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APPROACH OF IMPROVED DYNAMIC LINE RATING USING SENSORS ON OVERHEAD TRANSMISSION LINES

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Abstract: The boom of renewable energies and the constantly growing demand for energy are pushing the grid ever further to its limits, which requires a continuous expansion in transmission capacities. In addition to numerous projects dealing with far-reaching grid extensions, Austrian Power Grid (APG) attempts to strengthen the network's capacities by implementing technologies like Dynamic Line Rating (DLR). DLR comes with the advantage of increasing the capacity of transmission lines without any bigger construction effort and thus saves on expensive congestion management. Related to the clearance older transmission lines at APG were designed for a maximum conductor temperature of 40 °C. When upgraded to 80 °C clearance, lower outside temperatures and higher windspeeds enable a temporary limit of current above the rated value of the conductor and thus lead to a higher line capacity of the overhead line. This circumstance has been taken into account by APG for already many years by determining the increased limiting current for the day ahead, using weather forecasts which can be described as ambient adjusted forecast rating. Since weather forecasts, which are based on weather stations and computer models (artificial intelligence), become more and more accurate and sophisticated, the current model applied by APG does not utilize the full potential of DLR and could be further developed. Therefore, APG started an attempt to improve DLR by installing conductor-mounted sensors from different suppliers which measure additional parameters to determine the limiting current more precisely on a selected transmission line. Based on accurate location-based measurements such as conductor temperature and local wind speed, the project aims to improve the real time capacity and especially the capacity forecast. The paper will present an analysis of the gathered sensor data and a comparison to the existing DLR system. Special focus will be taken on the potential benefits of this sensor-based technology.

Keywords: Dynamic Line Rating, Temperature Monitoring, Conductor Temperature, Sensor Technology

INTRODUCTION

The energy transition results in a reduction of the use of fossil energy sources and a high rise in use of renewable energies. This increase of renewable energies in combination with the growing demand of energy leads to a grid which is pushed to its limits. Therefore, an expansion of the grid is essential. For a stable operating grid and a secure power supply APG has to carry out redispatch measures almost daily. To avoid bottlenecks in the grid APG those interventions summed up to 203 days in 2024 [1].

Besides numerous grid expansion projects, APG implemented a DLR system to operate overhead lines in dependence of the weather in 2013. This system takes advantage of the fact that the line transmission capacity of an overhead line (OHL) depends on its thermal load capacity and thus from ambient factors. For example, lower outside temperatures and higher wind speeds enable a temporary limit of current above the rated value of the conductor and thus a higher line capacity of the OHL [2]. Older OHLs at APG were designed for a maximum temperature of 40 °C, therefore those lines have to be upgraded to 80 °C regarding conductor sag and the resulting clearance to the ground and objects first, before DLR can be put in operation. The goal is, to make the hole APG-grid DLR ready, which results is in several ongoing upgrading projects. However, the parameters used in the APGs actual ambient adjusted operating system are based on conservative assumptions regarding weather parameters like solar radiation (hourly values, day and night), wind speed (defined fixed value) and the forecasted maximum temperature (hourly). Additionally, the environmental parameters (wind speed, ambient temperature) are measured by a weather station in the substations of the monitored line at a time resolution of 15 minutes (adjusted with a safety margin) and the hourly solar radiation.

The current model does not utilize the full potential of DLR and could be further developed to increase the limiting current. Therefore, APG started the pilot project "DLR Measurement Project" in 2021, where several DLR sensors

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from different manufactures were installed on a particular OHL. Those sensors are mounted directly on the conductor of the transmission line (see Figure 1) to measure the conductor temperature, which is complemented with local weather conditions (wind speed, ambient temperature) that are either measured with a weather station on a nearby OHL-tower or taken from weather service providers. The aim of the project is to evaluate the different sensors and the measured parameters and to improve the real time capacity and furthermore the day ahead forecasted capacity. The focus will be taken on potential benefits of sensor-based technology, to analyze the gathered data and to compare it with APGs current DLR system. This evaluation is intended to form a basis for deciding whether line sensors should be added to APGs DLR system in the future.

Figure 1: Location of a DLR Sensor on a 220-kV-OHL (marked by the yellow box)

1. METHODOLOGY

1.1. Sensor Overview

For the pilot project, DLR sensors of three different manufactures were chosen and installed on a selected circuit in APGs grid. Those three manufacturers provide sensors with different characteristics. All sensors measure the line temperature but not every manufacturer provides direct measurements of environmental factors such as wind speed but instead use weather data from weather service providers. An overview of the provided measured parameter can be seen in Table 1. In the beginning of the project all sensors got evaluated in laboratory test [3].

Table I: Measured parameters of the sensor models

Manufacturer	Line Temperature	Current	Sag	Ambient Temperature	Wind	Solar radiation
A	Y	Y	N	Y	N	N
B	Y	Y	Y	WP	WP	WP
C	Y	N	N	WS	WS	WS

Y... Yes N... No
WS…measured by a weather station on nearby tower
WP... not measured, weather service provider

1.2. Measurement Locations

Overall, there are 14 sensors installed at five different sites on the 103 km long 220 kV transmission line in Tyrol, western part of Austria (see Figure 2). The OHL is situated in an alpine area and passes through different valleys and mountainous terrain. The locations were chosen in a project together with Graz University of Technology to maximize the number of DLR relevant measurement sites. For example, location 1 is the highest point on the OHL.

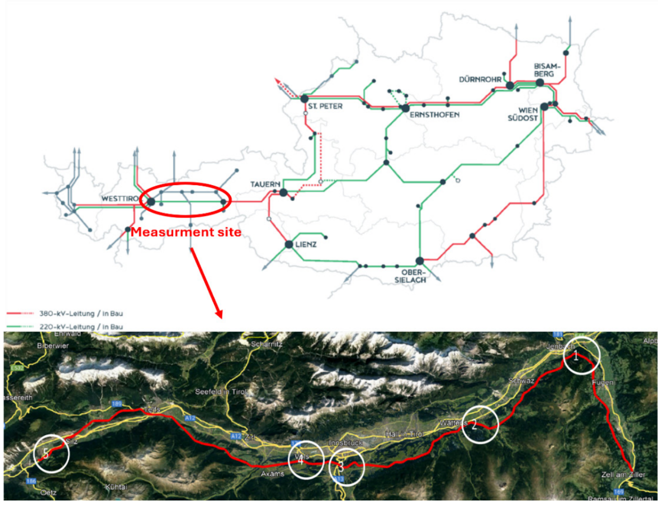

Figure 2: Measurement site of DLR measurment project, 103 km transmission line in western part of Austria

To get a good DLR model of the line the 14 sensors are distributed on different spots. The distribution can be seen in Table II.

Table II: Distribution of the DLR sensors on line

	Manufacturer		
Measurement location	A	B	C
1	3	1	2
2	1	0*	0
3	1	0*	1
4	1	0*	0
5	2	0*	2

*… further installations are planned

As it can be seen in the Table 2 above, more installation of sensor B are planned in April 2025. The exact measurement locations were chosen in consultation with the manufacturer and the OHL technicians on site.

1.3. Measurement Period

Once all sensors are installed, a measurement period of one year (April 2025 - April 2026) is planned, covering all four seasons. However, the measurement data collected so far also gives a first insight into the future DLR capabilities. The measurement periods of the different sensors (manufactures) are listed in Table III.

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Table III: Mesurement periods of the three sensors/ manufacturers

Manufacturer	Measurement Period
A	01.02.2024 – 10.06.2024
B	26.02.2024 – 20.05.2024
C	02.09.2024 – 10.03.2025

Sensors of manufacturer A had connection problems in June 2024 and were replaced, the data before the replacement is used to compare the initial values. Direct measurement data from sensor manufacturer B is only available until 20.05.2024, as this sensor became defective at that point and will also be replaced in April 2025. Despite this the manufacturer provides a line rating model based on the provided weather data using the CIGRE model. Data from sensor manufacturer C is available since its installation. In general, the reliability of sensors still seems to be an issue. This is viewed very critically from TSO site, as the necessary replacement are difficult to manage, as suitable switch-off times for the OHLs are often hard to find and resources get tied up. Another important aspect for evaluating the various manufacturers is the mounting method. Some sensor manufacturers have models that are easier and quicker to install/remove. This consideration is also interesting for ongoing operation of the OHL e.g. when changing of the measurement locations is needed.

2. DATA

For the evaluation of the three manufacturers following parameters are compared: line temperature, current and ampacity (calculated by the sensor manufacturer). No ampacity values are currently available for sensor manufacturer A. Sensor manufacturer B and C provide a calculated ampacity. The maximum values within a 15 minutes period are used for the comparison. The maximum values were chosen to present the worst-case scenarios, e.g. the highest temperature. The sensor data is send via GSM and can be accessed by a cloud system. In total, data is currently available from 01.02.2024 - 10.03.2025. After further installations the data will be recorded continuously for at least one year, as mentioned in the section above.

3. RESULTS AND DISCUSSION

In Figure 3 the measured line temperature obtained by the three sensors is shown. Therefore, the sensors from location 1 are chosen, since on this site sensors from all manufacturers are installed. This comparison provides information about the temperature measurement of the three different sensors.

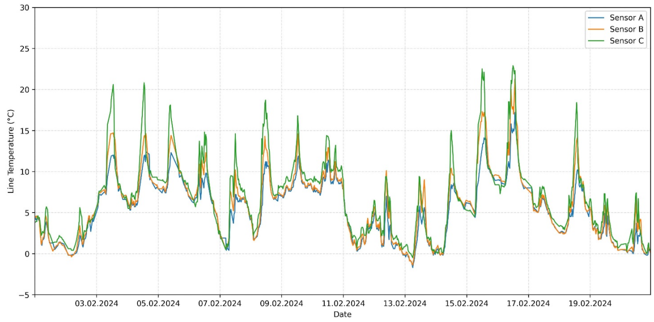

Figure 3: Temperature profile of the three sensors over time, Sensor A (blue), Sensor B (orange), Sensor C (green)

The graph shows the temperature profile of the three sensors on location 1 from February 1, 2024 to February 21, 2024. The conductor temperature ranged between around 0 °C and 20 °C. It shows that all three sensors follow the same trend as the day and night cycle but vary in their value. Sensor C (green) measured higher temperatures then Sensor A and B. Sensor A (blue) tented to have the lowest temperature readings. One explanation for the differences of the temperature profile could be the housing of the sensors, as some are mainly made from metal and others use composite materials. Previous research showed that the housings, that enclose the conductor, appeared to hinder heat dissipation, causing the conductor temperature to increase locally [3].

Figure 4 shows the differences of the temperature profile in a Bland-Altman plot, which plots the difference in the measured conductor temperature over the mean conductor temperature.

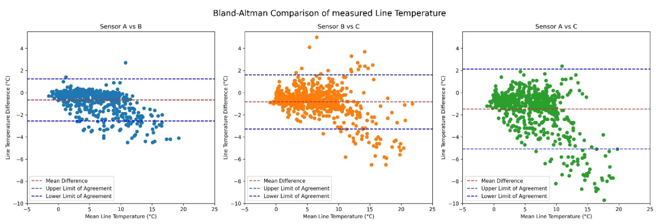

Figure 4: Direct comparison of the different sensor manufacturers.

The direct comparison clarifies the results from Figure 3. The far-right plot compares Sensor A (lowest in Figure 3) with Sensor C (highest in Figure 3) and therefore shows the greatest temperature difference of the three plots with a mean value of 1.5 °C and a maximum deviation of up to 10 °C. The graph also shows that the divergence of the values increases with the mean conductor temperature. The plot on the far-left shows that the measured temperatures value of Sensor A and Sensor B are more aligned to each other with a mean value of 0.7 °C and a maximum deviation of up to 4.5 °C.

Figure 5 shows a comparison of the ampacity of sensor manufacturer B and C with the current DLR system of APG.

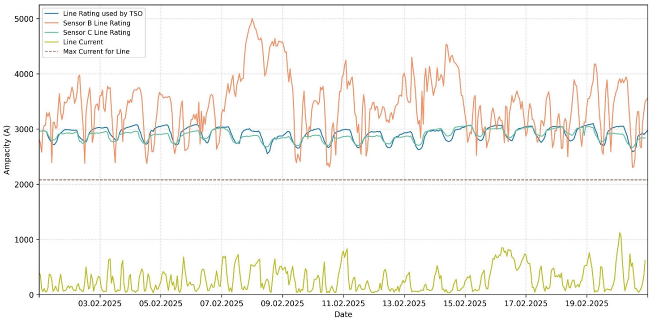

Figure 5: Comparison of the calculated Ampacity for Sensor B (orange), Sensor C (green), current line rating used by APG (blue), max current of the line/static line rating 2080 A (red)

The blue line shows the conservative line rating based on weather parameters, which is currently used by APG. The red line shows the static current rating of the conductor (twin-bundle) of 2.080 A at ambient conditions defined in standards. The comparison of Sensor C (green) with the applied line rating (blue) shows, that the curves follow the same trend. The reason for that is, that both systems use similar formulars in the calculation process. Sensor B (orange) compared with Sensor C (green) and the applied conservative line rating (blue) shows higher peaks and more variation, sometimes even below the applied conservative line rating. Since the wind speed is weighted more strongly in the CIGRE model of sensor B it is assumed that this causes the difference to the current APG line rating which uses conservative safety margins for the wind speed. This comparison demonstrates that the wind speed has a large impact when it comes to the DLR calculations.

4. CONCLUSION

The initial evaluation already provides interesting results regarding the different manufacturers. The measured temperature of the sensors showed relevant deviations from each other. It is assumed that the differences are due to the design of the housings, as some of them dissipate heat better than others. The results also show that the divergence of the measured temperature values increased with the mean conductor temperature. This issue requires further detailed evaluations of the summer months.

In terms of the ampacity, two sensors were compared with APGs current DLR system. The comparison shows that the wind speed has a great impact on the calculated ampacity. Accordingly, the rating of the OHL can be increased when weather-related factors are considered more precisely, and more accurate data is taken into account. A comparison of the values over a year, including the data from the third sensor, should provide more information. In this work the comparisons of the sensors were carried out at one location, but it should be noted that different weather conditions can prevail along the route, so that a DLR system requires several measuring points.

Further comparisons are planned, with the data from the planned measurement series from April 2025 to April 2026, whereby not only the values such as line temperature, current and ampacity are compared with each other, but also the sensors reliability e.g. the frequency of failures.

The other measurement sites should also be checked after the planned one-year measuring period to cover all seasons. Additionally, an evaluation, if the number and location of the measurement sites were sufficient should be carried out.

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BIOGRAPHY

Julia Maier completed her bachelor’s and master’s degrees in electrical engineering at Graz University of Technology in 2021 and 2024, respectively, and then worked as a research assistant at Graz University of Technology. There, she worked in the field of lightning research and real-time lightning risk assessment. Since fall 2024, she is employed at Austrian Power Grid AG in asset management in the overhead lines division. Julia Maier is a member of CIGRE NGN and OVE Austrian Association of Young Electrical Engineers, where she participates in workshops and excursions.

Oskar Oberzaucher earned his master’s degree in Electrical Engineering from the Vienna University of Technology in 2013. He then began his professional career at Austrian Power Grid AG, the Austrian transmission system operator (TSO), working in the Asset Management department with a focus on overhead lines. In this role, he is responsible for emission-related topics of overhead lines, including electric and magnetic fields as well as audible noise. Oskar Oberzaucher is an active member of the relevant working groups of the OVE – Austrian Electrotechnical Association and Oesterreichs Energie, the association representing stakeholders of Austria’s electrical engineering and energy sectors.

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Klemens Reich has been with APG for many years. He studied Electrical Engineering at the Technical University of Vienna and currently serves as Team Leader in the Asset Management division, where he is responsible for overhead lines and cables. He is the convener of the Austrian standardisation committee for overhead lines, an active delegate in various CIGRE study committees and working groups, served as Chairman of the CIGRE SEERC from 2019 to 2022, and contributes to ENTSO-E working group for asset management.

Martin Waldhart is currently studying Physics at the Technical University of Vienna and is writing his master's thesis on dynamic line rating. He is a trainee at APG in the overhead lines division.