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Dynamic line rating in the Spanish overhead transmission network

Alexandra BURGOS
Red Eléctrica de España
aburgos@ree.es

Antonio USEROS*
Red Eléctrica de España
Spain
auseros@ree.es

Lucía MATEO
Red Eléctrica de España
lucia.mateo@ree.es

Ricardo REINOSO
Red Eléctrica de España
rreinoso@ree.es

Jose María ABAD
Red Eléctrica de España
jabad@ree.es

Agustín GUTIERREZ
Red Eléctrica de España
agustin.gutierrez@ree.es

SUMMARY

The proposal of the Spanish transmission network planning 2021-26 has been recently released for public information and it includes about 700 km of circuits to be operated using dynamic ratings.

Based on this ministerial order, the Spanish TSO started to work in a dynamic line rating system, aimed at being fully functional and economically competitive, that allows the system operator make use of the lines idle capacity, changing from seasonal ratings to real time and predicted ones. The goal of this paper is to spread the approach and experience of the Spanish TSO regarding the deployment of the dynamic line rating system.

The first step was to assess different systems, ranging from commercially available sensors to pilot ones, from discrete to distributed solutions, both remotely and locally located. To do so, a specific span of the 220 kV Fuendetodos – María line was used as a test bed for 15 hours, which entailed a big technical challenge, since to properly assess the sensors it was necessary to increase the conductor temperature well above the ambient temperature.

Using a LiDAR survey performed during the test and a PLSCADD line model to create the sag/temperature pattern, the results of all the systems were evaluated by comparing them to the pattern.

Besides the aforementioned technical validation, there was also an economical assessment of the different solutions to determine up to what extent they were competitive.

With all this information together, the Spanish TSO decided what was the more suitable dynamic line rating system to deploy.
The second step, carried out during 2020 and 2021, consists of the actual deployment of the system in four complete circuits, encompassing voltage levels from 66 kV to 400 kV, along with the development of the software to compute the real time and short term (prediction) thermal rating.

During this phase were especially relevant the communication technology and the integration of all these data in the corporate IT systems and cloud, since the availability and coverage of IIoT systems is quite heterogenous along the territory and is not easy to make all this information fit in the general monitoring platform.

KEYWORDS

Dynamic Line Rating – Real Time Thermal Rating – IIoT – Tilt Sensor – Weather Station

1. INTRODUCTION

It is a well-known fact that, when operating overhead circuits using static or seasonal ratings, there is an idle capacity that the transmission operator cannot use. This has been widely documented in many papers and articles, and it is not the objective of this paper keeping developing the issue [1] [2].

The goal of the paper is to spread the approach and experience of the Spanish TSO regarding the deployment of dynamic line rating (DLR), show the final results of the technical and economical assessment of sensors performed, and explain the ongoing pilot project carried out to test the functioning of the whole DLR system in the overhead transmission network.

It is important to mention that the transmission grid planning, which is approved by the Council of Ministers and is binding for the Spanish TSO, includes (in its preliminary version) for the first time the DLR as a development way of the transmission network, considering around 700 km of overhead circuits to be operated in a dynamic fashion [3].

Therefore, the Spanish TSO must start to consider the DLR as an investment tool (more than an innovation project).

2. SPANISH TSO APPROACH

There are many possible ways to implement DLR in a transmission system. Without being exhaustive, there are commercial sensors and pilot sensors; to be installed in the conductors, in the towers, or in the ground; measuring and computing a variety of variables; communicating by means of different technologies; implementing several real thermal rating algorithms; and ranging a lot in their costs [4].

But before tackling that technical and economical issues it is advisable to set the ground of the governance or proprietary model of the DLR system. A TSO, in its transmission role, is responsible for the safety of its lines and for the damages their cause and, on the other hand, in its system operator function, it is responsible for the security of supply and for the balance between generation and demand. And the transmission capacity of the circuits is a key factor for a TSO to duly perform these tasks, since the transmission grid is the power system backbone.

This is the reason why the Spanish TSO considers that it must know the details of every component of the system, both software and hardware, and have access to the data, algorithms, and results. Third parties' close solutions working as black boxes do not fit this approach; do not forget that the power transmission system is strategic and critical.

3. TECHNICAL AND ECONOMICAL ASSESSMENT OF SENSORS

During 2019 the Spanish TSO carried out a test of some sensors focus on one span of the 220 kV Fuendetodos – María transmission line with the objective of assessing their technical performance along with their costs. The sensors were classified in two groups:

- Weather stations (WS).

- Sensors installed in the conductor.

And, in turn, the sensors to be installed in the conductor were divided into:

- Spot sensors: those installed in a specific place of the conductor that measure a variable at that point and representative only of that point. For example, a spot temperature sensor, which measures temperature at a specific point (that is not representative of the span temperature [2]).

- Discrete sensors: those installed in a specific place of the conductor that measure a variable at that point and compute a variable representative of the span. For example, a tilt sensor, which measures the catenary tilt at a specific point and computes the sag (that is a variable corresponding to the span, not to a catenary point).

- Distributed sensors: those installed along the conductor that measure a variable in a continuous way. For example, a fibre optic embedded into the conductor which measures temperature along it.

The sensors involved in the test were the following:

- A remote weather station which belongs to the national weather service. It measures ambient temperature, solar radiation and wind speed and direction.

- A local weather station installed in one of the towers of the test span. It belongs to the Spanish TSO. It measures ambient temperature, solar radiation and wind speed and direction.

- A pilot tilt sensor (discrete sensor).

- Two commercial sensors (CS#1 and CS#2, both discrete sensors).

- An optical phase conductor (OPPC). One of the subconductors of the twin bundle (lowest phase) of the 220 kV Fuendetodos – María circuit is an OPPC (distributed sensor).

3.1. TEST DESCRIPTION

The test was carried out in the 220 kV Fuendetodos – María circuit, span between towers T-83 and T-84 (247 m long, open field, not shielded by vegetation or buildings). The local weather station was (and still is) installed in the tower T-83 and the discrete sensors were installed in the lowest phase of the circuit (where the OPPC is).

It lasted 15 hours, from 7:00 to 22:00, and during it 5 current steps were applied which a duration of 3 hours each: 1,500 A, 750 A, 2,250 A, 1,200 A, and 2,400 A (the seasonal rating).

One of the challenges of the test was how to get those current values, some of them very high compared to the usual ratings of this circuit. By means of topological changes in the grid was not possible to get that values, since they depend on generation (specially wind generation), on demand and on the security of supply requirements in the system (the circuit is not an isolated element). The solution was to inject the current in the span from an external source, powerful enough to rise the conductor temperature up to 85 ºC (the maximum temperature allowed in the line) during some hours.

During the 15 hours a surveyor squad was scanning the span with a LiDAR system every 10 minutes to get the sag that was used as the pattern to check the performance of the sensors that compute this variable. From this sag pattern, a temperature pattern was built by means of a PLSCADD model of the span. This way, a sag/temperature reference was available during the test, developed independently of the sensors to be checked.

According to previous experiences in this very same transmission line (TWENTIES project), spot temperature sensors were not included in the 2019 test (not even low-cost ones), since it is difficult to apply a spot temperature measure to the whole span or section (in this paper, a section refers to the segment of a line between two consecutive dead-end towers).

3.2. WEATHER STATIONS

The use of remote weather stations, belonging to third parties, such as the national weather service or airports, is a fast and cheap way to get the necessary data to implement DLR in its ambient-adjusted ratings version (AAR). It is not needed to invest in equipment, but only in weather data acquisition and algorithms.

The ambient temperature measured by the remote weather station can be applied to the transmission line, but neither the solar radiation nor the wind speed and direction can be directly used in the real time thermal rating (RTTR) calculations. This was made clear by comparing the data of the remote weather station to those collected by the local weather station; ambient temperature was similar, but solar radiation and wind speed and direction did not correlate at all. The result is a moderate increase in the capacity compared to the seasonal rating.

An evolution of this methodology is the use of a local weather station, in this case, belonging to the Spanish TSO. It is evidently a more expensive solution (although still affordable), compared to the remote weather station, because there is to buy, install and maintain the equipment, but it yields higher capacity values, since it allows to include the solar radiation in the model.

Regarding wind speed and direction and considering that the test was focus on one span (reminder: 247 m long and not shielded), the wind data collected by the local weather station were used to compute the RTTR, which turned out in significant higher capacity values compared to the seasonal rating.

3.3. DISCRETE SENSORS

The pilot tilt sensor is a low-cost sensor which measures the tilt at a specific catenary point (that where it is located) and computes (in the sensor itself) the span sag. The fact that the sensor is a low cost one is not only a consequence of its design process, but a design requirement to be consider from the very beginning.

The results of this sensor during the test were very satisfactory, keeping almost all sag values within the tolerance band (±10 cm).

The results of the two commercial sensors were not good enough, since their values are mostly out of the tolerance band. Besides this, and related to their cost, both are considered expensive solutions in comparison with the low-cost alternative.

The next graph shows and compares the test results.

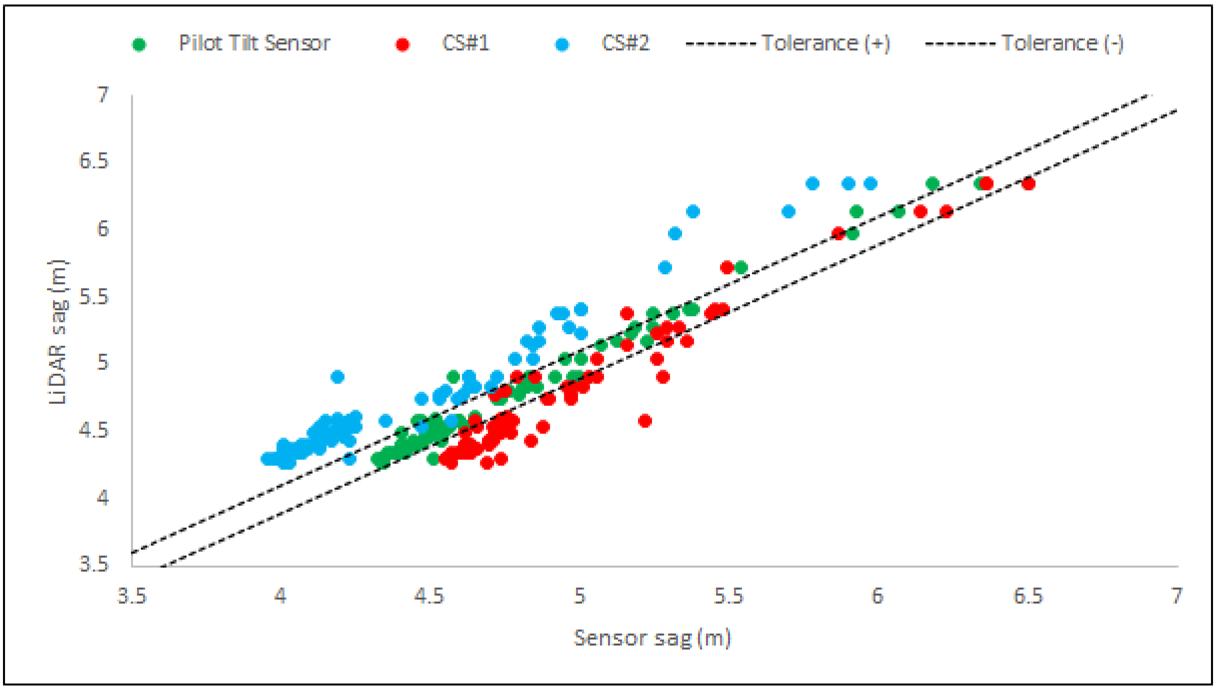

Figure 1 – Sensor versus LiDAR sag (test results)

3.4. DISTRIBUTED SENSORS

The OPPC worked well during the test, yielding temperatures quite close to the temperature reference and within the tolerance (±5 ºC, equivalent to the ±10 cm sag tolerance). The drawback of this technology is its high cost when it comes about implementing a DLR system in an existing overhead circuit. In the case of a brand-new transmission line, the cost is not that high, but the DLR is focus on the existing grid, at least in Spain.

The next graph shows the test results.

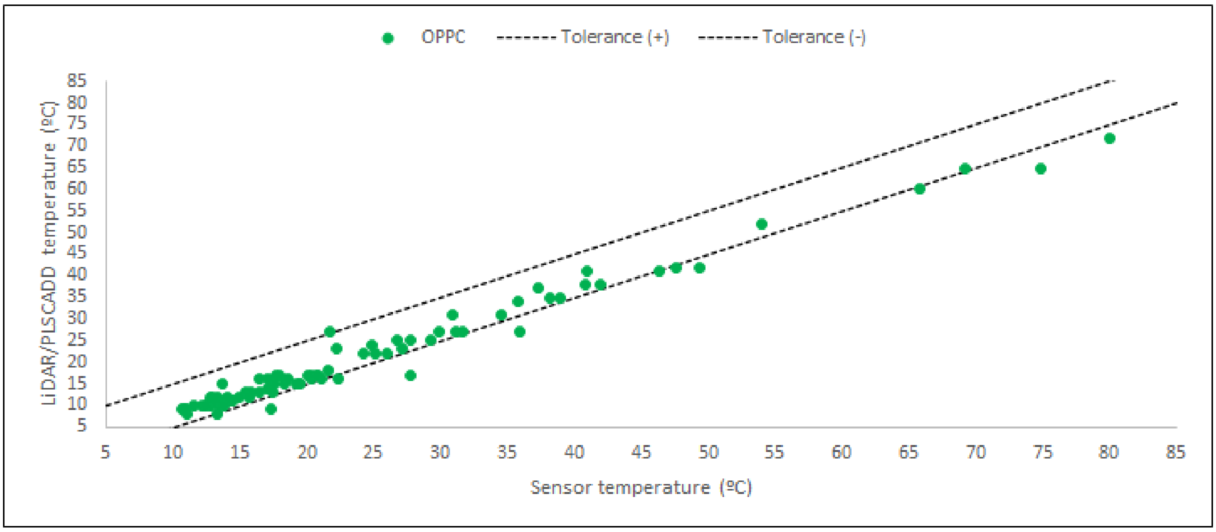

Figure 2 – Sensor versus LiDAR/PLSCADD temperature (test results)

3.5. SUMMARY OF TECHNICAL AND ECONOMICAL RESULTS

The next table sums up the 2019 test results. It is important to bear in mind that these results are only valid in the context of the test, i.e., one span and assessing only the sensor functioning, without considering neither communications nor RTTR algorithms.

Table I – Summary of 2019 test technical and economical results
✓: valid – ✓: partially valid – ✘: not valid

DLR system	TECHNICAL validation	ECONOMICAL validation	GLOBAL validation
Remote WS	✓	✓	✓
Local WS	✓	✓	✓
Pilot tilt sensor	✓	✓	✓
CS#1	✘	✘	✘
CS#2	✘	✘	✘
OPPC	✓	✘	✘

4. PILOT PROJECT

In light of the test results, it was decided to evolve from the span to the circuit and take into account the whole system, not only the sensors but also communications, cloud platforms, system architectures, RTTR algorithms and capacity forecasts.

Local weather stations are a good technical solution when it comes about one span. Wind speed and direction measurements can be applied to the span, but not much further than that, since wind it is very volatile in space and time (and the most important weather variable when computing RTTR). In order to cover all the circuit, it would be necessary to have many weather stations, and then, the economical feasibility decreases.

On the other hand, the pilot tilt sensor is a good technical and economical solution, but it is not enough by itself, since it does not measure neither ambient temperature nor solar radiation (it measures the tilt and computes the sag, and from the sag it is possible to calculate the equivalent conductor temperature and then the effective wind speed).

Therefore, the final DLR system solution to be deployed at circuit scale encompasses both local weather stations and tilt sensors following the next general rule: one tilt sensor in each circuit section plus a local weather station associated to every other tilt sensor. This way, the tilt sensors cover the effective wind speed and the local weather stations cover the ambient temperature and solar radiation (and a backup wind speed and direction).

To reduce the number of sensors and slash the cost of the DLR system, sometimes transmission companies and equipment suppliers resort to the critical span concept, which says, in a nutshell, that is not necessary to cover the whole circuit with sensors for duly applying DLR.

In this regard, previous experiences in the Spanish TSO (TWENTIES project) produced a different result, namely, that each and every span are sometime critical. Thus, it is not advisable to leave anyone out.

There were chosen four transmission circuits for the pilot project, ranging from 400 kV to 66 kV, and considering both mainland and one island.

All the necessary tilt sensors (71 units) and local weather stations (37 units) are already installed, and currently the Spanish TSO is working on the tilt sensors calibration (to consider the actual spans geometrical characteristics) and validation (to check that the calibration has been duly done). Till now, the results of the validation process are good.

Regarding communications, the DLR system do not require to be very fast (in comparison, for instance, to the protection system) or support a high amount of information. The data are sent every 5 minutes and are made up of the few measured variables. The demanding issues for communications are coverage and reliability.

Considering the number of sensors to be deployed in the long term, related and not related to DLR, and the aforementioned requisites, it was decided to communicate them using industrial internet of things (IIoT) technologies, being this pilot project the first point to point IIoT project in the Spanish TSO.

And in this regard, it is worth to mention that the coverage percentages are not always as high as it could seem. These coverage percentages are usually related to the population that have access to the technology, and people live concentrated in cities (at least in the developed countries, and more and more often in the developing ones). But transmission lines are widespread all along the territory, where this percentages do not apply. This is a key issue for a DLR system because communications are essential.

The company cloud platform has been adapted to receive the DLR data collected in the transmission circuits and to host the RTTR and forecasting algorithms, which are currently being developed.

The first results of the whole DLR systems deployed in this pilot project are expected by the end of 2022.

5. CONCLUSIONS

The experience of these three years of work on DLR brings the following conclusions.

Low-cost pilot tilt sensors are working well, yielding sag values within the tolerance when compared to the surveyor ones. Although tilt (sag) sensors are working well, the RTTR computation process would be much more straightforward if conductor equivalent temperature and/or effective wind low-cost sensors were available.

It is necessary to look for more sensor providers that meet the technical and economical requirements within the Spanish TSO approach. It is also advisable to keep collaborating with IIoT communication providers to extend the coverage areas.

RTTR is a necessary result but is not the final one; forecasting is indispensable for a system operator to use the DLR.

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