IOP Conf. Series: Materials Science and Engineering **227** (2017) 012129 doi:10.1088/1757-899X/227/1/012129

Choosing the optimal wind turbine variant using the "ELECTRE " method

I A Țișcă[1], D Anușca[2] and C D Dumitrescu[3]
[1,2,3]Politehnica University of Timișoara- Romania, Departament of Engineering and Management, Blvd. Mihai Viteazu, No.1, 300222, Timișoara, Romania

E-mail: tiscaionelaadriana@yahoo.com

Abstract: This paper presents a method of choosing the "optimal" alternative, both under certainty and under uncertainty, based on relevant analysis criteria. Taking into account that a product can be assimilated to a system and that the reliability of the system depends on the reliability of its components, the choice of product (the appropriate system decision) can be done using the "ELECTRE" method and depending on the level of reliability of each product. In the paper, the "ELECTRE" method is used in choosing the optimal version of a wind turbine required to equip a wind farm in western Romania. The problems to be solved are related to the current situation of wind turbines that involves reliability problems. A set of criteria has been proposed to compare two or more products from a range of available products: Operating conditions, Environmental conditions during operation, Time requirements. Using the ELECTRE hierarchical mathematical method it was established that on the basis of the obtained coefficients of concordance the optimal variant of the wind turbine and the order of preference of the variants are determined, the values chosen as limits being arbitrary.

1. Introduction

The "Electre" method (elimination et choix traduisant la realite) was developed by the SEMA company (Societe d′Economie et de Mathematique Appliquees), for choosing a new product, from a range of similar products, which could represent the object of a production program.

Given that a product can be assimilated to a system and that the reliability of the system depends on the reliability of its components, product selection (decision on the appropriate system) can be done using the "electric" and depending on the level of reliability of each product.

Reliability problem focuses around three issues [1]:

1. The operating conditions
2. The environmental conditions
3. The time conditions

These three issues can constitute criteria by which two or more products are compared from a range of available products. By using the "ELECTRE" method, there is the possibility to compare them separately, according to each criterion.

The operating conditions are defined in a unitary manner for each product (turbine power: MW, rotor diameter: m, minimum/maximum wind speed at blade engagement, accepted wind class etc.). The difficult problem that needs to be answered is that of achieving constant operating conditions throughout the activity of an equipment (The demand for a wind turbine is different in time depending on the wind speed, the state of the weather, the limits allowed for the generator speed etc.). As a result, operating conditions should be regarded as a distribution rather than as a single value. The key issue is to obtain the necessary data to build the distribution law. Obtaining this data is costly, and sometimes only by learning how to use the product can the problem be solved. After obtaining information on operating conditions, verification tests are required to determine whether the product will be able to withstand possible future challenges for a certain period of time.

Environmental conditions (wind speed, temperature, air humidity, vibrations generated during the operation of the turbine) are critical factors for wind turbines. The problem presents two aspects: determining the possible levels that environmental parameters can achieve and verifying the degree to which the product can meet the requirements imposed by these parameters [2].

The time conditions refer to: the testing time of the product, the permissible number of product failures, the maximum duration of the testing program [2].

Comparing the products according to each criterion implies the existence of a scale of appreciation for each criterion in such a way that each product corresponds to a certain level on the scale of appreciation.

2. Results and discussions

The criterias can be differentiated according to their importance, assigning to each of them a coefficient of importance k_f (f=1, 2,....,f); a score is assigned to each level of the rating scale and two indicators are calculated for each pair of products, called concordance indicators (β_{ij}) and discordance indicators (d_{ij}), which help to establish the order of priority [3].

The concordance indicators (β_{ij}) are determined with the relation (1):

$$\beta ij=\frac{\sum_{\beta \in N\beta} Kc}{\sum_{j=1}^{f} Kf} \quad (1)$$

Where:

$\sum k_c$= the sum of the coefficients of importance of the ordered criteria (βϵN), i.e. the criteria in which the quality assessment ”i” is equal to or superior to the quality assessment ”j”; $\sum_{j=1}^{f} Kf$ = the sum of the coefficients of importance of all criteria.

The discordance indicators (d_{ij}) are determined with the relation:

$$dij=\frac{\max \Delta d}{h_m} \quad (2)$$

Where:

Δd= the discordant interval for a criteria where the appreciation of ”j” is superior to the appreciation of quality ”i”, i.e. the difference between the mark of ”j” and the mark of ”i”; Δd_{max}=mark ”j”- mark ”i”

h_m= the maximum difference between the maximum mark and the minimum mark on the rating scale.

The ”ELECTRE” method reaches a decision based on concordance and discordance indicators. It is considered that an i alternative surpasses a j alternative if $\beta_{ij} \geq p$ și $d_{ij} \leq q$, p and q being limit values chosen by the decision maker (2).

In the example below we use the ”ELECTRE" method in choosing the variant of wind turbine required to equip a wind park in western Romania. The criteria used for the analysis are:

- For the operating conditions, we have focused on the maximum braking power of the shaft on which the three blades were mounted, expressed in MW; (A1)
- For the environmental conditions, we focused on the homogeneous load of the rotor shaft during operation, expressed as a percentage of the maximum allowable power.(A2)
- For the time conditions we focused on the annual service life prescribed by the supplier, expressed in operating hours per year.(A3)

For the analysis, four types of wind turbines with similar technical characteristics, frequently used in other wind farms in Romania, were used.

The coefficients of importance admitted for analysis together with the technical data are presented in table 1.

Table 1. Initial conditions imposed on wind turbines.

Type of product	A1- Operating conditions: maximum permissible power MW	A2- Environmental conditions: percentage of maximum permissible power (%P max)	A3- Time conditions, expressed in hours/year of operation.(hours/year)
VESTAS V80	2	83	7000
VESTAS V 90	3	75	6500
NORDEX N 90	2.5	62	8000
GENERAL ELECTRIC	2.5	92	8000

The expression of the value for each criterion by ratings for each variant is given in table 2.

Table 2. Granting ratings for each criterion and variant.

Type of product	A1- Operating conditions: maximum permissible power MW	A2- Environmental conditions: percentage of maximum permissible power (%P max)	A3- Time conditions, expressed in hours/year of operation.(hours/year)
VESTAS V80	WEAK	GOOD	VERY GOOD
VESTAS V 90	VERY GOOD	NORMAL	WEAK
NORDEX N 90	NORMAL	WEAK	GOOD
GENERAL ELECTRIC	GOOD	VERY GOOD	NORMAL
COEFFICIENT OF IMPORTANCE	2	1	3

For each coefficient of importance, a scoring scale, corresponding to the awarded rating, will be established, so as to differentiate not only the criteria among them, but also the ratings within each criterion, according to table 3.

Table 3. Granting specific scores for each criterion.

RATING	AWARDED SCORE		
	A1- Operating conditions: maximum permissible power MW	A2- Environmental conditions: percentage of maximum permissible power (%P max)	A3- Time conditions, expressed in hours/year of operation.(hours/year)
VERY GOOD	12	10	16
GOOD	9	8	10
NORMAL	6	6	6
WEAK	3	4	2
COEFFICIENT OF IMPORTANCE	2	1	3

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Furthermore, a graph can be drawn up, showing the variation of the ratings by variants, according to the criteria and the coefficients of importance granted, as shown in figure 1.

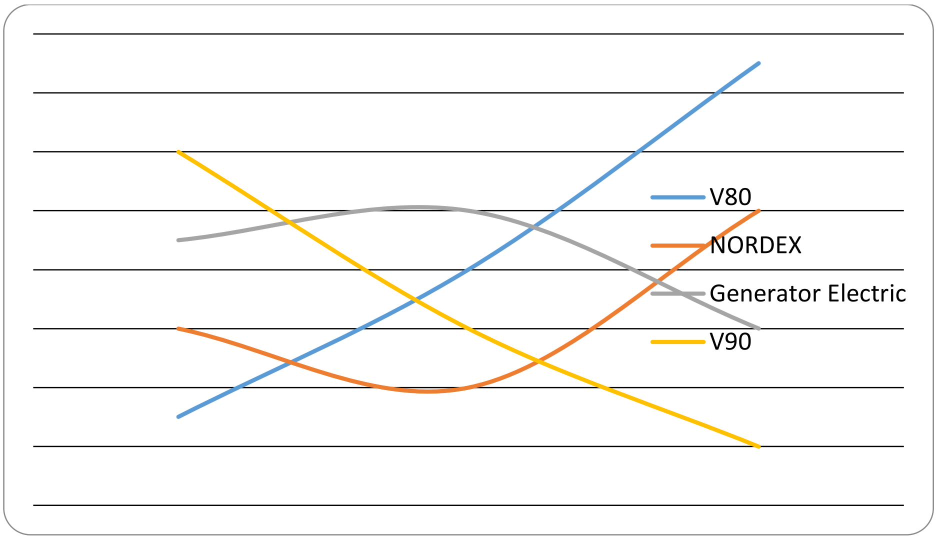

Figure 1. Score awarded.

The values obtained for the concordance coefficients can be represented in a table, according to table no. 4.

Table 4. The values concordance coefficients**.**

$B_{IJ=}$	X	V1	**V2**	**V3**	**V4**
	V1	X	1.5	0.33	1
	V2	1	X	1.33	0.66
	V3	0.66	1.33	X	1.5
	V4	0.66	0.33	0.66	X

The calculation of the concordance coefficients resulting from the comparison of variant V1 with the others, respecting the conditions that V1> Vj:

$$\beta(V_1V_2) = \frac{8-6+16-2}{6} = 2 \tag{3}$$

$$\beta(V_1V_3) = \frac{8-4}{6} = \frac{4}{6} = \frac{3}{3} = 0.66 \tag{4}$$

$$\beta(V_1V_4) = \frac{16-6}{6} = \frac{10}{6} = 1.66 \tag{5}$$

$$\beta(V_2V_1) = \frac{12-3}{6} = \frac{9}{6} = \frac{3}{2} = 1.5 \tag{6}$$

$$\beta(V_2V_3) = \frac{12-6+6-4}{6} = \frac{8}{6} = \frac{4}{3} = 1.33 \tag{7}$$

$$\beta(V_2V_4) = \frac{12-9}{6} = \frac{3}{6} = \frac{1}{3} = 0.33 \tag{8}$$

$$\beta(V_3V_1) = \frac{6-3}{6} = \frac{3}{6} = \frac{1}{3} = 0.33 \tag{9}$$

$$\beta(V_3V_2) = \frac{10-2}{6} = \frac{8}{6} = \frac{4}{3} = 1.33 \tag{10}$$

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$$\beta(V_3V_4) = \frac{10-6}{6} = \frac{4}{6} = \frac{2}{3} = 0.66 \quad (11)$$

$$\beta(V_4V_1) = \frac{9-3}{6} = \frac{6}{6} = 1 \quad (12)$$

$$\beta(V_4V_2) = \frac{10-6}{6} = \frac{4}{6} = \frac{2}{3} = 0.66 \quad (13)$$

$$\beta(V_4V_3) = \frac{9-3+10-4}{6} = \frac{9}{6} = 1.5 \quad (14)$$

The following is used to calculate the discordance coefficients:

$$d = \begin{matrix} (12-3) = & 9\ (for\ kf = 2) \\ (10-4) = & 6\ (for\ kf = 1) \\ (14-2) = & 12\ (for\ kf = 3) \end{matrix} \quad results\ for\ hmax = 12 \quad (15)$$

Discordance coefficient resulting from comparing the variant V_1 with V_j, on the condition that $V_1 \leq V_j$:

$$d(V_1V_2) = \frac{12-2}{12} = \frac{10}{12} = \frac{5}{6} = 0.833 \quad (16)$$

$$d(V_1V_3) = \frac{6-2}{12} = \frac{14}{12} = \frac{1}{3} = 0.33 \quad (17)$$

$$d(V_1V_4) = \frac{(9-2)+(10-8)}{12} = \frac{7+2}{12} = \frac{9}{12} = \frac{3}{4} = 0.75 \quad (18)$$

$$d(V_2V_1) = \frac{(8-6)+(16-2)}{12} = \frac{2+14}{12} = \frac{16}{6} = \frac{4}{3} = 1.33 \quad (19)$$

$$d(V_2V_1) = \frac{10-2}{12} = \frac{12}{12} = \frac{1}{6} = 0.166 \quad (20)$$

$$\mathrm{d}(\mathrm{V}_2\mathrm{V}_4) = \frac{10-6}{12} = \frac{4}{12} = \frac{1}{3} = 0.33 \quad (21)$$

$$\mathrm{d}(\mathrm{V}_3\mathrm{V}_1) = \frac{8-4}{12} = \frac{4}{12} = 0.33 \quad (22)$$

$$\mathrm{d}(\mathrm{V}_3\mathrm{V}_2) = \frac{12-6+6-4}{12} = \frac{8}{12} = \frac{2}{3} = 0.66 \quad (23)$$

$$\mathrm{d}(\mathrm{V}_3\mathrm{V}_4) = \frac{9-6+10-6}{12} = \frac{7}{12} = 0.50 \quad (24)$$

$$\mathrm{d}(\mathrm{V}_4\mathrm{V}_1) = \frac{16-6}{12} = \frac{10}{12} = \frac{5}{6} = 0.833 \quad (25)$$

$$\mathrm{d}(\mathrm{V}_4\mathrm{V}_2) = \frac{12-9+10-6}{12} = \frac{7}{12} = 0.50 \quad (26)$$

$$\mathrm{d}(\mathrm{V}_4\mathrm{V}_3) = \frac{10-6}{12} = \frac{4}{12} = \frac{1}{3} = 0.33 \quad (27)$$

Similarly, one can determine the discordance coefficients resulting from the comparison of variant V_2 with V_j, provided that $V_2 \leq V_j$: the values obtained for the discordance coefficients can be represented in a table, according to table 5.

Table 5. The values discordance coefficients**.**

$d_{IJ=}$	X	V1	**V2**	**V3**	**V4**
	V1	X	0.833	0,33	0.75
	V2	1.33	X	0.166	0.33
	V3	0.33	0.66	X	0.50
	V4	0.833	0.50	0.33	X

3. Conclusions

Based on the concordance coefficients obtained, the optimal variant and the order of preference of the variants are determined, the values chosen as limits being arbitrary. For a better understanding of the reasoning of the adopted decision. A conventional sense has been established in the figure: when the V1 variant surpasses the V_j variant, the vector has origins in V_1 and the extreme in V.

Choosing as limits for the two coefficients: β=1 și d=0, it can be noticed that no V variant surpasses any V_j variant. Choosing as limits for the two coefficients β= 0.833 and d= 0.166, it can be noticed that the V_2 variant is preferable to the V_3 variant, changing the limit of the discordance coefficient, d = 0.333 and leaving unchanged the value of β (β=0.833), it can be noticed that the V_3 variant is preferable to the V_4 variant; further changing the value of d=0.5, leaving unchanged the value of β= 0.833, it can be noticed that the V_2 variant is preferable to the V_4 variant.

By modifying the value of the concordance coefficient β= 0.666 and that of the discordance coefficient, d = 0.25, it can be noticed that the V_1 variant is preferable to the V_4 variant; changing now the discordance coefficient d=1.0, while maintaining the value of the concordance coefficient β= 0,666, it can be noticed that the V_1 variant is preferable to the V_2 variant.

Therefore, by applying the "ELECTRE" method, the order of preference of the variants: V_1, V_2, $V_{3,}V_{4,}$, subject to the application of the relevant coefficients of importance according to the initial data, for the analytical criteria used.

For the same data (the same variants, the same criteria) but for different coefficients of significance, similar analysis can be performed using the "ELECTRE" method, as a result of which the order of preference of the variants may change.

4. References

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