Dynamic Line Ratings

INTRODUCTION

Dynamic line ratings (DLRs) are a method for determining how much power can flow through overhead lines for a given allowable operating temperature. What differentiates DLR from other methods is the use of real-time data to account for local weather conditions that change every few minutes, such as wind speed and direction. Because DLR is a relatively affordable and quickly deployed method to directly impact overhead line capacity, interest in it has grown significantly in the last decade.

In the United States, electric companies have prioritized the adoption of ambient adjusted ratings (AAR) to comply with Federal Energy Regulatory Commission (FERC) Order 881 by the 2025 deadline. As a result, utility systems may be updated and better able to manage the types of data and communications needed to allow for DLR, which makes DLR a more attractive option. See Sidebar.

DLR can provide additional benefits compared to AAR by increasing the accuracy of line ratings and, under some conditions, unlocking greater transmission capacity. In addition, DLR may also prompt insights that can increase reliability by providing an improved understanding of the conductor temperatures experienced—which informs both the asset health models as well as calculations of line clearance. Minimum conductor-to-ground clearances are required by codes (such as North American Electric Reliability Corporation [NERC], National Electric Safety Code [NESC], or GO95) to mitigate the risk of flashover to vegetation, vehicles, and other objects—impacting public safety and system reliability. Data provided by DLR systems may also be leveraged for other needs.

KEY TERMS AND DLR OVERVIEW

Transmission Line Ratings

- The maximum power transfer capability of a transmission line, computed in accordance with a written methodology, regulations, and consistent with good utility practices
- Must consider limitations on conductors and relevant equipment (for example, thermal limits) as well as limitations of the transmission system (such as system voltage and stability limits)

Ambient Adjusted Ratings

- The rating is modified to reflects near-term air temperature changes
- In the United Ststes, under FERC Order 881:
  - AAR are adjusted hourly; globally, some utilities change AAR daily
  - Day/night adjustments are included for solar heating 10-day forecasts are required

Dynamic Line Ratings

- The rating is modified every few minuters to reflect near-term wind speed and direction changes and their influence on the operating temperature of transmission assets
- The DLR of overhead lines varies significantly because of wind speed and direction:
  - Some technology providers measure other variables such as sag, conductor temperature, and vibration to use in estimating the present and forecasted wind

To determine the DLR of a line, the weather conditions along that line must be known and forecasted. A common method to derive DLR is to collect weather data along transmission lines using dedicated weather stations and models. Some DLR technologies measure the present conductor temperature, sag, or other factors and combine those measurements with the line loading to estimate the local weather conditions. The weather conditions are used to calculate real-time and emergency ratings using industry standards. In some cases, the field measurements are also used to calibrate or "train" forecasting models. The more accurately a DLR technology can determine and forecast the conductor temperatures of an entire circuit, the more useful that rating will become. With any DLR measurement, there is measurement uncertainty, which results in risk. In addition, because of changes in terrain, weather, and line angles, the DLR will be different for each span and circuit. This adds uncertainty factors because direct measurements are usually not taken on every span. One method to manage risks is to derate the DLR proportional to the uncertainty level. This helps ensure safe and reliable operation.

STATE OF THE SCIENCE

Proportional to the booming interest, there has been rapid growth in the number of DLR technology providers. In addition to dozens of technology providers offering solutions, electric companies have access to weather networks and forecasts that can be used to develop DLRs. Each technology provider leverages different measurement technologies, algorithms, and communication platforms to align its approach with industry needs. This gives electricity companies a pool of options from which to find the best fit. In some cases, a combination of technologies may be optimal because there are no "one size fits all" solutions.

A classic technology readiness level (TRL) score may not be a meaningful descriptor for DLR technologies. Both new and established DLR providers are continuously evolving the software and hardware. These evolutions should improve the accuracy of the technology; however, each modification also "resets the clock" on the level of field experience and can change the advised best practices.

EPRI is working with members to develop a "maturity" scale that may better capture the key performance indicators. In parallel, EPRI is working globally to gather information from technology providers, asset owners, system operators, and other interested parties to disseminate experiences with the present generation of DLR technology. See Figure 1.

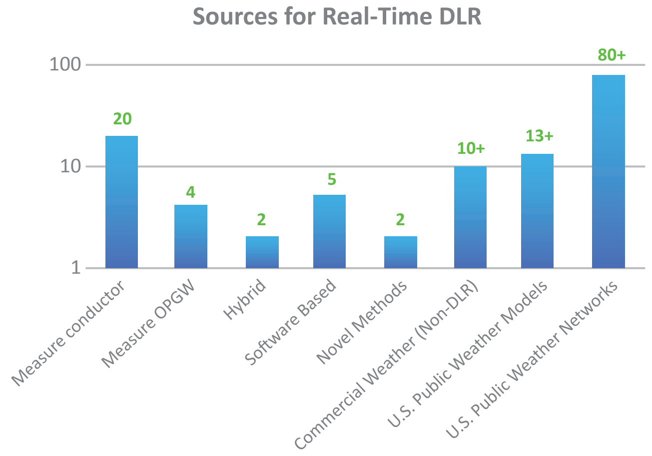

Figure 1. *Examples of DLR methodologies*
OPG = optical ground wire

By better understanding the existing experiences and the newest lessons learned, the industry can better determine where to focus efforts to close the remaining knowledge gaps.

EPRI is addressing DLR as part of ongoing research at an increasing pace. As the focus shifts from the FERC 881 mandated AAR ratings to DLR, increased understanding and confidence in these technologies will be needed. These efforts will include capturing experience from field trials and test results from laboratory evaluations, developing workflows, updating tools to determine when DLR is the optimum solution (vs. a traditional upgrade), and improving methods to find the key locations to deploy DLR.

BENEFITS AND USE CASES

An ideal DLR provides the most precise and accurate representation of the total transfer capacity of a circuit. When the rating and line loads are well defined, models and digital twins of asset health, line clearances, and other factors also become more precise and may be used to inform risk management and public safety power shutoffs (PSPS). Although there is no truly perfect DLR, the technology has many scenarios where it can be applied safely to address utility challenges with congestion, load growth, and new generation mixes. Some studies suggest that combining DLR with advanced power flow controllers (APFC) provides increased benefits of line congestion relief.

A high-value use case for DLR is as a bridge technology to relieve congestion while new or upgrading transmission line projects with long-lead times are implemented—for example, reducing congestion when renewables or a large load, such as a data center, connects to the grid (see Figure 3). Although DLR may not relieve all the congestion all the time (so traditional upgrades are still needed), the DLR may provide periods of increased capacity—enabling lower cost electricity to flow and reducing congestion costs. Statistically, DLRs have higher (annual average) ratings than traditional seasonal ratings at the times when renewable generation output is also high

In some circumstances, if small capacity gains are needed, DLR can be competitive with traditional upgrades or used to defer construction projects until the demand is beyond what DLRs can provide. This extra time can be particularly valuable as supply chain continues to extend the time required for upgrades and new lines beyond what are historically experienced from regulatory and permitting issues.

IMPLEMENTATION AND INTEGRATION

Prior to undertaking the significant effort of integration—for example, communications, software upgrades, cybersecurity compliance testing, training, and other factors—it can be prudent to ensure that there is a sound technical basis for a DLR selection. Lab and field testing can help ensure that a DLR system can provide the gains expected and the reliability needed and be accurate enough for safe and efficient operation of the grid. If a technology has performance challenges in a laboratory or field trial study, the time and costs associated with implementation can be avoided.

As part of the transition to hourly AAR and FERC 881 adoption, in the United States, most utilities and their respective independent system operator/regional transmission operator (ISO/RTO) will have the ability to manage frequently changing ratings. These efforts will ease the transition to DLR in operations, planning, data management, and so on. Despite the benefits of increased capacity, DLR adds uncertainty and variability to the system parameters that must be considered in operations. Different types of operational studies are performed over a wide time frame—ranging from days to years—to assess system reliability, determine the operating procedures to mitigate possible adverse effects, and to plan outages. Because DLR-based ratings are largely weather dependent, they are volatile and change rapidly, potentially requiring extra safety margins in operations to mitigate risks. Confidence levels could be introduced into the DLR calculation to rate lines more conservatively when confidence levels are low.

In long-term transmission expansion planning, the line ratings considered in the system studies may significantly impact the determination of transmission expansion needs and solutions. If DLR will be considered in expansion planning, a methodology to determine the line rating values to use in the system studies is necessary. The methodology should properly assess the selected rating values' reliability risks and investment implications. One approach could include improving seasonal ratings with new studies of weather conditions in a specific region and assessing the risk sensitivity of assets and designs in that region. This can allow long-term projections of capacity with a better understanding of uncertainty and risks.


Integrating large loads like data centers

Relieving congestion while new or upgrade transmissions are constructed

Reducing congestion and integrating renewable generation

Figure 2. *Areas where DLR can provide value*

AREAS FOR ONGOING STUDY TO IMPROVE THE BODY OF KNOWLEDGE ON DLR IMPLEMENTATION

One barrier to DLR adoption is the lack of broadly shared technical results from pilots and deployments. By conducting independent third-party evaluations and disseminating these results, electric companies can be better informed of the technical basis for DLR, accurately evaluating the benefits and reducing risks. The expected benefits appear widely known but potentially misunderstood—particularly given recent changes in operating practices in many regions. Often the available capacity gains are provided relative to a static rating that is no longer in use as utilities move toward AAR and, in the United States, FERC 881 adoption.

Developing a common approach to test and validate DLR can simplify technology selection processes rather than comparing individual field pilots where different approaches are taken. For example, comparisons between technologies are difficult if gains from DLR are cited based on measurements at a small number of locations that do not always reflect the limiting elements in a circuit and do not account for limits such as voltage drop and system stability. It is also challenging to compare evaluations that use data that do not reflect the conditions in the right of way, such as from a nearby airport, as evaluation criteria. At the same time, it is important to quantify when DLR reduces line ratings. Field pilots (including those implemented with and without EPRI collaboration) have shown that in a significant number of cases, the DLR is lower than the traditional ratings 20–40% of the time because of wind sheltering along lines. To correctly set up a DLR pilot, it is important to consistently define the number and location of data collection points. Failure to do so can bias the results.

Operational areas of study could include weather forecasting necessary for various operational needs such as outage planning, generation scheduling, evaluating potential rating safety margins to mitigate risks, and applying ratings smoothing techniques. Operators can benefit from a having a deeper understanding of best practices for implementing DLR, guidance on scaling up from pilots/small-scale projects, and updated training available to manage the volume of DLR data and the speed at which DLR change.

EPRI's Grid-Enhancing Technologies for a Smart Energy Transition (GET SET) initiative proposes to prioritize the following research and development (R&D) activities to improve the body of knowledge on DLR (see Figure 3):

- Develop a common framework for DLR specification and evaluations
- Perform laboratory testing simulating as many parameters as possible in a short time to accelerate learning
- Develop methods to assess critical span identification and sensor coverage area
- Conduct well-instrumented full-scale field trials
- Evaluate combining GETs for added benefits
- Evaluate the impact of DLR uncertainty on operational processes and studies such as day-ahead power flow and contingency analysis, outage coordination, Volt/VAR control and stability
- Study the market impact of DLR system uncertainty, errors, and outages
- Assess how DLR may change transmission planning strategy
- Demonstrate the expected benefits of DLR compared to new AAR when uncertainty and risk controls are in place

Figure 3. *Roadmap to successful DLR deployment*

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About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

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