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Preparatory analysis steps to establish a safe and efficient dynamic line rating (DLR) system

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SUMMARY

Dynamic line rating (DLR) is a sensor-based method for adjusting the transfer capacity of high voltage overhead lines to maximize the utilization of existing infrastructure. The demand for such smart technologies has increased, in concert with the current trend of changes in the electricity system. Using DLR makes it possible to operate the power lines near their allowable thermal state, which is a promising solution technically and economically. A well-structured DLR system results in significant surplus transfer capacity and safer line operation. This combination can be achieved by a DLR-based complex overhead line management system that includes a line rating subsystem such as forecasting, safety distance, and icing alert functions. Although the number of DLR pilot projects is growing worldwide, these are mostly demonstration projects to solve an existing problem regarding capacity problems. In these cases, there is no need to define tasks such as selecting the power lines, determining their current limiting element, or the number of sensors needed and their installation location. Another problem is that although several manufacturers specialize in line monitoring sensors, they do not provide additional information for addressing these questions. There is a gap in the international literature about the preparatory steps needed to establish a DLR system, making it challenging to implement an efficient and reliable monitoring system.

This paper aims to fill this gap based on theoretical approaches and practical experiences from EU-funded FARCROSS projects. The authors' main goal is to present a unified preliminary analysis system that lays the foundation for deploying a safe and efficient DLR system. This paper summarizes the necessary initial steps to maximize the benefits without violating the current level of safety and security. These preparatory steps contain new methodologies not yet discussed in the literature as well as existing processes supplemented with new approaches, such as selecting a transmission line on which installing a DLR system is most beneficial or setting up a ranking between power lines to determine which should be first equipped with sensors if there is a significant capacity problem on the grid. An example of reshaping existing preliminary steps is the concept of critical span analysis, which has already appeared in other related articles. This analysis identifies the necessary number and placement of line monitoring sensors. The complex analysis presented in the paper shows that some of the previously used methods do not give adequate results for the installation locations, and a new, hitherto untested parameter, low-frequency electric field, should also be considered in the simulation. The authors also present how the stochastic weather parameters' effect can be assessed, and a new approach for critical span analysis is also introduced based on the Monte Carlo simulation. The simulation's results show that there are

transmission lines where only a distributed monitoring system with densely placed sensors can provide a secure solution.
Based on the preparatory analysis system presented in this paper, it is possible to establish a reliable and efficient DLR monitoring system from the beginning of the process, which provides a solid basis for infrastructure implementation and the actual operation part of the projects.

KEYWORDS

dynamic line rating, DLR, line selection, critical span analysis, low-frequency electric field, distributed thermal sensing, system approach

INTRODUCTION

The strategic role of energy security and electricity is becoming increasingly important, which poses entirely new challenges for system operators [1], [2]. The growing demand for energy and the pursuit of the Internal Electricity Market led to an increasing focus on the dynamic change of transmission line constraints and the need for real-time monitoring of the system elements [3]. Adjusting the transmission line ampere capacity (ampacity) limits to prevailing environmental parameters is called dynamic line rating (DLR), which seems promising among cost-effective, load-bearing methods. DLR is based on the real-time monitoring of power line load, thermal behaviour, and weather parameters in the power line's vicinity. Given that the maximum thermal stress is known for each transmission line at safe operation, a thermal equation can be used to determine the line rating for a given operating condition [4], [5].

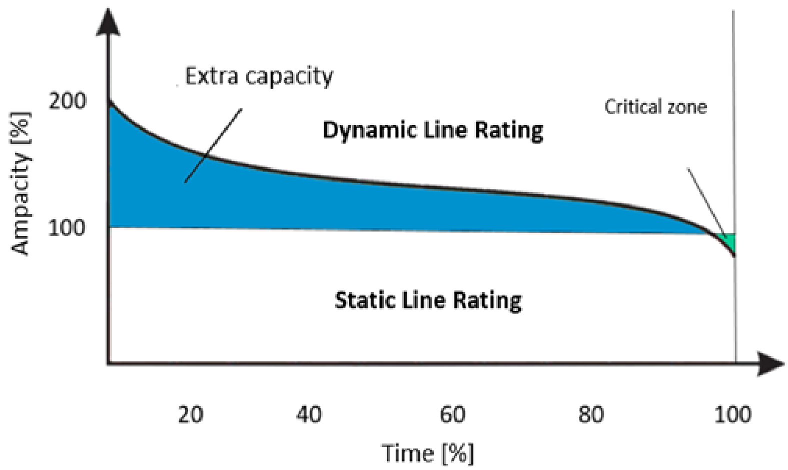

Figure 1. Surplus capacity gained with the application of DLR technology [6]

In contrast to the traditional static calculation, this method allows for an adaptive line rating calculation that can free up significant load capacities 90-95% of the year [4], [5]. This process also provides an opportunity to predict the load capacity and a sag-clearance calculation, and an icing alert subsystem that can be implemented using the measured and forecasted data. However, the application of DLR requires different input data that come from sensors, weather stations, and weather forecasts.
This paper is intended to show the main steps and key issues arising in the implementation stage of a DLR system based on the experiences of the European Union-funded FARCROSS (FAcilitating Regional CROSS-border Electricity Transmission through Innovation) project. FARCROSS aims to increase the exploitation of transmission grids in Europe and increase the electric grid's reliability and security. Within the framework of Work Package 5, the implementation of complex grid management with health index calculation based on DLR is in progress, and the results are described in [7].

POWER LINE SELECTION METHODOLOGY FOR DLR SYSTEM IMPLEMENTATION

Deploying DLR systems requires significantly lower investment costs than retrofitting the conductors or building new transmission lines. However, it is essential to carry out some fundamental analyses to achieve an efficient and economical implementation. The first step of this process is to select the right transmission line, which is a central issue for the system's success.

The main advantage of DLR, besides providing the ability to apply real-time line rating, is that the power line ampacity can be significantly increased with its application. Therefore, it is advisable to implement DLR on a transmission line that is considerably loaded most of the time. When selecting these power lines, it may be helpful to examine the load duration curves. In load duration curves, special attention must be paid to the relative load rather than the absolute one, because the utilization rate carries more information to system operators. When examining the duration curves, it is advisable to analyse the data series of several years to filter out the annual differences. It is necessary to include load limits and load calculation methods, such as static line rating, seasonal line rating, etc., in the analyses.

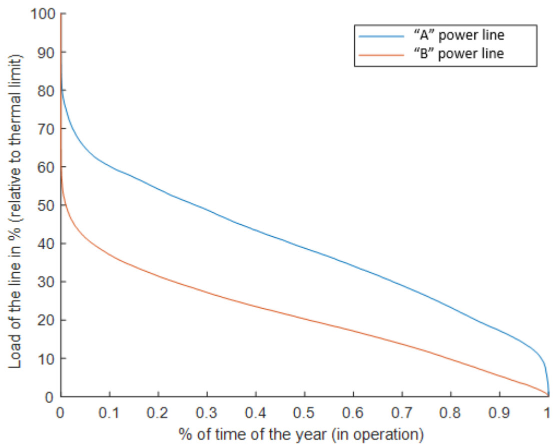

Figure 2. Relative load duration curves of power lines

As already highlighted, the essence of DLR is that it considers the current weather parameters' cooling and heating effect on the phase conductor to achieve higher ampacity. However, if the load capacity of the conductor is not the bottleneck in the transmission line, then its uprating with DLR will not lead to a meaningful result on the transmission line. For this reason, the limiting elements must be examined and, if they are located in the substation, e.g., circuit-breaker, disconnector, current transformer, wave trap, power transformer, etc., it is not advisable to install a DLR system on the transmission line.

When selecting a power line, another essential consideration includes congestion management and the density of the electricity network. The latter can be important, especially in Central and Eastern Europe, where cross-border lines are limited. Strategic considerations also include factors related to changes on the generation side. If a significant solar or wind power capacity is planned in an area they affect the power flow, and the capacity expansion may be justified due to the increased load on the transmission lines.

Finally, the choice of the transmission line may also be influenced by historical weather events. A complex, DLR-based grid management system also provides the ability to provide additional features such as the icing alert system for system operators. Therefore, installing a DLR system can also be beneficial on transmission lines where icing or failure due to extreme weather conditions has occurred in the past.

INNOVATIVE MODELS FOR DETERMINING SENSOR INSTALLATION LOCATIONS

Different dynamic line rating systems can be established in terms of the monitoring equipment used, such as a weather-based DLR system, a phase conductor monitoring strategy or a hybrid DLR system, which combines the two previous approaches. It is challenging to determine the necessary and sufficient number of monitoring equipment and their installation locations from the operational perspective. Generally, sensor manufacturers do not provide simulations or calculations to determine the acceptable number and location of the sensor infrastructure. Therefore, research centres have developed different methodologies to identify the so-called critical spans of the power lines, which supports this decision-making process. The presented methods developed by BME can be applied for DLR systems based on all monitoring strategies.

Existing methodologies

Critical span analysis aims to identify the spans that accurately represent the thermal and clearance conditions along the whole line. The simplest method for sensor allocation is the equidistant sensor placement methodology [8], based on which the sensors should be installed at equal distances from each other. Although this method does not require complex calculation or simulation, the criteria regarding the accurate thermal and clearance monitoring requirements are not met.

There are two other advanced critical span analysis methods available in the international literature. The basis of these methodologies is to examine the weather parameters in the vicinity of the overhead line in question. The heuristic method proposed by M. Matus et al. investigates the correlation between the ampacity calculated based on weather parameters from different locations [8]. Teh's model also uses weather parameters to determine the potential conductor annealing [9].

The disadvantage of the above-mentioned critical span analysis models is that they rely on weather data from different weather models or measuring equipment, usually placed in open areas. Therefore, a significant deviation between these weather data and local weather stations installed on the power line towers can be observed.

To address this issue, BME offers three different solutions based on novel concepts to perform effective power line monitoring and DLR. The first solution (BME critical span identification) is based only on the technical parameters of the power line, thus eliminating the deviation arising from weather parameters. This forms the basis of the second method extended with weather parameter changing and electric field distribution along the power line. The second method (BME distributed sensor installation) is based on the idea that environmental factors can be handled as distributions; therefore a probability function can be assigned to the weather parameters. Last, a third concept is also presented to guide the line monitoring sensor installation. This concept supports equipping all the tension sections with sensors since, in this way, the erected system can be extended for asset management and health index purposes. These three possible solutions are described in detail in the following chapters.

BME's critical span identification algorithm

The challenges discussed in the previous chapter required the development of a new critical span identification algorithm that eliminates the deviation caused by weather parameters. The novelty of BME's critical span analysis methodology is that it takes into account not only the ground clearance level of each span but also the additional clearance from any object located under the line.

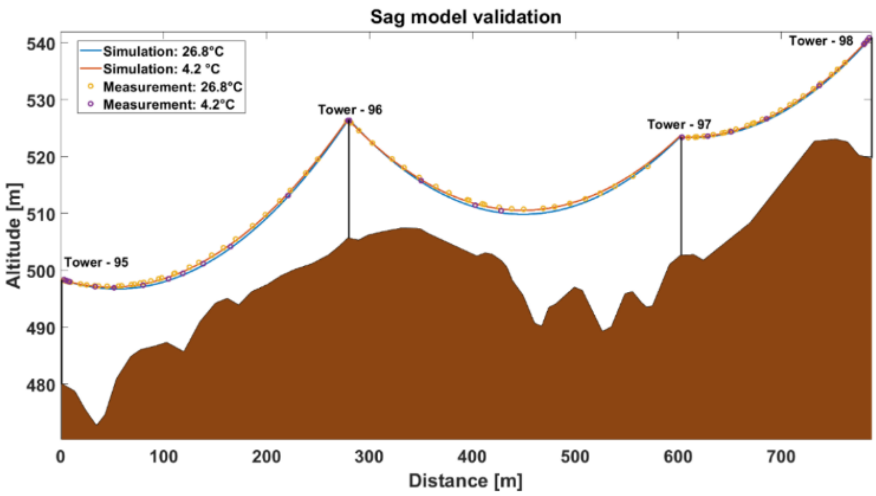

Figure 3. Validation of sag simulation algorithm on a 110 kV single circuit power line

The basis of the proposed algorithm is a sag simulation methodology, which determines the sag of the bottom phase conductors with a catenary curve. It also considers the topography along the line's route in two ways. Firstly, the catenary curve of the conductors is corrected with a skewness factor in the case of oblique spans. The elevation profile of the topography is also simulated in order to calculate the ground clearance of the spans. The sag simulation algorithm is validated with field measurements carried out using a Leica theodolite. Figure 3 illustrates the accuracy of the sag simulation algorithm at two different conductor temperatures, where the average deviation is less than 20 cm compared to the local measurements.

After the sag simulation of each tension section, the clearance is calculated for each span. If there is no object (e.g.: recreational area, overhead line crossing, railway, building, etc.) located under the investigated span, then the clearance of the span is the minimal distance between the ground and the bottom phase conductor. If any object is located under the span, then the ground-clearance and the minimal distance of the bottom phase conductor from that object are calculated.

Next, the clearance reserve is determined according to the locally applicable legal requirement, which is the EN 50341-1:2021 in European practice. The clearance reserve is defined as the difference between the legally required clearance, which depends on the object potentially located under the conductors, and the clearance of the span.

The required safety reserve of the clearance during the application of the DLR system is determined according to the TSO's needs, which affects the number of the required sensors. The BME's critical span analysis results are those spans in which the clearance reserve is lower than the necessary safety reserve determined by the TSO and in this way must be equipped with a sensor independently from the weather changes in any case. This method is really advantageous if a shorter transmission line is available or there is no significant weather change in different parts of the transmission line. [10]

BME's risk-based, distributed sensor installation concept

Previous studies have shown that interpolation of weather parameters measured away from the transmission line results in inaccuracy. At the same time, it is essential to properly manage the spatial distribution and heating effect of weather parameters, as the length of transmission lines can exceed a few hundred km. This was the motivation for introducing a novel, distributed sensor installation protocol aiming to monitor all the spans above the critical span analysis result, where sagging or annealing can also cause problems.

Besides weather changes, other parameters can also increase operational safety. An excellent example of this is the distribution of the electric field, the amplitude of which is subject to different limits in the European Union. This value is 5 kV/m for the general public and 10 kV/m for occupational safety. Previous simulation and measurement results have shown that there are transmission lines where the electric field exceeds this value at the height of 1.8 m with a sag at the maximum conductor temperature. One of these results is presented in Figure 4, performed by finite-element numerical simulation and local measurements. The point of a well-functioning DLR system is that the transmission line operates under maximum operating conditions at a high percentage of the time, so the electric field must also be considered as a relevant parameter. [11]

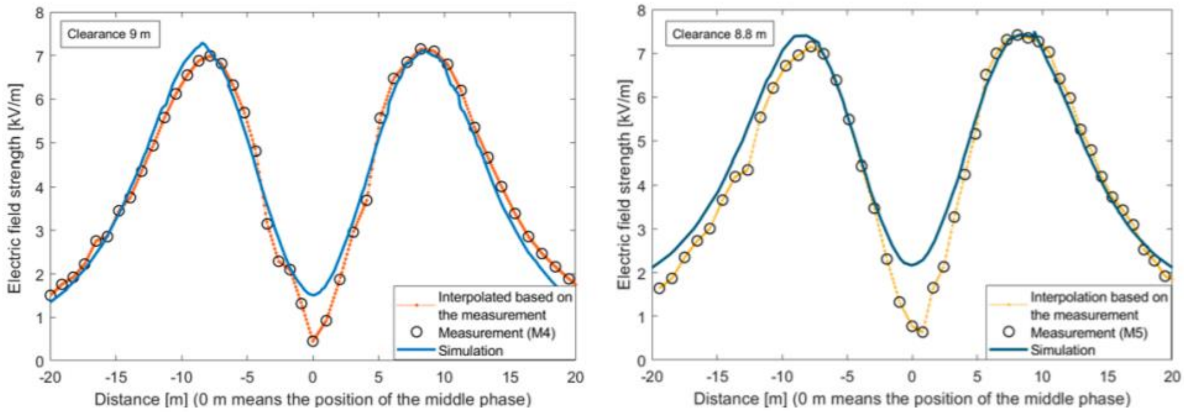

Figure 4. Comparing simulated and measured electric field distributions [11]

The risk-based, distributed sensor installation concept was developed to address the complex problem of sensor installation in three main steps. The first step of the methodology essentially follows BME's critical span analysis and can be matched with the important addition that the electric field amplitude around the phase conductors is also examined, which can also be a limiting factor. In the second step, a reference weather input is required for the first sensory point in the next step. From this, a new ampacity value can be calculated which can represent the new line load assuming full utilization. Some parameters (line load, ambient temperature, solar radiation) are expected to vary little along the transmission line. However, this cannot be ruled out for wind and precipitation. Distribution functions should be applied to these parameters from which multiple Monte Carlo samplings can determine a distribution for conductor temperature and ampacity. The absolute risk of these becomes essential in the third step. Tension sections should be ranked based on the minimum temperature causing a sag or annealing problem (these need to be separated and handled differently). The operator should define the level of acceptable risk for the DLR system. In the third step, evaluate the critical span based on the simulation results. Suppose the Monte Carlo simulated conductor temperature exceeds the allowable temperature limit at the span. In that case, the simulated number of events and the number of temperature exceedance conductor temperature ratios define the critical span. Suppose the ratio of the number of times the temperature exceeds the following ranked number of simulations unmonitored tension section's maximum temperature and the number of simulations exceeds the level specified by the operator. In that case, a sensor must also be installed in the next tension section.
From this point, the simulation process is repeated until the required safety level is reached. Of course, if more than one sensor installation location is already present, the lowest of the simulated ampacity values must always be considered, which characterizes the entire transmission line.
Figure 5 shows how the conductor temperature distribution and ampacity vary along the line using one or 17 sensors. There is no significant decrease in using more sensors in ampacity, but the risk from conductor temperature can be reduced by at least 10%. [12]

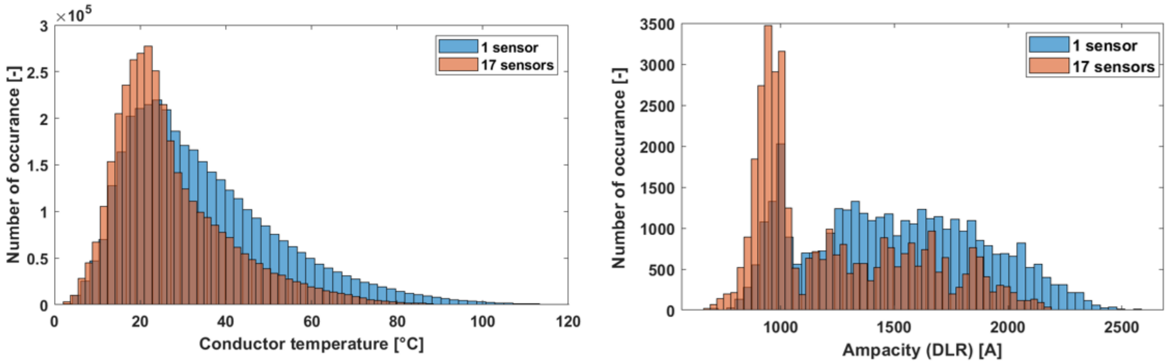

Figure 5. Differences in conductor temperature distribution along the power line and ampacity at different number of sensors [12]

DLR system implementation with low-cost sensors

The third possible concept for establishing a DLR system is based on installing line monitoring sensors into every tension section. Experiences and international studies showed, that the conductor temperature is nearly constant in a tension span, which demonstrates that a tension section is the smallest unit of a line that should be monitored according to the distributed thermal sensing concept [13], [14]. Supposing all the sections are equipped with monitoring devices that measure temperature, the longitudinal conductor temperature profile of the line becomes available. This method is favourable if the operator has an aging power line on which applying asset management seems reasonable. Monitoring all the sections can support avoiding local thermal overloads and allow observing thermal profiles to help implement a health index system for the phase conductors.
The main disadvantage of placing sensors into each tension section is the high capital expenditure due to the high cost of the currently available DLR sensors on the market. This is also valid for the BME's distributed sensor protocol since that method can also result in a high number of line monitoring devices. To cope with this challenge, the High Voltage Laboratory of BME developed a "low-cost" DLR sensor

to provide an economical but safe solution for line monitoring. During the development phase, the main goal was to create a device that has only one functionality, namely conductor temperature measurement, which is carried out with high accuracy. The monofunctionally sensor approach allows for favourable development and manufacturing costs.
The main components of the low-cost sensor are the 3D printed composite housing, an A-type Pt100 temperature sensor that is placed outside of the housing to eliminate the shielding effect of the housing, a current transformer-based energy harvesting system and an IoT based central processing unit, which is also responsible for GSM communication. The development phase of the low-cost DLR sensor, and the initial field experiences are discussed in detail in [15].
The first prototype of the low-cost sensor has been in operation on a 400 kV cross-border power line between Hungary and Slovakia since the beginning of 2021, shown in Figure 6.

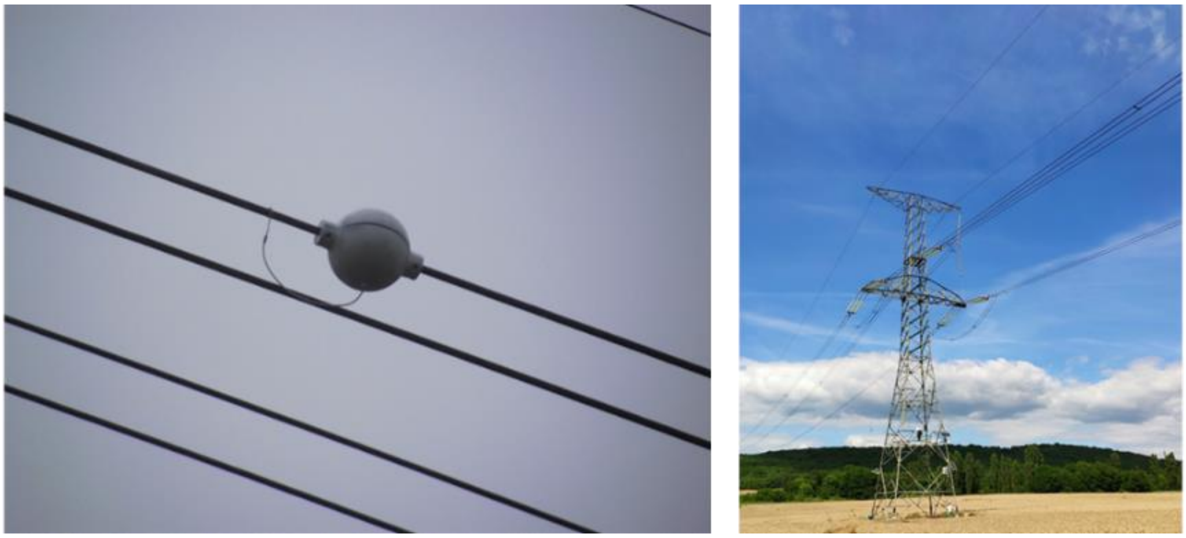

Figure 6. BME's low-cost sensor in operation on a 400 kV cross-border power line (left) and phase configuration of the demonstration line (right)

INSTALLATION AND INTEGRATION OF DLR SYSTEM COMPONENTS

The aim of the FARCROSS Horizon 2020 funded project is to promote a geographically large market through integrated hardware and software solutions. Within the framework of FARCROSS, WP5's target is to integrate DLR and health monitoring systems to utilize cross-border transmission capacities more efficiently than before.

Power line selection for DLR-H demo

The planning phase of the project was started with the exploration of the challenges of each TSO (APG, HOPS, IPTO and MAVIR) involved in the DLR-H demo within the framework of WP5. The main expectations were formulated regarding the application of the DLR-based expert system on their grid. These expectations, such as congestion management, handling of the accelerated expansion of renewables, preparation for increasing peak demands, etc., are closely related to the strategical point of view of the line selection methodology for DLR-H demonstration, thus those also formed the basis of it.
Then, each TSO's grid was analyzed according to the new criteria presented in the "Power line selection methodology for DLR system implementation" chapter. Firstly, the historical load levels from past years were determined for the most loaded power lines. In this stage, the load duration curve was selected to represent the maximum and average loads of the overhead lines (OHLs). As DLR technology can be applied most effectively on those lines where the thermal rating of the phase conductor is limiting the transmission capacity of the whole line, the substation equipment on both sides of the lines involved in the survey was analyzed. For a clearer comparison, the transmission capacity of all line or electrical

equipment, such as phase conductors, circuit breakers, disconnectors, power transformers, etc., was expressed in the Ampere.

The ice forecasting function of BME's DLR-based expert system can be mentioned as a comparative advantage of the system [16]. Accordingly, the historical icing events were also considered during the power line selection for the demo. The last criterion was the strategic characteristics of the investigated OHLs. Beyond the expectations defined in the planning phase, other aspects were also discussed in this stage, such as the line performance from a grid density point of view.

Then, the TSOs internally weighted the four main groups of criteria in order to make an optimal selection from the system operation's point of view.

Each TSO chose two power lines, from which one is a highly loaded internal line, and the other is a cross-border one. The outcome of the power line selection phase is summarized in Figure 7.

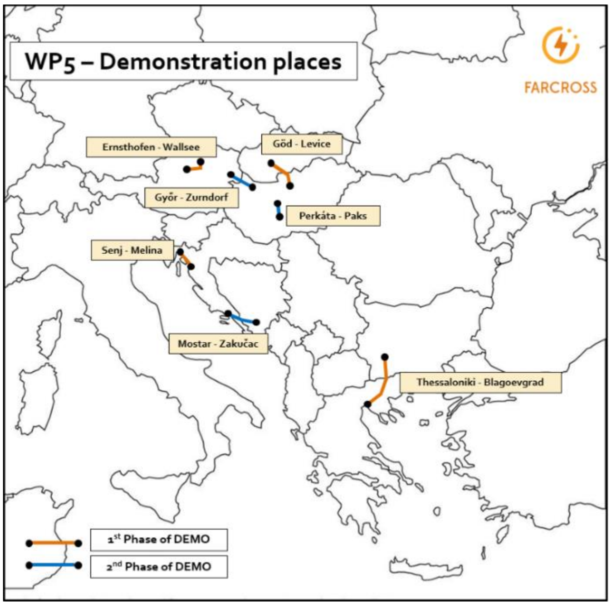

Figure 7. Demonstration lines in FARCROSS WP5 DLR-H demo [7]

Installation of measuring equipment

After the power line selection, the critical span analysis was performed with BME's model as presented in "BME's critical span identification algorithm" chapter. As in the FARCROSS project, one line monitoring sensor had to be installed on the phase conductor, another non-contact sensor on the leg of the selected tower, a weather station on the tower's lattice structure and also a tower health monitoring sensor had to be placed on the same tower. The span with the lowest safety reserve was suggested for the installation location.

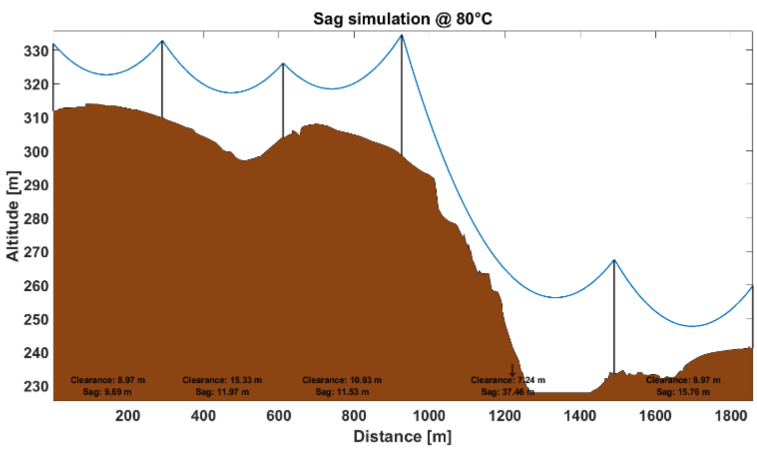

Figure 8. Sag-clearance simulation results during critical span analysis

However, the TSO's had considered further practical features for the final determination of the sensor installation span and tower, such as physical accessibility of the work zone or the mechanical stresses that affect the towers due to the surplus weight of the equipment. Nevertheless, the sensor system was installed on one of the five most critical spans.
The ground clearance determination for a tension section for one of the participating TSO's power lines is shown in Figure 8.
The installation of the measuring equipment was taking two days in each case. During the installation, the TSO's technician crew installed the line monitoring sensors and the weather station with the supervision of the technology providers. The health monitoring sensor was placed by the staff of the manufacturer, which started with the X-ray investigation of the tower legs. Then, a strain gauge system was placed for all legs of the selected tower. In addition to the installation process, the sag measurement of the conductor was also performed during this process. The field sag measurement is required as the boundary condition for the sensors' real-time sag measurement. After the installation process, the lines were energized and the communication of all sensors was established.

Integration of the IT platform

In the framework of FARCROSS WP5 an integrated solution was developed to collect all the data necessary for the DLR-based expert system. Therefore, the TSO's have to provide a server for the demonstration period with secure access to the technology providers and research centers. The field measurements, the load data from the SCADA system and the weather forecast are gathered in a central database on the given TSO's server. These records are available for further calculations, and comparison which BME completes as an independent organization.
BME's DLR-based expert system, which is under implementation, contains the following subsystems [17], [18]:

- Line rating calculation (both real-time and predetermined line rating are determined),
- Conductor temperature tracking,
- Sag-clearance simulation,
- Ice prediction.

CONCLUSION

In this paper, a dynamic line rating (DLR) technology was introduced for the uprating of power lines. In the initial steps of a DLR system implementation various challenges have to be considered, such as the justification of power line selection both from an economic and a technological point of view or the determination of the required monitoring system and its placement strategy.
In the framework of FARCROSS WP5, BME set up a novel criteria framework for line selection as the first step in DLR system implementation. The methodology considers the operational challenges and the technical side of the investigated power system to reach the optimal choice. The transmission system operators made the selection according to the established criteria, which are discussed in detail in this paper. The second step of the FARCROSS project was to define where to install the line monitoring devices. The research group of BME presented three possible options for sensor placement strategies in detail. The critical span analysis concept (method 1) is based on only technical parameters; the distributed sensor installation concept (method 2) considers the weather parameter changes and electric field while equipping all the tension sections with monitoring devices (method 3) supports asset management purposes. After the power line is selected for a DLR system implementation, the required sensor infrastructure and installation location are determined. Since the sensors' number was limited, the sensor places were chosen based on BME's critical span analysis. After the line monitoring devices were installed, the IT infrastructure was set up, and the data collection could start. Since then, the implemented demonstrations systems have worked reliable, and the initial results are promising. This indicates that the preparatory phase of the system implementation was successful.
In conclusion, the preparatory phase of the DLR system implementation has a significant role in establishing the long-term reliability of the system. It also indicates the demand for power line selection and critical span analysis methods. Moreover, pilot projects, such as the presented FARCROSS project

give a great opportunity to practice the algorithms developed through the collaboration of research centers, system operators and technology providers.

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BIBLIOGRAPHY

[1] ENTSOE, Dynamic Line Rating for overhead lines – V6, CE TSOs current practice 2015
[2] EEA Report, “Renewable energy in Europe – 2017 Update, Recent growth and knock-on effects”, 2017
[3] Massaro, F.; Ippolito, M.G.; Zizzo, G.; Filippone, G.; Puccio, A. Methodologies for the Exploitation of Existing Energy Corridors. GIS Analysis and DTR Applications. Energies 2018, 11, 979.
[4] CIGRE 601 WG B2.43 – Guide for thermal rating calculations of overhead lines, 2014
[5] IEEE Std 738™-2012, IEEE Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors, 2012
[6] B. Németh, G. Göcsei, D. Szabó and L. Rácz, “Development and realization of a complex transmission line management system”, 48th Cigre Session 2020, Paris, 24 August – 3 September 2020
[7] FARCROSS official website, https://farcross.eu/, accessed 06 January 2022
[8] M. Matus et al., “Identification of Critical Spans for Monitoring Systems in Dynamic Thermal Rating,” in IEEE Transactions on Power Delivery, vol. 27, no. 2, pp. 1002-1009, April 2012, doi: 10.1109/TPWRD.2012.2185254.
[9] Jiashan, Teh (2016) “Analysis of Dynamic Thermal Rating System of Transmission Lines”, PhD thesis, The University of Manchester, 2016
[10] Dávid Szabó, Bálint Németh, “A novel methodology for critical span identification for Dynamic Line Rating system implementation”, Energy Reports, Volume 7, Supplement 6, 2021, Pages 242-249, https://doi.org/10.1016/j.egyr.2021.08.050.
[11] L. Rácz and B. Németh, “Dynamic Line Rating—An Effective Method to Increase the Safety of Power Lines,” Applied Sciences, vol. 11, no. 2, p. 492, Jan. 2021., https://doi.org/10.3390/app11020492
[12] L. Rácz, B. Németh and G. Göcsei, “A risk-based, distributed sensor installation concept for high voltage grid monitoring”, Energy Reports, Volume 8, Supplement 1, 2022, Pp. 266-274, https://doi.org/10.1016/j.egyr.2021.11.102.
[13] CIGRE Working Group B2.12, Technical Brochure 299 - “Guide for selection of weather parameters for bare overhead conductor ratings,” 2006.
[14] CIGRE Working Group B2.36, Technical Brochure 498 - “Guide for Application of Direct Real-Time Monitoring Systems“, 2012
[15] Gábor Göcsei, Dávid Szabó, Levente Rácz, and Bálint Németh, “New concept of dynamic line rating”, 41. CIGRE International Symposium, Ljubljana, Slovenia, 2021

[16] Szabó, D., Rácz, L., Göcsei, G., Németh, B.: DLR-based ice prevention method. In: 18th International Workshops on Atmospheric Icing of Structures, Reykjavík, Iceland (2019)
[17] L. Rácz, D. Szabó, G. Göcsei and B. Németh, “Grid Management Technology for The Integration of Renewable Energy Sources into The Transmission System,” 2018 7th International Conference on Renewable Energy Research and Applications (ICRERA), 2018, pp. 612-617, doi: 10.1109/ICRERA.2018.8566852.
[18] D. Szabó, L. Rácz, G. Göcsei, B. Németh, "Valós idejű távvezeték termikus menedzsment rendszer" (In English: Real-time thermal management system for power lines), ELEKTROTECHNIKA 113 : 7-8 pp. 26-29. , 4 p. (2020)