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Risk Analysis for Assessment of Vegetation Impact on Outages in Electric Power Systems

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SUMMARY

Combination of severe weather conditions and vegetation impacts is the most dominant cause of outages in electric power systems. Instance of high speed wind and heavy precipitation may cause trees to come in contact with power lines due to the following reasons: a) branches break off and fly into lines; b) complete trees topple when moved by wind, or c) tree branches grow into the lines. The main mitigation management scheme today is trimming the trees around the power lines. The proposed research shows that the process of tree trimming can be substantially improved by using weather and tree growth data to automatically assess the risk. We introduce the predictive means for determining optimal tree trimming schedule that would minimize the risk of vegetation-related outages in both transmission and distribution systems based on analysis of extensive sets of historical and real-time data. By analyzing impact of vegetation characteristics and weather impacts on power system outages, it is possible to predict where and when vegetation may become a risk. Thus, this study is of great importance for automated power system monitoring and outage management. Automated analysis of data provides means for developing dynamic scheduler that takes into account current state of the network and surrounding vegetation, as well as changing weather conditions and its predicted impact on vegetation. The developed system is able to adapt to constantly changing weather and vegetation conditions. The risk analysis provides information about areas of network with highest risk to vegetation-related outages that are targeted as the most important areas to perform the tree trimming. The proposed method then utilizes the real-time risk mapping system in order to assist in developing an optimal tree trimming schedule.

KEYWORDS

Data Analytics, Geographical Information System, Outage Management, Risk Analysis, Vegetation Management, Weather Impact

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1. INTRODUCTION

In August 2003, a tree made contact with a transmission line leading to the relay misoperation resulting in an erroneous line tripping. In the next 90 minutes three other lines got overloaded, sagged and made contacts with trees, which caused more lines to trip. That caused a cascading failure resulting in a well-known 2003 Northeast blackout [1]. The estimated total cost impact ranged between $4 and $10 billion [2]. Similarly, the December 2008 ice storm in New Hampshire was started with ice damaged tree falling on the lines and more than 800,000 people were affected [3]. As a result, Federal Energy Regulatory Commission (FERC) requires the utilities to become more aggressive in vegetation management practices [4]. More studies also confirm that the combination of severe weather conditions and vegetation is the most common cause of power system outages [5]-[6]. Thus, it is of great interest for utilities to minimize the risk of vegetation-related outages in power system. Impact of weather and vegetation to power outages has been analyzed in several papers. Reference [7] describes decision support system to focus right-of-way maintenance and minimize the potential for vegetation caused outages. In references [8] and [9] vulnerability studies for vegetation management around both distribution and transmission lines have been proposed.

To become more proactive, the best mitigation strategy is to properly manage the vegetation near the power lines. Obviously, removing all the vegetation near the lines is nearly impossible, and therefore developing an optimal tree-trimming schedule is the ultimate solution to the problem. Developing such a schedule could be a complex and time-consuming task. To achieve it, three categories of data are spatio-temporally correlated: vegetation, weather, and power system data. The cross-domain data is analyzed in an automated fashion to become efficient and effective. In this paper, the predictive risk analysis performed to obtain optimal tree trimming schedule is described. The automated data analytics will be able to assess the risk using effective tools such as geographical information system (GIS).

The paper is organized as follows. First, data description and processing steps are provided in section 2. In section 3, the risk model for vegetation management is presented. Section 4, describes the development of the optimal tree trimming schedule. The results are presented and discussed in section 5, and conclusions are given in section 6.

2. DATA PROCESSING

Following data sources are used for development of the automated vegetation management scheduler: vegetation data, weather (historical and forecast data), historical power system outage data, power system assets data, and historical tree trimming data.

Vegetation data is listed in the Table I. The extraction of vegetation parameters for training the prediction model is presented in Fig. 1. These parameters determine the vegetation impact on network vulnerability. All data was spatially integrated in Esri ArcGIS [10]. 2004 Digital Orthographic data has been used to identify the green areas around the transmission lines [11]. The 2010 C-CAP Regional Forest Fragmentation Land Cover data has been used to identify the forest fragments [12]. Canopy height data has been extracted from 2007 St. Lucie LIDAR data [13] (historical) and MODIS data [14]. In order to estimate the potential of tree falling over the ground, erosion index has been extracted from soil data gSSURGO [15].

Table I. Vegetation data sources and datasets

Source	Data set name	Spatial res.	Contains
Land Boundary Information System	2004 Digital Orthographic, [11]	1 m	Imagery
National Oceanic and Atmospheric Administration	2010 C-CAP Regional Forest Fragmentation Land Cover, [12]	30 m	Forest fragmentation
Florida Division of Emergency Management	2007 St. Lucie LIDAR, [13]	Vertical 0.6 ft Horizontal 3.8 ft	LIDAR data
National Aeronautics and Space Administration	MODIS - Moderate Resolution Imaging Spectroradiometer, [14]	0.5 km	Vegetation indices
National Cooperative Soil Survey	gSSURGO, [15]	10 m	Soil data

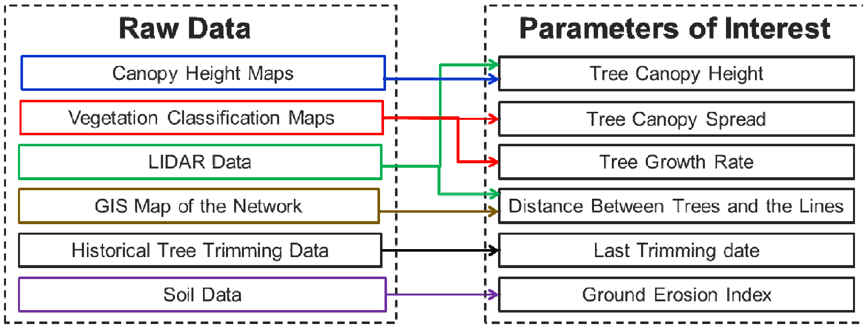

Figure 1. Vegetation parameters extraction

For the development of network vulnerability model historical outage data needs to be spatio-temporally correlated with historical weather data. As a source of historical weather data, data from four land-based weather stations was used. Locations of four weather stations, weather parameters of interest, and data path for processing historical data are presented in Fig. 2. For every vegetation caused outage, the weather parameters listed in Fig. 2 are collected from historical data from the weather stations in the area.

In order to evaluate expected levels of weather hazards, weather forecast data obtained from National Digital Forecast Database – NDFD was used [16]. In Fig. 3 hazard processing model is presented. In the background of Fig. 3 an example of GIS map for wind speed forecast is presented. In order to predict the level of hazard two types of data are used:

1. Forecast of Weather Conditions, such as wind speed and direction. This is a short term forecast data available for the next 7 days. These parameters are compared with the pre-set hazard limits presented in Table II, [9].
2. Forecast of Hazard Probabilities. These are medium-term predictions of extreme weather conditions for several months in the future.

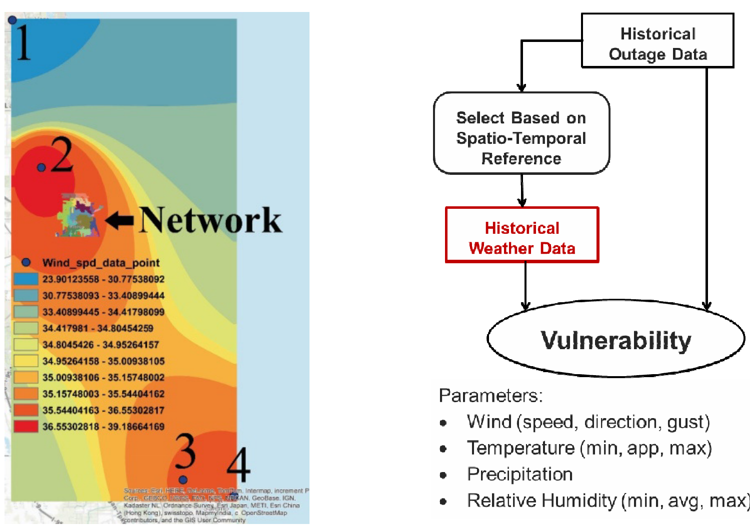

Figure 2. Land-based weather stations – processing of historical weather data

Table II. Impact of wind on vegetation

WS [m/s]	Effect on trees	Hazard	WS [m/s]	Effect on trees	Hazard
5.5-7.9	Small branches movement	0	17.2-20.7	Twigs broke from trees	2
8.0-10.7	Moderate size branches move	0	20.8-24.4	Large branches broke from trees	3
10.8-13.8	Large sized branches	1	24.5-28.4	Trees uprooted or broken	4
13.9-17.1	Whole trees in motion	1	>28.5	Severe vegetation damage	5

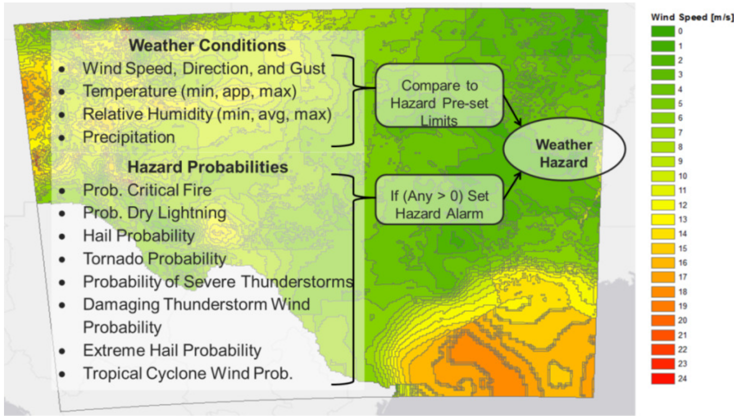

Figure 3. Weather forecast - data example and processing

3. RISK ANALYSIS

The risk assessment framework used for this research is defined as follows [19]:

$$R(X,t) = P[T(X,t)] \cdot P[C(X,t)|T(X,t)] \cdot u(C(X,t)) \tag{1}$$

where X represents the spatial parameter (longitude and latitude) and t represents the time parameter. R is the State of Risk for the system (or component), T is the Threat intensity (severity of environmental impact), Hazard P[T] is a probability of a combination of severe weather and vegetation impact in the vicinity of a network, P[C|T] is the Vulnerability or probability that combination of severe weather and vegetation activity will cause the fault in the network, and the Worth of Loss, u(C), is an estimate of financial losses in case of insulation total failure. Vegetation Risk Data Model is presented in Fig 1. The vulnerability prediction model is trained based on historical outage and weather data. The model is spatio-temporally referenced in order to explore spatial similarities between different areas of the network. Economic impact was calculated as in [19].

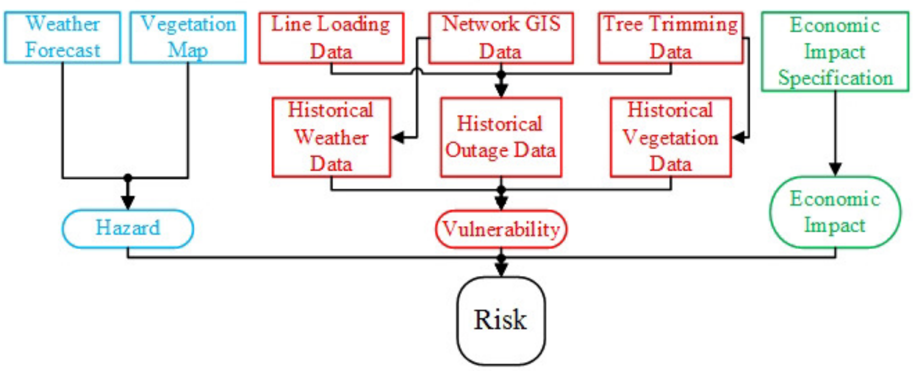

Figure 4. Vegetation Risk Data Model

4. OPTIMAL TREE TRIMMING SCHEDULE

The goal is to minimize the risk function using different options for a tree trimming schedule, in terms of both location and frequency of trimming. For the purpose of experiment, in Fig. 5 the network has been split into 24 tree trimming areas. Optimal tree trimming schedule is developed following these steps:

1) Find locations of high interest for tree trimming (main source – Vegetation Risk Maps). At each moment the random location is chosen as a trimming candidate. The risk for all areas is recalculated assuming the chosen area has been trimmed, and the next trimming area is determined in the same way.

2) Determine when is the best time to perform tree trimming (main source – Weather Forecast Data). Based on weather forecast, certain areas are assigned the tree trimming deadlines that represent the dates when the trimming of that area has to be finished. Trimming of the area can be performed any time before the deadline following the risk minimization procedure.
3) Evaluate reduction in risk and economic impact for different tree trimming schedules. After development of a tree trimming schedule the average risk value is calculated. The risk values for all tree trimming schedules are compared and the five schedules with the lowest risk are chosen.
4) Find the optimal tree trimming schedule by minimizing the economic impact. In this step economic impact is calculated for each one of five chosen schedules and the one with the minimum cost is chosen as an optimal schedule.

5. RESULTS

The example of the developed risk map is presented in Fig. 5. Areas in Fig. 5 are classified using different colors based on the probability of vegetation caused outages. The risk maps are produced in real time, where predictions for the next 24 hours are made with time resolution of 3 hours, and predictions for the next 6 months are made with resolutions of one week. The network is split into 24 tree trimming zones. As we can see from the Fig. 5 some zones, such as 1, 12, 24, 13, 21 have high values of vegetation risk, while zones such as 9, 20, 8, 15, 16, have very low vegetation risk and do not require any tree trimming. The order of tree trimming zones has been analyzed as described in Chapter 4. In Table III, a reduction in overall vegetation risk value and economic impact for top five tree trimming schedules is presented. Schedule 1 is the best schedule in terms of zone order; however, the tree trimming of zones 13 and 24 happens after the network is expected to have severe weather impact. Because of this in Schedule 2, zones 13 and 24 are moved to the earlier time following the step 2 described in Chapter 4. As a result, Schedule 2 has highest value of overall risk compared to the Schedule 1; however, the economic risk was decreased compared to the Schedule 1.

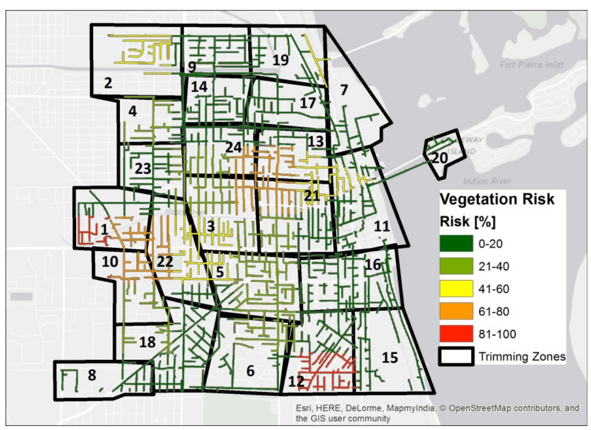

Figure 5. Vegetation risk map with trimming zones

6. CONCLUSION

This study introduces the risk analysis framework for development of optimal tree trimming plan for protection of power lines from vegetation caused outages. Following are main contributions of the paper:

- Hazard model for processing weather forecast data in a network area has been developed.
- Network vulnerability to vegetation caused outages has been modelled by analyzing historical outage, weather and network data.
- Comprehensive risk framework for vegetation management of power lines has been defined, combining hazard, vulnerability, and previously developed economic impact model.
- Optimal tree trimming scheduler that minimizes the overall vegetation caused risk of the network and associated economic impacts has been proposed.

Table III. Risk reduction after tree trimming

ID	Zone Order	Average Risk Reduction [%]	Economic Impact Reduction
1	12,1,21,22,**13,24**,2,3,10,19,11,5,6,18,4,23	32.18	0.39
2	12,1,**13,24**, 21,22,2,3,10,19,11,5,6,18,4,23	31.98	0.43
3	1,12,21,22,10,19,11,5,13,24,2,23,3,6,18,4	26.14	0.28
4	12,1,24,13, 2,3,10,21,11,5,6,18,4,22,19,23	23.84	0.25
5	1,12,21,22,24,13,3,10,2,19,6,4,11,5,23,18	20.89	0.26

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