INCREASING THE OPERATION EFFICIENCY OF EDP DISTRIBUIÇÃO OVERHEAD POWER LINES

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ABSTRACT

Utilities are facing increasing social concerns against the deployment of HV infrastructures, particularly overhead power lines. As electricity demand continues to grow, these issues challenge utilities to find innovative solutions, not only to reduce social impact of new infrastructures, but also to get maximum benefit from the existing ones. One way to increase exploration efficiency of overhead power lines is to increase transmission capacity, which is generally limited to the maximum value that simultaneously guarantees voltage stability, synchronism among generating units and thermal limit. The latter ensures compliance with minimum clearances between conductors and ground and is typically the determinant limit at distribution level. Overhead lines are designed to withstand maximum temperature values that, if not overlapped, ensure every span meet clearance requirements. The relation between these maximums and ampacity depends on the thermal equilibrium established at conductors, which in turn is determined by weather conditions at the corridor. As these conditions are not usually known in real-time, utilities use conservative scenarios to compute a static maximum current for grid operators. Such value may not match lines' real-time ampacity, not enabling a safe use of additional load margins when available, neither the detection of conditions that may lead to violation of maximum temperatures. EDP DISTRIBUIÇÃO is aware of the benefits real-time ampacity can represent to grid operation and planning and is interested in exploring the technical and economical feasibility of market solutions in this area. In this context, EDP DISTRIBUIÇÃO has been preparing a pilot to test two different temperature measurement systems and an ampacity estimation system. The pilot will focus in 5 lines near Trajouce (Lisboa), that were indicated by grid control department as being operated near their static limits.

INTRODUCTION

The project of an overhead power line takes in consideration the maximum power it can transmit without compromising voltage stability, synchronism among generating units and thermal limit of conductors. The latter, which generally defines the power limit at distribution level, can be defined by the elasticity limit of conductors (may happen if the line is equipped with high-temperature conductors) or, more frequently, by the maximum sag that doesn't compromise safety distances between conductors and objects on the ground.

In practice, the determination of thermal limit is based on the definition of a maximum operation temperature for the conductors, which in turn is applied to their thermal equilibrium condition in order to calculate a steady-state maximum current.

Equation 1 generically represents the thermal equilibrium established in a conductor exposed to open air conditions, between heat received from solar radiation (q_s) and Joule effect (q_j), the heat expelled to environment by radiation (q_r) and by convection (q_c) and heat transferred internally by conductivity (q_k), heat being represented in W/m. It can be detailed as shown in Equation 2, in which α_s is the absorption coefficient of conductor, d its diameter in m, T_c its temperature in K, R its electrical resistance at T_c, in $\Omega\cdot m^{-1}$, ε its emissivity coefficient, C its heating capacity in $J\cdot m^{-1}\cdot K^{-1}$, T_a air temperature in K, G solar radiation in $W\cdot m^{-2}$, I the current in A, h_c air average heat transfer capacity, σ the Stefan-Boltzmann constant ($5{,}6704\times10^{-8}$ $W\cdot m^{-2}\cdot K^{-4}$) and t the time.

$$q_s + q_j - q_r - q_c - q_k = 0$$

Equation 1

$$\underbrace{(\alpha_s G d)}_{q_S} + \underbrace{\left[R(T_C)\cdot I^2\right]}_{q_J} - \underbrace{\left[h_c d(T_C - T_a)\right]}_{q_C} - \underbrace{\left[\varepsilon\sigma\pi d\left(T_C{}^4 - T_a{}^4\right)\right]}_{q_R} - \underbrace{\left(C\frac{dT_C}{dt}\right)}_{q_K} = 0$$

Equation 2

This model has been gradually adjusted in order to better represent heat behaviour of overhead conductors, particularly regarding convection and radiation. One of these works resulted in Kuipers and Brown model [1], in which convection heat transfer is redefined as shown in Equation 3 (v is wind speed modulus in $m\cdot s^{-1}$).

$$q_c = 8{,}55 \cdot v \cdot d \cdot (T_c - T_a)$$

Equation 3

Another example is the model defined by IEEE [2], which differ from the previous in the radiation and in the convection heat transfer components. Indeed, in this model convection becomes defined by three possible equations, being applied one of them in each moment depending on wind speed (high, low or very low). Another difference in convection is the fact of explicitly including dependency on air characteristics like density, viscosity and thermal conductivity (as a function of altitude) and on wind speed direction.

Independently of the model used, it can be seen how the current that would lead conductors to their maximum temperature, rather than being a constant value in time, varies with the weather conditions at the corridor. As in practice these conditions are not monitored in real-time, utilities typically use fixed conservative scenarios to

calculate static ampacities as reference for SCADA operators.
Such ampacities do not adapt to the real-time fluctuations of weather conditions, thus don't allow to consider additional load margins that are safely available in the lines (when weather conditions are more favourable than considered in project, for instance in cold and rainy winter nights) or, on the other hand, to detect situations in which exploring the lines until them would not be safe (weather conditions more severe than project ones, for instance very hot summer days with no wind).

STATIC AMPACITY

EDP DISTRIBUIÇÃO is currently projecting its HV overhead lines for a maximum conductors temperature of T_c=65ºC and using the weather conditions and ampacities shown in Table 1 for its specified HV overhead ACSR conductors (Bear 325 mm^2 and Partridge 160 mm^2) [3].

		Summer	Winter
G [W·m^{-2}]		900	
v [m·s^{-1}]		0,6	
T_a [ºC]		35	20
I [A]	**Partridge**	360	450
	Bear	540	685

Table 1

In practice, safety coefficients considered in project allow grid operators to use 2 ampacity values (working as 2 level SCADA alarms) for the whole year. Table 2 shows the values used for Bear conductors (the pilot will mainly focus on this type, which represent most part of HV heavy loaded lines at EDP DISTRIBUIÇÃO).

	Low level alarm	High level alarm
I (Bear) [A]	680	720

Table 2

Applying the thermal models to real weather data collected from private weather stations located near Lisboa (Figure 1) and registered in Weather Underground website (http://www.wunderground.com), it´s possible to observe the differences between these static limits and the current that effectively would lead conductors to their allowed maximum temperature, given the corridor real-time conditions.
Figure 2 shows the results for three 2009 winter days. As expected, real-time ampacity appears above high level alarm for most part of the time (two of the days above 90%), reaching maximum currents higher than 1000 A. However, it's relevant to note that even the winter may have days in which low level alarm would violate maximum temperatures for more than 60% of the time.
On the other hand, Figure 3 shows results for two 2010 summer days. Although results are more equilibrated than in the winter, they show how it's possible to have days with real-time ampacities above high level alarm for almost 70% of the time.

Figure 1 – Location of Weather Underground stations.

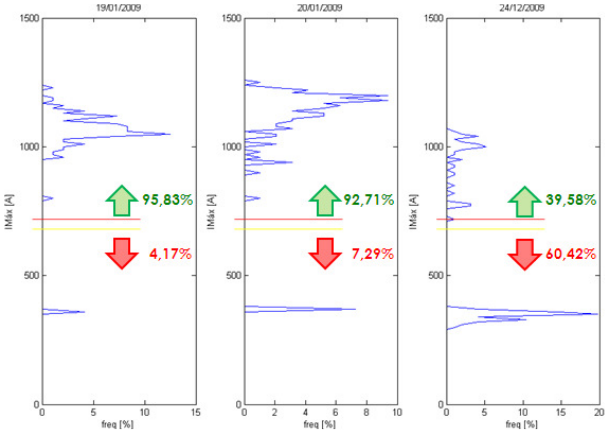

Figure 2 – Real-time and static ampacities for winter days.

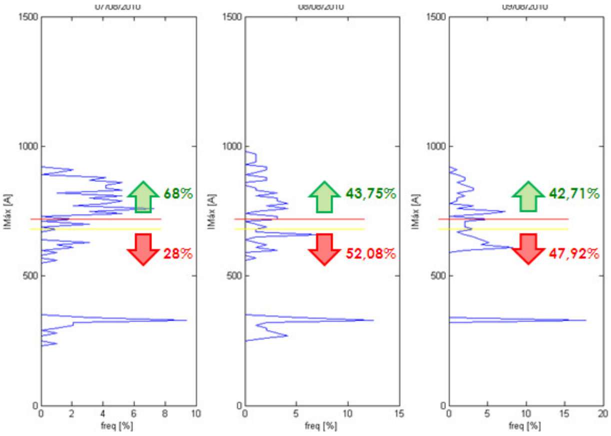

Figure 3 – Real-time and static ampacities for summer days.

PILOT

EDP DISTRIBUIÇÃO is aware of the benefits real-time ampacities can represent to the exploration of their overhead power lines. In this context, last year it started preparing a pilot in order to test some of the systems already available in the market that help providing such information to grid operators.

Lines

Grid operators were asked to identify HV overhead lines expected to be explored close to their static ampacities in few years. As a result, the following 5 lines (colored in blue in Figure 4) were indicated:

- L6105 Trajouce-Parede

- L6043 Trajouce-Alcoitão
- L6113 Trajouce-Capa Rota
- L6125 Trajouce-Zambujal
- L6140 Leião-Trajouce

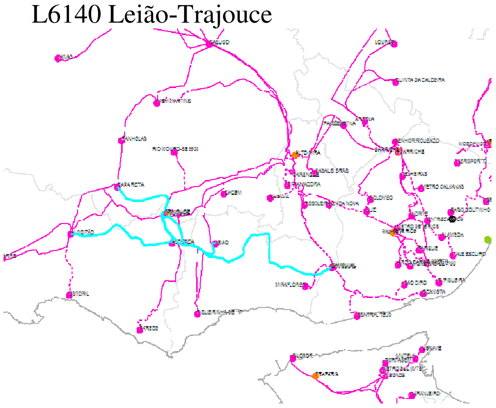

Figure 4 – HV overhead lines indicated for the pilot.

Systems

After a market research on the available technologies, EDP DISTRIBUIÇÃO to focus the pilot on 2 examples from each one of the following solutions (in brackets, the codes they're known by in the pilot):

- ARTECHE SMT (ART1 and ART2)
- FIBERSENSING T-MOL (FBR1 and FBR2)
- PIKE THERMALRATE (PKT1 and PKT2)

Also, it was decided to include the installation of a small weather station to help validating the information provided by the systems.

ARTECHE SMT

This system (Figure 5) measures temperature in a point of a conductor through a Pt1000 sensor. Data is sent by GPRS to a computer running a specific software application (data transmission to SCADA is not currently supported). It is powered from the magnetic field of the line (with currents above 100 A), through an integrated Current Transformer that is also used to read line load. GPRS coverage is its main installation requirement.

Figure 5 – ARTECHE SMT.[1]

FIBERSENSING T-MOL

FIBERSENSING solution (Figure 6) also measures temperature, but through Fiber Bragg Grating. It uses a Fiber Optic (FO) sensor that is placed in direct contact with the conductor through a bushing insulator and that connects to an available FO of the line's OPGW or ADSS (the line has to fulfill this requirement) at a joint box (the sensor has to be installed in a pole with this equipment). A Measuring Unit is placed at the Control Room of the Substation where the FO ends, powered in LV by auxiliary services. This equipment emits optical signals through the FO, determines sensor temperature from the signal reflection and send it to RTU as IEC 60870-5-103 messages (which in turn forward them to SCADA).

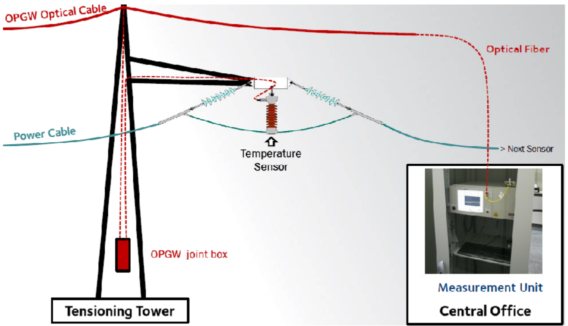

Figure 6 – FIBERSENSING system architecture.[1]

PIKE THERMALRATE

PIKE system estimates real-time ampacities (in steady-state and transient conditions). It consists in a T-shaped structure of 2 small conductors similar to the ones of the line (Figure 7) that senses the weather conditions of the corridor (not requiring weather stations) and in a controller that performs the calculations and sends results by GPRS to Substation's RTU (which in turn forwards the messages to SCADA). Both equipments are powered in LV. This solution does not need to be installed in direct contact with the lines' conductors, only requiring to be placed close to the corridor.

Figure 7 – PIKE THERMALRATE sensor.[1]

Building the Pilot

Weather conditions vary in time and, even in the same timeframe, may vary significantly along the corridor, which means there's no guarantee the sensor measurement meets the worst case (highest temperature or least real-time ampacity for the whole corridor). The most direct solution to increase the probability of getting line's worst case should be to place the respective sensor in a section aligned as close as possible with region's predominant wind direction. Figure 8 shows 10 minute average wind directions for 2 years taken from Oeiras weather station (referred in Figure 1).

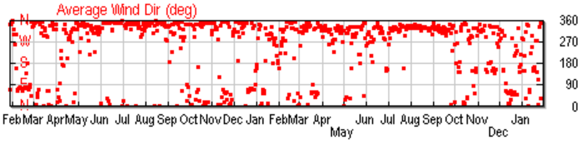

Figure 8 – 10 minutes wind direction average values at Oeiras.

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[1] Picture taken from manufacturer documentation.

This is what happens with ART1 and ART2, that only require GPRS coverage, which is not a problem near Trajouce. However, FBR1 and FBR2 only become feasible in lines with available FO (in OPGW or ADSS) and installed in poles with joint boxes. In turn, PKT1 and PKT2 need access to nearby LV power supply. An important note is that a line monitored by this latter technology requires a number of sensors at least equal to the predominant directions taken by the corridor. The pilot weather station has to be approximately central to all the sensors and needs access to LV power supply.

Considering these requirements, an inspection to the lines' installation conditions was performed in order to identify the best lines and locations for each equipment, which are illustrated in Figure 9.

Figure 9 – Overall distribution of the systems.

Experimental Results

So far, EDP DISTRIBUIÇÃO already installed (last December) the 2 ARTECHE SMT (Figure 10 shows sensors placed at L6043 and L6113, respectively at left and at right) and is waiting for the reception of the remaining systems.

Figure 10 – ARTECHE SMT at L6043 (left) and L6113 (right).

Every 10 minutes, both sensors send temperature and current values to a computer installed at Control Room of Trajouce, equipped with a conventional USB modem for internet access.

Every day the data is remotely collected and the obtained temperatures are compared with steady-state theoretical temperature values calculated from Kuipers and Brown and from IEEE models. A Matlab script was developed to correct and synchronize ART1, ART2 and weather data. Steady-state real-time ampacities from both models are also being computed and crossed with lines' loads. As the pilot weather station was not installed yet, weather conditions are temporarily being collected from the sources shown in Figure 1.

The results obtained so far show that IEEE values are closer to the temperature data than the ones from Kuipers and Brown (the latter tending to be more conservative). Most part of the time the difference between IEEE values and data is no more than 10%, but there are situations in which it rises up to around 60%. Figure 11 shows the differences registered for December 7th.

Using precipitation data from Oeiras weather station, it's possible to observe that rain occurrence is actually associated with higher deviations, as expected because precipitation influence is not represented in the models. However, abnormal deviations also occurs without rain. This can be explained by the distances sensors are in relation to weather stations that are temporarily supplying data for the pilot: 5 km to Oeiras and 40 km to Moita. Actually, these distances can play a major influence when wind shows local turbulence or with the partially cloudy sky. The installation of the pilot weather station is expected to lower the observed differences.

Last but not least, each sensor is collecting a single data sample per 10 min, which may hide significant load fluctuations. A deeper analysis with shorter time interval and taking into account conductors transient response will help to confirm this hypothesis.

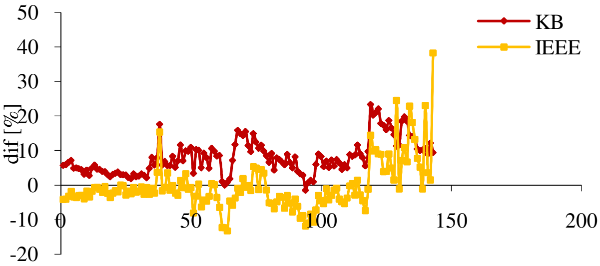

Figure 11 – Differences between models and data for December 7th.

CONCLUSIONS

The adoption of dynamic ampacities permanently adjusted to real-time fluctuations of weather conditions along the corridors may allow a significant increase in exploration efficiency of overhead power lines. Although it may not be economically viable to explore lines continuously at high rates, such data represents an important support for a safer management of the grid, particularly in emergency situations. In such scenarios operators will be able to easily identify how they may safely distribute load from a line out of service to the adjacent ones.

At the moment, EDP DISTRIBUIÇÃO has installed ARTECHE SMT sensors (ART1 and ART2) in 2 HV overhead power lines and is waiting the reception of the remaining solutions to be tested in the pilot (FBR1, FBR2, PKT1 and PKT2).

Results so far collected show some relevant deviations in relation to thermal models that are being analysed. The installation of a dedicated weather station for the pilot is expected to reduce these differences and to help confirming the formulated hypothesis.

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