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Enhanced Economic and Operational Advantages of Next Generation Dynamic Line Rating Systems

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SUMMARY

The traditional operational limits of a transmission line are established through "static" transmission line rating methodologies based on very conservative weather assumptions. Today, seasonally adjusted ratings (SAR) and ambient adjusted ratings (AAR) push upward a line's traditional static rating by simply acknowledging that more realistic environmental conditions exist. Dynamic Line Rating, or DLR, is a transmission line's actual real-time or forecast power carrying capacity and is the natural and logical extension of the seasonal and ambient adjusted ratings trend. Yet while DLR provides many operational and planning opportunities, it is sparsely deployed. This is largely due to previously weak economic rewards in the deregulating transmission environment, and that first generation DLR systems presented numerous issues to early adopters.

Dynamic line rating, in the face of today's transmission challenges, can produce demonstrable economic benefits. DLR is an exceptionally cost effective and time efficient means of advising operations of actual available or forecast capacity. Typically revealing 10-25% additional capacity, this is an effective alternative to upgrading and uprating existing transmission lines to increase power transfer capacity over existing infrastructure. This approach has the further advantage of utilizing existing right-of-way (ROW) corridors. Widely deployed DLR is also an effective means of enhancing grid resilience. Energy trading can be enhanced by DLR by reducing congestion, or employing DLR as a non-transmission asset.

Next generation DLR addresses the shortcomings of first generation DLR systems. This includes the use of directly measured key parameters such as clearance-to-ground, rather than monitoring other parameters (such as tension or sag) and then estimating the related key parameter. Next generation DLR systems now use line monitors that are self-contained, encompassing auxiliary power, communications, and all measurement sensors. These monitors also eliminate the need to de-energize the lines and make expensive modifications to transmission towers.

Compared to previous systems that provided primarily instantaneous DLR values, next generation systems now produce a variety of more actionable ratings including hours to days ahead forecasting.

KEYWORDS

Dynamic line rating, forecasting, non-transmission asset, resilience, transmission line, static rating

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What is Dynamic Line Rating?

The traditional operational limits of a transmission line are established through "static" transmission line rating methodologies. The common practice for transmission line rating is to select very conservative values for the environmental operating conditions of the line. The resulting static line rating is similarly very conservative.

Static transmission line rating methodologies are dependent on several environmental variables identified in IEEE standard 738 [1] and CIGRE brochure TB 207 [2] . These variables are related to the amount of heat generated in the line (resistance and current), heat being added to the line (solar radiation), and heat being removed from the line (convective and radiated cooling). The standard practice for transmission line rating is to select conservative values for these environmental variables which are fixed, and that equate to a low probability that conductor sag will exceed operational or regulatory limits for a very short duration. This methodology directly acknowledges that operational limits of transmission lines are conservative most of the time.

Today, seasonally adjusted ratings (SAR) and ambient adjusted ratings (AAR) push upward a line's traditional static ratings by simply acknowledging that different environmental conditions exist at different times of the year. Dynamic Line Rating, or DLR, is a transmission line's actual real-time or forecast power carrying capacity. It is based on the conductor's operating temperature using real-time line behavior data and weather conditions. Dynamic Line Rating (DLR) is the natural and logical extension of the seasonal and ambient adjusted ratings trend. [3] Why assume a line has only four ratings a year based on seasons when real-time data and line behavior modeling can provide reliable daily or even hourly ratings? This is especially significant as a line's DLR is typically 10 - 25% higher than its static rating.

Numerous studies have shown this additional capacity provides opportunities in economic dispatch, trading, operations, and congestion mitigation. Application of DLR is also a powerful tool for improving contingency planning, cost effectively addressing lines with slow load growth, and deferring or eliminating the need for line upgrades or reconductoring.

Yet with all these economic advantages, DLR is sparsely deployed. The reasons are two-fold. Demand drivers typically showed weak economic rewards in the deregulating transmission environment, and first generation DLR systems presented numerous issues to early adopters, discouraging wider deployment.

DEMAND DRIVERS FOR DYNAMIC LINE RATING ON THE MODERN GRID

Pressures on today's transmission grid come from many corners, but key topics such as competitive bidding, utility scale renewables, impact of the Clean Power Plan, the proliferation of distributed energy resources (DER), and non-transmission assets (NTAs) to alleviate congestion, underscore new opportunities that next generation DLR may address. Dynamic line rating, in the face of these drivers, can produce demonstrable economic benefits.

Reduced Budgets and Time Constraints

One of the well documented challenges for the power industry is the need for increased transmission line capacity with either existing or new infrastructure. However new transmission projects are faced with many challenges that often combine to stretch project timelines to ten or more years.

Therefore, upgrading and uprating existing transmission lines is often the preferred approach to increasing power transfer capacity over existing infrastructure. This approach has the further advantage of utilizing existing right-of-way (ROW) corridors, which are increasingly hard to obtain. Yet traditional reconductoring involves time and considerable investment. In comparison:

- DLR can provide 10 – 25% additional line capacity for a very small fraction of the $1 million to $8 million cost per mile of reconductoring [4]. It can be deployed quickly and becomes fully operational within days of installation.
- Slow-growth lines encroaching on their static ratings are even more difficult to justify upgrading. DLR is an ideal least-regrets approach to addressing such capacity shortfall. [5]
- Installation of large-scale renewables and distributed energy resources can tax lines that may not have been challenged even a few years ago. DLR can address these issues quickly and inexpensively, even if only as a short-term measure until a larger scale project is engineered and approved.

Energy Trading Opportunities

The ability to accurately forecast higher levels of transmission capacity present many opportunities for energy trading.

- Additional capacity allows for higher levels of trading.
- The additional capacity provided by DLR can relieve the congestion that results in congestion charges. If this congestion is regularly and consistently relieved, DLR may also reduce or defer the need for line upgrades or new construction.
- The capacity above static that DLR reveals could be considered a new, virtual parallel transmission path. In this light, DLR can be viewed as a non-transmission asset where any power transmitted down this virtual path could be monetized. [6]

Grid Resilience

Grid resilience is a key operational topic for utilities today. How can DLR improve grid resilience? Should one or more substations or transmission lines be lost to natural or man-made calamities, a resilient grid must be able to provide alternate transmission paths around the damaged portion of the grid. Alternatively, a generating facility forced off-line during peak load periods may require the utility to push additional power across lines that may already be heavily taxed. The ability to deal with either scenario is dependent on the capacity of those transmission lines still in service. In this case next generation DLR with reliable hour(s)-ahead to day(s)-ahead forecasting can provide both short- and medium-term "emergency-equivalent" ratings for all remaining in service lines.

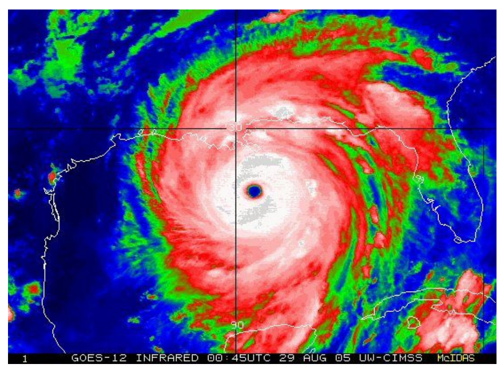

Figure 1:A resilient grid is critical to address natural and man-made calamities

As an additional consideration, uprating lower voltage lines for marginal contingency scenarios is often difficult to justify economically. DLR is a cost effective means to address line capacity upgrades where the economic case for normal contingency scenarios is difficult to make. [7]

Increased Competitiveness for New Line Construction

Competitive bidding on transmission line projects in the US and Canada can also be enhanced by next generation DLR. When DLR is integral to a line's design, this additional capacity may be included. Savings would follow from a variety of sources including the use of a less expensive, smaller conductor. The lighter conductor loads may allow the use of lighter, less expensive line hardware and towers.

Lighter towers and conductor loads may extend to less expensive foundations which may reduce construction cost and installation time.

This may provide an additional advantage to incumbent utilities. Installing DLR proactively on existing lines will provide an incumbent utility a history of operational DLR data and the additional capacity identified by the DLR deployment. When included in a competitive proposal this data offers strong rationale supporting the use of the additional DLR capacity as a base of the line design. While this logic could be used for any company submitting a proposal, the incumbent utility operator may have an advantage of validating the additional DLR capacity on their own system under the same climatic conditions which the proposed line may be constructed. [8]

ISSUES WITH FIRST GENERATION DYNAMIC LINE RATING SYSTEMS

First generation DLR systems all shared shortcomings which could be divided into three categories; unusable data, installation complexity, and dependence on indirect measurements.

Usable Data

- First generation systems provided only instantaneous DLR information in the form of a graph. By nature, DLR changes constantly, appears quite erratic, and is not practical for real-time operation. See Figure 2. This is because instantaneous DLR changes based on rapidly varying parameters such as wind speed, precipitation, and cloud cover. As most DLR benefits are actually dependent on knowing the DLR in the future, real-time only DLR is of limited value.

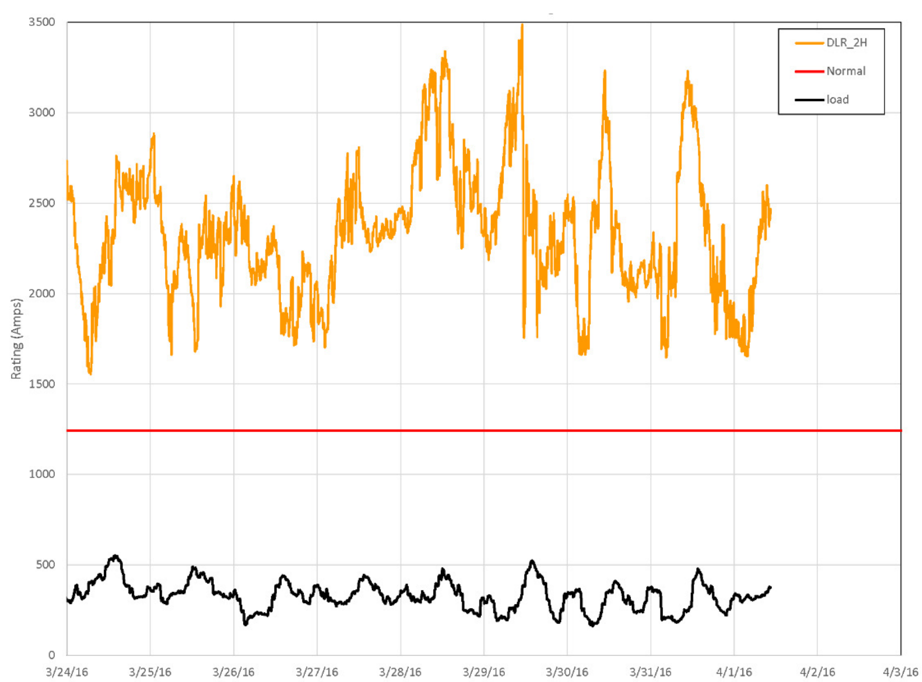

Figure 2: Dynamic Line Rating Chart. Upper line is instantaneous DLR which changes constantly, limiting its usefulness. Straight line is the static rating. Lower line is actual line current. (9-day period shown)

- Data was often processed by the DLR provider with minimal information being provided to the utility. The lack of underlying data transparency often led to a lack of confidence in the resulting rating.

Complexity Issues

- Some line sensors used by early DLR systems required the line to be de-energized during installation [9], and even required tower modifications to properly fit the sensor to the line. This approach introduced significant costs.
- Solar-charging: DLR sensors often communicated through battery-powered radios recharged via solar panels. A few days of cloudy or stormy weather, snow buildup, or even bird droppings could interfere with proper charging. As DLR requires continuous data feeds, the result was data dropout and compromised DLR system operation.
- Remote Installation: Optimized DLR systems often require monitoring of spans in remote or unpopulated locations, not close to existing communication infrastructure. This limits the practicality of cellular communications.
- Complex Installation: Radio systems require proper antenna positioning and alignment. Connection of line mounted sensors and stand-alone weather stations increased installation complexity.

Indirect Measurements

Accurate DLR depends on accurate and meaningful real-time data. Physical conductor data (current, temperature), spatial data (conductor clearance-to-ground), and weather are the most important parameters. First generation systems variously fell short in one or more of these areas. [10]

- Physical conductor data was either not monitored on the actual conductor (e.g. current was measured at a remote substation), or was simulated (e.g., using nearby thermal replica devices).
- As conductors heat, they expand and sag, affecting conductor clearance-to-ground. Early systems used quantities such as tension, vibration, or optical sights to estimate sag. This was then used to obtain clearance estimates from look-up tables or standard formulas.
- Local weather stations were often used for accurate real-time weather data, but these stations could not provide forecasting.

NEXT GENERATION DLR ADDRESSES FIRST GENERATION ISSUES

Next Generation DLR systems have evolved to address all these shortcomings, resulting in systems which are simple to install, transparent in their ratings, and most importantly, usable and actionable. Using this system as an example, next generation DLR systems provide:

Figure 3: Self-contained next generation DLR conductor monitor with built-in magnetic field harvesting power supply, communications, LiDAR, current sensing, and temperature sensors.

Meaningful Data

Conductor behavior data can now be continuously collected by self-powered, line mounted monitors that can measure critical data directly. This can include conductor current, conductor temperature, ground temperature, conductor vibration, and the actual conductor-to-ground distance measurement via built-in LiDAR. The latter eliminates the need for sag estimations. The sensor also monitors ground temperature and conductor vibration. See Figure 3.

Simple Installation and Communications

Simple live-line installation and built-in satellite radio addresses numerous issues. Most importantly:

- Next generation conductor monitors may be installed on energized lines up through 765kV. Power supply and communications are self-contained. See Figure 4.

- Some next generation monitors include built-in satellite radio, providing the ability to communicate the monitored data from any transmission span, regardless of location. This eliminates the need for additional or nearby communication infrastructure or equipment. The satellite radio also provides unique security as the radio is built-in to the sensor and transmits only non-operational, measured data directly to the DLR software.
- Self-powered devices require no battery or external power source, eliminating a major cause of maintenance. The unit shown in Figure 3 and Figure 4 harvests power from the magnetic field of the conductor, eliminating the need for external connections. This particular design has been operating in various environments without event for over 5 years; its life expectancy is greater than twice this time.

Figure 4: Next generation DLR line monitors can be installed live-line up through 765kV.

Actionable Ratings

Next generation systems use the line's instantaneous dynamic line rating as a starting point, not the end result. Next generation DLR eliminates the continuous variability of first generation DLR and provides power line capacity ratings and forecasts that are easy to interpret and act upon in the control room, on the trading floor, or at an engineer's desk.

Some systems also actively learn the line's behavioral characteristics, as it relates to weather and loading conditions. This eliminates reliance on standardized formulas. [11] Combined with real-time data using reliability-based rating and forecasting techniques, next generation DLR systems can provide ratings with 98% or greater equivalent confidence factors.

Next generation DLR systems provide a variety of ratings. See Figure 5.

- Next generation DLR is more useful than previous DLR ratings thanks to actionable clearance data. Systems using monitor's built-in, LiDAR-based, clearance-to-ground measurements produce ratings which obey clearance compliance limits in addition to traditional thermal limits.

The result is the line's maximum instantaneous current carrying capacity which ensures clearance requirements are not violated, while also eliminating the risk of conductor thermal damage.

- Reliability based ratings are statistically stabilized DLR ratings which act as a reduced-risk static line rating alternative. This rating is designed for operators to ensure the transmission line is operating over time within both clearance and thermal parameters. [12]
- Reliability based forecast ratings are reliability based ratings adjusted for forecasted future weather conditions. These ratings are tailored to address day(s) ahead energy dispatch and trading needs. [12]

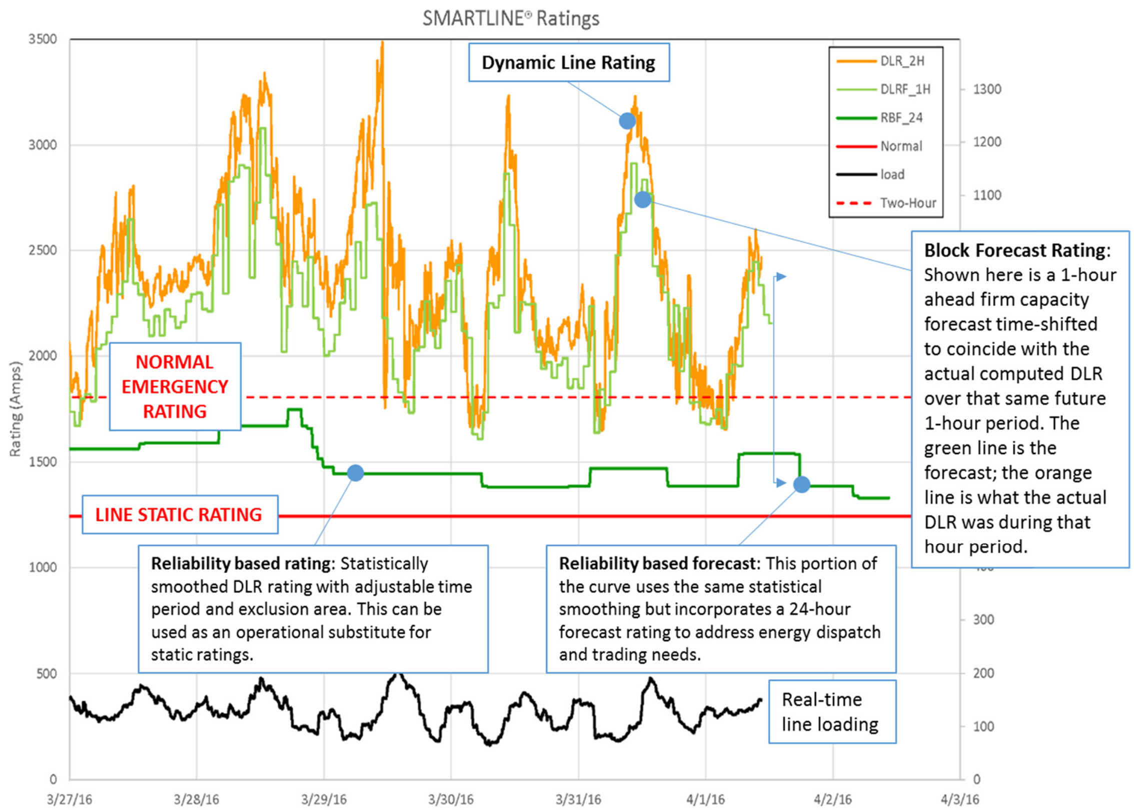

Figure 5: Next Generation DLR provides a full suite of ratings and forecasts. Presented here graphically, the data is supplied as discrete ratings to the EMS system. [13]

- Most recently, one supplier has introduced block forecasted DLR which is a forecast DLR value good for a fixed period of time (say one or two hours) based on forecasted weather conditions. That is, a 2-hour rating issued at 1pm will provide a fixed line rating capacity that is good until 3pm (a two-hour window). A line could be confidently operated up to that limit during this time without violating its thermal limit or clearance. [13]
- Typically, real-time streaming data views of all measured line parameters is also available for engineering purposes.

SUMMARY

Next generation dynamic line rating systems can now provide utilities with meaningful, actionable transmission line capacity forecasts and ratings. Compared to first generation systems, the required monitoring equipment is simple and easy to install, and communications are reliable and maintenance free. The diverse needs of today's transmission operators and dispatch authorities require additional transmission capacity from existing assets, but this capacity must be known in advance, not in real-time. Next generation DLR with its advanced capacity forecasting meets this need.

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