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Short Communication

OHL assessment and risk evaluation based on environmental and inspection data

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ABSTRACT

REN – Rede Eléctrica Nacional, S.A., Portuguese Transmission System Operator (TSO), has been using LiDAR technology in their aerial inspections. The acquired three-dimensional data in this Power Line Maintenance System are automatically processed, with support of the video inspections and geo-referenced systems. The national transmission grid was fully characterized at span level with urbanization and vegetation growth rate indices.

The collection of historical data, together with the knowledge of asset characteristics and system operation conditions, is structured in a generalized relational database, extended with a comprehensive set of different environmental, meteorological and geographic data over the years.

A methodology to evaluate operational risk was developed, taking into account the probabilistic nature of contingencies and their severity under specific operating conditions. Risk indices provide an insight to operators of the network state and of the constraints that operators face. Different optimization tools are also being developed.

Introduction

Nowadays, the difficulty to build new assets, the increasing demands for quality of service and system's operation closer to its security limits, are determining factors since in many countries, assets (such as towers to support power lines transmission) installed some decades ago are now reaching their end of life. In this context of cost reduction, higher efficiency and productivity, together with current environmental concerns and the desire to compare operation and maintenance efficiency with counterpart companies, REN – Rede Eléctrica Nacional, S.A., Portuguese Transmission System Operator (TSO), has been using LiDAR (Light Detection And Ranging) technology in their aerial inspections since 2007 [5]. The acquired three-dimensional data in this Power Line Maintenance System (PLMI) [10] are automatically processed, followed by human supervision for confirmation and adjustments, with support of the video inspections and geo-referenced systems. The national grid was thus fully characterized at span level with urbanization and vegetation growth rate indexes, following the ITOMS methodology [12], which were validated by a comparative analysis of inspections in subsequent years.

The collection of historical data, together with the knowledge of asset characteristics and system operation conditions, is now structured in a generalized relational database, allowing a multi-purpose, structured and complex data analysis. Information organization represents a big challenge and an extremely time-consuming task for a TSO, but it allows the development of methodologies that will improve the system performance in several domains. Data collection and organization become crucial to obtain better results and represent a major step for a TSO. This forces the TSO to maintain an updated and well structured asset database with all the required information. For example, a 'number crunching' analysis tools and statistical methods to infer valuable information, such as common cause failure and probability of failure under different conditions, which can be also combined with online operational and meteorological data. Real-time conditions play a very important role for system operation. Assets lifeline can then be more precisely estimated for several time frames. Additionally, this model is being

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extended with a comprehensive set of different environmental, meteorological and geographic data over the years, including hourly temperatures in Portugal's main land, all detected lightning strikes, levels of relevant pollution levels, fire risk with about 600 m^2 detail, and storks population. In fact, REN usually counts on dedicated inspections (with all its associated costs) just to detect and count stork nests in its towers. The authors, also in the scope of the LIONS (Lines Inspection Optimization System) project, are currently working on a tool to automatically identify such nests based on the videos produced from regular inspections, together with our geo-referenced data on the respective towers.

With such a system, more precise risk indices can be calculated based on the probability of failure for each span and aggregated for a whole overhead line (OHL), taking also into account the operation conditions, the severity of failures, and its estimated exposition time. Such approach is similar to Condition Based Risk Management (Earp [9] and Hughes [11]), but favors a broader analysis of factors affecting the lines in a shorter time frame. Moreover, the criticality of each line depends on its risk index, as well as on the grid topology as a complex graph [6], with its power sources, sinks, and available alternative power flow paths. Having such information reliably calculated allows to develop optimization tools, as we are currently doing [7], to reduce costs or to improve the quality of service by an appropriate use of resources, such as an intelligent maintenance policy or inspection planning. Equally important is the ability of more accurate asset life line estimation, to fully exploit its use with less risk, and better plan future maintenance and investments, reducing uncertainty.

A methodology to evaluate operational risk for a short-period of time was developed internally at REN, taking into account the probabilistic nature of contingencies and their severity under specific operating conditions. This new methodology aims to provide control room operators with risk-based security indices for the following period (such as 1 h). Risk indices provide an insight to operators of the network state and of the constraints that operators face [1–3]. The presented database allows this methodology to survive and succeed.

This paper is organized as follows: in the next section, we start by describing the risk factors that we are considering. In Section 'Information structure' we present the information structure used to represent and handle all relevant data, and then, in Section 'Risk evaluation', we discuss our risk model. We conclude in Section 'Conclusions'.

Risk factors

We are currently considering the following main risk factors for operation of OHLs:

- **Equipment:** in fact, one of the risk factors for electrical power transmission using OHLs comes from assets, the equipment itself, such as its own structure, i.e. the tower, and insulators, which may not perform its intended functions, due to its physical conditions.
- **Vegetation:** vegetation (and other objects) in the right-of-way is a major concern for OHLs since its proximity to phase conductors may cause a line tripping, and it has a dynamic nature (vegetation grows, wind blows, sag increases with temperature, etc.) [3].
- **Storks:** birds (in particular, storks, in Portugal and other countries) may nidify in towers. Collisions with conductors represent danger both to the bird and to system's security, since bird's electrocution may cause an unexpected outage of the line. In a more time consuming but frequent way, birds droppings (which are highly corrosive) over insulators will lead to their malfunctioning [3].
- **Pollution and fog:** pollution, especially when associated with fog, also largely affect insulators, in particular non-composite ones [3].
- **Lightning:** one of the major causes of concern with respect to OHLs is lightning, due to its power and unpredictability. A single strike at a line (or nearby) may easily cause it severe damages [3].
- **Fires:** forest fires, also known as wildfires, occurring under a line also represent a risk to OHLs, as they cause forced outages and may require the operator to take the line out of service to allow fire extinction [3].

Information structure

Our architecture [7] consists of a server with connections to geographical information systems (GIS) and asset management systems, running modular applications, with access to relational databases implemented over PostgreSQL, and with http-based communication.

There are three databases involved: (1) a database containing the electrical grid topology, with all its relevant components and features; (2) a 'lower-level' database containing the raw data produced by line inspections, such as vegetation management, equipment faults, navigation systems data, and so on; (3) environmental database.

The 'topology' database contains information concerning four categories. Without intending to delve into the details, a general picture of a schema is shown in Fig. 1, where each of the categories corresponds to a different rectangle region. Some regions overlap and, of course, are related to others:

1. **Graph** (blue & zoom): the grid topology itself, which defines a graph with nodes such as substations, plants, or sectioning posts, and where arcs are the electrical circuits connecting two nodes.
2. **Lines** (yellow): aerial lines carrying the electrical circuits, with their towers and respective numbers. It includes also underground circuit segments, and electrical characteristics.
3. **Assets** (green): towers and wires as grid assets, with their characteristics, their use, and their relations.
4. **Inspections** (pink): general part of inspections already performed, containing identification, and processed data, such as identified towers, wires, environment, and anomalies. Historical data lie mainly in this category.

On the left of Fig. 1, the 'Graph' region is magnified, as an illustrative example. Electrical circuits are the graph arcs, connecting two nodes, with a given operation voltage. Each node has geographical data and can be either a substation, or a plant (if not part of a substation), or a sectioning post. It can also be a simple derivation from some circuit. Border nodes are also considered when lines reach a different country to allow for cross border energy trade. Notice that substations are also modeled with transformation capacities between different voltages, via the Transformer table. This part of the database allows performing global analyses of the grid [6], calculating critical paths, for instance.

Regarding environmental data [8], for each tower we have registered its number of stork nests and whether it is located in a frequent thick fogs region, together with a rough estimate on the kind of pollution (industrial, salt, dust, birds, other) each tower was subject to. Maintenance information concerning washing of dirty insulators was also available and we registered its towers and dates, thus being able to determine critical areas, inferring pollution zones based on its effects, and their level based on the frequency.

More accurate and complete information was anticipated by referring to available national sensors (of several distinct