Dynamic Line Ratings Overview

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OC Special Session - Dynamic Line Ratings (DLR) Education

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Agenda

- Background Information
  - What are Dynamic Line Ratings (DLR)
  - Incremental Transmission Capacity of a Line with DLR
  - History of DLR Projects at PJM
- Impacts of Dynamic Line Ratings on PJM
  - Technical Impacts
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Background Information

What are Dynamic Line Ratings?

Static vs Dynamic Line Ratings

STATIC RATINGS

Transmission lines are typically operated using a Static Rating calculated using near worst-case values for assumed weather conditions.

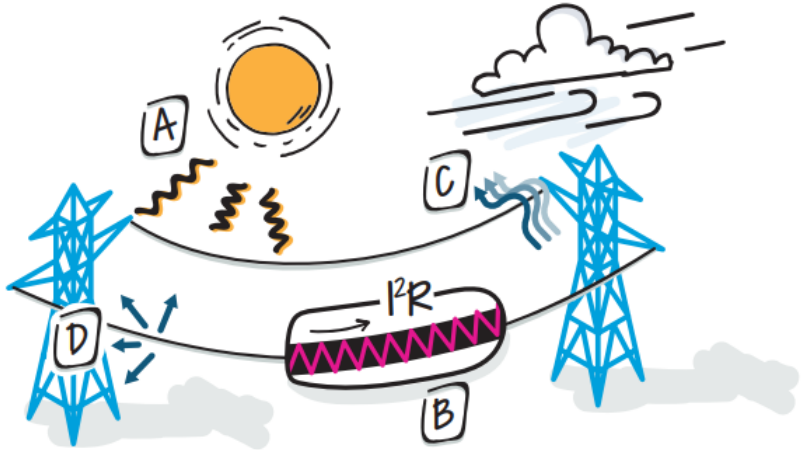
DYNAMIC LINE RATINGS (DLR)

The rating can be calculated in real-time if the variables in the conductor heat balance equation are known.

Wind Speed Increase	→	Capacity Increase
3 ft/s, 90° angle		+ 44%

Wind cools the conductor allowing more power to safely be transmitted on the line

Temperature of Overhead Conductors[1]



Conductor temperature is determined by:

A. Sunlight warming the conductor surface
B. Resistive heating (I^2R)
C. Convective cooling by wind
D. Blackbody (radiative) cooling of the conductor
E. Heat capacity of the conductor

1. IEEE Standard 738-2012

Dynamic Line Rating Technologies

Generally speaking, dynamic line rating deployments will involve the installation of a data collection sensor on or near an **existing** transmission line asset to collect real-time conductor temperature information.

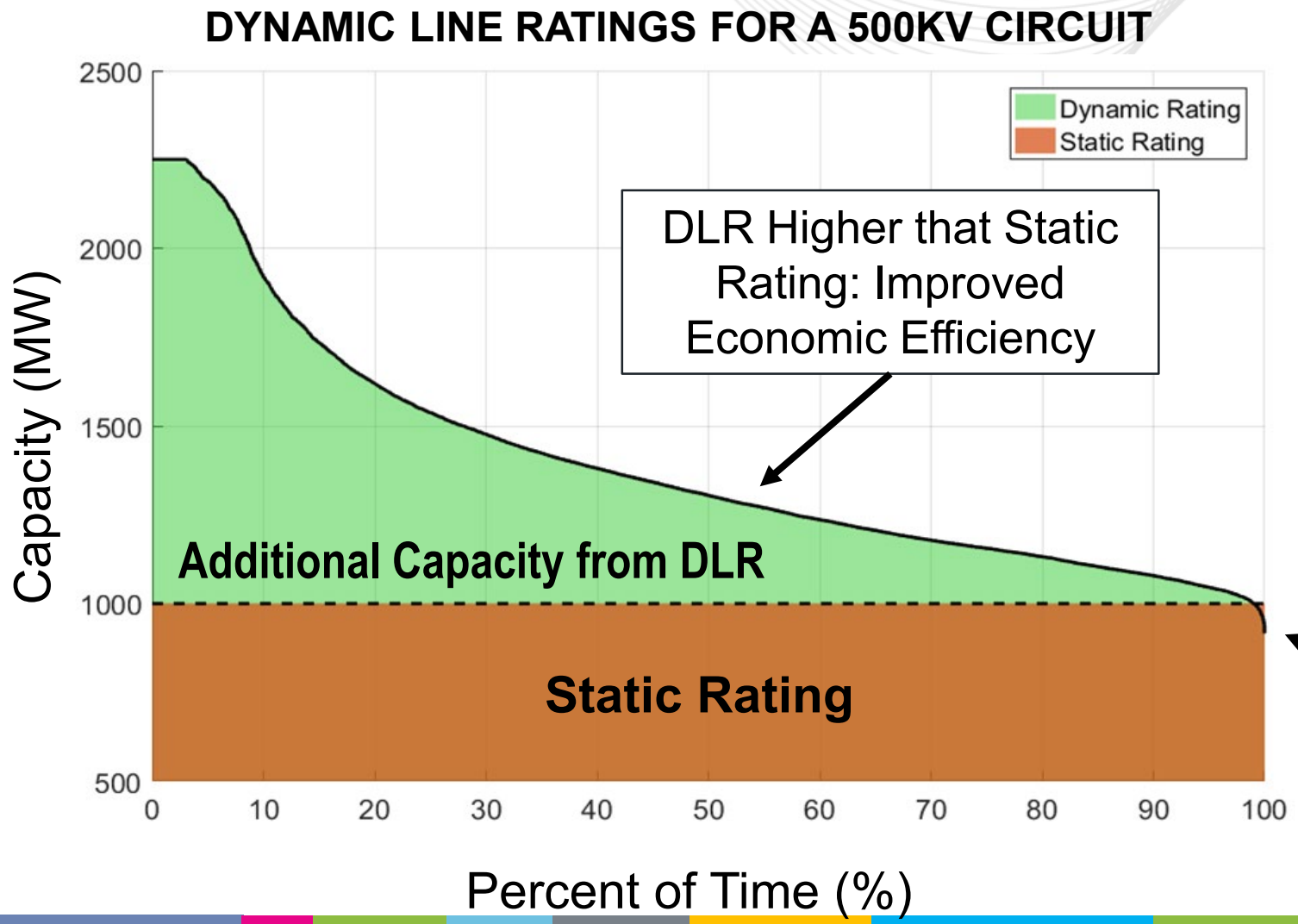
Sensor technologies include:

- Weather Stations
- Electromagnetic Field
- Light Detection And Ranging (LiDAR)
- Vibration
- Tension
- Thermal Cameras

DLR project installations should target:

- Congested transmission facilities where:
- The transmission conductor is the most limiting element

Incremental Transmission Capacity of a Line with DLR



DLR measures the actual atmospheric conditions which nearly always reveals additional capacity.

Static Ratings are calculated using very conservative assumptions for atmospheric conditions.

DLR Lower than Static Rating: Improved System Reliability

History of DLR Projects at PJM

- Early 2000s: EMS enhancements made to receive telemetered ratings for a small group of transmission lines in PJM. This project lasted ~2 years, and this EMS functionality was last tested in 2015.
- 2016/ 2017: PJM, AEP, and Genscape (LineVision) conducted a DLR pilot on a 345kV transmission line AEP. The focus of this pilot was to gain understanding of:
  - Design & Installation process
  - Passive data collection
  - Estimated economic impacts in an RTO
- 2017/2018: PJM, AEP, and Lindsey conducted a DLR pilot on a 138 kV transmission line in AEP located near a large wind unit with focus on:
  - Simultaneous benefit (co-convection) between DLR and wind unit output
- 2020 and beyond: DLR deployments on three 230 kV in the PPL transmission zone.

Dynamic Line Rating Pilot Project

AEP, PJM, and LineVision conducted a research project to quantify the potential economic impacts of DLR

AMERICAN ELECTRIC POWER	*Engineering & Field Support*
LINEVISION	*LineVision DLR System & Installation*
pjm	*Analysis of DLR's Economic Impact*

Project Overview:

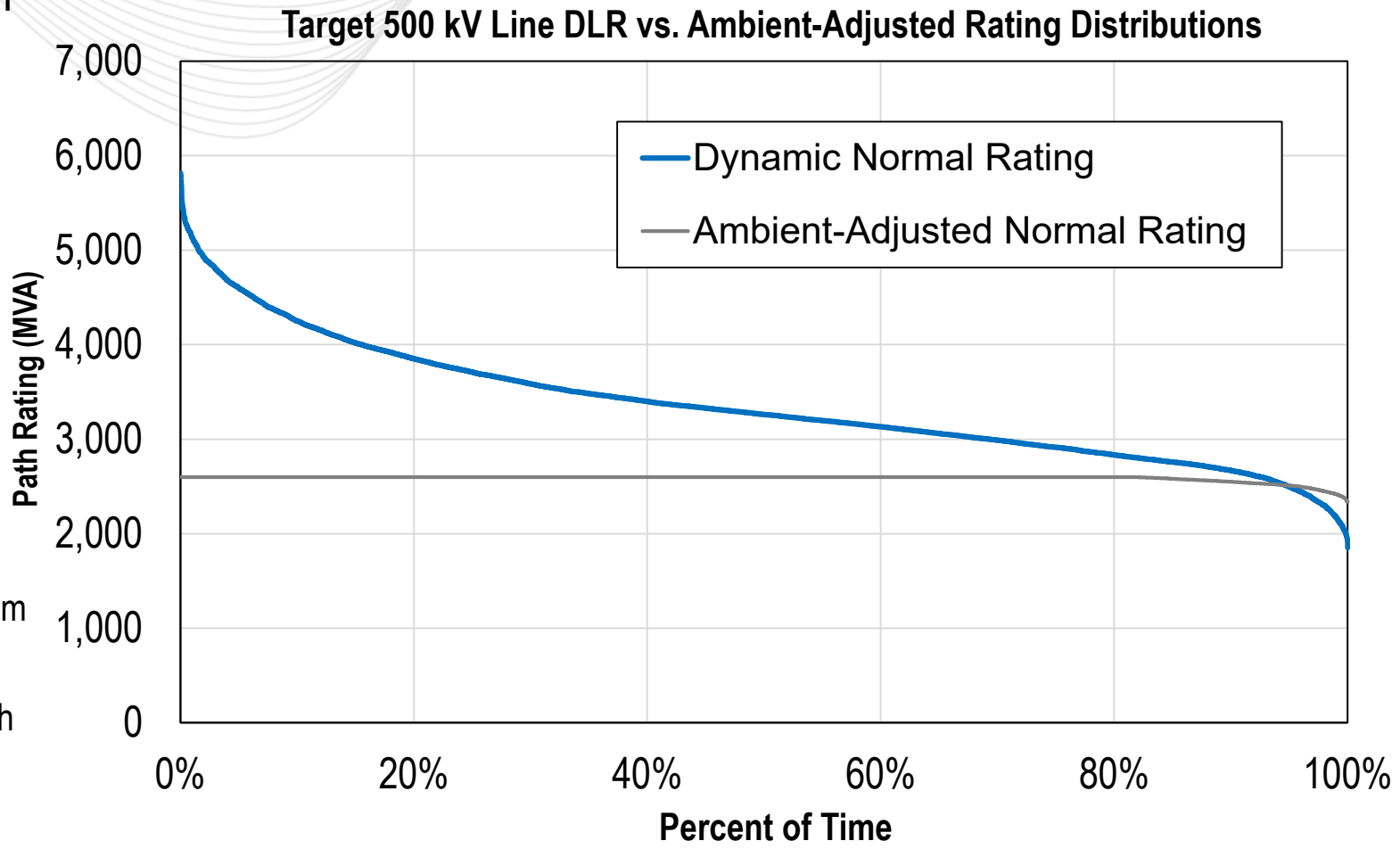
- AEP's Cook-Olive 345 kV transmission line selected
- LineVision sensors installed under three (3) spans along the circuit
- Line monitoring data was collected between November 2016 – August 2017
- PJM conducted an economic analysis to determine the potential improvements in system and market efficiency by using DLR in operations
- Project funding was provided by Oak Ridge National Laboratory

PJM DLR Economic Analysis Simulation

To study the economic impact of DLR on a congested line, PJM performed an analysis of a hypothetical DLR project using PJM's 2018 PROMOD Market Efficiency base case.

1. **Congested line in PJM selected**
2. **LineVision generated back-casted DLRs***
3. **PJM ran 2018 PROMOD Market Efficiency base case with adjusted line ratings from back-cased DLRs**

*DLRs were calculated using historical weather data from six NOAA meteorological stations surrounding the line path, the lowest observed wind speed at each hour (with the accompanying direction) was used for the DLR calculation for each section.



DLR was above the Ambient Adjusted Rating approximately 94% of the time.

Economic Simulation: Assumptions

- A DLR technology will only bring benefit when the transmission conductor is the most thermally limited element in the line – assumed acceleration of an equipment rating upgrade project.
- DLR installations should be prioritized on the most heavily congested areas of a power system.
- Ambient air temperatures were computed as average of the six stations.
- Wind speed and direction treated more conservatively by adopting the lowest observed wind speed at each hour (with the accompanying direction).
- Solar irradiance calculated using a conservative approximation - zero cloud coverage and was calculated for each hour of the day based the sun's position in the sky above the Target Line path.

Economic Simulation

- Two PROMOD simulations were performed:
  - "Base Case" - base simulation using planning ratings 2800 MVA normal and 3500 MVA emergency for the 500 kV Target Line.
  - "DLR Case" - PROMOD DLR simulation using dynamic hourly ratings.

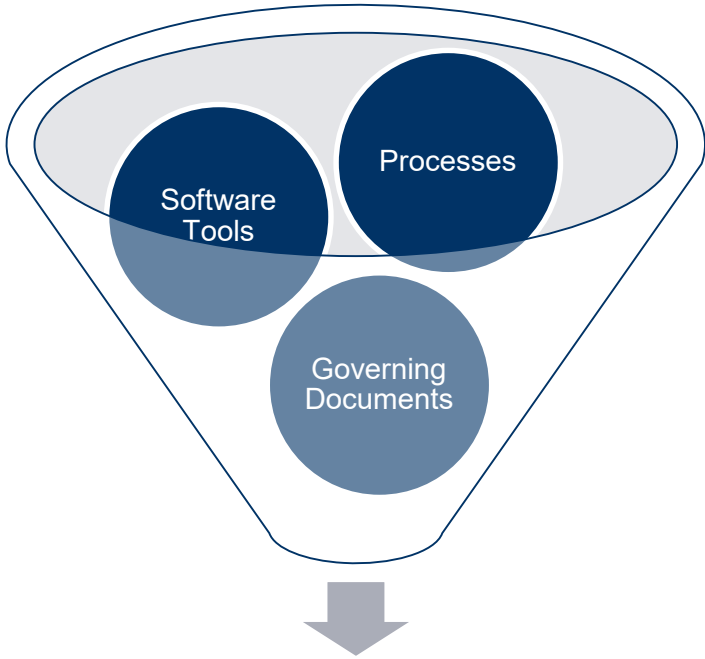
Total Annual Congestion			
Circuit	Base Case	DLR Case	Congestion Savings
Target Line 500 kV	$ (11,118,805)		$ 11,118,805
Target Line Terminus Substation Transformer 500/230 kV	$ (10,011,856)	$ (9,780,911)	$ 230,945
Downstream Line #1 230 kV	$ (20,386,483)	$ (22,773,039)	$ (2,386,555)
Downstream Line #2 to Downstream Reactor 230 kV	$ (13,491,444)	$ (16,180,653)	$ (2,689,209)
Downstream Reactor - Target Line Terminus 230 kV	$ (1,145,829)	$ (2,492,945)	$ (1,347,115)
Downstream Line #3 - Target Line Origin 230 kV	$ (2,867,503)	$ (3,336,319)	$ (468,816)
Downstream Line #4 230 kV	$ (19,570,723)	$ (19,824,341)	$ (253,619)
			$ 4,204,436

- Assuming $500k installation cost: 8.4:1 benefit to cost ratio for one year
- All congestion on Target Line eliminated
- Residual congestion pushed "downstream" – consistent with other transmission upgrade projects

Impacts of Dynamic Line Ratings on PJM

Introduction

- In August 2020, the Applied Innovation group began conducting interviews with various business areas of PJM to identify all:
  - Software tools requiring updates to handle Dynamic Line Ratings (DLR)
  - Processes affected by DLR
  - Governing documents and manuals requiring language modifications to support DLR
- This information was gathered and organized into the following slides.
- Various groups were interviewed, including:
  - Transmission Planning
  - Market Simulation
  - Day-Ahead Markets
  - Real-Time Markets
  - EMS & Telemetry Support
  - eDART Support
  - Transmission Services
  - Settlements



Technical Impacts

Dynamic Line Ratings are an existing feature of PJM's EMS SCADA system.

- DLR SCADA points[1] transmitted to PJM via ICCP.
- Points mapped to a particular transmission equipment end in EMS.
- Data points are validated against pre-configured quality thresholds.
- Two modes of operation:
  - Manual: Compare with Threshold 1. Await operator approval if successful.
  - Automatic: Compare with Threshold 1 & Threshold 2. Auto-approve if both comparisons are successful. Await operator approval if Threshold 2 comparison fails.
- Threshold comparisons based on default line ratings (Ambient Adjusted Ratings).

[1] – Normal, Short-term and Long-term Emergency and Load Dump ratings, consistent with PJM Manual 03

Technical Impacts

- eDART upgrades are needed to facilitate:
  - Auto ticketing & integration with workflow of EMS DLR functionality
  - Maintain an accurate rating historian
  - Maintain transparent rating postings
  - Receive and post next-day forecasted ratings

- eDART and EMS together handle the rating change and approval process. Real-time Operations and Markets applications are downstream consumers of this information.

Procedural Impacts

- Market Efficiency modeling:
  - Model a DLR proposal using provided weather data
  - Isolate impact of convective cooling from dynamic ratings
- Utilizing next-day DLR forecasts in Day-Ahead market
  - Forecasted ratings collected from eDART
  - Manually input into Day-Ahead. Automation work to follow initial implementation
- Utilizing DLR in Real-time markets
- Operator approval and manual override process
- Operator training

Impacted Governing Documents

PJM has identified that the following manuals **may** require guidance language on Dynamic Line Ratings:

- Manual 03, Section 2: Thermal Operating Guidelines
- Manual 03A, Appendix A: TERM Equipment Ratings Update Process

Additionally, PJM will develop a Dynamic Line Ratings desk reference guide to be used by control room staff.

Additional References

CIGRE Publications:

- A Non-Contact Sensing Approach for the Measurement of Overhead Conductor Parameters and Dynamic Line Ratings (2017)[1]
- Simulating the Economic Impact of a Dynamic Line Rating Project in a Regional Transmission Operator (RTO) Environment (2018)[2]

PJM Stakeholder Presentations:

- Emerging Technologies Forum (ETF)
  - DLR Primer (8/27/2020)[3]
  - Review of PJM's DLR impacts (11/13/2020)[4]
  - Modeling DLR in Market Efficiency (1/11/2021)[5]
- Transmission Expansion Advisory Committee (TEAC)
  - Modeling DLR in Market Efficiency (12/23/2020)[6]

1) https://watttransmission.files.wordpress.com/2017/11/genscape-cigre-gotf-whitepaper-2017.pdf
2) https://www.linevisioninc.com/wp-content/uploads/2020/11/CIGRE-GOTF-2018-NGN-PJM-AEP-LineVision-Final.pdf
3) https://pjm.com/-/media/committees-groups/forums/emerging-tech/2020/20200827/20200827-item-05-dynamic-line-ratings.ashx
4) https://pjm.com/-/media/committees-groups/forums/emerging-tech/2020/20201113/20201113-item-03c-dlr-impacts.ashx
5) https://pjm.com/-/media/committees-groups/forums/emerging-tech/2021/20210111/20210111-item-03-dlr-market-efficiency.ashx
6) https://pjm.com/-/media/committees-groups/committees/teac/2020/20201223-special/20201223-item-04-emergent-technologies-modeling-overview.ashx

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