SELECTION OF THE OPTIMAL INSULATOR TYPE FOR A NEW HV OVERHEAD TRANSMISSION LINE, USING THE METHOD OF THE MULTICRITERIAL DECISION MAKING

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ABSTRACT

A new methodology combining both High Voltage Techniques and Multicriterial Decision Making is presented in this paper. This method is applied on a Power Utilities' dilemma about the selection of the optimal insulator type at the construction of a new electrical network. This selection has been done among ten different types of insulators, which are widely used by Power Utilities. Initially the criteria on which the problem is based on are determined, in order the method to be applied. These criteria are four and concern the cost, the critical flashover voltage, the creepage distance and the diameter of the insulator. Each criterion has been expressed in a common reference scale and the values of the criteria have been normalized. A different weight is given to each criterion, characterizing its importance to the decision making. Finally, a matrix, which contains the four criteria and the possible choices is used to calculate the rate of agreement and the rate of disagreement. By making the proper combinations between the values of these two rates the method infers the optimal insulator type.

1. INTRODUCTION

The determination of priorities is multidimensional depended on the problem's needs and aspects. The different dimensions of a problem lead to the use of methods, which are different from the econometric ones (as the cost-utility analysis) [1]. The reason that this occurs, is that trying to bring all the dimensions in an economical aspect, may be very difficult or in many cases a very dangerous simplification. For this reason the use of the Multicriterial Methods, which take into consideration the different parameters and criteria [2-3], is necessary.

There was always a major interest for the insulation of transmission lines, due to the fact that the flashover of polluted insulators can cause a long duration outage of the transmission line over a large area. Flashover of polluted insulators is a serious threat to the safe operation of a power transmission system. In order to avoid such disturbances, it has been necessary to use insulators of reliable quality in the overhead transmission lines. Fortunately, technological progress has contributed to the improvement of the insulating techniques. In nowadays there is such a great variety of insulators that very often is difficult to select the optimal type.

According to IEC 815 [4] it is defined that there are four pollution levels for the pollution of the insulators, depending on the area in that they have been installed: the light pollution level (C<0.06 mg/cm^2), the medium pollution level (0.06<C<0.20 mg/cm^2), the heavy pollution level (0.20<C<0.60 mg/cm^2) and the very heavy pollution level (C>0.60 mg/cm^2).

Decision Making is a difficult issue, because the problem is based on many factors. A new method of the Decision Making Theory has been developed, helping to the selection of the optimal type of insulator. The Multicriterial Decision Making, as it is called, has been widely used in many problems, as for example the power conserving in the Greek energy system, based on many criteria as economical and environmental. Consequently, a combination both of High Voltage Techniques and Multicriterial Decision Making can lead to the desired solution as it is analytically described in this paper.

2. CRITERIA FOR THE DECISION MAKING

A Power Utility has to decide which will be the optimal insulator type to be installed at a new electrical network. According to the Multicriterial Decision Making Method [3] the most crucial point of the whole procedure is to define the set of criteria C_i ($1 \le i \le N$) for the possible choices P_j ($1 \le j \le M$), depending on the structure of the problem. This set must be clear and specified, having elements, which are not mutual accomplished. Each criterion has a different weight (w_{Ci}), expressing how important this criterion is, referring to the selection to be made.

A final matrix (with dimensions MxN) contains the criteria and the possible choices. Using the values of the matrix elements the rate of agreement A and the rate of disagreement D are computed. By making the proper combinations between the values of these two rates, the method leads to the unique solution of the problem.

Normalisation

The problem requires that each one criterion has to be expressed in a common reference scale. For this reason the values of each criterion are normalised, marking the most satisfactory value with 100 and the worst with 0. If M is the maximum value of the criterion and m the minimum, the normalized values of each criterion are calculated using the following formula:

$$\beta = \left| \frac{x - M}{m - M} \right| \cdot 100 \qquad (1)$$

where β is the normalized value and x the value before normalisation.

Investigated insulators

Ten different insulators (P1…P10) were investigated for the purposes of this paper. The insulators are of cap-and-pin type (standard suspension insulators and fog type). Each insulator has its own geometrical characteristics: a) the height of the insulator H (in cm), b) the form factor of the insulator F, c) the creepage distance L (in cm), d) the diameter of the insulator D_r (in cm). Table 1 summarises the above characteristics of the investigated insulators.

TABLE 1

Insulator	H(cm)	F	L (cm)	D_r (cm)	Uc (KV)	Cost (€)
P1	15.87	0.790	33.02	26.7	10.6	66
P2	15.87	0.860	40.64	26.8	11.8	70
P3	16.51	0.916	43.18	25.4	12.0	75
P4	14.6	0.840	27.94	25.4	10.0	65
P5	14.6	0.702	40.64	29.2	12.0	85
P6	14.6	0.716	31.75	25.4	10.2	83
P7	15.87	0.922	46.99	29.2	13.1	71
P8	15.56	0.757	36.83	27.9	11.3	73
P9	17.78	0.792	45.72	32.1	13.2	84
P10	19.68	0.754	42.54	32.1	12.7	77

Criterion C_1: The creepage distance

Pollution in the electrical networks is the overlay of dirt or sludge hovering on the air. The origin of dirt, transferred by the wind, is sea or the industrial activity of the area. The coexistence of pollution and fog or drizzle, highly contributes to the loss of the insulating ability and may reduce it in a great extent (40%-80%). Consequently, an electric arc is very possible to appear. The attributes of the insulators in a polluted environment are depended on the creepage distance.

The creepage distance L is defined as the shortest way on the insulator's surface between the two metallic terminals. Table 1 indicates the creepage distance of each insulator type. After normalization using eq. (1) the values of creepage distance are indicated in the second column of Table 2.

Criterion C_2:The critical flashover voltage

The most known model for the explanation and evaluation of the flashover process of a polluted insulator, consists in a partial arc spanning over a dry zone and the resistance of the pollution layer in series. The critical voltage U_c is given [5, 6] by the following formula:

$$U_c = \frac{A}{n+1} \cdot \left(L + \pi \cdot D_r \cdot F \cdot K \cdot n\right) \cdot \left(\pi \cdot D_r \cdot \sigma_p \cdot A\right)^{-\frac{n}{n+1}} \qquad (2)$$

where A, n are the arc constants. Their values $A=124.8$, $n=0.409$ have been determined using a complex optimisation method [5] based on genetic algorithms.

The coefficient K of eq. (2) was introduced by Wilkins [7] in order to modify the resistance of the pollution layer at the critical instant of the flashover, considering the current concentration at the arc foot point. A simplified formula [6] for the calculation of K for cap-and-pin insulators is:

$$K = 1 + \frac{n+1}{2 \cdot \pi \cdot F \cdot L \cdot n} \ln \left(\frac{L}{2\pi F \sqrt{\frac{\left(\pi \cdot D_r \cdot \sigma_P \cdot A\right)^{\frac{1}{n+1}}}{1.45 \cdot \pi}}} \right) \qquad (3)$$

F is the form factor of the insulator that is given as follows:

$$F = \int_0^L \frac{1}{\pi D(l)} dl \qquad (4)$$

$D(l)$ is the diameter of the insulator that varies across the creepage distance. The values of form factor F for the investigated insulators are also indicated in Table 1.

The surface conductivity σ_p of the pollution layer is:

$$\sigma_p = \left(369.05 \cdot C + 0.42\right) \cdot 10^{-6} \qquad (5)$$

C is the equivalent salt deposit density (ESDD) (in mg/cm^2). In this paper the value of ESDD, which has been used, is C=0.2 mg/cm^2. The critical voltage U_c of each insulator has been calculated using the eq. (2) and the results are summarised in the sixth column of Table 1. After normalization using eq. (1) the values of critical voltage are indicated in the second column of Table 2.

Criterion C_3: The diameter
It is known that the increase of the insulator's diameter leads to the decrement of its insulating ability. This occurs due to its bigger surface, which facilitates the overlay of dirt. Therefore, the diameter of the insulator is a criterion for the current analysis. Table 1 indicates the diameter of each insulator D_r, while the normalised values of the diameters are shown in the fourth column of Table 2.

Criterion C_4: The cost
Table 1 indicates the total manufacturing and installation cost for each insulator. After normalization, using eq. (1) the normalised values of all choices are shown in the last column of Table 2.

Due to the pollution on the insulator's surface is necessary for all insulators to be cleaned in regular times to avoid the overlay of dirt. This maintenance cost is the same for all insulator types, since they are cleaned in the same way, resulting that this cost is not a criterion.

3. SOLUTION OF THE PROBLEM

The above set of criteria is coherent, monotone and no redundant as it is demanded by the Multicriterial Decision Making Theory [3] in order to be applied.

TABLE 2

g	L	Uc	D_r	Cost
P1	26.7	18.8	81.0	95.0
P2	66.7	56.3	79.5	75.0
P3	80.0	62.5	100.0	50.0
P4	0.0	0.0	100.0	100.0
P5	66.7	62.5	43.0	0.0
P6	20.0	6.2	100.0	10.0
P7	100.0	96.9	42.9	70.0
P8	46.7	40.6	61.9	60.0
P9	93.3	100.0	0.0	5.0
P10	76.6	84.4	0.0	40.0

Rate of agreement
Using the values of the matrix in Table 2 the rate of agreement A expresses the percentage norm of the criteria, which are in accordance that solution a is dominated on solution b. A can be calculated using eq. (6):

$$A(a,b) = \frac{1}{W} \cdot \sum_{g_i(a) \geq g_i(b)} w_{Ci} \qquad (6)$$

where $g_i(a)$ is the value of the Table 2 for the choice a (with $a \in [P_1, P_M]$, and $a \neq b$). W is the sum of the weights w_{Ci}. ($W = \sum_{i=1}^{N} w_{Ci}$).

For the rate of agreement: $0 \leq A \leq 1$.

Rate of disagreement
In a same way using the matrix of Table 2 the rate of disagreement D can be calculated from eq. (7):

$$D(a,b) = \begin{cases} 0 & if \quad g_i(a) \geq g_i(b) \\ \frac{1}{\delta} \max_i \cdot (g_i(b) - g_i(a)) & g_i(a) < g_i(b) \end{cases} \qquad (7)$$

where $\delta = \max_{a,b,i} (g_i(a) - g_i(b)), \ \forall i$.

For the rate of disagreement: $0 \leq D \leq 1$.

The problem's kernel
Knowing that: a **S** $b \Leftrightarrow A(a,b) \geq \hat{a}$ *and* $D(a,b) \leq \hat{d}$, where the symbol **S** means that solution a is dominant on solution b. Decreasing $\hat{a}$ and increasing $\hat{d}$ the number of the kernel's elements decreases and the final solution arises.

For criterias' weights w_{c1}=2, w_{c2}=3, w_{c3}=1 and w_{c4}=4 the matrixes of agreement and disagreement are indicated in Table 3 and 4, respectively.

TABLE 3

A	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1		0.5	0.4	0.5	0.5	0.9	0.5	0.5	0.5	0.5
P2	0.5		0.4	0.5	0.7	0.9	0.5	1.0	0.5	0.5
P3	0.6	0.6		0.6	1.0	1.0	0.1	0.6	0.5	0.7
P4	0.5	0.5	0.5		0.5	0.5	0.5	0.5	0.5	0.5
P5	0.5	0.5	0.3	0.5		0.5	0.1	0.5	0.1	0.1
P6	0.1	0.1	0.1	0.6	0.5		0.1	0.1	0.5	0.1
P7	0.5	0.5	0.9	0.5	0.9	0.9		0.9	0.7	1.0
P8	0.5	0.0	0.4	0.5	0.5	0.9	0.1		0.5	0.5
P9	0.5	0.5	0.5	0.5	0.9	0.5	0.3	0.5		0.6
P10	0.5	0.5	0.3	0.5	0.9	0.9	0.0	0.5	0.5	

Finally for values $\hat{a}$=0.5 and $\hat{d} = 0.5$ the method leads to the optimal type of insulator, which is P3. This is shown in Table 5 as the column P3 is the only empty column of the table.

TABLE 4

D	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1		0.40	0.53	0.19	0.44	0.19	0.78	0.22	0.81	0.66
P2	0.20		0.21	0.25	0.06	0.21	0.41	0.15	0.44	0.28
P3	0.45	0.25		0.50	0.00	0.00	0.34	0.10	0.38	0.22
P4	0.27	0.67	0.80		0.67	0.20	1.00	0.47	1.00	0.84
P5	0.95	0.75	0.57	1.00		0.57	0.70	0.60	0.38	0.40
P6	0.85	0.65	0.60	0.90	0.56		0.91	0.50	0.94	0.78
P7	0.38	0.37	0.57	0.57	0.00	0.57		0.19	0.03	0.13
P8	0.35	0.20	0.38	0.40	0.22	0.38	0.56		0.59	0.44
P9	0.90	0.79	1.00	1.00	0.43	1.00	0.65	0.62		0.35
P10	0.81	0.79	1.00	1.00	0.43	1.00	0.43	0.62	0.17	

TABLE 5

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1		S		S	S	S		S		
P2	S			S	S	S	S	S	S	S
P3	S	S		S	S	S		S	S	S
P4	S					S		S		
P5										
P6										
P7	S	S			S			S	S	S
P8	S			S	S	S				S
P9					S					S
P10					S				S	

All calculations include a certain amount of uncertainty, due to the subjective selection of weights. The only variable element of this analysis is the values of weights for each criterion, since it is depended on the human factor. Therefore, a sensitivity analysis for the optimal determination of the values has to be done.

Various methods for the determination of weights have been developed. A more detailed presentation of such methods can be found in Rogers et al. [3]. Due to the fact that the selection of weights is subjective, six different sets of weights are tested using this method. Table 6 indicates the results of the above investigation.

TABLE 6

w_{c1}	w_{c2}	w_{c3}	w_{c4}	$\hat{a}$	$\hat{d}$	choice
1	1	1	1	0.5	0.5	P3
1	1	1	2	0.5	0.5	P3
1	2	3	4	0.5	0.5	P3
2	3	1	4	0.5	0.5	P3
2	2	1	1	0.5	0.6	P7
4	3	2	1	0.5	0.7	P7

4. CONCLUSIONS

The Multicriterial Decision Making Method is a useful technique for problems depended on numerous factors. The outcomes of the developed model include a data combination of these factors, and of the extent to which the human factor may influence the decision making. The main purpose of this methodology is to minimize the subjectivity of choosing the best solution, which is achieved by applying sensitivity analysis. The only variable element in the procedure of decision making is the relative weight of each criterion. The methodology application shows that the relative weight given to each involved group has a direct influence on the total grading of the suggested solutions. Apparently, the optimal insulator type is obtained very fast, due to the efficient algorithm. Therefore, this method is more preferable in comparison to other methods and techniques used for the same purposes.

5. REFERENCES

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