DETERMINATION OF DESCRIPTIVE ATTRIBUTES USED TO CALCULATE TECHNICAL LOSSES OF MEDIUM AND LOW VOLTAGE NETWORKS ACCORDING TO THE BRAZILIAN REGULATORY MODEL

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ABSTRACT

The paper presents the models that were developed in order to improve the representation of real medium and low voltage networks, which are used in the calculation of regulatory losses.
For medium voltage networks, the objective is to determine their descriptive attributes, which do not correspond to recorded data. The network is represented though a circular sector, which is defined through an action angle and a service area. The load is represented though density functions.
For low voltage networks, the objective is to establish a classification method of the real networks into one of the 5 optimized network patterns, which are established by the regulatory model.

INTRODUCTION

In Brazil, technical and non-technical losses are extremely high. They correspond to approximately 14% of the total energy injected into the distribution system, and cost around US$ 2.9 billion annually.
The technical losses correspond to approximately 7%. The Brazilian regulatory agency (ANEEL) establishes a regulatory value which is considered efficient regarding the characteristics of the concession area of each utility company.

O MODELO REGULATÓRIO

In general, the regulatory model used by ANEEL to calculate the technical losses consists of two steps. The first is the determination of technical losses by segment of the distribution system from a set of information and from attributes which are requested from the distributor. The second step consists in performing an energy balance from the calculations made in the first stage, in which an amount of energy has been estimated and an adjustment is proposed to adapt the losses evaluation, based on the energy effectively consumed.
Losses in medium voltage network are calculated statistically and multiple methodological assumptions are adopted in the model. Particularly, the demand loss is obtained from the calculation of a variable named "loss moment" [2,3].

For low voltage networks, the regulatory model considers five typical and optimized configurations of low voltage networks, where one seeks to represents every real circuit. Figure 1 illustrates the five typical envisaged by the model.

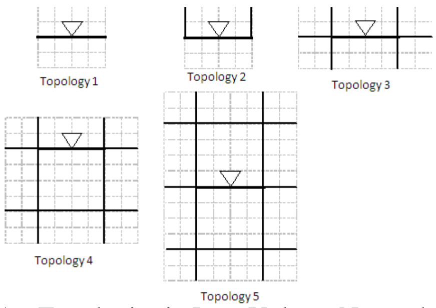

Figure 1 – Topologies in Low Voltage Network Model

Basically, the methodological concept is to calculate the loss by demand for each elementary section, which can be identified from either end of the circuits, following the load path to the source, until its first branch [1].
Energy losses are determined by distinct loss factors applied (each network has one) to the maximum demand losses calculated by the regulatory model.

THE MEDIUM VOLTAGE NETWORKS TECHNIQUE

For the medium voltage networks, a model based on geometrical adjustment techniques was developed, named "Descriptive Attributes Faithful to Real Medium Voltage Networks". Basically, this model defines the best composition of action angle, service area and load density. Through the real network's topology, it defines the initial values for the action angle and service area, according to the smallest circular sector, which contains the network's load points (distribution transformers) in its interior. These values will determine the load density for the network.

The "Descriptive Attributes Faithful To Real Medium Voltage Networks" Method

Initially, the model defines which load scenarios to consider in the processing. This option is necessary, since it excludes the low loads, located far from the source, which makes it pass through large uninhabitable areas.

Nevertheless, this action is of great significance for the model, since it mitigates any distortions while obtaining parameters from these networks. Figure 2 illustrates the outcome of the procedure.

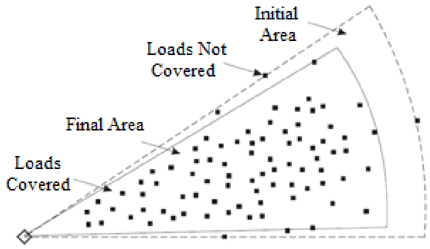

Figure 2 – Medium voltage network covering the most significant loads

Holding the five distinct load scenarios (we emphasize that it is possible to determine how many sets are allowed), the linear load density is calculated as the division of the load, by feeder, in multiple circular crowns [7], which will be named as σ_{real}, since it represents the real density for each analyzed feeder in each scenario. Based on five different regulatory density values adopted by the model (-1, -0.5, 0, 2 and 4), the scenario holding the nearest σ_{real} to a $\sigma_{regulatory}$ will be identified, in other words, the scenario whose difference between σ_{real} and $\sigma_{regulatory}$ is minimum. Table 1 describes, for a feeder, how this comparison is made. Nevertheless, this can be done for any number of feeders.

Table 1

Feeder	σ_{real}-(% load)	Nearest $\sigma_{regulatory}$	Δ (diference)
Feeder 1	$\sigma_{real\text{-}100\%}$	$\sigma_{regulatory\text{-}100\%}$	$\Delta_{100\%}$
Feeder 1	$\sigma_{real\text{-}95\%}$	$\sigma_{regulatory\text{-}95\%}$	$\Delta_{95\%}$
Feeder 1	$\sigma_{real\text{-}90\%}$	$\sigma_{regulatory\text{-}90\%}$	$\Delta_{90\%}$
Feeder 1	$\sigma_{real\text{-}85\%}$	$\sigma_{regulatory\text{-}85\%}$	$\Delta_{85\%}$
Feeder 1	$\sigma_{real\text{-}80\%}$	$\sigma_{regulatory\text{-}80\%}$	$\Delta_{80\%}$

After determining the adequate load scenario, it is imperative to compare the 100% scenario values of σ_{real} and $\sigma_{regulatory}$ with the results in order to verify if significant reductions, for each network, were accomplished.
Based on the scenario settled by the method, the medium voltage network attributes may be determined. They will be required by the regulatory model (action angle, service area and load density), insomuch as to represent the most accurate descriptive data.

THE LOW VOLTAGE NETWORKS TECHNIQUES

For low voltage networks, statistical grouping methods (dendrograms and k-means), hierarchical classifiers and neural networks were developed. The methods are based on real data from the power distribution company network, such as: quantity, length and geographical coordinates of buses and sections. Basically, it determines the best topology association of the power distribution company real networks with one of the five optimized network topologies.

Hierarchical Classifiers

Based on the typical configurations presented on Figure 1, the first stage association strategy, for each real network with one of the five typical and optimized topologies defined by the regulatory model, consists on, initially, classifying the network by the number of branches based on the georeferenced data, which are labeled as in Table 2.

Table 2

Typical Configuration	Number of Branches
Topologies 1 e 2	None
Topology 3	1 or 2
Topology 4	3 or 4
Topology 5	5 or more

Still, small segments are not contemplated in the process, because they lack representation in the topological composition. Figure 3 illustrates the case of a bar with three sections connected, one being not valid due to its short length (less than 10% of the arrangement).

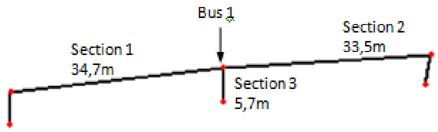

Figure 3 – One bus and associated sections of a low voltage network configuration

The need of the second stage is due to its difficulty of distinguishing between the topologies 1 and 2, because both configurations have no branches in their optimized topology. As predefined in the regulatory model, networks composed by only one type of cable **must** be classified as typology 1, causing the others to be classified as typology 2.

Dendrograms

Dendrograms belong to the class of agglomerative hierarchical classifiers, whose clustering method is based on the similarity of the elements that comprise a cluster, in other words, elements brought together in one group present a high degree of closeness.
Based on records from the low voltage circuits of the Eletropaulo distributor (one of the biggest power distribution companies from Brazil), this study has selected the following input parameters, presented in Table 3. The number of valid branches was determined by the hierarchic classifier.

Table 3

Parameter	Unit
Total Length	km
Number of Sections	Units
Number of Bars	Units
Number of Branches	Units

The distance between different networks, in this multivariable problem, is determined as in (1):

$$d_{ij} = \sqrt{\sum_{k=1}^{NP=7} (x_{ki} - x_{kj})^2}, \quad i \neq j \qquad (1)$$

Where:
d_{ij} = distance between the network i's parameters and j's;
x_{ij} = parameter k from network i;
x_{kj} = parameter k from network j;
NP = number of input parameters.

K-Means

K-means clustering is an algorithm used to classify individuals of a population, aiming to group them so that there is a great similarity between the elements of a same cluster, with minimal similarity between distinct groups.
The basics of the algorithm are divided in four stages illustrated in Figure 4. The input parameters are the same as the dendrograms' presented in Table 3, as well as the rules to calculate the Euclidian distance, as in (1)

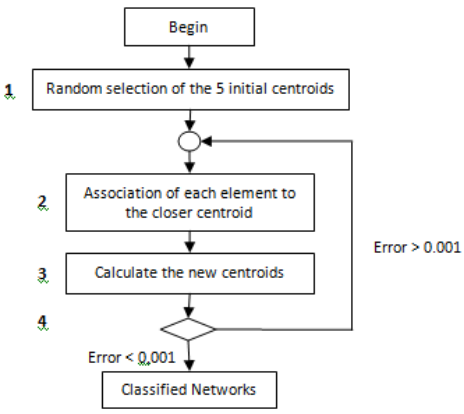

Figure 4 – Diagram of k-means's algorithm

1. First the algorithm randomly picks five networks in the database, which will be the initial centroids;
2. Each network is associated with the nearest centroid, based on the Euclidian distance concept;
3. The input parameters of the new centroids are recalculated by an arithmetic mean of the elements grouped in each cluster.
4. A routine is run in order to check for errors by calculating the variance of the parameters of the centroids relative to the past iteration. If the displacements of the new centroids are below a 0.1% error, the classified networks are obtained, otherwise the algorithm returns to step 2.

Self Organizing Map (SOM)

Also known as Kohonen map, the Self Organizing Map (SOM), is a method of unsupervised neural network with competitive learning, which allows vectors of large dimension, in smaller dimensions, to be represented with no effect to the topological characteristics of the input data. Furthermore the study with topological maps eases the results visualization [6].
Based on the five typical and optimized topologies on Figure 1, a sufficient number of neurons were listed in order to classify the typical methodological configurations of ANEEL presented in Table 4. Figure 5 is an example of a low voltage circuit, having its segments presented on (a), the bars (in green), the neurons organized in a rectangular grid before the training (b) and the SOM rearrangement (c).

Table 4

Topology	Number of Neurons
1	2
2	4
3	8
4	12
5	16

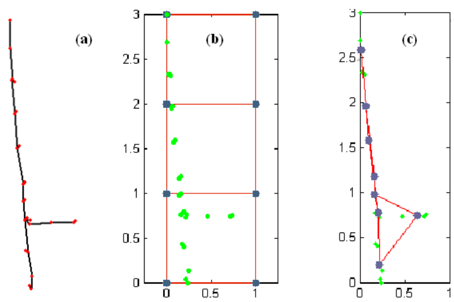

Figure 5 – Network configuration (a), before (b) and after (c) the training process

A quantization error is calculated according to the equation (2) so as to evaluate the results obtained in the training stage in order to measure the quality of the mapping.

$$E_q = fp \cdot \frac{\sum_{k=1}^{n} |v_k - w_k|}{n} \qquad (2)$$

Where:
v_k = input vector k;
w_k = nearest neuron to the input vector k;
n = number of input vectors;
fp = penalty factor = $n^{0.65}$

In practice, smaller errors are obtained in training by the neural network that has the largest number of neurons, so that implying a classification of all circuits by topology 5. In order to minimize this distortion, the error is multiplied by a penalty factor, which was obtained empirically, once SOM mapping has no converging error function, which imposes relevant obstacle to the mathematics analysis [5].

ANALYSIS OF RESULTS

The proposed methodology for calculation of the attributes descriptors of medium voltage networks (action angle, service area and load density) for the calculation of technical losses presents great adherence to the topological distribution of loads and networks for each medium voltage network. Table 5 presents the calculation of loss demand (step one) according to the simplified methodology applied by the Brazilian regulatory agency, compared with the detailed calculation used by the distributor Eletropaulo implemented in a software called Pertec, which performs the calculations by applying three-phase load unbalanced flow, and which is detailed in [1]. The values presented in Table 5 were obtained from the calculations made for 911 medium voltage networks of Eletropaulo.

Table 5

Model	Demand Loss [kW]
Regulatory (ANEEL)	59.721,21
Pertec	26.129,79

It is noteworthy that the attributes required by the regulatory model were obtained in order to represent as faithful as possible the real networks from Eletropaulo, in such a way that the differences verified in Table 5 occurs only because of the different methods used.
Regarding the low voltage networks, Table 6 presents the consolidation of the classification of 65.797 low voltage networks of Eletropaulo in each of the five typical and optimized networks, as illustrated in Figure 1.

Table 6

Topology	Hierarchic Classifier	Dendograms	K-means
1	41,21%	63,55%	59,66%
2	11,25%	22,70%	24,36%
3	30,13%	7,32%	8,88%
4	10,41%	4,23%	4,48%
5	7,00%	2,20%	2,63%

It was verified that the methodology that best represents the topological characteristics of Eletropaulo's low voltage network is the hierarchical classifier. Nevertheless, this paper also emphasized other methods that could be better associated with the reality of other power distribution company.

With respect to the SOM method, after application in some low voltage networks of Eletropaulo, it was verified that the method did not generate good results in the classification of networks into one of five typical and optimized topologies because it's general penalty factor is usually difficult to estimate and does not have a converging error function, which compromises the mathematical analysis, as quoted previously.

CONCLUSION

This paper presented different methodologies for obtaining descriptors attributes of medium and low voltage network subject to uncertainty in their determination and which are required by the regulatory model for the calculation of technical losses for later composition of the energy tariff to be charged from consumers.
The proposed models intent to determine the required attributes through analysis of the amount of registrated and georeferenced network and loads data present in the power distribution system of Eletropaulo.
These models allow the readjustment of the methodology used to calculate the regulatory technical losses making them closer to the technical losses found in reality and without damage to the regulatory model of seeking for efficiency and quality.

REFERENCES

[1] A. Meffe, 2007, "Cálculo de Perdas Técnicas em Sistemas de Distribuição – Modelos Adequáveis às Características do Sistema e à Disponibilidade de Informações", EPUSP, São Paulo, Brazil

[2] ANEEL – Agência Nacional de Energia Elétrica, 2007, "Perdas Técnicas nas Instalações de Distribuição – Descrição Detalhada da Metodologia", Nota Técnica N° 0035, Brasília, Brazil.

[3] ANEEL – Agência Nacional de Energia Elétrica, 2010. "Procedimentos de Distribuição de Energia Elétrica no Sistema Nacional Elétrico" - PRODIST - Módulo 7 – Perdas Técnicas Regulatórias, Brasília, Brazil.

[4] CODI – Comitê de Distribuição, 1996, "Método para Determinação, Análise e Otimização das Perdas Técnicas em Sistemas de Distribuição", Documento Técnico CODI-3.2.19.34.0, Brazil.

[5] ERWIN, E., OBERMAYER, K., & SCHULTEN, K., 1992. "Self-Organizing maps: Ordering, convergence proprieties and energy functions". Biological Cybernetics, v67 , pp. 47-55.

[6] KOHONEN, T., 1990, "The Self-Organizing Map". Proceedings of the IEEE , Vol. 78.

[7] M. R. Gouvea, 1993, "Bases Conceituais para o Planejamento de Investimentos em Sistemas de Distribuição de Energia Elétrica", EPUSP, São Paulo, Brazil.