U.S. DEPARTMENT OF ENERGY | Electricity Delivery & Energy Reliability

Oncor's Pioneering Transmission Dynamic Line Rating (DLR) Demonstration Lays Foundation for Follow-On Deployments

1. Summary

Oncor Electric Delivery Company (Oncor) successfully demonstrated a fully integrated dynamic line rating (DLR) system in its project funded under the U.S. Department of Energy's (DOE's) Smart Grid Demonstration Program (SGDP).[1] The DLR system monitored the real-time capacities of eight transmission lines for use in the daily operations and wholesale electricity market of both the transmission owner and the independent system operator, the Electric Reliability Council of Texas (ERCOT). Oncor demonstrated that the increased grid capacity available from DLR technologies can be practically and automatically applied on a commercial basis. This breakthrough brings the theoretical benefits of DLR into the real world, demonstrating increased reliability,[2] reduced cost of electricity, and improved access to renewable energy. The project's results confirm the high potential and commercial readiness of DLR systems. Oncor is making significant additional investments in the technology based on its SGDP project experience. Table 1 summarizes the key results.

Table 1. Summary of Key Results	
Operational Improvements	♦ Observed real-time transmission line capacities that were above ambient-adjusted ratings by 8%-12% for 138 kV lines and by 6%-14% for 345 kV lines 84%-91% of the time ♦ Ensured ratings were constantly available by structuring the DLR system to automatically integrate the dynamic ratings into the system telemetry used for real-time operations

[1] This case study summarizes the results found in Oncor's Final Technology Performance Report. All images are used with permission from Oncor.

[2] In this case study, the term "reliability" can be interpreted differently depending on context. DLR technologies are reliable in the sense that they operate dependably and within design parameters. DLR data is reliable when a consistent feed of accurate measurements of operational conditions is made available. Similarly, dynamic ratings are reliable when DLR data is analyzed and processed consistently. Finally, the transmission system as a whole is reliable when congestion issues and contingencies can be resolved without negatively affecting power quality.

Table 1. Summary of Key Results	
	♦ Established automatic data validation to ensure the reliability of ratings being transmitted to ERCOT ♦ Limited the additional capacity available on the lines to ensure that other grid elements did not exceed their physical operating limits and to minimize the risk of system protection misoperations (i.e., to maintain a safe relay settings range for operations)
Lessons Learned from Project Implementation	♦ Learned that the implementation of dynamic ratings in real-time system operations is repeatable and practical ♦ Found significant economic and congestion-relieving benefits of DLR technologies ♦ Observed that DLR systems provide wind generation with greater access to markets through increased transmission capacity ♦ Noted a need to monitor the entire transmission line, rather than a few "critical spans," to account for the spatial variability of wind
Implications for Future Technology Deployments	♦ Emphasized the benefits of a "total-system" approach to DLR integration (i.e., demonstrated the repeatable, practical implementation of DLR technologies from transmission line sensors to wholesale electric markets) ♦ Proved that dynamic ratings can be integrated into real-time system operations—*without* requiring operators to intervene ♦ Documented all aspects of project planning and implementation thoroughly to ensure that the results are readily repeatable ♦ Verified the overall accuracy, reliability, and commercial readiness of mature DLR technologies ♦ Concluded that DLR systems are more useful for real-time operations than for planning studies
Follow-on Investment Plans	Deploying additional DLR systems in West Texas for congestion relief

2. Introduction

Oncor serves over 3 million customers and operates over 15,000 miles of transmission lines. As an open-access transmission provider in the ERCOT region, Oncor's role is to efficiently and reliably provide energy delivery between any generation entity, wholesaler, and authorized power retail service within Texas. Oncor's SGDP project included the instrumentation of eight transmission lines in central Texas with DLR technologies. Oncor's service territory and the project's location are shown in Figure 1 below.

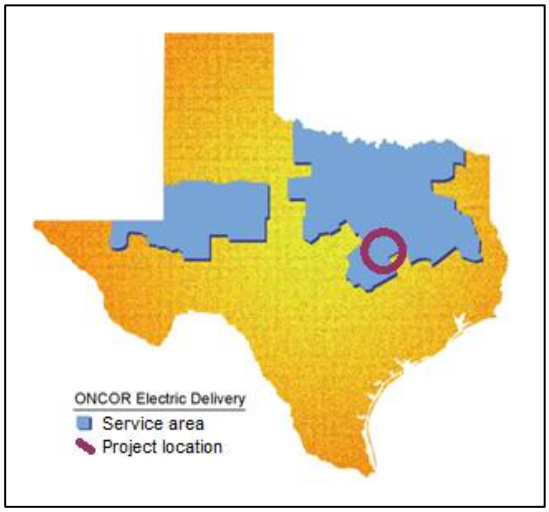

Figure 1. Oncor's Service Territory and Project Location

Oncor primarily deployed Nexans' CAT-1 System, which is composed of load cells to measure conductor tension and sensors to measure net radiation temperature (NRT). Oncor installed two other DLR technologies for validation and verification tasks:

- EDM International, Inc.'s Video Sagometer system,[3] which measures conductor sag
- Promethean Devices' Real-Time Transmission Line Monitoring System (RT-TLMS), which measures conductor clearance

The overall project budget was nearly $7.3 million, including almost $3.5 million of funding from DOE under the American Recovery and Reinvestment Act of 2009. Oncor's primary objective was to demonstrate the repeatable, practical implementation of DLR technologies from transmission line sensors to wholesale electric markets. To enable others to easily replicate Oncor's results, Oncor fully vetted and documented each aspect of the integration:

- The site selection process
- Standards and guidelines covering placement and optimization of the number of monitors required to accurately rate the transmission line (i.e., monitoring the entire transmission line rather than a few "critical spans")
- A "best practices" guide for future installations

[3] The Electric Power Research Institute (EPRI) originally developed the Video Sagometer system, which EDM International, Inc. now markets.

- Guidelines for the introduction of dynamic ratings into the grid operations environment and facilitating the real-time streaming of the data to the grid management system while maintaining reliability, security, and economic dispatch
- The viability of utilizing DLR technologies in system planning
- Interoperability and cybersecurity with transmission owner's and system operator's control systems

With ERCOT's assistance, Oncor performed a study of the DLR system's economic impact as it related to congestion relief.[4] Oncor also demonstrated that dynamic ratings can be integrated into the system operator's state estimator tool for reliable, automatic implementation in real-time grid operations.

3. DLR System Improves Grid Efficiency and Reliability

Oncor's project demonstrated that dynamic ratings are a valuable and successful tool to increase the real-time capacity of a transmission line, enabling transmission owners and system operators to mitigate congestion, increase system reliability, and follow a "least-regrets" strategy for capital spending. Oncor determined that, for most transmission lines, the dynamic rating typically delivers an increased real-time capacity above the ambient-adjusted rating 80%-95% of the time and above the static rating 97%-99% of the time. While quarterly results varied, the real-time capacity delivered by dynamic ratings was 6%-14% greater than ambient-adjusted rating for 345 kV lines and 8%-12% greater than ambient-adjusted rating for 138 kV lines. This additional capacity was available 84%-91% of the time.

DLR systems create potential system reliability benefits. Because dynamic ratings reflect real-time conditions, the system operator's Wide-Area Situational Awareness (WASA) improves relative to static or ambient-adjusted ratings. When transmission lines have greater capacities, the lines' operational margins improve, providing greater flexibility to address congestion or contingencies if or when they occur. Both of these improvements enable system operators to react more quickly and effectively to resolve potential problems on the grid, translating to improved reliability.

[4] Due to the limitations of accessing "what-if" scenarios from ERCOT's real-time state estimator model, Oncor was unable to directly quantify the congestion-related benefits of its project. However, Oncor performed studies using ERCOT's Day-Ahead Market (DAM) model to estimate how DLR technologies can reduce congestion and its associated costs.

Oncor could not quantify the real-time, congestion-related benefits of deploying DLR technologies, but it was able to estimate them by analyzing ERCOT's Day-Ahead Market (DAM) model. In this analysis, Oncor determined that 5% additional capacity would likely relieve congestion by up to 60% on the target lines with DLR installed, while 10% additional capacity would practically eliminate all congestion on the target lines. Based on 2012 congestion levels and costs, Oncor extrapolated that the total congestion impact savings potential resulting from an ERCOT-wide DLR deployment[5] would amount to approximately $20 million, a 3% reduction. Oncor notes that congestion is highly volatile, making it difficult to compare congestion—and, therefore, congestion costs—from year to year. Nevertheless, Oncor's studies demonstrate that DLR systems can yield significant congestion-relieving benefits.

Oncor also calculated the savings associated with the deferral of other transmission upgrades. Oncor determined that installing DLR systems is often only a fraction of the cost of other solutions (although the rating increase is less than with other transmission upgrades).

Table 2. Alternative Solutions for a 138 kV Line

Line Type	Alternative Description	New Rating (% of Static)	Cost per Mile
138 kV Lattice, Wood H-Frame	Reconductor Aluminum Conductor Composite Core (ACCC) cable	193%	$321,851
	Install DLR system	110%	$56,200
138 kV Wood H-Frame	Rerate from 90 °C to 125 °C and modify structures, as needed	130%	$10,561
	Rerate 90 °C to 125 °C and replace structures, as needed	130%	$6,919
	Rebuild	209%	$750,000
	Install DLR system	110%	$29,471
138 kV Wood H-frame	Rebuild	140%	$237,871
	Install DLR system	110%	$16,767
138 kV Wood H-Frame	Reconductor	212%	$750,000
	Install DLR system	110%	$28,323

[5] For the purposes of the study, Oncor assumed that approximately one-twentieth of the lines in ERCOT were instrumented with DLR technologies.

Oncor found that there was an increased shift toward wind generators when dynamic ratings were applied to the study lines in the congestion relief study, which is unsurprising, since both transmission line capacity and wind generation increase when the wind is blowing. The net increase in wind generation was 3% for the year. Only three of the study lines were located in the wind zone, so this potential increase was significant. While this data is not definitive since its sample size is limited, it is nevertheless significant in that ERCOT's Security Constrained Economic Dispatch tool appeared to utilize the increased capacity to recommend shifts to more wind generation when wind was available and the line capacity could accommodate increased power flow. Based on these observations, Oncor's brief assessment of the impact on environmental drivers indicates that greenhouse gas emissions could be reduced through DLR technologies.

Oncor's DLR system improved grid operations by providing additional transmission line capacity that was reliable and cost-effective. Although the study lines did not experience congestion, Oncor confirmed that a DLR system can reduce or even eliminate transmission constraints and can facilitate the integration of wind generation. Oncor's findings are significant, but the true breakthrough of Oncor's project lies in its implementation, as discussed in the next section.

4. Project Implementation Overcomes Historical Challenges

DLR technologies face several known challenges, which can complicate their deployment. For example, many DLR technologies can only gather data about a specific location along a span and cannot accurately reflect conditions on the entire line. Most DLR technologies cannot calculate accurate ratings when lines are lightly loaded, as explained in Table 3. Transmission owners have also struggled to apply dynamic ratings in an operating environment, as system operators may resist additional training and question the accuracy of the ratings.

If left unaddressed, these issues can potentially cripple DLR deployment efforts. Oncor structured its SGDP project to successfully overcome these challenges. As a result, Oncor faced few setbacks during its project. This section discusses Oncor's strategy for success, including its "total-system" approach to integrating the DLR system with the grid and its strategies for implementing dynamic ratings in ERCOT's real-time operations.

Table 3. Oncor's Solutions to Known DLR Challenges

Challenge	Oncor's Solution
Some DLR technologies can only monitor "points" along a transmission line, rather than the entire line. If too few devices are used, spatial data (i.e.,	Oncor deployed Nexans' CAT-1 System, which gathers spatial data, not point data. Oncor determined the optimal number of monitors

Table 3. Oncor's Solutions to Known DLR Challenges	
dynamic ratings) will not be accurate.	needed to accurately characterize the study lines.
Dynamic ratings for lightly-loaded transmission lines are not as accurately modeled, since the wind's impact on ratings may not be fully determinable.	Oncor's DLR system automatically reverted to a rating based on NRT when dynamic ratings were not available. At least one of three ratings (dynamic, NRT-based, or the lines' original ambient-adjusted ratings) was *always* available, regardless of load conditions.
Dynamic ratings may release more additional capacity on transmission lines than the rest of the transmission system can safely accommodate.	In consideration for the next limiting element on the line being monitored, Oncor limited the additional capacity available to ERCOT operators to 125% of the lines' static ratings.
System operators may be reluctant to embrace the steep learning curve inherent in a DLR system, and they may question whether the dynamic ratings are satisfactorily reliable.	Oncor automated the validation of DLR data and its incorporation into ERCOT's real-time operations, ensuring data reliability and minimizing the efforts required from grid operators.

4.1 Oncor's "Total-System" Approach

In the past, DLR systems have been deployed for transmission system planning purposes or research and development (R&D) tasks. These deployments generally monitor only the "critical spans" of transmission lines—the span(s) that have minimal clearances or the sections of the line that are most shielded from the wind and therefore have lower capacities than other spans. Oncor realized that the critical span is not static; because the wind along a line is volatile, the location of the critical span often changes. Oncor undertook a full and complete deployment on eight transmission lines, monitoring the entire line, rather than a few spans.

Transmission line capacity is not the only limiting factor in a transmission system. Switches, circuit breakers, wave traps, and current transformers also have limited capacities that cannot be exceeded during operations. Oncor realized that, once a line has been selected for DLR implementation, all of the elements on the path or monitoring the load flow on the path must be checked to ensure that their rating exceeds the anticipated increase in capacity being gained via the DLR system. In keeping with its "total-system" approach, Oncor limited the increased capacities of the study lines to 125% of the static rating. The capacities of many of the next limiting elements of the system are approximately 133% of the static rating, so Oncor selected the 125% cap to maintain a small "buffer" for those elements. This ensured that the next limiting element on the grid would not become constrained when dynamic ratings were utilized.

Finally, Oncor sought to forecast the impact of the deployment of DLR systems on the entire ERCOT system. Oncor determined that a DLR system impacts wind generation and system congestion. As previously discussed, Oncor observed that ERCOT's Security Constrained Economic Dispatch tool utilized the increased capacity on the study lines to recommend increased wind farm output and performed an economic impact study of the DLR system on congestion relief, with ERCOT's assistance. Refer to Section 3 above for the results of these studies.

4.2 Automatic Integration with System Operations

Oncor sought complete, real-time integration with ERCOT's wholesale electricity market. Historically, transmission owners have struggled to integrate dynamic ratings with system operations. This integration generally involves the addition of a new terminal at the system operations center and additional training for grid operators, who must examine the dynamic ratings and decide whether to manually apply them.

Oncor took an innovative approach to DLR system integration. DLR data was fed directly into ERCOT's economic dispatch tool for automatic use in real-time system operations. Oncor built data validation tools into the DLR system to ensure that the ratings being transmitted to ERCOT were accurate. If the ratings were invalid, the system defaulted to the lines' ambient-adjusted ratings. ERCOT operators did not need to determine the accuracy of the dynamic ratings, or even whether to apply them in operations. Oncor fully automated this process, guaranteeing optimal, reliable dispatch. Oncor's methods pave the way for future DLR deployments, proving that the use of dynamic ratings in real-time system operations can be practical and reliable. The automatic flow of data from the field to ERCOT's operations telemetry is shown below in Figure 2.

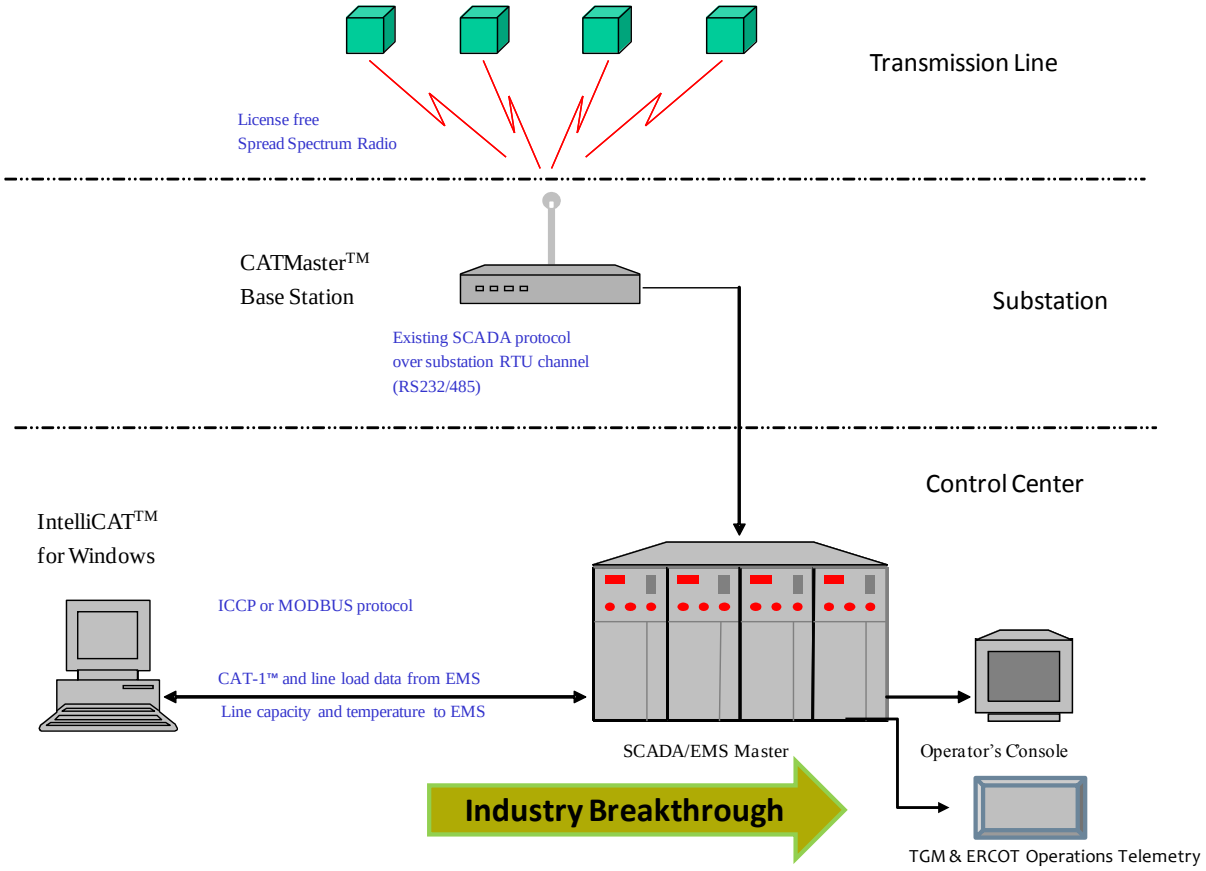

Figure 2. Oncor's Integrated DLR System

4.3 Project Conclusions

Oncor thoroughly documented all aspects of project planning and implementation to develop a "best practices" guide for future DLR deployments, ensuring that other transmission owners can replicate the results of the SGDP project. Oncor's "best practices" guide, which can be found in Section 5 of Oncor's final Technology Performance Report, walks transmission owners through the process of planning and carrying out a DLR deployment. In addition to general guidance on installation site selection, cybersecurity considerations, and integration of the DLR system with the operator's control room, Oncor offers direction on several aspects of a DLR deployment that may not be readily apparent from other transmission owners' DLR projects:

- The need to monitor the entire transmission line rather than a few "critical spans"
- The benefits of a "total-system" approach to DLR integration, which considers the next limiting element on the grid and the role of the DLR system in the greater context of grid

operations (i.e., maintains a safe operating range of the relay protection settings on the line)

- The reality that, while a DLR system can increase ratings by as much as twofold on a line, the "usable" range of increased capacity is between a 5% and 30% above the static rating, depending on the probability that the increased capacity is available
- The superiority of utilizing dynamic ratings in real-time operations, which fully captures the technology's benefits in terms of increased WASA and improved grid reliability and flexibility, rather than in planning studies, which focus on the probability that a rating is available a certain percentage of the time

Overall, Oncor documented a high degree of commercial readiness and technological maturity for the DLR technologies it deployed. The project demonstrated that the technologies are highly reliable, flexible, and can be fully and automatically integrated with the transmission owner's and system operator's control systems. Oncor considers its SGDP project to be a complete success, and the project was recognized as one of two finalists in the Smart Grid category for the *POWERGRID International* Projects of the Year award.[6]

5. Future Plans Include Follow-on DLR Deployments

Oncor is investing in additional DLR systems to address capacity needs elsewhere in its service territory. Oncor undertook a second DLR project, the West Texas DLR Project, in early 2013 to relieve congestion around Odessa, Texas. Oncor selected five lines, which are rated 69 kV and 138 kV, for DLR system installation. These lines were selected because they are often heavily loaded (approximately 70% of the static rating) and frequently experience congestion.

The implementation of this project was smooth and fast-paced. The West Texas DLR Project was initiated in January 2013 and became operational in June 2013, including full, real-time integration with ERCOT's economic dispatch tool. For this project, Oncor has continued using the CAT-1 System, based on its successes with the technology during its SGDP project. Additional lines for DLR deployment are under assessment, based on planning needs and congestion exposure during the rest of 2013 and beyond.

[6] See *Electric Light & Power*'s article, POWERGRID International names Projects of the Year finalists.

6. Where to Find More Information

To learn more about national efforts to modernize the electric grid, visit the Office of Electricity Delivery and Energy Reliability's website and SmartGrid.gov. DOE has published several reports and other documents on topics similar to those addressed in Oncor's SGDP project and this case study. Related web links are listed in Table 4.

Table 4. Related Web Links

Oncor's DLR Project	♦ Project Description ♦ Final Technology Performance Report ♦ Oncor Demonstrates Small Investments in DLR Lead to Big Increase in Capacity
DOE's DLR Topical Report	Dynamic Line Rating Systems for Transmission Lines: Topical Report