INNOVATIVE SOLUTION OF SAFETY CORRIDOR DESIGN FOR OVERHEAD LINES: INCREASING RESILIENCE TO EXTREME WEATHER EVENTS WHILE PROVIDING ENVIRONMENTAL BENEFITS

Ricardo PRATA Portugal ricardo.prata@edp.pt

Silvestre PEREIRA Portugal silvestre.pereira@edp.pt

Miguel VIEIRA Portugal miguel.vieira@florasul.pt

Maria Inês VERDELHO Portugal mariaines.verdelho@edp.pt

ABSTRACT

This paper proposes the concept of the Risk Management Buffer, consisting in the extension of the existing safety corridors in HV/MV lines. We present the pilot project in Louriçal, which is being implemented with this concept.

This approach aims at increasing line resiliency, based on a risk assessment for MV and HV overhead lines, due to falling or contact of trees located outside the safety corridors, particularly when associated with Extreme Weather Events, while providing environmental benefits.

The methodology associated with the creation of the Risk Management Buffer concept was developed with the involvement of an environmental agency. The deployment of that methodology in the areas where a positive cost-benefit analysis is achieved must involve the landowners on the intervention areas, thus being conceived in order to guarantee benefits for all of the stakeholders.

INTRODUCTION

Portugal has a very large proportion of its territory covered by forests – 3.2 million hectares, 35 % of the territory.

EDP – Distribuição (EDPD), the Portuguese DSO, operates MV and HV overhead lines that are established within forests (8,300 km included in protected areas for nature conservation) and, therefore, exposed to hazards like wildfires and damages caused by tree falling, particularly under extreme weather events.

Portuguese legislation obligates the DSO to establish and manage overhead line safety corridors, including forest fuel management (Decree No.124/2006 [1]).

Nevertheless, those safety corridors have revealed to provide an inadequate protection during extreme weather events (EWE). Trees, as high as 40 m, located outside the safety corridor, might fall under those conditions.

Portugal has also experienced several EWE recently, which had a negative impact on the reliability of the distribution network. Figure 1 shows daily interruption time (in minutes), highlighting the impact of four storms that occurred since 2009 [2].

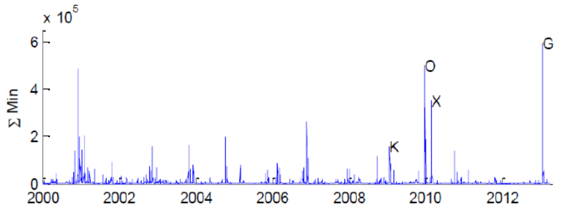

Figure 1 Daily interruption minutes

EDPD developed two separated research efforts, aiming not only at increasing the resilience of overhead lines established within forests, but also managing safety corridors with solutions that yield positive environmental impacts.

The concept of a Risk Management Buffer (RMB) was developed. EWE might originate tree falling or agitation, leading to contacts with branches. These events are more likely to occur in areas with strong wind turbulence, high trees (particularly isolated pine trees or eucalyptus), pine trees weakened by a parasite (nematode), or isolated trees on instable soils.

On those areas, RMB must be wider, being defined by the location and size of trees that might fall off over the line. RMB is identified through the use of helicopter-mounted LiDAR surveys.

Through a study of the Portuguese Institute of the Sea and the Atmosphere (Instituto Português do Mar e da Atmosfera – IPMA) with University of Lisbon (ULisboa) on the meteorological impact on the electrical infrastructure of continental Portugal [2], we are implementing a pilot project in Louriçal which is a vulnerable region to EWE (combining high wind exposure with the existence of extensive forest covers, and instable soils) using the RMB concept.

RMB is expected to increase resiliency of overhead lines to extreme meteorological events. The results of this pilot project will be evaluated and, if proved worthy, this approach will be used in other areas identified as vulnerable.

METHODOLOGIES

Given the goal of this project, to increase overhead line resilience, we introduce the Risk Management Buffer concept, RMB.

Adverse weather conditions is the main cause of contacts with branches, due to tree falling or agitation. Exposure to this phenomena of natural origin can be estimated by consulting the following cartographies:

- Territorial conditions;
- Land use conditions (forest cover);
- Other potential aggravating conditions.

The territorial conditions' cartography includes the average map of turbulence of winds exciding 30%, the soil map of structural instability and the orographic map.

The Land Use Cartography (LUC) includes forest species in the neighbouring of overhead lines, and the pine trees potentially affected by pests and diseases.

Other potential aggravating conditions are described in

the Forest Fire Risk Chart and the Natural and Technological Hazard Map [3].
With the LUC, those maps and EDPD's experience, we are able to identify which lines are more exposed to these conditioning factors.
Besides this methodology, and using the IPMA and ULisboa study, we are able to map the overhead electric infrastructure vulnerability to meteorological effects in order to support strategic decision-making networks evolution.
This study consisted in the analysis of the network disruptions situations and its conditioning by atmospheric phenomena. The same weather event can cause major damage to the network in vulnerable areas, but have zero impact in other areas where the network is more resilient. Roughly speaking, the wind has a dynamic forcing on large trees that could fall on power lines [2].
After identifying the lines particularly vulnerable to EWE, we implement the RMB concept, which consists in subareas outside the safety corridors that jeopardize the HV and MV lines due to falling or agitation trees. In Fig. 2. We present the RMB implementation process.

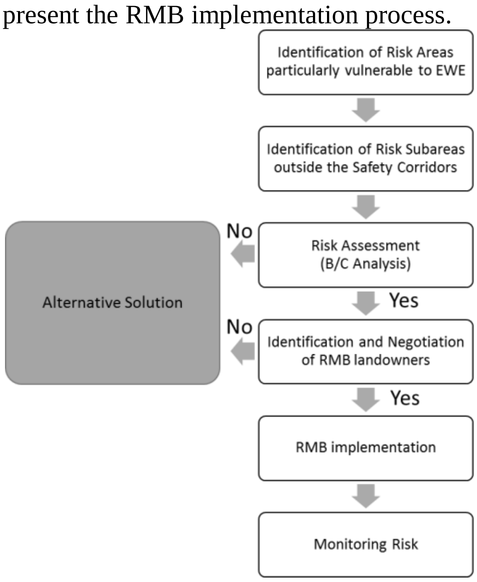

Figure 2 RMB implementation process

In order to identify RMB, it is required to compile LUC with helicopter-mounted LiDAR surveys with sufficiently large areas to cover large trees away from the lines, but that can still endanger them.
However, we must keep in mind that this system might have some uncertainty, so we improve it by selecting the RMB with LiDAR and, afterwards, by visiting critical areas, making forest characterization by location, type and size of trees presenting potential risk before negotiating the required interventions with landowners.
RMB intervention will only be performed after an economic and financial evaluation as a typical distribution network investment project [4]. The expected economic value of a project is estimated based on operating cash-flows, which result from the provisional account of exploration and represent the difference between benefits and investment costs. Among other possible expected profitability measures, Benefit Cost Ratio (B/C) and Net Present Value, NPV, can be used to investment decisions. The RMB will be chosen depending on this evaluation.
One crucial part of this project is the lines parcels owners' identification and negotiation. After the owner's identification by interactions with various stakeholders, including local authorities, land owners and environmental associations, the negotiation will be made with the tabulated values of compensation for trees of the current safety corridors and a possible additional compensation premium will be given since RMB is not protected by law.
For RMB implementation there are many possibilities, wherein the best solution is to eliminate the risk completely during the line lifecycle by making a reforestation on the intervention area.
An invasive tree species, *Acacia sp.*, was identified as being present in safety corridors. Due to its fast growth, the existence of this species increases maintenance costs by up to 4 times the average cost. Furthermore, this species is considered a problem by environmental authorities. *Acacia* management strategy is schematically presented in Fig. 3. This strategy involves other stakeholders also interested in this species control [5],[6].

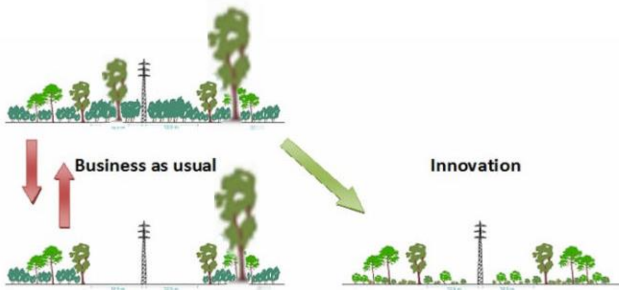

Figure 3 Corridor Management

With Figure 3 intervention we will acquire environmental benefits and we will be able to reduce risk during the line lifecycle.
Although this is the ideal solution, it may not be the most cost-effective, therefore in the implementation of RMB we have two scenarios, which will be selected depending on the outcome of cost-benefit analysis carried out the RMB:

1. Reforestation of intervention areas with slow-growing species, with the expectation that they cannot reach a size/height likely to be able to fall on the line branches during its life (Figure 3).
2. Compensation of owners, committing them not to consent the growth of large trees in the area corresponding to the compensation paid. However, this intervention does not guarantee that there will be no necessity for further interventions during the line lifecycle.

In both scenarios, a register of the quantity of carbon associated to the trees that are cut off is being kept, in

order to eventually compensate it with plantation of indigenous tree species.
The evaluation and monitoring of the RMB in the surrounding of safety corridors will anticipate prevention and mitigation of the potential risk to the lines. This strategy is incorporated throughout the lifecycle of infrastructure, from the planning and construction of the overhead line to the maintenance until its refurbishment or decommissioning. This RMB will have a dynamic and variable width depending on the species and heights of the existing trees.

RESULTS AND LOURIÇAL PILOT

On this section, we present some results of Louriçal Pilot, the project which is being implemented to validate and refine the RMB concept.
In Table 1 we show the results for the overhead lines which are under risk conditions of falling and agitation of trees, produced by the interceptions of the cartographies in Figure 4 using GIS.

Table 1 Results for HV and MV overhead lines under risk conditions

Conditioning Factors at National Level	***HV***		***MV***	
	Km	**%**	**Km**	**%**
Large trees	1997	22,75	9414	16,18
Pine wood nematode	411	4,68	1976	3,40
Wind turbulence exceeding 30%	3054	34,79	20912	35,93
Unstable soil	1017	11,58	6468	11,11
Large trees + Unstable soil	291	3,31	1143	1,96
Large trees + Wind turbulence exceeding 30%	1014	11,55	5260	9,04
Large trees + Unstable soil + Wind turbulence exceeding 30%	116	1,32	460	0,79
Potential isolated trees + Unstable soil + Wind turbulence exceeding 30%	275	3,13	1943	3,34

The results show that there is a significant percentage of HV and MV lines exposed to these conditioning factors which justify the strategies and precautionary measures assessment to prevent incidents that arising from contacts and falling trees existing outside the safety corridors.
In Fig. 4 we show the combination of terrain features in the 50m range around the EDPD network with the maps of the percentage of forest (deciduous and coniferous) and the percentage of sandy soils (Geological Map of Portugal).

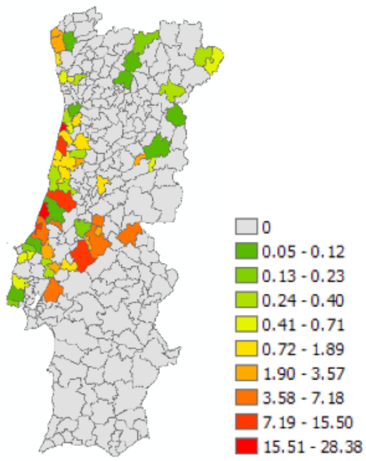

Figure 4 Conjugation of the maps % of land in the surrounding range of EDPD lines with forest and sandy soils [2].

IPMA and ULisboa study showed that meteorological impacts are distributed very unevenly, being associated mainly to a small number of highly energetic extreme weather events, occurring less than once a year in the selected period, and mainly affecting certain parts of the country, e.g. coastal area north of Lisbon. Data analysis showed that these are strongly associated with wind storms, often accompanied by precipitation, but with variable wind to play a decisive role. Lightning discharges, however, were not identified as the wind magnitude comparable element of risk, at least in the case of the larger events and with regard to the impact on the network quantified by TIEPI parameter (average interruption time weighted by the installed capacity).
In Fig. 5 we present the results of the expected number of EWE per year with TIEPI>100 by municipality, using as forecaster the observed/simulated wind.

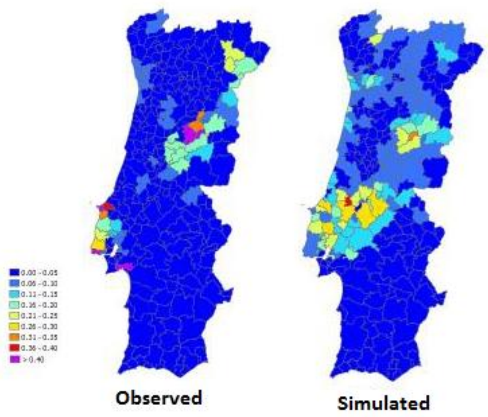

Figure 5 Number of expected events per year with TIEPI>100 by county, using as forecaster the observed/simulated wind.

The results show that there are more chance of extreme events with TIEPI in the west region, between Sintra and Pombal, extending inwards north of Lisbon.

Louriçal is one of the vulnerable regions regarding EWE, combining high exposure with the existence of extensive forest covers, and instable soils. In 2013 Louriçal suffered a great storm (Gong) which did plenty damage to its overhead network. Therefore, we are using this area as a pilot of RMB concept. This area combines three counties: Figueira da Foz, Soure and Pombal.
The pilot project involves interactions with various stakeholders, including local authorities, land owners and environmental associations, in order to maximize the opportunities associated with safety corridor management. Intervention area is shown in Figure 6, and it includes 614 km of MV and HV overhead lines.

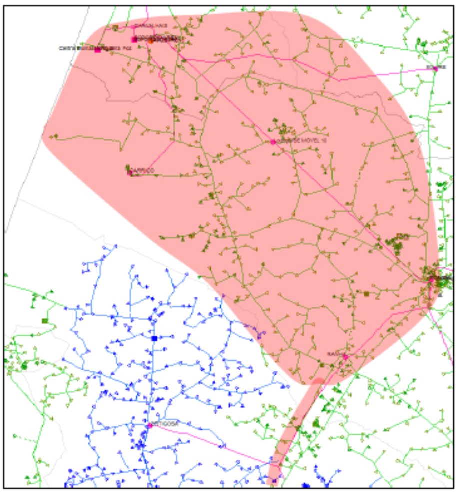

Figure 6 Intervention Area

The implementation of the Louriçal pilot project has provided some preliminary results, shown in Table 2, on the areas in the surrounding of the tracks of the overhead lines needing management.

Table 2 Louriçal Pilot Project's Preliminary Results

Evaluation dimension		***HV***	***MV***
Length [km]		78,6	535,8
Safety Corridor Area established [ha]		196,5	803,6
Buffer Area Analyzed (width of 200 m) [ha]		1.529,5	10.071,0
Area with Forest Occupation in Critical Buffer / Buffer	[km]	39,6	146,2
Area analyzed 200 m (Pine and Eucalyptus)	[ha]	1.166,9[1]	3677,0[2]

[1]Except 100 ha of Existing safety corridors
[2]Except 220,7 ha of Existing safety corridors

The guidelines for the selection of critical heights of Pine and Eucalyptus, in the neighbourhood of safety corridors, are established by "Administrative Easements for Electric Lines HV-MV" document of EDP Distribuição [7].
In the Louriçal pilot, we have analysed the heights of a sample of 300 points pre-selected with pine trees and eucalyptus by using a hypsometer laser and it was found that the trees located outside the safety corridors far exceed the recommended heights. The preliminary results showed that there are, on average, about 140 pine trees and 30 eucalyptus per km of the 40 km line crossing areas with critical forestry occupations.
Therefore, we expect that with the implementation of this project in Louriçal we will have some benefits, namely:

- Improve the energy quality service
- Reduce the risk of destruction of networks by exceptional intensity winds;
- Reduce the risk of destruction of the networks by forest fire;
- Promote biodiversity and to mitigate CO2 by reforestation;
- And finally to have a sustainable management of the interaction of networks with the surrounding areas.

CONCLUSION

The Risk Management Buffer project consists on the implementation of a sustainable overhead line buffer management system, where warranted, in the neighbourhood of safety corridors of overhead HV and MV lines, in order to provide them with adequate resilience to the effects of the fall and agitation of trees.
The areas where the RMB is being established have been considered critical areas, i.e., they are have high exposure to extreme weather events, low soil consistency and high water saturation, combined with a high density of forest cover and the existence of trees that potentially affect the lines, even though located outside the safety corridors.
After identifying the critical areas, a preliminary study of the potential risk management buffer is made, identifying the areas where, due to their risk profile, the intervention is required, with the identification of the landowners on those areas and the performance of an economic assessment of the interventions. If the economic assessment yields positive results, then EDPD begins the intervention, ideally, with a reforestation whose terms are subject to an agreement of the land owners.
The successful implementation of the proposed methodology can only be achieved through the involvement of the involved stakeholders, including environmental agencies who help to determine the species more suitable for reforestation, the municipal authorities that help to coordinate the activities performed and, particularly, the landowners.
We expect with this approach to increase the resilience of the lines to extreme weather events, while achieving both economic and environmental benefits.
It will be further implemented a methodology for promotion by EDP Distribuição awareness and involvement of owners, local authorities, NGOs, Entity Trusteeship and Market Operators conducive to adherence to recommended actions.

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