Decision Making in Distribution System using different MADM Methods

S. G. Kamble
Dr. Babasaheb Ambedkar Technological University, Lonere, Maharashtra, India

U. V. Patil
Government College of Engineering, Karad, Maharashtra, India

K. Vadirajacharya
Dr. Babasaheb Ambedkar Technological University, Lonere, Maharashtra, India

ABSTRACT
Distribution system (DS) delivers electrical power to the end users and is the first interface of the utility with the consumers. Distribution system contributes the highest power loss due to its operation in low voltage level. Due to deregulation and competition, distribution utilities are under pressure to minimize operation cost by reducing losses and to improve reliability to enhance the overall performance. The distribution system is reconfigured for the purpose of loss minimization, load balancing on the feeders, relieving overloads, maintenance etc., it also affects voltage profile, reliability, power factor, etc. In each configuration (switching combinations), these parameters are affected (changed) and these alternatives are available for the decision makers (DM). Multi-attribute decision-making (MADM) is the well-known branch of decision making which deals with decision problems through a number of qualitative and quantitative criteria. In this paper different MADM methods SAW, WPM, TOPSIS and PROMETHEE are proposed for finding the compromised best radial configuration by considering loss minimization, reliability indices etc. from available alternatives and results are compared.

General Terms
MADM methods, Reconfiguration of Distribution system.

Keywords
Distribution system Reconfiguration, Loss minimization, Multi-attribute decision making, SAW, WPM, TOPSIS, PROMETHEE.

1. INTRODUCTION

1.1 Motivation
Power system consists of three main components generation, transmission and distribution system. The distribution system consists of the distribution lines and substations. Distribution system has losses in the range of 5-13% and is considered the weakest link in the power system. Due to improper and insufficient investments in the distribution system and increasing demand power losses and failure rate have increased. After many decades of negligence, distribution system is getting greater focus now-a-days. Utilities are under pressure to improve reliability and supply quality power to consumers due to deregulated, competitive environment[1]. Therefore, utilities must have accurate information about system performance to reduce operating and maintenance cost and to meet customer expectations. An improved distribution infrastructure and innovative practices can reduce losses and improve reliability [2].

In India consumers are becoming more demanding with respect to service standards. Consumer will have more options while choosing their power supplier due to open access, private participation and parallel licensee. Competition in distribution utilities will force them to look at innovative solutions for customer retention. Implementation of standards of performance (SOP) and making utilities pay for deficient service standards will be a reality. Therefore, considering all these parameters the distribution system managers will have to operate the DS in most efficient manner and improve their working by maintaining the standards of performance (SOP). Researchers have used reconfiguration, optimal capacitor placement and DG placement approach to improve overall network performance.

1.2 Reconfiguration of Distribution system
Nowadays, the electricity demand is increasing day by day and hence it is very important not only to use renewable energy sources but also to reduce the power losses existing distribution system. For the better planning of distribution system, topology is required to change. System reconfiguration means rearranging the distribution lines which connect various buses (loads) in a power system. Network reconfiguration in distribution systems is performed by opening sectionalizing (normally closed) and closing tie (normally open) switches of the network. These switching are performed in such a way that the radiality of the network is maintained and all the loads are energized without violating system operational constraints. By changing status of switches, the power flow to loads will be changed and consequently affects the power loss, voltages, harmonic distortion level, as well as the system reliability. Hence in normal operation condition performance of distribution system can be improved by selecting the correct status of switches. Past work [3]-[13] has proposed various approaches to network reconfiguration. Finding the optimal feeder configuration with different criteria and constraints is a complex mixed-integer nonlinear optimization problem.

1.3 Multi attribute decision making (MADM) methods
Multiple criterion decision making (MCDM) methods are used for making decisions in multiple criteria problems. The MCDM methods are further classified into: Multiple objective decision making (MODM) methods and Multiple attribute decision making (MADM) methods.

MODM methods are used when objectives are many, and we have to choose the best while satisfying the constraints and preference priorities. MADM methods can be applied to limited number of predetermined alternatives. MADM is an approach used to solve problems with limited number of alternatives. In recent decades, for complex decisions in terms of the consideration of multiple factors, researchers have been focused on Multi Attribute Decision Making (MADM) techniques [14]-[16].

In MADM, several alternatives (options) according to some attributes (criteria) are ranked and selected. Ranking and selecting will be made among decision alternatives described by some criteria (factors) through decision-maker knowledge and experience.

Each decision table or decision matrix in MADM methods have alternatives, attributes, weight or relative importance of each attribute, and measures of performance of alternatives. The decision table is shown in Table 1. The decision table shows alternatives, Ai (for i = 1, 2, ….. , N), attributes, Bj (for j = 1, 2, ….. , M), weights of attributes, wj (for j=1, 2, ….., M) and the measures of performance of alternatives, mij (for i= 1, 2, ….., N; j=1, 2, ….., M).

The job of the decision maker is to obtain the best alternative from the given alternatives in the form of decision table or matrix. All the elements in the decision table or matrix must be normalized to bring all the attributes on the common platform.

Table 1. Decision table or Matrix in MADM methods

	Attributes					
Alternatives	B1 (w1)	B2 (w2)	B3 (w3)	- (-)	- (-)	BM (wM)
A1	m11	m12	m13	-	-	m1M
A2	m21	m22	m23	-	-	m2M
A3	m31	m32	m33	-	-	m3M
-	-	-	-	-	-	-
-	-	-	-	-	-	-
AN	mN1	mN2	mN3	-	-	mNM

2. MADM METHODS

2.1 Simple Additive Weighting (SAW) Method

This is also called the weighted sum method (WSM) developed by Fishburn, and is the simplest, and still the widely used MADM method [14]. In this method, each attribute is given a weight, and the sum of all weights must be 1. Each alternative is assessed with regard to every attribute. The performance index of an alternative is calculated by using equation 1.

$$\mathrm{Pi} = \sum_{j=1}^{M} \mathrm{wj}\ (\mathrm{mij})\mathrm{normal} \qquad (1)$$

2.2 Weighted Product Method (WPM)

This method is similar to SAW [14]. The only difference is that, instead of addition there is multiplication and developed by Miller and Starr. The performance index is given by equation 2.

$$\mathrm{Pi} = \prod_{j=1}^{M} [(\mathrm{mij})\mathrm{normal}]^{\mathrm{wj}} \qquad (2)$$

2.3 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method

The TOPSIS method was developed by Hwang and Yoon. This method is based on the concept that the chosen alternative should have the shortest Euclidean distance from the ideal solution, and the farthest from the negative ideal solution [15]. Hence, TOPSIS gives a solution that is not only closest to the hypothetically best, that is also the farthest from the hypothetically worst.

The procedure for TOPSIS method [2] for the selection of the best alternative from available is described below:

Step1: Identify and short-list the alternatives on the basis of the identified criteria.

Step2: Prepare a decision table or decision matrix.

Step3: Obtain normalized decision matrix, Rij, by using the following expression.

$$\mathrm{Rij} = \mathrm{mij}/\sqrt{\textstyle\sum_{j=1}^{M} \mathrm{m}^2\mathrm{ij}} \qquad (3)$$

Step 4: Decide the relative importance i.e. weights of the different attributes wj (note that ∑wj=1). The weights of the attributes are generally assigned by the decision maker based on his/her preference.

Step 5: Obtain the weighted normalized matrix Vij by the multiplication of each element of the column of the matrix Rij with its corresponding weights wj. The weighted normalized matrix Vij can be prepared by using following equation.

$$\mathrm{Vij} = \mathrm{wj}\ \mathrm{Rij} \qquad (4)$$

Step 6: Obtain the ideal (best) and negative ideal (worst) solutions. The ideal (best) and negative ideal (worst) solutions can be expressed as:

$$\mathrm{V+} = \left\{ \sum_{i}^{\max} \left(\frac{\mathrm{Vij}}{\mathrm{j} \in \mathrm{J}}\right), \sum_{i}^{\min} \left(\frac{\mathrm{Vij}}{\mathrm{j} \in \mathrm{J'}}\right) / \text{ for } = 1,2,.\mathrm{N} \right\} \qquad (5)$$

$$\mathrm{V+} = \{\mathrm{V1+}, \mathrm{V2+}, \mathrm{V3+}, \ldots\ldots, \mathrm{VM+}\} \qquad (6)$$

$$\mathrm{V-} = \left\{ \sum_{i}^{\min} \left(\frac{\mathrm{Vij}}{\mathrm{j} \in \mathrm{J}}\right), \sum_{i}^{\max} \left(\frac{\mathrm{Vij}}{\mathrm{j} \in \mathrm{J'}}\right) / \mathrm{f} = 1,2,\ldots,\mathrm{N} \right\} \qquad (7)$$

$$\mathrm{V-} = \{\mathrm{V1-}, \mathrm{V2-}, \mathrm{V3-}, \ldots\ldots, \mathrm{VM-}\} \qquad (8)$$

Where,

J = (j = 1, 2, …, M)/j is associated with beneficial attributes andJ' = (j = 1, 2, …, M)/j is associated with non-beneficial attributes.

• Vj + indicates the ideal (best) value of the attribute. In case of beneficial attributes (i.e. whose higher values are desirable for the given application), Vj + indicates the higher value of the attribute. In case of non-beneficial attributes (i.e. whose lower values are desired for the given application), Vj + indicates the lower value of the attribute.

•Vj - indicates the negative ideal (worst) value of the attribute among the values of the attribute for different alternatives. In the case of beneficialattributes (i.e., those of which higher values are desirable for the givenapplication), Vj- indicates the lower value of the attribute. In the case of non-beneficialattributes (i.e., those of which lower values are desired for the givenapplication), Vj- indicates the higher value of theattribute.

Step 7: Obtain the separation measures. The separation of each alternative from the ideal one is given by Euclidean distance by the following equations.

$$Si+= \sqrt{\sum_{j=1}^{M}(Vij - Vj+)2}, \quad i = 1,2,...., \quad N \qquad (9)$$

$$Si-= \sqrt{\sum_{j=1}^{M}(Vij - Vj-)2}, \, i = 1,2,...., N \qquad (10)$$

Step 8: The relative closeness of a alternative to the ideal solution, Pi, can be expressed in this step as follows.

$$Pi = S- / (S- + S+) \qquad (11)$$

Step 9: A set of alternatives is made in the descending order according to the value of performance index Pi indicating the most preferred and least preferred feasible solutions.

2.4 Preference Ranking Organization Method for Enrichment Evaluations(PROMETHEE)

The PROMETHEE method was introduced by Brans et al. and belongs to the category of outranking methods. PROMETHEE [15], [16] proceeds to a pairwise comparison of alternatives in each single criterion in order to determine partial binary relations denoting the strength of preference of an alternative a1 over alternative a2.

The steps for PROMETHEE are as follows:

Step1: Identify and short-list the alternatives on the basis of the identified criteria.

Step2: Prepare a decision table or decision matrix.

Step3: Get the information on the decision maker preference function. The preference function (Pi) translates the difference between the evaluations obtained by two alternatives (a1 and a2) in terms of a particular attribute, into range from 0 to 1. Let Pi, a1a2 be the preference function associated to the attribute bj.

$$Pi, a1a2 = Gi[ci(a1) - ci(a2)] \qquad (12)$$

$$0 \leq Pi, a1a2 \leq 1 \qquad (13)$$

If the decision maker specifies a preference function Pi and weight wi for each attribute 'bj' of the problem, then the multiple attribute preference index Ga1a2 can be calculated as the weighted average of the preference functions Pi.

$$\prod a1a2 = \sum_{i=1}^{M} wiPi, a1a2 \qquad (14)$$

Step 4: Calculate the leaving flow φ+(a).

$$\varphi^{+}(a) = \sum_{x \varepsilon A} \prod xa \qquad (15)$$

Step 5: Calculate the entering flow φ-(a).

$$\varphi^{-}(a) = \sum_{x \varepsilon A} \prod ax \qquad (16)$$

Step 6: Calculate the net flow φ (a).

$$\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a)(17)$$

Step 7: Decide the ranking based on the scores of net flow.

The PROMETHEE method provides a ranking of the alternatives from the best to the worst one using the net flows.

3. CASE STUDY

The application of the different MADM [17]-[21] methods is proposed to a distribution system test network [19] based on an existing distribution network in an electricity distribution company is considered.

The test network includes seven load centers, representing the accumulated load of the 11 kV distribution network at each connection point, as well as 17 existing transformers and a number of existing underground cables and overhead lines. In our case study, five different alternatives are to be evaluated by decision makers. Attributes short listed for thiscase study are:

- gl = Annual energy losses (MWh);
- g2 = System security: number of customers interrupted per 100 connected customers;
- g3 = Supply availability: average customer minutes lost per connected customer;
- g4 = Capacity constraints: load unsupplied (MWh);
- g5 = Environmental impact: the total circuit length of new or modified network circuits (km);
- g6 = Capital cost (£‟000).

All these attributes are required to be minimized.

Table 2. Distribution system data

Solution	g1	g2	g3	g4	g5	g6
a1	17420.24	6.64	150.12	23.4	0.27	2580
a2	17470.41	6.37	134	23.4	1.04	2053
a3	17401.69	6.34	128.47	110.18	1.19	2040
a4	17496.41	6.07	112.24	110.18	1.95	1513
a5	17410.24	6.58	150	23.4	0.27	2930

Table 3. Normalized data for Distribution system

Solution	g1	g2	g3	g4	g5	g6
1	0.9989	0.9142	0.7477	1.0000	1.0000	0.5864
2	0.9961	0.9529	0.8376	1.0000	0.2596	0.7370
3	1.0000	0.9574	0.8737	0.2124	0.2269	0.7417
4	0.9946	1.0000	1.0000	0.2124	0.1385	1.0000
5	0.9995	0.9225	0.7483	1.0000	1.0000	0.5164

3.1 Application of SAW AND WP Method

Table 4. Results for SAW and WP Method

Solution	SAW Method		WP Method	
	Scores	Ranking	Scores	Ranking
1	0.8458	1	0.8265	1
2	0.7916	3	0.7315	3
3	0.5972	5	0.4910	5
4	0.6736	4	0.5045	4
5	0.8297	2	0.8018	2

3.2 Application of TOPSIS method

Table 5. Normalized data for TOPSIS

Solution	g1	g2	g3	g4	g5	g6
1	0.4467	0.4638	0.4947	0.1453	0.1063	0.5069
2	0.4480	0.4449	0.4416	0.1453	0.4096	0.4033
3	0.4462	0.4428	0.4233	0.6843	0.4687	0.4008
4	0.4487	0.4239	0.3699	0.6843	0.7680	0.2973
5	0.4465	0.4596	0.4943	0.1453	0.1063	0.5757

Table 6. Weighted Normalized matrix

Solution	g1	g2	g3	g4	g5	g6
1	0.0223	0.0696	0.0742	0.0363	0.0160	0.1267
2	0.0224	0.0667	0.0662	0.0363	0.0614	0.1008
3	0.0223	0.0664	0.0635	0.1711	0.0703	0.1002
4	0.0224	0.0636	0.0555	0.1711	0.1152	0.0743
5	0.0223	0.0689	0.0741	0.0363	0.0160	0.1439

Table 7. Best and Worst Values

Solution	BEST V+	WORST V-
1	0.0223	0.0224
2	0.0636	0.0696
3	0.0555	0.0742
4	0.0363	0.1711
5	0.0160	0.1152

Table 8. Separable measures

S +	S -
0.0560	0.1682
0.0538	0.1516
0.1478	0.0637
0.1674	0.0723
0.0723	0.1674

Table 9. Result of TOPSIS method

Solution	Pi	Ranking
1	0.7504	1
2	0.7379	2
3	0.3010	5
4	0.3017	4
5	0.6985	3

3.3 Application of PROMETHEE method

Table 10. Preference values w.r.to criterion annual energy losses

C1	A1	A2	A3	A4	A5
A1	-	1	0	1	0
A2	0	-	0	1	0
A3	1	1	-	1	1
A4	0	0	0	-	0
A5	1	1	0	1	-

Table 11. Preference values w.r.to criterion no. of customers interrupted per 100 connected customers

C2	A1	A2	A3	A4	A5
A1	-	0	0	0	0
A2	1	-	0	0	1
A3	1	1	-	0	1
A4	1	1	1	-	1
A5	1	0	0	0	-

Table 12. Preference values w.r.to criterion supply availability

C3	A1	A2	A3	A4	A5
A1	-	0	0	0	0
A2	1	-	0	0	1
A3	1	1	-	0	1
A4	1	1	1	-	1
A5	1	0	0	0	-

Table 13. Preference values w.r.to criterion capacity constraint

C4	A1	A2	A3	A4	A5
A1	-	0	1	1	0
A2	0	-	1	1	0
A3	0	0	-	0	0
A4	0	0	0	-	0
A5	0	0	1	1	-

Table 14. Preference values w.r.to criterion circuit length

C5	A1	A2	A3	A4	A5
A1	-	1	1	1	0
A2	0	-	1	1	0
A3	0	0	-	1	0
A4	0	0	0	-	0
A5	0	1	1	1	-

Table 15. Preference values w.r.to criterion capital cost

C6	A1	A2	A3	A4	A5
A1	-	0	0	0	1
A2	1	-	0	0	1
A3	1	1	-	0	1
A4	1	1	1	-	1
A5	0	0	0	0	-

Table 16. Performance matrix

Solution	A1	A2	A3	A4	A5
A1	-	0.2	0.4	0.45	0.25
A2	0.55	-	0.4	0.45	0.55
A3	0.6	0.6	-	0.2	0.6
A4	0.55	0.55	0.55	-	0.55
A5	0.35	0.2	0.4	0.45	-

Table 17. Dominance matrix and Ranking

Solution	**(φ+)**	**(φ-)**	**Net Dominance**	**Ranking**
A1	1.30	2.05	-0.75	5
A2	1.95	1.55	0.40	2
A3	2.00	1.75	0.25	3
A4	2.20	1.55	0.65	1
A5	1.40	1.95	-0.55	4

Table 18. Comparison of different MADM methods

Solution	**SAW**	**WPM**	**TOPSIS**	**PROMETHE**
1	1	1	1	5
2	3	3	2	2
3	5	5	5	3
4	4	4	4	1
5	2	2	3	4

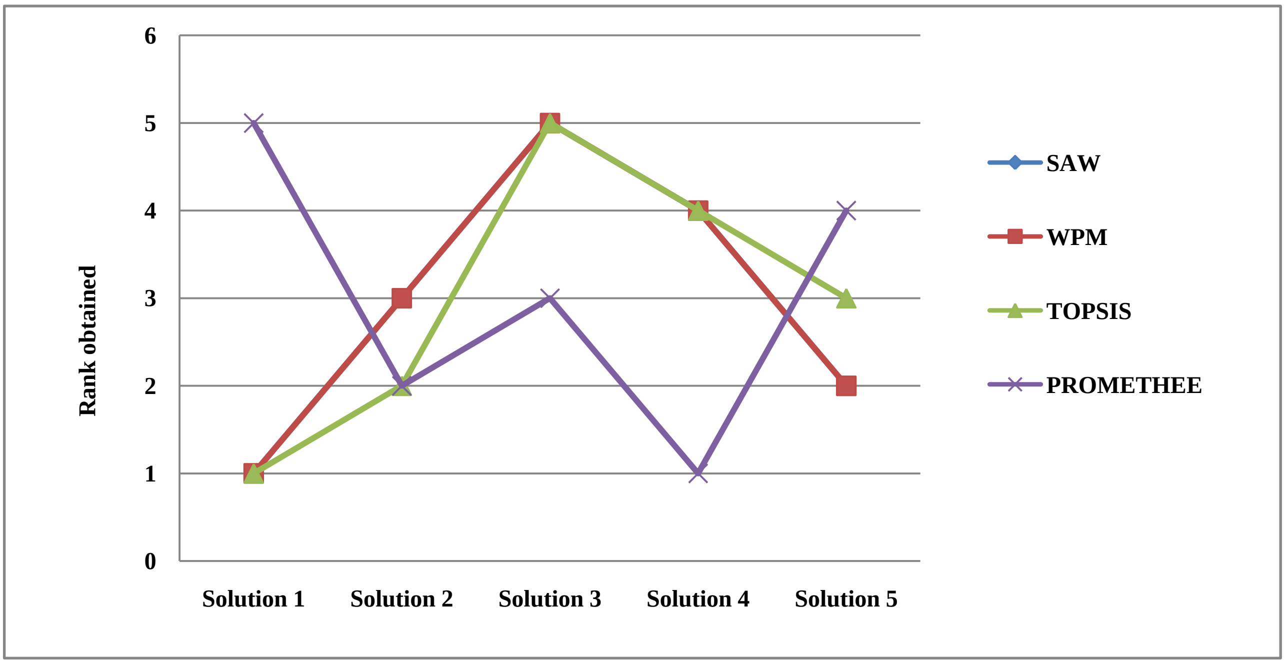

Fig 1. **Graphical representation of comparison of different MADM methods**

4. CONCLUSION

In this paper, SAW, WPM, TOPSIS, and PROMETHEE methods are used in distribution system for decision making. The attributes and weights decided were, Annual energy losses (0.05), System security (0.15), Supply availability (0.15), Capacity constraints (0.25) and Circuit length (0.15), Capital cost (0.25). The results obtained by all the MADM methods are compared and solution number 1 has obtained rank 1 in SAW, WPM, and TOPSIS method and solution number 4 has obtained rank 1 rank by PROMETHEE.

The purpose of this paper is to find the compromised best configuration for the considered distribution system by using different MADM methods. The PROMETHEE method considers values of the criteria and their relative importance together. In the TOPSIS method, the alternatives are ranked based ontheir closeness to the best virtual value. The MADM methods are systematic, logical and convenient to implement and can be used for any practical decision-making problem.

5. REFERENCES

[1] S. Wong, K. Bhattacharya and J.D. Fuller, Electric power distribution system design and planning in a deregulated environment, *IET- Generation, Transmission & Distribution*, 3(12) (2009) 1061-1078.

[2] IEEE Guide for Electric Power Distribution Reliability Indices, IEEE Std. 1366-2003, May 2004.

[3] Merlin and H. Back, "Search for a minimal-loss operating spanningtree configuration in urban power distribution systems," in *Proc. 5th Power Syst. Comp. Conf.*, Cambridge, U.K., Sep. 1–5, 1975.

[4] M. E. Baran and F. F. Wu, "Network reconfiguration in distribution systems for loss reduction and load balancing," *IEEE Trans. Power Del.*, vol. 4, no. 2, pp. 1492–1498, Apr. 1989.

[5] D. Shirmohammadi and H. W. Hong, "Reconfiguration of electricdistribution networks for resistive line losses reduction," *IEEE Trans. Power Syst.*, vol. 4, no. 2, pp. 1492–1498, Apr. 1989.

[6] S. K. Goswami and S. K. Basu, "A new algorithm for the reconfigurationof distribution feeders for loss minimization," *IEEE Trans. PowerDel.*, vol. 7, no. 3, pp. 1484–1491, Jul. 1992.

[7] K. Nara, A. Shiose, M. Kitagawa, and T. Ishihara, "Implementation ofgenetic algorithm for distribution systems loss minimum re-configuration," *IEEE Trans. Power Syst.*, vol. 7, no. 3, pp. 1044–1051, Aug. 1992.

[8] T. E. McDermott, I. Drezga, and R. P. Broadwater, "A heuristic nonlinear constructive method for distribution system reconfiguration," *IEEE Trans. Power Syst.*, vol. 14,no. 2, pp. 478–483, May 1999.

[9] C. T. Su and C. S. Lee, "Network reconfiguration of distribution systems using improved mixed-integer hybrid differential evolution," *IEEE Trans Power Del.*, vol. 18, no. 3, pp. 1022–1027, Jul. 2003.

[10] E. López, H. Opazo, L. García, and P. Bastard, "Online reconfigurationconsidering variability demand:Applications to real networks," *IEEETrans. Power Syst.*, vol. 19, no. 1, pp. 549–554, Feb. 2004.

[11] R. Srinivasa Rao, S. V. L. Narasimham, M. Ramalinga Raju, and A. Srinivasa Rao, "Optimal network reconfiguration of large-scale distribution system using harmony search algorithm," *IEEE Trans. Power Syst.*, vol. 26, no. 3, pp. 1080–1088, Aug. 2011.

[12] B. Amanulla, S. Chakrabarti, and S. N. Singh, "Reconfiguration of power distribution systems considering reliability and power loss," *IEEE Trans. Power Del.*, vol. 27, no. 2, pp. 918–926, Apr. 2012.

[13] A. Kavousi-Fard and T. Niknam, "Optimal distribution feeder reconfiguration for reliability improvement considering uncertainty," *IEEE Trans. Power Del.*, vol. 29, no. 3, pp. 1344–1353, Jun. 2014.

[14] E. Triantaphyllou, B. Shu, S. Nieto Sanchez, and T. Ray, “Multi-Criteria Decision Making: An OperationsResearch Approach”*Encyclopedia of Electrical and Electronics Engineering*,(J.G.Webster, Ed.), John Wiley & Sons, New York, NY, Vol. 15, pp. 175- 186, (1998).

[15] R.Venkata Rao, *Decision Making in the Manufacturing Environment*, Springer-Verlag London Limited, 2007, pp. 27-41.

[16] R. Venkata Rao, B. K. Patel, “Decision making in the manufacturing environment using an improved PROMETHEE method” International Journal of Production Research, pp. 1-18, 2009, iFirst

[17] P. Espie, G.W. Ault, G.M. Burt and J.R. McDonald, Multiple criteria decision making techniques applied to electricity distribution system planning, *IEE Proceedings-Generation, Transmission and Distribution*, 150(5)(2003) 527-535.

[18] Tiefeng ZHANG, Guangquan ZHANG, Jun MA, Jie LU, "Power Distribution System Planning Evaluation by a Fuzzy Multi-Criteria Group Decision Support System", International Journal of Computational Intelligence Systems, Vol.3, No. 4 (October, 2010), 474-485

[19] Tiefeng Zhang, Jie Lu, Guangquan Zhang, Jianwei Gu “A Novel Evaluation Approach for Power Distribution System Planning based on Linear Programming Model and ELECTRE III”, 2014 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE), pp. 1921 - 1928

[20] Nikolaos G. Paterakis, Andrea Mazza, Sergio F. Santos, Ozan Erdinç, Gianfranco Chicco, AnastasiosG.Bakirtzis, and João P. S. Catalão, " Multi-Objective Reconfiguration of Radial Distribution Systems using Reliability Indices," *IEEE Trans. On Power Systems*, vol. 31, pp. 1048-1062, March 2016.

[21] S.G.Kamble and U.V.Patil, “Performance improvement of distribution systems by using PROMETHEE – Multiple Attribute Decision Making method", International Conference on Communication and Signal Processing (ICCASP-2016) at Dr. Babsaheb Ambedkar Technological University, Lonere-Raigad.