MULTI-CRITERIA ANALYSIS FOR ESTABLISHING AUTOMATIC PRIORITY LEVELS FOR MAINTENANCE ACTIVITIES IN DISTRIBUTION SYSTEMS USING FUZZY TECHNIQUES

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ABSTRACT

Problems of maintenance planning can have several aspects to be considered involving characteristics such as characteristics technical, financial and operational, which cannot be evenly attended because of their different natures. The proposal of this paper is the use of a decision making multicriterial method for decision making, with the help of fuzzy techniques in the identification of feeder priority for maintenance accomplishment. The objective is to promote a hierarchization of several feeders in function of their urgency in receiving maintenance services, considering criteria of several natures, either quantitative or qualitative. The fuzzy technique is used in the translation of linguistic values to numeric values, both in quantitative and qualitative analysis. For the mathematical modeling of the qualitative characteristics is used the algorithm of Bellman-Zadeh, that estimates in quantitative terms the qualitative characteristics, starting from specialists' estimates. The purpose allows reunion of all formal information with the knowledge and experience of specialists from concessionaries to adjust a tool accordingly their interests, and moreover to take in consideration the real conditions of operation of electric distribution networks. The results presented in this paper and the elaborated program constituted parts of a research and development project of the State Company of Electric Energy (CEEE) executed by the Federal University of Santa Maria (UFSM).

INTRODUCTION

Problems of maintenance planning, development and reconstruction of distribution networks represent an important role in the routine of any concessionary. Considering the present technical, financial and operational characteristics, of the electric power distributors, the comparison of several improvement alternatives for distribution networks cannot satisfy all criteria in an equalitarian way. In these conditions it is necessary to use, in an optimal and appropriate way, the available data in the concessionary to analyze all possible versions of solution of the problem and to find out which one is the best among them. This paper proposes, as an alternative form, the use of multicriterial methods of decision making, where partial objective functions can be presented through natural indicators, as well as the use of fuzzy logic for the mathematical representation of the experience of the company specialists. The proposed algorithm allows taking into account several operational characteristics of the system and it gives the possibility of use of flexible restrictions appropriated for the temporary operational modes. In this case, the "level of flexibility" can be defined through the concessionary specialists' opinion. It allows the reunion of all formal information from the knowledge and experience of engineers and technicians from the concessionary for decision making in relation to accomplishment of the maintenance plans.

ALGORITHM FOR MAINTENANCE PRIORITY

In the analysis of maintenance priority of feeders, it will be simultaneously considered several characteristics; some of these cannot be introduced in a quantitative way. For its estimate, it is intended the use of the presented specialists' estimates, particularly, under the linguistic form. The following section presents the methodology used in this work.

Multicriterial method - operator product

In systems analysis, the initial problem to be approached refers to the different natures of the criteria and that, therefore, they cannot be directly related. It becomes necessary to normalize them so that they pass of several quantitative values (coin, time, amounts, etc.) with different scales of measurement, to non-dimensional values, varying from 0 (zero) to 1 (one). To accomplish this normalization, it is defined what function type represents the characteristic to be analyzed, and it is verified whether the objective function is a maximization or minimization function. In the case of maintenance priority it will be used the maximization type. Therefore, in the present method the normalization of the data [1] happens accordingly to (1):

$$\mu_{A_j}(x) = \left[\frac{F_j(x) - \underset{x \in D_x}{mín} F_j(x)}{\underset{x \in D_x}{máx} F_j(x) - \underset{x \in D_x}{mín} F_j(x)} \right]^{\lambda_{j(x)}} \quad (1)$$

where: $\mu_{Aj}(x)$ is the normalized and weighed value of the characteristic F_j; F_j is the original value of the criterion in analysis; $max\,F_j$ represents the maximum non-normalized value among the criteria values; $min\,F_j$ represents the minimum non-normalized value among the values of the analyzed criterion; $\lambda_{j(x)}$ is the weight attributed to each criterion.

Like this, according with equation (1), the data of a criterion are normalized at the same time in which it is introduced its level of importance in the equation. That leads to the weighed value of this characteristic. The level of importance, in each feeder multicriterial analysis will be obtained through the membership fuzzy functions of each characteristic, observing the predicated and objective they perform in the analysis.

All obtained the normalized and weighed characteristics it will be necessary to obtain a final numeric index for each feeder. Several methods can be used for that, and they can be pointed the multicriterial methods of the type: operator product, minimum operator and operator sum. The multicriterial-operator product method comes as the most appropriate to reach the proposed objective [2]. The index of each feeder is obtained from (2), as [3]:

$$Y(x) = \prod \mu_A(x) \quad (2)$$

At last, then, it is available the indicators that will make possible to form a ranking of the several feeders with the objective of determining which one of them comes in worse operational conditions, and in which should be prioritized the maintenance actions. Therefore, the priority feeder, in this case, is obtained from (3):

$$X^0 = \arg máx \prod \mu_A(x) \quad (3)$$

Levels of importance - fuzzy techniques

The theory and concepts of fuzzy logic will be used to translate in mathematical terms the imprecise information expressed by a group of linguistic rules, defined by the specialists in the area. Fuzzification of those linguistic values is accomplished through fuzzy groups, represented by membership functions. In general, to guarantee a reasonable precision it is used between 2 and 7 linguistic fuzzy groups in a membership function and an overlap degree in between 25% and 75%, according to [4]. For this work, 3 linguistic fuzzy groups are used for each criterion in analysis and an overlap degree of 50%. In the representation of the membership functions, the formats more frequently used are triangles and trapeziums. In this work it is used the triangular representation. Figure 1 presents an example of the used membership, in the case for the revenue criterion, following the specifications above.

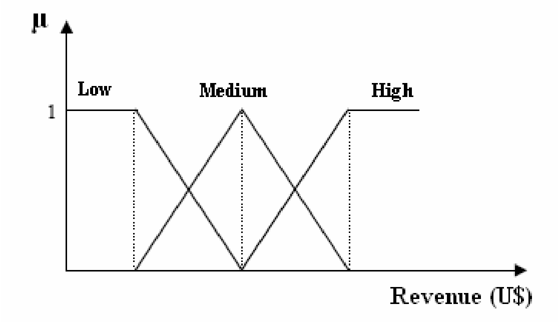


Fig. 1. Fuzzy membership function for factoring

Other membership fuzzy functions can be used, depending on the fuzzy group and on the characteristic in analysis.

Qualitative analysis

Due to the low precision of some information about some distribution criteria to which the system is submitted, its full formalization can be committed. Consequently, in practice, it is used methods that make possible the use of the experience and knowledge of specialists in the search of the best thoroughly solutions. Now, many problems related to the control and system development include the human factor as an integral part. This fact reinforces the tendency of use of mathematical methods, together with informal knowledge, obtained through specialists, in the process of analysis of complex objects, as it is the case of distribution systems [1]. A specialist can, from his/her knowledge and own experience, distribute objects in his/her preferable order, considering one or more indicators.

Like this, it is determined which objects are more or less important according to the specialist's experience. However, when he/she works with a large number of objects, most of the time, it is difficult to supply direct estimates or to accomplish the direct ordination for all of them. In this situation, it is preferable to use comparisons in pairs, where each specialist should define, for each pair of objects, which ones have higher preference. But in most cases, the estimates are accomplished by a group of specialists, supposing that the estimate of a group of specialists is more reliable than a single individual's opinion. Besides, the collective responsibility allows to the participants to make riskier decisions and, in this way, the interval of estimates received through the specialists' group should include the estimate “true” with higher level of probability. As initial step, the specialists should accomplish the ordination of factors under the point of view of their importance. The average estimate reflects all the specialists' opinion and it is made calculations according to (4):

$$k_1 = \frac{\sum_m x_{ij}}{m} \qquad (4)$$

where: k_1 is the average estimate; x_{ij} is the estimate of the level of importance of factors i with respect to factor j; m is the number of specialists.

When the specialists' numeric estimate is presented under the form of (4), it is possible to calculate the estimate through (5):

$$k_2 = 2 - k_1 \qquad (5)$$

From these data, it is possible to complete Table I with the factor priority. In this table, all cells above the main diagonal are completed with the data from calculations as k_1, and the cells that are below the main diagonal are completed with the data from calculations as k_2.

Table I. Priority of the Factors

Factors	1	...	n	Σ	k_p	Factor priority
1 ... n						

With auxiliary coefficients and from Table I it is possible to calculate the priority coefficient for each factor, from (6):

$$k_p = \frac{\sum_{i=1}^{n} k_i}{n(n-1)} \qquad (6)$$

where: k_p is the priority coefficient for each factor; n is the number of factors that should be compared; k_i are the estimates for k_1 or k_2.

So, priority is obtained, or its level of importance, for each qualitative characteristic. The specialists' estimates are multiplied by their respective priority factors, being obtained, like this, the weighed qualitative characteristic of each feeder.

PRACTICAL EXAMPLE

As a practical example, a group of 10 feeders is analyzed with the objective of establishing the priority order in the execution of preventive maintenance. Three characteristics of each feeder will be considered: Violations of SAIDI, Revenue and Number of Consumers. Figure 2 presents the initial screen of the developed computer tool where it is possible to choose the characteristics that will be the criteria considered in the process.

Initially, according to (1), the data of a criterion are normalized, at the same time in that it is introduced in the equation its level of importance, what takes to its weighed value. The level of importance comes from the membership fuzzy function of each characteristic, as previously described and following the model presented in Figure 1. Therefore, it should be previously determined the values of the membership fuzzy function for each characteristic. With base in the final index of each feeder, it is possible to form a ranking of feeders in function of the analysis of their quantitative characteristics, according to Figure 3.

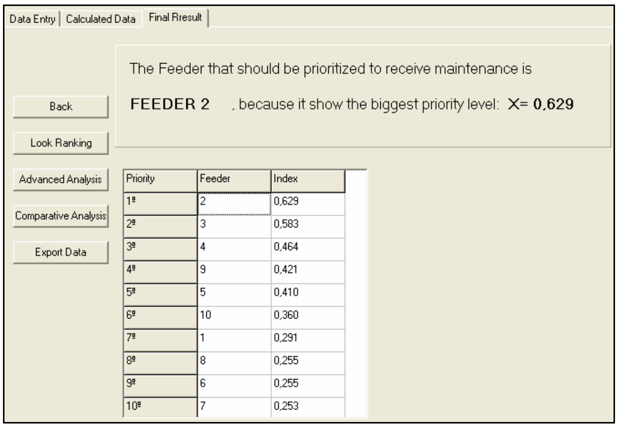


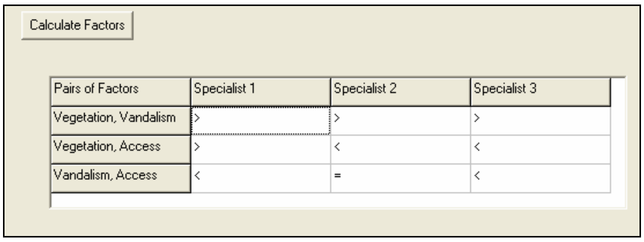
Fig. 3. Ranking in function of the final index for each feeder - quantitative characteristics.

The next stage consists of introducing a qualitative analysis of the feeders. The computer tool developed allows the determination of how many specialists will do the estimate and which ones are the qualitative characteristics that will be analyzed.

For this example, the following qualitative criteria are used: vegetation, vandalism and access.

Once established the characteristics for the qualitative analysis, the next stage consists of the analysis of those data from the specialists, in other words, marks 0 (zero) to 10 (ten) will be attributed for each characteristic. Like this, the more critical is the condition closer or equal to ten will be the mark that should receive and vice-versa. After attribution of the marks, the average is calculated with the purpose of just obtaining a final value for each characteristic.

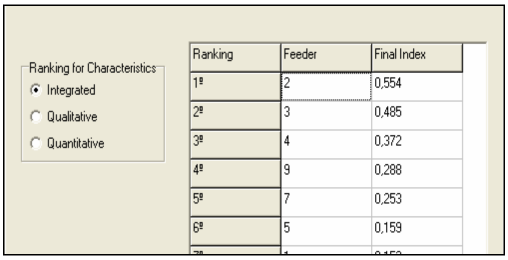
Initially, the qualitative characteristics are grouped pair to pair, with the purpose of accomplishing a comparison between them. In other words, the specialist should evaluate which is the level of importance that a given characteristic possesses in comparison with other. For instance: if the specialist judges that the vegetation characteristic is more important than the vandalism characteristic, it should fill out the input table with the symbol “>”; or to feel what characteristics possess equal importance, with the symbol “=”; and so forth. The data input for processing the qualitative characteristics is shown in Figure 4.



Pairs of Factors	Specialist 1	Specialist 2	Specialist 3
Vegetation, Vandalism	>	>	>
Vegetation, Access	>	<	<
Vandalism, Access	<	=	<

Fig. 4. Input to the qualitative pair to pair process.

Once obtained the averages of each qualitative characteristic for each feeder, it is necessary to calculate the indexes for each one of them, in other words, to determine its importance in the qualitative analysis as a whole. Obtained the index, it is enough to multiply the averages of the notes given by the specialists for each characteristic of each feeder, for its respective index, to complete them. Then, to obtain a just final index of the qualitative characteristics for each feeder is enough to add all the normalized and weighed qualitative characteristics. Applying Equation (1) to normalize the final qualitative indexes of each feeder, and using a level of importance equal to 1 (one), it is possible, to complete the quantitative final results with the qualitative final results, according to Equation (2). It is possible to obtain a final ranking to determine the priority of the maintenance activities, according to Figure 5.



Ranking	Feeder	Final Index
1º	2	0,554
2º	3	0,485
3º	4	0,372
4º	9	0,288
5º	7	0,253
6º	5	0,159

Fig. 5. Final ranking of the feeder's priority.

CONCLUSION

This paper presents the method of multicriterial analysis - operator product, using a fuzzy technique, with the objective of identifying among a group of feeders which one presents higher needs under the point of view of the preventive maintenance accomplishment. The multicriterial method of analysis for a harmonic solution that includes different criteria to be taken into account in the process of decision making. The use of the algorithm of Bellman-Zadeh associated to fuzzy logic represents an optimal progress in the analysis of electric power systems, because it allows the use of specialists' estimates, makes possible a more current representation of the system and of the group of feeders. Furthermore, it has the possibility of accomplishing the data input through linguistic variables, giving more freedom to the specialist with respect to the form of expressing his/her opinion, increasing significantly the objectivity of those estimates. Finally, a prototype of computer tool was developed to accomplish the whole proposed algorithm in an automatic way and that will contribute with the project of Research and Development of CEEE / ANEEL, in partnership with CEEMA/UFSM.

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