Multi objective Approach for Overloading and Service Restoration through Feeder Reconfiguration to minimize I^2R losses

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Abstract: This paper presents the method to solve the over loading problem and service restoration strategies for affected zones due to fault in a three feeder distribution network which deals with the estimation of load changes through feeder reconfiguration using the heuristic search technique. This method is based on minimum number of switching operations and minimum total I^2R losses. Software has been developed using C for the above work.

Key-Words: Reconfiguration, Loss reduction, Service restoration, Distribution network, Heuristic search.

1.Introduction

Distribution feeders are usually radial to simplify the over current protection. The functions carried out through a distribution system control centre depend on the state, the system is in. For example, if the load is being supplied and all operating constraints are being satisfied, then the objective may be say minimization of system losses. But, if some load has been disconnected due to a major fault, then the objective will be to restore service as soon as possible. Such apparently distinct functions share a common feature. However, both require solving a combinatorial problem whose solution is a set of switching operations. To help restore power to customers following a fault, most feeders have several interconnecting tie switches to neighboring feeders which are used for fault isolation and service restoration.

There is numerous numbers of switches in the distribution system which results in tremendous number of possible switching operations. Feeder reconfiguration, thus becomes a complex decision making process [1].

Distribution feeder reconfiguration can be used as a planning tool as well as a real-time control tool. It is a very important and useable operation to reduce distribution feeder losses and improve the system security and also enables load transfer from heavily loaded regions to the lightly loaded, which are performed by changing the status of network switches in such a way that radiality is ensured, after the operations are completed.

Service restoration problem can be solved with the application of automation techniques to electric utility distribution systems which would allow better investment utilization as well as improved service quality [6]. Most specifically, automation may reduce the time for fault isolation and service restoration to unfaulted areas. The conventional approach to power system computer applications rely on the use of numerical algorithms coded in procedural languages like C and C++. While the conventional approach is suited for quantitative applications, the Artificial Intelligence approach is more oriented to qualitative resolving [8].

Heuristic programming technique used in this paper for service restoration and overloading falls somewhere between the conventional and the Artificial Intelligence approach. This programming technique is used to solve combinatorial problems i.e. problems in which finding a solution normally involves analysis of a large number of alternatives or possible combinations. [2]

Feeder reconfiguration problem is solved by using the solution method whose features include:

- The capability to estimate with minimal computational efforts and the change in losses resulting from feeder reconfiguration.
- The criteria that may be used to eliminate undesirable switching options in order to alleviate the dimensionality problem.

The formula used in estimating the change in losses requires little additional information over the base case and it also suggests a filtering mechanism for eliminating those switching options which would not yield loss reduction. Optimal solutions have been obtained both in the case of system overloading as well as restoration by using the methods proposed.

2.Problem Statement

Fault location and isolation of a faulty section in a distribution network in a real-time is made possible with the help of monitoring and control functions in an automated distribution system. But, service restoration to the non-faulted out of service area in real-time poses a real challenge. Fast restoration strategies are necessary to reduce the inconvenience to the user during such interruptions [3]. Overloading is also one such real-time problem that can be solved by feeder reconfiguration which is performed by opening or closing two types of switches i.e. sectionalizing and tie switches respectively. A whole feeder or part of a feeder may be served from another feeder by using a tie switch linking the two, while an appropriate sectionalizing switch must be opened to maintain radial structures. Even for a distribution system of moderate size, the number of switching options is so great that, conducting many load flow studies for all the possible options becomes not only extremely inefficient from a computational stand point but also impractical as a real-time feeder reconfiguration [4].

The problem addressed in this paper is to identify the tie and sectionalizing switches that should be opened and closed respectively to achieve a maximum reduction in losses.

3.Heuristic Search

The decision problem we face involves deciding on switch/breaker status (open/closed). We proposed to solve this problem by heuristic search on a binary decision tree. By heuristic search, we mean a general search method armed with domain-specific knowledge to guide the search. The search methods allow us to traverse the space of possible system states, whereas domain-specific knowledge is essential in limiting the size of the decision tree [9].

3.a. Binary decision variables

The decision whether the switch is open/closed is denoted by the binary decision variable.

x_k = 1 if the k-th switch is closed.

0 if the k-th switch is open.

3.b. Decision vector

There are 2^m possible combinations of switch positions in the system, each one corresponding to a decision vector.

$$x_k = \{x_1, x_2, x_3, \ldots\ldots x_m\} \quad \text{-------- (1)}$$

Where x_k = 0 or 1.

3.c. Decision tree

The decision process is best illustrated by a binary tree as shown in fig-1 and fig-2. At the beginning of the process (root node), all the decision variables are undeclared i.e., we have the original problem with m unknowns. As we move down on the tree, the decision variables are declared either as 0 or 1: at level i of the tree, we have (m-i) undeclared variables left. At the bottom of the tree (level m), all the decision variables are declared: each of the 2^m nodes (leaves of the tree) is associated with a possible solution (not necessarily a feasible one).

Though the tree that must be searched could in principle be built explicitly, this is neither practical nor necessary. An implicit representation of the tree, given by the rules used to generate new nodes from the existing ones, is adopted instead. Thus, as the search process is carried out, only part of the tree is constructed explicitly and most of the tree never needs to be traversed. Domain-specific is used to avoid unnecessary search. At each node of each tree level, we can choose any undeclared variable to be declared next. When a variable is declared, two new nodes (called successors) are created. The process of tree expansion (called branching) is illustrated. The choice of next variable to be declared will depend on:

- Previous decisions taken on a particular path
- Practical rules, based on operator experience, used to guide the search.

Thus, it is possible to simulate what an experienced operator would do under the same circumstances. In addition to guiding the search, practical rules can be used to prune the tree, which may be important in limiting the growth of the number of alternatives to be considered.

3.d. Search strategy

The effectiveness of the method depends on the strategy used to control the search. Strategies such as breadth-first, depth-first can be adopted. In the present implementation of the method, we are using a depth-first search, which allows the direct stimulation of operator procedures as part of the search process like the search shown in the fig-1 and fig-2. Used without heuristics, the depth-first search is simply an exhaustive search on the decision tree. Even though exhaustive search is not suited for practical implementation, it is very useful in testing the effect of heuristics on the optimality of these solutions. As for practical implementations, the appropriate use of heuristics (the ones whose effect on the solution process is known) may be crucial regarding the efficiency of the method [2].

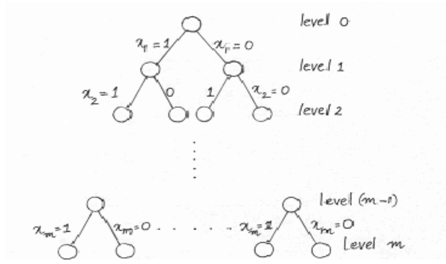

Fig.1 Decision Tree

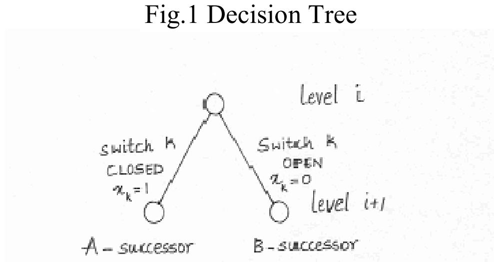

Fig.2 Successor of a Decision Tree

4. Flow Chart

In this section, we describe an implementation of the proposed approach by presenting a simple flowchart as shown in Fig 3. For simplicity, neither heuristics nor pruning rules are considered at this stage. This knowledge includes practical rules and procedures normally applied by system operators to carry out switching operations aimed at restoring service or improving system operating conditions [5].

Let us consider there is a permanent fault occurring at the load point-(6) which results in affecting the load point-(7) in the given three feeder distribution system shown in Fig 4. The optimal solution obtained in this case by using the flow chart shown in Fig 3 is “to open the section switch 13 and close the tie switch 26” [7]. The switch positions for this optimal solution are given below in Table 1:

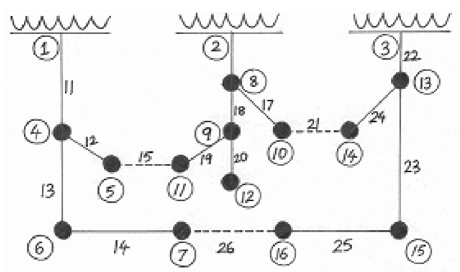
Fig.4 Three feeder Distribution System

Table 1 Switch positions

Switch	Status	Switch	Status
1.	Closed	14.	Closed
2.	Closed	15.	Open
3.	Closed	16.	Closed
4.	Closed	17.	Closed
5.	Closed	18.	Closed
6.	Closed	19.	Closed
7.	Closed	20.	Closed
8.	Closed	21.	Open
9.	Closed	22.	Closed
10.	Closed	23.	Closed
11.	Closed	24.	Closed
12.	Closed	25.	Closed
13.	Open	26.	Closed

5. Estimation of the loss changes

The amount of loss change resulting from transferring a group of loads from Feeder-II to Feeder-I can be estimated from the following simple equation [1]:

$$\Delta P = \mathrm{Re}\{2(\sum_{i \in D} I_i (E_m - E_n))\} + R_{loop} \sum |I^2| \tilde{\}}. \quad \text{--- (2)}$$

Where:

D: Set of buses which are disconnected from feeder-II and connected to Feeder-I.

m: The bus of Feeder-I to which loads from Feeder –II will be connected.

n: Tie bus of Feeder-II that will be connected to bus m via a tie switch.

$\mathbf{I_i}$: complex bus current at bus i

$\mathbf{R_{loop}}$: series resistance of the path connecting the two substation buses of Feeder-I and Feeder-II via closure of the specified tie switch.

$\mathbf{E_m}$: component of $E = R_{BUS} I_{BUS}$ corresponding to bus m. R_{BUS} is the "bus resistance matrix" of Feeder-I before the load transfer which is found using the substation bus as reference. I_{BUS} is the vector of bus currents for Feeder-I.

$\mathbf{E_n}$; Similar to E_m but defined for bus n of Feeder-II.

$\mathbf{R_e}$: real part, complex conjugate and magnitude operators respectively.

It is to be noted that E_m and E_n are computed using base-case bus currents I_i before the load transfer. It is suggested to incorporate the effects of capacitors into bus currents to facilitate computational efficiency. ΔP represents a kW loss reduction (increase) when it is negative (positive).

The second term on the right-hand side of Eq. (2) is always positive. Therefore, a reduction in losses cannot be achieved unless the first term becomes significantly negative. Since complex values are dealt within the first term, it may not be simple to draw any definite conclusions. However, we note that voltage phase-angle differences are small on most distribution systems, and those complex bus currents I_i may be mostly in phase with voltage pharos due to capacitor VAR compensation on well designed systems. Under these circumstances, loosely speaking, the first term becomes negative. $|E_m|<|E_n|$ It follows the above observation that loss reduction can be attained only if there is a significant voltage difference across the normal open tie switch and if the loads on the higher voltage drop side of the tie switch are transferred to the other side. It will be seen that the above observation can be used as a most attractive criterion to eliminate undesirable switching options during the elimination process. It is also note worthy that in Eq. (2), information regarding E is required only at the terminal buses where the tie switch is located, and that the configuration of the group of loads to be transferred or the geographic extent of the overall distribution system does not matter to the result [4]. Let us consider a three feeder distribution system shown in Fig 3 having the data as shown in Table 2 whose capacities are: 20 MW, 14.5 MW and 7 MW respectively. The loadings of each feeder being 8.5 MW, 15.1 MW and 5.1 MW respectively. The loading & capacity values show that the second feeder is overloaded and the cases of reconfiguration are presented:

Case 1: The load at bus 11 is transferred from Feeder-II to Feeder-I by closing the tie line switch 15 and opening the sectionalizing switch 19. In this case, D={11},m=5,n=11 and $\Delta P = \mathrm{Re}[2I_{11}(E_5 - E_{11}) + R_{loop}|I_{11}|^2$

Where R_{loop} is the total resistance of the path along the branches 11, 12, 15, 19, 18 and 16.

Table 2 Data of the three feeder system

Bus to Bus	Section Resistance (P.U)	End Bus Load (MW)	End Bus Voltage (P.U)
1-4	0.075	2.0	0.991/-0.370
4-5	0.08	3.0	0.988/-0.644
4-6	0.09	2.0	0.988/-0.697
6-7	0.04	1.5	0.985/-0.704
7-8	0.11	4.0	0.979/-0.763
8-9	0.08	5.0	0.971/-1.491
8-10	0.11	1.0	0.977/-0.770
9-11	0.11	0.6	0.971/-1.625
9-12	0.08	4.5	0.969/-1.836
3-13	0.11	1.0	0.994/-0.332
13-14	0.09	1.0	0.995/-0.469
13-15	0.08	1.0	0.992/-0.627
15-16	0.04	2.1	0.991/-0.698
5-11	0.04		
10-14	0.04		
7-16	0.09		

Table 3 Percentage of Real Power losses

Case	Percentage of Real Power Losses (ΔP)
I	2.56
II	2.41
III	34.26

Case-2: The load at bus 10 is transferred from feeder-II to feeder-III by closing the tie switch 21 and opening the sectionalizing switch 17.In this case, D={10}, m=14,n=10 and $\Delta P = \text{Re}\,[2I_{10}(E_{14} - E_{10})] + R_{loop}|I_{10}|^2$

Where R_{loop} is the total resistance of the path along the branches 16, 17, 21, 24 and 22.

Case-3: The loads at the buses 9, 11 and 12 are transferred from Feeder-II to Feeder-I by closing tie switch 15 and opening Sectionalizing switch 18. In this case, D= {9, 11, 12}, m=5, n=11 and $\Delta P = \text{Re}\,[2(I_9+I_{12}+I_{11})(E_5 - E_{11})] + R_{loop}|I_9+I_{12}+I_{11}|^2$

Where R_{loop} is the total resistance of the path along the branches 11, 12, 15, 19, 18 and 16.

Losses are calculated as percentage of the total load of all the three feeders and are tabulated in Table 3. The calculation of the system losses in the above three cases show that, the CASE-II has the minimum increase in losses (ΔP) which can be considered as an optimal solution for the overloading problem considered.

6. Conclusion

A heuristic search approach to distribution system restoration has been proposed. The method uses a knowledge guided search strategy to solve problems such as service restoration and is based on operating procedures which investigate alternatives that normally would not be considered by system operators which may be very helpful under certain critical operating conditions. It also facilitates to investigate the effect of practical rules on the optimality of the final solution. Computational complexity arising in reconfiguration due to overloading is identified and a criterion is developed for reducing the number of candidate options which eliminates the study of numerous load flow studies. The algorithm and expression presented in this paper shows promising flexibility that will allow their ready incorporation into the overall feeder reconfiguration and restoration strategies.

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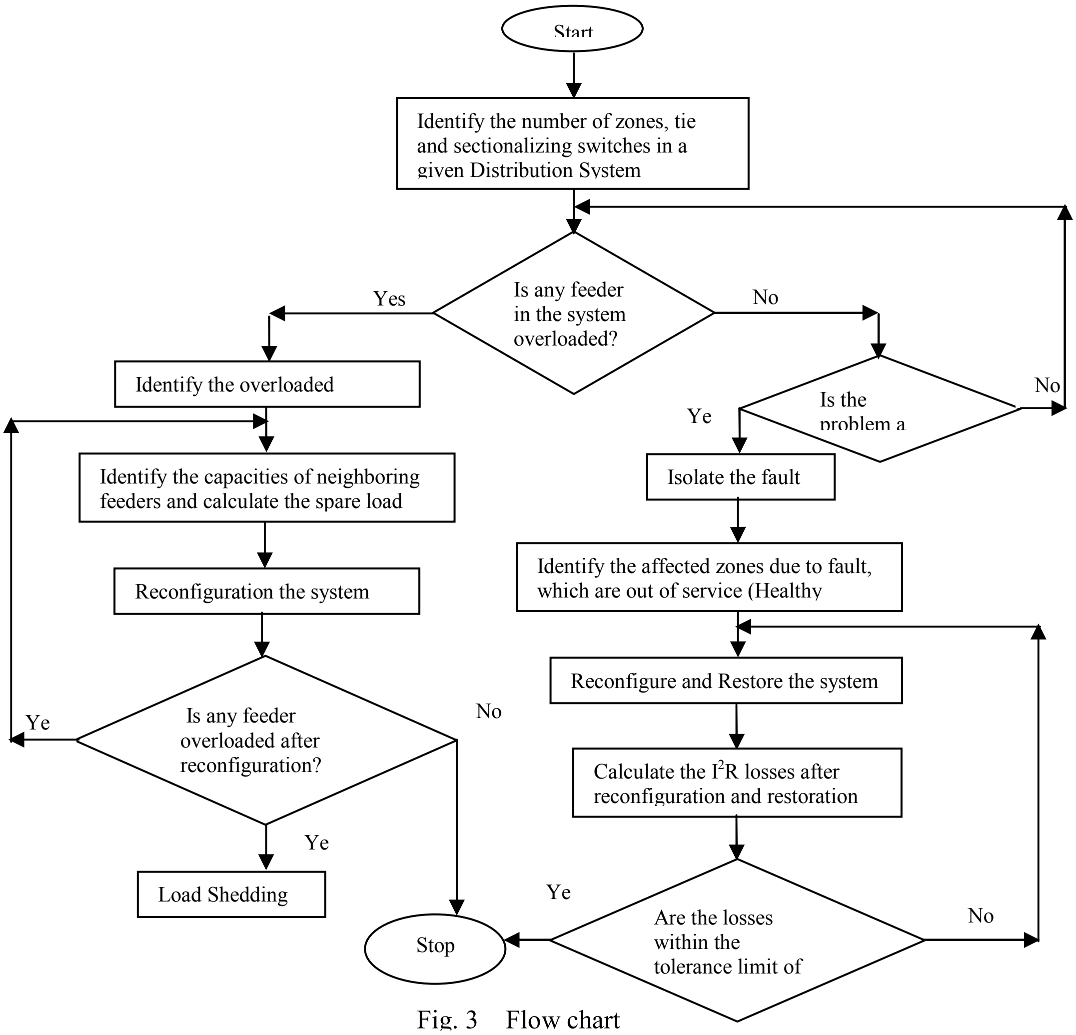

Fig. 3 Flow chart

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