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Investigation of Power Line Sag Uncertainty in Day-Ahead DLR Forecast Models

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Abstract. Dynamic line rating method (DLR) is a novel and cost-effective way to extend power overhead lines (OHLs) transfer capacity based on real-time monitoring of the weather parameters in the vicinity of the conductor. Via DLR models not only real-time, but also day-ahead transfer capacity calculation is possible which is more important from the aspect of TSOs. It is important to mention, that these DLR predictions are based on weather forecasts that usually has some uncertainty. The aim of the paper is to identify the potential risk of forecasted power line ampacity due to uncertain weather forecast. To investigate this rarely studied topic, several simulations were carried out applying real power line parameters and forecasted weather data. The results of the simulations showed that under unfavorable weather conditions the uncertainty of the weather prediction could significantly increase the sag of the OHLs if they fully utilized. To monitor the real-time state of the conductor's sag, a novel risk factor calculation method was also investigated that provides additional safety information for the system operators in real time.

Keywords: dynamic line rating, DLR, transmission system, sag, clearance, weather forecast, ampacity

1 Introduction

Today's rising demand for energy and the increasing pace of renewable energy production pose many challenges for engineers and electricity system operators. Although the emission of renewable energy sources is more favorable than conventional power plants, there are many problems with irregular, non-periodic energy production. This affects not only the producer and consumer side, but also the transmission and distribution network between them. The role of this existing power system is becoming more and more important as the close interrelation between the level of security of supply and safe operation is a central issue today. This was recognized by the transmission system operators (TSOs) responsible for the operation of the transmission network, which enabled the emergence of new technologies and methods. One of these methods is the dynamic line rating (DLR), which is used to calculate the transfer capacity of power lines in real time. While this can significantly increase transmission capacity, several other factors, such as sag and clearances need

to be taken more carefully than previously due to potential physiological effects (possible carcinogenesis) of the operating OHLs [1-4]. The aim of this paper is to present the potential risk of sag-clearance deviation due to the uncertainty of weather forecast within the application of DLR.

2 Contribution to Life Improvement

With the advancement of technology, new approaches - such as DLR - become available for transfer capacity calculation of the power lines. The essence of DLR is to install special sensors and weather stations in the vicinity of the power lines to collect real-time data on load and environmental parameters. Sensors are mostly installed on the conductors as they measure mostly conductor temperature, while weather stations are usually installed on the structure of the towers. Using real-time data, it is possible to adjust transfer capacity to environmental changes at all time intervals without exceeding the maximum conductor temperature limit. Applying this method, transmission capacity could be extended by 5-30% in more than 95% of the time, which significantly contributes to increase network resilience.

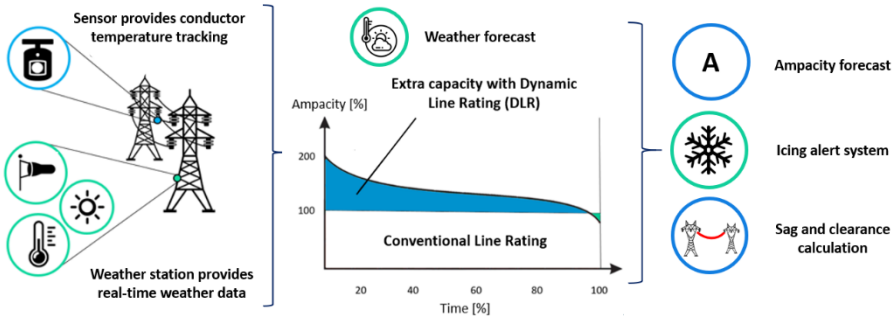

Fig. 1. Complex grid management system based on dynamic line rating

The application of DLR leads much further as it can serve as a basis for a complex transmission grid management system. The implementation of the DLR enables, inter alia, real-time conductor temperature tracking, real-time ampacity calculation, transfer capacity forecast, sag and clearance modeling and implementing an icing alert system for the conductor [5-7]. It is important to mention that this complex grid management increase the resilience of the existing grid and enables a higher level of energy supply. Another important issue is that while the quality of energy service increases the level of safety is not allowed to reduce. The aim of this paper is present the potential threats of potential sag problems due to weather forecast uncertainty and to present a novel risk calculation method to redound the exploitation of the DLR technology benefits.

3 Sag and Clearance of the OHLs

The design of power lines is a very complex task, as both electrical and mechanical aspects - which are interconnected on many fibers - need to be considered. It is important to mention, that for most power lines, the possibility of using DLR method has not yet been considered, so the thermal conditions, sag and clearance calculation are worth to be explored in more detail [2-3].

3.1 Conductors' Thermal Behavior

One important factor that influences the OHLs ampacity is the temperature of the conductor, due to the transferred current heats up the conductor according to Joule-law. All OHLs has a maximum temperature that cannot be exceeded (in the range of 40°C - 95°C) due to mechanical issues. Applying SLR it is extremely rare to exceed this temperature limit due to in most cases the environment is not worse than the designed case. However, applying DLR, the goal is to ensure the maximum transfer capacity while the maximum conductor temperature is not exceeded. This can be achieved by observing the ambient elements that affect the temperature of the conductor in real time and adjusting the conductor ampacity for their combined heat effect [2], [8].

3.2 Sag and Clearance

Exceeding the maximum allowable temperature of the conductor leads to a deterioration of the mechanical properties of the conductor. However, the increased conductor temperature also affects another important factor, the sag. As a definition sag is the minimum distance between the imaginary line that links the suspension points and the live conductor. However, from the aspect of safety and security, not the value of the sag, but the value of the clearance is significant. The clearance is the minimum distance between the conductor and any other potential points (ground, buildings, trees etc.) [2-3].

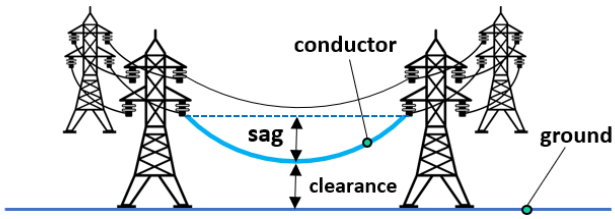

Fig. 2. Visualization of sag and clearance in case of a simplified OHL

The live parts of the power lines need to be separated and insulated from the other potential parts. Depending on whether the other potential object is part of the transmission line or not, there is a difference between internal and external clearance. Moreover, the design must also consider overvoltage cases in addition to the operating frequency range. Clearance values vary across voltage levels, the higher the operating voltage, the greater the required protection distance. Theoretically, the use of DLR does

not violate the legally defined clearances, since the aim of this method is to always maintain the maximum allowable temperature. However, measurement and model errors or control inaccuracies may cause the temperature limits to be exceeded for a short time that need to be treated proper [2-4], [8].

4 Weather Forecasts

Although the great advantage of DLR is to calculate transfer capacity in real time based on the environmental parameter values, conductors' real-time ampacity is not sufficient for the system operator. From the aspect of TSOs, the emphasis is on scheduling the next day's network loads, which anticipates the need for the real ampacity of each OHL to be available day-ahead. However, applying DLR-based grid management system, this can be achieved, but for model inputs as solar radiation, ambient temperature, wind speed etc. forecasted values are necessary [5-6].

4.1 Weather Forecast Systems

As it was mentioned, the input of DLR model needs to be forecasted weather data. It is important to mention that in case of DLR forecasts, there is no dedicated weather station, so meteorological data and models are in use. All over the world different meteorological forecasting models exist depends on the required forecasting issues. In Europe the most common models are the ALADIN and ECMWF models. For these models, the forecasting time and the temporal and spatial resolution of the data are different [6]. Table 1 summarizes their most important properties.

Table 1 Meteorological forecast models in Europe

	ALADIN	**ECMWF**
Forecasting period	1 – 3 days	2 – 10 days
Temporal resolution	1 hour	1 – 3 hours
Spatial resolution	1 km	5 – 10 km

Based on Table 1, ALADIN model fits better for DLR as hourly resolution is a basic requirement for day-ahead load schedules and day-ahead electricity market.

4.2 The Effect of Weather Forecast Uncertainty

From the ALADIN model, the day-ahead forecast values for the weather parameters with hourly resolution are available. Applying these data as an input of the CIGRE DLR model, the transfer capacity limit for each hour can be determined considering the maximum allowable conductor temperature. This ampacity can be the basis for the TSOs' day-ahead load schedule. On the other hand, it is important to mention that all weather forecast has an uncertainty which need to be considered properly. If the combination of the real weather parameters results a worse case than the predicted one, applying the forecasted ampacity could lead to sag increment if the OHL is fully

utilized. In these cases, it is important to take care of the reduced clearance whether it still meets the legal requirements of safety and security [9].

6 Risk Factor Analysis of OHL Sag

In order to find out the effect of weather forecast uncertainties a case study was carried out with the data of an existing power line within the framework of FLEXITRANSTORE project.

For the simulations data of a 110 kV single-circuit OHL with 240/40 mm^2 AlFe conductor on each phase was applied. This OHL is equipped with conductor temperature sensors and weather stations on the tower which provides real-time data for every 15 minutes. The maximum allowable conductor temperature is 40 °C and the static line rating is 530 A for the summer period. Due to legal requirements, most of the spans need to fulfill 7 m as a clearance criterium, but there are some exceptions where 5.5 m is the safety distance [4-7].

6.1 The Applied Weather Forecast

The day-ahead weather forecasts applied in the simulations are from the ALADIN, which is a numerical weather prediction model applied for limited geographic areas. However, the spatial resolution of this model is still 1 km which is not proper for a long OHL. In order to get more precise forecast data, the national weather service interpolates these ALADIN data to the section of the OHL which is equipped with weather station equipped with solar radiation detector, anemometer etc. While these local weather station operates all day, the forecasted and real-time data for the forecasted are available for the same place which is the basis of the comparison

Table 2 Forecasted parameters available from the meteorology

Forecasted parameter	Dimension	Forecasted parameter	Dimension
Ambient temperature	°C	Wind speed	m/s
Precipitation	mm/h	Wind direction	°
Solar radiation	W/m^2		

6.2 Simulation Result

The simulation was carried out for the whole period of a summer months (July), due to the heating effect of the environment is the most dominant in this part of the year. For each hour of each day, a day-ahead transfer capacity limit was calculated for the OHL based on the thermal behavior of the conductor. All OHL has a maximum temperature value that cannot be exceeded due to legal and safety issues. If this temperature value and weather forecast is available, the transfer capacity – ampacity – of the OHL can be clearly calculated. Knowing the forecasted ampacity values, it was simulated how the conductor temperature varies on the next day if the real-time weather data are applied and the OHL is fully utilized. In these cases, the main problem is that the forecasted

weather data and the real weather data for the forecasted period rarely matches. This could lead to sag-clearance problems that could be seen in Fig. 3.

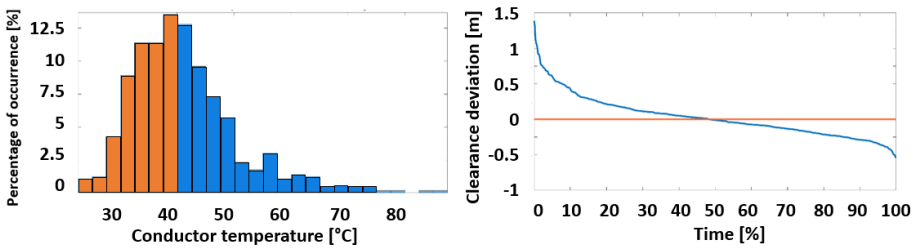

Fig. 3. Simulation results of conductor temperature and the duration curve for clearance in July

Fig. 3 represents the deviation of sag due to weather forecast inaccuracy. It can be seen, that roughly in the half of the time the conductor temperature exceeds the 40 °C limit value. According to this, sag increases which means lower clearance value shifting the risk factor to the higher region.

6.3 Risk Factor Calculation for the Sag and Clearance

When designing power lines, a safety margin in addition to legal distance is always insured for clearance, but its value varies in a great range, from a few centimeters to a few meters. It is therefore advisable to split the whole clearance value into a legal component and a safety margin component. This safety margin belongs to the worst-case condition and varies from span to span. For this OHL this safety margin value for the worst-case conditions is nearly 50 cm on the lowest conductor of the lowest span.

Thus, according to the Fig. 3, this safety margin is exceeded almost 8% of the time which results more frequent violation than the designed value and legally not permissible. However, this worst-case combination is very rare in reality, so it distorts the calculated risk. To eliminate this distortion, a dynamic clearance analysis was investigated that handles the risk according to the environmental conditions and not according to the worst-condition. This model defines a region between two boundaries and represents how the clearance calculated with the forecasted ampacity and the real-time weather fits into it. One of the two boundaries is the legal component, while the other one is the clearance simulated with real-time weather parameters and the static line rating.

In order to find out the real risk, which means that the conductor reaches the edge of the legal component, calculated clearances are reduced with the legally defined clearance components. The safety factor is calculated from the ratio of the reduced clearances obtained.

$$safety\ factor = \frac{X - legal\ component\ of\ clearance}{Y - legal\ component\ of\ clearance} \tag{1}$$

Where X [m] is the clearance calculated with real weather parameters and static line rating and Y [m] is the clearance calculated with real weather parameters and forecasted

ampacity. According to **(1)**, Fig. 4 represents how safety factor of clearance varies in the whole months.

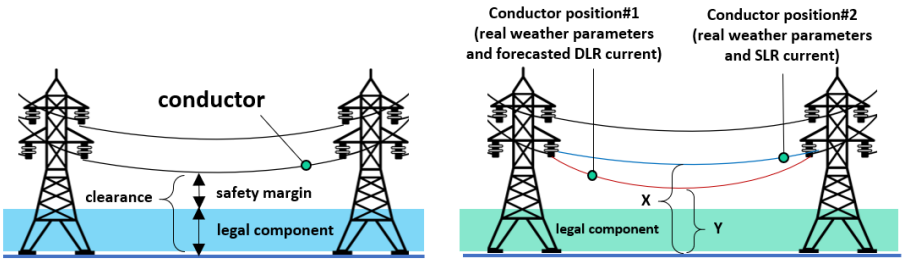

Fig. 4. Components of clearance and the visualization of dynamic clearance model

In Fig. 5 the region marked with blue means that safety factor is higher than 100%. This means that clearance calculated with the forecasted ampacity is less than the clearance calculated with the static line rating. In normal cases, these cases are extremely rare, and the area marked with green is more significant. However, for this OHL due to the sag and clearance limit the static line rating is also modified that makes weather forecast uncertainty less spectacular. One big advantage of dynamic clearance risk calculation is that the size of the range between the boundaries changes from hour to hour as the weather changes. In this model when safety factor reaches zero or turns into the negative range, it means that the sag increment of the conductor harms the legal component of the clearance which cannot be tolerated due to safety and security.

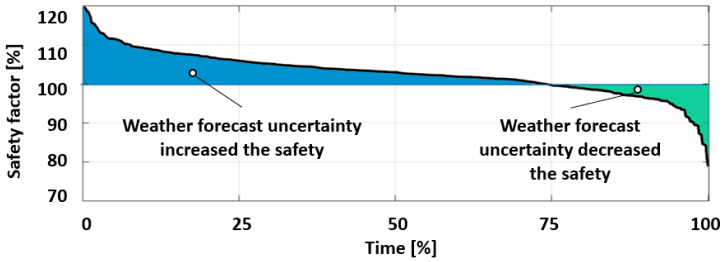

Fig. 5. Duration curve of safety factor for clearance in July

7 Conclusion

From the aspect of TSOs the most relevant issue is to calculate the day-ahead transfer capacity of each power lines that requires proper weather forecast. The major aim of this paper is to present that sag/clearance problems that could appear due to weather forecast uncertainty. Investigating this phenomenon, conductor sag deviation was simulated for an existing, fully utilized OHL. Simulations showed that the ampacity of the line calculated with weather forecast data could be different that the ampacity calculated with the real time weather parameters present at the forecasted time. Due to this, in almost half of time higher ampacity is predicted than the real transfer capacity which reduces the safety factor of clearance. In those cases, when the forecasted

weather is close to the worst-case design parameters this deviation could be significant and need to be handled. For other, so-called more general cases, a new dynamic clearance risk calculation method was implemented to represent the effect of the weather forecast uncertainty. According to the simulation, the risk increment for the clearance was not significant on the observed OHL. However, due to every OHL is different, further simulations are required to get a broader picture of how clearances could change in case of day-ahead DLR forecasts.

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European Commission | Horizon 2020 European Union funding for Research & Innovation

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