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# Transmission Line Ampacity Improvements of AltaLink Wind Plant Overhead Tie-Lines Using Weather-Based Dynamic Line Rating

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***Abstract*—Overhead transmission lines (TLs) are conventionally given seasonal ratings based on conservative environmental assumptions. Such an approach often results in the underutilization of the overhead TL capacity as the most conservative environmental conditions occur only for a short period over an year/season. We present computational fluid dynamics (CFD) enhanced weather-based dynamic line rating (DLR) as an enabling smart grid technology that adaptively computes ratings of TLs based on local weather conditions to utilize the additional headroom of line ampacity due to concurrent cooling of existing lines. In particular, a general line ampacity state solver is proposed to utilize measured weather data for computing the real-time thermal rating of the TLs. The performance of the proposed CFD enhanced weather-based DLR is demonstrated from a field study of DLR technology implementation on four TL segments at AltaLink, Canada. The performance is evaluated by comparing the existing static and the proposed dynamic line ratings, and the potential benefits of DLR for enhanced transmission assets utilization are quantified. For the given line segments, the proposed DLR results in real-time ratings above the seasonal static ratings for most of the time (up to 95.1%) with a mean increase of 72% over static rating.**

***Keywords*—Computational fluid dynamics, dynamic line rating, general line ampacity state solver, power system planning**

## I. Introduction

Overhead transmission lines (TLs) are limited to the amount of electrical current they can carry to avoid excessive thermal heating [1]. Conventionally, the line ampacity limits are set to a static value based on a conservative assumption of the environmental conditions over a year/season [2]. Such conditions may result in the under-utilization of the existing transmission assets as there exists additional headroom on line ampacity due to inherent cooling of the conductors. Therefore, real-time monitoring of electrical systems and environmental parameters can help to dynamically rate TLs for maximizing the thermal capacity of critical overhead lines. Moreover, dynamic line rating (DLR) helps to increase wind energy hosting capacity of the TLs due to the natural synergy between wind generation and increased conductor capacity at times of high local wind speed [3]. As one of the key objectives of a smart grid is to optimally utilize the existing assets to avoid or delay the need of new infrastructure, DLR can serve as a potential tool to maximize the ampacity utilization of existing TLs and to delay the need of costly grid upgrades [4].

Realizing the potential benefits of DLR technology, the U.S. Department of Energy identified DLR as one of eight smart grid transmission and distribution infrastructure metrics [2]. In addition, professional organizations, such as IEEE and CIGRE, have developed standards (e.g., IEEE Standard-738) and formed working groups to define methods for computing temperatures of overhead lines with time-varying weather conditions [1], [5]. Significant research and development efforts are also being invested in the technological advancement of DLRs to facilitate grid operators in making better planning and operational decisions in terms of capacity utilization of the existing TLs. For instance, the authors in [6] provides a comparison of thermal line rating applications in the United States and the United Kingdom to provide insights on the potential benefits of DLR. Similarly, the influence of environmental conditions on line rating is studied in detail in [7], and the potential application of DLR for improved wind energy integration is presented in [8] and [9]. In addition, the integration of complex electrical and thermal dynamics of the TLs are studies in [4] for mitigating perturbations in the TLs. In addition to technological aspects, the authors in [10] presents the regulatory framework and requirements for the effective deployment of DLR technology. However, one of the key challenges is to quantify potential benefits of DLRs to electric utilities through field studies on actual utility grids.

This study implements DLR on four TL segments at AltaLink (SummerView Fidler 624L East-West, SummerView Fiddler 624L North-South, WindyPoint Fidler 893L East-West, and WindyPoint Fidler 893L North-South) and quantifies potential benefits of DLR in increased line ampacity utilization. To realize the DLR enhancements, weather stations (WSs) are installed at optimal, predetermined locations on the TL to collect weather data (e.g., wind speed, wind direction, ambient temperature, solar irradiance). A windSim, Idhao National Laboratory (INL) customized commercial simulation software that works based on computational fluid dynamics (CFD), consumes weather data to accurately capture wind effects in the terrain and estimate weather conditions at mid-span coordinates. The WS data and mid-point coordinates are then integrated into the general line ampacity state solver (GLASS), a core engine of the proposed DLR, for real-time computation of line ampacity. Finally, comparisons are made between the existing static rating and proposed CFD enhanced

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weather-based DLR, and the potential benefits for enhanced TL utilization by DLR are quantified.

The remainder of the paper is structured as follows. First, the details of the study area are presented in Section II. Section III presents DLR methodology and its implementation. A comprehensive analysis of the findings is presented in Section IV, and the paper is concluded in Section V.

## II. Test Site Description

As mentioned in the preceding section, the test site comprises two transmission corridors of AltaLink, each having east-west and north-south line segments and located in a southern part of Alberta, Canada. Fig. 1 provides specific details of the studied line segments, including relative locations of the line segments and WSs. It can be seen that the SummerView and WindyPoint cirtuits share the same structures on the north-south segment, while the other two TL segments run independently. The test site is of particular interest to us as majority of the transmitted power over those lines is from wind energy, and there exists significant potential for a wind farm expansion. In particular, those lines are representative to examine the effectiveness of DLR technology, as well as to provide key recommendations to utilities for making both planning decisions (expansion of load without a major capital expense on replacing conductors or other grid reinforcements) and operational decisions (maximum utilization of available line ampacity near real-time operations). Moreover, east-west and north-south line segments are selected to demonstrate how wind direction impact the line ampacity improvements.

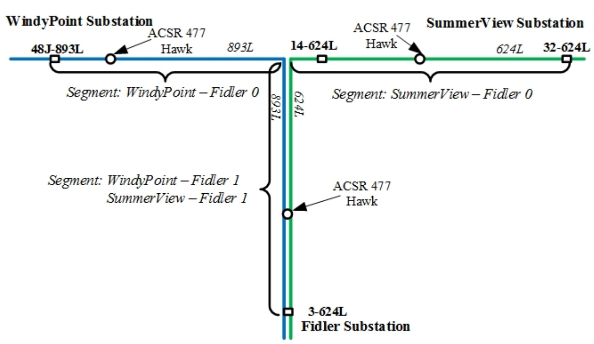


Fig. 1. Relative location of line segments and their details.

TABLE I. Specification of four line sections under study.

| Line Segment | Conductor Type | Cond. Angle ($Degree$) | # of Poles |
|---|---|---|---|
| SummerView East-West | ACSR-266-Partridge | 89.4 | 19 |
| SummerView North-South | ACSR-477-Hawk | 9.6 | 10 |
| WindyPoint East-West | ACSR-477-Hawk | 90.5 | 14 |
| WindyPoint North-South | ACSR-477-Hawk | 9.6 | 10 |

## III. Proposed Methodology

CFD enhanced weather-based DLR primarily collects weather data (e.g., wind speed, wind direction, ambient air temperature, and solar irradiance levels), computes mid-span coordinates using CFD, and utilizes the weather data and mid-span coordinates to dynamically compute the real-time line ratings of the TLs of interest. Fig. 2 depicts how CFD accurately capture the wind effect in the terrain and high level overview of the proposed method and its integration of different component. The following sub-sections present the details of the each component, including collection of weather data and their integration to weather-based DLR for computing real-time line ampacities.

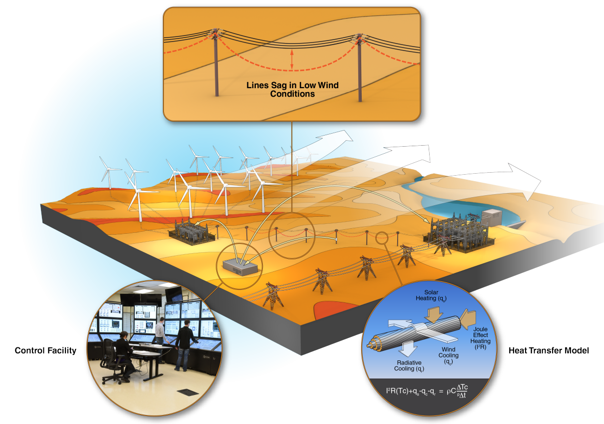


Fig. 2. Proposed CFD enhanced weather-based DLR model.

### A. Data Collection and Analysis

As weather and environmental measurements are key to dynamically rate TLs, the WS configuration to collect weather data is of utmost importance. In our test network, four WSs, namely WS49, WS14, WS32, and WS3, were installed at four different locations along the line segments. The WS naming is taken from the unique number of the power system structure where each WS were installed (i.e., 48J-895L, 14-624L, 32-624L, and 3-624L). Weather parameters obtained from those WSs are used to model and calculate a complete and accurate picture of the weather conditions and temperatures along the full length of TLs of interest.


Fig. 3. Implementation of WS in a TL structure.

Each WS package consists of custom mounting brackets, a weather data logger, communications equipment, a 50 W photovoltaic solar cell array with a charge controller and battery (55 Ahr), an Apogee pyranometer, a wind anemometer sensor, a wind vane sensor, and an ambient air temperature sensor with solar radiation shielding. Each WS is installed with pole mount systems using banded strapping as seen in Fig. 3. For this pilot study, AltaLink periodically retrieved the data from the data logger and electronically transmitted the data to Idaho National Laboratory (INL) along with corresponding line load data acquired from their supervisory control and data acquisition (SCADA) system for these line segments. The weather data were collected with 3 minutes resolution (i.e., every 3 minutes), and the collected weather patterns were compared to assumptions made by AltaLink for defining their static ratings.

### *B. Weather-Based DLR Approach*

We have implemented a weather-based DLR developed by INL for this study. It primarily comprises two major components: WindSim and GLASS. In particular, GLASS is a computational engine and the heart of the DLR system, while WindSim is a wind simulation software that works based on a CFD model. The overall framework of the DLR system developed by INL for the processing of real-time and/or forecasted computation of line rating based on measured weather data is illustrated in Fig. 4. Note that the same basic structure is used to compute historical data with an additional software agent coordinating the feed of data and tabulation of results to GLASS. The Subsections III-B1 and III-B2 present the details of major processing components, namely WindSim and GLASS.

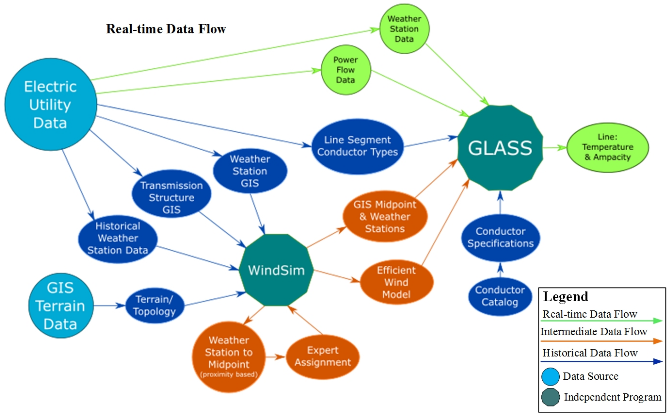


Fig. 4. Configuration and data flow for the INL DLR method.

*1) WindSim:* WindSim is a wind simulation software that is used to provide an accurate estimation of the weather conditions at mid-span coordinates using WS data. In particular, WindSim uses geographic information about the topology and roughness of the terrain of the area surrounding the TL, the locations of WS and TL structures, and weather data (e.g., wind speed, wind direction, ambient temperature, and solar irradiance levels) from all WSs. This information is used to map those data to estimation wind speed and direction at TL midpoints. As WindSim uses a Cartesian layout for its solution grid, pre-processing of terrain data is required. In particular, ”Global Mapper” is used to transform those raw elevation and roughness terrain data into a transverse mercator projection so as to provide a suitable domain for use in the Cartesian mesh of WindSim. The terrain layout for the study area with TL and WS locations is illustrated in Fig. 5. WindSim uses historical WS data to validate and refine the models and provide an output containing assignment of line segments and computationally efficient lookup tables to map the WS data. The following are the key outputs of WindSim that acts as input to GLASS for computation of real-time line ratings.

- The lookup table file containing speed and direction shifts for each of the TLs span middle points. Note that middle points are also referred to as model points, whereby the nearest WS is used to assign solar irradiance and ambient temperature for the associated model point.
- Midpoint files contain the association with one of the four line segments. This is important because part of the IEEE Standard-738 that is being implemented in GLASS uses the line current supplied by the utility for a given segment.

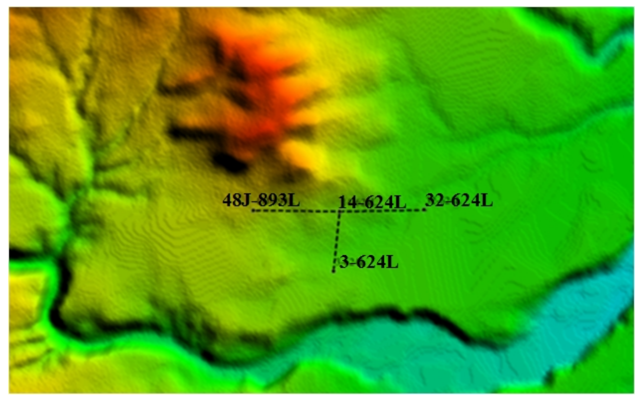


Fig. 5. Global Mapper terrain layout in transverse mercator projection.

It is worth mentioning that this study was performed with measured weather data from different WSs rather than fully deploying the CFD model. Nonetheless, the key intent here is to provide a generic weather-based DLR developed by INL that can be fully or partially deployed by electric utilities for TLs of their interest.

*2) GLASS:* Glass is a core engine of a DLR system that computes real-time ampacity at each of the midpoints of the line between supporting TL structures under consideration. It enables integration of advanced sensors and sensor networks, communication and data transfer channels, secure and reliable data management, and real-time processing through a flexible system architecture, with the ability to support and integrate with any utility enterprise system. The GLASS is designed to provide information to the grid operators about the state of their thermally limited transmission and distribution networks, namely bare overhead power TLs. The methodology implemented within the GLASS reduces the need to use a large number of WSs to achieve the necessary accuracy in estimating the ampacity of individual TLs. GLASS achieves this by coupling real-time grid operations data with field-deployed WS measurements and computationally efficient models. Mathematical models based on the IEEE Standard-738 are used to build off the provided iterative solution using modern software paradigms and programming styles to provide a more robust and modular software system.

GLASS is interfaced to real-time WSs and utility data through a standard text file folder. In particular, data can be pushed out to the input folder by the utility's historian or otherwise provided to GLASS by the utility SCADA system. Those data will immediately be processed to provide an output file containing the calculated line ampacity and line temperature estimate, provided line current from the utility is available. Fig. 4 illustrates a flow diagram with all the necessary inputs and corresponding output from GLASS. The flow shows the potential for using forecast information to project line ampacity availability in the future. Note that GLASS uses thermal and geometric properties of the specific conductors in those calculations. The GLASS engine can also be used to calculate historical ampacity versus load using the weather data collected in this study.

## IV. Implementation and Results

This section presents the effectiveness of implementing DLR at AltaLink TLs and its comprehensive analysis.

### A. *Implementation*

To implement DLR methodology at TLs of interest, AltaLink periodically collected data from all WSs and electronically transferred those weather data along with corresponding line load current for each line segment to INL. Upon receipt of the data from AltaLink, INL processed the data with GLASS to obtain calculated ampacity values for each of the line segments. Ratings were computed for the spans within each of the four line segments (SummerView East-West, SummerView North-South, WindyPoint East-West, and WindyPoint North-South) based on a simplified flat terrain model. It is worth mentioning that 'WS32', which typically measures the lowest calculated ampacity ,is used for the direct comparison to the static rating. A single DLR value for a TL segment for each point in the time series was determined by taking the minimum calculated ampacity of all spans in that line segment.

### B. *Results and Discussion*

The performance of the proposed method is evaluated through the analysis of the following two operating scenarios:

*1) Calculated vs. Existing Static Ratings:* In this section, we compared the current static ratings of each of the four line segments contained in the pilot study area to the calculated ampacity juxtaposed to the load data for illustrating the potential increase in headroom and feasibility of accepting additional proposed wind energy in that area. To concisely show a comparison of the DLR to the static rating, the difference between the DLR and the static rating was found for each data point in the time series. This was necessary since the static rating varies with season. The result of that difference was then sorted in order of decreasing magnitude. The distribution of the load was also found by normalizing to the static rating in the same manner to give a measure of the headroom available to increase load compared to the static rating. Particularly, the DLR ampacity and load distribution relative to the static line rating for the four segments were compared and analyzed. Fig. 6 and Fig. 7 illustrates the performance comparison between calculated and current static ratings of the WindyPoint north-south (highest improvements) and the SummerView east-west (lowest improvements) line segments. Because the two selected line segments are perpendicular to each other, the impact of wind direction can also be demonstrated with those scenarios. Note that the normalized static rating reference is shown as zero and a sorted list of the line load is shown as the difference between the static rating and the line load to show the value as a negative value indicating headroom to the static rating.

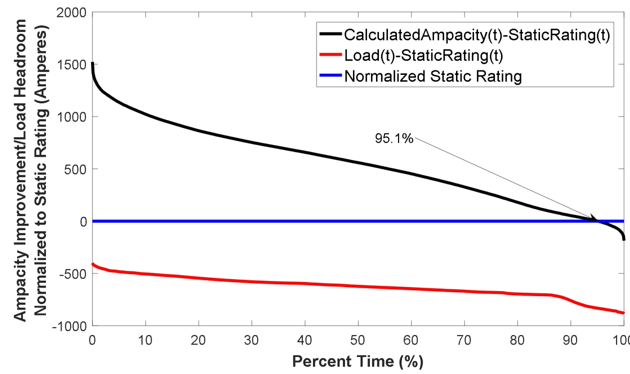


Fig. 6. WindyPoint north-south segment with sorted values of the improvement of the weather based ampacity calculation versus the static rating.

The summary of findings from analysis on all four line segments is illustrated in Table II. It can be seen that WindyPoint line segments have significant line current headroom even with the static rating. However, the SummerView east-west line segment load is near the static limit for some period of time and, therefore, may have the most to gain from application of DLR. Fig. 12 and Fig. 13 do not show the correlation of load to rating in a temporally coherent manner but merely summarizes the differences in calculated ampacity and the static rating juxtaposed to the range of the line load.

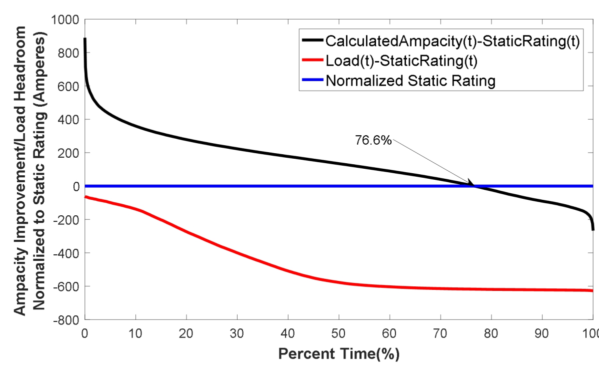


Fig. 7. SummerView east-west segments with sorted values of the improvement of the weather based ampacity calculation versus the static rating.

TABLE II. Key outcome of four different case studies

| Line Segment | Real-Time Rating Results |
|---|---|
| SummerView Fidler 624L East-West | Above 150 static rating 76.6% of study period, with mean increase of 22% over static |
| SummerView Fidler 624L North-South | Above hypothetical 230 static rating 77.4% of study period, with mean increase of 35% over static |
| WindyPoint Fidler 893L East-West | Above seasonal 173/214 static rating 95% of study period, with mean increase of 47% over static |
| WindyPoint Fidler 893L North-South | Above seasonal 173/214 static rating 95.1% of study period, with mean increase of 72% over static |

*2) Load Dynamics vs. Static/Calculated Ratings:* In this section, we present the analysis of load versus weather -based

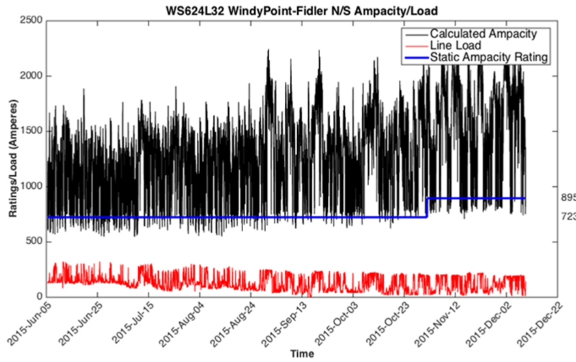


Fig. 8. Weather-based calculation of ampacity compared to the static rating and line loading for WindyPoint east-west line segment.

calculated and static ratings of the TLs under consideration. The analysis was done for each line segment over the duration of the data collected incorporating calculated dynamic ratings, static ratings, and line loadings. All the comparisons were made using WS32 as the reference WS which has the least improvement over static rating. It is worth mentioning that the WindyPoint line segments were rated with dual-season ratings to account for ambient temperature differences in rating assumptions. Fig. 8 illustrates the WindyPoint north-south segment with static and computed ratings compared against the loads. It can be observed that load never exceeded the static rating over the study period. In fact, the load shown is comfortably below the static ratings. One notable attribute of the calculated ampacity is that it may fall below the static rating under conditions of low wind or a higher than static rating assumed ambient temperature. Note that the DLR ampacity of the WindyPoint east-west segment tracks proportionally with the north-south segment. The only difference was expected due to North-South lines being oriented preferentially normal to the prevailing wind direction.

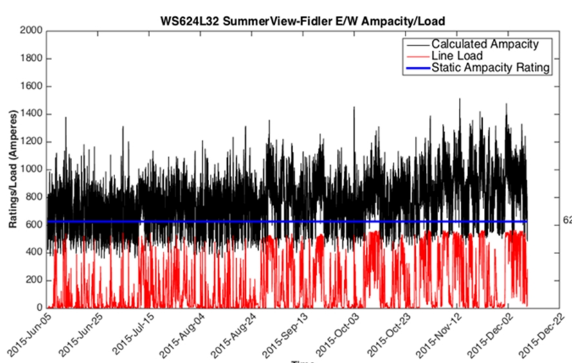


Fig. 9. Weather-based calculation of ampacity compared to the static rating and line loading for SummerView north-south line segment.

The static and computed dynamic ratings of the SummerView east-west line segment is illustrated in Fig. 9. It can be observed that this section has the most potential for congestion with respect to both static and dynamic ratings. In fact, the weather-based DLR produced ampacities below the static rating most of the time. However, in a small number of instances during the study period, the calculated rating was lower than the line load for short periods of time. The total time that the load was higher than the calculated ampacity was for 21 minutes totaling from seven instances. A possible cause of the load exceeding the DLR is that the weather conditions were such that the wind reached the wind farm before reaching the TL. Nonetheless, the DLR provides better real-time situational awareness in these cases also. Note that SummerView north-south TL segment is very closely correlated with the calculated ampacity of the WindyPoint north-south line as both of these line segments are using the same supporting structures and conductor type.

## V. Conclusion

This study presented field implementation of weather-based DLR technology to transmission corridors of AltaLink and quantified any untapped ampacity of the TLs that could be utilized. The potential value to enhanced utilization of capital intensive assets, improved optimization of planning upgrades and new lines, as well as improved situational awareness for operators making real time decisions relative to TLs were presented. Furthermore, comparisons were made between the existing static rating and proposed DLR, and the potential benefits for enhanced transmission assets utilization by DLR were quantified. In fact, for the given TL segments, the real-time ratings are above the seasonal static ratings for up to 95.1% of the time, with a mean increase of 72% over static rating. This shows significant potentials for improvement in terms of line capacity utilization. Future work includes implementation of a complete CFD model and utilizing those data to obtain dynamic trending of line temperature using non-steady state heat transfer models.

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