Multiple Criteria Decision Making in Distribution System Planning

İsmail Şahin[1], and Mustafa Bağrıyanık[2]

[1]Power Technologies International (PTI), Siemens Turkey.
34870,Kartal, Istanbul, Turkey
sahin.ismail@siemens.com
[2]Department of Electrical Engineering, Istanbul Technical University
34469 Maslak, Istanbul, Turkey
bagriy@elk.itu.edu.tr

Abstract

Making a decision with taking into account many criteria under uncertainty cases is really tough problem for decision authorities in all business sectors. In order to handle the problem, multi-criteria decision making techniques are developed. Multi-criteria decision problem is come up for planning engineers in electricity distribution sector to select the best solution. In this paper, three different planning solutions for problems in the sample distribution system are evaluated by using TOPSIS technique to decide the best option. For understanding the importance of weight coefficients, these evaluations are done under three different cases. The results show that the weight of each criteria can affect the decision directly.

1. Introduction

Electrical energy is inevitable part of daily and business life. Demand for the electrical energy is increased significantly according to developing technology and economic factors. In an outage situation, there may be significant production and revenue losses for industrial and commercial customers and dissatisfaction for residential consumers given their dependency on electrical energy. Therefore, all the power systems beginning from generation units to low voltage distribution networks should be planned to provide appropriate quality of service.

According to comparison of power systems between generation, transmission and distribution, distribution systems are the most complicated one. For this reason, distribution systems should be planned with taking into account the detailed location of future load demands and distributed generation additions.

In distribution system planning, some goals and criteria should be satisfied. These goals and criteria are defined as mostly technical ones. However, it should not be forgotten that, distribution systems are operated by private sector companies and these companies need to have profits and be economically sustainable. In addition, distribution companies need to comply with regulations ensuring the safety of workers, general public and assets. Due to these reasons, distribution planning solutions should satisfy not only the technical constraints but also economic, environmental and regulatory criteria among other. It means that decision makers for distribution planning should select investments according to multi criteria decision making process.

After determining the goals, criteria and constraints, the hardest part is selection of the most suitable planning solution. Even if the same criteria are used for evaluation, the results can be differed person to person or company to another one because of the importance of the criteria. In order to overcome this problem, multi criteria decision making techniques should be used. The aim of multi criteria decision making techniques is helping the planner or decision maker to think systematic, decide an investment with taking into account all criteria and their importance [1,2].

In this study, three different planning solutions will be compared by using multi criteria decision making technique (TOPSIS) for a sample distribution system.

2. Multi Criteria Decision Making Techniques

Multi criteria decision making techniques are developed since 1960 because of the requirement for decision makers. In case of uncertainties and multi criteria, decision makers may think insufficiently or unhealthy to cover the all variables or select just one of to end the decision process with doubts. The main goal of these techniques is keeping the decision process under control in case of having too many options and criteria and finishing it quick and easy as much as possible [3].

The most common used multi criteria decision making techniques are written below.

- Weighted Sum Method
- Weighted Product Method
- ELECTRE (For Elimination and Choice Translating Reality)
- AHP (Analytic Hierarchy Process)
- TOPSIS (For the Technique for Order Preference by Similarity to Ideal Solution) [3]

3. TOPSIS Technique

TOPSIS technique are developed by Hwang and Yoon in 1980 and used by Zeleny and Hall 1982 and 1989 respectively. The basis of TOPSIS technique is selection of the option which is the closest one to the positive ideal solution and the furthest one to the negative ideal solution. Ideal solution means that solution satisfies all criteria according to their positive or negative maximum possibilities. Thus, ideal solutions can be impossible or impracticable. Since, solution which is the closest one to ideal should be selected as the best for the case [3].

TOPSIS technique can be summarized step by step in Fig. 1.

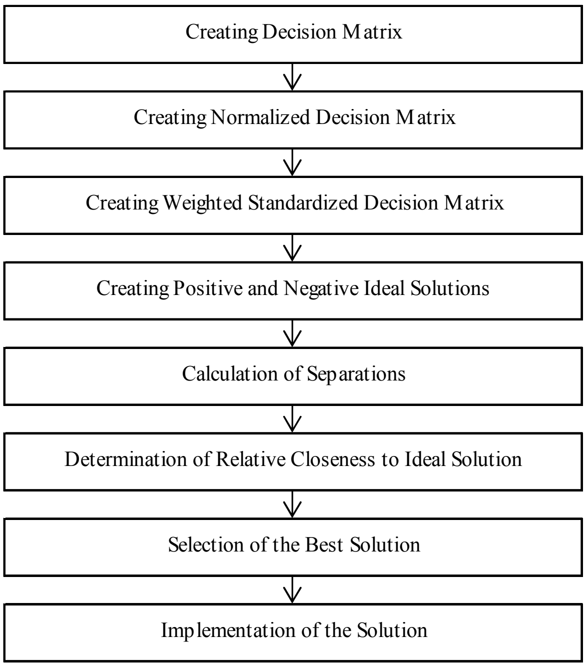

Fig. 1. Flowchart of TOPSIS technique

3.1. Creating Decision Matrix

The process starts with creating decision matrix. In decision matrix, options (solution alternatives) are placed in rows and criteria are placed in columns. A matrix is an initial matrix which is defined by the decision maker. In A matrix, m means number of options and n means number of criteria [3].

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \quad (1)$$

3.2. Creating Normalized Decision Matrix

Second step is normalization of A matrix by using the Equation 2. R matrix is the normalized decision matrix [3].

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{k=1}^{m} a_{kj}^2}} \quad (2)$$

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (3)$$

3.3. Creating Weighted Standardized Decision Matrix

Third step is creation of weighted standardized decision matrix. Each element in normalized decision matrix is multiplied by weight coefficient according to their importance to calculate V matrix. V matrix is the weighted standardized decision matrix. Summation of weight coefficients for the criteria should be 1 [3].

$$\sum_{i=1}^{n} w_i = 1 \quad (4)$$

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_n r_{mn} \end{bmatrix} \quad (5)$$

3.4. Creating Positive and Negative Ideal Solutions

TOPSIS technique assumes that each criterion tends toward a monotonically increasing or decreasing. In order to create positive ideal solution, maximum values of each column in V matrix are selected. In order to create negative ideal solution, minimum values of each column in V matrix are selected. This calculation can be summarized in Equation 6.

$$A^* = \{(\max_i v_{ij} \,|j \in J), (\min_i v_{ij} \,|j \in J')\} \quad (6)$$

In Equation 6, J and J' mean that benefit (maximization) and loss (minimization) respectively. Both positive and negative ideal solutions have m elements which equal the number of criteria [3].

3.5. Calculation of Separations

By using Euclidian approach, distances to positive and negative ideal solutions are calculated. These distances are defined as S_i^* for separation of positive, and S_i^- for separation of negative. S_i^* and S_i^- are calculated by using Equation 7 and Equation 8.

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \quad (7)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad (8)$$

3.6. Determination of Relative Closeness to Ideal Solution

In calculation of relative closeness to ideal solutions, separation indices are used. This index means the percentage of negative separation index in the summation of separation indices. It can be formulized in Equation 9.

$$C_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad (9)$$

C_i^* value should be between 0 and 1. For maximization decisions the options should be ranked largest to smallest. It should be vice versa for minimization decisions.

4. Distribution System Planning by using TOPSIS Technique on Sample Network

In this study, the sample distribution system is supplied by MV/MV substation and power transformer 31,5/15,8kV 10(12,5) MVA. There is no distributed generation unit connected to distribution system. In secondary side (15,8kV), there are 5 feeder outgoings. The sample system is shown in Fig. 2. Feeder 1, 2, 3, 4 and 5 are colored as blue, green, orange, purple and claret red. The system is operated radially. There are 142 MV/LV distribution transformers and 141km MV overhead lines and cables. The sample distribution system is modeled geographically and analyzed in PSS®Sincal v9.0 which is developed by Siemens AG.

4.1. Weak Point Analysis

Creating the solutions for distribution network begins with analyzing the system according to existing and forecasted future loads. The load demand of existing system is 10,11 MW. At the end of 5 year horizon, the forecasted load demand is 13,39 MW with 5,8% load growth per year.

According to existing load, there are some voltage drop issues which are greater than 7% in Feeder 1 and Feeder 2. On the other hand, there is no overloading issue in existing case.

According to forecasted load demand, the existing voltage drop problems still exist and some additional voltage drop problems can be seen in the system. In addition to voltage drop problems, there can be overloading problems in power transformer (MV/MV) and 5 distribution transformers (MV/LV). Voltage drop issues are shown for existing and future cases (in red circles) in Fig 3. (Green means no overloading or no voltage drop issues. Red means overloading or voltage drop issues in figures.)

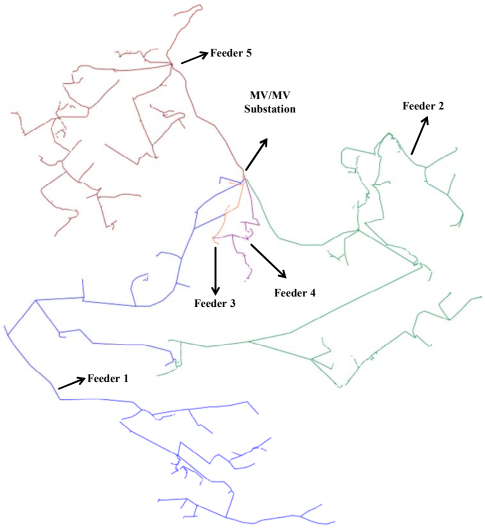

Fig. 2. Sample distribution network

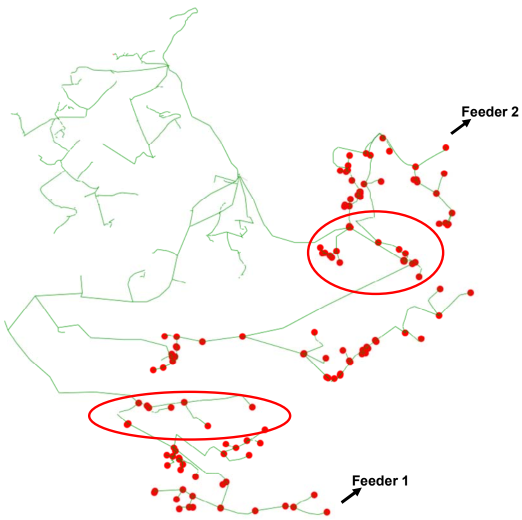

Fig. 3. Voltage drop issues in existing and future load demand

4.2. Planning Solutions

In order to solve these problems, three different planning solutions are proposed.

- Solution 1: Operating the system in existing voltage level (15,8kV) and reinforcing the system
- Solution 2: Converting voltage level up to 31,5kV
- Solution 3: Connecting new distributed generation units with usage of potential hydroelectric resources in the region

In solution 1, the voltage level of system is kept in 15,8kV. Thus, reinforcing the system is inevitable. Mainline conductor of Feeder 1 is upgraded from SW to 3/0 AWG. Insufficiency of one circuit 3/0 AWG as mainline conductor of Feeder 2 forces to build second circuit 3/0 AWG in the same route. In addition to these line investments, second power transformer (MV/MV), same rated with existing one, is placed in the MV/MV station and 5 distribution transformers (MV/LV) are upgraded with appropriate rated powers.

In solution 2, the voltage level of system is converted to 31,5kV. Since, the only investment necessary is the replacement of all distribution transformers (MV/LV) with the suitable rates and the decommissioning of power transformers (MV/MV). Overhead lines and cables have 36kV insulation level. They can be operated in 31,5kV network level as well.

In solution 3, according to potentials in the region 2 Hydro Electric Power Plants (HEPP) are connected to the system via Feeder 1 and Feeder 2, and the voltage level of system is kept in 15,8kV. In addition to connection of HEPPs, 5 distribution transformers (MV/LV) are upgraded with appropriate rated powers. There is no additional line investment.

4.3. Evaluation Criteria

These solutions are evaluated by using 8 different criteria. These criteria are written below:

- Initial investment cost [TL]
- Operation and maintenance costs [TL]
- Losses cost [TL]
- Maximum voltage drop [%]
- MV technical losses ratio [%]
- Reserve power capability [%]
- CO_2 emission [Tone]
- Power supply quality (n-1) [MW]

Initial investment costs are shown in Table 1 for each solution. In these calculations, the unit prices of transformers and lines are provided by Turkish Electricity Distribution Company (TEDAŞ). For HEPP investment calculation the unit prices are provided by International Renewable Energy Agency Renewable Energy Technologies: Cost Analysis Series Hydropower Report with safety factor [4]. Total investment costs are calculated annually by using weighted average cost of capital (WACC) according to Energy Market Regulatory Authority (EMRA) [5,6].

Table 1. Investment costs of each solution

Solution	Yearly Investment Cost [TL]
Solution 1	110.766
Solution 2	610.481
Solution 3	6.541.697

Operation and maintenance (O&M) costs except HEPP are assumed according to distribution system operators' experiences [7]. O&M costs of HEPP are assumed 4% of installation of power plant according to International Renewable Energy Agency Renewable Energy Technologies:Cost Analysis Series Hydropower Report [4]. O&M costs are summarized in Table 2.

Table 2. Operation and maintenance costs of each solution

Solution	Yearly Operation and Maintenance Cost [TL]
Solution 1	44.385
Solution 2	42.583
Solution 3	303.179

Losses costs are calculated by using network analysis results of transformers, overhead lines and cables power losses. Losses costs are summarized in Table 3.

Table 3. Losses costs of each solution

Solution	Yearly Losses Cost [TL]
Solution 1	511
Solution 2	255
Solution 3	653

Maximum voltage drop shows the node in the system which has the lowest voltage value. Maximum voltage drop values of each solution are shown in Table 4.

Table 4. Maximum voltage drop values of each solution

Solution	Maximum Voltage Drop [%]
Solution 1	6,995
Solution 2	2,572
Solution 3	6,205

MV technical losses ratio is the share of losses in the power flow. The technical losses ratios are summarized in Table 5.

Table 5. MV technical losses ratios of each solution

Solution	MV Technical Losses Ratio [%]
Solution 1	5,81%
Solution 2	2,97%
Solution 3	7,53%

Reserve power capability is the highest load growth ratio capability within the technical constraints. According to this explanation, the ratios for each solution are summarized in Table 6.

Table 6. Reserve power capability of each solution

Solution	Reserve Power Capability [%]
Solution 1	1,09
Solution 2	112,37
Solution 3	12,13

CO_2 emission is taken into account related to losses. Loss reduction in solutions means less CO_2 emission. CO_2 emissions for each solution are calculated by using the emission value per generation of MWh in Turkey according to International Energy Agency Report (2012) [8]. The CO_2 emission results are summarized in Table 7.

Table 7. CO_2 emissions of each solution

Solution	Yearly CO_2 Emission [Tone]
Solution 1	1424
Solution 2	712
Solution 3	1820

In this study, power supply quality means the maximum served load power if the supply is out of service as n-1 cases. According to this explanation, maximum load powers of each solution are summarized in Table 8.

Table 8. Power supply quality of each solution

Solution	Power Supply Quality [MW]
Solution 1	0,000
Solution 2	0,000
Solution 3	5,366

4.4. TOPSIS Process

In this study, three different weight coefficients are used to show their importance on decisions. The coefficients for each case are shown in Table 9.

Table 9. Weight coefficients of criteria for 3 cases

Criteria	Weight Coefficient for Cases		
	Case 1	Case 2	Case 3
Investment Cost [TL]	0,3	0,4	0,1
O&M Cost [TL]	0,1	0,05	0,1
Losses Cost [TL]	0,2	0,05	0,1
Maximum Voltage Drop [%]	0,1	0,1	0,1
MV Technical Losses Ratio [%]	0,1	0,05	0,1
Reserve Power Capability [%]	0,08	0,05	0,05
CO_2 Emission [Tone]	0,02	0,05	0,05
Power Supply Quality [MW]	0,1	0,25	0,4

All the results of solutions for each criterion are used by TOPSIS in three cases. The results for three cases are shown in Table 10.

Table 10. Closeness coefficient for 3 cases

Solution	C+		
	Case 1	Case 2	Case 3
Solution 1	0,329	0,398	0,757
Solution 2	0,246	0,404	0,719
Solution 3	0,767	0,615	0,282

According to the criteria and their goals, the best solution must have the lowest C+ value. That's why; C+ values for each solution and for each case should be sorted ascending. Preference order can be ranked as shown in Table 11. regarding to C+ values.

Table 11. Preference order for 3 cases

Solution	Preference Order		
	Case 1	**Case 2**	**Case 3**
Solution 1	2	1	3
Solution 2	1	2	2
Solution 3	3	3	1

5. Conclusions

In this study, distribution system planning with multiple criteria is evaluated. Multi-criteria decision techniques have ability to evaluate too many criteria at the same time and with the same point of view and to handle the problems like uncertainties. Maybe the hardest part of these techniques is defining the criteria and their importance. All criteria, goals and constraints must be defined by the decision makers carefully, and weighted coefficients for criteria should be determined according to strategy. In the sample case, preference order which is created by TOPSIS clearly shows that usage of different weight coefficients can affect decisions directly. For this reason, goals and criteria should be defined by a group which includes experienced people in different position level in distribution sector under control of regulatory authority. For future studies, multi-criteria decision making can be also used investment prioritization in distribution companies.

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