ANTI-ICE AND SNOW COATING FOR EDP DISTRIBUIÇÃO'S OVERHEAD LINES

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ABSTRACT

EDP Distribuição is interested in analyzing competitive solutions that help reducing the impact of ice and snow in its overhead power lines. In this context, EDP Distribuição has been working with Instituto Superior Técnico (IST) in the development of an innovative icephobic coating that may be applied on conductors of already existing High Voltage (HV) or Medium Voltage (MV) overhead power lines, in order to prevent ice and snow accretion. Building on EDP Distribuição's requirements, IST developed 7 different solutions based on nanocomposite materials. These possible solutions were applied in small ACSR 50 conductor samples (with one additional bare sample for reference) that were placed at an high altitude location in Serra da Estrela, subjected to natural snow and icy conditions. The team has been registering accretion on bare and coated sample conductors in order to assess the effectiveness of the solutions and aging impact on their performance. This information, together with commercial price estimations (supplied by IST) will be used to identify the solution that best fits the needs of EDP Distribuição. The next step will be to test the most suitable solution with a pilot experience on a critical overhead power line. The performance of the coating will be assessed through the use of load cells that will be permanently measuring mechanical tension of both coated and uncoated conductors. This paper gives an overview of the problem, of existent market solutions and of the coatings developed by EDP Distribuição and IST, as well as of the pilot experience and of results obtained so far.

INTRODUCTION

EDP Group is a vertically integrated utility company from Portugal with operations in electricity and gas value chains. EDP Group has a relevant presence in the world energy outlook, supported by a workforce of around 12,000 employees spread over 14 countries around the world. During 2015 EDP's generating assets summed up to 24,4 GW and produced 63,7 TWh of electricity (57% of which came from wind farms and hydro power plants). In the same period, EDP supplied electricity and gas to around 10 million electricity customers and 1,4 million gas customers.

EDP Distribuição, an EDP Group utility, is the main Portuguese electricity Distribution System Operator (DSO), managing and exploring High Voltage (HV), Medium Voltage (MV) and Low Voltage (LV) electricity networks in the Portuguese inland territory. It supplies more than 6 million customers, through over than 400 HV/MV Substations, 60 thousand MV/LV Substations, 80 thousand km of HV and MV networks and 140 thousand km of LV networks.

EDP Distribuição, a utility fully committed to the energy efficiency, sustainability and Quality of Service (QoS) demands, projects its power structures in order to withstand the loads associated with ice or snow accretion. However, it is also analyzing novel solutions that may help reducing the impact of such adverse weather conditions in older overhead power lines with lower mechanical performance.

During the winter, HV and MV overhead power lines operated by EDP Distribuição, in the inner north east of mainland Portugal, are regularly exposed to adverse weather conditions, namely the combination of snowfalls or ice with wind. Ice or snow accretion (Figure 1) increase mechanical load stress on conductors, poles and accessories, not only due to the additional weight they represent, but also because they increase the conductors' surface that is exposed to wind. Additionally, those periods are typically characterized by low heat coming from solar radiation and from Joule effect (as most of those lines supply rural networks with low load levels, particularly at dawn), leading to a poor melting of accreted ice layers.

Such ice and snow conditions may push the mechanical stability of infrastructures to their limits and may cause short duration (a phase-phase contact resulting from galloping, due to ice dropping or wind) or medium to long duration outages (broken conductors, poles or accessories).

Figure 1 – Accumulated ice on a HV overhead power conductor.

In the last 5 years, ice and snow conditions were responsible for damages in 109 different MV overhead power lines operated by EDP Distribuição. In the same period, the top 6 lines with more incidents due to ice and snow have been suffering an average of 1,2 long term incidents of this kind per year. On average, each one of these incidents represented a direct impact on around 2 thousand customers.

POSSIBLE SOLUTIONS

Currently available solutions for ice and snow accretion in overhead power lines may be divided in two main categories: anti-icing (to prevent accretion of ice and snow on conductors) and de-icing (to remove already accreted ice or snow).

Anti-icing solutions are mostly passive, thus do not require any external force beyond natural agents (gravity, wind or solar radiation). They can consist in solutions that belong to the line structure, such as counterweights or rings that prevent snow from accreting on the conductors' surface, in constructive approaches such as flexible poles, more resistant conductors and short spans, or in solutions that are applied on already existent overhead power lines, such as coatings with icephobic characteristics.

On the other hand, de-icing solutions are typically active methods (require an external power supply to operate). Such solutions may be thermal, purely mechanical or electromagnetic. Thermal methods use the Joule effect to melt accreted layers and solutions range from controlled short-circuit systems that apply a high current in a line section (more tailored to transmission networks due to the infrastructure costs) to special power cables whose conductors may be commuted between parallel (normal) and series (de-icing) modes (more tailored to distribution networks). Mechanical solutions range from accessories that allow personnel on the ground to manually remove the accreted layers to more sophisticated robots[1] that run on the cables and that directly hit the layers. Electromagnetic solutions include electronic systems that apply high frequency signals in the power conductors, which in turn transmit vibrations to the cables in order to help accreted layers to fall.

From the above solutions, the ones more tailored to distribution networks would be the passive coatings (anti-icing) and the parallel/series commutated conductors (de-icing). However, both solutions are not mature enough to become market available and, even if a product exists, the number of pilot experiments and, thus, of field results are still very limited.

Given an utility such as EDP Distribuição, with geographically dispersed distribution networks, a solution has to present a low application complexity for the daily operations and the minimum possible number of potential failure points. Such requirements suggest the adoption of passive solutions.

DEVELOPED SOLUTIONS AND TESTS

In order to address the ice and snow accretion in its networks, EDP Distribuição invited Centro de Química-Física Molecular of Instituto Superior Técnico (CQFM-IST) to develop an innovative anti-icing coating for overhead power cables. EDP Distribuição presented a set of requirements that the product should fulfil, such as to not compromise the thermal rating of the conductors, to not have a density higher than a predefined value and to maintain its characteristics after the expected aging (natural sun conditions and temperature, as well as the thermal expansion of conductors). EDP Distribuição also defined a set of laboratory tests to be conducted in order to assess the product characteristics, before and after aging. The team at CQFM-IST developed seven solutions with different application requirements, based on the on-going research on anti-icing coatings.

An anti-icing coating needs to be superhydrophobic (with no affinity to water), and has to obey to one of the following conditions:

(I) to decrease the surface energy and create a multi-modal nano rugosity (*Lotus* leaf effect);[1,2]
(II) to be so slippery that the residence time of the water droplets is minimum (slippery effect).[3,4]

The development was supported by the following two strategies:

1 http://mir-innovation.hydroquebec.com/mir-innovation/en/transmission-solutions-linerover.html

Strategy I: The surface's nano-rugosities were created by superhydrophobic silica nanoparticles, synthesized by a sol-gel process in basic medium (Stöber process). The nanoparticles had an average diameter of 360 nm. Four coatings were prepared using this strategy:

- Coating A was prepared from an aqueous emulsion of the silica nanoparticles with a commercial fluorinated acrylic copolymer (Capstone) that lowers the surface energy. The nanoparticles:water:copolymer proportions and the mixing times were optimized, in order to maximize hydrophobicity, improve the mechanical resistance and adhesion to the cable;
- Coating E was prepared by mixing an aqueous emulsion of the silica nanoparticles with a non-fluorinated acrylic copolymer;
- Coating F was prepared by mixing an aqueous emulsion of the silica nanoparticles with a long chain carboxylic acid (lauric acid) in acetone, using a di-isocyanate as catalyst;
- Coating G consisted in a dispersion of the silica nanoparticles in a polysiloxane (polydimethylsiloxane) above a first layer of a silicon alkoxide.

Strategy II: The slippery effect was achieved by application of layers of long chain carboxylic acids or of fluorinated lubricants, chemically bonded to the surface. The following coatings were prepared following this stratagey:

- Coating B consisted of a monolayer of a fluorinated silica precursor, in a water-methanol solvent;
- Coating C was obtained from a colloidal silica solution and a hybrid silica precursor, previously hydrolyzed in acidic medium;
- Coating D consisted of a monolayer of a long-chain carboxylic acid (lauric acid) in ethanol.

Surface pre-treatment:

The bare power lines are typically covered with oxide and accumulated dirt. In order to clean them and improve coating adhesion, different processes were rehearsed:

a) washing with organic solvents (acetone, ethanol);
b) dirt removal with metal sandpaper, washing with water and detergent, followed by treatments with a mixture of inorganic acid solutions;
c) deposition of a primary coating of alkyl resins or aeronautic paint.

Pre-treatment c) was later abandoned due to the weight increase of the cables and because of environmental reasons, namely the release of chromates. Pre-treatment b) showed to assure a better adhesion and was the preferred one. Additionally, the latter may be adapted to the *in situ* conditions.

Coatings Application:

The coatings synthesized according to Strategy I may be applied as paint, with a brush (Figure 2). The rheological properties assure no dripping during application and drying between layers is rather fast (~2 h). The slippery coatings are applied by dipping.

Figure 2 – Sample of a cable covered with coating A.

Laboratory Characterization of the Coatings

The initial tests of adhesion and homogeneity of the coatings were made on aluminum dishes (following the characteristics of Norm IEC 60889).

Superhydrophobicity of the coatings was proved by measuring the water contact angle on Al surfaces, bare and coated (Figure 3).

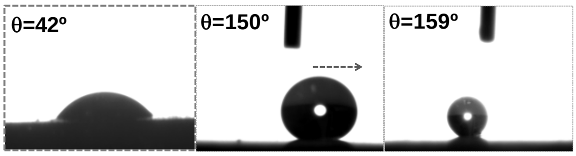

Figure 3 – Comparison of the contact angle of water droplets on a clean Al substrate (left) and covered with coatings A (center) and B (right).

Preliminary behavior tests were performed at laboratory scale, by measuring the weight gain of power lines' samples (50 cm long) kept for 60 h at -7 ºC in a humid atmosphere (relative humidity of 85%). The obtained results are summarized in Table 1.

Table 1. Weight increase of naked and coated prototypes due to ice accretion after 60 h at -7 ºC in humid atmosphere.

Prototype	Synthesis strategy	Weight increase (%)
Bare cable	-	0.22
A	I	0.02
B	II	0.07
C	II	0.10
D	II	0.07
E	I	0.12
F	I	0.03
G	I	0.06

There is a drastic difference between the ice accumulated on the bare and on the coated prototypes, especially when using coatings A and F (both prepared following strategy I). The results were encouraging towards an experiment *in situ*.

These solutions were applied on small 50 cm long conductor samples that were placed (alongside with a bare conductor sample) in a high-altitude facility, exposed to severe weather conditions similar to the ones faced by the utility's overhead networks (Figure 4).

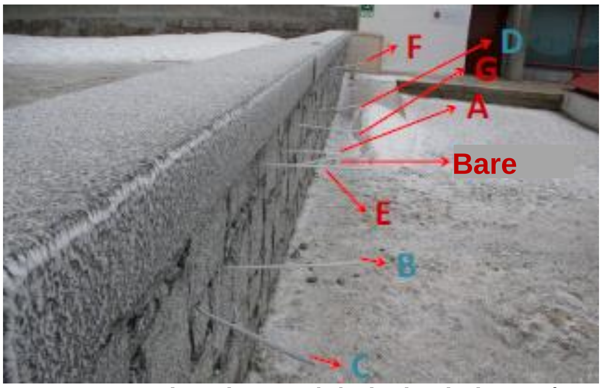

Figure 4 – Sample conductors with the developed solutions after exposure to several snowstorms *in situ* (Serra da Estrela).

Since the prototypes' weight was not measured *in situ*, the results were only qualitative. Although all the prototypes were covered in ice after several snowstorms, the ice thickness was different and, for the coated samples, the accreted layers showed more vulnerable to the wind effect than the ice layers on the bare sample.

Despite the tests have presented promising results, it will only be possible to fully evaluate a coating performance by implementing it in an overhead power line with a track record of incidents related to ice and snow accretion.

Differences in accretion on bare and coated samples, together with commercial price estimations (supplied by IST) made it possible to identify the most adequate solution for a close to 1:1 scale pilot experiment.

PILOT EXPERIMENT IN A MV OVERHEAD POWER LINE

EDP Distribuição is currently designing a pilot project that will comprise the application of the selected coating on 2 spans a critical overhead power line. In order to assess the coating performance, in both spans only one of the phases will be covered by the solution, while the 2 remaining phases will remain in bare conditions.

This experience intends to evaluate on the field and under real conditions the effectiveness of the selected solution and its evolution along the aging process. Presenting a positive outcome the validated solution has the potential to reduce the number of incidents with material damages, resulting from the triggering of mechanical stresses greater than the allowable and, consequently, to reduce associated service replacement costs.

The pilot will take place in a MV overhead power line that was selected according to predefined requirements, such as incident history, location and access conditions for the application of the coating. The selected power line is located in Serra da Estrela, at an altitude of around 1.600 m (Figure 5), and is composed by AACSR conductors supported by 12 m height metallic poles.

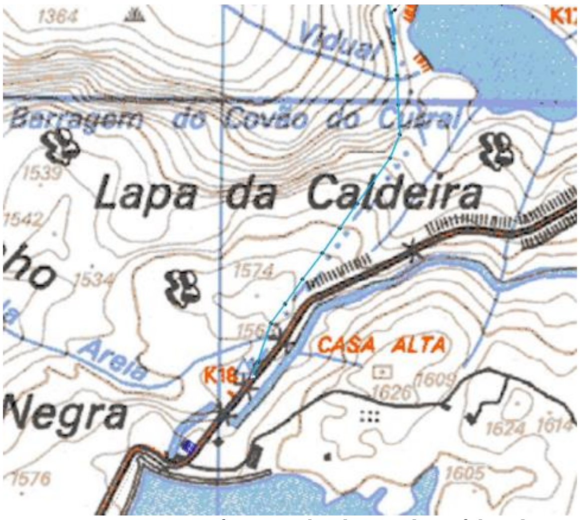

Figure 5 – Location of MV overhead power line of the pilot.

This pilot project will also provide more information regarding the mechanical stresses to which the assets are subject in this type of phenomena. The integration of this knowledge will be possible through the installation of permanent measurement equipment. Figure 6 shows the architecture of the pilot. Mechanical load cells will be installed in the middle pole, between insulators' strings and the pole's structure. These load cells will continuously measure mechanical tension of both coated and uncoated conductors. Data from load cells will be complemented by weather information collected by a small station that will be placed on the top of the pole. Together, those data streams will be used to compare mechanical stress applied on coated and on bare conductors and, thus, to assess the effectiveness of the coating in preventing ice and snow accretion.

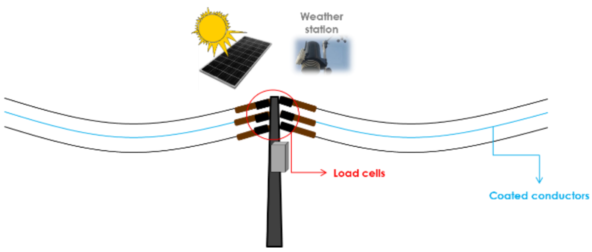

Figure 6 – Pilot architecture.

PRELIMINARY CONCLUSIONS

EDP Distribuição is interested in finding a cost effective solution to prevent incidents caused by ice and snow accretion on its overhead power lines during winter. Market research reveals that the most suitable solutions for distribution overhead power lines (as the ones typically operated by EDP Distribuição in the regions most affected by those incidents) are passive anti-icing coatings.

However, given the lack of mature solutions of such kind in the market, EDP Distribuição decided to start the development of an anti-icing coating from scratch in collaboration with IST. Such coating has to meet mechanical and thermal requirements defined by EDP Distribuição and its application on already existing overhead power lines has to be cost effective (regarding material, application workforce and time, effectiveness and reapplication frequency).

So far, IST developed seven coatings that were tested in laboratory and in the field, at an high-altitude location in Portugal (applied in small samples of ACSR power conductor). Based on the results obtained in such tests, two of the developed coatings showed potential to become an anti-icing solution for already existing overhead power lines:

- an aqueous coating of hydrophobic silica nanoparticles functionalized with a fluorinated acrylic copolymer, applied after cleaning the conductor and after performing a pre-treatment with a mixture of diluted inorganic acids;
- a mixture of an aqueous emulsion of hydrophobic silica nanoparticles with a long chain carboxylic acid in acetone, using a di-isocyanate as catalyst, applied on a clean conductor and after performing a pre-treatment procedure.

In terms of estimated costs and simplicity of procedure, the first solution is preferable and the production is being scaled-up in order to proceed to a real-scale field test. In this pilot experiment, the coating will be applied along two spans of an existing overhead power line of EDP Distribuição with a track record of incidents related with ice and snow. In order to assess the effectiveness of the solution, only one phase's conductors will be coated (with the other phases' conductors remaining bare) and the mechanical loads applied in bare and coated conductors will be permanently measured and compared through load sensors applied between insulator strings and the pole.

This field pilot experiment will allow EDP Distribuição to validate the effectiveness of the selected solution in real conditions and to assess the evolution of such effectiveness under operating and aging conditions, such as thermal dilatation and contraction of power conductors, temperature and solar radiation cycles, moisture, wind and dust, among others.

REFERENCES

[1] S. Farhadi, M. Farzaneh, S. A. Kulinich, 2011, "Anti-icing performance of superhydrophobic surfaces", *Appl. Surf. Sci.* vol 257, 6264-6269.

[2] J.-D. Brassard, D. K. Sarkar, J. Perron, 2013, "Fluorine based superhydrophobic coatings", *Appl. Sci.* vol. 2, 453-464.

[3] P. W. Wilson, W. Lu, H. Xu, P. Kim, M. J. Kreder, J. Alvarenga, J. Aizenberg, 2013, "Inhibition of ice nucleation by slippery liquid-infused porous surfaces (SLIPS)", *Phys. Chem. Chem. Phys.* vol. 15, 581-585.

[4] H. Y. Erbil, 2016, "Improvement of lubricant-infused surfaces for anti-icing applications", *Surf. Innovations* vol. 4, 214-217.