Grid Enhancing Technologies



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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:

Real-time Intelligence

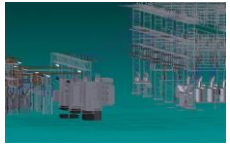
Digital Substations

Online Monitoring

- 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.

New Tools

Asset Health Tech (AI/ML/UAS/Robotics)



Intelligent Design

- 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 deign capabilities.

Renewable Integration

Energy Storage

Power Flow Control

- 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 i***ncrease 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.***

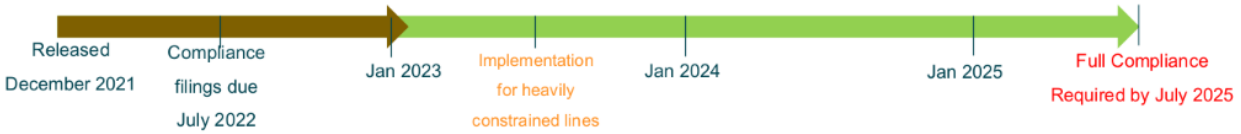
FERC Order 881

The Industry Challenge

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

FERC
FEDERAL ENERGY REGULATORY COMMISSION

FERC Order 881 - Timeline



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 +/- 10^0F above or below historic static rating temperatures
- Compliant with IEEE-738 line ratings standard
- Maintain all information within a database

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Project Management Milestone

FERC Example for AAR Project Management Milestones

Initial set-up and ongoing maintenance of AAR program:

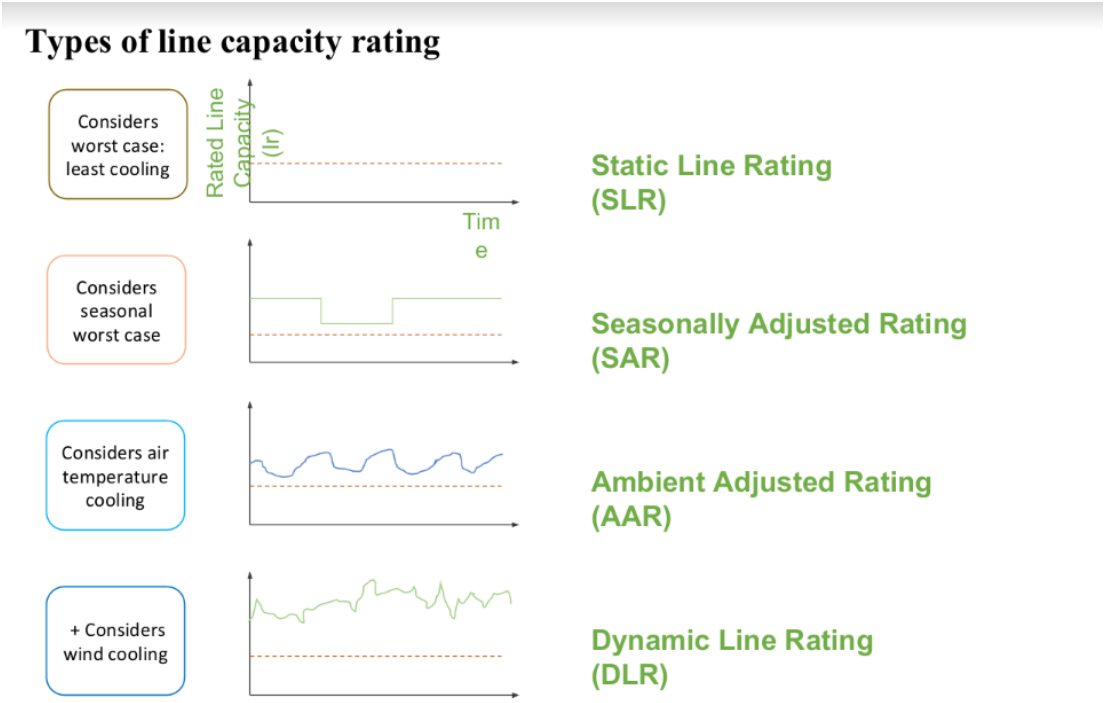
Identify AAR lines and candidate rating points	Compile technical/ electrical data for conductors/equipment	Compile geographic data	Set up calculation procedures/ methodologies	Set up provision of weather forecast data

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



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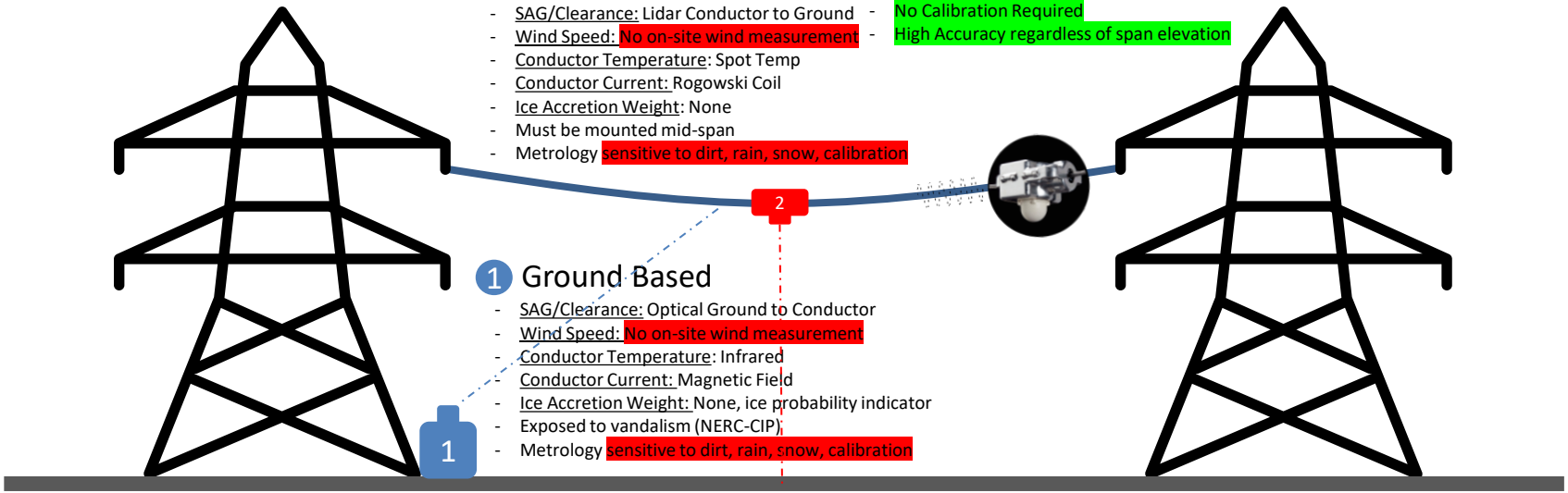
Potential Solutions for a Thermal Line Overload

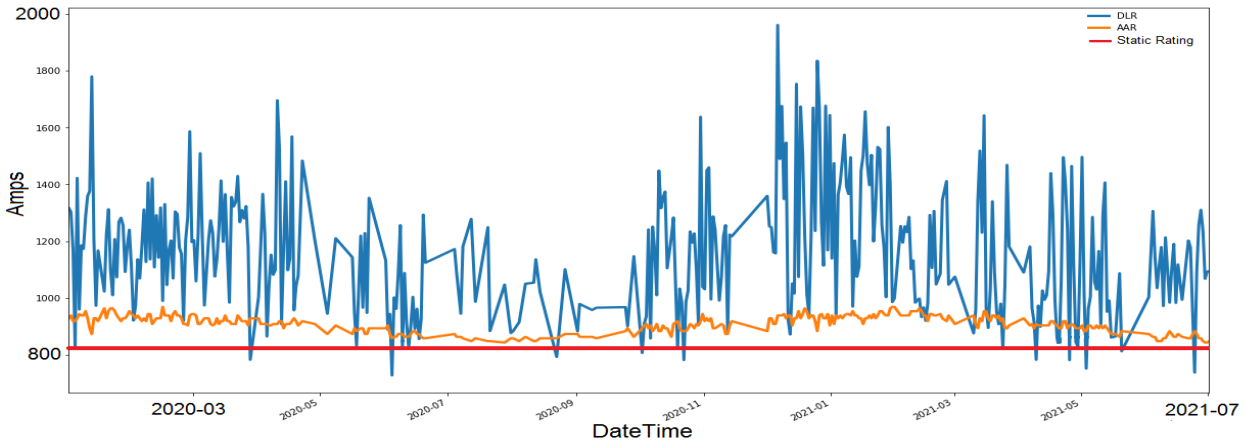
	Reconductor	Rebuild	Dynamic Line Rating
			
Time to Implement	2 – 3 Years	3 – 5 Years	~1 Year
Downtime	Extended Outages	Extended Outages	No Outages
Cost	$0.5 M per mile	$2 - 3 M per mile	< $1 M
Est Capacity Benefit	+ 34%	+ 106%	+ 10 – 30%

Evaluation of DLR Methodologies



*Critical Spans Monitored

Line Capacity Gain Using real-time DLR and AAR



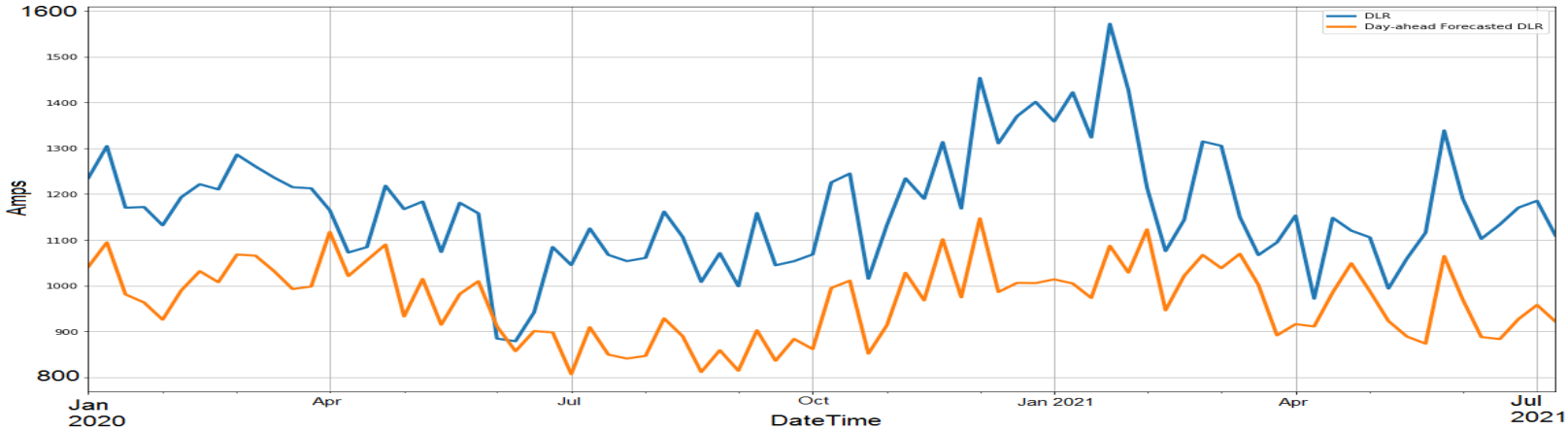
1- DLR exceeds the Static Rating for 94% to 97% of the time.

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.

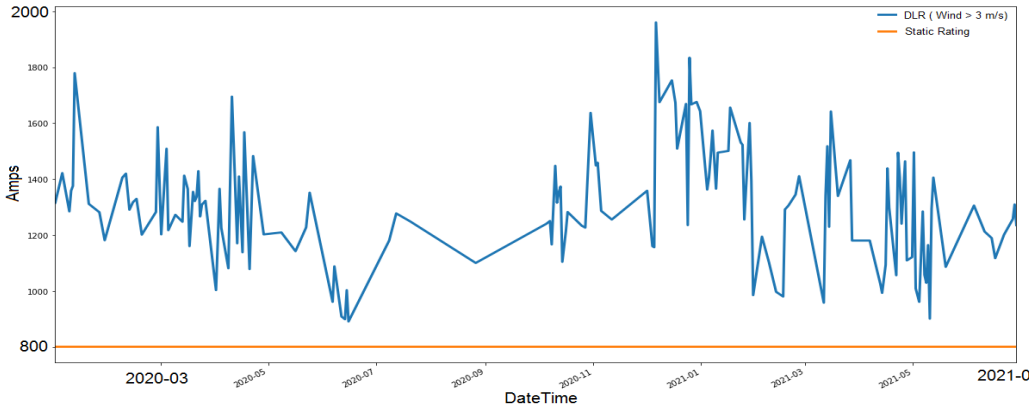
DLR Sensors provide real-time and forecast ratings

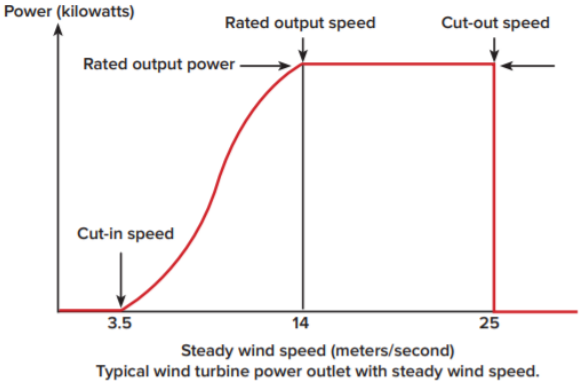


- Forecast follows the DLR with sufficient conservative assumptions. Hence, forecast rating is slightly lower than DLR.
- Day-ahead Forecast rating exceeds the Static Rating 81% to 87% of the time.
- Recorded day-ahead forecast data shows a mean (average) increase of 26% in line's capacity above Static Rating.

Forecast ratings should be utilized for day-ahead market operations to maximize the utilization of the existing transmission line capacity.

Line Capacity During Wind Generation





Typical wind turbine power outlet with steady wind speed.

Reference: New York Wind Energy Guide for Local Decision Makers: Wind Energy Basics
Published by NYSERDA

- 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.

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Wind is the key factor to increasing capacity

U.S. Department of Energy | April 2014

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

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

Forecasted Weather Data

Algorithms Calculate Forecasted Ratings

TMS operates based on Dynamic Ratings

Machine Learning Feedback Loop

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]"**

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

Annual congestion costs saved

Extra capacity through DLR (90% of the time)

*"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…"***

*"DLR **ensures reliable operations** to protect the DLR facilities and transmission system while **reducing overall congestion** and **promoting market efficiency"***

*"**PPL** Electric Utilities **estimates** that this **DLR** project **can save** customers **$23 million annually** in congestion costs"*

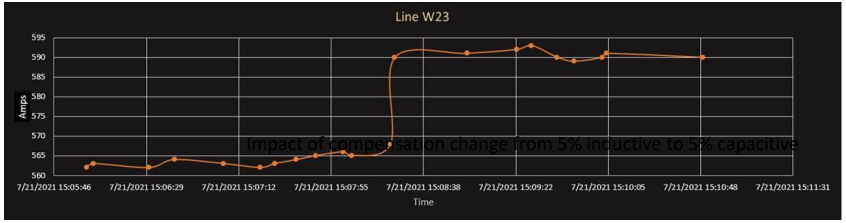
Source: https://insidelines.pjm.com/dynamic-line-rating-activated-by-ppl-electric-utilities

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



Impact of compensation change from 5% inductive to 5% capacitive

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
- ✓ Conse ng

FUTURE

- ✓ Control the power flow of the transmission lines
- ✓ Potential line upgrade deferrals
- ✓ Smart decision making on power flow management

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