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Transmission Planning in a Dynamic Environment

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SUMMARY

Those charged with planning the future of our electric transmission grid face a far more challenging task than did their predecessors. Today's grid planners must still ensure that when the future arrives all loads are reliably served and can expect unconstrained access to all generation options. But, the environment in which they must do that has been radically altered. Gone are the days when the location, capacity, and in-service date of all generating plants were well defined for 5 to 10 years into the future. Today, new plants can appear anywhere on the map in as little as 18 months and demand that a widely varying output be instantly accommodated by the grid at the same time that older but perfectly functional plants are suddenly mothballed or retired. The accuracy of load forecasts has been traditionally very good. That too has begun to change as new loads suddenly appear (extraction of natural resources, industry relocation) and old loads suddenly dwindle (net metering). The emergence of demand response is also complicating load forecasting. The planning environment has become quite dynamic necessitating a flexible and dynamic plan for the future… a plan that expects to adjust to the unexpected and do so at acceptable levels of cost, speed, and reliability.

Dynamic Line Rating (DLR) provides exactly the flexible capability needed by transmission planners to mitigate congestion, increase system reliability and redeploy capital to its most efficient uses through a least-regrets strategy. We see five potential applications for DLR in the planner's tool box.

1) Enhancing operations planning by providing safety and reliability in the face of uncertainty.
2) Preparing a more cost efficient least-regrets capital transmission investment strategy
3) Providing a bridge to accelerate and facilitate transmission builds
4) Resolving present and future line derating situations
5) Addressing the next limiting element

KEYWORDS

Reliability, Ratings, Planning, Dynamic Line Ratings, Contingencies, Congestion, Real-time, WASA, Least Regrets Capital Management, Transmission Capacity.

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Planning in a Dynamic Environment

N-1 (and beyond) contingencies drive the transmission business from operations to planning. Planning is continuously studying the grid running N-1 scenarios that assess the capability of the grid to reliably meet system demands for load and generation availability versus available grid transmission paths to economically and reliably deliver power from source to load sink. Most utilities run 1,000s of what-if N-1 contingency events against a grid model. In daily operations a similar analysis is performed for as many contingency event scenarios, considering real-time generation output, load-sink demand, actual outages and clearances, and ratings of in-service transmission assets. When the system reaches a point where the N-1 scenarios indicate transmission elements are overloaded, generation is redispatched or the grid is reconfigured by switching operations to maintain reliability constraints. The ideal scenario is to also maintain the grid at optimum dispatch.

In planning for future capital investments and grid improvements, reliability issues identified during N-1 studies are noted and developed into solution plans that ultimately become capital projects. Load growths in specific areas that strain the ability of the grid to adequately provide service are typical examples. Ultimately is too strong a term here because some, if not many, issues identified during studies and subsequent planning cycles never develop into a need that requires a large capital expenditure solution, like a new line or reconstruction or upgrading of an existing line. These projects may stay at a slight deficiency; say 101% to 110% loading of a transmission element for a few N-1 constraints under specific conditions. These types of issues may grow in severity with time or they may disappear entirely due to some other grid topology change that mitigates the issue. Generation shift is one key factor that can affect grid configuration within the planning cycle.[1]

How much additional capacity is available from DLR?

Providers of dynamic line rating technologies point out that there is a tremendous amount of capacity available in the existing transmission assets above the typical static limit rating. The static limit is typically set at the highest expected temperature for the regions with full sun and a modest wind speed of 2 feet per second, typically; roughly 1.4 miles per hour. Wind is the dominant parameter driving the heat balance equation between solar heating and joule heat from current flow versus radiating heat and convection cooling of wind flow past the conductor and the differential to the ambient temperature. Since wind cooling has the greatest impact, line orientation to the wind is very important and the capacity varies along a transmission line depending on its orientation. DLR provides the transmission operator the ability to assess the effective wind cooling effect adjacent to and continuously along the transmission line in the field and establish the real-time available rating.

If DLR is installed on a line and the statistical distribution of ratings available over time is plotted, you would get a plot similar to the three lines in Figure 1 which was obtained from the DOE-Oncor Smart Grid Demonstration Project on DLR. Each of the three curves shows the statistical probability of having a given capacity by percentage of the time. There are three curves because they represent the distributions for three different lines in varying exposures to the prevailing winds, i.e., orientation to the end of the line and terrain, open exposed or suburban/urban locations. The plots show that 50% of the time the ratings are 140-150% of the static rating. Even higher ratings are available but at less availability to operations. Note also that as the percentage of time increases the variation between the three lines tightens.

How much of DLR's additional capacity can be used during planning?

Figure 1 is extremely important to the planner at a utility. Their charge is to maintain the N-1 post contingency loading below equipment rating. They do not take conditions, i.e., potential favorable climatic conditions, into account during this analysis. The planners may elect to change their ratings to a higher level if the statistics support that they are "guaranteed" the higher ratings. For example, from

[1] « Guide for Thermal Rating Calculations of Overhead Lines", CIGRÉ Working Group B2.43, TB 601, December 2014.

Figure 1 they may elect to use a 5% increase in ratings since they are shown to be available over 96% of the time, but not willing to accept a 30% rating increase, which has a probability of availability between 64 and 74% of the time depending on the line. Note that in operations one has to take into consideration the probability of a contingency happening and the rating not being available at the same time. This is very low and it is estimated to be less than 0.05% in many cases**.** Even in such cases, the operator, with DLR information, will know the actual capacity of the transmission line and will have ample time to react, if necessary, once these two conditions coexist. The time lag is because while electrical events happen instantaneously and loading increments occur instantly, thermal events take minutes to reach their maximum value. This is due to the thermal time constant of the conductor which is measured in a few minutes.

Note the green line across the plot. This is set at the value of 125% of the static rating. This is a ratings increase cap value that is applied for two reasons. First, the line section rating is composed of the ratings of several elements in the electrical path: the line conductor, any switches, wave traps, CTs and PTs and other current carrying elements. Increasing the conductor ratings may be constrained by the rating of one of these elements. Options are to upgrade all the equipment so higher ratings can be utilized or constraining the increase to a limit within the capability of all the elements. DLR can be utilized to expose the “next limiting element” and the planner can then make upgrade decision based on his needs and economic considerations.

The second reason for a cap level is concerned with relay settings for the line section and elements. If the ratings are set for too broad of a range, there is greater potential for miss-operations while sensing within the broader range. On top of that, the probability of the higher capacity is a smaller percentage of the time and you are increasing your exposure to the majority of the time.

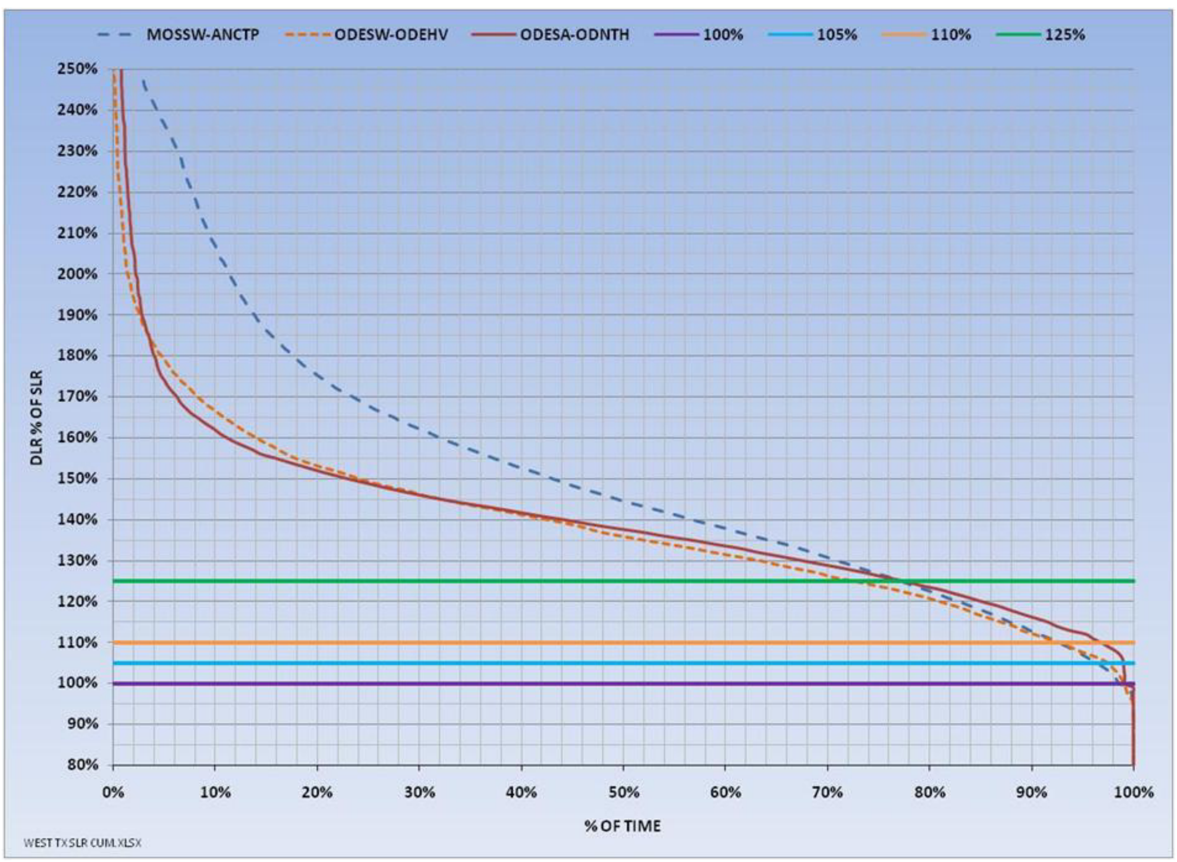

Figure 1 Cumulative Dynamic Ratings Availability

How much increase in capacity do I need?

As we mentioned N-1 contingencies drive system operations. Almost all grids are run in real-time based on state estimator reliability analysis that runs the 1,000s of N-1 contingencies every couple of minutes, e.g., PJM operates on a two-minute cycle and ERCOT operates based on a five-minute interval between cycles. So every cycle the analysis uses real-time system telemetry and a robust system model to assess the reliability at each node or zone. If the post-contingency results indicate a need to adjust the system, operations takes measures to maintain reliability. These actions can be automated within the system controls or require manual operator intervention. Depending on severity of the issue, solutions may include any combination of generation redispatch, switching operations to alter load flows, execution of special protection schemes or plans and, in worst case situations, load-shedding.

Today's automated systems that are designed for management of reliability, economics and power quality are constantly assessing and tweaking the system to maintain prescribed operating limits. These tweaks are subtle and frequent such that there are minimal disturbances across any element of the grid, unless a forced event occurs. These systems start a "watch list" of elements that have post-contingency loadings approaching 100%. The list may start at 75% of the rating or higher, but as specific elements enter the "watch" zone, the system starts to assess mitigation measures to maintain security and economic dispatch. In nominal operation, line capacity increases of a few percent make a big difference in operations. Figure 1 has two additional horizontal lines plotted for 105% and 110% of static rating. The curves indicate that those levels of capacity were available 93 – 97% of the time. There is a good probability that capacity was concurrent with when the system needed that capacity. Further introducing that small amount of additional capacity most likely avoided any constrain issues.

The Oncor – DOE DLR project identified this specific situation. Six lines that had exhibited constraints were reanalyzed with adjusted ratings representing an increase of 5% or 10% over their actual ratings. The system model was re-optimized for these adjustments and the system showed the reduction in constraint costs illustrated in Table 1. The benefits of DLR are substantial. When the "Peak Day", the day on which the most constraints occurred, was assessed, a 5% or 10% increase in line ratings derived 59% and 77% reduction in congestion costs. The analysis looked at one day each month, the second Tuesday, and assessed the impact of 5% and 10% more capacity on six lines and identified substantial reduction in congestion again.

	Peak Day	**Annual Trend**
DLR % Increase	**% Congestion-cost Reduction**	**% Congestion-cost Reduction**
+5%	**59%**	**34%**
+10%	**77%**	**45%**

Table 1 - DLR Constraint Mitigation

There are a couple key takeaways from this discussion:

1. Each line has its own ratings probability distribution curve. There is no one blanket fits all ratings values that can be assigned by region or design.

2. Significant ratings increases are available but not necessary to make a significant impact on system operations, 5-10% increase in capacity is sufficient.

3. This level of capacity increase is available 93-97 % of the time.

Developing a Least-regrets Capital Strategy

DLR solutions can be utilized in the planning process to enable a least-regrets capital strategy, which minimizes any potential stranded investment[2][3]. The SGDP Project[4] demonstrated that DLR is a valuable tool to be applied during project identification and solution development. DLR solutions can be an effective screening tool that can be used in identifying and analyzing the value of proposed transmission investments and help avoid potential capital-intensive stranded assets. DLR solutions can be a filtering gate allowing utilities to redirect scarce capital to higher-value projects for the long term. DLR solutions as a screening tool can enable planners to choose the highest-value project first, enabling them to better deal with the demands NERC and FERC policies place on planners.

Each year as the budget cycle is reviewed for each project in the queue and for new projects being identified, any topology changes, actual loading history and projected load growth are incorporated into the system model and future line capacity requirements are projected. Budget estimates for each project are updated. The new system requirements provide a prioritized list of projects that are then measured against the anticipated budget available for construction. The queue is managed from highest priority down, depending on funding available.

DLR can provide a mechanism to address many projects that do not make the funding cut yet are deemed necessary to maintain reliability, meet load growth or mitigate congestion. Most capital investment solutions for small incremental capacity increases fail the cost-to-benefit rationale. DLR is a way to extend the available funding to a broader number of projects by applying more efficient investment of the funding budget.

A secondary benefit of the DLR solution is that in future years as the grid topology changes, some of these projects in the queue never mature to where the capacity requirements change the solution to a larger capital investment. In some cases, the capacity increase even decreases as topology provides different line loading patterns. In either case, DLR can be a tool to optimize the timing and allocation of capital investments.

DLR as a Bridge to Planned Transmission Build-up

The demand for capacity often presents itself faster than time and capital can address it. DLR can provide a bridge that immediately addresses the need while keeping system reliability intact. Planning and construction can proceed at a pace that precludes cost overruns. Capital can be scheduled to take advantage of lower costs in the marketplace, especially if the demand for capacity is steadily ramping up. Capital can also be redirected to more urgent or desirable projects. And, of course, DLR provides the least-regrets option when the supposed demand fails to materialize.

Solutions for Derated Lines

Another application for DLR may be in resolving issues with lines that were derated as a result of addressing the reporting requirements of the NERC Alert, "Consideration of Actual Field Conditions in Determination of Facility Ratings." DLR can also be an effective tool to support NERC's Reliability Assurance Initiative (RAI). Many utilities identified line sections with clearances where the design and construction of a transmission line did not meet the NESC clearance requirements or where subsequent changes, such as landslides, construction activities, etc., reduced the design

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[2] Duke University, "Calculating Regret Scores," presented to SEARUC, June 9, 2013.

[3] The Brattle Group, "The Benefits of Electric Transmission: Identifying and Analyzing the Value of Investments," July 2013

[4] US DOE Contract ID: DE-OE0000320, "Final Report, Oncor Electric Delivery Smart Grid Program", August 2013.

clearances. The resolution to regain full line capacity may be obtained by traditional capital investments such as increasing structure heights or rebuilding/reconductoring the line. Many resolutions may require substantial investments or extended lead time to secure additional permissions to complete the modifications, e.g., new easements, permits or outage time.
Some DLR vendors market their products more like an alarm system that notifies the line manager if an operation constraint will be imposed due to a clearance restriction. Such an alarm system requires several steps, including detection, notification, acknowledgment and a corrective action decision.

DLR, on the other hand, mitigates the constraint via an automated WASA that provides System Operations with a quasi-continuous update of the available capacity of the line section. The State Estimator uses the real-time data as efficiently as possible. If a constraint develops due to ambient weather conditions or increased loading in the area or on the line, the DLR maintains system awareness and the EMS automatically adjusts and optimizes the system on a continuing basis. There is no abrupt change in system characteristics that must be addressed. The Static Line Rating remains at the derated level, i.e., maximum operating temperature based on the available line clearance. By installing DLR, the line can be operated at the full available capacity of the line based on real-time operating and ambient conditions.

The key aspect in this application is the continuous stream of data to System Operations and its ability to work an optimum solution for real-time grid conditions. An alarm-type system requires a more drastic response. A fully integrated DLR system (iDLR) maintains grid reliability automatically and allows the system to adjust to whatever transfer capacity the real-time parameters allow. An iDLR system is exemplified by the DOE-Oncor SGDP project that streams real-time DLR ratings to ERCOT's Security-Constrained Economic Dispatch system for reliability analysis and optimized economic dispatch of generation.

Planning for Replacement of the Next Limiting Element

The transmission line is not the only element that can constrain the capacity of a line. Switches, circuit breakers, wave traps and transformers on equipment all have ratings that cannot be exceeded in terms of real loading and for N-1 contingency. Once a line has been selected for DLR, 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 by the DLR equipment. Some utilities use adjustable ratings on these elements similar to the adjustment they are making on their lines. A line that is being rated with temperature-based adjusted ratings may also have its associated equipment ratings adjusted for ambient temperature. Some utilities adjust the lines and not the terminal equipment. In designing a DLR deployment, the associated equipment ratings must also be considered. The lowest rating assigned to the line section or the equipment dictates that line's rating. Another area that requires review is relay settings. If the allowable ratings change is over a range broader than the relay settings are governing, they must also be addressed to accommodate whatever range is allowed with the DLR. One way to manage this is to cap the maximum ratings increase allowed with DLR at 125% or another value of the Static Rating. This contains the ratings swing and makes settings tasks easier. When these elements are identified for upgrading, they need to be coordinated with the DLR deployment so they also have the appropriate ratings range to accommodate the conductor rating's adjustment and are completed prior to going live with the DLR equipment.

Comparison of Alternative Solutions

In previous sections, we have established the effectiveness of DLR as a means of providing additional transmission capacity for reliability, wide area situational awareness, and the mitigation of grid congestion. In this section, we will compare DLR to alternative solutions from a cost/benefit, performance, and capital management standpoint.

Bulk/backbone transmission lines operating at 345 kV, 500 kV, or higher are thermally constrained less often than the medium voltage 115 kV to 169 kV lines that are typically thermally constrained under N-1 conditions. In the comparisons offered below, most of the examples are based on 138 kV lines as being representative of the medium voltage class.

As previously noted, grid congestion is typically the result of less than a 10% rating (capacity) shortfall. Therefore, the comparisons are focused on eliminating that level of shortfall. Note that some of the alternative solutions provide far more capacity than the 10% increase required to complete the mission. It is beyond the scope of this discussion to assess whether or not the excess capacity can be justified by economic or other means.

The comparison evaluates four alternative solutions to providing the capacity needed to mitigate a 10% rating shortfall:

- Applying DLR including real-time monitoring of the transmission line and automated delivery of the DLR to the ISO's Security Constrained Economic Dispatch.

- Rerating the line to a higher maximum operating temperature, requiring some structure modifications or replacements for obtaining additional clearances where needed.

- Reconductoring the line, assuming it has sufficient structural capacity and height to support a new conductor that has the required capacity and maintains minimum ground clearances.

- Rebuilding the line by replacing it with structures that support a larger-capacity conductor.

Table 2 summarizes the increase in line rating (compared to the original static rating) and the cost per mile that is delivered by alternative solutions on different line designs. The variation in cost per mile is the direct result of using actual projects for the comparison. Each project had variances in line design, topology, number of dead-ends, etc., that impacted both the amount of DLR instrumentation and the alternative solution costs. All costs are "installed costs" including materials and labor.

Line Type	Alternative Description	New Rating (% of Static)	Work Required	Cost Per Mile
138 kV Lattice & Wood H-frame	**Reconductor ACCC**	**193%**	**Reconductor**	**$ 321,851**
	DLR	**110%**	**DLR**	**$ 56,200**
138 kV Wood H-frame	**Rerate 125 °C Modify Strs**	**130%**	**Modify 6 H-frames**	**$ 10,561**
	Rerate 125 °C Replace Strs	**130%**	**Replace 6 H-frames**	**$ 6,919**
	Rebuild	**209%**	**Rebuild Line**	**$ 750,000**
	DLR	**110%**	**DLR**	**$ 29,471**
138 kV Wood H-frame	**Rebuild**	**140%**	**Rebuild Line**	**$ 237,871**
	DLR	**110%**	**DLR**	**$ 16,767**
138 kV Wood H-frame	**Reconductor**	**212%**	**Reconductor**	**$ 750,000**
	DLR	**110%**	**DLR**	**$ 28,323**
345 kV Lattice Tower	**Raise structure heights**	**120%**	**Raise Str Heights**	**$ 73,600**
	DLR	**110%**	**DLR**	**$ 26,626**

Table 2 - Alternative Solution Comparisons to Dynamic Line Rating – Project Descriptions

Note that in addition to DLR typically being the least cost option, it is also the only option that provides capacity and wide area situational awareness on the physical and thermal status of the transmission line in real time.

Conclusion

Dynamic line rating has statistically proven that ratings in transmission lines are higher than their Static Rating over 98% of the time, yet we do not take advantage of that capacity to resolve reliability issues, mitigate congestion or extend the capital budget's capability to solve issues. Conversely, NERC requirements and planning procedures dictate that lines should not exceed their rating for post-contingency line loading of N-1 scenarios. While Planning would like to take advantage of that inherent capacity in the lines, they must plan to be able to meet the N-1 constraint; they want assurance that the capacity is there. Fortunately, that capacity can be taken advantage of when DLR monitoring of the lines streams the available line capacity to the state estimator performing reliability assessments every few minutes on the grid. The grid now gets to take advantage of the inherent capacity of the lines to provide reliability, flexibility and a more optimum dispatch of resources. Planning can utilize DLR in their tools of finding solutions to different line capacity requirements during the annual planning cycles. Many projects only exceed their ratings by a few percent for one or multiple N-1 contingencies. DLR can deliver this capacity if it is deployed on the lines and streams its data to the state estimator. DLR has been shown to be significantly lower in cost than traditional upgrade solutions of raising conductors, reconductoring, or rebuilding and adding new lines, while providing capacity and line status in real time. The application of DLR as a solution has a shorter lead time, lower cost, and minimizes risk to capital.

The topology and operation of today's transmission grids change daily as market influences change the generation mix and availability; maintenance and new construction projects take outages; and new lines and assets are placed in service to meet load growth, new generation and reliability concerns. The grid is a very dynamic engine that requires a flexible solution with short lead times, proven capacity and extended reliability

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