Load Distribution and Feeder Routing Using Fuzzy Clustering and Context Aware Decision Algorithm

SHABBIRUDDIN[1], SANDEEP CHAKRAVORTY[2]

[1]Department of Electrical & Electronics Engg. Sikkim Manipal Institute of Technology. Sikkim. India.

Email: shabbiruddin85@yahoo.com

[2]Associate Prof. Lovely Professional University.Punjab. India.

Email: sandeep_chakravorty@yahoo.com

Abstract: *Choosing an optimum location of a distribution sub-station and grouping the various load points to be fed from a particular distribution sub-station has always been a concern to the distribution planners. A lot of work has been carried out in this regards but all have made either the use of man machine interface or have made some approximations. Here this paper presents a Fuzzy c-means clustering method applied to various loads which are at different location to form a cluster so that a sub-station could be placed for each cluster for the distribution of power. Context Aware Decision Algorithm based on the Analytical Hierarchy process(AHP) is then applied on each cluster comprising of load points to be fed and an optimum feeder layout is obtained depending on some reliability factors. The feeder layout thus obtained will lead to optimum feeder path and will hence lower long range distribution expenses.*

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Key words: *Clustering, FCM, Context Awareness, Decision Algorithm, Analytical Hierarchy Process.*

1.Introduction:

In general, the decisions in the planning of power distribution system include:

- Optimal location of sub-stations
- Optimal allocation of load
- Optimal allocation of sub-station capacity

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 [4, 5], mixed integer programming [6], dynamic programming [7] 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 algorithm have been used to find the optimum location of sub-station 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.

Here in this paper we suggest the location of the sub-station and the various load points to be fed by the sub-station by means of fuzzy c-means clustering technique. No man machine interface is required for determining the clustering of loads to be fed by a sub-station as indicated in the previous works.

A complete survey of the proposed techniques for the solution of the planning problem of primary distribution circuits can be found in [8] and [9]. 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.

Heuristic search methods have been developed [10], [11], 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 [9] and [12] 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 sub-station sizes also new genetic operators were proposed to improve the performance of the algorithm.

Clustering involves the task of dividing data points into homogeneous classes or clusters so that items in the same class are as similar as possible and items in different classes are as dissimilar as possible. Clustering can also be thought of as a form of data compression, where a large number of samples are converted into a small number of representative prototypes or clusters.

In this study Fuzzy clustering method is used to divide various load points into clusters which depends on the number of sub-station required to feed the given load points. A sub-station is placed for each of the classes obtained from the clustering in the centre of the cluster obtained which shall be the optimum location for the sub-station as the point will be closest to the load points grouped in a cluster. Fuzzy Clustering Method (FCM) is a data clustering technique wherein each data point belongs to a cluster to some degree that is specified by a membership grade. It provides a method that shows how to group data points that populate some multidimensional space into a specific number of different clusters.

After getting a suitable location of the sub-station, Context Aware Decision Algorithm in association with Analytical Hierarchy Process (AHP) is applied taking various factors (cost, miles of conductor etc.) into consideration to come out with a suitable feeder layout such as single, two and three feeder layout.

Thus the method is useful in placement of sub-station for a group of load points without knowing the MVA value of the load points. This method is advantageous over Genetic Algorithm and other methods because by the use of fuzzy each load points share a membership value ,so in case the load demand increases for a particular sub-station the load point could be shifted to other sub-station depending on the membership values.

2. Problem Definition:

Let us have the problem discussed by S. Chakravorty *et.al.*,[15] where a thirteen load points are to be fed from two sub-stations depending on the capacity and the load demands. The thirteen load points with their respected MVA values and coordinates are represented in table 1 and fig. 1. The thirteen load points considered are now clustered using Fuzzy C-Means Clustering, such that the load points are divided into two clusters giving a sub-station location for each cluster. After getting the location of sub-station**,** now there is a need to connect sub-station to the load points considering five factors : Miles of conductor, Feeder losses, Estimated relative cost, Maximum interruption, Customer interruption/year. The Context Aware Decision algorithm is applied to get a suitable connection between sub-station and the load points in single feeder, two feeder and three feeder mode such that all the five factors mentioned are minimum.

Table 1: The coordinates of the various load points with their respective load demands in MVA

Load points	**X coordinate**	**Y coordinate**	**Load demands in MVA**
1	8	7	5
2	10	7	12
3	11	8	7
4	6	9	5
5	1	1	7
6	3	1	11
7	5	2	8
8	7	2	3
9	1	3	4
10	5	4	12
11	2	5	6
12	3	7	3
13	9	5	4

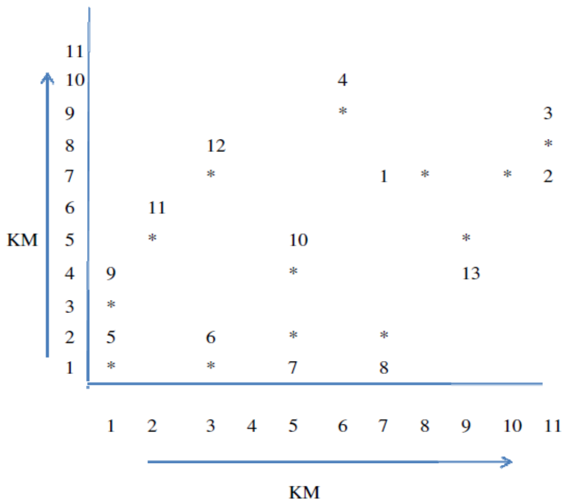

Fig 1 : Pictorial representation of the problem

3. Proposed Methodology

3.1Architecture of Fuzzy c-Means Clustering

Fuzzy c-means (FCM) is a data clustering technique wherein each data point belongs to a cluster to some degree that is specified by a membership grade. This technique was originally introduced by Jim Bezdek in 1981 as an improvement on earlier clustering methods. It provides a method that shows how to group data points that populate some multidimensional space into a specific number of different clusters.

The FCM algorithm attempts to partition a finite collection of elements $X=\{x_1, x_2, \ldots, x_n\}$ into a collection of c fuzzy clusters with respect to some given criterion. Given a finite set of data, the algorithm returns a list of c cluster centers V, such that $V = V_i$, i =1, 2, ... , c and a partition matrix U such that $U = U_{ij}$ i =1, ..., c, j =1,..., n ,where U_{ij} a numerical value in [0, 1] that tells the degree to which the element X_j belongs to the i-th cluster. The following is a linguistic description of the FCM algorithm, which is implemented in Fuzzy Logic.

Step 1: Select the number of clusters c ($2 \leq c \leq n$), exponential weight μ ($1 < \mu < \infty$), initial partition matrix U^0, and the termination criterion €. Also, set the iteration index l to 0.

Step 2: Calculate the fuzzy cluster centers $\{V_i^1 \mid i=1, 2, ..., c\}$ by using U^1.

Step 3: Calculate the new partition matrix U^{1+1} by using $\{ V_i^1 \mid i=1, 2, ..., c\}$.

Step 4: Calculate the new partition matrix $\Delta = \| U^{1+1} - U^1 \| = \max_{ij} | U_{ij}^{1+1} - U_{ij}^{1} |$. If $\Delta >$ €, then set l = l + 1 and go to step 2. If $\Delta \leq$ €, then stop.

3.2Architecture of the Decision Algorithm

The task of context-aware decision algorithm is to select the most suitable interface (connection) for a given application among multiple options that would satisfy some primary objectives based on the values of some context parameters. In this regard, the AHP model which is a well-known and proven mathematical process to identify the most suitable choice among multiple alternatives based on some predefined objectives, perfectly fits into our decision making process.

In accordance with the AHP method, at first, we have to define some *primary objectives* for our decision algorithm taking into account the preferences likely to be the most interesting to users (e.g. cost, miles of conductor etc). Here we have chosen the following five primary objectives:

- Miles of conductor.
- Feeder losses.
- Estimated relative cost.
- Maximum interruption.
- Customer interruption/year.

Stage 1: Taking User Inputs

User preferences are taken as *discrete* values or *scores*. However, in order to make the model more user-friendly available options, in each case, are labeled with suitable *literals*. The user only needs to arrange the literals in a descending order starting with the one with the highest priority. Based on the arrangement of the literals priority scores between 1 and 9 are assigned automatically at the backend, where 1 denotes the most preferred one and 9 denotes the least preferred one. Priority scores are equal-spaced integers whose space-gap is defined by eq (1), where *Np* denotes the number of parameters, *Lu* and L_l denote the highest and lowest possible scores i.e. 9 and 1, respectively, and *G* denotes the numeric space-gap between two subsequent scores, which is rounded off to the nearest integer.

$$G = \frac{L_u - L_l}{N_p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Here *Lu (upper limit)* = 9, L_l *(lower limit)* = 1, and *Np* equals to the number of interfaces on which the modeling depends.

Stage 2: Assigning Scores to Networks

Assignment of scores to the available networks based on discrete preferences like interface priority and cost constraint is straightforward. The same interface priority score, already defined by the user in stage 1, is assigned to the available network depending on its type. In case of cost objective, all the available networks are compared with each other and assigned with appropriate equal-spaced scores between 1 and 9 based on (1) in a descending order, where the cheapest network has a score of 1. If a particular network does not advertise the cost information it is assigned with a score of 9 (costliest network) as a default value.

$$S_i = \left(1 - \frac{n_i - l_i}{u_i - l_i}\right) \times 10 : l_i \langle n_i \langle u_i$$
$$= 1 : n_i \geq u_i \quad \ldots\ldots\ldots\ldots \quad (2)$$
$$= 9 : n_i \leq l_i$$

If u_i and l_i denote the upper and lower limits of a particular continuous preference (that is in general all the available networks are compared with each other and assigned with appropriate equal-spaced scores between 1 and 9) and n_i denotes the value offered by a network for that particular parameter the network score, S_i, based on the preference is calculated using (2). Eq. (2) is used for continuous preferences like mean throughput, where the target value is preferred to be as high as possible. If there is any missing parameter i.e. not advertised by a particular network its default value is used. Values of l_i and u_i are the default values for (2).

Stage 3: Calculating Network Ranking

At this stage, *ranking* of the available networks are performed based on the objective priority scores (the scores assigned to the five factors considered using equation1 depending on the preferences) and network scores (Data given in appendix is used and each data is assigned with a value between 1 to 9 for example data between 1to2 is assigned a value 9 , data between 3 to4 as 8 and so on thus score is found out using equation 2) assigned at stage 1 and 2, respectively. The calculations use the AHP method, which is a three step process.

Step 1: At first, the relative scores among the objective priority scores set by the user at stage 1 are calculated. Relative scores are scaled linearly between 1 and 9. Relative scores between any two particular scores are calculated using (3), (4), and (5), where RS_{ab} is the relative score between parameters *a* and *b*, and S_a and S_b are their respective scores.

$$\frac{1}{RS_{ab}} = \left(1 - \frac{S_b}{S_a}\right) \times 10 : S_a \rangle S_b \quad \ldots\ldots\ldots \quad (3)$$

$$RS_{ab} = \left(1 - \frac{S_a}{S_b}\right) \times 10 : S_a \langle S_b \quad \ldots\ldots\ldots. \quad (4)$$

$$RS_{ab} = 1 : S_a = S_b \quad \ldots\ldots\ldots \quad (5)$$

With the calculated relative scores the priorities (i.e. weights) for the six objectives in terms of the overall goal i.e. selecting a suitable network are calculated using *pair wise comparison matrix* for objectives. It consists of the relative scores calculated in the previous step. The dimension of the pair wise comparison matrix *A* for the objectives, as shown in (6), is flexible and dependent on the number of chosen objectives. Matrix *A* is then normalized by dividing each element by individual sum of column. The normalized matrix *A norm* is shown in (7). At the end, the average values of each row for objective *i* are calculated to give the priorities for each objective (*p1*, *p2*, *p3*, *p4*, *p5*, *p6*) with respect to the overall goal using (8).

$$A = \begin{bmatrix} 1 & RS_{12} & RS_{13} & RS_{14} & RS_{15} & RS_{16} \\ \frac{1}{RS_{12}} & 1 & RS_{23} & RS_{24} & RS_{25} & RS_{26} \\ \frac{1}{RS_{13}} & \frac{1}{RS_{23}} & 1 & RS_{34} & RS_{35} & RS_{36} \\ \frac{1}{RS_{14}} & \frac{1}{RS_{24}} & \frac{1}{RS_{34}} & 1 & RS_{45} & RS_{46} \\ \frac{1}{RS_{15}} & \frac{1}{RS_{25}} & \frac{1}{RS_{35}} & \frac{1}{RS_{45}} & 1 & RS_{56} \\ \frac{1}{RS_{16}} & \frac{1}{RS_{26}} & \frac{1}{RS_{36}} & \frac{1}{RS_{46}} & \frac{1}{RS_{56}} & 1 \end{bmatrix} \ldots.. (6)$$

$$A_{norm} = \begin{bmatrix} b_{11} & b_{12} & b_{13} & b_{14} & b_{15} & b_{16} \\ b_{21} & b_{22} & b_{23} & b_{24} & b_{25} & b_{26} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} & b_{36} \\ b_{41} & b_{42} & b_{43} & b_{44} & b_{45} & b_{46} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} & b_{56} \\ b_{61} & b_{62} & b_{63} & b_{64} & b_{65} & b_{66} \end{bmatrix} \quad \ldots\ldots\ldots \quad (7)$$

$$P_1 = \frac{b_{i1} + b_{i2} + b_{i3} + b_{i4} + b_{i5} + b_{i6}}{6} \quad \text{where i = 1 to 6 ..(8)}$$

Step 2: The relative scores among the scores of the available networks assigned at stage 3 in terms of individual objective are calculated using (3), (4), and (5). Then the network conformances (i.e. weights), C_{ij}, for *i* number of available networks in terms of each of *j* number objectives are calculated in similar fashion as described in step 1.

Step 3: The overall ranking of each available network is determined by calculating the sum of products of network conformances in terms of individual objective (obtained from step 2) and objective priorities for that particular objective (obtained from step 1). For *i* number of available networks and *j* number of objectives, the overall ranking R_i can be obtained. R_i is always in the range of 0-1. The network with the highest rank is finally selected

4. Result Analysis:

Let us have the problem discussed by S. Chakravorty *et.al.*,[15] where a thirteen load points are to be fed from two sub-stations depending on the capacity and the load demands. The problem is mentioned in section 2.

Step1: The data form Table 1 are taken and is applied with Fuzzy clustering technique to divide the load points into two groups and to get a suitable sub-station location.
Initially it is assumed that load points 3,4,5,6,7,8,9, 10,11,&12 belongs to cluster1 and load points 1&2 belongs to cluster 2 as shown in table 2.when algorithm is applied to the assumed value as mentioned in section 3.1., the result converges after 2 iteration; the iteration results are shown in table 3 & 4. Thus all the membership values belonging to load points which are above 0.5 are grouped in one cluster and which are below 0.5 in another cluster. The two cluster centers obtained after the final iteration is considered as the location of sub-station for each cluster.

Table 2: Initial Assumption

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13
C1	0	0	1	1	1	1	1	1	1	1	1	1	1
C2	1	1	0	0	0	0	0	0	0	0	0	0	0

Table 3: Result after Iteration 1

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13
C1	0.053	0.028	0.087	0.0353	0.798	0.837	0.887	0.745	0.831	0.995	0.862	0.770	0.181
C2	0.946	0.971	0.912	0.646	0.201	0.162	0.112	0.254	0.168	0.004	0.137	0.229	0.818

Table 4: Result after Iteration 2

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13
C1	0.020	0.029	0.080	0.277	0.863	0.884	0.864	0.626	0.912	0.909	0.934	0.773	0.10
C2	0.979	0.97	0.919	0.722	0.136	0.115	0.135	0.373	0.087	0.090	0.065	0.226	0.899

Thus from the results it is clear that load points (1,2,3,4,13) are in class C1 while load points(5,6,7,8,9,10,11,12) are in class C2.The location for sub-station in Class1 cluster is (3.176,3.79) and for sub-station in Class2 is (8.77,6.882).

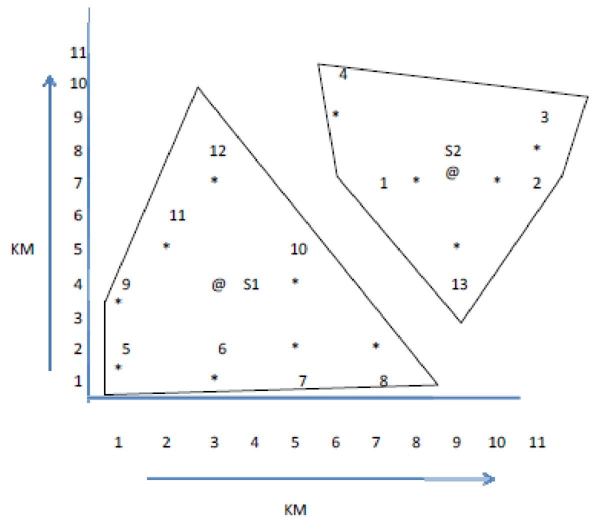

Fig2: Pictorial representation after clustering

Advantage: suppose a given sub-station is not capable to supply the given allotted load points then in that case any load point from a given cluster could be shifted to other cluster depending on the membership values.

Step 2: Now a suitable connection is found out considering all the factors of data mentioned in Appendix A.
Applying the algorithm mentioned in stage 1.
Results:
Taking user inputs

$$G = \frac{L_u - L_i}{N_p} = 1.6$$

Now each of the factors are allotted a weight age with a space gap of 1.6
Here we allot scores to the given criteria giving priority to the factors as shown :
Estimated relative cost
Maximum interruption
Customer interruption/year
Feeder losses
Miles of conductor
So the scores given are:

- Miles of conductor used for feeder configuration – 1.6
- Feeder losses used for feeder configuration .- 3.2
- Estimated relative cost used for feeder configuration - 8
- Maximum interruption used for feeder configuration.- 6.4
- Customer interruption/year used for feeder configuration- 4.8.

Applying the algorithm mentioned in stage 2 and 3 the result obtained for both the sub-station is shown in table 5 & 6. The optimized values for each load points from the sub-station can be easily seen. Now the algorithm has worked with highest the value, better the value. So seeing 1st row of table 5 node 6 has the highest value so substation 1 should be connected to node 6 first and thus all the connections are made in single, two and three feeder mode.

Table 5: Final result obtained for loads to be fed from sub-station 1

	S1	N5	N6	N7	N8	N9	N10	N11	N12
S1	-	78.922	119.699	88.739	51.976	61.692	30.688	23.934	16.545
N5	66.702	-	108.627	41.009	34.498	117.701	11.251	22.494	26.247
N6	134.11	135.58	-	86.601	85.083	64.294	26.262	28.417	19.185
N7	104.14	66.152	88.353	-	148.102	32.780	103.417	34.34	22.291
N8	54.497	26.981	51.403	109.224	-	9.808	91.558	9.147	22.446
N9	83.433	135.577	59.995	35.172	27.28	-	31.896	141.527	52.387

N10	34.14	31.024	32.456	86.601	120.348	32.78	-	90.523	99.964
N11	13.70	18.916	16.398	17.31	10.321	123.173	72.179	-	176.086
N12	6.75	13.923	6.542	6.497	18.349	11.66	29.553	141.366	-

Table 6: Final result obtained for loads to be fed from sub-station 2

	S2	N1	N2	N3	N4	N13
S2	-	69.628	72.756	44.459	34.869	86.155
N1	86.58	-	55.230	32.00	155.43	70.554
N2	84.347	51.599	-	140.236	22.026	70.554
N3	21.464	7.895	72.756	-	23.146	28.070
N4	8.803	69.618	7.458	11.398	-	7.979
N13	67.902	39.139	44.478	42.936	30.694	-

Graphs representing the connection of sub-station to the load points in single feeder, two feeder and three feeder mode.

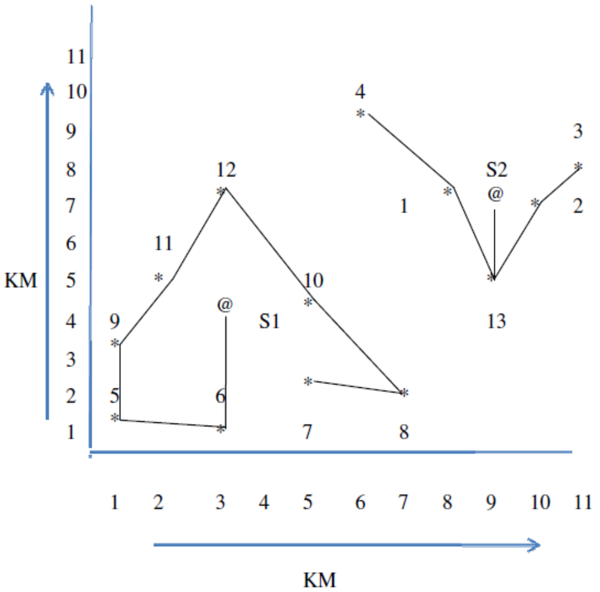

Fig 3: Single feeder layout obtained

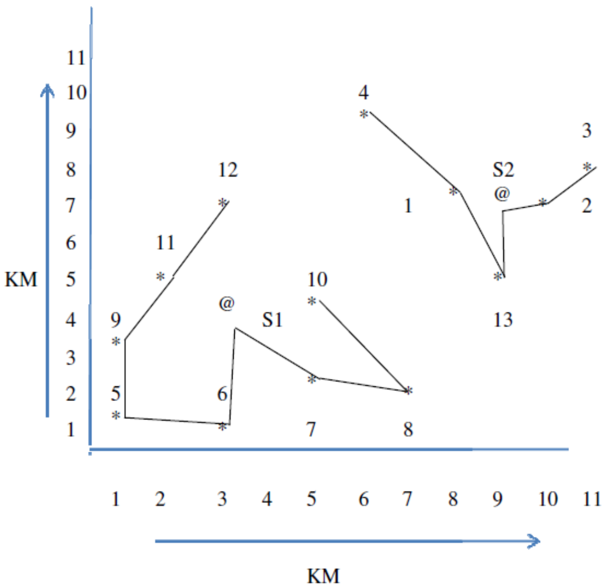

Fig 4: Two feeder layout obtained

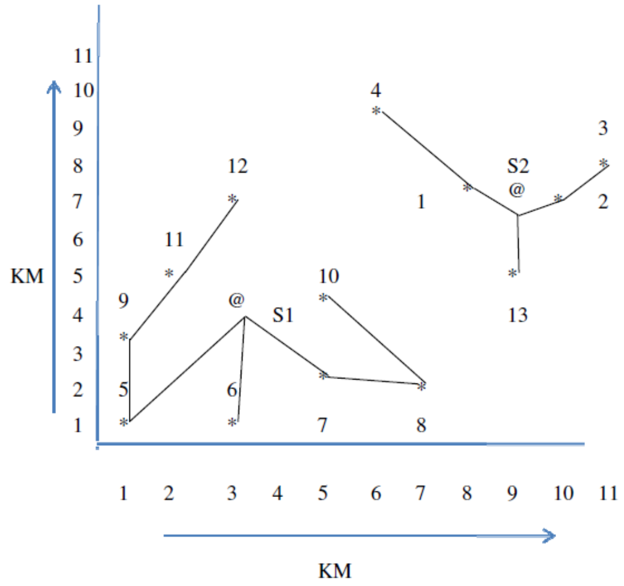

Fig 5: Three feeder layout obtained

where @ represents the location for Sub-Station and * for Load point

5. Discussion and Conclusion:

In the paper of S. Chakravorty *et.al*.,[15] the load distribution was proposed using the concept of genetic algorithm in which the capacity of the sub-station was pre assumed on the basis of which the distribution of the load points was carried out. In the work done by K.K.Li and T.S. Chung [3] genetic algorithm have been used to find the optimum location of sub-station 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 above mentioned drawback is removed in the present work, the clustering of the load points is done irrespective of the capacity of the sub-station. One may decide on the capacity of the sub-station depending on the load points required to be fed from the sub-station. A new methodology, based upon the FCM algorithm , is proposed for the planning of electrical power distribution system. Thus by applying Fuzzy Clustering method, various load points which are at different location can be grouped into number of clusters depending on the number of distribution sub-stations available. Also the location of the sub-station can be determined. Further applying context Aware Decision Algorithm depending on various factors mentioned a suitable connection is found out between sub-station and load points so that factors such as cost, miles of conductor etc. are minimum. The technique suggested is simpler than all the existing methods. The technique suggested can also be used for network reconfiguration as in case a sub-station is over burdened loads from that sub-station may be transferred to the nearest cluster depending on the membership values obtained. The technique is shown as a flexible and powerful tool for the distribution system planning engineers. The result encourages the use and further development of the methodology.

APPENDIX – A

Table A1: Data of miles of conductor in respective units,used for feeder configuration

	Sub-station 2	Node 1	Node 2	Node 3	Node 4	Node 13
Sub-station 2	-----	5	5	10	12	7
Node 1	5	-----	7	13	6	8
Node 2	5	7	-----	5	16	7
Node 3	10	13	5	-----	18	9
Node 4	12	6	16	18	-----	18
Node 13	7	8	7	9	18	-----

	Sub-station 1	Node 5	Node 6	Node 7	Node 8	Node 9	Node 10	Node 11	Node 12
Sub-station 1	-----	7	3	6	14	7	9	12	16
Node 5	7	-----	6	10	16	6	17	14	20

Node 6	3	6	-----	7	12	9	12	13	18
Node 7	6	10	7	-----	6	12	7	13	17
Node 8	14	16	12	6	-----	17	7	18	19
Node 9	7	6	9	12	17	-----	12	6	13
Node 10	9	17	12	7	7	12	-----	10	11
Node 11	12	14	13	13	18	6	10	-----	6
Node 12	16	20	18	17	19	13	11	6	-----

Table A2: Data of feeder losses in respective units,used for feeder configuration

	Sub-station 2	Node 1	Node 2	Node 3	Node 4	Node 13
Substation 2	-----	3	3	7	10	4
Node 1	3	-----	4	10	3	4
Node 2	3	4	-----	3	12	4
Node 3	7	10	3	-----	14	7
Node 4	10	3	12	14	-----	14
Node 13	4	4	4	7	14	-----

	Sub-station 1	Node 5	Node 6	Node 7	Node 8	Node 9	Node 10	Node 11	Node 12
Sub-station 1	-----	6	3	5	7	5	8	10	12
Node 5	6	-----	3	5	7	3	7	8	10
Node 6	3	3	-----	3	5	5	7	9	11
Node 7	5	5	3	-----	3	6	3	8	10
Node 8	7	7	5	3	-----	8	4	10	12
Node 9	5	3	5	6	8	-----	6	3	9
Node 10	8	7	7	3	4	6	-----	5	6
Node 11	10	8	9	8	10	3	5	-----	3
Node 12	12	10	11	10	12	9	6	3	-----

Table A3: Data of estimated relative cost in respective units,used for feeder configuration

	Sub-station 2	Node 1	Node 2	Node 3	Node 4	Node 13
Sub-station 2	-----	5	5	10	12	7
Node 1	5	-----	7	13	6	8
Node 2	5	7	-----	5	16	7
Node 3	10	13	5	-----	18	9
Node 4	12	6	16	18	-----	18
Node 13	7	8	7	9	18	-----

	Sub-station 1	Node 5	Node 6	Node 7	Node 8	Node 9	Node 10	Node 11	Node 12
Sub-station 1	-----	7	3	6	14	7	9	12	16
Node 5	7	-----	6	10	16	6	17	14	20
Node 6	3	6	-----	7	12	9	12	13	18
Node 7	6	10	7	-----	6	12	7	13	17
Node 8	14	16	12	6	-----	17	7	18	19
Node 9	7	6	9	12	17	-----	12	6	13
Node 10	9	17	12	7	7	12	-----	10	11

Node 11	12	14	13	13	18	6	10	-----	6
Node 12	16	20	18	17	19	13	11	6	-----

Table A4: Data of maximum interruption in respective units,used for feeder configuration

	Sub-station 2	Node 1	Node 2	Node 3	Node 4	Node 13
Sub-station 2	-----	3	3	8	10	4
Node 1	3	-----	3	6	4	5
Node 2	3	3	-----	4	8	5
Node 3	8	6	4	-----	10	8
Node 4	10	4	8	10	-----	12
Node 13	4	5	5	8	12	-----

	Sub-station 1	Node 5	Node 6	Node 7	Node 8	Node 9	Node 10	Node 11	Node 12
Sub-station 1	-----	7	3	5	7	6	8	10	12
Node 5	7	-----	5	8	9	5	9	12	14
Node 6	3	5	-----	4	5	4	6	8	10
Node 7	5	8	4	-----	3	6	4	8	10
Node 8	7	9	5	3	-----	8	4	12	14
Node 9	6	5	4	6	8	-----	7	3	8
Node 10	8	9	6	4	4	7	-----	5	6
Node 11	10	12	8	8	12	3	5	-----	3
Node 12	12	14	10	10	14	8	6	3	-----

Table A5: Data of customer interruption/yr in respective units,used for feeder configuration

	Sub-station 2	Node 1	Node 2	Node 3	Node 4	Node 13
Sub-station 2	-----	300	300	700	1000	400
Node 1	300	-----	400	1000	300	400
Node 2	300	400	-----	300	1200	400
Node 3	700	1000	300	-----	1400	700
Node 4	1000	300	1200	1400	-----	1400
Node 13	400	400	400	700	1400	-----

	Sub-station 1	Node 5	Node 6	Node 7	Node 8	Node 9	Node 10	Node 11	Node 12
Sub-station 1	-----	600	300	500	700	500	800	1000	1200
Node 5	600	-----	300	500	700	300	700	800	1000
Node 6	300	300	-----	300	500	500	700	900	1100
Node 7	500	500	300	-----	300	600	300	800	1000
Node 8	700	700	500	300	-----	800	400	1000	1200
Node 9	500	300	500	600	800	-----	600	300	900
Node 10	800	700	700	300	400	600	-----	500	600
Node 11	1000	800	900	800	1000	300	500	-----	300
Node 12	1200	1000	1100	1000	1200	900	600	300	-----

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