maintenance of AAR program:

- Identify AAR lines and candidate rating points
- Compile technical/electrical data for conductors/equipment
- Compile geographic data
- Set up calculation procedures/methodologies
- Set up provision of weather forecast data

Establish IT systems to process, communicate, archive, query, and update these data

### Real-time implementation of AARs:

- Load local data (technical/electrical line/equip data)
- Obtain/process updated weather data
- Perform AAR calculations
- Implement AAR calculations
- Archive line ratings
Types of Line Capacity Ratings

Types of line capacity rating

- Static Line Rating (SLR)
- Seasonally Adjusted Rating (SAR)
- Ambient Adjusted Rating (AAR)
- Dynamic Line Rating (DLR)
Potential Solutions for a Thermal Line Overload

<table>
<thead>
<tr>
<th>Solution</th>
<th>Time to Implement</th>
<th>Downtime</th>
<th>Cost</th>
<th>Est Capacity Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reconductor</td>
<td>2 – 3 Years</td>
<td>Extended Outages</td>
<td>$0.5 M per mile</td>
<td>+ 34%</td>
</tr>
<tr>
<td>Rebuild</td>
<td>3 – 5 Years</td>
<td>Extended Outages</td>
<td>$2 - 3 M per mile</td>
<td>+ 106%</td>
</tr>
<tr>
<td>Dynamic Line Rating</td>
<td>~1 Year</td>
<td>No Outages</td>
<td>&lt; $1 M</td>
<td>+ 10 – 30%</td>
</tr>
</tbody>
</table>
Evaluation of DLR Methodologies

Critical Spans Monitored

1. Ground Based
   - SAG/Clearance: Optical Ground to Conductor
   - Wind Speed: No on-site wind measurement
   - Conductor Temperature: Infrared
   - Conductor Current: Magnetic Field
   - Ice Accretion Weight: None, ice probability indicator
   - Exposed to vandalism (NERC-CIP)
   - Metrology sensitive to dirt, rain, snow, calibration

2. Lidar-Based
   - SAG/Clearance: Lidar Conductor to Ground
   - Wind Speed: No on-site wind measurement
   - Conductor Temperature: Spot Temp
   - Conductor Current: Rogowski Coil
   - Ice Accretion Weight: None
   - Must be mounted mid-span
   - Metrology sensitive to dirt, rain, snow, calibration

3. Vibration-Based
   - SAG/Clearance: Conductor Vibration-based
   - Wind Speed: Conductor Vibration-based
   - Conductor Temperature: Mean Conductor Temp
   - Conductor Current: Rogowski Coil
   - Ice Accretion Weight: Vibration and Tension-Based
   - No Calibration Required
   - High Accuracy regardless of span elevation

Ground Based
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- Wind Speed: No on-site wind measurement
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- No Calibration Required
- High Accuracy regardless of span elevation
1- DLR exceeds the Static Rating for 94% to 97% of the time.
2- Recorded DLR data shows a mean (average) increase of 31% in line’s capacity above AAR.
3- Recorded DLR data shows a mean (average) increase of 47% in line’s capacity above Static Rating.
4- Recorded AAR data shows a mean (average) increase of 11% in line’s capacity above Static Rating.
Forecast follows the DLR with sufficient conservative assumptions. Hence, forecast rating is slightly lower than DLR.

Day-ahead Forecast rating exceeds the Static Rating 81% to 87% of the time.

Recorded day-ahead forecast data shows a mean (average) increase of 26% in line’s capacity above Static Rating.

Forecast ratings should be utilized for day-ahead market operations to maximize the utilization of the existing transmission line capacity.
• Recorded DLR data that corresponds to Wind Speed ≥ 3 m/s shows a mean (average) increase of 60% in the line capacity above the static rating.

• DLR must be considered as a tool in the toolbox for wind generation integration to the grid.

Published by NYSERDA
Wind is the key factor to increasing capacity

<table>
<thead>
<tr>
<th>Operating Conditions</th>
<th>Change in Conditions</th>
<th>Impact on Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature</td>
<td>2 °C decrease</td>
<td>+ 2%</td>
</tr>
<tr>
<td></td>
<td>10 °C decrease</td>
<td>+ 11%</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>Cloud shadowing</td>
<td>+/- a few percent</td>
</tr>
<tr>
<td></td>
<td>Total eclipse</td>
<td>+ 18%</td>
</tr>
<tr>
<td>Wind</td>
<td>3 ft./s increase,</td>
<td>+ 35%</td>
</tr>
<tr>
<td></td>
<td>45° angle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3 ft./s increase,</td>
<td>+ 44%</td>
</tr>
<tr>
<td></td>
<td>90° angle</td>
<td></td>
</tr>
</tbody>
</table>

Source: Navigant Consulting, Inc. (Navigant) analysis; data from (7)

Table 1. Impacts of Changing Operating Conditions on Transmission Line Capacity
Dynamic Line Ratings Process

Weather Measurements

Line Measurements

Algorithms Calculate Real Time Ratings

Algorithms Calculate Forecasted Ratings

Forecasted Weather Data

TMS operates based on Dynamic Ratings

Machine learning with wind measurements allow for 98% confidence interval capacity forecast while retaining significant gains
PPL utilities projects $23M annual savings in congestion costs

**FERC Mandate**

“As part of Federal Energy Regulatory Commission FERC Order 881 issued in December 2021, regional transmission organizations and independent system operators (RTOs and ISOs) are required to establish and maintain systems and procedures to accommodate Transmission Owner projects to implement DLR technology [by July 2025].”

“Initiated in 2020 by transmission owner PPL Electric Utilities and facilitated by PJM, PPL Electric Utilities has said it expects the activation of dynamic line rating (DLR) technology to expand capacity and promote market efficiency…”

“PPL Electric Utilities estimates that this DLR project can save customers $23 million annually in congestion costs.”

**DLR - Overhead lines**

PPL, Allentown USA

- **Challenge:** Conventionally expensive uprating is required to relieve grid congestion causing high nodal prices
- **Solution:** DLR system installed on 3 transmission lines since 2021, 5 more by mid 2023, with real time monitoring and forecast SW

$23M Annual congestion costs saved

20% Extra capacity through DLR (90% of the time)

“DLR ensures reliable operations to protect the DLR facilities and transmission system while reducing overall congestion and promoting market efficiency”
Power Flow Control

In September 2020, a utility in the Northeast US commissioned its first Smart Valve Power Flow Controller.

Installation:
- Installation on a 69kV line
- Integrated to EMS
- Remote control and monitoring

Benefits:
- Enables clean energy transition
- Potential deferred capital investment for reliability system upgrades by maximizing the utilization of the existing transmission line capacity.

CURRENT
- Smart Wires was selected as the vendor
- No control over the magnitude of the power flow
- Traditional Line Upgrade Solutions
- Conservative Decision Making

FUTURE
- Control the power flow of the transmission lines
- Potential line upgrade deferrals
- Smart decision making on power flow management
Contact: Babak Enayati

Babak.Enayati@ampacimon.com