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FELLING AND PRUNING OPTIMIZATION OF THE VEGETATION AROUND THE HIGH VOLTAGE DISTRIBUTION LINES

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Abstract

One of the most important activities carried out by distribution companies in Spain is the maintenance of the power lines. A key issue regarding the maintenance of the power lines in economic terms, quality of supply and social impact are outages caused by vegetation around the power lines. Therefore, DSOs must maintain corridors around the circuits clear of vegetation to avoid the greatest number of incidents and consequently, reduce the number of hours of energy not served to the maximum. In addition, distances between lines and vegetation are mandatory.

Cleaning of the corridors is an activity carried out by distributors since the beginning of the business. However, in most of the cases not in an efficient way. In this master's thesis has been designed a maintenance plan for the optimization of this activity for the high voltage distribution lines belonging to GNF. The plan is designed according to a level of risk assigned to each unitary element of the power lines. Level of risk is calculated by considering different parameters that determine the probability and the severity of failure.

Resumen

Una de las actividades más importantes llevadas a cabo por las empresas de distribución en España es el mantenimiento de líneas eléctricas. Una cuestión clave con respecto al mantenimiento de las líneas eléctricas en términos económicos, de la calidad del suministro e impacto social son las interrupciones causadas por la vegetación alrededor de las líneas eléctricas. Las empresas distribuidoras deben mantener los pasillos de alrededor de los circuitos despejados de vegetación para evitar el mayor número de incidentes y consecuentemente, reducir al mínimo el número de horas de energía no servida. Además, las distancias entre las líneas y la vegetación están reguladas por la administración.

La limpieza de los pasillos de las líneas eléctricas es una actividad realizada por las distribuidoras desde siempre. Sin embargo, en la mayoría de los casos no de manera eficiente. En esta tesis de master se ha diseñado un plan de mantenimiento para la optimización de esta actividad para las líneas de distribución de alta tensión pertenecientes a GNF. El plan está diseñado de acuerdo con un nivel de riesgo asignado a cada elemento unitario de las líneas eléctricas. El nivel de riesgo se calcula considerando diferentes parámetros que determinan la probabilidad y la gravedad del fallo en cada elemento unitario

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Chapter 1

INTRODUCTION

Nowadays, electricity represents a basis for the development of common life. Societies are highly dependent on electric power as it is necessary for the main activities of a city: industry, transportation, communication and domestic uses. Electricity is a significant sign of the level of development of a society and the quality of human life. In addition, this electricity dependency is growing thanks to the increasing use of electronic devises and the growing of population.

In the electricity business, the network plays a crucial role. No matter where and how the electricity is produced, a grid is needed to transport the electricity from the generation points to the consumers. If the network suffers from an interruption, consumers are impacted. Therefore, utilities must deliver electricity under certain standards of quality of service. To prevent electrical outages the maintenance of the transmission and distribution lines is critical.

One of the main reasons for electrical outages in the overhead power lines is the vegetation around the circuits and the incidence of a tree in the line as it is shown in the contiguous picture.

Figure 1-1 Cubillos del sil – Fabero (45 kV)

In order to improve the quality of service by reducing failures caused by vegetation located on distribution lines, clearances between vegetation and electric lines are needed. Due to the relevance of this task, it is a regulated activity. There must be a mandatory corridor without vegetation around the power lines depending on the characteristics of the lines.

Figure 1-2 Facilities belonging to Gas Natural Fenosa

Vegetation maintenance in the corridors of the network is a common problem faced by all the utilities in the world. However, the circumstances of each company may be different (regulation, environmental and orography conditions). Hence, a specific solution is needed according to the different scenarios of the different distribution companies to deal with.

Maintaining clearances in the corridors implies positive externalities to the distribution company in terms of safety and quality of service.

This chapter will present the purpose and scope of this master's thesis regarding the problem of vegetation around the overhead distribution lines.

1.1. Objective

Felling and pruning is a high capital intensive activity for the distribution companies (DSOs) and also has a crucial role in the quality of service. The aim of the present master thesis is to properly allocate the costs of felling and pruning activities around the high voltage distribution lines belonging to Gas Natural Fenosa. The output of the project is a most effective vegetation maintenance plan.

To carry out this activity, the organization has a fixed budget that has to be spent in a reasonable and efficient way. The decision of the allocation of the budget will be assigned by means of a hierarchy of the sections of the lines according to some variables that determine the quality of the sections related to vegetation.

Some of the variables that will be consider to implement the study are: the historical incidences in the corresponding line segments and the historical penalties related to vegetation that have suffered the lines. Both variables introduce a signal of what are the most critical segments that are susceptible to cause outages and interrupt the service.

On the other hand, to make the decision it is also important to quantify the severity of the circuits in order to be able to evaluate the number of clients that are supplied by each line. This regard provides information about how large the consequences of having an interruption in a certain line in terms of quality of supply and in economic terms would be.

For the last consideration, there will be used a vegetation management model developed by Gas Natural Fenosa. The model determines the amount of money that would need to be spent to properly maintain each 25 m^2 of land around all the lines.

These results provide information on the effectiveness of each € spent. That is, what is the profitability of each segment (how many kilometers could be kept in each circuit with a certain amount of money). This variable is expressed in € / km and will also be considered for the design of the maintenance plan since it is advisable to spend the money as efficiently as possible.

Once the hierarchy is done, it is necessary to allocate the limited budget among all the segments. The appropriate settlement of resources will be designed with the help of the model considering the amount of money that needs to be spent on the maintenance of each segment until the total budget available is exhausted.

1.2. Scope

Distribution companies are encouraged to reduce OPEX and CAPEX as much as possible. This, consequently, may cause a decrease in the quality of the service. To maintain a certain quality in supply, there are some mandatory standards that have to be met by DSOs.

Vegetation is one of the main causes in the continuity of supply. Besides, a considerable amount of money is spent in the maintenance of the circuits. In addition, in places where vegetation is voluminous, there is a high capital intensive expenditure dedicated to the operation of felling and pruning the vegetation that represents one of the most important activities in the budget of OPEX.

So far, vegetation management has been carried out by means of a general approach in Gas Natural Fenosa and there has been no focus on improving the quality of supply or on reducing possible negative externalities. By managing the activity in a most efficient way, there can be achieve considerable advantages.

The main advantage of controlling this activity is to save money in the budget dedicated to the maintenance of the network. This budget is provided by the regulator as the maintenance of the lines is a mandatory activity. There is an incentive-based regulation in force which distribution companies receive a fixed amount of money every year to finance the activity. Therefore, the more the organization saves, the bigger the revenue.

On the other hand, introducing efficiencies in the process of cleaning the corridors reduces electric outages and it will produce positive externalities to the operation of the lines. When a short circuit happens, the distribution company involved must fix up or even replace the devices affected such as conductors, electric towers, transformers or switches which implies high expenditures for the distribution company. In addition, depending on the degree of the accident and on the importance of the line involved, these outages may cause interruptions in the supply which can be penalized by the regulator. Penalties represent more expenses to the company.

Besides, it allows the company to have more control over the activity, and consequently over the contracted company in charge of vegetation trimming.

The management of the activity can always be improved by learning on the experience once the methodology has been applied. However, it is expected to introduce a higher quality of service, a reduction of the costs and an improvement in the supervision of the activity.

Chapter 2

STATE OF ART

The aim of this chapter is to introduce the different techniques available to improve the activity of maintaining the corridors of the lines clean, how this activity has been done in the past and where these techniques are evolving to.

2.1. A considerable concern for the utilities

Trees around the electric ways are one of the leading causes of electrical short circuits which has an impact in the continuity of supply and, consequently, in the reputation of the utility in charge. This problem is a challenge for the utilities since the first overhead line was installed.

Due to the number of outages caused by vegetation, distribution companies are concern about clearances of the lines corridor. However, utilities must face a lot of challenges and find a trade-off between a reliable and economic system, public perceptions and environmental concerns. Some important accidents caused by vegetation have made regulators think that the practices used now were not enough to ensure a reliable system within the limits required.

That is why, there are a lot of studies regarding this problem proposing different practices to reach the most economical and most efficient method considering each specific problem. A lot of optimization tools has been introduced in the practice and, nowadays, controlling vegetation around the power lines is a reality that many utilities are currently use.

A study from the San Francisco University named “Evaluation of Methods for Control of Vegetation in Utility Corridors” exposes that there are three remarkable methods used in line clearance activities which are: planting management, mechanical trimming and use of tree growth regulators.

2.1.1. Planting management

Planting management is considered as the most beneficial method for managing the vegetation in utility corridors. It consists on selecting the vegetation to plant around and below the lines. It requires a big cooperation between the utility, the local government, the regulatory agencies and the homeowners. It also calls for public education to aware the landowners and municipalities of the practices carried out. [1]

To choose the most suitable vegetation for a place, there are a lot of variables to consider like humidity, ground, wind exposure, sunlight, pollution, stressful conditions and available growing space.

This technique distinguishes between three zones around the lines regarding the distances at each side of the circuit where trees of different heights may be planted at each layer depending on the distance to the circuit and the characteristics of the circuit (voltage, height, etc). [1]

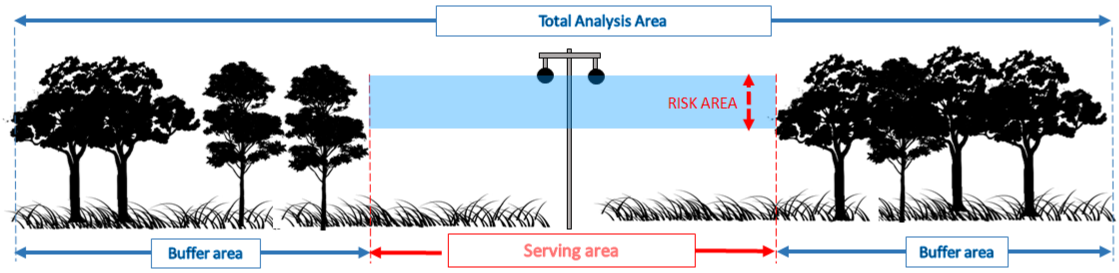

Figure 2-1. Scheme of the corridors [1]

The advantages of planting are to reduce the future outages and fires associated with contact between vegetation and electrical infrastructures, the improvement of the ecosystems near the infrastructure, reduction in the use of herbicides and chemicals and the reduction of unnecessary mechanical trimming. [1]

The disadvantages of planting are manageable as it is a programmed activity. However, there can be potential disadvantages related with regulations and private properties owners to maintain the corridors cleaned, difficulties to make the stakeholders understand the practice or the requirement of planting selected tree species imposed by regulators. In addition, it requires a high intensive capital. [1]

In conclusion, if the costs of the process are reduced in the process, planting management is worth considering.

2.1.2. Mechanical vegetation trimming

Mechanical trimming is the traditional and most common practice of controlling the vegetation surrounding the lines. However, it can be done in many different ways which implies considerable differences in the budget and, consequently, in the efficiency of the process. [1]

The method is about a variety of strategies to stablish a schedule for effective felling and pruning of the vegetation. The tree trimming must fulfill with the local regulation in force which implies control the height of the vegetation below the standards required and respect the mandatory periods of intervention. [1]

Figure 2-2 Mechanical vegetation trimming [1]

The factors that condition the amount of trimming are the kind of the vegetation, environmental aspects, proximity to the line and line configuration.

The main advantage of this method is related with the cost. Although it can be more expensive than the others depending on the technology used, it is normally the cheapest. In addition, directional pruning is less harmful for the tree as the trimming is minimized, it focuses only in the problem. [1]

There are several disadvantages regarding mechanical trimming as the number of workers that are killed by contact with the power lines, it takes a lot of time and human resources and, additionally, corrective pruning is often required which represents a higher cost for the utility. By last, it generates a lot of biomass which must be removed. [1]

Figure 2-3 Brush cutter [1]

In the long term, it is the most expensive method but it is normally chosen by the utilities due to the public perception and the absence of entry barriers.

2.1.3. Tree growth regulators

Tree growth regulators are chemicals that reduce the plant hormones which control cell elongation and, consequently, growth rate without changing development patterns or being phytotoxic. This method can represent a considerable saving for the utility company regarding the trimming budget and the removal of biomass. [1]

Chemical growth regulators have been used since 1940 in agriculture and horticulture. Nowadays, it is starting to be used for vegetation management around the power lines as they are becoming more effective, cheaper and less labor intensive. In the picture on the side, it can be observed the soil injection method which is a method for protecting the tree from pests and for correction of nutrient deficiencies.

The main advantage of this technique is the reduction in vegetation growth, trim time and biomass. It is also remarkable, the prevention of fungal infections thanks to the regulators properties and the possibility of cure for declining trees. [1]

Figure 2-4 Tree growth regulators [1]

However, it often does not have a good public perception as there has been a conflict between chemical control and environmental movements for more than 40 years. I addition, it requires cost and time to prepare the environmental approval. [1]

It is a very new method and not much used by utilities yet. However, it is improving and becoming more effective. In addition, costs are being reduced which makes it increasingly competitive.

Chapter 3

PRESENTATION OF THE PROBLEM

In Chapter 3, the specific problem of Gas Natural Fenosa will be exposed regarding the significant variables that affect the overhead lines of the company and the current regulation in Spain. Scenarios to face may be completely different depending on the location of the circuits.

In addition, the current treatment received by the lines in terms of maintenance of the corridors around the overhead distribution lines will be explained in this chapter as well. All the felling and pruning process made by Gas Natural Fenosa will be described.

3.1. The distribution business in Spain

In Spain, network business is separated between transmission and distribution. Transmission circuits include all lines from 400 kV to 220kV while distribution circuits are all those lines with a lower voltage. Almost all transmission lines are managed and belong to Red Eléctrica de España (REE) whilst distribution lines are owned and managed by different distribution companies (DSOs).

According to article 38.1 of Law 24/2013, of December 26, of the Electricity Sector, the activity of distribution is that which has as its object the transmission of electrical energy from the transport networks, or, where applicable, other transmission networks. Distribution or from the generation connected to the distribution network itself, to points of consumption or other distribution networks in the appropriate quality conditions with the ultimate purpose of supplying it to consumers. [2]

Network business is a natural monopolistic activity since competition (duplicate of lines) is meaningless (economy of scale). However, compared with competitive markets, monopoly allows a dominant position which implies higher prices, greater producer surplus, lower consumer surplus and, in general, less social benefit. In addition, a dominant position prevents all the generators from joining the grid in equal conditions. To avoid the inefficiencies discussed above, network management is a regulated activity.

On the other hand, distribution activity incurs in the following costs:

- New investments and reinforcements
- Operation and maintenance costs
- Costs of the losses of distributing the energy through the network

- Cost related to the commercial attention (lecture, billing)

The authorized incomes approved by the regulator are recovered by the distribution company through the tariffs charged to the consumers.

On the other hand, to encourage competitiveness in generation and retail is necessary to guarantee free access to the grid for all the agents, named as “three party access” to ensure the independence of DSOs and avoid discriminatory behaviours between agents.

Distribution circuits can be separated between high voltage (subtrasmission), medium voltage and low voltage (more distributed lines). Depending on the voltage, the maintenance requested is different as well as the corridors around. This project is focused in high voltage overhead distribution lines which refers to lines of 220 kV, 132 kV, 66 kV and 45 kV belonging to Unión Fenosa Distribución.

3.2. Overhead high voltage lines of Gas Natural Fenosa

Unión Fenosa Distribución is one of the leading distribution companies in Spain. It has a market share of 15%, being the third largest distribution company in Spain after Endesa and Iberdrola.

Figure 3-1 Main distributors in Spain

Facilities that belong to Unión Fenosa Distribución are divided in two different areas with very different characteristics. The northern zone includes the facilities located in Galicia and a part of León and Zamora while the central part includes circuits from Ciudad Real, Segovia and a part of Cuenca, Toledo, Madrid and Guadalajara. The properties that condition the maintenance in both zones, are very different and it is fundamental to consider them to develop the plan of vegetation maintenance. In the northern area, most of the circuits are overhead while in Madrid, lines are almost all underground.

Regarding the vegetation, the species are totally different in both areas and have different growth rates. Galicia has a high percentage of forests (about 70%) being one of the Autonomous Communities with the highest amount of biomass. The main species of vegetation in Galicia are: Eucalyptus, Pines and European Chestnut. The most dangerous species to be managed is eucalyptus, which could reach more than 60m in height. A forest of eucalyptus trees can create uncontrollable fire problems due to its altitude. In addition, they have a very short growth time and detaches bark from the trunk that can fly and cause short circuits in the lines. [3]

Vegetation in the central area are more controllable and have a lower growth rate. It belongs to Mediterranean floral region. The vegetation formation is characterized by the evergreen forest and the thicket. [4]

The kind of vegetation and the growth rate are highly related to the climate. In addition, environmental conditions will also determine the good condition of the lines. In Galicia, there is a very favorable climate for vegetation as well as high level of humidity and rainfall. However, the central zone is a very dry area where the hard environmental conditions determine the low growth rate. [4]

Another issue to consider in designing any maintenance plan is the population and its distribution in both areas that happen to be totally different. Distribution facilities from GNF feed different amount of people which is important to consider as reliability measures imposed by regulation depend on the amount of clients and the area. Distributors have to fulfil with different values of reliability indices depending on the location of the features distinguishing between: urban area, semi-urban area, concentrated area and rural area. Regarding the different locations:

2016	Population	Population density (hab/km2)
Galicia	2.714.084	92
Madrid	6467000	795
Segovia	155625	23,7
Castilla la Mancha	2042000	25,9

Table 3-1 Population [11]

3.3. Regulation

Regulation is a key issue for planning the vegetation maintenance to achieve the most efficient solution fulfilling the law and, consequently, avoiding potential penalties and complaints.

Regarding the topic of the thesis, it is important to review the regulation related to how distribution activity is remunerated, the quality of supply and also to review the specific legislation about vegetation around the lines.

3.3.1. Remuneration of the distribution activity

Remuneration of the distribution activity is regulated according to the Royal Decree 1048/2013 where there are described the methodology to establish the remuneration of the CAPEX and OPEX encouraging the improvement of management effectiveness, economic and technical effectiveness, the quality of supply and the decrease of fraud. The remuneration of the distribution activity shall be determined according to regulatory periods of six years duration. [5]

The ministry of Industry, Energy and Tourism establishes the set of technical and economic parameters to calculate the remuneration of the activity during the whole regulatory period. [5]

3.3.2. Regulation of the quality of supply

As there are incentives for the DSOs to reduce costs, there must be also incentives to control the quality of supply to avoid low costs at the expense of the quality. The distribution activity is a key issue regarding the quality of supply received by the client. Around 90% of the interruptions suffered by consumers are due to failures in distribution circuits. Therefore, the quality of supply (continuity of supply, power quality and commercial quality) is also regulated under certain standards. It guarantees the adequate provision of the services with homogeneous criteria throughout the State and at the lowest cost for the system. [2]

The consumer has the right of receiving the service with the levels of security, regularity and quality that are determined by regulation. The remuneration perceived by utilities must allow the financial viability of the organization as well as be as low as possible. The regulator has to encourage the company achieving an optimal equilibrium between: [2]

- Investments
- Operation and maintenance costs
- Losses and the quality of supply

The more quality and the less losses, the higher the costs for utilities.

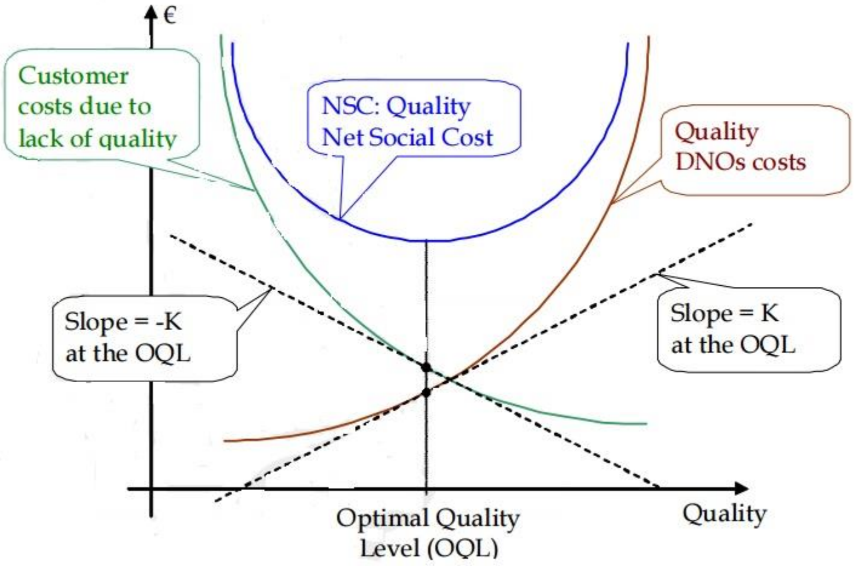

Figure 3-2 Customer costs due to lack of quality vs quality DSO costs[8]

The quality of supply is defined according to three main aspects: continuity of supply (related to the number and the duration of interruptions in the supply), power quality (related to the quality of the product electricity and the adequacy of the parameters of the voltage) and commercial quality (how well in treated the client and timings related to the requirement of the services). [6]

Continuity of supply is the aspect that is most linked to the investment policy and to maintenance carried by the distribution company.

The allowed interruptions in Spain are measured with two indices of reliability of supply which are: TIEPI and NIEPI. The first one refers to the time duration of the interruptions while the second one refers to the number of interruptions greater than 3 minutes allowed.

The index TIEPI is defined as equivalent interruption time of the installed capacity (Tiempo de Interrupción Equivalente a la Potencia Instalada): [7]

$$TIEPI = \frac{\sum_{i=1}^{k} IC_i \times H_i}{\sum_{i=1}^{n} IC_i}$$

ΣIC = sum of the installed capacity of the MV/LV transformation centers of the distributor plus the power contracted in MT (in kVA).

IC_i = installed capacity of the MV/LV transformation centers of the distributor plus the power contracted in MV, affected by the interruption "i" (in kVA).

H_i = supply interruption time affecting power IC_i (in hours).

k = total number of interruptions during the period considered.

NIEPI (Numero de Interrupciones Equivalente a la Potencia Instalada) measures the number of interruptions greater than 3 minutes equivalent of installed capacity: [7]

$$NIEPI = \frac{\sum_{i=1}^{k} IC_i}{\sum IC}$$

ΣIC = sum of the installed capacity of the MV/LV transformation centers of the distributor plus the power contracted in MT (in kVA).

IC_i = installed capacity of the MV/LV transformation centers of the distributor plus the power contracted in MV, affected by the interruption "i" (in kVA).

k = total number of interruptions during the period considered.

According to the Spanish law, the distributor is obligated, in relation to each of its consumers, to ensure that the time (TIEPI) and the number of interruptions (NIEPI) greater than three minutes are below the following figures where

- Urban: more than 20000 consumers [8]
- Semi-urban: between 2000 and 20000 consumers [8]
- Rural: less than 2000 consumers [8]

AREA	TIEPI (hours)	NIEPI (number)
Urban area	2	4
Semi-urban area	4	6
Concentrated rural area	8	10
Scattered rural area	12	15

Table 3-2 Duration and number of interruptions allowed per costumer [12]

Indices are calculated according to historical values per DSO and national average. [8]

3.3.3. Regulation regarding vegetation

In addition, the regulator imposes some extra measures to achieve this required quality of service. As commented before, one of the main reasons for interruptions in the supply of electricity is vegetation around the circuits.

The Regulation of High Voltage Lines establishes a tree-free distance in the passage area (below the line) and on both sides of the line that allow the energy flow according to the required security. In addition, incidences of supply should be reduced by ensuring the minimum possible environmental impact. These resolutions are set according to the type of conductor of the line and the most unfavorable conditions to which it may be subjected. [9]

In general terms, distances set according to the voltage at national level are:

Voltage (kV)	Distances (m)
>220	40
220 - 66	30
66 - 30	20

Table 3-3 Mandatory distances between high voltage lines and vegetation [9]

Moreover, the Law 54/1997 provides each Autonomous Community several powers to set its own rules. On the following section, the legislation of Galicia that concerns this project will be explained.

The Law 3/2007 about prevention and protection against forest fires, establishes the creation of linear fire prevention and defense infrastructures called "primary biomass management networks" that will run along the transmission and distribution lines of electricity and natural gas.

On the other hand, the Decree 275/2001 defines the width of the corridors surrounding the lines to a minimum. In addition, at a national level, the cleaning of the corridors of the lines is required at least once every three years.

3.4. Analysis of the specific problem

In this section will be analyzed some relevant aspects of the GNF problem and the current situation of the company regarding important issues related to vegetation.

3.4.1. Quality of supply

As explained in the section *3.3. Regulation*, companies are highly encouraged to improve the quality of its services for several reasons. First, a good quality in the services provided enable a good social perception of the company. Otherwise, the company would be socially penalized.

On the other hand, the service is regulated in such a way that company will receive incentives for fulfilling the standards allowed and will be penalized in the opposite case. Therefore, the worse quality of supply, the higher expenses for the company due to penalties and complaints.

By last, in the case of continuity of supply, when an incident occurs, company may incur in new costs for fixing or replacing the devices affected. In the case of GNF the historical values of the TIEPI are shown below: [10]

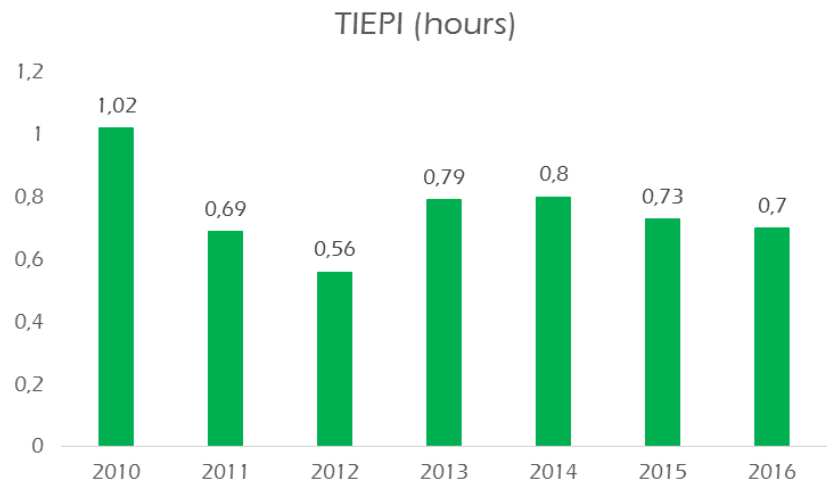

Figure 3-3 Historical TIEPI of GNF [10]

As we may observe, there is a small evolution over the years with the exception of the years 2011 and 2012 where TIEPI fell considerably compared to previous years there is an evolution.

If we compare with the rest of large distributors in Spain (Endesa and Iberdrola), GNF results are the most competitive:

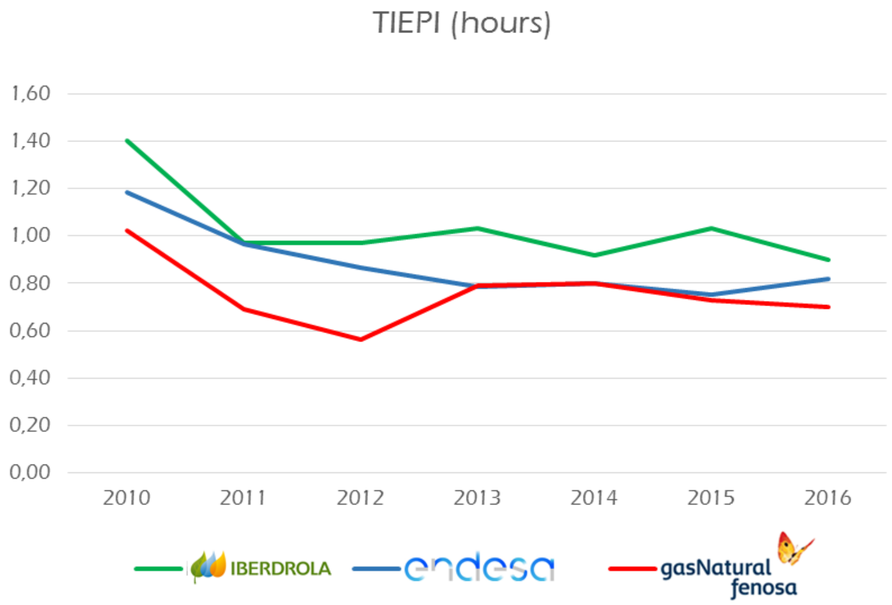

Figure 3-4 Historical TIEPIS of the main DSOs in Spain

3.4.2. Current costs incurred in vegetation

As explained in section *3.2. Overhead distribution lines of GNF,* there are totally different conditions in both areas belonging to GNF. These differences are reflected in the costs incurred in the different areas. In *figure* __ are shown the evolution of costs considering the different zones.

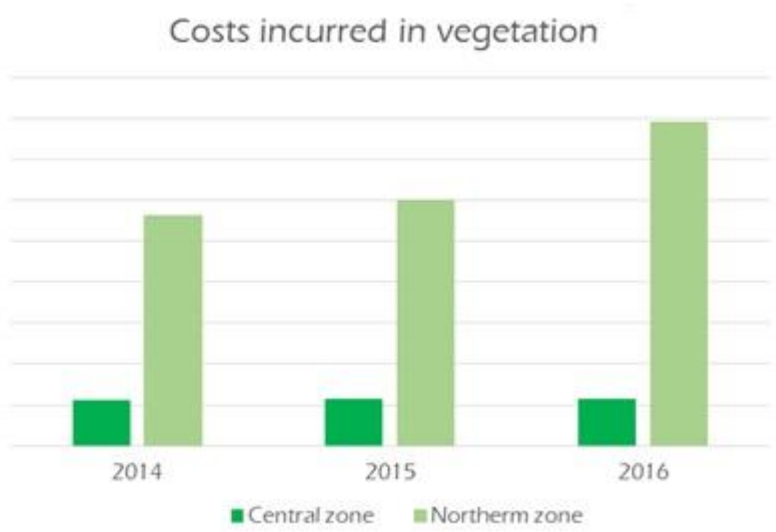

Figure 3-5 Cost incurred in vegetation by GNF regarding the different areas

The exact amount of money incurred has been removed for confidentiality reasons. However, the reader can get an idea of the comparative amounts between the different areas and years.

These figures present that we should focus much more in Galicia and Leon where much more money is spent and therefore the potential improvements regarding the maintenance of vegetation are much greater.

3.4.3. Seasonality of incidences caused by vegetation

It is also important to analyze the historical incidences and to observe how they are distributed throughout the year to identify which are the most critical stations and to take it into account when planning the maintenance works.

There have been analyzed incidences that could have been caused by vegetation problems during the years 2015 and 2016.

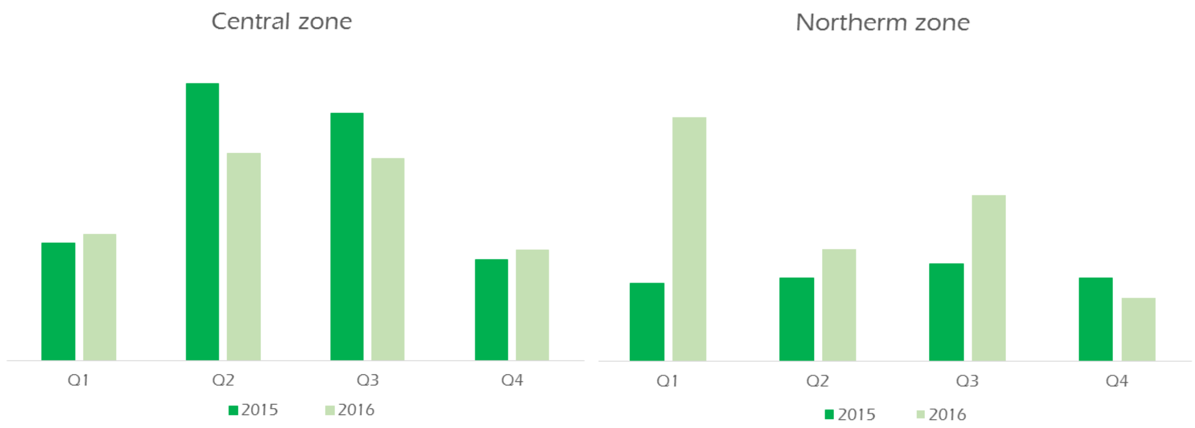

Figure 3-6 Incidents occurred in both areas in the different quarters of the years

The exact number of incidents has been removed for confidentiality reasons. However, the reader can get an idea of the comparative amounts between the different times of the year.

As we may observe, in the central area, most of incidences are clearly distributed between the second and the third quarter. This is due to the heat in summer and the fall of leaves in autumn. This is usually the normal pattern of distribution of incidents during the year.

Nevertheless, Galicia is an exception again as it does not follow the general pattern. The most determined factor for the incidences in Galicia are the large storms that occur from time to time and cause many incidences in a very little period of time and provokes high expenditures for the company.

In the first quarter of 2016, it was a period of strong temporaries that caused that huge amount of incidences (see figure__). The storms is Galicia usually occur in the months of January and February.

3.5. Practices currently applied by Gas Natural Fenosa

As a rule in Unión Fenosa Distribución, the activity is carried out employing a fixed frequency for the maintenance of the regulatory easement. Each 3 years all the lines are maintained at least once as determines the regulation.

However, the methodology is inefficient since, as commented before, there is a high heterogeneity of vegetation along the lines and areas with very different growth rates.

In addition, costs incurred are higher than what needed as there is not a defined methodology to developed and allocate costs.

3.6. Vegetation works contracted

Felling and pruning works are computed in constructive units (UUCC in Spanish) or in work units (UUOO in Spanish) depending on the work. In addition, there are administrative units (A) which are costs related to the hours worked by managers, third parties or assistants.

The constructive units offered to GNF by the contracted company can be discriminated between the surface constructive units and the constructive units of unitary elements as the cutting of an isolated tree. The first kind of constructive units will be named as MS and the second ones will be M1.

Name
100 m2 opening/extension of the wooded corridor
100 m2 maintenance of the wooded corridor
100 m2 opening/extension/maintenance of the corridor in mount with bushes
100 m2 corridor maintenance in areas inaccessible to common mechanical tools
100 m2 corridor opening/extension in areas inaccessible to common mechanical tools
100 m2 maintenance of corridor in zone of affeccion of rivers
Felling of a tree
Felling of a tree located in isolation
Complement by tree pruning in height spilled complex

Table 3-4 Constructive units available for GNF

On the other hand, works that cannot be classified as any constructive unit, are called work units. Work units are much more expensive and their use should be avoided by the company. That is why it is very important that the constructive units are well defined before their execution and involve all the necessary work.

Prices of these constructive and work units are negotiated between GNF and the contracted company in charge of carrying out the vegetation works around the overhead lines.

Schedule should be design according to these units.

Chapter 4

PROPOSED METHODOLOGY

This chapter describes the analysis of the different variables that have been considered and studied to determine the vegetation maintenance plan. It also presents the methodology that has been used and the process to achieve the results.

The methodology proposed in this master's thesis is based on vegetation trimming as it is the most widespread technique in Spain. In addition, it is the one with the best social impact and with the least barriers to entry.

From now on, the theme of the thesis will focus exclusively on the Northern area since it is much more interesting and conflictive regarding vegetation.

4.1. Characterization of high voltage lines

In case of overhead lines, a circuit is divided in spans which is the space between two electric towers. Spans can measures 20 meters or even 800 meters depending on the area. A set of spans forms a stretch or a section. A section changes occurs when a characteristic of the line changes such as an overhead and an underground branch or a division of lines as shown in the figure below where lines are drawn with a dashed line and each section is represented with an orange box.

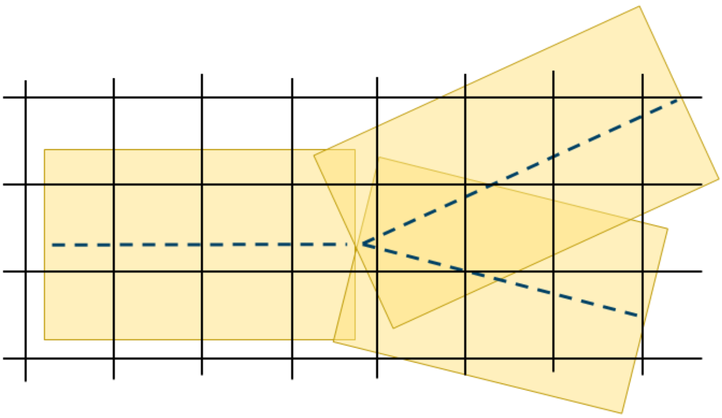

Figure 4-1 Scheme of a line

Vegetation works are computed by square meters. However, it does not make sense to develop a deep study and characterized each square meter since those responsible for felling and pruning will not be working in critical areas that are very small and far from each other. It does not have economic sense for the contracted company.

Therefore, although some of the studies carried out to do this thesis have been computed with small unit elements, when designing the vegetation maintenance plan, the unit element considered is the section, which is big enough for scheduling the vegetation works.

A high voltage distribution circuit comes upstream from a substation or from another circuit and dies in another substation or line. Each circuit has two positions, the first one refers to the substation or line where it is born and is associated with the breaker at the beginning and the other position of the line is associated with the destination point of the line and with the breaker located there. A set of circuits can have the same origin substation but they would have different positions are circuits are different.

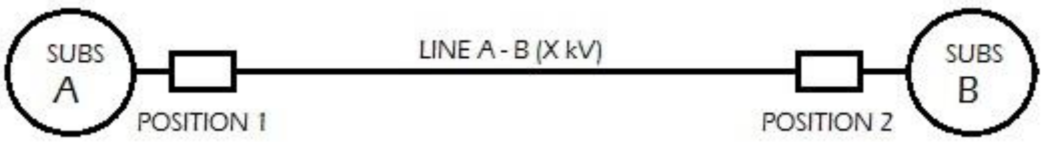

Figure 4-2 Nomenclature of the GNF circuits

Each substation is called as the name of the area where it is located, lines are named according to the origin substation, the destination substation and its nominal voltage as it is indicated in the picture. In the same path, positions are named according to the name of the substation and the line where are located.

In addition, substations, circuits, positions and sections are classified with codes that start with different number depending on the unit as it is described in the chart _. Each circuit (96…) is divided in several sections (98…) comes from a substation (20…) or from another circuit (96…), ends in a circuit (96…) or in a substation (20…) and has two positions (33…) associated (one in the origin and another in the destination.

Unit	Starting by…
Substation	20
Position	33
Circuit	96
Section	98

Table 4-1 GNF codes

4.2. Methodology applied

The methodology of elaboration of the Maintenance Plan is based on the optimum use of the available resources for the execution of the maintenance activities.

To optimize resources, a vegetation maintenance methodology based on Risk Management is implemented, where actions are prioritized based on the risk assessment associated with the section to be maintained.

The risk assessment of stretches is carried out by evaluating several factors of each section. For the application of the Maintenance criteria on the High Voltage Lines, priority will be given to the circuits based on the risk, taking into account several factors:

- Probability of failure (based on an historical analysis).
- Severity of the lines (based on several sub-factors that quantify consequences in case of an outage).
- Legal complaints.
- Which of the constructive units scheduled for those sections are more critical, that is to say, which constructive units can avoid more outages.

There is computed a risk value per each unitary element (the sections) according to the following formula:

$$Risk = Probability \times Severity$$

The aim is not only to minimize incidents by also the severity of the incidents. These concepts are explained in a more detailed way in the following sections.

From this risk value assignment of the sections, we can establish a prioritization of the stretches of the lines in such a way that we obtain a list of all the sections from the most critical to the less one. Once this prioritization is done and using the vegetation model developed by GNF, where the money necessary to maintain each section is determined, a maintenance program can be carried out considering a fixed budget.

4.3. Probability of failures: historical incidents analysis

In high voltage circuits in GNF, each position as is related with a breaker, has a protection distance. The protection distance measures the cable impedance between where the incident has occurred and the location of the relay. From the measured impedance and knowing the impedance and the total distance of the line, the distance protection can calculate an approximate distance of the fault location from the breaker.

When an incident occurs in a circuit, both breakers (origin and destination) act in such a way that should be two different measures for calculating the location of the incident from two different points. This method introduces a greater precision degree. However, sometimes, one of the two or both of them (although this last case is much more unusual) trips. In case both trip, the breaker of the previous circuit acts. That is why sometimes, distances provided by the protection are larger than the total length of the circuit.

These devices have an error of up to 20%. It is another reason to consider the section as a unit element of the study.

When classifying outages and locating them in the corresponding span of the circuit, there are some of them than have had to be removed. Those are the cases where distances are higher than the length of the circuit as there is not any key for knowing which was the circuit affected and the cases where distances are 0 which means that the protections did not work properly and we do not have a clue to locate those incidences.

To carry out the study, incidences of the last 3 years (2015, 2016 and the first quarter of 2017) have been considered. In addition, incidents considered are the ones susceptible of have been caused by vegetation or, in other words, there have been removed those incidents that surely have not been caused by vegetation. According to the classification criterion used by the organization, the incidents are classified in:

- Atmospheric agent
- External agent
- Animals
- Unknown cause

Incidents selected for the study are those classified as: "Atmospheric agent" and "Unknown cause".

Once this selection is done and incidences are classified by the date when occurred, the circuit and the distance from the position, there has been carried out a process to locate outages in the corresponding span. This tool has been developed calculating distances of each electric tower from the origin with its location. The output of the program is to have classified all the spans with the number of incidents occurred in the last 3 years. It has been carried out in the VBA environment.

Then, incidents are located in the map with a free code geographical information system called QGIS. The system allows to represent a vegetation layer in such a way that those incidents that are not surrounded by vegetation in the map are removed. This is the last filter applied to the process.

The following picture depicts historical failures on the map with a red circle. In addition, large red circles represent the number of incidents in the section such that the larger the circle, the more incidents in the section.

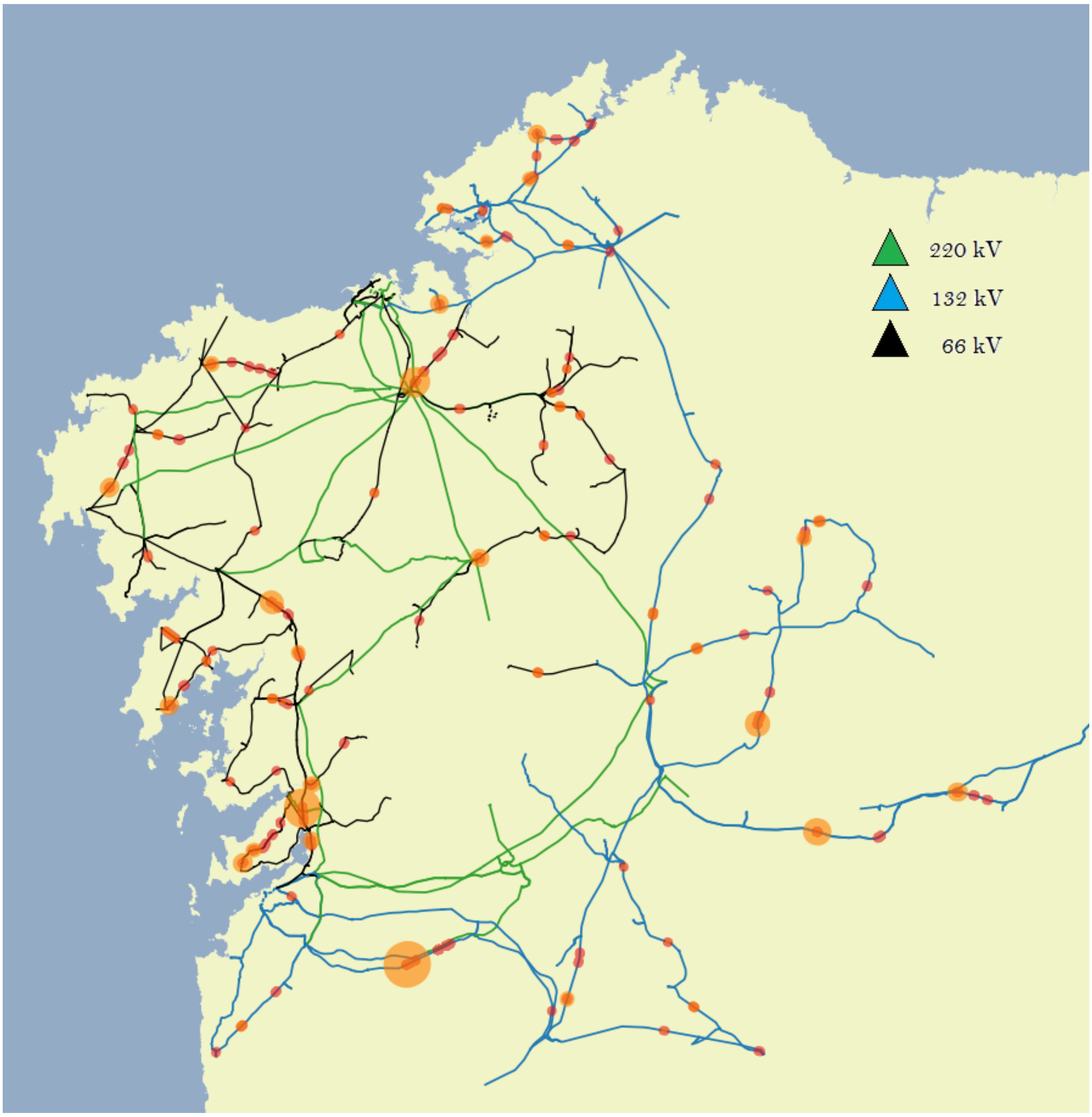

Figure 4-3 Representation of the incidents in the last 3 years in the Northern area

Although the unit element of the program is the span, incidences can be classified by sections or circuits. Taking into account the possible mistakes made, it is more reliable to group incidents in sections as is represented with the large circle.

The results obtained indicate that incidents in Galicia are more distributed than in the central zone where there are some very critical sections. This means that the profitability in the central area may be higher as investing a bit in the circuits more affected, incidences and consequently, costs related to vegetation can be drastically reduced.

The picture below shows the incidents distribution in the Northern area. As we may observe, all incidents considered are located in the 33% of the circuits.

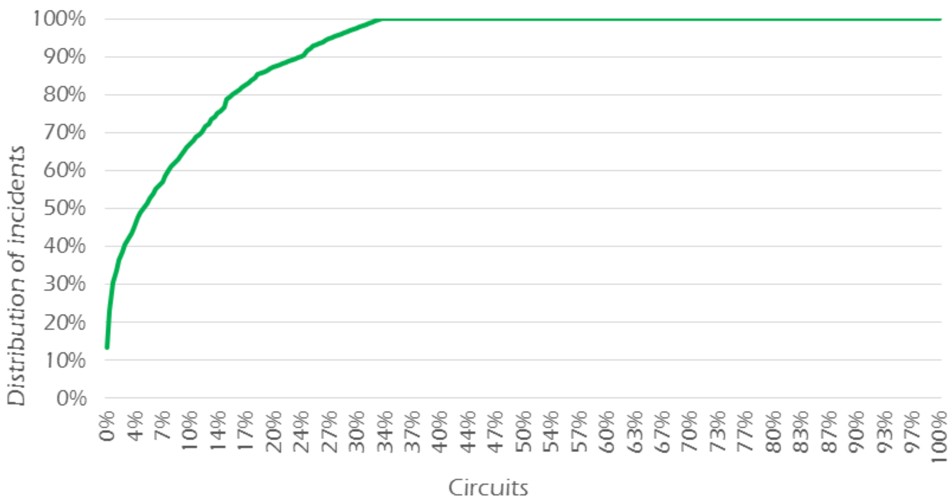

Figure 4-4 Incidents distribution by circuits in the Northern area

The picture above shows the incidents distribution in the Northern area. As we may observe, all incidents considered are located in the 33% of the circuits.

4.4. Severity of the lines

With a view to achieving optimal use of available resources, a classification of the circuits has been carried out. The result is a prioritization of circuits considering certain criteria that is understood as determinant. The hierarchy has been done considering the following aspects:

- Average load power of the line in the period of the last exercise.
- Non-guaranteed power in case of failure in a scenario of normal operation of the network. This measures the redundancy of the lines (does a fault in the power line imply a lack of power supply or is there another line that can replace the affected line?).
- Served market (urban, semi-urban, concentrated rural market or dispersed rural market).
- Time of arrival to the facility in the event of a breakdown from the maintenance.

According to this criterion, circuits have been classified into 3 groups from more to less risk: A1, A2 and A3. Every sub-factor has been classified with a value in a scale from 0 to 10 and weights have been assigned for the computation of the total value.

Weights assigned are set according to the experience in maintaining circuits when a failure occurs. The most relevant factor is the lad power of the line as it is related to the number of costumers that depend on the line. It has been weighted with a value of 30%. The second most important factor is the redundancy and has been weighted with a value of 25%. Time to arrival to the facility and the kind of served market are both weighted with 22,5% points

4.5. Legal aspects and complaints

Sometimes, felling and pruning works are carried out because of a legal complaint received as a corrective measure. These complaints suppose extra-expenditures to the company so circuits susceptible to received complaints must be considered.

However, most of these allegations do not come to fruition and are only warnings from the administration that they strongly recommend cleaning up the corridors. Only in case the company does not take part, fines will be imposed. Therefore, the most important issue of complaints is not the money involved in the vegetation maintenance but the social impact that could result if an incident occurs when the circuit has been already demanded. If the company receives a complaint, does nothing and there is an incident in that period, the consequences for the company would be enormous.

Regarding GNF circuits, most of the reports are received in the northern zone where vegetation is much more aggressive and growth rates are larger.

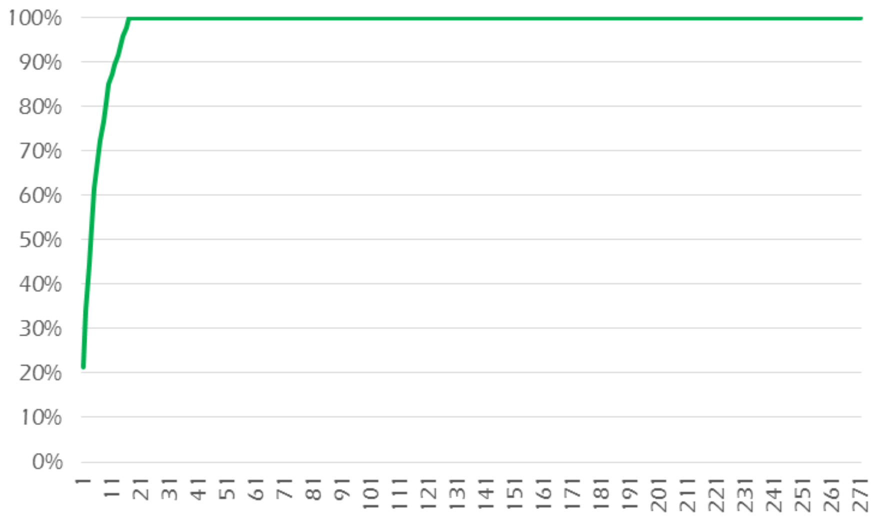

Figure 4-5 Complaints distribution by circuit in the Northern zone

Analyzing the complaints received since 2014, we have realized that there are not many circuits with complaints. However, few circuits have been demanded very often. This means that focusing in just few of them, complaints can be reduced drastically.

The picture above shows that, in the Northern zone, the 100% of incidents, a total of 47, are concentrated in only 17 circuits out of 271 which means that demands can be drastically reduced by acting in just a few circuits. Complaints have supposed to the company hundreds of thousands of euros since 2014. This is a very important variable to consider has the potential savings are large and the social impact is at stake.

4.6. Vegetation management model

In GNF, a model has been developed to estimate the costs necessary to properly maintain clean corridors. It has been carried out with a free code geographic information system called QGIS.

As commented in section *3.6. Vegetation works contracted,* there are certain constructive works offered by the contracted company that may determine costs of the clearances of the corridors. These constructive units are basically set by:

- how easy is the access to the circuit (if it can be accessed with machinery or by feet)
- the kind of vegetation (trees mass, bushes or isolated trees)

For these reasons, the model considers 3 variables that are represented in 3 different layers in such a way that each 25 square meters of the mandatory corridor are characterized. The first layer is a vegetation layer where the kind of vegetation is considered, there is also a layer where inclination of the land is represented in each element unit (it determines the accessibility) and the other layer represents the GNF high voltage circuits. The output of the model is an estimation of the amount of money needed to maintain every 25 square meters of the power line considering the worst case possible.

From this data and taking into account the hierarchy of the sections, there is going to be established the vegetation maintenance plan with a limited budget.

4.7. Criticality in function of the constructive units

Regarding the different constructive units determined by the model, not all of them avoid the same risk in the circuit.

The mere fact of needing to apply a particular constructive unit, implies the existence of a greater or lesser risk of incident. In principle, if there the model determines that there is the need of applying many unitary constructive units in a section, it may imply the existence of a lot of trees (instead of bushes) and, consequently, it means that the risk of outage is higher as trees represents a higher risk to the circuit than bushes.

In some way, this variable in providing the risk of incident measured by the kind of work needed or, in other words, by the kind of vegetation around the power lines. It might be related to the number of incidents in the lines since the most critical the constructive unit needed is, the more incidents will be.

To measure this variable, once the number and the kind of constructive units are determined for each section by the model, the cost per constructive unit type and section can be calculated (€/CU*section).

The way in which constructive units has been grouped is described in the following chart:

Surface constructive units	9027, 90271, 90M60, 90M61, 90M62, 90M63	0 - 3
Unitary constructive units	90M64, 90M65, 90M66	0 - 5
Administrative units		0 - 1
Work units		0 - 1
Total		**0 - 10**

Table 4-2 Criteria for grouping the constructive units

Due to the different orography of the corridors and the different costs of the constructive units, this variable is very different from one section to the other.

To check which group of constructive units is more critical, we are going to analyze the correlation between those number and the historical incidents in the section. By doing this, we analyze the relation between the constructive units and the incidents.

M1	MS	A1	UO
0.53	0.63	0.64	0.40

Table 4-3 Correlation indices of the different constructive units with the number of incidents

As we may observe, correlation is not very large, but these variables will be worth considered when determine the hierarchy.

4.8. Properly allocation of the resources

The aim of the project is to determine a hierarchy of the power sections to establish an order of priority when applying vegetation maintenance.

To build the model to determine which sections are more critical regarding vegetation topics, we have 4 variables: historical incidents, the level of severity, the historical complaints and the relevance of the constructive units to apply. Once those variables are determined, how to build the model? Which variable is more relevant? How to distribute weights?

There are 2 variables that affect all the circuits (severity of the line and the criticality related to the constructive units) while the other 2 (historical failures and complaints) do not characterize all the circuits. In case of incidents in many cases there is no information about failures or information is incomplete as explained in section *4.2. Historical analysis of failures* and many of the failures are not registered.

Note that for establishing the methodology only those sections which have suffer any incident in the last 3 years have been used. However, in *chapter 5 Analysis of results*, the methodology will be applied to all the sections.

4.8.1. First approximation: probability of failure

First, we have to set the expected output. Which are the conditions of the final output? The model is going to be developed with the objective of minimizing incidents, but also minimize the consequences of the incidences, which is measured by the severity as described in *4.4. Severity of the lines*.

A first approximation of the model is made through a regression where incidents are the independent variable and the relevance in the criticality of construction units is the explicative variable.

In performing this study, the result will be a function that, when entering the type and number of each required building unit in a section, will return a number proportional to the number of potential incidents.

$$a_0 + a_1 \times Ms + a_2 \times M1 + a_3 \times A1 + a_4 \times UO = \hat{\imath}$$

a_0, a_1, a_2, a_3 and a_4 are the coefficients of the different variables

MS are the costs of the superficial constructive units required in the section

M1 are the costs of the unitary constructive units required in the section

A1 are the costs of administrative units required in the section

UO are the costs of work units required in the section

As shown in section *4.7. Criticality in function of the constructive units,* in principle all the explicative variables could be related to the number of incidents. Therefore, in a first approximation, there will be considered the four groups of constructive units. the money needed for applying each group of constructive units in each section, varies a lot.

To make things clearer, those variables have been classified from 0 to 10 in such a way that a section can have 4 numbers from 0 to 10 regarding the four different groups. Once this classification is made, there has been carried out the first approximation of a regression function where results are below:

	Coefficients	Typical error	T Statistics
Interception	0.788658142	0.195594298	4.032112129
M1	-0.014305261	0.121288283	-0.117944297
MS	0.608749598	0.146088797	4.166983429
A1	-0.354815867	0.16452272	-2.156637499
UO	-0.15368232	0.13916576	-1.104311288

Table 4-4 First regressive function

To assessed the results, we have to focus both in the T-Statistics. T-Statistics provides information about the significance of the variable considered. When T-Statistics is higher than 2 in absolute value, we can assume that the variable in significance. [11]

M1 and UO do not seem to be significance, that is why, we are going to calculate coefficients without considering them.

	Coefficients	Typical error	T Statistics
Intercepción	0.766211991	0.191110757	4.00925622
MS	0.596170903	0.120909199	4.930732361
A1	-0.423489495	0.153666999	-2.755890975

Table 4-5 Second regressive function

T statistics are higher than in the previous model. R2 is the same value in both cases (0.11). The bottom line is that the second model is better and introduces less noise. The results obtained are not very good since the error is large and the coefficients are not very significant. The output of the model, the expected incidents, will be very different from the real ones. But it should be remembered that the goal is not to predict future incidents in each section (for which this model would fail badly), but to evaluate which sections are most susceptible to an incident.

4.8.1. Second approximation: introducing the severity of the power lines

In the second approximation, we will also consider the severity of the power lines, which is a relevant aspect. It does not provide any clue about the probability of failure of the circuits but about the large of the consequences in case of a failure. GNF is interesting in both minimizing the risk of failure and minimizing the consequences.

Probability of failure and severity are both equally important and therefore, they are considered with the same weight. Introducing the severity of the lines, the first order achieved in the previous section is expected to change.

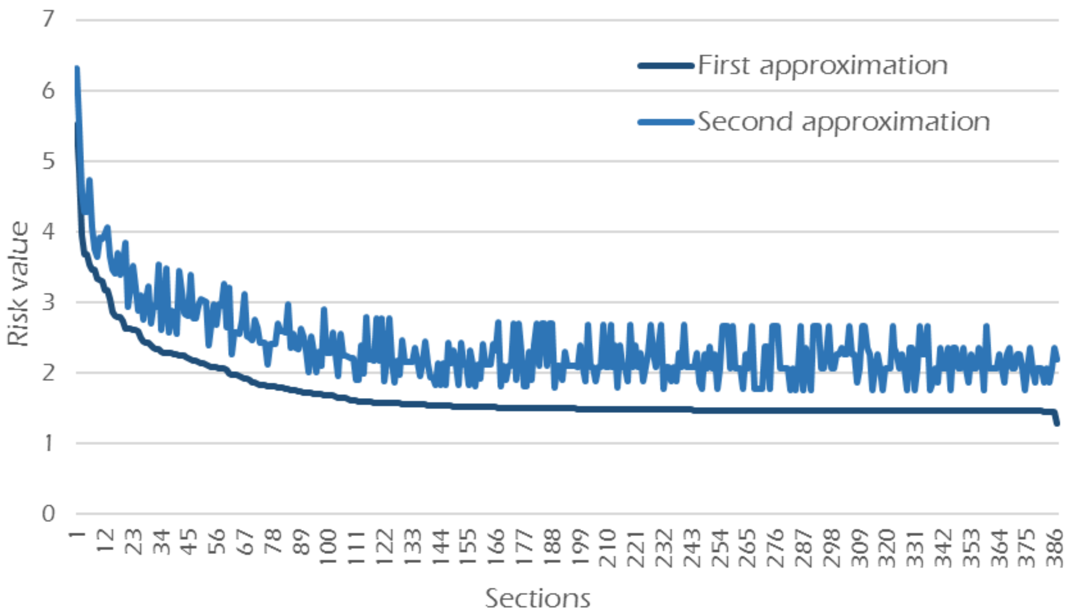

Figure 4-6 Representation of the circuits classified

4.8.3. Third approximation: introducing complaints

To end up with the model, it is important to introduce, in a much more smaller measure, the risk of receiving a complaint. As analyzed in section *4.5. Legal aspects and complaints,* there are a few number of circuits very susceptible to be demanded. All complaints are concentrated in 17 circuits out of 271. As there are few of the total amount, frequency is very high.

By introducing this variable, the order is also expected to change but only regarding the circuits affected by this variable which are expected to occupy a higher position in the list.

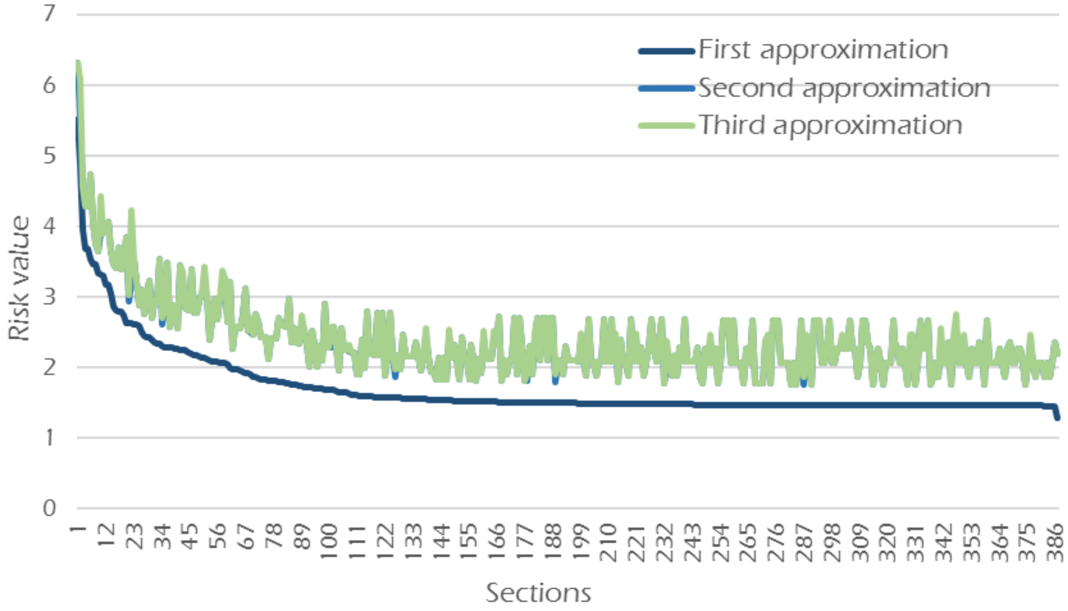

Figure 4-7 First, Second and Third hierarchy of the circuits

The weight of the complaint-related variable has to be high enough to place the sections with the highest number of complaints at the top of the list.

Chapter 5

ANALYSIS OF RESULTS

In the present chapter, the solutions proposed will be analyzed as well as the benefit implied in terms of quality of supply and in terms of costs.

There are going to be analyzed all the circuits of Galicia belonging to GNF. Once the risk is calculated, they will be commented and compared to the previous priority applied in the maintenance plan.

Applying this methodology to all circuits and calculating the costs of maintaining them, the results obtained are the following:

Valuation interval	Number of sections	Vegetation costs associated
[0 - 1.5)	0	0%
[1.5 - 3)	348	18%
[3 - 4.5)	35	52%
[4.5 - 6)	2	25%
[6 - 8.5)	2	6%

Figure 5-1 Grouping of circuits by risk intervals

As in some way costs of maintaining the corridors clean have been used as an input for evaluating the risk in each section, we realized that there is a relation between the final valuation and the cost per unit element. The higher the valuation, the higher the cost required to maintained the section.

5.1. Testing the results

In the picture below, are going represented results highlighting their characteristics. The sections represented in red mean that they have suffered at least one incident in the last 3 years, the green sections refer to the sections that have been demanded at least once in the last 3 years and the green points are related to those sections that have not suffered incidents or complaints in the period analyzed

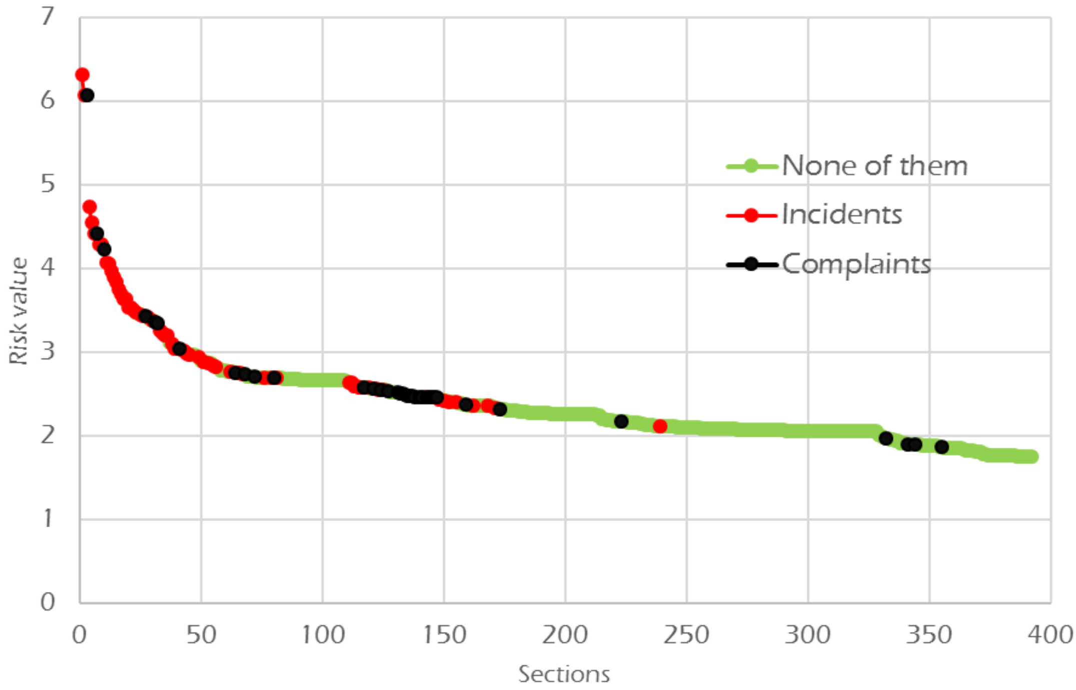

Figure 5-2 Hierarchy of the sections

According to the results obtained, almost the total of circuits that have had incidents or complaints in the last years are classified at the beginning. This means that the classification is in accordance to the reality.

However, there are some of the problematic sections that have low risks values. This is because these sections have a very small number of complaints or belong to circuits that do not have a high severity. If the budget is limited and there is not enough money to properly maintain all circuits, maybe these circuits are not worth maintaining.

In addition, there can be appreciated by looking at the graph, that around ¾ of the sections are valuated between 1.7 and 2.7. This is because most of the risk is concentrated in a few circuits. By maintaining 30% of them, the risk could be significantly reduced.

5.2. Analyzing the current techniques

There are some circuits that have not be maintained in the last 3 years (since 2014). In this section, there will be analyzed those circuits. In the following picture, risk value of those sections are compared to the maintained-sections.

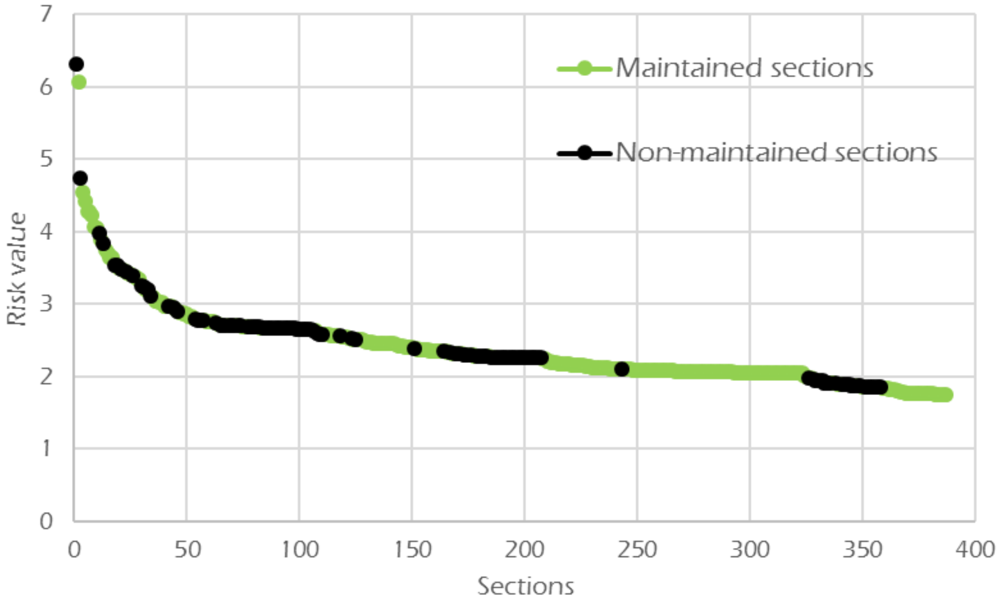

Figure 5-3 Risk value of maintained and non-maintained sections in the last 3 years

According to the study, *Figure 5-3* shows that maintenance plan carried out by GNF does not manage the risk in a proper way as are maintaining circuits that have a low risk while other that are more problematic are not being maintained.

Chapter 6

CONCLUSIONS AND FUTURE WORKS

For the construction of the vegetation maintenance plan we have used historical data of the last 3 years of the high voltage lines and the results of the vegetation maintenance model developed by GNF. However, there are several possibilities for the improvements. The accuracy of the results can be improved by analyzing more years and testing the results by applying this methodology.

On the other hand, as commented before, there is a considerable error in analyzing the historical incidents which could be improved with the experience when solving those incidents. For example, in the cases where there is not information provided by the protection about the location of the failure, the distance could be introduced once the incident has been repaired. The problem is that there are many cases that incidents are repaired without human intervention and in those cases, there is no clue to guess where the failure is located.

In addition, with respect to the incidents that have been considered, there is no full assurance that they have been caused by issues related to felling and pruning. This information can be also implemented with the experience.

Nevertheless, as a general conclusion, this methodology is expected to introduce efficiencies in the process and to take into more consideration those circuits susceptible to suffer incidents or received complaints.

Improvements are expected in economic terms since controlling vegetation in a more optimum way implies the reduction of failures and the consequences in case a failure occurs and, consequently, all costs that an outage implies as replacement of devises and payments of penalties in some cases.

In addition, by applying this methodology is expected an increment in the quality of supply and in the number of complaints which matter to the company is terms of social impact. GNF is a large company subject to many criticisms of the media and therefore of the public opinion reason why the social impact caused is of great importance for the company.

Chapter 7

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