Modeling Dynamic Line Ratings in the Market Efficiency Planning Process

PJM Interconnection

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Nicolae Dumitriu, Principal Engineer – Market Simulation

Shaun Murphy, Senior Business Solution Engineer – Applied Innovation

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I. Introduction

As utilities begin to install dynamic line rating (DLR) equipment on their transmission systems inside the PJM footprint, it has been recognized that the technology can improve transmission system efficiencies and provide cost savings to consumers. This paper explains the method PJM intends to use to incorporate simulated historic hourly ratings to represent a particular deployment of DLR in PJM's Market Efficiency process.

DLRs are a sensor-based transmission line monitoring technology used to determine the real-time transmission capacity, or ampacity, of a selected transmission asset. In a majority of applications, DLR sensors are deployed on historically congested overhead transmission lines to identify additional, intermittent transmission capacity that is available but may not be apparent through conventional analysis. The key value of this technology is that its sensors are able to monitor real-time conductor temperature along a transmission line and report the real-time perpendicular wind speed at the conductor surface – an element critical to determining a transmission conductor's operating temperature.

In traditional utility practice, the perpendicular wind conditions in a particular hour are largely unknown, and utilities must act conservatively and assume low-wind conditions when formulating a line rating. The goal is to avoid overestimating a conductor's current-carrying capacity and potentially damaging or shortening the useful life of the equipment. These conservative assumptions are developed to determine reliable transmission ratings that ensure continuous conductor temperature at or below the maximum operating temperature as stipulated by the cable's manufacturer. As this traditional rating practice tends toward conservative operation of the line, it is recognized that additional transmission capacity will exist in some form whenever real-time weather conditions are less extreme than their assumed values.

While DLR sensor technologies exist in varying forms and physical approach, each system will monitor and report real-time transmission capacity based on measured real-time conductor thermal conditions. PJM recognizes the value in the additional transmission capacity that this technology can identify, as well as the technology's unique technical challenges. PJM's Emerging Technologies Forum has been the central area for discussing this technology, and the group has explored how areas of PJM's operations, markets and planning software tools and processes may be impacted by the adoption and use of DLR technologies. Materials from these discussions are available on the forum's webpage.[1]

The impacts of deploying this sensor technology will go beyond real-time operations and markets. The anticipated behavior of this rating technology must also be considered in various planning studies including PJM's Market Efficiency process. The intent of this white paper is to outline a general approach to model hourly ratings of a simulated DLR technology deployment in the PJM Market Efficiency planning process. Absent highly accurate weather forecasts far into the planning horizon, this approach will utilize historical weather data consistent with other

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[1] See the following PJM stakeholder presentations:

- "Introduction to Dynamic Line Ratings," Aug. 27, 2020. (PJM)
- "Dynamic Line Ratings – Impacts to PJM," Nov. 13, 2020. (PJM)
- "What is DLR?" Oct. 1, 2020. (PPL)
- Vendor Presentations, Nov. 13, 2020:
  - Lindsey Systems
  - LineVision

weather data inputs used in PJM's Market Efficiency process. It is important to note that this white paper will focus exclusively on the congestion-oriented Market Efficiency planning process, and will not propose any changes to the remainder of PJM's transmission planning process.

II. Modeling Dynamic Line Ratings in the Market Efficiency Process

This section will provide an overview of the development of the power system model used in the traditional Market Efficiency planning process, and how the development of this model will be modified to incorporate the DLR technology. For the purposes of this discussion, the power system model includes:

A. Electrical generation resources and load centers
B. Electrically connective equipment (transmission lines, transformers, substation connection points, etc.)
C. Equipment rating information
D. Economic generator dispatch parameters
E. Hourly load profiles

> For more information on DLR, go to PJM.com > About PJM > Advanced Technologies

Traditionally, the development of PJM's Market Efficiency planning model begins with the planning power flow model developed in the PJM Regional Transmission Expansion Plan (RTEP) process. This model includes the electrical equipment and rating information from the above list. Ratings associated with transmission equipment are traditionally represented as the seasonal (summer and winter) planning ratings. Adjusting these equipment ratings to reflect hourly changes in ambient temperature data is not part of the traditional Market Efficiency planning process.

As mentioned above, the key value of a DLR system is recognizing additional transmission capacity brought by convective cooling. Thus, a modeling technique is needed to isolate the incremental transmission capacity gained by the convective cooling as monitored by DLR devices from the transmission capacity based on ambient temperature. The modeling approach in this paper will utilize a DLR Hourly Ratings Modifier profile based on the difference between forecasted DLR ratings and forecasted ambient-adjusted ratings (AAR) for each hour (see Figure 1, DLR Rating Calculation Steps). Ratings for lines equipped with DLR devices will be represented as the sum of the Hourly Ratings Modifier profile and the traditional planning (seasonal) line ratings.

In other words, the following Hourly Ratings Modifier will be developed and then added to the planning winter/summer ratings of the DLR target line.

$$R_{HRM} = R_{DLR} - R_{AAR}$$

Figure 1. **DLR Rating Calculation Steps**

1. Backcast hourly DLR ratings: R_{DLR}
(Based on historic hourly ambient temperature, wind direction/speed and solar irradiance)
2. Calculate hourly ambient adjusted ratings: R_{AAR}
(Based on hourly ambient temperature profile used for the DLR calculation)
3. Develop Hourly Ratings Modifier: $R_{HRM} = R_{DLR} - R_{AAR}$
(Difference between "backcasted" DLR ratings and ambient ratings for each hour)
4. Determine planning winter/summer static ratings for the DLR line: $R_{W/S}$
5. Apply Hourly Ratings Modifier to the planning winter/summer ratings.
6. Market Efficiency hourly DLR ratings for the DLR line: $R_{DLR-eq} = R_{W/S} + R_{HRM}$

Therefore, the Market Efficiency production cost simulations will use the following hourly line rating dataset for dynamically rated transmission lines (see Figures 2 and 3, equivalent DLR ratings calculation example):

$$R_{DLR-eq} = R_{W/S} + R_{HRM}$$

Where:

R_{AAR}	Ambient-adjusted rating calculated using forecasted ambient temperature, solar irradiance (time of day to determine day vs. night temperature sets), and the line's ambient temperature rating set
R_{DLR}	DLR calculated using the same inputs as used above plus forecasted wind direction/speed data
$R_{W/S}$	Planning winter/summer peak rating currently used in PJM's planning processes
R_{DLR-eq}	Equivalent line rating to be used for the dynamically rated transmission line in the Market Efficiency planning process

Consistent with other line ratings used in PJM's Market Efficiency process, the ambient-adjusted hourly rating set R_{AAR} and the hourly DLR set R_{DLR} shall be provided to PJM by the transmission owner. The ambient temperature and wind speed datasets to be used in the formulation of these two datasets should be consistent with the wind and solar forecasts used in the Market Efficiency models. Then PJM will calculate the hourly equivalent DLR set R_{DLR-eq} and use this new line rating in the Market Efficiency planning process.

The figures below provide a visual illustration of how Market Efficiency DLR ratings are calculated. Figure 2 shows the DLR Hourly Ratings Modifier profile calculated as the hourly difference between the forecasted hourly DLR ratings and the forecasted hourly ambient-adjusted ratings. Figure 3 shows the results of applying the DLR hourly modifier (calculated in the previous step) to the planning static ratings to determine the final DLR ratings to be used in the Market Efficiency process. Figure 3 reflects the results of subtracting the ambient-adjusted ratings (green-shaded region) from the forecasted DLR ratings (yellow-shaded region). Note that removing the green-shaded region from Figure 2 will result in Figure 3. These figures show how this method will identify additional incremental capacity available on a particular transmission line.

Figure 2. **DLR Hourly Modifier**

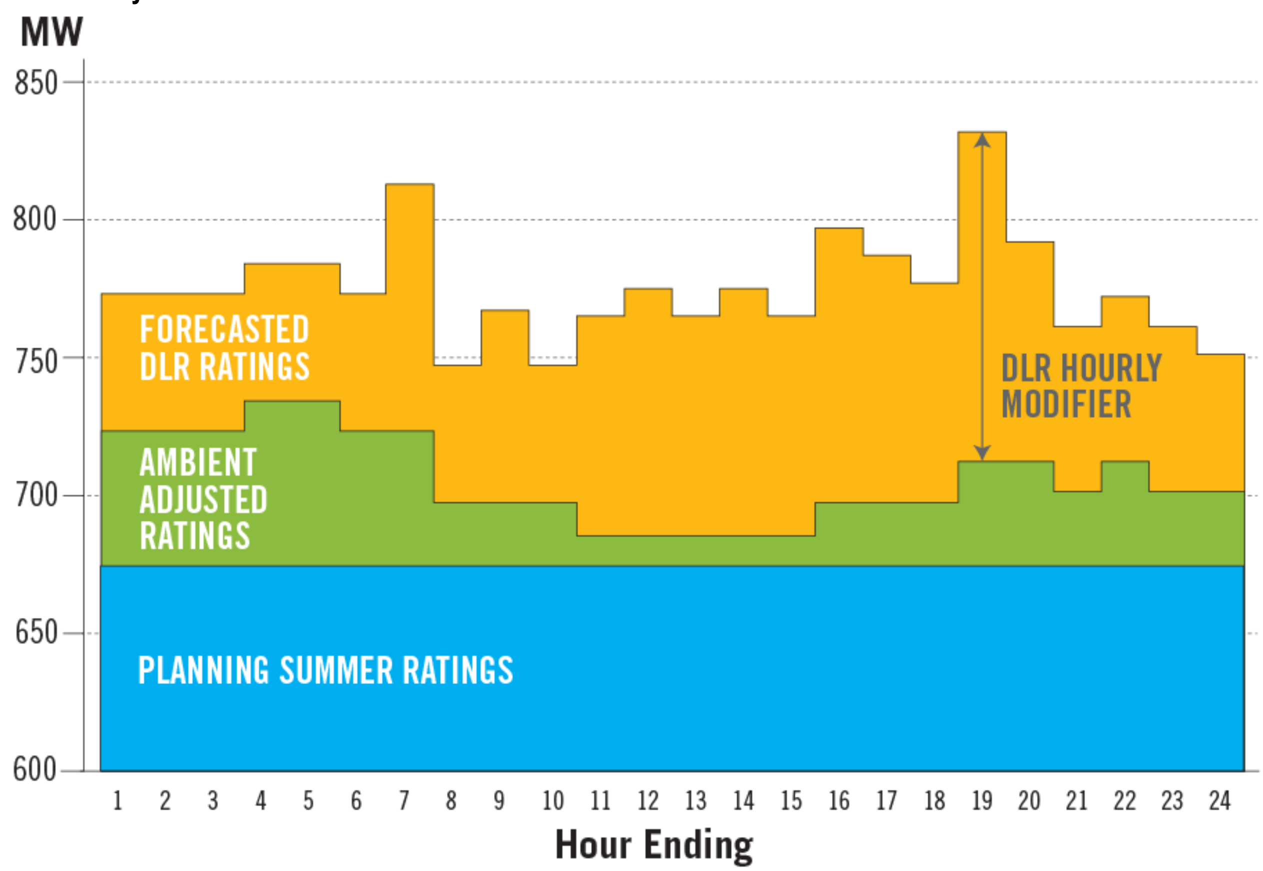
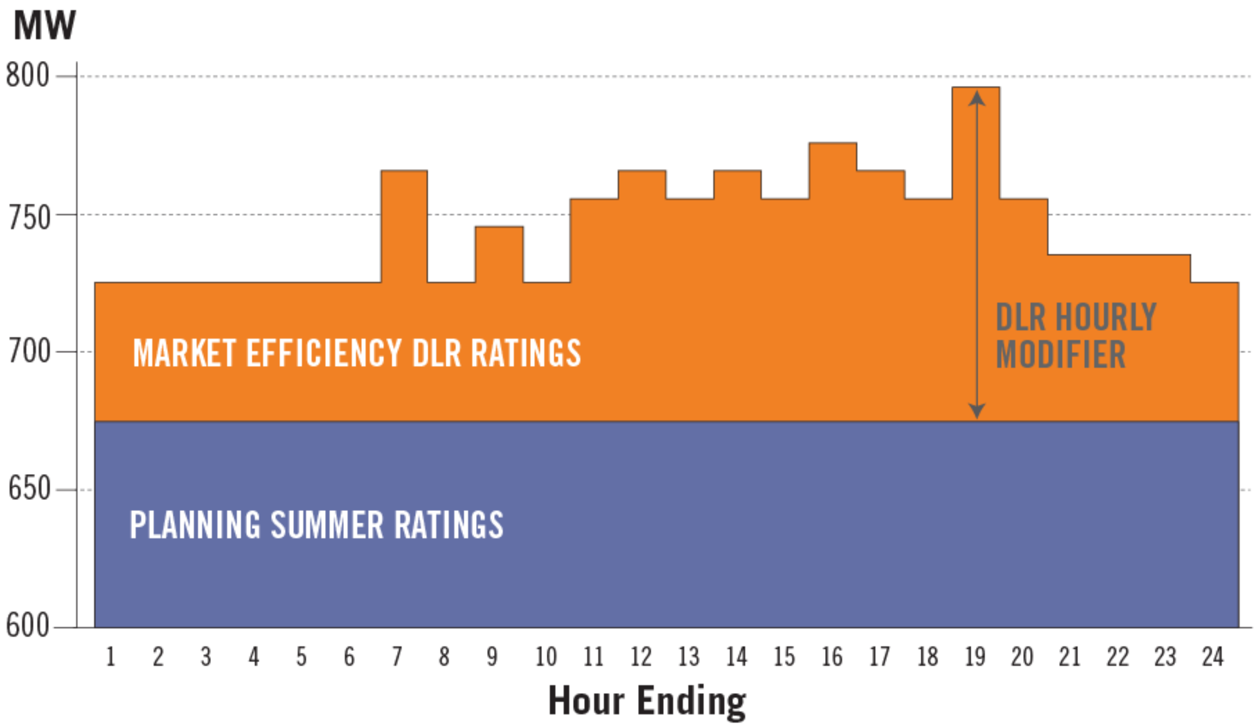


Figure 3. **DLR Hourly Modifier Applied to Planning Static Ratings**



III. Conclusion

In this paper, PJM has outlined a simple method to model a transmission line asset outfitted with a DLR system in PJM's Market Efficiency planning process. This method balances several objectives, including:

- ✓ Modeling the key value of a DLR system installation (hourly incremental transmission capacity)
- ✓ Avoiding rating overestimation
- ✓ Minimizing additional model complexity

PJM will continue to monitor the evolution and deployment of DLR technology and will refine this modeling approach as necessary.