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An intelligent decision support tool for management of tree maintenance in power systems

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Abstract

Tree-related power outages represent significant costs and failure rates in power supply. The existence of trees implies that the solution to this problem should focus on optimizing pruning cycles. This optimization is of great importance because of the costs associated to such maintenance. This paper is intended to propose a methodology for the maintenance of trees based on data analysis. Starting from the information captured in the field, we use techniques and models based on fuzzy logic and genetic algorithms, which keeps maintenance tasks on the optimal time and place. The strategy is aimed at two key aspects: first, the history of failures caused by trees on medium-voltage power supplies, this information is used to calculate quality indicators (energy not supplied [ENS] and number of users affected [NU]*) only regarding to tree-associated failure. We use a fuzzy logic based system to ponder and find the critical circuits on which forest maintenance should be performed. Second, we construct an objective function based on tree-network distance and growth patterns of trees per species in order to simulate forest maintenance. To this end, a genetic algorithm is used to determine the optimum pruning cycle of a given power supply. We use

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real historical data of medium voltage circuits for the system setting as well as for the evaluation of performance.

Key words

Fuzzy systems, genetic algorithms, maintenance, power distribution networks, trees.

1 Introduction

The electricity distribution aerial networks may be affected by temporary or permanent contact with trees, which has an impact on service quality. This is the reason why distribution companies of electricity in Colombia include forest care within maintenance programs, which entails a large investment.

On behalf of the Colombian government, the Energy Regulatory and Gas Commission agency (CREG) with act (resolution) 097, 2008 [1] established the methodology and quality indices ITAD (Grouped Quarterly Index of Discontinuity), IAAD (Grouped Annual Index of Discontinuity), and IRAD (Grouped Benchmark Index of Discontinuity) applied to promote the new scheme of incentives and compensations to users, which allows network operators (OP) to increase or decrease their usage charges of connected assets to a particular Local Distribution System (SDL). The aim of this new regulation is to standardize the quality of service around the average quality, i.e. reduce the dispersion of quality by improving the indices for the worst-served users. The issue of trees becomes important because the new regulatory philosophy requires improving quality indices in rural areas.

To manage the ITAD part, involving the maintenance of networks, i.e. the NTG (Quarterly Level of Discontinuity by Quality Group) component (the part not manageable in maintenance corresponds to Energy Sales VT, this component is inversely proportional to the ITAD and its management is of commercial nature), we propose an analysis involving only the interruptions caused by trees. In this way, we think that we can identify the circuits with higher energy that is not supplied and affects most users together with the parameters that directly affect the ITAD.

Our ideas for the projection of tree maintenance are strongly influenced by research on maintenance services priority in electrical feeders [2], [3], [4], [5], [6], [7]. According to these research studies, there is a strong relationship between system parameters such as reliability and power quality, and environmental parameters such as the vegetation presence, seasonal loading and even vandalism.

To prioritize the circuits, we are first inspired by the power of abstraction used in fuzzy systems [4], [8], [9], [10]. As it is common in many approaches, we use the experience of experts to establish the growth of trees as a high impact variable in the failure of circuits in the city of Bogota D.C. (Colombia). Subsequently, we perform a graphical analysis of the hierarchy obtained in order to perform a technical analysis and validate the results.

Our research also wants to find answers to questions that arise once we have found the critical circuits: What trees need pruning? When to prune them and how much are the maintenance costs? These problems have been addressed from different perspectives. One option uses the philosophy of Reliability Centered Maintenance (RCM), based on four principles: best pruning techniques, documentation of the work, training and competence requirements, quality control and auditing [11].

Another reported approach, which is also related to our work, uses a mathematical model based on Artificial Neural Networks (ANN) [12]. This study relates the failure rates of the feeders to the variables that affect the nature of vegetation, such as ambient temperature, rain and the time elapsed since the last pruning. A variation of the latter model uses a genetic algorithm (GA) [13] involving variables such as the feeder length, height and growth rates of trees by species, and time of the year, giving costs associated with maintenance and estimated ENS. Our research also estimates the optimum time for pruning through a genetic algorithm, which uses models of growth of native trees.

This paper is organized as follows. Section 2 presents preliminary concepts together with problem formulation. Section 3 illustrates the methodology, some details of the prioritization of the circuits, and the optimal pruning cycle. Section 4 presents the performance of the methodology, and Section 5 concludes the paper.

2 Problem Formulation

Let $W \subset \mathbb{R}$ be the closure of a contractible open set in the line that has a connected open interior. Let $P \subset W$ be the *priority values* assigned to the prioritization of the circuits, which is the open subset of W. Let $E \subset \mathbb{R}$ be the closure of a contractible open set in the line that has a connected open interior. Let $EPNS \subset E$ be the *average energy not supplied* for a given breakdown, transformer and circuit, which is the open subset of E. Let $N \subset \mathbb{R}$ be the closure of a contractible open set in the line that has a connected open interior. Let $NU \subset N$ be the *number of users affected* for a given breakdown, transformer and circuit, which is the open subset of N. The prioritization model depicted in Figure 1 is obtained by a prioritization mapping of the form:

$$h: Y \longrightarrow P \qquad (1)$$

in which:

$$Y = EPNS \times NU \qquad (2)$$

We define $\hat{y} : [i,j,k] \longrightarrow Y$ to be the *priority assignment* that is obtained from $\hat{y}$ by applying fuzzy inference for a given interruption i, transformer j, and circuit k.

Let $Z \subset \mathbb{R}$ be the closure of a contractible open set in the line that has a connected open interior. Let $C \subset W$ be the *maintenance cost values* assigned by a process of uninformed search of the optimal cost, which is the open subset of Z. Let $M \subset \mathbb{R}\times\mathbb{R}$ be the closure of a contractible open set in the space that has a connected open interior. Let $Mn \subset M$ be the *information matrix* for n trees in a given circuit encoding: the tree ID, the cost code, the species code and the Di, which is the open subset of M. Let $K \subset \mathbb{R}$ be the closure of a contractible open set in the line that has a connected open interior. Let $NC \subset K$ be the circuits to be considered for forest maintenance, which is the open subset of K. The optimization model depicted in Figure 2 is obtained by an optimization mapping of the form:

$$h: X \longrightarrow C \qquad (3)$$

in which:

$$X = Mn \times NC \qquad (4)$$

We define $\hat{x} : [k] \longrightarrow X$ to be the *valuation of cost of maintenance* that is obtained from $\hat{x}$ by applying genetic search for a given circuit k.

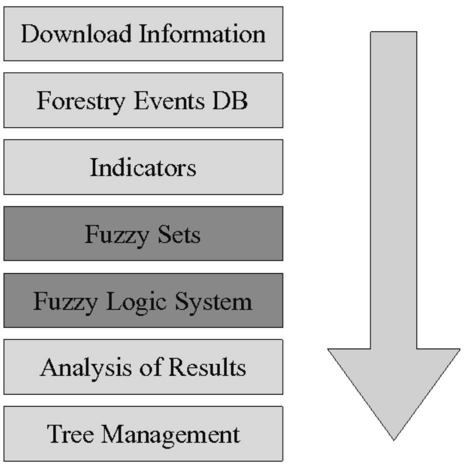
3 Methodology

The first part of the analysis establishes a maintenance priority for each network circuit of medium voltage, from a "measure" of criticality due to forestry events. In the second part of the analysis, once the most critical circuits are identified, we analyze their characteristics in order to define a period of pruning, a degree of pruning, and a stable budget for each feeder.

3.1 Prioritization of Circuits

The prioritization of the circuit begins with downloading and debugging information from the unified system information registry at the network operator's (OR). We only retrieve information related to forestry events taking into account the events for transitory faults, permanent faults, circuits associated with events, duration of interruptions, customers affected by transformer, and transformer energy demand (Figure 1).

Figure 1. Flow diagram of information management for prioritization of circuits



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With the downloaded information, we implement a forestry database to calculate the indicators of EPNS (the load factor is not included in equation 5) and NU. These are the input data that feed the fuzzy logic system, which is responsible for prioritizing the circuits. This calculation should be performed by transformer, circuit and period.

The EPNS variable is defined as the average energy not supplied due to interruption i, for transformer j and circuit k in the period l. This variable is calculated as:

$$EPNS_{i,j,k,l} = \frac{\sum T_{i,j,k,l} * DEP_{j,k,l}}{minutes_l} \quad (5)$$

Where:

$T_{i,j,k,l}$ is the length (in minutes) of the interruption and $DEP_{j,k,l}$ is the average energy demand.

Similarly we calculate the sum of users affected (*NU*) as the number of users affected by interruption i, transformer j and circuit k in period l.

The system output variable and priority P, as well as the input variables *EPNS* and *NU*, which are associated with linguistic variables, define fuzzy sets. An overview of rules that govern the inference engine is illustrated in Table 1.

Table 1. Set of fuzzy rules for prioritizing circuits

NU \ EPSN	Uncritical	Little critical	Critical	Very critical
Uncritical	No maintenance is performed	Maintenance with low priority	Priority maintenance	Very priority maintenance
Little critical	Maintenance with low priority	Maintenance with low priority	Priority maintenance	Very priority maintenance
Critical	Priority maintenance	Priority maintenance	Priority maintenance	Very priority maintenance
Very critical	Very priority maintenance	Very priority maintenance	Very priority maintenance	Very priority maintenance

Source: own elaboration

The prioritization performed by the fuzzy logic system can be visualized as a 3D surface where the X and Y axes correspond to the inputs, and the Z axis corresponds to the output. We evaluate the prioritization using both Mamdani and Takagi-Sugeno inference, using also different sets of rules. Figure 5 shows the results of four of these experiments.

The fuzzy logic system provides the possibility of periodic monitoring of indicators of critical circuits on which preventive and corrective measures are applied. Graphically speaking, we expect that all circuits tend to come together at the lower part of the surface containing the majority of the population.

3.2 Optimal Pruning Cycle

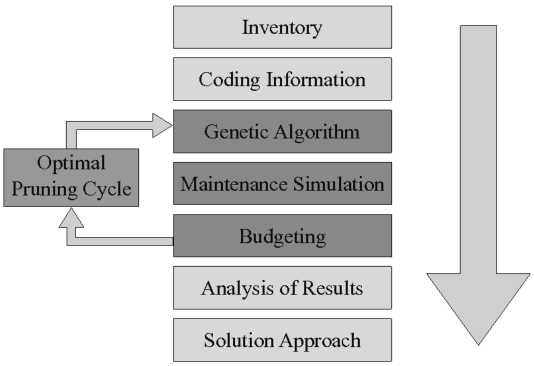
At this stage we process the information collected in the field, which corresponds to forest inventories conducted for each feeder. The inventory information is entered into a genetic algorithm (GA), and so we get a curve that describes the *optimal pruning cycle* (CPO) and the budget.

Some of the most important data contained in a particular inventory includes: location of tree, species, physical condition, health, geographical coordinates, height, diameter at breast height (DAP), plate identification, actions performed (either pruning or felling) and a photographic record of each individual. From this database, for the optimization process in our research, we use the following data: identification plate, height, species, and tree-network distance (distance between the medium voltage network and the nearest point of the tree).

The time between pruning on the same tree is called *pruning cycle* (CP). The optimal pruning cycle is then the optimal time that should elapse between forest maintenance performed on a circuit in order to minimize the possibility of contact between the trees and the medium voltage network, thus minimizing service interruptions.

The analysis methodology is summarized in Figure 2. The inventory information is encoded in a matrix. This matrix consists of n rows representing the number of trees, and four columns that correspond to the parameters: *Tree ID, Cost code, Species code, and Di*.

Figure 2. Flow diagram of information management to determine the optimal pruning cycle



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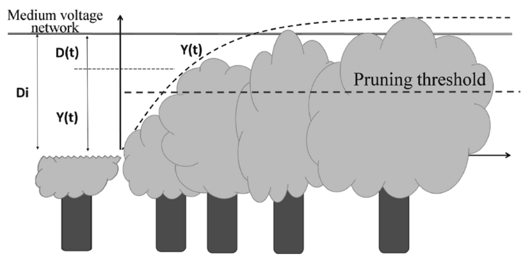
The *ID* identifies a unique tree. The *Cost code* is the cost of pruning the tree according to its height. We assign to this parameter three possible values: 0, 1 and 2. Thus, 0 corresponds to a height of less than 7 m, 1 corresponds to a height between 7 m and 15 m, and 2 correspond to greater heights. The species are coded with values from 0 to 18. Finally, *Di* is the initial tree-network distance in cm.

We handle a total of 19 native species throughout the savannah of Bogotá. The growth curves for these species have already been determined in previous research [14]. These studies described the cumulative growth of trees after having been subjected to pruning. With this information, we can simulate the implementation of forest maintenance, thus we can make the performance evaluation of the genetic algorithm.

We build the objective function to be minimized from two elements: the tree-network distance coming from the inventory, and the growth models by species (Figure 3). We define three distances:

- *D(t)* = Distance to optimize [cm].
- *Di* = Initial distance [cm]. It's the same tree-network distance.
- *y(t)* = Cumulative growth [cm] of the tree in time *t* [days] This depends on the growth function of each species.
- *Pruning threshold* is the distance that serves as a criterion to discriminate between the trees that should be pruned and those that should not be pruned.

Figure 3. Distances involved in the objective function



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The optimum distance for an individual tree is defined as the distance difference between initial and cumulative growth. Thus, Equation 6 attempts to find the maximum time *t* to wait for pruning, i.e., the time at which the distance *D* is equal to or approaching zero:

$$D(t) = Di - y(t) \qquad (6)$$

Negative values of *D* in Equation 6 (when *y(t)* > *Di*) are produced by the growth of a tree which is already higher than the desired value, that is, greater than the tree-network distance found in the inventory. Accordingly, the optimal distance should not have negative values, therefore:

$$D(t) \geq 0 \qquad (7)$$

$$Di - y(t) \geq 0 \qquad (8)$$

Equation 8 is the constraint equation to optimize *D* without obtaining negative values.

Since along an air electricity network there are certain number of trees of different species and heights, it is necessary to find, not only the cycle of pruning each tree but the best pruning cycle which leads to general maintenance. For a number *n* of trees, the *objective function* (FO) is defined as the sum of distances *D* for all trees in the inventory, namely:

$$D_{opt}(t) = \sum_{k=1}^{n} Di_k - y(t)_k \qquad (9)$$

Likewise, for a number *n* of trees, we define *n* constraint equations as follows:

$$Di_k - y(t)_k \geq 0 \qquad (10)$$

The simulation of maintenance is shown in Figure 4. From this figure, the behavior by individual or by species can be analyzed according to the cumulative growth. The process that occurs at each step corresponds to:

1. Recording the distance *Di* in the inventory as found in the field.
2. In the first PC, growth *y(t)* is calculated and subtracted from *Di* (Ec. 9). Then it is estimated that trees are within the threshold of pruning, i.e.:

$$D(t) \leq Threshold \qquad (11)$$

3. Then it is assumed that necessary pruning takes place by assigning a new value of *Di*

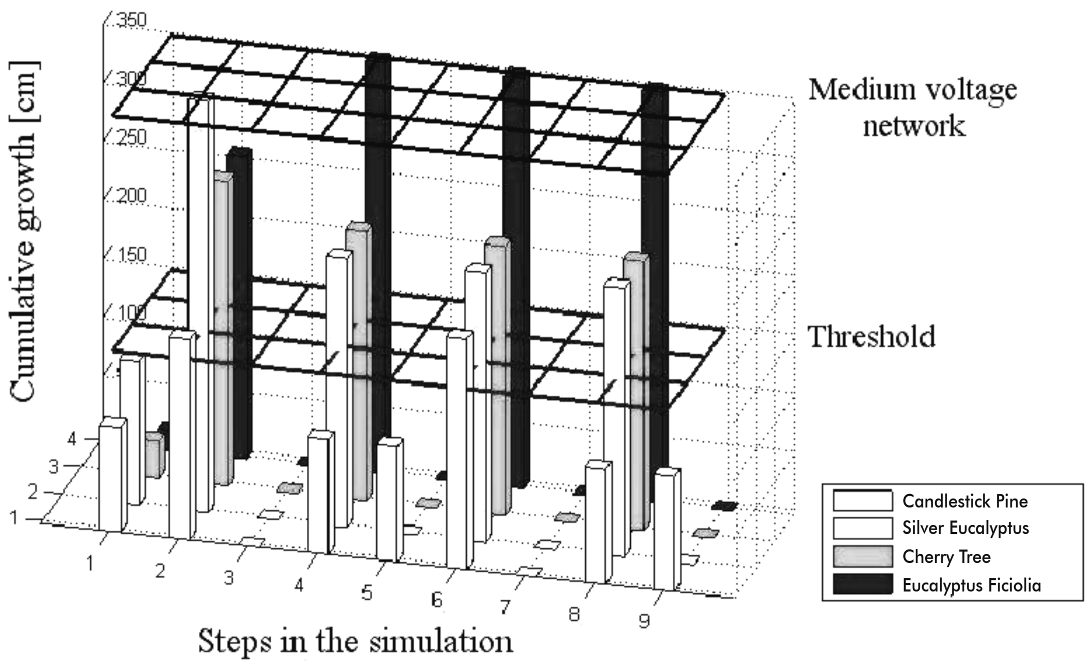
(350 cm for this example) for those trees whose cumulative growth is within the threshold, according to the previously-set value. The new value of *Di* for trees that are *not* within threshold *D(t)* is the same as calculated above, i.e.:

$$Di = D(t) \tag{12}$$

4. Then the three previous steps are repeated as the number of cycles to simulate, according to a previously defined value.

Finally, we obtain curves that describe the characteristic CP of the circuit and the amount of pruning that takes place in each cycle. On these graphs, we analyze the execution time of maintenance and the number of individuals to be pruned. The cost of maintenance in each CP value is calculated according to the costs of pruning, considering the *Cost Code* associated with each tree. Note that this budget is the minimum required in each CP to minimize the possibility that some trees generate outages. The methodology concludes with an analysis of the data obtained from the simulation and the proposals for solutions in accordance with the analysis.

Figure 4. Simulation of carrying out forest maintenance



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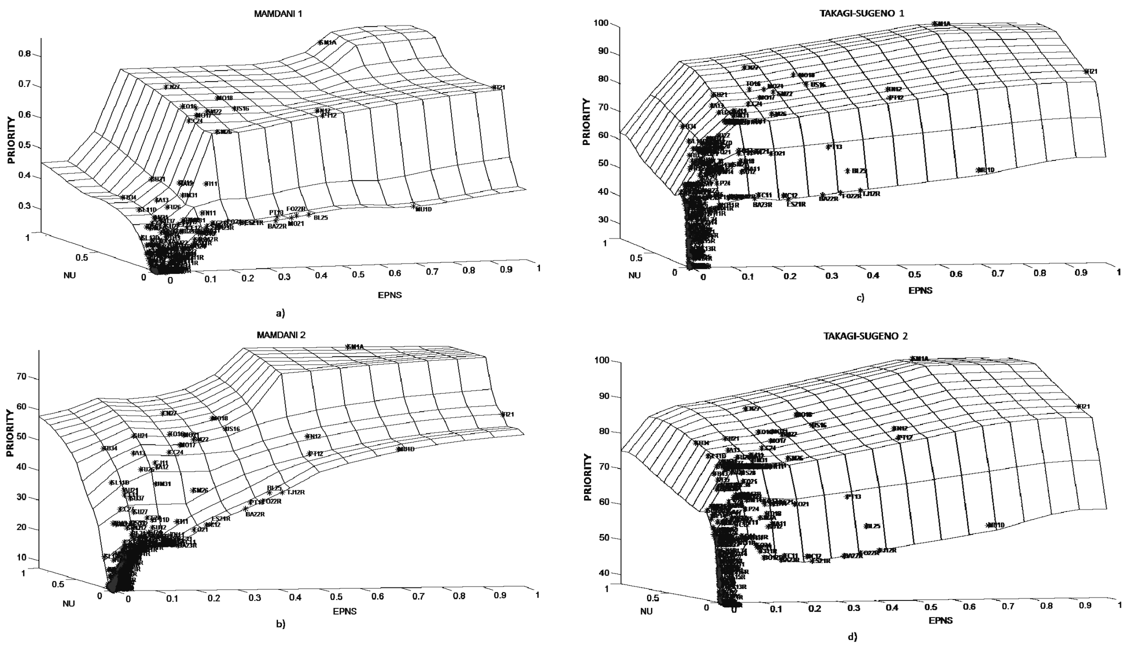
4 Performance

We prioritize the circuits by first introducing the historic events in 2009 into the fuzzy logic system for all unplanned events caused by trees, particularly in the medium-voltage circuits, in the area of influence of Bogota and in the neighboring municipalities of the savannah. The upper surface of Figure 5 shows the most critical circuits, and there is a clear priority among them. By contrast, at the bottom of the figure lies the majority of the population.

It is obvious that the modification of rules and fuzzy sets directly affects the way the system prioritizes the circuits, but this becomes visible when comparing the four graphs. We used the two Mamdani systems with three fuzzy sets in the output. The design difference between them is that it has changed the core and the boundary of the input fuzzy sets, and also the scale priority. With these changes, the output is a bit more uniform and hierarchy between priority circuits is more visible.

The first system ranks the 44% of the population, while the remaining 56% were grouped at the bottom of the graph with the same priority value. With the second Mamdani system we ranked 95% of the population and only 5% share the same value. We also changed some rules to give more priority to circuits with a very high rate relative to the other; the effect of this is seen in Table 2.

Figure 5. Surfaces of priority



Source: own elaboration

Mamdani's 2 ranking is achieved including circuits that did not previously exists but which deserved more priority characteristics, this is the case of circuits SU21, MU1D and TB34. By analyzing their indicators, we can observe that they exhibit an industrial customer profile, i.e., high consumption and few users, or otherwise, many users and low consumption. Both cases are of concern, both for the profile and for the Colombian regulatory framework. It is worth noting that if sales of energy are low in proportion to the number of users, the ITAD increases.

Table 2. Priority Circuits - Mamdani 1 and 2

Circuit	EPNS	NU	Mandani 1
SM1A	0,755	1	0,816
TI21	1	0,282	0,751
CN27	0,254	0,737	0,725
MO18	0,348	0,592	0,703
TN12	0,527	0,304	0,692
TO16	0,231	0,52	0,691
PT12	0,517	0,22	0,688
MO21	0,262	0,499	0,687
US16	0,36	0,478	0,683
SM22	0,277	0,458	0,679
MO17	0,239	0,425	0,672
CC24	0,204	0,38	0,662
SM26	0,237	0,243	0,642
TI11	0,183	0,164	0,484
Circuito	EPNS	NU	Mandani 2
SM1A	0,755	1	79,817
TI21	1	0,282	62,412
CN27	0,254	0,737	60,343
MO18	0,348	0,592	59,727
US16	0,36	0,478	57,016
TN12	0,527	0,304	55,727
TO16	0,231	0,52	55,28
MO21	0,262	0,499	54,951
SU21	0,14	0,497	54,874
SM22	0,277	0,458	53,833
MU1D	0,695	0,005	53,327
MO17	0,239	0,425	52,221
TB34	0,068	0,516	50,732
PT12	0,517	0,22	50,575

Source: own elaboration

In the figure, these customers were found toward the ends, which is very useful because it displayed sectors that represent grouped circuits with special characteristics. Another example of this can be observed at the bottom-right edge of the surface, where some 34,5 kV circuits have been located (suffix R). These circuits are also very important because although they have few users, the service of substations or industrial customers depends on them, hence the EPNS is high. While some of them are not included in the ranking, having a look at them may be useful as a warning flag.

Figure 5(c) and 5(d) correspond to two Takagi-Sugeno systems with four fuzzy sets in the output. The most obvious difference compared to Mamdani systems is that the surface is uniform, i.e., the prioritization is more uniform. The organization along the z axis is more vertical; consequently, there is a better distribution of the data range. In the first case, an 83% of the data were ranked completely, while in the second case, an 85% of the data were ranked completely. As in the previous comparison, the second case has a change in the rules to give some importance to circuits with extreme indicators; however, this is not visible in the ranking of the most important circuits because in the high hierarchy there were no differences.

Table 3. Priority Circuits - Takagi-Sugeno 1 and 2

Circuit	ENS	UN	TS 1	TS 2
TI21	1	0,282	100	100
SM1A	0,755	1	90,06	90,06
CJ11	0,157	0,313	87,974	87,974
SM22	0,277	0,458	86,916	86,916
US16	0,36	0,478	84,527	84,527
MO18	0,348	0,592	84,36	84,36
TI11	0,183	0,164	82,761	82,761
MU1D	0,695	0,005	82,53	82,53
TN12	0,527	0,304	82,238	82,238
SM26	0,237	0,243	82,176	82,176
FO21	0,203	0,045	80,979	80,979
IA12	0,158	0,297	80,597	80,597
TB34	0,068	0,516	78,852	79,635
CC27	0,054	0,219	78,382	78,852

Source: own elaboration

To evaluate the optimal pruning cycle, we use a 2009 forest inventory of the circuit CY12 code, which contains 27 trees distributed in six species, namely Acacia Melanoxylum, Ficus Andicola, Prunus Serotina, Cupressus Lusitanica, Eucalyptus Globulus and Salix Humboldtiana. According to the information processing detailed in Figure 2, we coded the information with the following parameters: *threshold* = 200 cm, *Di* = 400 cm, CP = 10. The results are shown in Table 4.

Table 4. Simulation of forest maintenance. Circuit CY12

CP	Days	Prunings Realized	Budget
1	2	14	14
2	80	23	23,7
3	100	25	25,7
4	140	25	25,7
5	347	26	26,7
6	347	25	25,7
7	347	26	26,7
8	347	25	25,7
9	347	26	26,7
10	347	25	25,7

Source: own elaboration

According to the simulation, the first maintenance campaign is performed in the very short term, but this time gradually increased until a point of stability. The same was true for the amount of pruning, which stabilized at between 25 and 26 pruning per CP.

To simulate the maintenance cost, we assume values for the type of pruning: Code 0 costs 0.9, Code 1 costs 1, and Code 2 costs 1.4. By optimizing the amount of pruning, the budget is also optimized (Figure 6).

Figure 6. Results CPO, CY12 circuit

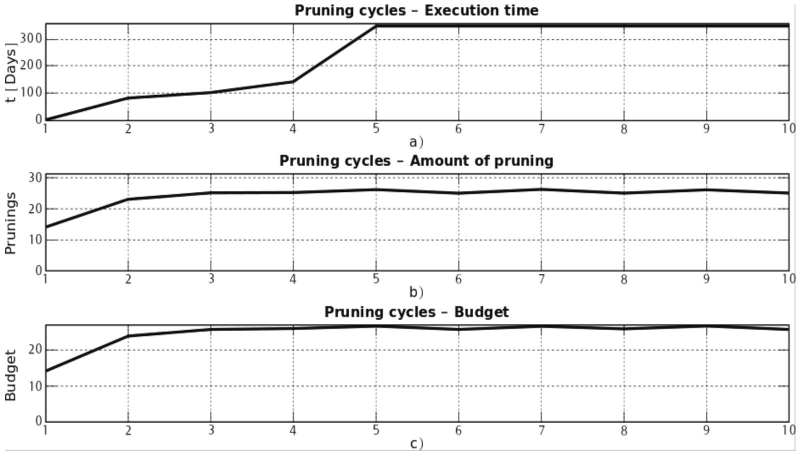


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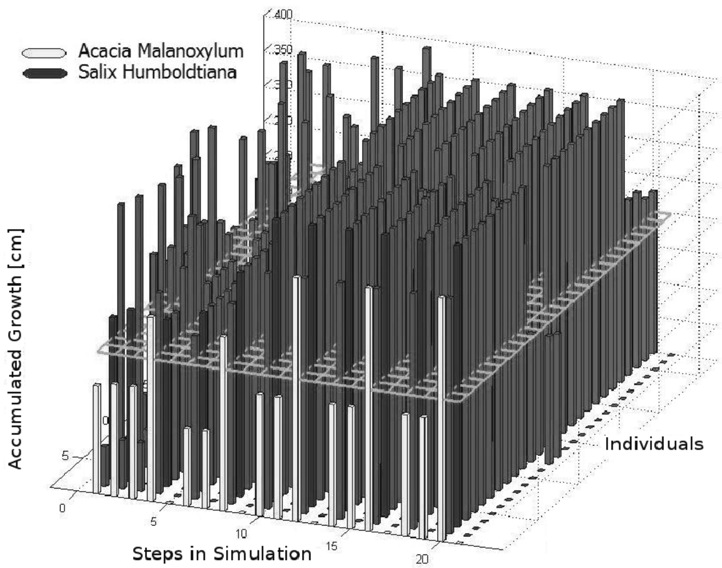
Figure 7 shows the behavior of the trees along the simulation. This figure highlights two individuals whose growth contrasts, namely the growth curve of the Salix Humboldtiana increases faster than the curve of Acacia Melanoxylum. The red stripe exceeds the threshold in all cycles of pruning, so the tree should be pruned in all cycles of pruning. On the other hand, the yellow stripe exceeds the threshold only five times. This last individual never reaches the maximum point. The pruning cycle period depends on the faster individuals.

Figure 7. Tree growth in CY12 circuit



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To verify the performance of the algorithm with more data, the TI21 circuit inventory is entered into the system. This inventory is among the most critical one according to initial weighting. The experiment is performed with 463 individuals, which are divided into eleven species. The results are shown in Table 5 and Figure 8. In this case, the number of trees was not an inconvenient to find a point of stability.

Table 5. Simulation results, circuit TI21

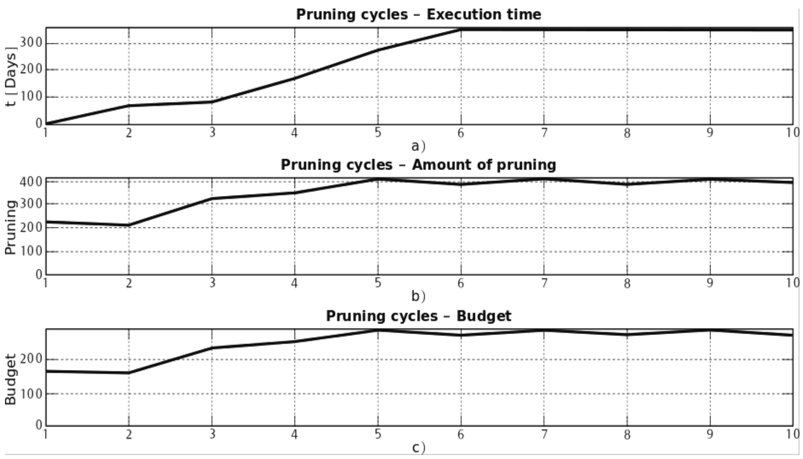
CP	Days	Prunings Realizad	Budget
1	3	201	151,3
2	70	235	171,2
3	78	305	218,8
4	160	364	258,3
5	294	406	292,2
6	347	389	275,3
7	347	406	292,2
8	347	389	275,3
9	347	406	292,2
10	347	389	275,3

Soruce:

The last methodological block is the approach to solutions. To do this, it is necessary to propose alternatives that emerge, such as the analysis of the simulated results, a technical analysis of the design conditions of the medium voltage network, a geographic analysis, and the analysis of individual trees. Some possible solutions are as follows:

- Identify the optimum time for pruning, when the best solution is to simply perform pruning along the circuit.
- By combining the analysis of CP with the location of individual trees along the network, we can identify sectors in which technical measures are taken to mitigate the indicators and/or extend the CP.
- It is possible to identify individuals whose tree management is not expensive or complicated (as a trade-off for extending the CP) in terms of cuttings, transportation network, replacement of species, and other issues associated to each particular case.

Figure 8. Tree growth in TI21 circuit



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5 Conclusions

In this paper we applied fuzzy logic techniques to design a tool that would guide the management of trees in medium voltage networks globally. This tool also allows grouping, viewing and tracking circuits according to the linguistic qualifiers that denote key technical criteria in maintenance management as well as considering the quality indicators established by the regulator. From a specific point of view, we find that there is a stable pruning time for all trees that affect a circuit, despite the diversity of species and the uneven growth of such trees.

The methodologies proposed, from real data, are purely theoretical and the nature of the problem requires monitoring, at least in the medium term. The prioritization of circuits must be a periodic process that evidences the effectiveness of the maintenance performed as well as the projection of the indicators of circuits. Similarly, analysis of the optimal CP requires monitoring and feedback, both on the growth curves used and on the pruning to be done. For the application of the integrated methodology we propose the following:

- Pilot tests should be performed for implementing and monitoring of maintenance, allowing for adjustment of the growth curves, either by mistake or in the model, including environmental factors such as humidity, temperature, soil conditions, time of year and, in general, any other factor affecting the growth of trees. Here we consider and follow all technical measures applied and their impact on the CP.
- The work in [14] should be continued, developing cumulative growth curves for species that have not yet been included.
- A fuzzy logic system should be designed and implemented as proposed in this research, but allowing prioritizing circuits using all possible causes of failure.

References

[1] Comisión de Regulación de Energía y Gas, "Resolución 097 de 2008", 2008. [En línea]. Disponible: http://www.creg.gov.co

[2] P. Hilber and L. Bertling, "Multiobjective maintenance policy for a distribution system an application study", *Proc. 10th Int. Conf. Probabilistic Methods Applied to Power Systems PMAPS '08*, pp. 1-6, 2008.

[3] I. G. Torne and S. L. Choy, "Considerations about the maintenance in electrical networks", *Proc. IEEE Russia Power Tech*, pp. 1-3, 2005.

[4] L. Canha, A. Abaide, F. Farret, E. Daza, and G. Cassel, "Automatic priority of the maintenance activities in distribution systems using multicriterial analysis and fuzzy techniques", *Proc. Int. Conf. Power Engineering, Energy and Electrical Drives POWERENG 2007*, pp. 237-242, 2007.

[5] Jun-Jing Tian, "Research on the maintenance strategy of electrical supply equipment based on rcm", *Proc. Int Information Management, Innovation Management and Industrial Engineering (ICIII) Conf*, vol. 1, pp. 105-108, 2010.

[6] G. Parise and L. Martirano, "System management strategy to monitor insulated power cables", *Proc. 39th IAS Annual Meeting Industry Applications Conf. Conf. Record of the 2004 IEEE*, vol. 3, pp. 1755-1759, 2004.

[7] J. A. Wischkaemper, C. L. Benner, and B. D. Russell, "Electrical characterization of vegetation contacts with distribution conductors - investigation of progressive fault behavior", *Proc. T&D Transmission*

and Distribution Conf. and Exposition IEEE/PES, pp. 1-8, 2008.

[8] M. A. Awadallah and M. M. Morcos, "Application of ai tools in fault diagnosis of electrical machines and drives-an overview",Energy Conversion, IEEE Transactions on, vol. 18, no. 2, pp. 245-251, June 2003.

[9] B. Nemeth, S. Laboncz, and I. Kiss, "Condition monitoring of power transformers using dga and fuzzy logic", *Proc. IEEE Electrical Insulation Conf. EIC 2009*, pp. 373-376, 2009.

[10] K. V. Kumar, S. S. Kumar, B. Praveena, J. P. John, and J. E. Paul, "Soft computing based fault diagnosis" *Proc. Int Computing Communication and Networking Technologies (ICCCNT) Conf*, pp. 1-7, 2010.

[11] M. F. Ariffin, "Advances and challenges in mitigating tree-related faults in TNB distribution network", *Proc. th Int Advances in Power System Control, Operation and Management (APSCOM 2009) Conf*, pp. 1-6, 2009.

[12] D. T. Radmer, P. A. Kuntz, R. D. Christie, S. S. Venkata, and R. H. Fletcher, "Predicting vegetation-related failure rates for overhead distribution feeders", IEEE Trans. Power delivery vol.17, no. 4, pp. 1170-1175, Abril 2002.

[13] Liliani A. V. Apolinario and Jose R. Sanches Mantovani, "Modelo de programacao matematica para controle do crescimento da vegetacao sob redes de distribuicao de energia eléctrica", *Sba Controle & Automacao Sociedade Brasileira de Automatica*, Vol. 22, No. 3, pp. 284-295, Mayo/Junio 2011.

[14] T. Contreras and D. K. Rojas. "*Modelación del crecimiento de quince especies arbóreas que interfieren con redes eléctricas de media tensión en Bogotá luego de ser sometidas a podas*". Master's thesis, DistritalUniversity, Bogotá Colombia, 2010.