Reconfiguration of Distribution Network using Best First Search

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***Abstract*—Electrical Distribution networks are generally configured radially. The operating conditions such as, voltage, power loss etc. change with changing load profile. The operating conditions can be improved significantly by changing the status of the tie-switches (normally open) and sectionalizing switches (normally closed) while maintaining the structure radial and keeping all nodes connected. Several AI based techniques have been applied to search for optimal configuration. However, they are all computationally complex and time consuming, making them unsuitable for online applications. This paper illustrates the use of best-first search technique to find the optimal or near optimal configuration with minimal computational burden. Simplified Distflow equations are employed to compute the load flow. They give approximate loss calculation and are efficient in guiding the search. The proposed method has been successfully applied to IEEE-16 bus system.**

Keywords—Reconfiguration, Best-first search, simplified distflow equations.

I. INTRODUCTION

Power Distribution Systems are formed by many interconnected feeders. Each feeder is further partitioned into many load zones along its radial structure. Distribution feeders are configured in a radial manner i.e. each load is supplied by a single source. Feeders contain a number of closed switches along its length which divide the feeder into sections, these normally closed switches are called sectionalizing switches. The feeders are separated from each other by normally open switches which are called tie switches.

Radial structure of Distribution Network can be modified from time-to-time in order to achieve objectives such as loss minimization, load balancing, fault isolation, etc. This can be achieved by closing a tie switch (normally open) and opening a sectionalizing switch (normally closed) to regain the radial structure. These modifications by changing open/closed states of the switches to transfer load from one feeder to another, may significantly improve the operating conditions of the overall system. The set of these modifications is called Reconfiguration of Distribution System.

Under normal operating conditions, reconfiguration can be done for the purpose of loss reduction and load balancing. While under faulty conditions, it is performed so as to clear the fault, thereby restoring the power to maximum number of consumers. This is called supply restoration [1].

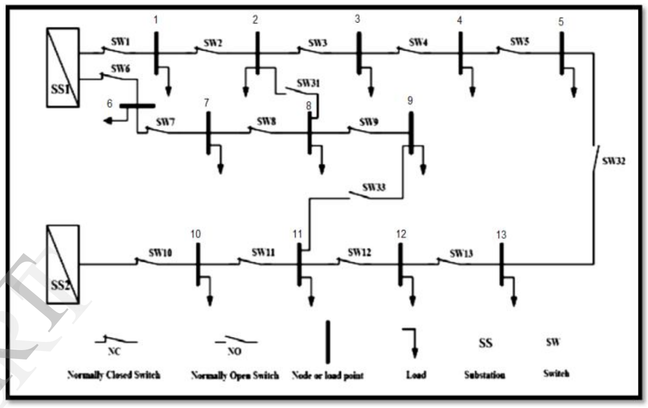

Fig. 1 Schematic diagram of distribution system

Fig.1 shows a schematic diagram of a distribution network. The network can be reconfigured by first closing an open switch, say SW33. This closing results in the formation of a loop that consists of the branches b6, b7, b8, b9, b33, b11, b10. Say switch SW8 is opened to regain radial structure. Now feeder 1 supplies load points 6, 7 and feeder 2 supplies load points 10, 11, 9, 8 of the formed loop. This operation relieves the overloaded feeder, while a lightly loaded feeder is given some load. This can also be seen from perspective that now the newly loaded feeder is utilizing its hardware capacity better [2]. It is essential to meet some operating constraints while performing switching exchange.

Radial Distribution Network configuration problem is a combinatorial optimization problem. It basically means to find the best possible tree that has minimized losses as well as better voltage profile amongst all possible trees for the graph while obeying radiality and reliability constraints. It is obvious that a search examining all the possible trees for a graph using an efficient load flow technique would eventually lead to the solution tree (or configuration); however, such a search would be exhaustive one and will be computationally difficult. As the search demands repetitive load flow computations, the time in which the problem converges increase as the size of the network increases. A number of AI based techniques have been applied to the problem efficiently but they too need time in reaching the solution network configuration. AI as well as exhaustive search techniques are unsuitable for online purposes. Thus, there is a need of finding an optimal or near optimal solution network configuration with minimum computational burden.

Proposed method represents the switching options in the form of a decision tree. The best first search is used to evaluate the switching options based on some heuristic rules. Simplified Distflow equations [3] are used to carry out the load flow. They are linear equations and can be solved directly. Thus, the computational burden reduces and optimal configuration is reached in less time. The equations efficiently guide the search process in order to reach the minimum loss configuration. The methodology has been tested for 16 bus system. The voltage profile for the initial and final network has been compared.

A number of papers have been published on distribution network reconfiguration. Civanlar, Grainger, Yin, Lee [4] proposed a simple formula to find the best switching option. Baran, Wu [3] gave two load flow methods to guide the search. Loss minimization and load balancing formed the two objectives. D. Das [5] proposed a fuzzy multi-objective approach. Chang, Kuo [6] used Simulated Annealing to solve minimum loss configuration problem. Ming, Jian and Wen Yian [7] used Genetic algorithm. They utilized the radial nature of the network to form chromosome. J. Z. Zhu [8] employed refined genetic algorithm. They coded the chromosome only with number of open switches. Batrinu, Carpaneto and Chicco [9] proposed a PSO based technique. Lu, Luo, Liu and Long [10] proposed a hierarchical structure poly-particle swarm optimization (HSPPSO) to reach the optimal configuration.

The following paper is organized in the following manner. Section II gives the problem formulation. Section III gives the proposed methodology. Finally, section IV gives the results of reconfiguration process.

II. PROBLEM FORMULATION

Fig. 2 shows a schematic representation of a single line diagram.

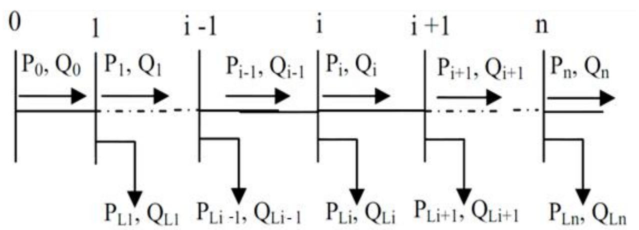

Fig.2 Single line diagram for radial network

$$P_{i+1} = P_i - P_{Li+1} \qquad (1)$$
$$Q_{i+1} = Q_i - Q_{Li+1} \qquad (2)$$

$$V_{i+1}^2 = V_i^2 - 2(r_i P_i + x_i Q_i) \qquad (3)$$

Another way to write relationship for P_{i+1}, Q_{i+1} is

$$P_{i+1} = \sum_{k=i+2}^{n} P_{Lk} \qquad (4)$$
$$Q_{i+1} = \sum_{k=i+2}^{n} Q_{Lk} \qquad (5)$$

These equations are called Simplified Distflow equations [4]. The computations are done in per unit, ∴ the loss in a particular branch can be re-written as

$$Loss\ (ith\ branch) = r_i \frac{(P_i^2+Q_i^2)}{V_i^2} \approx r_i(P_i^2 + Q_i^2)\ \text{p.u.} \qquad (6)$$

∴ the initial voltage is considered to be 1 p.u.

The sum of the losses in all the branches of the radial network is

$$Loss(total) = \sum_{i=0}^{n-1} r_i (P_i^2 + Q_i^2)\ \text{p.u.} \qquad (7)$$

Simplified Distflow equations are used to compute the load flow of the network. They are linear and can be solved directly. They give approximate loss profile but it will not degrade the quality of the solution of the minimal loss configuration problem. The computation time is reduced using the equations.

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III. PROPOSED METHODOLOGY

The switching options are represented in the form of a decision tree. The switching options are generated by exchanging the tie switch with sectionalizing switch on its left and right.

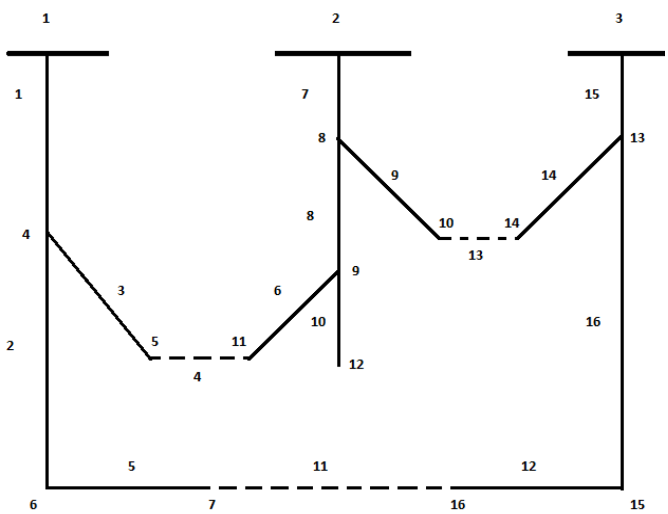

Fig. 3 Initial configuration

The available switching possibilities out of base configuration of IEEE 16- bus system are represented in the fig. 3. The infeasible options are eliminated as possible switching options. Any switching that result in isolation of any load point is considered infeasible. The best first search technique is used to evaluate the options using the following heuristic rules:

Rule 1 Keep the options that transfer the load from higher voltage drop side to lower voltage drop side.

Rule 2 Implement the switching option that has maximum ΔV_{tie} .

According to rule 1, the valid switching options left would be C4O6, C11O5 and C13O9. Rest of them are eliminated as possibilities. Then, using voltage at the nodes of the tie switch ΔV_{tie} is computed. According to rule 2, the switch with maximum ΔV_{tie} is the candidate switch to be implemented. After applying both the rules, C13O9 is selected for implementation.

The configuration of the network is altered. The load flow is carried out to compute the new loss and new voltage profile. Fig. 4 gives the possible switching

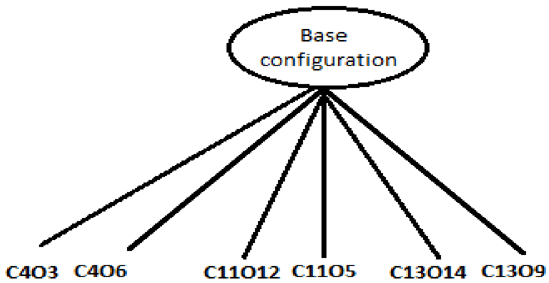

Fig.3 Switching possibilities from base configuration

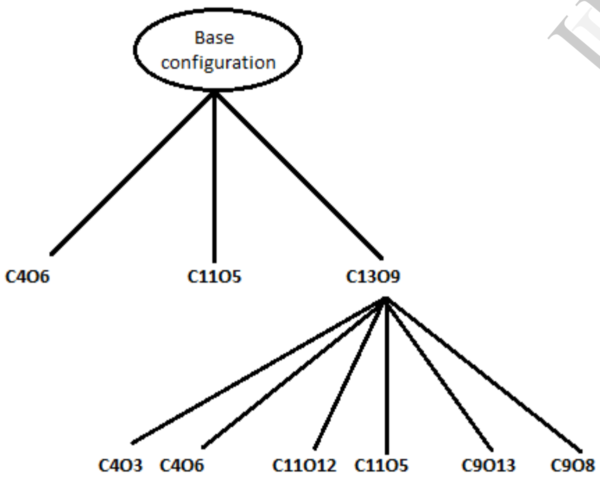

Fig 4.Tree growth after implementing Close 13, Open 9

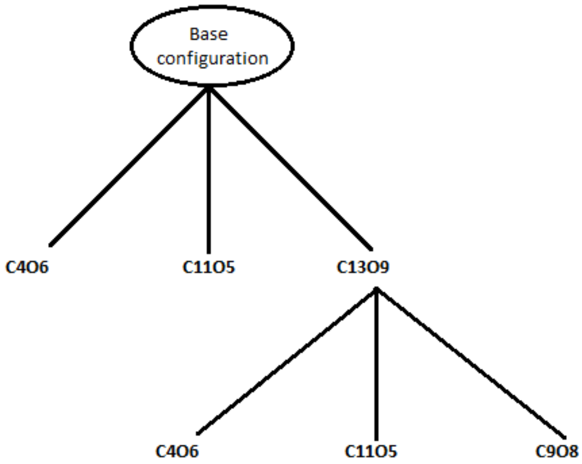

Fig. 5 Tree after implementing Rule 1

Search process is continued until the switching results in loss reduction.

A. *Algorithm*

Steps involved in the search process are summarized in the following steps:

Step 1 Read Network data.

Step 2 Identify the set of possible switching options.

Step 3 Apply Rule 1 to prune out switching options.

Step 4 Apply Rule 2 to find the tie switch with ΔV_{tie}(max).

Step 5 Implement the switching option, update the network configuration. Carry out the load flow.

Step 6 Repeat steps 1-4 until switching results in loss reduction.

B. *Flowchart*

The following figure illustrates the best first search process implementation to the Reconfiguration problem.

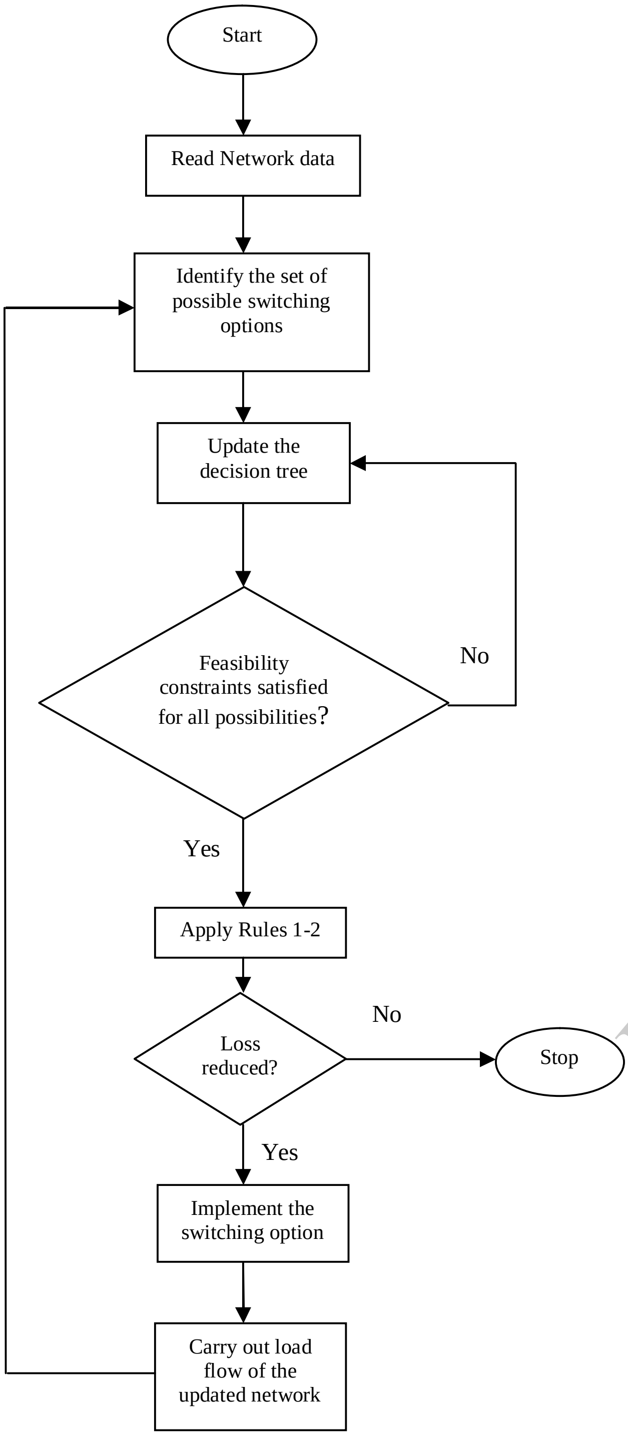

Fig.7 Flow chart representation of the search process

IV. RESULTS

The search process is successfully applied to the IEEE-16 bus system [11]. The data is given in table IV.

The simplified Distflow equations are used to carry out the load flow [4]. They give approximate loss and voltage calculations but are efficient in the guiding the search process. The loss of the system reduced when best switching option is performed. The mean voltage of the network also improved.

The loss profile and voltage profile are given in the table I and table II. The final configuration is given in figure 8.

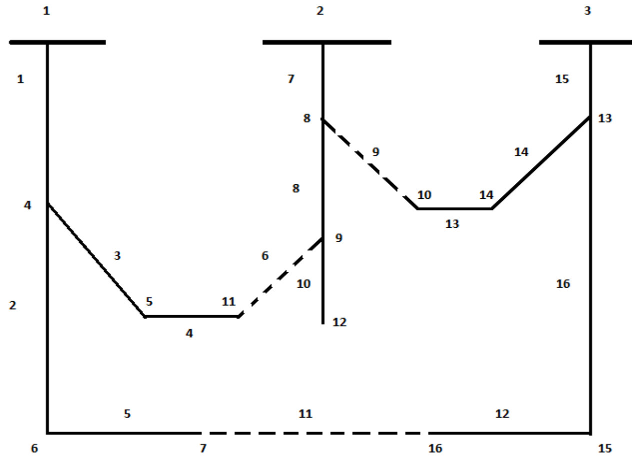

Fig.8 Final configuration.

TABLE I. LOSS PROFILE

Configuration	Loss(approx.)
Initial	.5114 MW
After Closing 13, Opening 9	.4663 MW
After Closing 4, Opening 6	.4498 MW

TABLE II. VOLTAGE PROFILE(IN PER UNIT)

Node no.	Initial voltage	Intermediate voltage	Final voltage
4	0.9907	0.99078	0.99083
5	0.9878	0.98791	0.98803
6	0.9860	0.98613	0.98618
7	0.9849	0.98504	0.98509
8	0.9791	0.98179	0.98190
9	0.9711	0.97398	0.97402
10	0.9769	0.98955	0.98955
11	0.9710	0.97386	0.98800
12	0.9693	0.97220	0.97224
13	0.9944	0.99238	0.99238
14	0.9948	0.99032	0.99032
15	0.9918	0.98976	0.98976
16	0.9913	0.98924	0.98924

Mean Voltage	0.9837	0.98484	0.98596

The methodology proposed is able to reach the same optimal configuration with minimized computation as compared to method employing global optimal search technique with iterative load flow process.
The results have been compared with ref [8].

TABLE III. RESULT COMPARISON

RADIAL NETWORK	INITIAL CONFIG.	FINAL CONFIG. REF[8]	FINAL CONFIG. PROPOSED
OPEN SWITCHES	4 11 13	6 9 11	6 9 11
POWER LOSS (MW)	.5114	.4661	.4498

V. CONCLUSION

Reconfiguration of distribution networks can improve overall operating conditions of the system. It results in better load distribution, reduced power losses and improved voltage profile of the system. Simplified equations avoided the iterative process, this reduced the computational burden. Reconfiguration using Best first search and Simplified Distflow equations can be applied for real time applications because of minimized time in reaching optimal solution configuration with satisfactory accuracy.

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TABLE IV IEEE 16 BUS SYSTEM DATA [11]

Line No.	Node *i*	Node *j*	Resistance R (Ω)	Reactance X (Ω)	Receiving Node *j* P (MW)	Q (MVAr)	Receiving Node *j* Voltage (p.u.)
1	1	4	0.0750	0.1000	2.0	1.6	$0.9907 \angle -.3968$
3	4	5	0.0800	0.1100	3.0	0.4	$0.9878 \angle -.5443$
2	4	6	0.0900	0.1800	2.0	−0.4	$0.9860 \angle -.6972$
5	6	7	0.0400	0.0400	1.5	1.2	$0.9849 \angle -.7043$
7	2	8	0.1100	0.1100	4.0	2.7	$0.9791 \angle -.7635$
8	8	9	0.0800	0.1100	5.0	1.8	$0.9711 \angle -1.452$
9	8	10	0.1100	0.1100	1.0	0.9	$0.9769 \angle -.7701$
6	9	11	0.1100	0.1100	0.6	−0.5	$0.9710 \angle -1.526$
10	9	12	0.0800	0.1100	4.5	−1.7	$0.9693 \angle -1.837$
15	3	13	0.1100	0.1100	1.0	0.9	$0.9944 \angle -.3293$
14	13	14	0.0900	0.1200	1.0	−1.1	$0.9948 \angle -.4562$
16	13	15	0.0800	0.1100	1.0	0.9	$0.9918 \angle -.5228$
12	15	16	0.0400	0.0400	2.1	−0.8	$0.9913 \angle -.5904$
4	5	11	0.0400	0.0400			
13	10	14	0.0400	0.0400			
11	7	16	0.0900	0.1200			