ASSESSING THE SERVICE QUALITY PROVIDED BY ELECTRICITY DISTRIBUTION UTILITIES

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ABSTRACT

Service quality is an important issue in the electric power distribution sector. Consumers are sensitive to various aspects of service quality. These include continuity of power supply, represented by the Equivalent Duration of Interruption per Consumer Unit - DEC; Equivalent Frequency of Interruption per Consumer Unit – FEC; Voltage Level Compliance, represented by the Consumer Units with Critical Voltage Index – ICC; Quality of Commercial Services, represented by the Average Duration of Complaints per Thousand Consumer Units – DER; and Frequency of Complaints per Thousand Consumer Units – FER. This study aimed to evaluate the technical performance of the services provided by electric power distributors in Brazil, with the use of a metric based on the Multi Criteria Decision Making (MCDM) method.

INTRODUCTION

Service quality is an important issue in the electricity distribution sector. Consumers are highly sensitive to all aspects of service quality, namely the speed and accuracy with which their complaints are handled, the reliability of the electricity supply, and supply voltage levels [1].

In Brazil, there has been an increasing demand by society for improvements in the quality of public services: sanitation, telephone, electricity, etc. These services are part of everyday life.

In the case of the public service of electricity, the demand for better service quality has intensified in society, given that electricity has become the main source of light, heat and power used in the modern world. These services have an impact on the operation of equipment in industries, commerce, and household appliances, particularly computers, mobile phones and other communication devices, in a society in which people are increasingly connected to the worldwide network - Internet.

Thus, measuring the quality of service has come into its own. This measurement requires power distribution performance indicators, currently available by Brazilian regulation.

This issue gains greater importance given the capacity of the regulatory and supervisory body to act preventively, based on a systematic evaluation of the performance of each distribution utility.

This study aimed to evaluate the technical performance of the services provided by electric power distributors in Brazil, with the use of a metric based on the Multi Criteria Decision Making (MCDM) method.

PROBLEM FORMULATION

The electricity distribution sector in Brazil has introduced several technical indicators that depict various dimensions of the service quality provided by distributors [2,3]. Defining which dimensions should be part of the performance evaluation of a utility company has not been an easy task. Determining the most relevant dimensions of service quality, considering the various indicators available in the electricity distribution sector, is crucial to obtain the expected results [4,5].

This problem involves multiple conflicting criteria, which represents one of the characteristics of an MCDM problem. In said problem, the criteria and the alternatives are defined. Each criterion has its own units, and certain criteria may be minimized or maximized. Since a given alternative may rarely present the best performance simultaneously for all the criteria considered, an MCDM may be defined as an attempt to address the conflicting criteria dilemma [6].

MULTI-CRITERIA METHODS

General Considerations

There are several methods that solve this problem. The most common are given in the literature [8,9]: the Analytic Hierarchy Process - AHP (American School) [7]; and the Preference Ranking Organization Method for Enrichment Evaluations – PROMETHEE (French school).

The AHP involves comparing alternatives and criteria in pairs. Comparisons can be made for the values of the weights for the criteria; and PROMETHE is a method of over- outranking: comparisons are made between action potentials by means of binary relations given the option of one overcoming the other. The procedures of the GAIA plane (Geometric Analysis for Interactive Aid) visually complement the PROMETHEE technique. This excellent tool is used to analyze the influence of the weights of the criteria in alternatives.

The Analytic Hierarchy Process Method (AHP)[1]

This method is used to support complex decision-making. Rather than determining what the correct decision is, the method helps to choose and justify the choice. This

1 http://bpmsg.com/ahp-online-calculator/
* This paper does not express the opinion of the Brazilian Electricity Regulation Agency - ANEEL.

method allows you to include all the important, tangible or intangible factors that may be expressed qualitatively or quantitatively [7].

AHP is based on the pairwise comparison of criteria, seeking to answer two main questions: What are the most important criteria? What is the proportion of this importance? The AHP methodology consists of decomposition hierarchies and synthesis by identifying relationships through conscious choices.

The practice of decision-making is linked to the assessment of alternatives, all satisfying a set of desired objectives. The problem consists in choosing the alternative that best meets the full set of objectives.

The hierarchy structure of the problem is showed in Fig.1. Here, C represents criteria (indicators) and S represents alternatives (distributors).

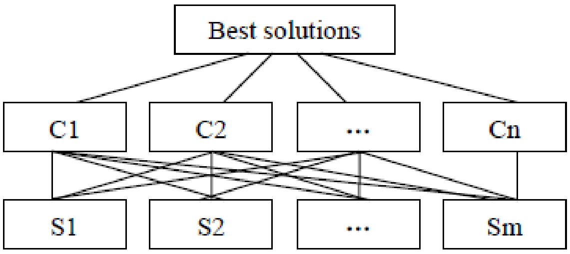

Fig. 1 – The hierarchy structure of problem.

With the help of AHP, we can deduce the weights of criteria by a matrix $K = (k_{ij})_{nxn}$, where n is the number of criteria. The weight vector W satisfies:

$$AW = \lambda_{max} \; x \; W \tag{1}$$

where, λ_{max} is the biggest eigenvalue of A.

To fill in the matrix, the recommended range is 1 to 9, with 1 signifying indifference to a criterion of importance in relation to another, and 9 meaning extreme importance of a criterion over another. Furthermore, disregarding the comparisons between the criteria themselves, representing 1 on the scale, only half of the comparisons to be made, because the other half is made up of reciprocal comparisons in the matrix of comparisons, which are the reciprocal values already compared [7].

It is relevant to note that the most important element of the comparison is always used as a full scale value, and the least as the inverse of that unit. If the line element is less important than the element-column matrix, it is entered at the corresponding position of the reciprocal value in the array.

Due to the reciprocal relationship and the need for consistency between two activities or criteria, the reciprocals of the values above zero are inserted into the array created when a comparison between two activities has been carried out. The process is robust because subtle differences in a hierarchy in practice do not become decisive.

The Consistency Index is given by CI (Eq. 2), where RI is the Random Index. If CI <= 0.1, the weight vector $W = (w_1, w_1 \dots w_n)^T$ is acceptable.

$$CI(A) = \frac{\lambda_{max}(A) - n}{(n-1) * RI} \tag{2}$$

The PROMETHEE and GAIA Method

The PROMETHEE [8.9] belongs to the family of outranking methods. These methods aim to build a outranking relationship to represent the preferences of decision-makers and solve the problem of ordering.
Suppose $A = \{a_1, \dots, a_1\}$ is a finite set of possible alternatives and $G=\{g_1, \dots g_2\}$ is a set of evaluation criteria. Without loss of generality, we can assume that these criteria must be maximized (Eq. 3).

$$max\{g_1(a), g_2(a), \dots, g_j(a), \dots, g_k(a) | a\epsilon A\} \tag{3}$$

These evaluations should be in real numbers. Each criterion can have its own units, and generally it is feasible that some criteria to be minimized and some maximized. The expectation of the decision-maker is to identify a security control set optimizing all the criteria. However, since there is no absolute best solution and the choice of solutions depends mainly on the decision-maker's preference.

For each criterion a preferable function or generalized criterion should be specified. This represents the behavior or attitude of the decision-maker regarding the differences between controls for a given j criterion. It also represents the decision-maker's preference in face of the relative differences to each evaluation criterion, as well as to eliminate the scales effects associated to the units in which the criteria are expressed.

The preferably function or generalized criterion can be defined as followed, by (4).

$$\begin{cases} P_j(a,b) = 0, a \; e \; b \; are \; indifferent \\ P_j(a,b) \approx 0, a \; is \; weak \; preferred \; to \; b, g(a) > g(b) \\ P_j(a,b) \approx 1, a \; is \; strong \; preferred \; to \; b, g(a) >> g(b) \\ P_j(a,b) = 1, a \; is \; absolutely \; preferred \; to \; g(a) >>> g(b) \end{cases} \tag{4}$$

where:

$$P_j(a,b) = F_j[d_j(a,b)], \forall \; a, b \; \epsilon A \tag{5}$$

$$d_j(a,b) = g_j(a) - g_j(b) \tag{6}$$

$$0 \leq P_j(a,b) \leq 1 \tag{7}$$

In order to facilitate the identification, six types of particular preference functions have been proposed in the literature [8,9], which are the linear criterion, level criterion, U-shape criterion, V-shape criterion, and the

Gaussian criterion, which satisfy most real-world applications.

A multi-criteria preference weighted index π should be defined, as in (Eq. 8) below, for all the alternatives,

$$\pi(a,b) = \sum_{n=1}^{k} \mathrm{P_j}(\mathrm{a},\mathrm{b})\mathrm{w_j} \qquad (8)$$

where w_j is the weight and measures the importance of each criterion to assess controls.

The weights should be determined by the decision-maker. Index π indicates the preferred percentile of control *a* regarding control *b*.

The following properties hold for all $(a,b) \in$ A:

$$\begin{cases} \pi(a,a) = 0 \\ 0 \leq \pi(a,b) \leq 1 \\ 0 \leq \pi(b,a) \leq 1 \\ 0 \leq \pi(b,a) + \pi(a,b) \leq 1 \end{cases} \qquad (9)$$

Thus, we obtain $0 \leq \pi(\mathrm{b},\mathrm{a}) + \pi(\mathrm{a},\mathrm{b}) \leq 1, \forall \mathrm{a},\mathrm{b} \in \mathrm{A}$. It is clear that,

$$\begin{cases} \pi(\mathrm{a},\mathrm{b}) \sim 0 \text{ implies } a \text{ is weak preferred to } b \\ \pi(\mathrm{a},\mathrm{b}) \sim 1 \text{ implies } a \text{ is strong preferred to } b \end{cases}$$

The leaving flow $\varphi^+(a)$, entering flow $\varphi^-(a)$ and net flow $\varphi \ (a)$ of each control can be deduced. Each control is facing *n*-1 other controls in A.

Thus, we can define $\varphi^+(a), \varphi^-(a)$ and $\varphi \ (a)$ by (10), (11) and (12), respectively.

$$\varphi^+(a) = \frac{\sum_{x \neq a} \pi(a,x)}{n-1} \qquad (10)$$

$$\varphi^-(a) = \frac{\sum_{x \neq a} \pi(x,a)}{n-1} \qquad (11)$$

$$\varphi(a) = \varphi^+(a) - \varphi^-(a), \forall a \in A \qquad (12)$$

The positive outranking flow $\varphi^+(a)$ represents how much the alternative is superior to the others, taking into account all the criteria. In other words, how this alternative outranks the others. Conversely, $\varphi^-(a)$, characterizes the level to which this alternative is outranked by the other. The ranking is simply computed according to the value of the difference between positive and negative outranking flows of the alternatives: net flow $\varphi(a)$. Roughly, the higher $\varphi(a)$, the better the alternative *a*.

The GAIA method provides graphical information regarding the conflicting aspects of the criteria and the impact of the weights on the final decision, enriching the view decision-makers have of the problem [10].

METHODOLOGY

In this section, we describe the methodology used to evaluate the technical performance of the services provided by electric power distributors, according to the following process steps:

1) AHP is defined as a theory of measurement by pairwise comparisons and relies on the judgments of experts to derive priority scales. Comparisons are made to determine weight values for the criteria (indicators) to evaluate the alternatives (distribuidors);

2) The PROMETHEE method is used to prioritize the alternatives (distributors). The evaluation is performed by using the metric defined by AHP, setting the weights. The procedures for the GAIA (Geometric Analysis for Interactive Aid) method serve as visual complements to the PROMETHEE techniques. This tool allows analyzing the influence of the criteria weights on the alternatives.

Dimensions of Quality

The performance of a utility company is traditionally assessed in terms of quality of service, according to the following dimensions: continuity, voltage level compliance, and commercial services [1].

Indicators of Quality

The indicators of service quality are presented below:

1) Electricity Supply Continuity Indicators

The DEC and FEC are strictly related to the reliability of the system. These indicators measure the respective average duration and frequency of interruptions for each consumer unit, in which each consumer unit was interrupted. These indicators are equivalent to the worldwide known indicators SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index).

DEC - Equivalent Duration of Interruption per Consumer Unit (time)

$$DEC = \frac{\sum_{i=1}^{Cc} Ca(i)\, x\, t(i)}{Cc} \qquad (13)$$

FEC - Equivalent Frequency of Interruption per Consumer Unit (number of interruptions)

$$FEC = \frac{\sum_{i=1}^{Cc} Ca(i)}{Cc} \qquad (14)$$

where:

i - index of the number of consumers interrupted by each incident;

Ca (i) – number of consumers interrupted by each incident;

t(i) - restoration time for each incident;

Cc = total number of consumers of the set of consumers or any portion of the system;

2) Consumer Units with Critical Voltage Index

The steady state voltage variation is assessed in terms of the RMS value of the voltage. It is a continuous phenomenon, and measurements to assess it at a given point of the distribution network are taken over a one week period. Average values are stored every 10 minutes of this period, leading to 1008 average measurements.

Each average measurement is classified into three nominal voltage ranges: adequate, poor, and critical. Then, two indicators are computed for each weekly measurement: DRP (Relative Duration of Poor Voltage Transgression) and DRC (Relative Duration of Critical Voltage Transgression). The DRP or DRC are considered if this indicators are above 3% and 0.5%, respectively.

The Consumer Units index with Critical Voltage (ICC) is given by

$$ICC = \frac{N_C}{N_L} \cdot 100[\%] \qquad (15)$$

where

NC - number of consumers with non null DRC;
NL - total number of annual consumer measurements.

3) Indicators of Commercial Quality

The Commercial Quality covers the quality of a number of services, such as the provision of a new connection, as well as meter reading, billing, and the handling of customer requests and complaints.

Specifically with regard to consumer complaints, Resolution [3] states that any contact made by the consumer should be classified according to 16 different patterns.

The DER (16) and FER (17) indicators seek to assess the duration and the average frequency at which the distributor responds to valid complaints submitted by consumers in its concession area.

DER – Average Duration of Complaints per Consumer Units

$$\mathrm{DER} = \frac{\sum_{i=1}^{n} \mathrm{FC(i)} \times \mathrm{PMS(i)}}{\sum_{i=1}^{n} \mathrm{FC(i)}} \qquad (16)$$

FER – Frequency of Complaints per Thousand Consumer Units

$$FER = \frac{\sum_{i=1}^{n} FC\ (i)}{Ncons} \times 1000 \qquad (17)$$

where:
i - type of complaint;
FC(i) - number of founded complaints in pattern i;
PMS(i) - average time of conclusion of founded complaints;
Ncons - total number of consumers.

RESULTS AND DISCUSSION

Results

We present below the simulation applied to a group of four electricity distributors in Brazil with more than 400,000 consumer units, a total of 63 distribution companies, whose data are available at ANEEL[2] for the year 2013.

The definition of the matrix of judgments according to the AHP method was performed based on the opinions of experts. Table I shows the weights of the indicators used in the work.

Table I – Weights

DEC	FEC	ICC	DER	FER
0,36	0,18	0,30	0,10	0,06

Table II shows the ranking of the distributors under study, using the PROMETHEE GAIA[3] program. The preference function used for the indicators was linear.

Table II – Ranking

Ranking	Distributor	Flow		
		$\varphi\ (a)$ (net)	$\varphi^{+}(a)$	$\varphi^{-}(a)$
1	A7	0,2135	0,216	0,0025
2	A38	0,0071	0,1256	0,1186
3	A34	-0,0497	0,0845	0,1341
4	A51	-0,1709	0,0247	0,1956

Fig. 1 below shows the position of the distributors according to a spatial view presented by PROMETHEE GAIA.

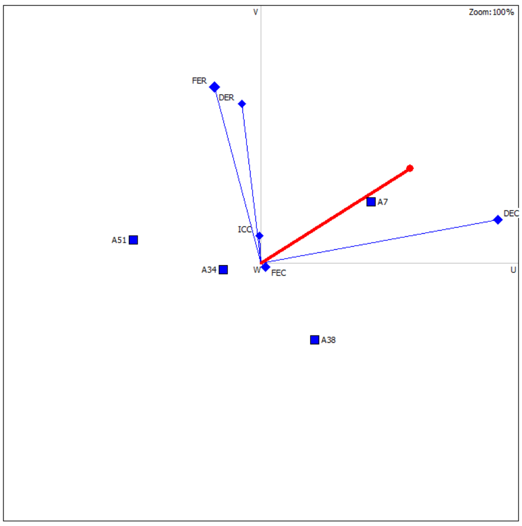

Fig. 1 - Ranking of distributors.

2 www.aneel.gov.br
3 PROMETHEE GAIA - Academic Version - 1.4.0.0 (2011 – 2013)

The GAIA plane shown in Fig. 1 is a 2D representation (two dimensions) of a picture which was originally in 3D (three dimensions). In this case, a two dimension projection of the plane was made, with a 100% representation of quality.

Discussions

Fig. 1 shows the resulting vector (red) and the indicator vectors (criteria) used in the assessment.

The advantage of this result is due to the additional information showing the position of the distributor in relation to the indicators evaluated. By designing the distribution vector with respect to the resulting vector, we obtain its position in relation to the others. This position is represented by φ (a).

It was noted that A7 was the largest segment in the positive projection of the resulting vector, while the A51 presented the highest projection in the negative segment. This result shows A7 as being the best distribution utility and A51 as the worst.

Furthermore, one can consider the projection of each distributor for the indicator vectors in the same way as done for the analysis of the resulting vector.

Another important point concerns the provision of indicator vectors. It was observed that the DEC, FEC and ICC indicators were more aligned with the resulting vector, given that the weights of these indicators were more pronounced than the others.

CONCLUSIONS

This study has introduced the technical performance of the services provided by electric power distributors, with the use of a metric based on the Multi Criteria Decision Making (MCDM) method.

The results show that the proposed metrics based on the AHP and PROMETHEE GAIA methods prove to be a promising way of evaluating the technical performance of distributors.

The AHP method has also shown to be promising for the definition of weights. In this work, the research was done with the evaluation of experts.

Regarding PROMETHEE, the method's results were presented in a ranking format. Furthermore, the GAIA module includes the ranking provided by the PROMETHE method, producing a rich analysis of the results, and thus assisting decision-makers.

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