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Generation Expansion Planning Using Multi-Criteria Decision Making Method

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Abstract:
The Generation expansion planning (GEP) problem is a large scale, mixed integer and the most complicated optimization problem. To calculate for best combinations of conventional and non-conventional sources, GEP problem is considered for a test system to satisfy the constraints, EENS and LOLP. By computing the optimal point i.e., best compromise solution using multiple objectives for objective functions like minimization of best investment and best outage costs through MCDM methods. Various multi-criteria decision making (MCDM) methods have been proposed to solve diverse applications of decision problems. One of the MCDM methods is Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). However, by knowing about some MCDM methods decision making methodology based on Technique for Order of Preference by Similarity to Ideal Solutions (TOPSIS) is applied for finding the best compromise solution from the set of Pareto-optimal solutions through ranking.

Keywords: ***Generation expansion planning (GEP), Best compromise solution, TOPSIS, MCDM methods.***

1. Introduction:

Renewable energy (Wind, PV, etc.) is critically improving the security of energy supply by drawing upon sustainable natural sources and reducing environmental impacts. The wind power generation is holding the first rank in terms of use and importance .In the last decade, the growth rate of the global installed wind capacity has been about 30% per annum. However, wind resource is intermittent, stochastic and fluctuant, the large- scale integration of wind generation will bring new obstacles to the GENSCOs' planning. The traditional single-objective approach is no longer suitable for the expansion planning of utilities. So to solve this problem we are using generation expansion planning (GEP) problem which is a large scale, mixed integer and the most complicated optimization problem is finding the most economical generation mix, achieving certain reliability level to meet out the forecast demand which satisfying the constraints. The criteria are to minimize the total investment cost and outage cost under several operational constriants.GEP describes which generating unit to be constructed or when generating units should come on time over a planning period The main purpose of GEP has been to give the sufficient supply of electrical energy at least cost. The fore-most purposes of GEP are to minimize the sum of the investment cost and operating cost of generating units, and to meet the demand and the reliability standards . The optimization techniques are applied to the GEP problem. This GEP problem are largely effective for developing countries, where planning is coordinated by central and state government possessed utilities for capacity addition.

Decision making becomes an integral part in our daily lives and will be used for complex problems including problems with multiple conflicting criteria. Multi-criteria decision making (MCDM) is a well-known decision making process based on the progression of using methods and procedures of multiple conflicting

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criteria into the management planning process. In other words, MCDM refers to making decision in the presence of multiple, numerous and usually conflicting that involve numbers of criteria. MCDM provides a step by step procedure for which a consensus decision can be made by a group of decision makers. This well-defined procedure can reduce the amount of arguments or conflicts involved. MCDM plays an important role in solving complicated problems. The development of MCDM discipline is closely related to the advancement of computing technology. With this development, it is possible to conduct systematic analysis of complex MCDM problems. Furthermore, the extensive use of computing software has generated a huge amount of information, which makes MCDM increasingly important and useful in supporting decision making. There exist a number of methods in each of the mentioned approaches. This second category is built around methods which utilize various ways to assess the relative importance of multiple attributes and alternatives. Under this category, most the methods were concentrated on weight determination. It comprises simple additive weighting (SAW), analytic hierarchy process(AHP),weighted product method(WPM) and Technique for Order of Preference by Similarity to ideal solution(TOPSIS).In this TOPSIS is preferred for obtain the best results.

2.Integrated Approaches

Integrated approaches are defined in cases where more than one approach was used to solve various MCDM problems.

2.1 SAW

Simple Additive Weighting (SAW) is one of multi-criteria decision making technique consisting in assigning to each alternative a sum of values, each one associated to the corresponding evaluation criterion, and weighted according to the relative importance of the corresponding criterion. This method is also known as a weighted linear combination or scoring method. It is simple and the most often method used multi- attribute decision technique. The method is based on the weighted average using arithmetic mean. An evaluation score can be calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by the decision makers followed by summing of the products for all criteria.

The advantage of SAW method is that it is a proportional linear transformation of the raw data. It means that the relative order of magnitude of the standardized scores remains equal.

Procedure for SAW

$A=(a_1, a_2, a_3 \ldots a_n)$

Let $A=(a_1, a_2, a_3 \ldots a_n)$ be a set on alternatives.

$C=(c_1, c_2, c_3 \ldots c_n)$

Let $A=(a_1, a_2, a_3 \ldots a_n)$ be a set of criteria.

Step 1: Construct the decision matrix:

$$\begin{matrix} d_{11} & d_{12} & \cdots & d_{1n} \\ d_{21} & d_{22} & \cdots & d_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ d_{n1} & d_{n2} & \cdots & d_{nn} \end{matrix}$$

Where, d_{ij} is the rating of alternative Ai with respect to criterion Ci.

Step 2: Construct the normalized decision matrix.

For beneficial attribute (criteria of benefit): $r_{ij} = \frac{d_{ij}}{d_{ij}^{max}}$

For non beneficial attribute (criteria of cost): $r_{ij} = \frac{d_{ij}^{min}}{d_{ij}}$

Step 3: Construct weighted normalized decision matrix

$v_{ij} = w_{ij} * r_{ij,} \sum_{i=1}^{n} w_i=1$

Step 4: Calculate the score of each alternative.

$S_i \sum_{j=1}^{m} v_{ij,}$ i=1,2,3..,n

Step 5: Select the best alternative.

$BA_{SAW} = \max\sum_{i=1}^{n} S_i$

Where, BA saw is Best Alternative in Simple Additive Weighting (SAW) method and S_i is matrix score.

2.2 AHP

The Analytic Hierarchy Process (AHP) decomposes a complex MCDM problem into a system of hierarchies. The final step in the AHP deals with the structure of an m*n matrix (Where m is the number of alternatives and n is the number of criteria). The matrix is constructed by using the relative importance of the alternatives in terms of each criterion. Analytic Hierarchy Process (AHP) is an MCMD method based on priority theory. It deals with complex problems which involve the consideration of multiple criteria/alternatives simultaneously.

Procedure for AHP

- Establish priorities among the elements of the hierarchy by making a series of judgments based on pair wise comparisons of the elements. For example, when comparing potential purchases of commercial real estate, the investors might say they prefer location over price and price over timing.
- Synthesize these judgments to yield a set of overall priorities for the hierarchy. This would combine the investors' judgments about location, price and timing for properties A, B, C, and D into overall priorities for each property.
- Check the consistency of the judgments.
- Come to a final decision based on the results of this process.

2.3 WPM

Weighted Product method(WPM)is another scoring method where the weighted product of the criterion is used to select the best alternative. This method is similar to Simple Additive method. The main difference is that, instead of addition in the model, there is multiplication (Miller and Starr, 1969). The normalized values are calculated as explained under the SAW method. Each normalized value of an alternative with respect to an attribute , i. e (m)ij normal is raised to the power of the relative weight of corresponding attribute. The alternative with the highest Pi value is considered the best alternative. The WPM is the simplest available method, applicable for both single and multi-dimensional case. Due to the fact that it follows an intuitive process. In the background of this method, the additive utility Energies hypothesis is applied, which implies that the overall value of every alternative is equivalent to the sums of total product. In problems with the same units' ranges across criteria, WPM is easily applicable; however, when the units' ranges vary, for example when qualitative and quantitative attributes are employed, the problem becomes difficult to handle, as the aforementioned hypothesis is violated, and hence, normalization schemes should be employed.

Procedure for WPM:

The WPM uses multiplication to rank alternatives. Each alternative is compared with others by multiplying a number of ratios, one for each criterion. Each ratio is raised to the power of the relative weight of the corresponding criterion. Generally, in order to compare the two alternatives $A_k$and A_l, the following formula is used

$$R\left(\frac{A_k}{A_l}\right) = \prod_{j=1}^{n} \frac{a_{kj}}{a_{lj}}^{w_j}$$

If the above ratio is greater than or equal to one, then (in the maximization case) the conclusion is that alternative A_k is better than alternative A_l.Obviously, the best alternative is the one which is better than or at least as good as all other alternatives. Note that the WPM is very similar to the WSM. The WPM is sometimes called dimensionless analysis because its structure eliminates any units of measure. Thus, the WPM can be used in single- and multidimensional decision problems. Also, the relative values of the measure of the i-th alternative in terms of the j-th criterion can be replaced with actual values in this method.

2.4 TOPSIS

The general multi-objective minimization problem, is solved by using this MCDM method TOPSIS – (**T**echnique for **O**rder **P**reference by **S**imilarity to **I**deal

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Solution). In TOPSIS method we assume that the ratings of alternatives and weights are represented by numerical data and the problem is solved by a single decision maker. Complexity arises when there are more than one decision makers because the preferred solution must be agreed on by interest groups who usually have different goals. The classical TOPSIS algorithm for a single decision maker and for group decision making is systematically determined. When solutions based on the estimated Pareto-optimal set are found, it is required to choose one of them for implementation. Among many methods, TOPSIS is used extensively in different areas of research. This deterministic methodology on the selection of the most desirable support structure of an offshore wind turbine, among three design options, under the consideration of a combination of multiple qualitative and quantitative criteria.

Procedure for TOPSIS

The idea of TOPSIS procedure can be expressed in a series of following steps:

Step 1. Construct the decision matrix and determine the weight of criteria.

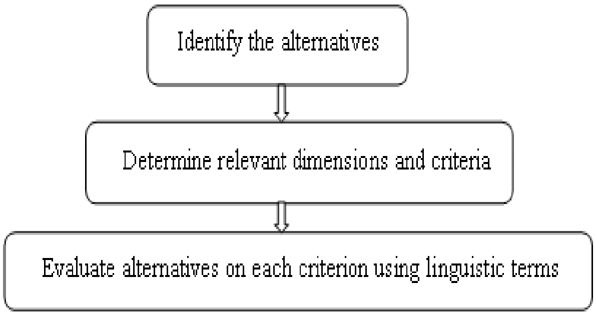
Let X $=(x_{ij})$ be a decision matrix and W = $[w_1, w_2 \ldots w_n]$ a weight vector, where $x_{ij} \in R$, $W_J \in R$ and $w_1 + w_2 + \cdots + w_n = 1$.

Criteria of the functions can be: benefit functions (more is better) or cost functions (less is better)

Step 2. Calculate the normalized decision matrix.

This step transforms various attribute dimensions into non-dimensional attributes which allows comparisons across criteria. Because various criteria are usually measured in various units, the scores in the evaluation matrix X have to be transformed to a normalized scale. The normalization of values can be carried out by one of the several known standardized formulas. Some of the most frequently used methods of calculating the normalized value r_{ij} are the following:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i=1,\ldots m,\ j=1..,n$$



Implementation of TOPSIS

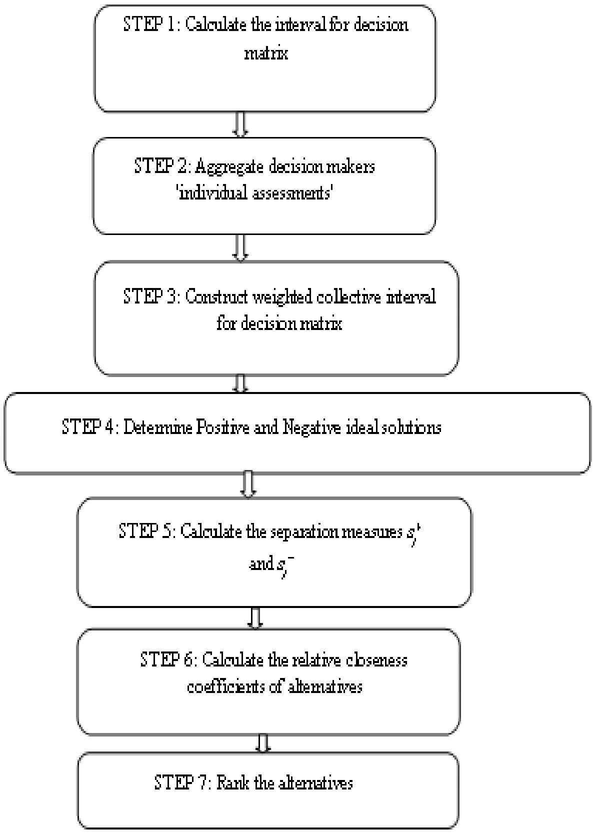


Figure Flow chart for TOPSIS Method

Step 3. Calculate the weighted normalized decision matrix.

Suppose, the MCDM problem has n alternatives $A_1, \ldots A_n$ and m decision attribute $C_1, .. C_m$ then each alternatives is evaluated with respect to m criteria attribute. The values which are obtained by the alternating with respect to the each criteria of decision making denoted by

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$D = (x_{ij})_{mxn}$ and D is calculated as,

$$D=\begin{bmatrix} x_{11}\cdot & \cdot & x_{1n} \\ & & \vdots \\ x_{m1}\cdot & \cdot & x_{mn} \end{bmatrix}$$

Step 4. Determine the positive ideal and negative ideal solutions.

Identify the positive ideal alternative (extreme performance on each criterion)and identify the negative ideal alternative (reverse extreme performance on each criterion). The ideal positive solution is the solution that maximizes the benefit criteria and minimizes the cost criteria whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria.

Positive ideal solution $A+$ has the form:

$$A^+ = \{V_1^+,...,V_m^+\} = \{(max_j \; v_{ij/i\in j}) \; cl(min_j v_{ij/i\in j})$$

Negative ideal solution $A-$ has the form:

$$A^- = \{V_1^-,...,V_m^-\} = \{(min_j \; v_{ij/i\in j}) \; (max_j v_{ij/i\in j})$$

where, i and j are associate with benefit cost criteria.

Step 5. Calculate the separation measures from the positive ideal solution and the negative ideal solution.

The separation of each alternative from the positive ideal solution is given as

$$s_j^+ = \sqrt{\sum_{i=1}^{m}(v_{ij} - v_1^+)^2} \quad j=1,..n$$

The separation of each alternative from the negative ideal solution is given as

$$s_j^- = \sqrt{\sum_{i=1}^{m}(v_{ij} - v_1^-)^2} \quad j=1,..$$

Step 6. Calculate the relative closeness to the ideal solution.

$$c_j = \frac{s_j^-}{s_j^+ + s_j^-} \quad j=1,...n$$

since, $s_j^- \geq 0$ and $s_j^+ \geq 0$ then, clearly $cj \in [0,1]$

Step 7. Rank the preference order or select the alternative closest to 1.

A set of alternatives now can be ranked by the descending order of the value of c_j

3. RESULTS

Table 3.1 TOPSIS result for GEP without Wind farm

Stages	Rank	Total capacity of Generating units to be added					Attributes			
							EENS	LOLP	Investment Cost	Outage Cost
Stage 1	**1**	1000	900	500	0	0	11.43	0.0035	11725000000	1598000
	5	1000	900	1000	0	0	11.78	0.0038	11930000000	1620000
	3	1000	450	500	0	0	10.59	0.0025	11830000000	1621000
	4	1000	1350	500	0	0	13.04	0.0042	11890000000	1636000
	2	1000	450	1500	0	0	13.25	0.0044	11810000000	1629000
Stage 2	**3**	600	0	500	0	0	9.059	0.0023	11984500000	1320100
	4	200	450	500	0	0	7.121	0.0021	11992320000	1330520
	1	200	0	1000	0	0	6.079	0.0020	11960000000	1310000
	2	400	900	0	0	0	10.44	0.0025	11964787000	1345600
	5	200	900	0	0	0	8.195	0.0022	12216000000	1610000
Stage 3	**3**	200	0	0	0	0	2.2035	0.0006	11298980000	1291000
	5	400	0	0	0	0	4.5451	0.0012	16100000000	1273000
	2	0	450	0	0	0	3.6432	0.0011	11296000000	1210000
	1	0	0	500	0	0	2.9877	0.0010	11290000000	1296000
	4	200	450	0	0	0	6.7814	0.0015	16021400000	701400

Table 3.2 TOPSIS result for GEP with Wind farm

Stages	Rank	Total capacity of Generating units to be added					Attributes			
							EENS	LOLP	Investment Cost	Outage Cost
Stage 1	**2**	1000	900	500	2000	200	204.7	0.032	$1.196x10^{10}$	$1.511x10^{6}$
	5	800	1350	1500	0	600	140.9	0.028	$1.220x10^{10}$	$1.650x10^{6}$
	4	1000	1350	1000	1000	200	201.2	0.030	$1.216x10^{10}$	$1.612x10^{6}$
	3	600	1350	1500	0	800	148.2	0.029	$1.214x10^{10}$	$1.614x10^{6}$
	1	600	900	1300	1000	600	204.9	0.031	$1.193x10^{10}$	$1.525x10^{6}$
Stage 2	**3**	200	900	1000	0	400	209.5	0.041	$1.201 x10^{10}$	$1.552x10^{6}$
	5	800	0	1500	0	200	215.6	0.038	$1.221 x10^{10}$	$1.609x10^{6}$
	1	600	0	1500	0	400	210.8	0.044	$1.194 x10^{10}$	$1.524x10^{6}$
	2	600	0	2000	0	200	212.4	0.046	$1.199 x10^{10}$	$1.537x10^{6}$
	4	600	450	1000	0	400	208.2	0.040	$1.206 x10^{10}$	$1.604x10^{6}$
Stage 3	**2**	200	0	500	0	200	250.2	0.058	$1.075x10^{10}$	$1.596x10^{6}$
	4	600	0	0	0	600	212.7	0.047	$1.599 x10^{10}$	$1.632x10^{6}$
	3	600	0	500	0	200	225.7	0.050	$1.569 x10^{10}$	$1.624x10^{6}$
	1	400	0	500	0	400	230.1	0.051	$1.059 x10^{10}$	$1.690x10^{6}$
	5	200	0	500	0	600	235.9	0.052	$1.609 x10^{10}$	$7.012x10^{5}$

In the above table 3.1, table 3.2 the ranking is obtained by the TOPSIS method for the GEP values obtained from MODE. In TOPSIS method the ranking is evaluated for the attributes and total capacity combinations of generating plants like Oil, LNG (gas), Coal Nuclear (PWR) and Nuclear (PWHR). EENS,

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LOLP, investment cost and outage cost considered as the attributes in TOPSIS method.

In paper "Generation expansion planning using multi-objective differential evolution " describes that the Best Investment Cost and Best outage Cost in every combination are compared with minimum and maximum vice versa. MODE gives minimum investment cost at maximum outage cost and maximum investment cost at minimum outage cost. We describe the optimal solution of Investment cost and outage cost evaluated by MODE algorithm in each best combination without and with wind farms in table 3.3 and table 3.4 respectively. Table 3.5describes the details of best investment cost and best outage cost along with EENS and LOLP

Table 3.3 Best Investment costs and Best Outage costs without Wind farm in each combination.

1st Best combination	Min Investment cost Max Outage cost	$1.195x10^{10}$ $1.526x10^{6}$
	Max Investment cost Min Outage cost	$1.221x10^{10}$ $1.66x10^{6}$
2nd Best combination	Min Investment cost Max Outage cost	$1.196x10^{10}$ $1.310x10^{6}$
	Max Investment cost Min Outage cost	$1.2216x10^{10}$ 1.610×10^{6}
3rd Best combination	Min Investment cost Max Outage cost	$1.129x10^{10}$ 1.21×10^{6}
	Max Investment cost Min Outage cost	$1.61x10^{10}$ $7.014x10^{5}$

Table 3.4 Best Investment costs and Best Outage costs with Wind farm in each combination.

1st Best combination	Min Investment cost Max Outage cost	$1.193x10^{10}$ $1.525x10^{6}$
	Max Investment cost Min Outage cost	$1.22x10^{10}$ $1.65x10^{6}$
2nd Best combination	Min Investment cost Max Outage cost	$1.194x10^{10}$ $1.524x10^{6}$
	Max Investment cost Min Outage cost	$1.221x10^{10}$ $1.609x10^{6}$
3rd Best combination	Min Investment cost Max Outage cost	$1.059x10^{10}$ $1.69x10^{6}$
	Max Investment cost Min Outage cost	$1.609x10^{10}$ $7.012x10^{5}$

Table 3.5 Best Costs with EENS and LOLP Values with and without Wind Farm

	Best investment cost	Best outage cost	EENS	LOLP
Without wind farm	$1.195 x10^{10}$	$1.66 x10^{6}$	11.781	0.0038
	$1.196 x10^{10}$	$1.610 x10^{6}$	13.504	0.0047
	$1.129 x10^{10}$	$7.014 x10^{5}$	10.591	0.0027
With wind farm	$1.193 x10^{10}$	$1.65x10^{6}$	206.3	0.032
	$1.194 x10^{10}$	$1.609x10^{6}$	120.00	0.022
	$1.059 x10^{10}$	$7.012x10^{5}$	101.02	0.011

5. Conclusion

In this paper, we observe that by applying the Multi criteria decision making techniques to the generation expansion planning problem . Also, the program was supported to perform the clustering and extract the best compromise solutions for the objective functions of minimization best investment cost and minimization best outage cost. By applying TOPSIS ranking is given and Compare the results obtained for six-years planning prospects of best cost of generation expansion planning problem to the modified.

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