Ambient-Adjusted Ratings and Dynamic Line Ratings

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NOTICE

This white paper was prepared for ACORE. All perspectives and opinions are the authors and do not necessarily reflect those of The Brattle Group, its clients, or other consultants. We are grateful for the valuable contributions of Jay Caspary of Grid Strategies and many consultants of The Brattle Group.

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I. Executive Summary

The U.S. energy industry has been recognizing the need to enhance its transmission facilities and various studies have indicated the urgent and massive need for transmission, generally estimating the U.S. will need to double or even triple its electric transmission capacity within the next decade or two. While new transmission buildout remains essential, Ambient-Adjusted Ratings (AAR) and Dynamic Line Ratings (DLR) can increase the usable capacity of existing transmission lines by replacing conservative static assumptions with ratings that better reflect actual operating conditions.

AAR and DLR both rely on the same basic thermal principles for overhead conductors, and until recently, were not distinguished while they do differ materially in scope and capability. AAR, now required under FERC Order 881 as a baseline operational practice, adjusts line ratings primarily for ambient temperature and can unlock meaningful capacity relative to static or seasonal ratings, often in the range of 5% to 15%. DLR can provide larger gains—often 10% to 40% or more—because it captures wind cooling and other localized conditions. In some cases, DLR can measure conductor temperature, sag, tension, or clearance. As a result, DLR provides a more accurate (and often higher) line rating together with better situational awareness.

Recent FERC actions suggest a clear policy distinction. AAR, as codified in Order 881, is treated as the mandatory minimum for near-term operations, while DLR is positioned as a higher-value technology for selective deployment, and recognized as an option for long-term transmission planning under Order 1920. The industry has historically viewed DLR as a method that should not be deployed universally; only in places where capacity can be unlocked. With this perspective, once AAR is broadly implemented, opportunities for DLR to deliver highest value as a capacity expansion tool are likely to be on persistently congested corridors, wind-rich areas, outage-sensitive interfaces, and lines awaiting rebuilds or reconductoring (with DLR serving as a bridging solution). The recent persistent load growth environment has potentially increased opportunities for DLR applications. Additionally, evidence reviewed in this report indicates that DLR can reveal situations where AAR or seasonal ratings may overstate safe line capacity.

Although DLR can involve additional hardware, sensors, and communications systems, operating costs and day-to-day operational complexity appear comparable to AAR once deployed. Utility experience suggests limited incremental staffing needs. And the low cost and short payback periods of DLR systems lead to low stranded-asset risk.

Overall, AAR is an important baseline reform that should improve transmission utilization across the system. DLR, as the most accurate representation of the true carrying capacity of transmission lines, is recognized as one of the most sophisticated solutions that allows operators to fully utilize the grid without compromising safety or reliability, offering greater capability and flexibility and delivering situational awareness that provides clear operational, reliability, or economic value.

II. Introduction

The U.S. energy industry has been recognizing the need to enhance their transmission facilities and various studies have indicated the urgent and massive need for transmission, generally estimating the U.S. will need to double or even triple its electric transmission capacity within the next few decades.[1] The recent evolution of new loads is further accelerating the pace of such needs. At the same time, the uncertainty surrounding the industry (e.g., new loads either not materializing or growing at an even faster pace than projected) has also increased, leading to a more challenging environment for utility investments, in general, leaving the public with potential shortage of transmission capacity.

The Federal Energy Regulatory Commission (FERC) has recognized various technologies including Ambient-Adjusted Ratings (AAR) and Dynamic Line Ratings (DLR) as potential solutions that will allow better utilization of the existing transmission lines, which in turn could lower costs of electricity in both the short- and long-term. The conservative static line ratings that transmission operators used historically assumed worst-case weather conditions. Seasonal line ratings have been the most commonly used and consist of static ratings set by season (e.g., summer and winter). AAR and DLR recognizes actual (and forecasted) real-time weather conditions for calculating line ratings. Both methods utilize the same thermal balance of bare overhead conductors – i.e., heating caused by current flow is affected by factors such as convective cooling, radiative cooling, and solar heating. The terms AAR and DLR have often been used inconsistently, in part because of this similarity between the two methods. However, they are different. The key distinction on the technical side is that AAR primarily adjusts ratings to account for ambient temperature and potentially solar heating (FERC Order 881 simply recognizes daytime/nighttime in terms of solar), whereas DLR accounts for additional factors, such as windspeed and direction. DLR can also provide situational awareness of the asset, such as line sag, which AAR that focuses solely on ambient temperature cannot. On the regulatory side, AAR is now mandated by FERC as a baseline operational standard and transmission operators are in the course of implementing it, while DLR is viewed as more advanced and perhaps better installed for select target applications.

This report discusses the differences between AAR and DLR from two sides—the regulatory developments and technical capabilities.

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[1] Several examples of studies are discussed in *Building a Better Grid: How Grid-Enhancing Technologies Complement Transmission Buildouts*, available at: https://watt-transmission.org/wp-content/uploads/2023/04/Building-a-Better-Grid-How-Grid-Enhancing-Technologies-Complement-Transmission-Buildouts.pdf

III. Regulatory Developments

Historically, AAR and DLR have been treated as the same, if not similar, methods. For example, the study performed by Oncor Electric Delivery Company (Oncor) included in the 2014 U.S. Department of Energy (DOE) Topical Report titled *Dynamic Line Rating Systems for Transmission Lines* (*2014 DOE Topical Report*) technically used AAR, in which static ratings are adjusted "daily, hourly, or...more frequently to account for different ambient temperatures."[2] Similarly, DOE's 2019 report titled *Dynamic Line Ratings* cites, as an example of DLR benefits, how ISO New England (ISO-NE) utilized AAR during the bomb-cyclone and increased flows between New England and New York.[3] In addition, FERC applies the same rationale to both methods–that line ratings are not mere engineering inputs in isolation; they are tariff-relevant practices that shape wholesale rates–equally to AAR and DLR.[4] The difference between the two methods has only been highlighted in recent years.

In August 2019, FERC released a staff paper titled *Managing Transmission Line Ratings* (*2019 Staff Paper*) that discussed line ratings covering both AAR and DLR (AD 19-5).[5] Importantly, this paper highlighted the inconsistent industry use of AAR and DLR terminologies. Following a technical conference on AAR and DLR in September 2019, FERC issued a Notice of Proposed Rulemaking (NOPR) on AAR reforms (RM 20-16) in November 2020. This was one of the first instances in which AAR was clearly distinguished from DLR.

In December 2021, FERC issued Order 881, mandating the use of AAR to replace static ratings that have historically underutilized transmission capacity.[6] Five months later, in May 2022, FERC

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[2] The *2014 DOE Topical Report* contains two studies performed respectively by Oncor and the New York Power Authority, and was developed as part of the DOE's Smart Grid Program. The report is available at: https://www.energy.gov/sites/prod/files/2016/10/f34/SGDP_Transmission_DLR_Topical_Report_04-25-14.pdf

[3] DOE *Dynamic Line Rating* report, July 2019, available at: https://www.energy.gov/oe/articles/dynamic-line-rating-report-congress-june-2019
Also see slide 41 of ISO-NE presentation *Cold Weather Operations, December 24, 2017–January 8, 2018* available at http://www.nepool.com/uploads/NPC_20180112_Cold_Weather_Ops.pdf

[4] See paragraphs 12-18 of 881-A, where FERC reiterated that both understated and overstated ratings distort congestion, transmission availability, dispatch, and ultimately wholesale market pricing.

[5] *Managing Transmission Line Ratings*, August 2019, available at: https://www.ferc.gov/sites/default/files/2020-05/tran-line-ratings.pdf

[6] Order 881 exempts transmission lines whose transfer capability is not affected by ambient air temperature or solar heating, or whose true limit is a system voltage or stability limit rather than a thermal one, from the AAR requirement. The actual implementation status varies. For example, PJM publicly announced it as being the first Regional Transmission Organization (RTO) to have operational AAR implemented in March this year while ISO-NE and the California ISO (CAISO) are scheduled for late 2026. The Mid-Continent ISO (MISO) and New York ISO (NYISO) are scheduled for no later than 2028.

issued Order 881-A, clarifying and affirming Order 881. The combined Order 881 defines AAR as a transmission line rating that:

a. Applies to a time period of not greater than one hour;
b. Reflects an up-to-date forecast of ambient air temperature across the time period to which the rating applies;
c. Reflects the absence of solar heating during nighttime periods (where the local sunrise/sunset times used to determine daytime and nighttime periods are updated at least monthly, if not more frequently); and
d. Is calculated at least each hour, if not more frequently.

In parallel, in February 2022, FERC issued a Notice of Inquiry (NOI) to investigate mandatory DLR implementation. In June 2024, FERC issued an Advance Notice of Proposed Rulemaking (ANOPR) to mandate the use of DLR (RM24-6). As of this writing, no final decisions have been made. Accordingly, unlike AAR, the definition of DLR has not yet been formally codified.

However, FERC's expectation for DLR appears to be different from AAR, which FERC defined to be largely operational (up to ten days) in Order 881. In May 2024, FERC issued Order 1920, which was augmented by 1920-A issued in November 2024, and 1920-B issued in April 2025. The combined Order 1920 mandates the consideration of certain advanced transmission technologies, including DLR, for long-term transmission planning.[7] Order 1920 does not provide similar treatment for AAR. This suggests that AAR represents FERC's minimum mandate for near-term operations, while DLR is expected to have a broader and a more complex potential application that FERC has not yet imposed.

It is generally viewed that once AAR is widely implemented, DLR would be deployed selectively on high-value corridors rather than universally. This is because once AAR is widely deployed, opportunities for DLR, from a congestion mitigation purpose, could be targeted to areas of greatest needs. For example, in the *2014 DOE Topical Report*, Oncor suggests transmission operators would need about 5% to 10% additional capacity (above static ratings) to address congestion. The report estimates 5% of additional capacity would relieve congestion up to 60% and 10% would likely address most. Therefore, the strongest candidates for DLR may be

[7] Order 1920's sister Order, Order 2023 (both Orders stemmed from the same ANOPR), which reformed the generator interconnection procedures, requires advanced transmission technologies to be studied as part of the interconnection study process. Interconnection queue delays were observed to be correlated with high network upgrade costs, which could be reduced with advanced transmission technologies that are often implemented more quickly and improve utilization of existing lines. See Order 2023A, footnote 1087.

transmission paths congested even after AAR, wind-rich corridors where cooling and generation are correlated, outage-sensitive interfaces, and lines where existing ratings are known to be conservative but conventional upgrades are not yet ready. The industry appears to understand this. For example, Great River Energy has installed DLR systems on their most (thermally) congested lines. These lines are naturally candidates for future rebuilds or reconductoring efforts and Great River Energy, thereby, is using DLR as a bridge that helps until the permanent solution (rebuilt or reconductored line) is developed.

These policy developments together with the *2019 Staff Paper* highlights FERC's view of line rating spectrum – that it starts at static ratings to seasonal ratings, then evolves to AAR, and finally to DLR. The *2019 Staff Paper* describes DLR as the most dynamic approach.[8] Furthermore, FERC has clarified that a compliant DLR can satisfy the AAR requirement because DLR inherently includes ambient-temperature- and solar heating-based forecasting, indicating that DLR, which incorporates additional variables beyond AAR in determining line ratings, is of the highest quality within the spectrum.[9] Most recently, FERC issued a series of orders requiring FERC-jurisdictional Regional Transmission Organizations (RTOs), Independent System Operators (ISOs), and the transmission owners (TOs) in each region to adopt certain large load interconnection processes to the extent they have not yet done so. These include requiring the evaluation of certain technologies, such as DLR, when determining the transmission needs and required network upgrades for large loads. FERC noted that such technologies can "add more capacity on existing transmission lines quickly."[10]

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[8] The National Renewable Energy Laboratory (NREL) assumes a spectrum of seven line ratings, namely Static line rating, Seasonal line rating, Ambient-adjusted line rating, Nighttime-adjusted line rating, Clearsky-adjusted line rating, Irradiance-adjusted line rating, and Dynamic line rating. Order 881 discusses both Ambient-adjusted line rating and Nighttime-adjusted line rating as AAR, and the FERC DLR ANOPR discusses Clearsky-adjusted line rating, Irradiance-adjusted line rating, and Dynamic line rating. See slide 14 of NREL, *Hourly dynamic line ratings for existing transmission across the contiguous United States (preliminary results)*, October 2024, available at: Hourly Dynamic Line Ratings for Existing Transmission Across the Contiguous United States (Preliminary Results)

[9] Order 881 required transmission providers to maintain a database of transmission line ratings and methodologies on OASIS or another password-protected website, including a full record of the ratings used in real-time operations and future market periods for which transmission service is offered. Ratings are to be archived for five years. While the decisions on the DLR NOI is not yet made, these mandates are assumed to be applicable for DLRs as well.

[10] See for example, Order Instituting Proceeding Under Section 206 of the Federal Power Act, PJM Interconnection, L.L.C., 195 FERC ¶ 61,211 (June 18, 2025), at P 61. The same language was included in the Orders for the other RTOs.

IV. Technical Capabilities of AAR and DLR

Both AAR and DLR increase the utilization of transmission lines beyond the capacity that results from conservative static ratings (or seasonal ratings). The capacity increase reduces curtailments and alleviates congestion, providing cost savings for consumers. They do so by incorporating environmental conditions into the assessment of conductor heating, which determines thermal limits.[11] Both methods utilize forecasts for operations. Where they differ significantly is in the complexity and data inputs, which then leads to operational impacts.

AAR modifies the traditional static line ratings using forecasted or measured ambient conditions, typically focusing on air temperature and potentially on heating from the sun. Static ratings are generally based on conservative assumptions about weather conditions that adversely impact transmission line ratings (e.g., high temperature, low wind), which do not occur all the time, leading to inefficient use of transmission capacity.[12] AAR relaxes these assumptions by updating ratings periodically (e.g., hourly) based on more realistic ambient temperatures (actual measurements or forecasts). This typically results in modest increases in line capacity (from statics ratings)—often in the range of 5% to 15%.[13] AAR is relatively simple to implement, as it relies on readily available weather data and does not require extensive new hardware. However, it will require software along with adjustments for existing equipment, including sensors and relay settings. Furthermore, AAR will still require assumptions for factors it does not capture (e.g., windspeed and direction, and solar heating) and these conservative assumptions limit AAR's ability to fully capture the conductors' capability.

DLR goes further by calculating transmission capacity using localized weather conditions and, in some cases, direct conductor measurements. DLR systems typically incorporate windspeed and direction and humidity in addition to ambient temperature and solar irradiation, and could also provide real-time conductor temperature, tension, and sag (via sensors or models). Because wind

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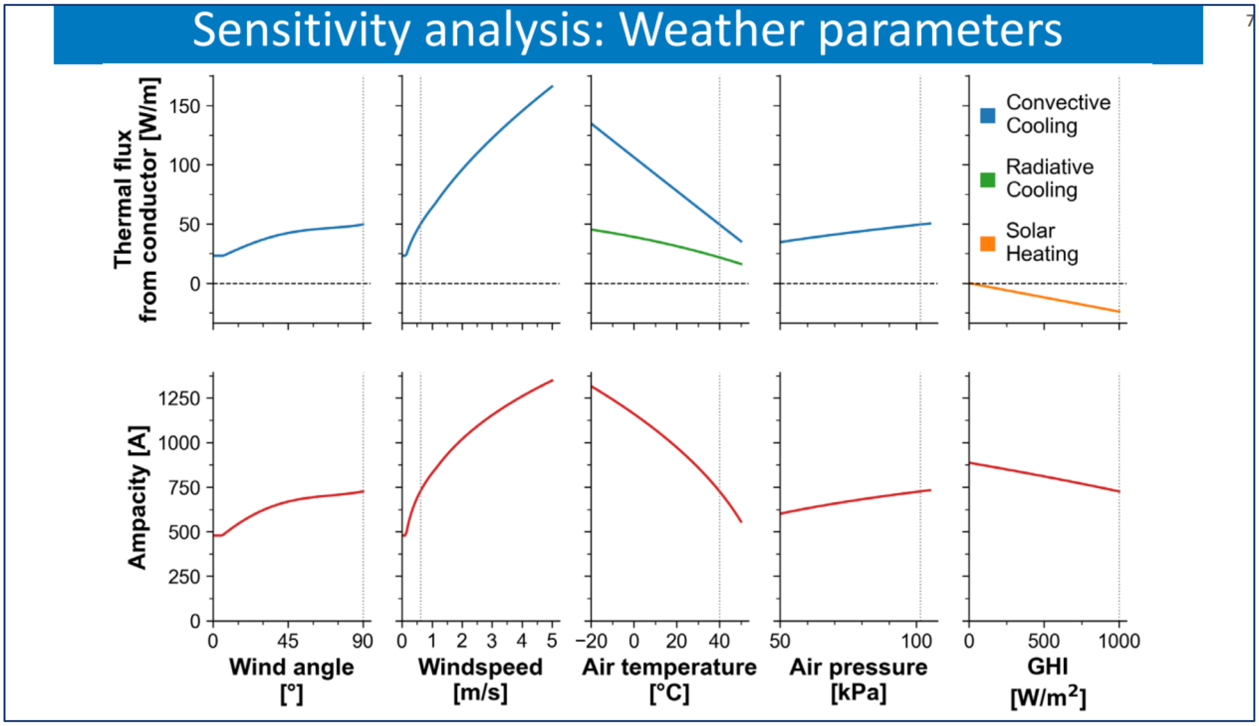
[11] It is well understood that conductor heating is highly correlated with ampacity (the flow on the line). The Institute of Electrical and Electronics Engineers (IEEE) defines the maximum allowable conductor temperature as the temperature selected for line-rating purposes to limit conductor strength loss and sag so that electrical clearances are maintained.

[12] This is similar to setting low speed limits for highways, assuming adverse weather conditions (e.g., 30 miles an hour under heavy snow conditions) for the entire winter period and enforcing it, even when the weather is clear and driving conditions are good.

[13] AAR gains are highly dependent on the location and selected wind assumptions. Assuming the CIGRE-recommended 2 feet per second, the expected gain would be around 1% per 1 degree C change in ambient temperature. This gain will diminish greatly when using seasonal ratings and in climates which do not experience large temperature variance by season.

has a significant cooling effect, DLR systems can increase capacity (from static ratings) by 10% to 40% or more, depending on conditions.[14] Naturally, DLR will have the most impact at locations with constant and higher speed wind. Figure 1 shows the sensitivity of various weather-related parameters to ampacity of the conductor analyzed by the National Renewable Energy Laboratory (NREL).[15] Both ambient air temperature and windspeed show the largest level of impacts.[16]

FIGURE 1: WEATHER PARAMETERS AND AMPACITY



Like AAR, DLR systems update frequently—at times on a more granular timescale (e.g., every 5 to 15 minutes)—and can capture spatial variability along the path with DLR installed, providing increased situational awareness. While DLR systems are more accurate than AARs, they are also more complex, requiring sensors, communications infrastructure, and data validation in addition to the software and adjustments to existing equipment that are already required for AAR.

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14 Similar to AAR, DLR gains are highly dependent on the location and wind conditions.

15 See slide 7 of NREL, *Hourly dynamic line ratings for existing transmission across the contiguous United States (preliminary results)*, October 2024, available at: [Hourly Dynamic Line Ratings for Existing Transmission Across the Contiguous United States (Preliminary Results)]

16 AAR only looks at the air temperature while DLR also considers wind conditions. DLR is akin to checking both the temperature and wind conditions to decide what to wear outside, while AAR is akin to relying solely on temperature to decide how to dress warm enough without considering wind chill effects (and "feels like" temperature.).

We note that DLR (and perhaps so for AAR) is not limited to just one type of technology. Rather it contains a variation and the specific technologies and measurement approaches used for DLR vary by vendor. Direct measurement methods use devices that are directly coupled to the transmission line. These devices measure temperature, tension, sag, and/or clearance from which the thermal rating is determined. A unique approach includes measuring the vibration of the wires to calculate wind strength for any location within a given span. Indirect measurement methods often use weather stations and modeling.

Figure 2 compares the DLR and AAR limits for the Susquehanna to Harwood 230 kV path that PPL Electric Utilities (PPL, formerly known as Pennsylvania Power and Light) and DLR vendor Ampacimon measured over a full month (January 2023).[17] This Figure shows that DLR for this specific case provided significantly higher capacity gains than AAR, resulting in elimination of all congestion for the two winter periods observed.

FIGURE 2: DLR VS AAR LIMITS FOR THE SUSQUEHANNA TO HARWOOD 230 KV PATH

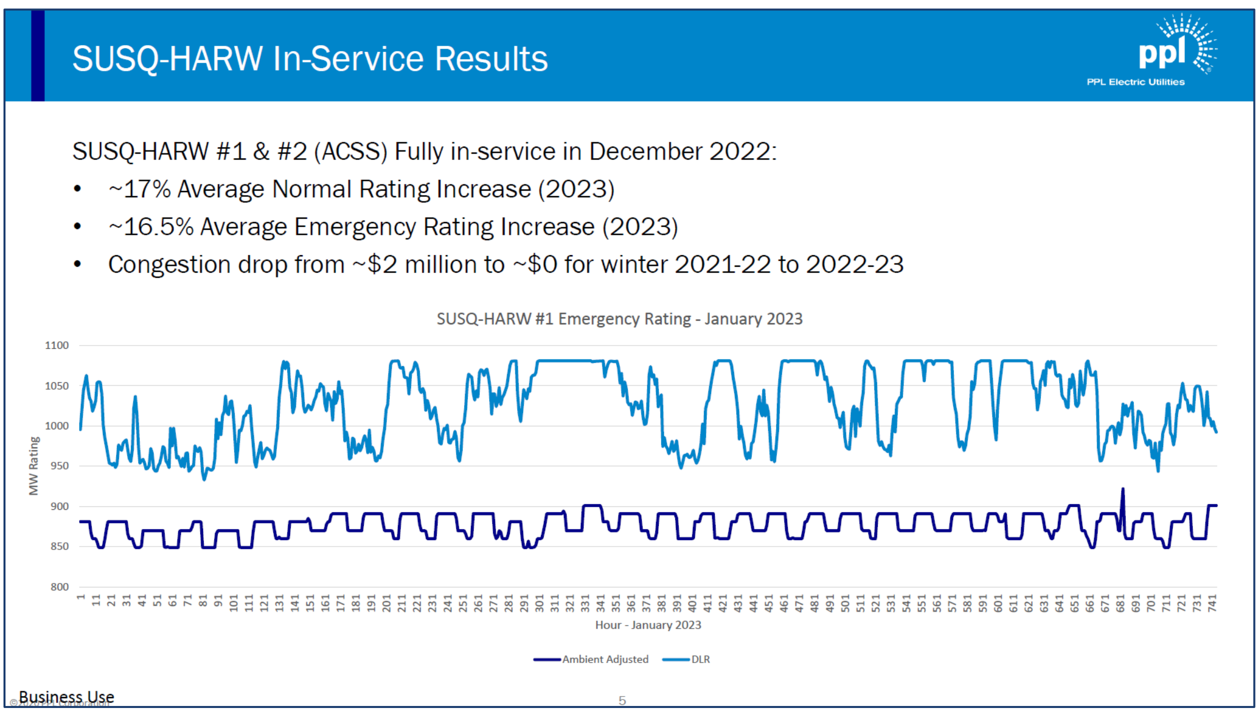

Figure 3 sorts in descending order (from highest to lowest) the DLR gain compared against AAR and static limits Ampacimon collected over a six-month period for a location in northern U.S.[18]

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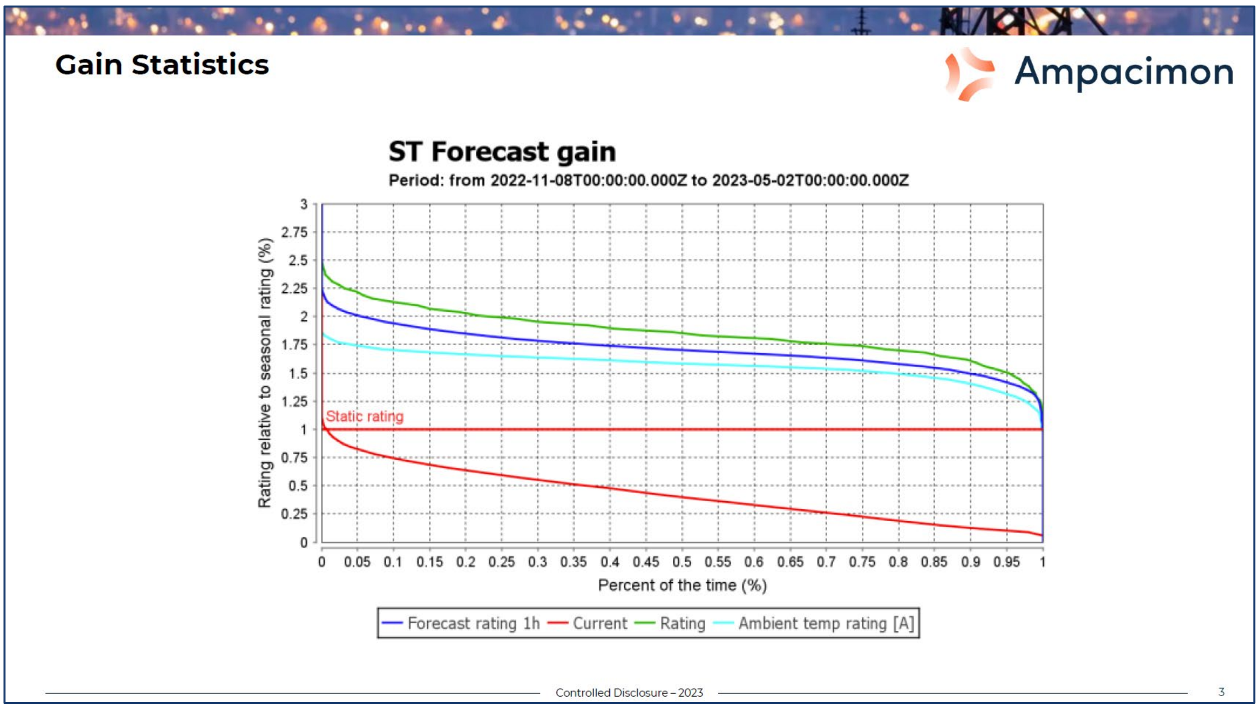
[17] See slide 7 of PPL Electric's *Dynamic Line Ratings (DLR)* presentation, October 2024, available at: https://www.energypa.org/wp-content/uploads/2024/10/Dynamic-Line-Ratings-E-Rosenberger.pdf

[18] *DLR vs AAR* presentation, provided by Ampacimon.

The horizontal red line with the Y axis value of 1 represents the static line ratings. The green line shows the real-time DLR-based capacity compared against the static line ratings. For example, the green line shows the Y axis value of 2 where the X axis value is 0.25. This indicates that DLR provided more than 2x (i.e., double) the static rating limits for a quarter of the time. The blue line shows the forecasted (hour-ahead) DLR-based capacity compared against the static line ratings. The blue line is lower than the green line because Ampacimon naturally embeds conservatism in its forecasting. The light blue line shows the AAR-based capacity compared to the static line ratings. Like Figure 2, DLR gains are larger than AAR gains.[19]

FIGURE 3: DLR VS AAR LIMITS OVER A SIX MONTHS-PERIOD



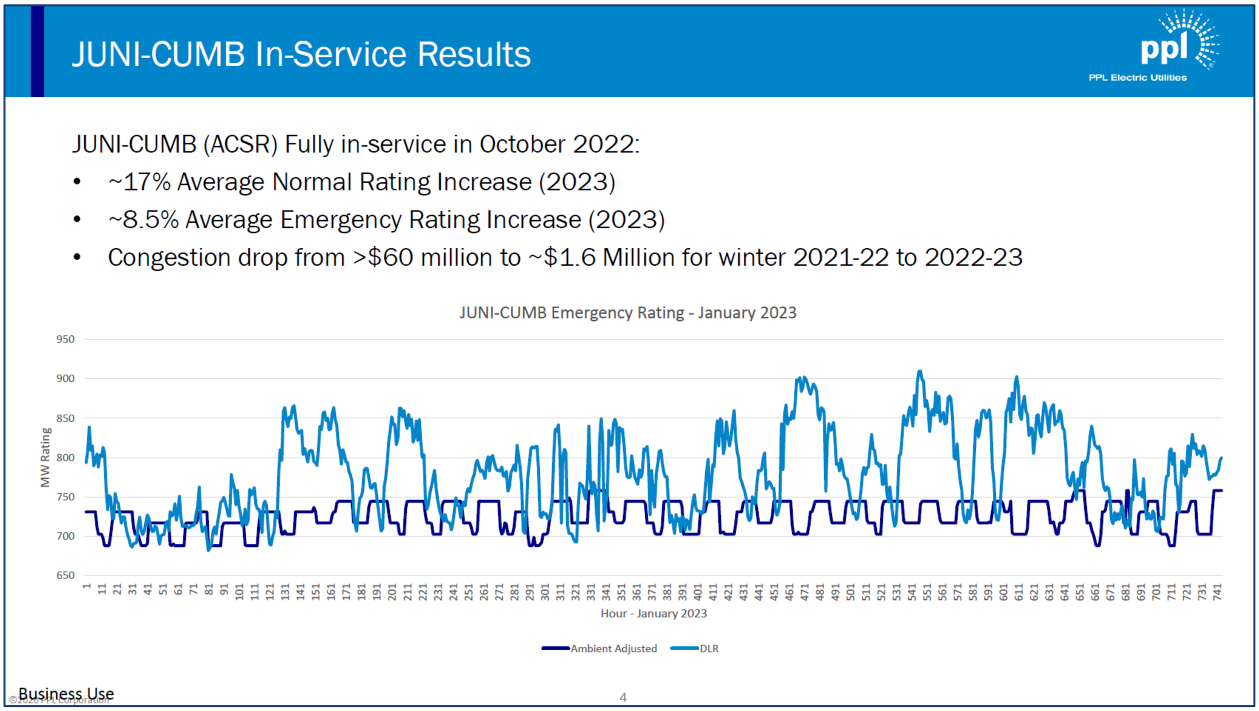
DLR and AAR limits may not always be higher than the static limits. This depends on the underlying assumptions, such as temperature and windspeed, used for calculating the static limits (and AAR limits, when comparing against DLR). There are times when DLR limits could be lower than AAR (or static) limits. Figure 4 below compares DLR to AAR for the Juniata to Cumberland 230 kV path that PPL and Ampacimon measured over the full month of January 2023.[20] Similar to the previous Figures, it shows DLR limits to be materially higher than AAR limits

[19] For example, DLR (green line) with the x-axis value of 0.05 shows a rating of 2.25x of the static rating (red horizontal line), compared to 1.75x for AAR (light blue line), indicating that DLR gain over the static rating is about 30% higher (2.25 / 1.75) than that of AAR.

[20] See slide 8 of PPL Electric's *Dynamic Line Ratings (DLR)* presentation, October 2024, available at: https://www.energypa.org/wp-content/uploads/2024/10/Dynamic-Line-Ratings-E-Rosenberger.pdf

in most hours. This capacity gain led to the reduction of nearly $60 million In annual congestion costs. The Figure also shows that DLR limits can occasionally be lower than AAR limits.

FIGURE 4: DLR VS AAR LIMITS FOR THE JUNIATA TO CUMBERLAND 230 KV PATH



The observation of DLR limits being lower than AAR limits indicates two factors. One is the risk inherited in AAR ratings (and in static ratings). For example, if the actual windspeed is lower than what is assumed for AAR ratings (or static ratings), DLR, which reflects the actual wind data, would (and should) show a lower rating. Without DLR, the operator will not know and could potentially be running the system with current flowing above the theoretical conductor limit.[21]

Great River Energy's experience with Heimdall Power's DLR system also illustrates these dynamics. Figure 5 shows the average conductor capacity gains (real-time values) from DLR and AAR against the previously implemented seasonal rates for one specific line, observed for the period of July 2024 through July 2025.

[21] The Electric Power Research Institute (EPRI) warns that AAR limits on a cool day with limited wind could lead to line operations of more than 30°C hotter than assumed, with consequences for annealing and clearance. See EPRI, *Increasing Transmission Line Capacity Through Ratings*, available at: https://www.epri.com/research/products/000000003002023333.

FIGURE 5: AVERAGE CONDUCTOR CAPACITY GAINS FROM DLR AND AAR (VS PREVIOUS SEASONAL RATING)

Average Conductor Capacity Gain	DLR	AAR
Summer	50.5%	20.1%
Winter	22.5%	- 8.8%

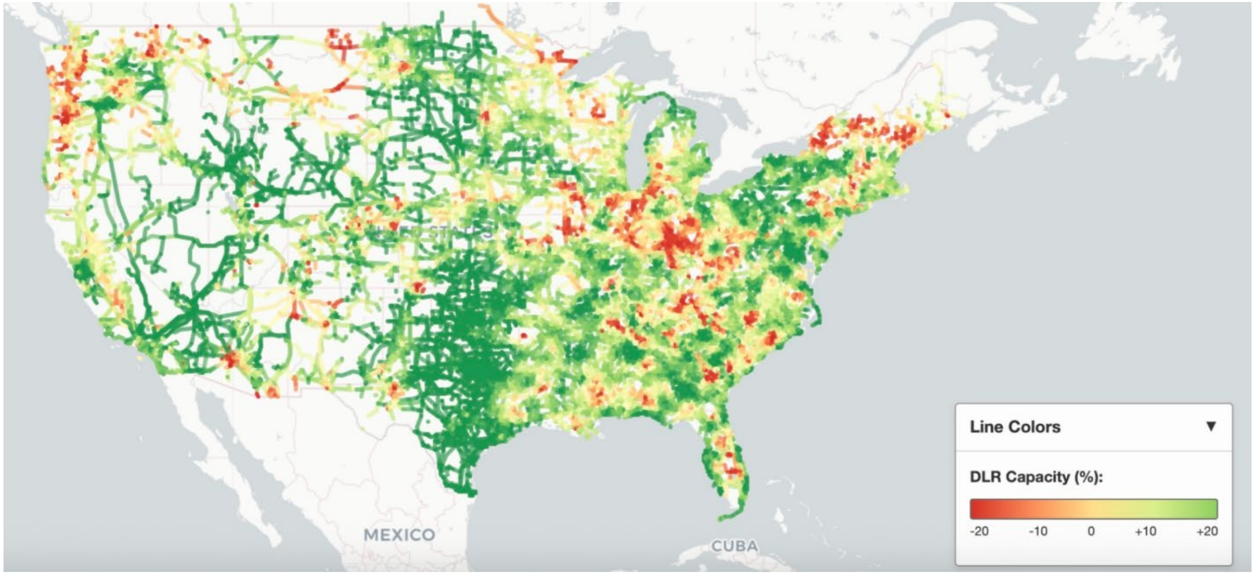
Here, the AAR limits in the winter called for an 8.8% decrease from the seasonal limit that was in place. This was caused by the ambient temperature in the winter of 2024/2025 being generally higher than Great River Energy's seasonal ratings' assumption. Fortunately, real-time conditions on the line were different – winter winds significantly cooled the lines, and by directly measuring line temperature and the wind's cooling effect across all critical spans and sections, the DLR system helped Great River Energy unlock conductor capacity gains averaging 22.5%.

The Great River Energy observation shows the advantage of DLR over AAR and static limits. First, the gain from DLR compared to AAR shows how impactful the wind factor is to line ratings, complying with the observations NREL made in Figure 1. Second, the AAR rating being lower than the static rating should be alarming. This was not just for winter. Great River Energy and Heimdall Power observed that roughly 2% to 3% of the time in summer, DLR ratings were lower than the seasonal summer ratings. These observations are examples of how seasonal ratings which utilities operate to might not be accurate based on weather conditions.

Figure 6 compares AAR and DLR capacities from a high load period in summer 2025. The Figure shows where DLR provides excess capacity (in green) and where capacity is lower (in red) than AAR ratings.[22] Similar to the Great River Energy example, red indicates the seasonal ratings that was less restricting than the actual weather conditions-based DLR. This could lead to equipment overloads for this specific time. It also indicates that red paths should be upgraded.

[22] Visual from LineVision. The figure is based on publicly available information from https://www.openstreetmap.org/copyright. The AAR assumes windspeed of 2 feet per second, and the map reflects the actual carrying capacity of transmission lines. The figure demonstrates where DLR could provide excess capacity (green) and where the true rating would be below the AAR ratings.

FIGURE 6: DLR CAPACITY GAIN (SNAPSHOT)



The advantages of DLR over AAR are clear. However, as discussed earlier, DLR requires a more complex system that could include sensors and communications infrastructure, in addition to the software and adjustments to existing equipment that are already required for AAR.[23] This could lead to cost concerns for implementing DLR.

The operational costs and resource needs for operating DLR (once the DLR system is installed) appear to be very comparable to AAR. For example, Great River Energy has installed Heimdall Power's DLR system on ten lines that were thermally constrained. The costs Great River Energy faced were largely initial costs (i.e., hardware, integration, and installation costs) and yearly subscriptions cost (i.e., DLR software) that is based on a per DLR sensor basis. Subscription costs include the Application Programming Interfaces (API) built into a cloud-based software that is compatible with Great River Energy's Supervisory Control and Data Acquisition (SCADA) system. The software provides line ratings (actual and forecast) and allows Great River Energy to integrate the ratings with their SCADA tools and with the system operator (Mid-continent Independent System Operator, or MISO). Great River Energy recognizes that AAR also requires paying the SCADA vendor licensing fees for similar services. Great River Energy observed minimal O&M costs associated with the DLR hardware after installation and integrations beyond yearly vendor fees.[24]

23 While the DLR equipment are generally designed to be maintenance-free, they may require specialized support if issues arise.

24 Great River Energy assumes that the maintenance costs of the DLR sensors may be lower than traditional relay meters, which require periodic maintenance and calibration.

Further, while DLR systems do introduce greater variability and require grid operators to manage limits changing by a number of factors, not just ambient temperature, the actual day-to-day operations do not vary much from that of AAR. Both AAR and DLR provide frequently updated line ratings, which in the case of Great River Energy, are shared with MISO. For AAR, Great River Energy uses a temperature (5 degrees granularity) lookup table that is shared with MISO through Great River Energy's SCADA system. For DLR, the data points are simply more granular and there is little (if any) difference in the daily activities required by the Great River Energy operators. The internal training program Great River Energy developed for operators on AAR and DLR share many of the same processes. Great River Energy's experience is that once AAR is put in place, the operational costs and complexity between AAR and DLR are very similar.

Perhaps because of this similarity and that AAR is mandated by Order 881, Great River Energy's experience shows the incremental human resources needed for deploying DLR also to be minimal.[25] Great River Energy did not hire new staff for deploying DLR. Many DLR vendors share similar observations—that there is little need to hire additional staffing to deploy DLR, especially given that utilities already have staff that are familiar with Order 881 and NERC Reliability Standard FAC-008.[26] This should be the case because transmission owners are working to make DLR an integral part of their transmission operations and planning processes, as mandated by Order 1920, rather than treat it as a siloed project that has to be attended by a dedicated team.

Finally, the initial cost of DLR systems (hardware, integration, and installation costs) is small and there should be little concern of DLR becoming stranded assets. Many examples indicate DLR's payback periods to be measured in months, if not weeks. Great River Energy assumes a 5x payback based on the past five years' experience. PPL's DLR examples from Figure 2 and Figure 3 also show very short payback periods.[27] Also, DLR can provide additional benefits beyond increasing conductor capacity, including situational awareness. For example, Great River Energy intentionally installed DLR on a line that had some spans that would sag and be clearance limited before they hit their thermal limit (due to unique factors like a railroad crossing). Great River

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[25] Great River Energy recognizes there were huge efforts and costs of implementing AAR and assumes they were driven largely by the massive scope of deploying AAR on all, if not most, lines. Because Great River Energy only utilizes DLR for select lines, the same issue does not exist.

[26] FERC Order 881 and NERC Reliability Standard FAC-008 are closely linked regulatory frameworks that mandate how transmission utilities calculate and document the ratings of their power grid equipment.

[27] The two Figures show congestion cost savings for the winter was $2 million for the Susquehanna to Harwood 230 kV path and nearly $60 million for the Juniata to Cumberland 230 kV path. By comparison, the estimated costs of the DLR solution provided by Ampacimon were less than $1 million. See slide 3 of PPL Electric's *Dynamic Line Ratings (DLR)* presentation, October 2024, available at: https://www.energypa.org/wp-content/uploads/2024/10/Dynamic-Line-Ratings-E-Rosenberger.pdf

Energy compared the measurements from the DLR to their engineering model and confirmed the engineering models were very accurate based on the temperature and loading of the line. And DLR devices (i.e., hardware) are reversible and portable – they can be uninstalled from conductors and moved to other conductors, as needed (and largely without outages). Great River Energy is currently planning to transfer their DLR sensors installed on one of the lines that will be rebuilt, to another line.

V. Conclusion

Overall, DLR systems offer advantages over both AAR and static line ratings by providing more accurate—and often higher—limits that reflect the conditions surrounding each conductor. This is expected because, as NREL observed in Figure 1, ambient air temperature and wind are the two dominant factors impacting conductor ampacity, and AAR captures only one of them. However, AAR would unlock transmission capacity in many places today, and as indicated by Oncor in the *2014 DOE Topic Report*, the mandated implementation of AAR is expected to alleviate a large portion of the congestion that were observed under static (or seasonal) line ratings. Therefore, DLR should be deployed purposely for select applications.

The select DLR application can be for severe congestion that AAR alone cannot alleviate. Such application can be for a limited time, such as bridging until another solution (e.g., reconductoring or rebuilt of the line) can be deployed. Alternatively, many DLR systems (by design) provide additional situational awareness, such as the actual conductor conditions, which AAR or static ratings simply cannot. Such features enable broader application of DLR beyond conductor capacity enhancements. For example, one could install DLR on newly constructed conductors to measure the sag (as Great River Energy did). Understanding the temperature, humidity, and wind could also provide insights in assessing conditions that could lead to undesired conditions, such as wildfires or icing events. Should the need for a specific DLR device diminish, that DLR device could be uninstalled and moved elsewhere (again, as Great River Energy did), although the situational awareness alone may be enough to keep these assets in place, as their payback period is very short (sometimes measured in weeks, if not months). FERC likely understands these advantages and that can be seen in their Orders that are associated with AAR and DLR, where the expectations for DLR appear to be much higher.

Finally, while DLR systems involve hardware installation (which AAR does not), operational complexity and costs do not appear to vary much from AAR. Furthermore, international experience suggests these technologies are robust and proven for the long run. DLR is recognized as one of the most sophisticated solutions allowing system operators to fully utilize the grid without compromising safety or reliability. At worst, the operator can go back to AAR or seasonal ratings while a malfunctioning DLR component is being attended.

Glossary

AAR	Ambient-Adjusted Rating
ANOPR	Advance Notice of Proposed Rulemaking
API	Application Programming Interfaces
CAISO	California ISO
CIGRE	International Council on Large Electric Systems
DLR	Dynamic Line Rating
DOE	U.S. Department of Energy
EPRI	Electric Power Research Institute
FERC	Federal Energy Regulatory Commission
GETs	Grid-Enhancing Technologies
IEEE	Institute of Electrical and Electronics Engineers
ISO	Independent System Operator
ISO-NE	ISO New England
MISO	Mid-Continent ISO
NERC	North American Electric Reliability Corporation
NOI	Notification of Inquiry
NOPR	Notice of Proposed Rulemaking
NREL	National Renewable Energy Laboratory (aka National Laboratory of the Rockies)
NYISO	New York ISO
RTO	Regional Transmission Organization
SCADA	Supervisory Control and Data Acquisition

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