Optimal Source Substation Location Selection in Radial Distribution Networks

Shah Jahirul Islam, Mohd Wazir Mustafa, *Member, IEEE* and Ismail Hasan, *Member, IEEE*

Abstract**– New computer algorithm has been developed to select the optimal location of source substation in redial distribution networks. Selection methodology has been developed based on the geo-graphical location of connected substation of source substation, user's defined obstacle area by determining minimal route of the networks based on minimal loss of the networks and economic consideration. For the best location selection of source substation two steps selection method has been implemented for minimizing computer computation time. In the first steps it determines the projected area for the selection of optimal location of source substation. In the seconds step precise calculation is involved. Depending on the precise calculation of area selection computation time will be varied. Simulated example has been introduced for detail explanation of the output of computer algorithms.**

Index Terms**— Computer algorithm, optimal location selection, radial distribution networks, source substations.**

I. Nomenclature

D_{ijk} is the distance from jth node to kth node that is the distance of ith branch of feeders

x_j, x_k are geographical horizontal co-ordinates of jth node and kth node respectively

y_j, y_k are geographical vertical co-ordinates of jth node and kth node respectively.

IR indicates the interest rate of total investment PNL Planner's proposed network life

$P_{2*(n-1)+1}$ indicates the position of 1st node of nth sequence of node selection

$P_{2*(n-1)+2}$ indicates the position of 2st node of nth sequence of node selection

N_{n1} 1st node of nth sequence of node selection

N_{n2} 2nd node of nth seq. of node selection

P^{acil}_{i} is actual iron loss of ith load node transformer

P^{accu}_{i} is actual cu loss of ith load node transformer

P^{acil}_{ss} is the actual iron loss of the source substation transformer

P^{accu}_{ss} is the actual cupper loss of the source substation transformer

I^{n}_{i} is the current rating of ith demand node

S^{N}_{m} is the node sequence indicator for mth node

S_m is the sequence node set for mth node

S^{n}_{mn} is nth node of the seq. node set for mth node

JS^{N}_{m} is joint node seq. indicator for mth jont node

JS_m is the sequence joint node set for mth joint node

JS^{n}_{mn} is the nth demand node of the sequence joint node set for mth demand node

DS^{n}_{mn} is the nth joint node of the sequence joint node set for mth demand node

DS_m is the seq. demand node set for mth load node

DS^{n}_{mn} is the nth joint node of the sequence joint node set for mth demand node

I^{JSN}_{m} is the current flow of the sequence indicator for mth joint node

I^{JSn}_{mn} is current flow of the nth demand node of the sequence joint node set for mth demand node

I^{DSn}_{mn} is the current flow of nth joint node of the sequence joint node set for mth demand node

VS^{N}_{m} is voltage drop of the node sequence indicator for mth node

VS^{n}_{mn} is voltage drop of the nth node of the sequence node set for mth node

I^{Sn}_{mn} is current flow of the nth node of the sequence node set for mth node

P^{JSN}_{m}, Q is the power loss of the sequence indicator for mth joint node, power factor of the feeder respectively

$P^{JSn}_{m(n-1)}$ is power loss of the (n-1)th node of the sequence joint node set for mth joint node

P^{JSn}_{mn} is power loss of the nth demand node of the sequence joint node set for mth demand node

P^{DSn}_{mn} is power loss of nth joint node of the sequence joint node set for mth demand node

P^{DSn}_{mn} is the nth joint node of the sequence joint node set for mth demand node

$F_{loss,\, n}$ is loss factor & total no. of load substation

C^{cpk}_{ij} is cable cost per km of jth feeder segment of ith demand load substation route.

C^{ipk}_{ij} is cable installation cost per km of jth feeder segment of ith load substation route.

C_{kwh}, L_{nf}, I_{rf} is cost per kWh, the desired life of networks and load factor of the network respectively

X_{11} indicates 1st rectangular obstacle type and X co-ordinates of starting reference point of 1st corner point

Y_{11} indicates 1st rectangular obstacle type and Y co-ordinates of starting reference point of 1st corner point

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X_{12} indicates 1^{st} rectangular obstacle type and X co-ordinates of starting reference point of 2^{st} corner point which is adjacent of the 1^{st} corner point

Y_{12} indicates 1^{st} rectangular obstacle type and Y co-ordinates of starting reference point of 2^{st} corner point which is adjacent of the 1^{st} corner point

X_{n1} indicates n^{st} rectangular obstacle type and X co-ordinates of starting reference point of 1^{st} corner point

Y_{n1} indicates n^{st} rectangular obstacle type and Y co-ordinates of starting reference point of 1^{st} corner point

X_{n2} indicates n^{st} rectangular obstacle type and X co-ordinates of starting reference point of 2^{st} corner point which is adjacent of the 1^{st} corner point

Y_{n2} indicates n^{st} rectangular obstacle type and Y co-ordinates of starting reference point of 2^{st} corner point which is adjacent of the 1^{st} corner point

$P_{2(N+1)*(n-1)+2(5-1)}$ indicates the internal storage position of 5^{th} position of data source which indicates X coordinates of first corner point of the nth rectangular obstacle type

II. Introduction

In distribution network design a large amount of data is required, e.g. information of present networks, design objectives, etc. Complicated calculations are necessary in some cases to optimize network configurations. Computer programs can act as an efficient tool for long planning and the study of more complex aspects [1]. The high investment cost of electricity distribution systems and the increasing cost of energy, equipment and labor has caused design engineers to look for more efficient planning methods and techniques to reduce these costs [2]. The problem of distribution planning is so complicated that it is usually divided into two sub-problems, namely: sub-problem of substations optimization and sub-problem of feeder optimization [3]. In such approaches, first the optimization problem of source substation is solved. The main contributions of this paper are to develop new computer algorithm to select optimal location of source substation. Mapping of power distribution networks including precise direction change and measurement of cable length and node-to-node distance considering practical scenario are also related.

The optimal distribution system planning problem becoming increasingly important in the context of the increasing cost of construction, materials, and the wide range of alternatives usually open to power system planners, which makes the determination of an optimal plan very difficult. In this case load magnitude and location of all joint nodes and demand load substations have to be mentioned.

An iterative procedure that improves on a user-defined initial location is employed to determine the optimal site to locate the source substation. The programming approach allows the designer to choose the best site ignoring the obstacle location for the source substation. The number of consumer supplied and the length of the distribution feeders are reflected in the size of the conductor voltage regulation and the losses incurred. The test results indicate the importance of including voltage drop constraints in the planning models to find more realistic optimal solutions.

III. Mapping of Feeder Routes and Problem Formulation

The methods of mapping of feeder routes will be more transparent if we consider all necessary things to explain it properly and precisely. Main program will handle the mapping after retrieving data from the data bank and getting the information about the initialization of graphics interfaces. Output of this program will be the mapping of entire networks. This output depends on the proper handling of related data structures.

A. Connection Sequence Selection Method

Connection sequence selection method is a systematic numbering selection method for calculation of distance of towers. Systematic numbering of nodes and branches is not an essential criterion for calculation of distance of towers of distribution network but it will be better for node sequence selection. Nodes that will be used for getting more accurate distance, load substation nodes, joint nodes, source substation nodes are considered in the distribution network. Load substation nodes are to be numbered at first. On completion of the numbering of all the load substation nodes joint nodes have to be numbered. There are three types of joint nodes. Joint node of

- two or more than two load substation nodes
- load substation feeders
- load substation node and load substation feeder

The last number will be source substation node. It is not essential to follow this procedure of numbering. But if this procedure is followed it will be easy to find out the node number of the demand load substations, joint nodes and source substation. Extra nodes of each route will be numbered after finishing of numbering of source substation node. The mapping of the node connection is shown as below:

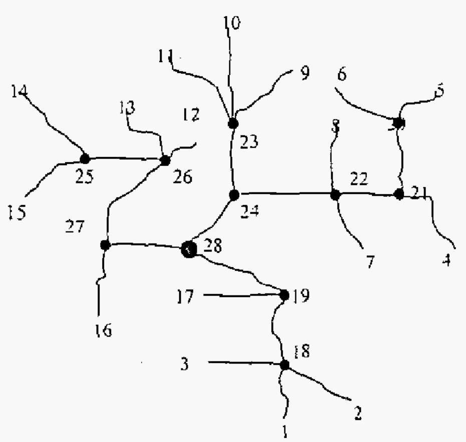

Fig. 1. Typical distribution network

Any extra node number will be bigger than substation number and it will be start after the number of source substation. On completion of the numbering of all nodes it is needed to arrange the node sequence selection. For each feeder branch it is needed to mention the connecting node numbers. The node-to-node connection sequence will be

$18\rightarrow 1$ $18\rightarrow 2$ $18\rightarrow 3$ $19\rightarrow 17$ $19\rightarrow 18$
$20\rightarrow 5$ $20\rightarrow 6$ $21\rightarrow 4$ $21\rightarrow 20$ $22\rightarrow 7$
$22\rightarrow 8$ $22\rightarrow 21$ $23\rightarrow 9$ $23\rightarrow 10$ $23\rightarrow 11$
$24\rightarrow 23$ $24\rightarrow 22$ $25\rightarrow 14$ $25\rightarrow 15$ $26\rightarrow 12$
$26\rightarrow 13$ $26\rightarrow 25$ $27\rightarrow 16$ $27\rightarrow 26$ $28\rightarrow 19$
$28\rightarrow 24$ $28\rightarrow 27$

Total number of load substations is 17. Joint nodes number is 18 to 27. 28 is the source substation node in Fig. 1. There are a lot of hidden nodes between two adjacent nodes those make the mapping accurate and practical based.

B. Selection of The Obstacle Type

The source substation must be placed and sized in such a way it serves the load at maximum cost effectiveness by minimizing feeder losses and construction costs while considering area for selection of source substation. We have to consider several types of obstacles. If the substation location is

1. on a river
2. on the provincial highway
3. on the freeway
4. within an earthquake area
5. a right of way problem
6. to cause social problems
7. undesirable because the land is too expensive, etc.

then the location of source substation have to be ignored.

Two types of obstacles are created for representing all types of obstacles. These types are

1. Rectangular type
2. Circular type

All types of obstacles have to be mentioned as rectangular area or circular area. The types of obstacles have to be selected according to the similarity of the obstacles.

C. Problem Formulation

To determine the distance between two nodes, at first it is needed to select the location of the nodes. The location of nodes are stated by geographical co-ordinates then the distances are determined as follows:

The required distance between two nodes [3] is

$$D_{ijk} = \sqrt{[(x_j - x_k)^2 + (y_j - y_k)^2]} \qquad (1)$$

Total distance of a single route of n number of nodes is

$$D_n = \sum_{i=1}^{n} D_{ijk} \qquad (2)$$

Total length of cable of complete route of network is

$$D^T_n = \sum_{i=1}^{n} D_i \qquad (3)$$

The present worth factor for proposed network life

$$PWF = (1 + IR/100.0)^{PNL} \qquad (4)$$

The memory location for this node selection is maintained as below:

$$\begin{aligned}
&[P_{2*(1-1)+1} \rightarrow N_{11},\ P_{2*(1-1)+2} \rightarrow N_{12}],\\
&[P_{2*(2-1)+1} \rightarrow N_{21}, P_{2*(2-1)+2} \rightarrow N_{22}],\\
&[P_{2*(3-1)+1} \rightarrow N_{31}\ \ P_{2*(3-1)+2} \rightarrow N_{32}],\\
&\vdots\\
&[P_{2*(n-2)+1} \rightarrow N_{(n-1)1},\ P_{2*(n-2)+2} \rightarrow N_{(n-1)2}]\\
&[P_{2*(n-1)+1} \rightarrow N_{n1},\ P_{2*(n-1)+2} \rightarrow N_{n2}]
\end{aligned} \qquad (5)$$

To determine the feeder route selection it is needed to separate the demand load of the end point of the networks and the joint nodes. The sequence is the most important to generate the appropriate route determination.

The sequence of node number

$$\begin{aligned}
&S^N_1 \rightarrow S_1 \{S^n_{11}, S^n_{12}, S^n_{13}, S^n_{14} \ldots\ldots S^n_{1(n-1)}, S^n_{1n}\}\\
&S^N_2 \rightarrow S_2 \{S^n_{21}, S^n_{22}, S^n_{23}, S^n_{24} \ldots\ldots S^n_{2(n-1)}, S^n_{2n}\}\\
&S^N_3 \rightarrow S_3 \{S^n_{31}, S^n_{32}, S^n_{33}, S^n_{34} \ldots\ldots S^n_{3(n-1)}, S^n_{3n}\}\\
&\vdots\\
&S^N_{(m-1)} \rightarrow S_{(m-1)} \{S^n_{(m-1)1}, S^n_{(m-1)2}, S^n_{(m-1)3}, S^n_{(m-1)4} \ldots\ldots S^n_{(m-1)(n-1)}, S^n_{(m-1)n}\}\\
&S^N_m \rightarrow S_m \{S^n_{m1}, S^n_{m2}, S^n_{m3}, S^n_{m4} \ldots\ldots S^n_{m(n-1)}, S^n_{mn}\}
\end{aligned} \qquad (6)$$

Connection sequence of joint node

$$JS^N_m \rightarrow JS_m \{JS^n_{m1}, JS^n_{m2}, JS^n_{m3}, JS^n_{m4} \ldots\ldots JS^n_{m(n-1)}, JS^n_{mn}, DS^n_{m1}, DS^n_{m2}, DS^n_{m3}, DS^n_{m4} \ldots\ldots, DS^n_{m(n-1)}, DS^n_{mn}\}$$

The nth joint node of the sequence joint node set for mth joint node

$$JS^n_{mn} = DS^n_{mn} \{DS^n_{m1}, DS^n_{m2}, DS^n_{m3}, DS^n_{m4} \ldots\ldots DS^n_{m(n-1)}, DS^n_{mn}\}$$

The current flow of joint node

$$I^{JSN}_m = \sum (I^{JSn}_{m1} + I^{JSn}_{m2} + I^{JSn}_{m3} + I^{JSn}_{m4} + \ldots\ldots + I^{JSn}_{m(n-1)} + I^{JSn}_{mn} + I^{DSn}_{m1} + I^{DSn}_{m2} + I^{DSn}_{m3} + I^{DSn}_{m4} + \ldots\ldots + I^{DSn}_{m(n-1)} + I^{DSn}_{mn}) \qquad (7)$$

The current flow of nth joint node of the sequence joint node set for mth joint node if all connecting node are demand nodes

$$I^{JSn}_{mn} = \sum (I^{DSn}_{m1} + I^{DSn}_{m2} + I^{DSn}_{m3} + I^{DSn}_{m4} + \ldots\ldots + I^{DSn}_{m(n-1)} + I^{DSn}_{mn}) \qquad (8)$$

The voltage drop of the particular node is

$$VS^N_m = \sum \{VS^n_{m1} + VS^n_{m2} + VS^n_{m3} + VS^n_{m4} \ldots\ldots + VS^n_{m(n-1)} + VS^n_{mn} \qquad (9)$$

The individual node voltage drop of the sequence node set

$$VS^n_{mn} = \sqrt{3} I^{Sn}_{mn} \left(\sum_{i=1}^{n} D^T_i (R^n_i \cos Q + X^n_i \sin Q) \right) \qquad (10)$$

The power loss of joint node feeder and all associated sequence node feeder

$$P^{JSN}_{m} = \sum (P^{JSn}_{m1} + P^{JSn}_{m2} + P^{JSn}_{m3} + P^{JSn}_{m4} + \ldots\ldots + P^{JSn}_{m(n-1)} + P^{JSn}_{mn} + P^{DSn}_{m1} + P^{DSn}_{m2} + P^{DSn}_{m3} + P^{DSn}_{m4} + \ldots\ldots + P^{DSn}_{m(n-1)} + P^{DSn}_{mn}) \quad (11)$$

The power flow of nth joint node of the sequence joint node set for mth joint node if all connecting nodes are demand nodes

$$P^{JSn}_{mn} = \sum (P^{DSn}_{m1} + P^{DSn}_{m2} + P^{DSn}_{m3} + P^{DSn}_{m4} + .+ P^{DSn}_{m(n-1)} + P^{DSn}_{mn}) \quad (12)$$

Total power losses is

$$P_{tpl} = (\sum_{i=1}^{n} P^{acil}_{i}) + P^{acil}_{ss} + F_{loss}\{\sum_{i=1}^{n} P^{accu}_{i} + P^{accu}_{ss} + P^{JSN}_{m})\} \quad (13)$$

In this case demand loss is same for all possible complete routes of the feeders. For this reason demand loss is ignored. All fixed cost is also ignored.

After proper allocation of all corner points of each individual rectangular type obstacle the object will take in the proper position. The following arrangement is used to retrieve the rectangular type obstacle using associated coordinate of the corner point of the particular obstacle:

$$
\begin{aligned}
&[\, P_{2(N+1)*(1-1)+2(1-1)} \text{ --- } X_{11},\ P_{2(N+1)*(1-1)+2(1-1)+1} \text{ --- } Y_{11},\\
&\ \ P_{2(N+1)*(1-1)+2(2-1)} \text{ --- } X_{12},\ P_{2(N+1)*(1-1)+(2-1)+1} \text{ --- } Y_{12},\\
&\ \ P_{2(N+1)*(1-1)+2(3-1)} \text{ --- } X_{13},\ P_{2(N+1)*(1-1)+2(3-1)+1} \text{ --- } Y_{13},\\
&\ \ P_{2(N+1)*(1-1)+2(4-1)} \text{ --- } X_{14},\ P_{2(N+1)*(1-1)+2(4-1)+1} \text{ --- } Y_{14},\\
&\ \ P_{2(N+1)*(1-1)+2(5-1)} \text{ --- } X_{11},\ P_{2(N+1)*(1-1)+2(5-1)+1} \text{ --- } Y_{11} \,]\\
\\
&[\, P_{2(N+1)*(2-1)+2(1-1)} \text{ --- } X_{21},\ P_{2(N+1)*(2-1)+2(1-1)+1} \text{ --- } Y_{21},\\
&\ \ P_{2(N+1)*(2-1)+2(2-1)} \text{ --- } X_{22},\ P_{2(N+1)*(2-1)+(2-1)+1} \text{ --- } Y_{22},\\
&\ \ P_{2(N+1)*(2-1)+2(3-1)} \text{ --- } X_{23},\ P_{2(N+1)*(2-1)+2(3-1)+1} \text{ --- } Y_{23},\\
&\ \ P_{2(N+1)*(2-1)+2(4-1)} \text{ --- } X_{24},\ P_{2(N+1)*(2-1)+2(4-1)+1} \text{ --- } Y_{24},\\
&\ \ P_{2(N+1)*(2-1)+2(5-1)} \text{ --- } X_{21},\ P_{2(N+1)*(2-1)+2(5-1)+1} \text{ --- } Y_{21} \,]\\
&\ \vdots\\
&[\, P_{2(N+1)*(n-1)+2(1-1)} \text{ --- } X_{n1},\ P_{2(N+1)*(n-1)+2(1-1)+1} \text{ --- } Y_{n1},\\
&\ \ P_{2(N+1)*(n-1)+2(2-1)} \text{ --- } X_{n2},\ P_{2(N+1)*(n-1)+(2-1)+1} \text{ --- } Y_{n2},\\
&\ \ P_{2(N+1)*(n-1)+2(3-1)} \text{ --- } X_{n3},\ P_{2(N+1)*(n-1)+2(3-1)+1} \text{ --- } Y_{n3},\\
&\ \ P_{2(N+1)*(n-1)+2(4-1)} \text{ --- } X_{n4},\ P_{2(N+1)*(n-1)+2(4-1)+1} \text{ --- } Y_{n4},\\
&\ \ P_{2(N+1)*(n-1)+2(5-1)} \text{ --- } X_{n1},\ P_{2(N+1)*(n-1)+2(5-1)+1} \text{ --- } Y_{n1} \,] \qquad (14)
\end{aligned}
$$

IV. SOLUTION TECHNIQUE

For the best location selection of source substation two steps selection method has been implemented for minimizing computer computation time. In the first steps it determines the projected area for the selection of optimal location of source substation. In this step it is needed to confirm that the best location of the source substation will be in the selected projected area. A reference point is considered to determine the projected area. Based on this reference point location of all other connected substations of source station is determined. Nearest and farthest geo-graphical horizontal co-ordinate and vertical co-ordinate are calculated from geo-graphical location of connected source substation. Projected area will be selected based on these nearest and farthest geo-graphical points. In the seconds step precise calculation is involved. Depending on the precise calculation of 'step selection' computation time will be varied. The 'step selection' choice will be available for the engineer of the power distribution planner. Two types of selection choice will be available. One is step selection of the horizontal coordinator and another is step selection of vertical coordinator. Combination of these two steps every projected source substation location will be selected. After selection of the every projected source substation location all related computation will be completed. Total number of projected source substation location depends on combination of these two types of selection step. If projected locations of source substation are very close each other, total number of projected source substation location will be increased and the computation time will be increased. But best location selection for the source substation will be more precise due to more projected source substation location selection. Heuristic technique has been applied for comparison of the computational output for all projected location of source substation. The programming structure is as below:

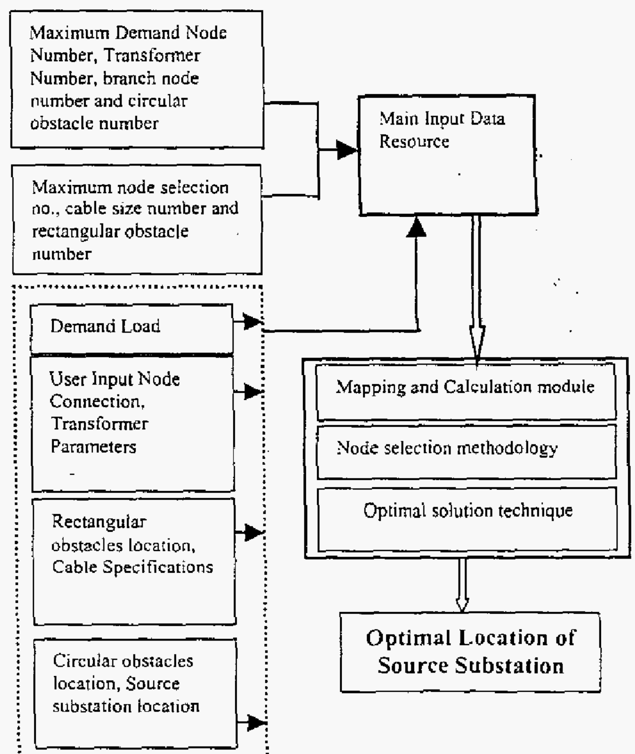

Fig. 2. Programming Structure of Solution Technique

The area of the obstacles those are restricted for the location selection of source station is strictly considered during determination of each projected location of source substation.

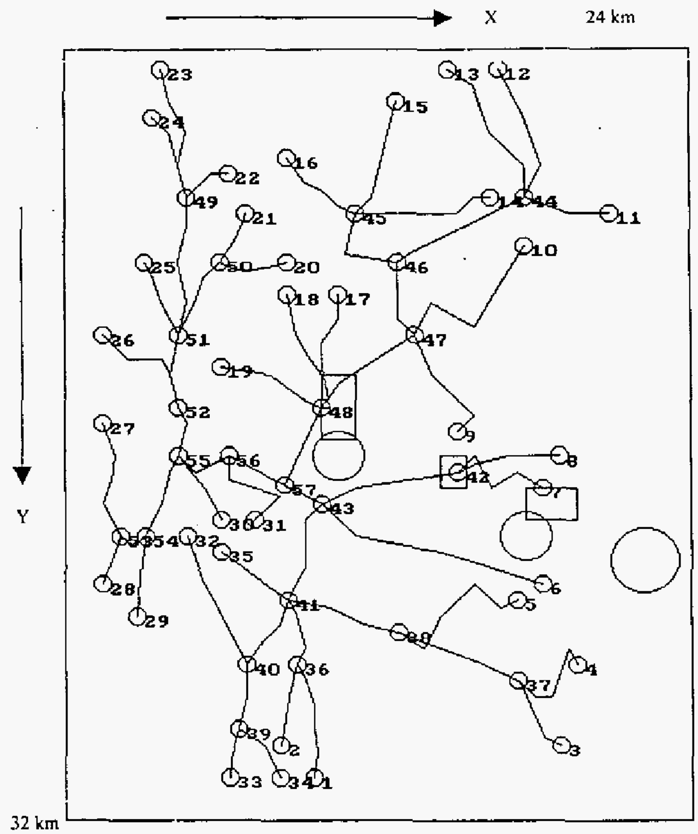

Fig. 3. Mapping of the distribution networks

All obstacles will be converted into two types of predefined obstacles. One is rectangular obstacle which will be selected for the obstacles those are similar to rectangular area. Another is circular obstacle, which will be selected for all other obstacles. Two types of predefined obstacles are introduced for better computational performance. According to mentioned methodology optimal location of source substation will be determined in the radial distribution networks.

V. Results

An example of distribution network is considered. In this case total 57 number of nodes are used in which 35 nodes are load substation nodes and 21 nodes are joint nodes and one is source substation node. The selected source substation is 57. The output screen is generated 24km X 32km. The maximum area is considered 23.333X30 square km. The ratio factor is considered 15. Ratio factor is described as the ratio of actual input of the program and practical coordinate in km. The source substation rating is 17.5MVA. The mapping of distribution system is shown in Fig. 3. The voltage drop, transformer rating and cable size of each node is shown in TABLE 1. The optimal location of source substation geographical coordinate is (8.33, 18.667). The unit is in km.

FN, TR, CA, A and B indicates feeder number, transformer rating in KVA, cable size and type, cable type UCA11 and UCA11X respectively. Cable details have been taken from reference no. [4].

VI. Conclusion

Consideration of geographical location of substation has made complex whole optimal solution technique. Demand load and location of load substations, selection of the rating of transformers of the substations according to the load etc. are also essential factor for consideration. The power flow through every segment of the feeder has been specified. The task was that of selecting a conductor type for each feeder segment of a radial feeder, which has minimized the sum of the cost of capital investment and the cost of feeder losses and at the same time meeting all capacity requirements. Considering all these factors for optimal site selection of source substation different types of obstacles have also been considered.

TABLE I
VOLTAGE DROP AND RATING OF TRANSFORMERS

FN	TR	CA	FD	TR	CA
1	250	50B	29	630	50B
2	300	50B	30	2000	120A
3	200	25A	31	1500	50B
4	500	120A	32	500	120A
5	500	120A	33	630	50B
6	1500	120A	34	250	50B
7	500	50B	35	630	50B
8	630	50B	36		50B
9	500	50B	37		120A
10	630	120A	38		120A
11	300	50B	39		120A
12	200	50B	40		120A
13	250	185A	41		120A
14	500	120A	42		50B
15	250	120A	43		300A
16	200	50B	44		300A
17	1500	50B	45		120A
18	2000	120A	46		120A
19	2000	120A	47		185A
20	500	120A	48		300A
21	300	120A	49		185A
22	500	120A	50		50B
23	200	120A	51		300A
24	250	120A	52		185A
25	630	50B	53		120A
26	630	50B	54		120A
27	500	50B	55		300A
28	630	50B	56		300A

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VII. Biographies

Shah Jahirul Islam received his B.Sc. in Electrical and Electrinic Engineering from Bangladesh Institute of Technology (BI), Khulna, Bangladesh in 1994 and his M.E in Electrical from Universiti Teknologi Malaysia (UTM), Malaysia in 1998. He is doing Ph. D on optimal cable and substation location selection of distribution networks.

He worked in the Design Method and Research Development, Production Planning and Control Department of General Electric Manufacturing Company Ltd. from 1995 to 1996. Presently he is working as Software Engineer in Willowglen Services Pte. Ltd.

Mohd. Wazir Mustafa received his B.Eng degree (1988), M.Sc (1992) and PhD (1997) from University of Strathclyde. His research interests include HVDC system modelling and simulation, power system equivalence studies, power system stability, Flexible AC Transmission System, wireless power and power system distribution & automation. He is currently an Associate Professor of Faculty of Electrical Engineering, Universiti Teknologi Malaysia. Dr. Mustafa is also a member of Institution of Engineers, Malaysia (IEM) and a Member of IEEE.

Datuk Professor Ismail Hassan currently holds the post of Rector at Kolej Universiti Teknikal Kebangsaan Malaysia (KUTKM) in Melaka. He obtained his degrees in Electrical Engineering from the University of Tasmania, Australia and Imperial College of Science and Technology, London specializing in Electrical Machines and Power Systems. Before serving KUTKM, he worked with Universiti Teknologi Malaysia from 1973 until 2000 holding various administrative posts including as Dean of Electrical Engineering Faculty.

Professor Ismail Hassan has worked on various research projects related to energy planning and management, hydrothermal plant optimization, and power system analysis and computing. His present research interest is in the area of fast power system computation. He has also worked on a number of engineering consultancy projects and notably was a member of the consultant team involved in Malaysia's first 500-kilovolt-transmission system development project.