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Dynamic Line Rating Integration in Transmission Networks – Benefits and Challenges

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SUMMARY
Load growth and generation developments, such as the integration of renewable and distributed energy resources, are motivating the need for improved operations and more efficient usage of transmission line capacity. One solution for improving the efficiency of power line utilization is real-time monitoring of transmission line capacity. Dynamic line rating technology enables the utilization of additional transmission line capacity that is available on the network under favorable ambient weather and wind conditions. This paper presents an overview of two real-time monitoring technologies deployed on National Grid's transmission network in Rhode Island. This paper evaluates the potential benefits and challenges faced in implementing this technology.

KEYWORDS
Dynamic Line Rating, Line Monitoring, Static Line Rating, Transmission line clearance/sag and Thermal capacity

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1. INTRODUCTION

The ability of a transmission grid to survive system disturbances without causing blackouts is defined as grid reliability [1]. To maintain transmission system reliability, it is important not to exceed the thermal and voltage limits of transmission lines, transformers, and other transmission equipment. Exceeding the thermal and voltage limits of transmission equipment increases the risk of damage to the equipment, thereby reducing system reliability.

There are four different types of transmission line ratings: static line rating (SLR), seasonal static line rating (SSLR), dynamic line rating – ambient adjusted rating (AAR), and day-ahead and real-time dynamic line rating (DLR) [2]. Static line ratings are transmission line ratings that do not change with time. They are calculated using conservative values of local weather conditions, such as wind speeds and solar irradiance, and the conductor's maximum temperature (T_c^{max}) [3] [4]. Typically, transmission lines have four SLRs: Normal rating (continuous), which is used during system intact conditions, long-term emergency (30-minute rating), short-term emergency (15-minute rating), and drastic action limit (5-minute rating) which is used under post-contingency conditions [2]. Seasonal ratings include summer and winter ratings for transmission lines, based on assumed ambient temperature for each season [2]. AARs change more dynamically compared to seasonal or static ratings because they use the weather conditions to calculate the line rating. Thus, these ratings are higher than SLRs [2].

DLR technology computes the line ratings by using sensors to measure real-time or forecasted local weather conditions, such as solar irradiance, wind speed, tension, and sag. The advantage of using DLR is the ability to utilize the higher transmission line capacity when weather conditions are more favorable, while also complying with limitations, such as maximum conductor temperature and the most limiting element [5]. Similarly, when the weather conditions are not as advantageous, transmission line ratings can be determined more accurately. This helps to stay within the thermal limits of lines while also using the line capacity more effectively and efficiently [6].

DLRs can help system operators relieve congestion on transmission lines and increase grid reliability by providing more accurate estimates of real-time line capacity [7]. Utilizing the dynamic ratings of transmission lines, instead of the static or seasonal ratings, during times of high congestion or when system disturbances occur, may provide an increase in transmission line capacities, thereby helping manage the congestion or contingency situation more effectively. By coupling the line's electrical, thermal, and inertial behavior, DLR brings significant operational flexibility [8] [9]. This contributes towards improved system reliability [4] [7]. DLR can provide a more accurate rating for the lines' power capacity that can be used in day-ahead and real-time operations and markets. When the wind speed increases, the dynamic line rating of a transmission line increases above its SLR, seasonal rating, or AAR. Similarly, increased wind speed also results in an increase in the output of wind turbines. Thus, employing DLR on transmission lines may help accommodate additional wind generation output due to the increased capacity available on the lines [7].

Multiple transmission operators around the world have already started to study the impact of DLR on their systems, such as pilot projects by the Texan utility Oncor, and the New York Power Authority (NYPA). Oncor's DLR pilots were installed on eight transmission lines, rated 138 kV and 345 kV [2]. The DLRs were integrated into ERCOT's economic dispatch tool for use in real-time system operations [7]. Their DLR deployment found a correlation between an increase in the monitored transmission circuits' ratings and a relative increase in wind generation. The project observed a 6 to 14% increase in real-time rating over ERCOT AARs, excluding periods during which DLRs were lower than AARs, outages, or errors in the data [2]. NYPA's DLR project installed sensor technology from the Electric Power Research Institute (EPRI) on three 230 kV transmission lines [2]. The measured conductor temperature, weather conditions, and conductor sag were used to compute dynamic line ratings. This DLR was used to assess the feasibility of using the computed ratings for use in engineering, and operations. NYPA also sought to study how increased wind generation and increased dynamic ratings are correlated. NYPA's project demonstrated that static ratings were about 30 to 44% lower than the calculated dynamic line ratings.

National Grid, a transmission owner in the New England and New York regions, has also started to study how DLR can positively impact its system operations. Over the past few years, the State of Rhode

Island has sought to develop clean energy resources through three separate large-scale procurement efforts, totaling 1,190 MW [10]. There are 880 MW of offshore wind projects proposed in the State's interconnection queue [11]. ISO New England is currently working on two Economic Study requests (in accordance with Section 4.1(b) of Attachment K to Part II of the ISO-NE Tariff), that are looking at the impact of 8 to 12 GW offshore development off the coast of Rhode Island, Massachusetts, and Connecticut, in the 2030 - 2035 timeframe. [12] [13]. With this increased penetration of intermittent DER, National Grid is faced with new challenges related to more efficiently utilizing the grid infrastructure while maintaining system reliability. This is particularly true for areas with high wind generation where unpredictable increases in output of wind farms is correlated with increased indirect cooling effects on the lines [14].

Considering these large "wholesale" changes facing its transmission infrastructure, National Grid researched several technologies to integrate more renewable generation, while reducing the cost to serve the customers. National Grid seeks to improve asset management decision making, reduce asset operation expenses, enhance system resiliency, and improve outage restoration through the implementation of DLR technology. This paper details the dynamic line rating real-time monitoring technologies that were installed in National Grid's electric service territory in Rhode Island in 2019.

The rest of this paper is organized as follows: section 2 summarizes the physics of Dynamic Line Rating, section 3 describes the National Grid project, section 4 evaluates the DLR technology implemented on National Grid's transmission lines, potential benefits, and challenges that were faced. Section 5 summarizes the key results.

2. Physics of Dynamic Line Rating

IEEE 738 is an IEEE standard for calculating the current-temperature relationship of bare overhead conductors. This standard defines a numerical method that relates the core and surface temperatures of a bare conductor to electrical current and weather conditions. This method also could calculate conductor current limits to stay within temperature restrictions. [15]. Based on IEEE 738, the rate of change in temperature of a conductor, *k*, is calculated by the following heat balance equation :

$$mC_p\dot{T}_k(t) = Q_k^{sun}(t) + Q_k^{loss}(t) - Q_k^{conv}(t) - Q_k^{rad}(t) \qquad (1)$$

where T_k is the temperature (°C) of conductor *k*, mC_p represents heat capacity per unit length of the conductor [J/m-°C] and Q_k^{sun} is the rate of energy gained by solar heating. The solar heat gain rate is not dependent on temperature and is a function of the position of the sun with respect to the conductor and time of the day. Moreover, $Q_k^{loss}(t)$ is the rate of active power loss per unit (W/m), and can be expressed in terms of current flows through the line as $Q_k^{loss}(t) = RI(t)^2$. Q_k^{conv} is the heat loss from convection (i.e., convective heat loss), which is related to conductor temperature, ambient temperature, and wind speed and direction (i.e., effective wind). Q_k^{rad} represents the rate of heat lost by radiation [16].

Static rating employs a set of conservative assumptions for certain physical parameters to determine $Q_k^{\mathrm{sun}}, Q_k^{\mathrm{conv}}$, and Q_k^{rad}, such as [17]:

- Effective wind speed is fixed to 2 ft/s (0.61 m/s),
- Q_k^{sun} is fixed and determined based on a sunny summer day,
- Ambient temperature is set to 40°C summer air temperature,
- Lines and air constant parameters are independent of the temperature of the conductor.

Determining the maximum allowable temperature of conductor *k*, T_k^{max}, helps in satisfying the minimum clearance requirements by limiting sagging. This helps meet the expected lifespan of the conductor and avoids premature aging. At steady state, the total input heat to a conductor must be equal to the output heat. The ampacity of the line, based on equation (1), can be shown as :

$$(\boldsymbol{I_k^{max}})^2 = \frac{1}{R}\left(\boldsymbol{Q_k^{conv}} + \boldsymbol{Q_k^{rad}} - \boldsymbol{Q_k^{sun}}\right) \qquad (2)$$

where $Q_k^{\mathrm{sun}}, Q_k^{\mathrm{conv}}$, and Q_k^{rad} are chosen conservatively.

The steady-state thermal rating is calculated based on the current ampacity and the base voltage, V_b, as follows:

$$S_k^{max} = \sqrt{3} V_k I_k^{max} \quad (3)$$

DLR provides the real-time power capacity of the transmission lines by measuring the operating conditions without having to employ overly conservative assumptions of $Q_k^{\mathrm{sun}}, Q_k^{\mathrm{conv}}$ and Q_k^{rad} [18]. There are two types of dynamic line ratings, primarily those that use ambient adjusted ratings and those that use real-time monitoring. The AAR is computed using real-time ambient temperature values, while the RTM uses both the real-time temperature monitoring as well as the effective perpendicular wind speed to compute the dynamic line ratings.

For cases where the real time effective perpendicular wind speed is higher than the assumed wind speed used to compute the AAR, it can be concluded that the AAR line rating calculated would be lower than the RTM rating. This is because the computed AAR Q_k^{conv} would be lower than the RTM. Since in the case of RTM, the actual heat dissipated through convection is higher than in the case of AAR, the current carrying capacity of the line would be higher than the AAR value.

3. Introduction to National Grid' deployment

3.1 Business Needs

Dynamic line ratings have the potential to improve operations by allowing the transmission system to be efficiently utilized in the real-time and day-ahead operation. The planning criteria, informed by either static line ratings, seasonal line ratings, or ambient adjusted ratings, sets limits on the transmission system's capacity. These limits are not reflective of the actual weather conditions or wind speed experienced by the conductor, which may permit higher current to be safely carried by the conductor.

Dynamic line rating technologies also have the potential to address congestion management on the transmission system by improving the accuracy of forecasting and congestion estimates. Congestion on the electrical network occurs when power demand or power generation exceeds the physical capacity of the network, which forces dispatch decisions that deviate from the lowest-cost approach and increases the price of electricity [19]. These congestion costs can be large, with ISO-NE reporting $44M of congestion charges in 2019, and NYISO reporting $596M of congestion charges in 2018 [20], within the regions that National Grid operates. Dynamic line rating technology can be used to predict a transmission line's actual capacity (which may be greater than the static line rating) days ahead. This insight can allow more favorable commitment of generators in the day-ahead markets to reduce congestion costs and the overall efficiency of the market.

3.2 National Grid Project

There are many different commercially available technologies for monitoring overhead transmission lines for forescasting real-time ratings. These technologies generally come with auxiliary equipment, such as communication devices (e.g. modems or antennas), solar panels and batteries, and supporting electronics devices. The purpose of these technologies is to provide the real-time measurements of ambient weather and wind conditions needed for real-time and forecasted rating calculations.

Seeking to explore the advantages of DLR technologies, National Grid field-tested two technologies (Tech A and Tech B) to monitor two overhead transmission lines. The lines identified for this project were two 115 kV lines in Rhode Island, which both run approximately North-South. The engineering information for the selected monitored lines is presented in Table 1.

Table 1: Monitored overhead Lines specifications

Parameter	Line 1	Line 2
Design tension/sag @ 15.6°C	~5783 N	~5783 N
Conductor in-service date	1924	1926
Conductor code name	477 ACSR PELICAN	477 ACSR PELICAN
Sag / Clearance limit	110°C	110°C
Max operating temperature	100/110°C	100/110°C

Overview of Tech A

The monitoring sensors of Tech A were installed in July 2019 for continuous monitoring of transmission lines. Shown in Figure 1, the monitoring equipment was mounted on a transmission line structure and uses a combination of patented electromagnetic sensors (EMF) and optical sensors to measure the electrical parameters of the line and the physical position of the conductors.

Fig.1 Photograph of the structure and installed equipment (Tech A)

The monitoring system provided by Tech A calculates the real-time and forecasted line ratings, based on the conductor temperature, and local weather conditions. This technology uses sensors that collect EMF data and monitor the physical position of the transmission line, and feed the collected data into an analytical model to determine the line temperature, clearance/sag, and the DLR. National Grid is also provided with log-in credentials to review real-time, forecasted, and historical monitoring data via a secure cloud interface and graphical dashboard which provides data visualizations and data export capabilities. The provided dashboard displays changes in dynamic ratings, actual line loading, and conductor/ambient temperatures over the course of a few days.

It should be noted here that in December 2019, National Grid, in coordination with the developer of Tech A, modified the housing of the optical sensor from being enclosed to being exposed, which did not require any modification to the original electronics components. By exposing the sensor, the visibility of the conductors was improved, and the sensor's accuracy increased while its power consumption decreased.

Overview of Tech B

In addition to Tech A, an alternative, Tech B, was also deployed by National Grid to provide a complete picture of conductor behavior, including actual conductor clearance-to-ground, conductor temperature, and line current. This technology consists of a conductor mounted system, shown in Figure 2. Instead of using ancillary measurements to infer sag and clearance, this technology provides actual measured clearance-to-ground distance.

Fig 2. Photographs of the installed equipment (Tech B)

This technology measures the distance of the nearest object to the conductor using an on-board LiDAR sensor providing line clearance measurement (+/-0.3% at 40m) regardless of tower or insulator sway or other line conditions. Unlike static ratings and other systems that compute DLR based on sag estimates and inferred clearance estimates, this technology directly measures conductor clearance and can accurately (+/- 1%) determine the transmission line's ampacity.

Tech B also includes a dashboard interface to display the measured, calculated and forecasted parameters and create data reports.

4. National Grid Project Evaluation

4.1 Benefits

Day-ahead Forecasted Ratings:

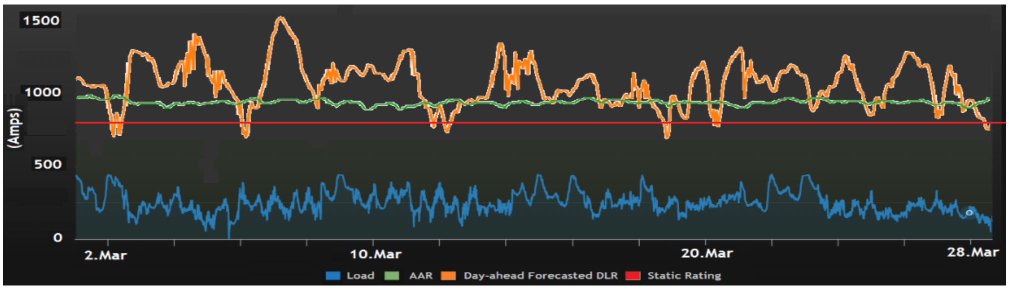
The static line rating (SLR) is determined based on conservative assumptions about the operating environment of the transmission line, and does not account for the actual ambient conditions, such as tangential winds that cool the line. These environmental assumptions represent the worst-case scenario (i.e. no wind, maximum ambient temperature, hottest midday sun), so there may be instances when the maximum safe rating is higher than the SLR. Seasonal static line ratings (SSLR) are an improvement on static line ratings that apply a different maximum capacity based on the time of year, recognizing that ambient temperatures are lower in the northern hemisphere in the winter. In North America, the summer ratings are applied from May through October and assume 95-100°F ambient temperature. Winter ratings are applied November through April and assume 32°F ambient temperature. As they represent an improvement on the static rating approach, SSLR are more commonly used to set the maximum power rating of transmission lines [2].

As a further refinement on the SSLR, the ambient adjusted ratings (AARs) are ratings that are adjusted daily, hourly, or more frequently to account for ambient air temperatures [2]. Forecasting the ambient air temperature is critical to apply AARs, so transmission owners rely on online weather monitoring services to calculate updated line ratings. For example, in ERCOT and PJM, AARs are implemented using step functions at 5-degree increments (5°C in PJM but 5°F in ERCOT for historical reasons) [2]. While AARs are more accurate than SSLRs, there is an incumbent operational challenge of properly communicating reliable and accurate temperature forecasts to the transmission system operators for the appropriate time horizon. With proper implementation and data validation processes, these human factors can be eliminated.

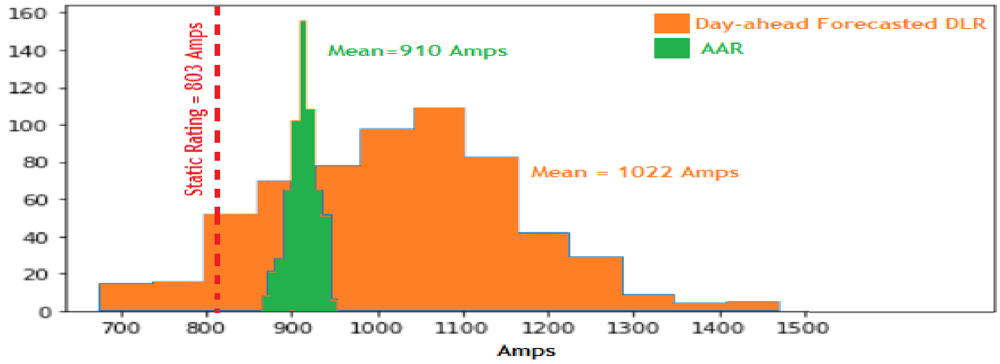
Day-ahead DLR is a generic term for technologies that determine conductor thermal ratings using improved, more finely measured forecast data. Day-ahead DLR methodologies variously incorporate ambient weather conditions, as forecasted from local weather stations, measurements of line tension, photo-spatial measurements of line sag and sensors mounted on, or near, the monitored lines. By combining these input sources, day-ahead DLR can predict a more accurate rating for the lines' power capacity that can be used in day-ahead operation and markets.

National Grid's Experience:

National Grid's experience confirms that the day-ahead DLR forecast shows significant potential for improving the utilization of its lines beyond that provided by existing methods. This experience is based on nine months of collected data confirming that the day-ahead DLR-forecasted line rating exceeds the AAR-forecasted ampere rating for 80% to 85% of the time, as shown in Figure 3.a. This represents a mean increase of 13% in the line's current capacity above what was forecasted using AAR methods (Figure 3.b). This data also confirms that both forecasted DLR and AAR methods predicted the lines under consideration could carry more current than what the assigned static rating would permit, showing their unused potential current capacity. By using actual ambient conditions, DLR technology can compute the forecasted current rating of the line and offer transmission system owners the flexibility to safely load the line beyond its static line rating, should the weather conditions allow it.



(a)



(b)

Fig 3. (a) Day-ahead forecasted DLR vs AAR, Static Rating and Line loading (b) Histogram plot of Day-ahead forecasted DLR and AAR (Average Forecasted DLR compared with Average AAR)

One straightforward way to evaluate the quality of the forecasted line ratings is to compare them to the applicable static ratings and verify their correlation to changes in ambient temperatures or wind. For example, one would expect that when ambient temperatures are lower than the temperature assumed for the static rating determination, the actual line ratings would be higher than the applicable static ratings. Figure 4 illustrates the strong positive correlation (R2 = 0.79) between forecasted DLR and forecasted wind speed. Figure 7 further illustrates the negative correlation (R2=-0.45) between the forecasted DLR and forecasted ambient temperature, as measured by one of the DLR devices, to show the forecasting accuracy of this key input variable. Thus, a critical aspect of forecasting the day-ahead line rating is the use of reliable inputs from the DLR devices, such as forecasted local ambient temperature and wind speed.

Sag/ Temperature Monitoring

In mechanical transmission line calculations, it is assumed that the shape of a hanging conductor is a function of weight per unit length, tension, span length, ambient thermal and mechanical elasticity. Having these parameters, the mechanical state estimation is performed for the determination of length and maximum allowable temperature and sag. However, operation of the conductors at high temperature reduces mechanical integrity and the accuracy of initial estimations over time. In order to overcome these disadvantages, line temperature control and sag monitoring are required.

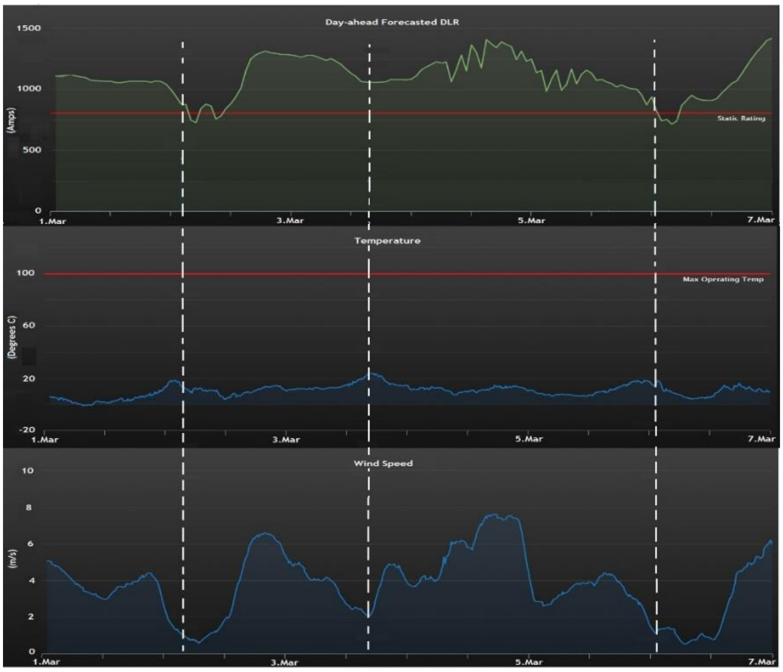


Fig 4. Correlation between Day-ahead forecasted DLR, Ambient Temperature and Wind speed

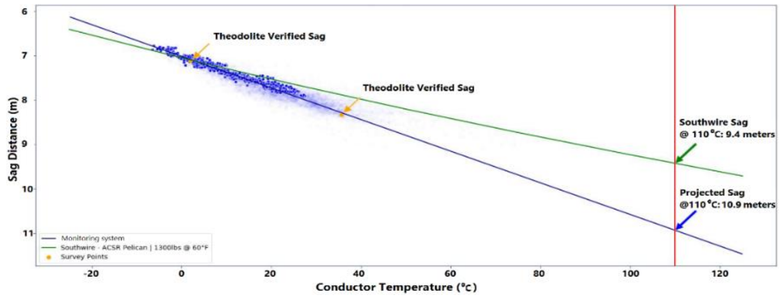


Fig 5. Observed sag/temperature relationship for monitored Line 1

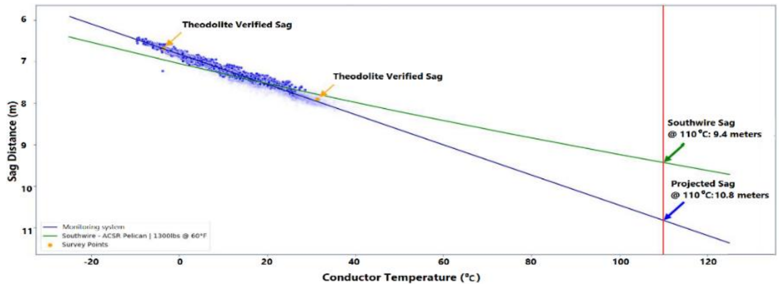


Fig 6. Observed sag/temperature relationship for monitored Line 2

National Grid's Experience:

Since the installation of the monitoring systems in July 2019 and a subsequent calibration period, National Grid has been consistently monitoring the conductor sag to temperature relationship on the target lines. Based upon the available engineering information for the monitored conductors, National Grid observed a discrepancy between the expected and observed sag/temperature behavior of both lines. The monitored data indicates that both lines are exhibiting greater sag variation in response to temperature change than the designed model.

Figures 5 and 6 show the observed sag/temperature relationship for the first and second monitored lines, which are both the Southwire ACSR Pelican design. The sag/temperature relationship for the line based on the Southwire ACSR Pelican model is shown in green in both figures. The sag/temperature scatter plot generated by the monitoring system is used to create the solid blue line. For line fitting, we are using a subset of periods with high confidence when there is no solar irradiation and the line loading is low. These periods are chosen to limit the uncertainty associated with wind cooling. The periods with lower conductor temperature confidence are plotted for reference with a lighter shading but are not used for the line fitting.

In Figure 5, the preliminary data indicates that conductor sag movement is 60% more dynamic than the Southwire models show. For every 10°C change in conductor temperature, Southwire models show about 22cm in sag while the National Grid monitoring system is observing 35cm of sag movement. Projecting these curves out to a T_{max} of 110°C, yields approximately 1m to 1.5m of additional sag versus the Southwire models.

The data is similar at the second monitored line: 37cm of movement for every 10°C change in conductor temperature, which is 68% more than Southwire's 22cm. Figure 6 shows the observed sag/temperature relationship for the second monitored conductor.

The observations presented above confirm that using the monitoring systems may provide a better understanding of how the mechanical integrity of overhead transmission lines changes over time, thereby helping to manage critical situations more effectively.

1.1 Challenges

DLR and the Electricity Market

Although DLR technologies can help utilities make day-ahead and real-time markets, as well as operations, more efficient, further exploration in two key areas is necessary before DLR technologies can be fully employed by utilities. Firstly, transmission owners and independent system operators (ISOs) need the correct tools and procedures to dynamically rate and redispatch in real-time, while ensuring reliable grid operation. Secondly, DLR impact on the real-time and day-ahead markets needs to be fully assessed and proper incentives need to be put in place. Each of these is described in detail below.

To develop accurate system models and maintain the reliable operation of the transmission system, the timely submission of accurate and complete data is critical. It is the responsibility of the transmission owner (TO) to submit the required NX-9 data for all high-voltage overhead lines and transmission equipment. The transmission owners must collaborate with their ISOs in developing rating procedures, establishing ratings for new transmission facilities, and modifying ratings of existing transmission facilities. Considering the complexity of this process, the electric utility industry needs a new and practical model for developing and sharing dynamic ratings and incorporating them in their operating standards.

For the potential economic benefits brought on by DLR of reducing congestion and increasing the efficiency of the existing transmission system to be realized, market rules may also have to be altered. DLR introduces another source of variability in the perceived state of the power system and the market place in day-ahead and real-time time frames. This will impact the clearing of the day-ahead and real-time markets, the value of hedging products such as Financial Transmission Rights or Transmission Congestion Contracts, and regulation or reserve requirements. Once the full impact and benefit to the market is quantified and understood, market rules or other tariff provisions may also need to be modified to ensure that proper incentives are provided to the entities that create additional capacity through the use of DLR.

Cyber Security

Cloud Services and Data Monitoring:

A high priority consideration with DLR technology implementation and evaluation is where the data is stored and how it can be accessed (and by whom). DLR technologies often archive data using a vendor-owned cloud service. While cloud services have security protocols to keep data safe and secure, this method of storing data does open the threat of a cloud service data breach. This could reveal sensitive asset information including line loading and health data, or GPS signals that could allow the hacker to track which utility the line data belongs to. When storing data with cloud services, assets should be labeled with generic names or tags that do not directly identify the utility owner.

A solution to these concerns is to create a private cloud service so that all security protocols could be closely monitored and regulated. With a private data cloud service, the owner could create a VPN tunnel to access the data, and stage data in a series of protective security layers. Determining the most efficient and secure way of accessing the data should be a joint effort between the control center and IT security teams to address all needs.

It is preferable to integrate the EMS with traditional methods of polling the devices from the OT network to monitor the asset and its data. This requires heightened communication between the EMS and the DLR sensors, so the control centers should be actively involved in this integration process.

Penetration Testing:

A common practice with DLR technology implementation is to perform cyber security penetration testing to find any weakness in the technology, software, or data storing/accessing abilities that could be threatened by hackers. Penetration testing involves attempting to hack a software or network to analyze any technical vulnerabilities and report them back to the client or host. This type of testing provides a zoomed-out view of the DLR technology project and implementation to ideally reveal weak points before the technology is fully integrated and deployed. These tests could reveal if data is secure or if it could be easily hackable or manipulated by an attacker. Similarly, penetration testing would reveal if the cloud services and VPNs used to store and access data are truly private and secure. This includes further testing to reveal if a computer program could guess login credentials. Attackers could add software to the modem and could implement a data manipulation attack. Similarly, modems connected with a cellular device could be vulnerable to a hacker gaining access and eavesdropping on the DLR data.

Some DLR technologies may also include a GPS receiver. If hacked, this could reveal which utility owns the DLR technology and data stored within it. If an attacker obtains DLR data (including estimated load) along with GPS data, this could be vulnerable information.

Physical Security:

While increasingly digital technologies present an array of new cybersecurity concerns, standard precautions should still be taken seriously for the physical aspect of the technology. Weatherproof DLR cabinets, when mounted on tower lattices, should be mounted high enough that they are not easily accessible by ladder or climbing. The doors to the cabinets should be locked and monitored by a sensor that alerts the control room when the door is being opened. Also, there should be a procedure in place for how operations will react to alerts of unplanned accessing of the cabinets.

If the physical device houses serial ports, these should be tested during penetration testing to evaluate if an attacker could gain access to the device or its data through a physical connection. Serial ports should require authentication to communicate with the DLR device. Similar to the cybersecurity best practices, multiple failed login attempts through a physical connection should result in a lockout.

Sensors that are physically attached to a conductor should be made secure against unwanted external connectivity. All unnecessary wireless communications should be disabled or removed from the device's capabilities.

Utilities should investigate previous hardware attacks to gauge the risk that they might face by installing new DLR hardware either on a tower or on a conductor. Based on this history, more specific actions may be taken to further secure the asset.

2. Conclusion

The intent of this paper is to explore National Grid's experiences with two dynamic line rating (DLR) technologies installed in National Grid's Rhode Island electric service territory. With increased penetration of renewable generation, National Grid is faced with new challenges related to the more efficient use of transmission line capacity for day-ahead operations. To address this, one of the key aspects is to improve the reliability of the transmission grid by adding more flexibility to the network.

This National Grid project indicates that dynamic line-rating technologies can be considered as a potential solution to reduce the asset operation expenses, and possibly to enhance system resiliency and outage restoration performance. In National Grid's the day-ahead forecasted DLR exceeds the AAR rating for 80% to 85% of the time which represents a mean increase of 13% in the line's current capacity above what were forecast using AAR methods. The evaluation of DLR technologies also shows that by measuring and monitoring the conductor sag to temperature relationship, it is possible to have better understanding of how the mechanical integrity of overhead transmission lines changes over time.

According to National Grid's experience, for DLR technologies to be used in real-time operation and markets, utilities need to update their existing tools to dynamically rate and redispatch the flows on these lines in real-time. Further market tariffs may need to be updated to compensate the utilities for providing additional capacity on transmission lines. Lastly, increasingly digital technologies require further security practices to secure the data against an attack.

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