Power Distribution Planning Using Multi-Criteria Decision Making Method

Sandeep Chakravorty , Smarajit Ghosh

Abstract— **Conductor layout plays a vital role in distribution planning. This paper presents an improved mathematical model to optimize the network routing problem. The model was formulated to minimize the feeder routes subject to a set of constraints. The computational results of a devised sample problem indicate that the developed optimization model is adequate for planning of distribution systems.**
Here in this paper we suggest the distribution planning by the means of a hybrid model which includes Taguchi and Analytical Hierarchy Process (AHP) and Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) where we take into consideration some aspects of reliability such as miles of conductor, feeder failures, customer interruption, maximum interruption, estimated relative cost. The method suggested here firstly determines the priority of these aspects of reliability and then it determines the weight of these factors and ultimately distribution planning has been carried out by Technique of Order Preference by Similarity to Ideal Solution (TOPSIS). The results of the discussed techniques will lead to lower long range distribution expenses as it will lead to optimum feeder path.

Index Terms— **Power distribution planning, Taguchi technique, AHP technique, TOPSIS, optimization methods**.

I. INTRODUCTION

Decision making features occurs in all the fields of the human activities such as scientific and technological and affects every sphere of the life. Engineering design, which entails sizing, dimensioning, and detailed element planning is also not exempt from its influence.

Normally, any engineering problem will have large number of solutions out of which some of are feasible and some are infeasible. The designer's task is to get the best solution out of the feasible solutions.

The available literature consists of work of only few researchers on the field of distribution planning. Most of them are based on mathematical programming such as transportation, transshipment algorithms [8, 9], mixed integer programming [10], dynamic programming [11] etc. Unfortunately only near optimal solutions have been obtained by these mathematical programming methods because almost every method has made some approximations on the model of distribution planning, moreover these methods are often complicated and time consuming.

In the work done by K.K.Li and T.S. Chung [3] genetic

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algorithm have been used to find the optimum location of substation to meet the load demands of 13 load points whose coordinates and MVA demands are given.

Similar work has been carried out by Belgin Turkay and Taylan Artac [1], work has also been carried out by J.F.Gomez *et.al.*, [2].

In all the above cases planning of laying the feeders or distribution planning has been done either by man machine interface or heuristic algorithm. The papers further don't take into consideration aspects of reliability which are very much essential in power distribution factors such as line down, transformer out of service, interruption, estimated relative cost etc. In the work done S. Chakravorty *et.al.*,[36] distribution planning by means of Analytical Hierarchy Process have been done where some aspects of reliability such as miles of conductor, feeder failures, customer interruption, maximum interruption, estimated relative cost have been taken care of but the priority of these factors have been decided in random. No technique has been used to determine the priority of importance of these factors. In this paper a model has been proposed where a systematic solution process has been used to determine the priority of these factors then an Analytical Hierarchy Process has been applied for finding the weight of these factors and ultimately distribution planning has been carried out by Technique of Order Preference by Similarity to Ideal Solution. Thus we can claim the suggested method to be more robust and more close to practical than the one suggested by S. Chakravorty *et.al.*,[36].

A complete survey of the proposed techniques for the solution of the planning problem of primary distribution circuits can be found in [15] and [16]. Initially the proposed methods were mainly based upon the generation and evaluation of possible solutions, oriented to small size problems, and requiring important efforts for the production of the alternatives to be evaluated. Among these the heuristic zone valuation and the generation of service areas methods may be mentioned. They rely completely upon the experience of the planning engineer and have the disadvantage that the best alternative may not be considered.

The planning problem of primary distribution networks has been basically stated as a classical mixed integer linear programming problem, where an objective function that includes both the investment and the operation cost of the network, is minimized subject to technical constraints related with the characteristics of the electric service [17]. This formulation includes binary variables linked to the fixed costs associated to some of the decision variables as well as linear approximations to represent the variable costs.

Stated as such the classical branch and bound techniques [17] have a natural application. Although the continuous

research and improvement of these techniques keeps them as an alternative always to be considered, the linear approximations as well as the combinatorial complexity of the problem question their application to electric systems of real dimensions due to the requirements of excessive computing resources. This is the main reason for the application of alternative approaches, such as those classified as metaheuristic methods that are able to locate good solutions with reduced computational effort.

In order to reduce the computation requirements of the branch and bound optimization technique, the identification of the set of variables that affects most of the results was proposed in order to reduce the complexity of the mathematical model [16] however a linear approximation of the variable costs is required and excessive solution times are reported as the number of binary variables increases. Heuristic search methods have been developed [17], [18], showing faster performance than the conventional optimization techniques but with some limitations in the goodness of the solutions to the problem that are obtained.

In [20] an open loop planning procedure is proposed where an expert system based upon the use of geographical information is applied to automate the selection of the primary and secondary circuit routes. GA's have also been applied to the solution of this problem, reducing the solution time and enhancing the obtained results [15],[18],[21],[22],[23]. In [22] a solution methodology based upon a GA is proposed for the design of primary distribution circuits considering multiple system expansion stages, where a special coding procedure is proposed to reduce the number of unfeasible solutions evaluated by the algorithm. These methodologies have been improved significantly. An evolutionary programming algorithm is presented in [25], considering the uncertainties of the possible scenarios. In [16] and [24] the potential of the GA's is shown in comparison with classical optimization techniques to solve the planning problem in a very complete and detailed formulation considering the nonlinearity of the cost function, the limits of the voltage magnitudes and a term in the objective function to take into account the reliability of the system, reporting significant improvements in the solution times. An integer variable coding scheme was used to facilitate the consideration of different conductor sizes and substation sizes also new genetic operators were proposed to improve the performance of the algorithm. In [26] the approach is expanded to consider the multiple development stages as well as multiple objectives. In [31] an evolutionary approach is applied to the design of a medium voltage network using a detailed model of the network. All the suggest methods fail to take into consideration aspects of reliability. This new methodology suggests a distribution planning technique taking into consideration aspects of reliability according to the priority of them.

II. PROPOSED METHODOLOGY APPLIED TO A CASE STUDY

Let us have the problem discussed by S. Chakravorty *et.al.*,[36] where a thirteen load points are to be fed from two substations depending on the capacity and the load demands. The layout of feeders for feeding the thirteen load points depends on the following factors:

a). Miles of conductor.
b). Feeder failures/year.
c). Customer interruption/year.
d). Maximum interruption/customer.
e). Estimated relative cost.

Substation location has been obtained by the use of genetic algorithm stated in [33].

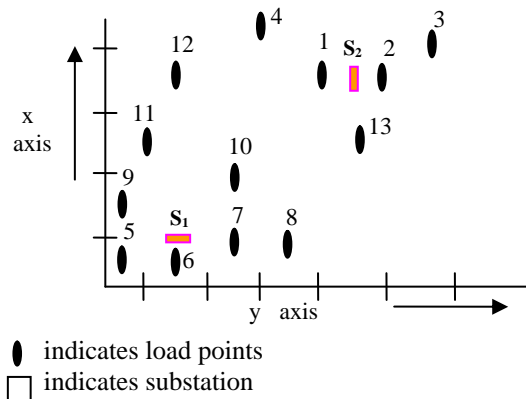The pictorial representation of the problem is as shown in fig 1.

Figure 1 (Representation of the problem)

Results of genetic algorithm allots load points (7 10 8 6 11 9 12 5) to substation 1 and load points (13 1 4 2 3) to substation 2 and gives the optimum location of substation 1 as (3 2) and that of substation 2 as (9 7). Now for determining the conductor layout we apply the *Multi-Criteria Decision Making methods.*

Analytical Hierarchy Process is a multi-criteria decision making process that allows working with both numerical factors and those that are un-tangible and subjective. It provides a structured way to determine the weighting factors for each criterion and applies the weights to the comparison of alternatives. AHP uses pair wise comparisons of design concepts to convert a statement ("this is vary important", "this is not so important") into a numerical value.

To determine the conductor layout following factors have been considered:

a). Miles of conductor.
b). Feeder failures/year.
c). Customer interruption/year.
d). Maximum interruption/customer.
e). Estimated relative cost.

In deciding how much more strongly does this criterion influence the outcome than the other criterion a nine point scale has been used (1 indicates equal importance; 3 indicates moderate importance; 5 indicates strong importance; 7 indicates very strong importance; 9 indicates extreme importance). However the priority of these factors or which of these factors are more important over others have not been considered in the work of [36]. Here before applying AHP we go for Taguchi to decide how strongly one factors influence the others. Here a three level design has been followed with 27 combinations.

	Level 1	Level 2	Level 3
Miles of conductor	5	10	20

Feeder failures/yr	0	1	2
Customer interruption/year	100	200	300
Maximum interruption/customer	10	50	100
Estimated relative cost	20	50	100

Table: 1 (Three level input taken for Taguchi analysis)

A	B	C	D	E	Yield
1	1	1	1	1	135
1	1	1	1	2	165
1	1	1	1	3	215
1	2	2	2	1	276
1	2	2	2	2	306
1	2	2	2	3	356
1	3	3	3	1	427
1	3	3	3	2	457
1	3	3	3	3	507
2	1	2	3	1	330
2	1	2	3	2	360
2	1	2	3	3	410
2	2	3	1	1	341
2	2	3	1	2	371
2	2	3	1	3	421
2	3	1	2	1	182
2	3	1	2	2	212
2	3	1	2	3	262
3	1	3	2	1	390
3	1	3	2	2	420
3	1	3	2	3	470
3	2	1	3	1	241
3	2	1	3	2	271
3	2	1	3	3	321
3	3	2	1	1	252
3	3	2	1	2	282
3	3	2	1	3	332

Table: 2 (Result obtained after applying Taguchi three level design)

A = Miles of conductor
B = Feeder failures/yr.
C = Customer interruption/year
D = Maximum interruption/customer
E = Estimated relative cost
Yield = Output

Result of Taguchi analysis is as shown:

Smaller is better

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Level  A         B         C         D         E
1     -49.2304  -49.4539  -46.6810  -48.3988  -48.6389
2     -49.8194  -50.0577  -50.0855  -49.7093  -49.6036
3     -50.1793  -49.7174  -52.4626  -51.1210  -50.9867
Delta   0.9489    0.6038    5.7816    2.7222    2.3478
Rank    4         5         1         2         3
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Response Table for Means

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Level  A      B        C        D        E
1      316    321.667  222.667  279.333  286
2      321    322.667  322.667  319.333  316
3      331    323.667  422.667  369.333  366
Delta  15     2.000    200.000  90.000   80
Rank   4      5        1        2        3
```

After doing the Taguchi analysis and getting the rank we get the factors according to priority basis as:
1. Customer interruption/year
2. Maximum interruption/customer
3. Estimated relative cost
4. Miles of conductor
5. Feeder failures/yr

Now applying AHP on the basis of the priority obtained by Taguchi analysis we have:

Applying AHP:
Determining weighing factors:

	Miles of conductor	Feeder failures /yr	Customer interruption/year	Maximum interruption/customer	Estimated relative cost
Miles of conductor	1	3	1/7	1/5	1/3
Feeder failures /yr	1/3	1	1/9	1/7	1/5
Customer interruption/year	7	9	1	3	5
Maximum interruption/customer	5	7	1/3	1	3
Estimated relative cost	3	5	1/5	1/3	1

Normalization matrix for criteria:

	Miles of conductor	Feeder failures/yr	Customer interruption/year	Maximum interruption/cust	Estimated relative cost

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Miles of conductor	0.06	0.12	0.08	0.04	0.03
Feeder failures/yr	0.02	0.04	0.06	0.03	0.02
Customer interruption/year	0.43	0.36	0.56	0.64	0.52
Maximum interruption/customer	0.31	0.28	0.19	0.21	0.31
Estimated relative cost	0.18	0.2	0.11	0.07	0.10

Priority vector for criteria:

Miles of conductor = (0.06 + 0.12 + 0.08 + 0.04 + 0.03)/5=0.066

Feeder failures/yr. = (0.02 + 0.04 + 0.06 + 0.03 + 0.02)/5=0.034

Customer interruption/yr. = (0.43 + 0.36 + 0.56 + 0.64 + 0.52)/5=0.502

Maximum interruption/customer = (0.31 + 0.28 + 0.19 + 0.21 + 0.31)/5=0.26

Estimated relative cost = (0.18 + 0.2 + 0.11 + 0.07 + 0.10)/5=0.132

After we have obtained the priority of the factors and their respective weights we proceed for distribution planning using the Technique of Order Preference by Similarity to Ideal Solution (TOPSIS). In this method two artificial alternatives are hypothesized:

  Ø Ideal alternative: the one which has the best level for all attributes considered.
  Ø Negative ideal alternative: the one which has the worst attribute values.

TOPSIS selects the alternative that is the closest to the ideal solution and farthest from negative ideal alternative.

In the problem stated above let us first proceed to find the conductor layout from substation2. First to determine as to where to connect node 1 we proceed by constructing the normalized decision matrix.

Normalized decision matrix

	miles of conductor	estimated cost	feeder failure	customer interruption	maximum interruption
S2	5	5	3	3	3

2	7	7	4	4	3
3	13	13	10	10	6
4	6	6	3	3	4
13	8	8	4	4	5

Weighted normalized decision matrix

	miles of conductor	estimated cost	feeder failure	customer interruption	maximum interruption
S2	0.017818325	0.03563665	0.0083282	0.122964385	0.080026311
2	0.024945655	0.04989131	0.0111043	0.163952513	0.080026311
3	0.046327645	0.09265529	0.0277608	0.409881284	0.160052623
4	0.02138199	0.04276398	0.0083282	0.122964385	0.106701749
13	0.02850932	0.05701864	0.0111043	0.163952513	0.133377186

The above matrix is formed by considering the Priority vector for various criteria that were obtained as their weights.

The set of ideal solution A*

0.017818325	0.03563665	0.008328265	0.12296438 5	0.080026311

The set of negative ideal solution A'

0.046327645	0.09265529 1	0.027760884	0.409881284	0.160052623

Separation from ideal alternatives S_i*

0	0.044065037	0.305232781	0.027840214	0.071453034

Separation from negative ideal alternative S_i'

0.305232781	0.263530943	0	0.297752712	0.25111241

Relative closeness to ideal solution C_i*

	C_i*
S2	1
2	0.856744
3	0
4	0.914494
13	0.778485

Thus node 1 gets connected to substation 2

Second to determine as to where to connect node 2 we proceed by constructing the normalized decision matrix.

Normalized decision matrix

	miles of conductor	estimated cost	feeder failure	customer interruption	maximum interruption
S2	5	5	3	3	3

1	7	7	4	4	3
3	5	5	3	3	4
4	16	16	12	12	8
13	7	7	4	4	5

Weighted normalized decision matrix

	miles of conductor	estimated cost	feeder failure	customer interruption	maximum interruption
S2	0.01641811 4	0.032 836227	0.007 32317 3	0.108 12449 9	0.070 33023 2
1	0.022 98535 9	0.045 97071 8	0.009 76423 1	0.144 16599 8	0.070 33023 2
3	0.016 41811 4	0.032 836227	0.007 32317 3	0.108 12449 9	0.093 77364 2
4	0.052 53796 4	0.105 07592 7	0.029 29269 3	0.432 49799 5	0.187 54728 4
13	0.022 98535 9	0.045 97071 8	0.009 76423 1	0.144 16599 8	0.117 21705 3

The above matrix is formed by considering the Priority vector for various criteria that were obtained as their weights.

The set of ideal solution A*

0.016418 114	0.032836 227	0.007323 173	0.108124 499	0.070330 232

The set of negative ideal solution A'

0.052537 964	0.105075 927	0.029292 693	0.432497 995	0.187547 284

Separation from ideal alternatives S_i*

	0.038994 769	0.023443 411	0.354913 905	0.060983 326
0				

Separation from negative ideal alternative S_i'

0.354913 905	0.318784 129	0.347875 752	0	0.304679 872

Relative closeness to ideal solution C_i*

	C_i*
S2	1
1	0.891009
3	0.936865
4	0
13	0.833225

Thus node 2 gets connected to substation 2

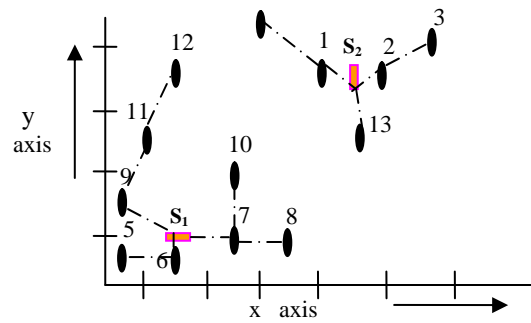Proceeding in the manner stated above we get the conductor layout as shown in fig 2.

Figure 2 (Showing the final conductor layout from the substations)

III. CONCLUSION

Experts rating on various factors such as

i). Miles of conductor.

ii). Feeder failures/year.

iii). Customer interruption/year.

iv). Maximum interruption/customer.

v). Estimated relative cost.

are to be considered before deciding the conductor layout in distribution planning system. Conventional techniques for suggestion of conductor layout do not take into consideration such factors and decisions of experts. In conductor layout using Analytical Hierarchy Process reliability aspects have been taken care of but the priority of these factors have been decided in random. No technique has been used to determine the priority of importance of these factors. In this paper a model has been proposed where a systematic solution process has been used to determine the priority of these factors then an Analytical Hierarchy Process has been applied for finding the weight of these factors and ultimately distribution planning has been carried out by Technique of Order Preference by Similarity to Ideal Solution. Thus we can claim the suggested method to be more robust and closer to practical than the existing ones.

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