FEEDER RECONFIGURATION FOR LOSSES REDUCTION IN DISTRIBUTION SYSTEMS

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ABSTRACT

A novel algorithm is presented in this paper to perform Feeder Reconfiguration in Distribution Systems with the aim to reduce electrical losses. The algorithm modifies heuristic methods proposed by previous researchers to overcome some weaknesses of their approach. This allows a faster evaluation with more accurate results.

The nature of Radial Distribution Systems is fully utilized to propose a procedure to order the nodes in such a way that fast running times may be achieved. The ordering method does not impair the flexibility of the algorithm but it rather could be used in other applications of Distribution Automation.

1 INTRODUCTION

Feeder Reconfiguration consists of the modification of the topology of an Electrical System by closing or opening tie and sectionalizing switches, in order to obtain a better performance of the system. This technique is used especially to reduce losses in Distribution Systems but can be an important tool for planning purposes. Feeder Reconfiguration could also be used for real time applications, which are common nowadays with the fast deployment of modern control centres and communication systems.

In addition, with a proper Cost Analysis, it can be shown that Feeder Reconfiguration leads to important savings. When other applications of Distribution Automation such as Load Management, Voltage Control and Service Restoration are considered besides Feeder Reconfiguration, its benefits are enhanced even further.

2 FEEDER RECONFIGURATION METHODS

Two basic approaches are used to carry out Feeder Reconfiguration: Linear Programming and Heuristic Techniques. Out of the two the latter one is the most commonly used since it can produce fast results with good accuracy. Linear Programming is used mainly in planning applications to minimize the capital investment.

In the heuristic approach there are in turn several methods. In the work developed by Merlin and Back [1], the network is treated first with all the tie switches closed, which converts it into a meshed one. Then one by one the tie switch with the lowest current is opened until the network becomes radial. This approach was later modified by Shirmohammadi and Hong [2] to overcome some weaknesses of the initial method.

Another method within the heuristic techniques, which was proposed by Civanlar et al [3], considers the closing of one tie switch and opening one sectionalizing switch at the same time, in order to transfer loads from feeders with higher voltage drop to those with lower voltage drop, but still keeping the network radial. They proposed an equation to evaluate the reduction in losses when a switching action takes place.

A more recent work has been carried out by Goswami and Basu [4], where a new algorithm of Feeder Reconfiguration is proposed, by using optimal flow pattern. In this case unlike the procedure of references [1] and [2], only one tie switch at a time is closed and the radial configuration is restored by opening the same or another switch, depending upon the result of the optimal flow. Although this method gives good results, its implementation can be very long and therefore difficult to apply in real time environments.

3 ALGORITHM PROPOSED FOR FEEDER RECONFIGURATION

The algorithm presented here is based on the improvement of the heuristic formula proposed by Civanlar et al. The accuracy of the method can be greatly improved if the effect of the load transfer in the current is considered independently for the tie link and for every line of the loop formed by the elements of the two feeders involved in the reconfiguration. This gives a more accurate calculation for the Power Losses prior to the reconfiguration and after the reconfiguration has taken place. Although the procedure has to be applied to every possible switching, the computing time is very short because no further load flow runs are required and therefore no more matrix operations are involved.

Transferring of the Load Associated to the Lower Voltage End

To explain the algorithm suggested in this paper, a very basic system will be considered with two main feeders, a and b as shown in Fig. No. 1. Their nodes starting from the source substations , will be called respectively a_1, a_2,...a_n and b_1, b_2, ...b_m. Initially the loads will be considered concentrated at the nodes; a model for distributed loads along the feeder will be treated later.

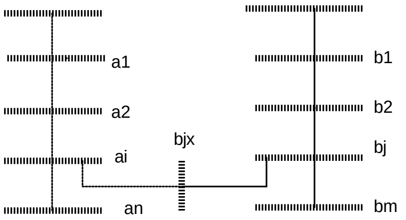

Figure No. 1 - Basic Topology

It is assumed that after a load flow solution, the voltage at bus b_{jx} is lower than that at bus a_i. Since these nodes can be connected via a tie link, a switching action should be considered to find out whether or not it yields to a reduction in power loss. The losses associated to the elements of the loop for the initial configuration are called P1 and can be calculated by using equation (1) as follows:

$$P1 = I_{a_1}^2 R_{0-a_1} + I_{a_2}^2 R_{a_1-a_2} + \dots$$
$$+ I_{a_i}^2 R_{a_{(i-1)}-a_i} + I_{b_1}^2 R_{0-b_1} + I_{b_2}^2 R_{b_1-b_2}$$
$$+ \dots + I_{bj}^2 R_{b_{(j-1))}-b_j} + I_{b_{jx}} R_{b_j-b_{jx}} \dots\dots(1)$$

In order to transfer the load of bus b_{jx} from feeder b to feeder a, the switching action to be done involves the closing of the line a_i-b_{jx}, and the opening of the line b_j-b_{jx}. The new losses within the affected path are called P2 and are calculated by adding the current of node b_{jx} to every loop element associated to feeder a and subtracting it from every loop element of feeder b. On the other hand the losses through the tie link have to be considered. The expression is given in equation (2) as follows:

$$P2 = (I_{a_1} + I_{b_{jx}} CVF)^2 R_{0-a_1} +$$
$$(I_{a_2} + I_{b_{jx}} CVF)^2 R_{a_1-a_2} + \dots$$
$$+ (I_{a_i} + I_{b_{jx}} CVF)^2 R_{a_{(i-1)}-a_i} + (I_{b_1} - I_{b_{jx}})^2 R_{0-b_1}$$
$$+ (I_{b_2} - I_{b_{jx}})^2 R_{b_1-b_2} + \dots$$
$$+ (I_{b_j} - I_{b_{jx}})^2 R_{b_{(j-1)}-b_j} + I_{b_{jx}}^2 R_{a_i-b_{jx}} \dots\dots(2)$$

The Corrective Voltage Factor -CVF- is obtained as the ratio of the old to the new voltages of the node b_{jx}; it is used to decrease the current at this node as its voltage improves when the reconfiguration takes place. The CVF is recommended to be used only to calculate the losses reduction when the first load is transferred i.e. that associated to the lower voltage end of the tie link. This is due to the fact that when more loads are transferred, the exact voltage improvement is not certain without a full load flow solution.

Transferring of Larger Amounts of Loads

The procedure explained so far gives the losses reduction when the load of the lower voltage end of the tie link (associated with feeder b) is transferred to the higher voltage end (associated with feeder a). Calculations of losses reduction in remote lines of feeder b when transferring larger amounts of loads by opening subsequent switches are done in the same way but care must be exercised to use the correct current components. This means that for the lines located between the new opening point under consideration and the tie link, the currents must be taken from the values corresponding to the initial network minus the currents of the loads located downstream. For the lines of feeder a, the procedure is the same as before.

The former can be illustrated by using again figure No. 1 and considering a switching action that involves the closing of the same switch as before and opening the line b_1-b_2; this means that all the loads from b_2 downstream, are transferred to feeder a. The CVF is not used in this case for the reason already mentioned. Obviously the expression for P1 remains constant. Therefore the equation for P2 is given in equation (3) as follows:

$$\begin{aligned}P2 &= (I_{a_1}+I_{b_2})^2 R_{0-a_1} + (I_{a_2}+I_{b_2})^2 R_{a_1-a_2} + \ldots\\ &+ (I_{a_i}+I_{b_2})^2 R_{a_{(i-1)}-a_i} + I_{b_1}^2 R_{0-b_1} +\\ &(I_{b_2}-I_{b_3})^2 R_{b_1-b_2} + \ldots + (I_{b_{j-1}}-I_{b_j})^2 R_{b_{j-2}-b_{j-1}} +\\ &(I_{b_j}-I_{b_{jx}})^2 R_{b_{(j-1)}-b_j} + I_{b_{jx}}^2 R_{a_i-b_{jx}} \ldots..(3)\end{aligned}$$

It is important to emphasize that equations (2) and (3) account for the losses within the path affected by the reconfiguration and do not give the total losses for the feeders a and b. Therefore only the difference between P1 and P2 must be taken to assess if whether or not the reconfiguration is worthwhile.

Consideration of Non-Uniformly Distributed Loads

A general model for the analysis will now be considered, when the loads can be uniformly distributed along the feeders instead of being concentrated at the ends. If the total feeder current at the source end is I_1 and the concentrated load at the other end is I_2, the value for the current along the feeder depends on the distance from the source and can be expressed according to the equation (4):

$$i(x) = I_1 - (I_1 - I_2)x \ldots..(4)$$

If a factor $p = I_2 / I_1$ is introduced, the equation becomes:

$$i(x) = I_1\left[(p-1)x + 1\right] \ldots..(5)$$

The expression for the current given in Eqn. (5) should be substituted into Eqns (1), (2) and (3) to obtain more accurate results for losses reduction when feeder reconfiguration is investigated and when the system has both concentrated loads at some nodes and uniformly distributed loads along some lines.

4 IMPLEMENTATION

The aforementioned algorithm was implemented in a program written in FORTRAN 77 version for WINDOWS. A Load Flow subroutine was included, since the data for the base case is required as a starting condition. The Load Flow was prepared with the Full Newton Raphson technique due to the low X/R ratio inherent to Distribution Systems.

Program Structure

The program has been structured in the following subroutines to increase its flexibility and allow the possibility of improving it in future works:

- Data Input
- Nodes ordering
- Newton Raphson Algorithm
- Matrix Inversion
- Load Flow Results
- Feeder Reconfiguration

All the above subroutines except the Matrix Inversion, were developed in the course of this work.

Nodes Coding

A coding for the nodes in a Distribution System is paramount to handle the data properly. In this work a simple but powerful coding methodology is proposed where the node number has four figures. The first two figures, which are in the range of 01 to 99, represent the number of the main feeders leaving the source substations. The third figure represents the section number within the respective feeder, from which other loads are connected or tapped. The fourth figure is zero for nodes that belong to the main feeder or 1 to 9 for secondary nodes.

According to this code, up to 99 main feeders can be considered, each one having up to 10 tapping nodes and each of these in turn having up to ten different nodes. For example: 8011 is the load No. 1 of the first section of feeder 80; 4020 is the second tapping node of the feeder 40. If more divisions are required, the coding could be easily adjusted by adding more figures provided that the same procedure is kept.

Before the reconfiguration analysis is started, all the lines are arranged by considering the receiving end node number. This allows the program to identify quickly the nodes associated to any particular location. This is achieved by giving a TYPE NUMBER to every receiving end node, which indicates the role of that node. This is vital to determine if the element is whether or not in the already referred loop or main path and therefore if its current and resistance has to be considered. The coding used for the Type Number in this work is as follows:

1	Principal first node of any feeder
2	Principal intermediate node
3	Principal end node
4	Secondary node
5	Principal first node of the system.

The procedure for ordering the receiving end nodes starts always from the very last node which has the largest number. The program then counts down in steps of one until the following adjacent receiving end node that belongs to the main path is identified which has a type of 2. The process is continued until the node type 1 is reached, which corresponds to the feeder connected to the source substation. At this point the program jumps to the end of another feeder and the process is repeated until the node type 5 is obtained which corresponds to the first feeder of the whole system.

5 RESULTS

The evaluation was done with the system depicted in reference [3] for the eight alternatives suggested by the authors. The system is reproduced in Fig. No. 2 but with the coding number proposed here.

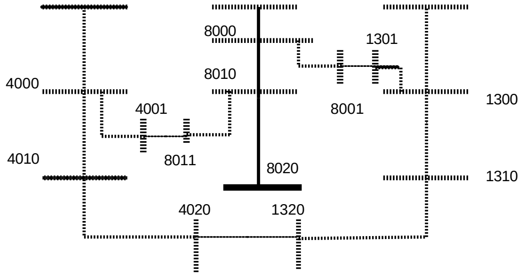

Fig. No. 2 Example Network

The results for the eight cases are shown in Table No. 1. It is interesting to notice the high accuracy of the figures for the losses reduction obtained with this method given in column 6, which are very similar to the full load flows values given in column 5.

TABLE No. 1
COMPARISON OF RESULTS OBTAINED WITH A LOAD FLOW AND THE PROPOSED METHOD

CASE DESC	SWIT CLO	SWIT OPEN	TOT. LOSS MW.	L.F. RED. KW.	METH RED. KW.
BASE	-	-	0498	-	-
1	4001 8011	9999 8000	1.203	-0.705	-0.662
2	4001 8011	8000 8010	0.688	-0.190	-0.280
3	4001 8011	8010 8011	0.485	+0.013	+0.015
4	8001 1301	9999 8000	1.387	-0.889	-1.150
5	8001 1301	9999 8000	0.476	+0.022	+0.023
6	4020 1320	9999 40000	0.925	-0.427	-0.342
7	4020 1320	4000 4010	0.558	-0.06	-0.073
8	4020 1320	4010 4020	0.510	-0.012	-0.005

From the table clearly the application of the method produced consistent results for all cases, even for those where the opening switch was far away from the closing switch.

6 CONCLUSIONS

A modification of the methods based on heuristic considerations has been proposed, to assess losses in Distribution System when Feeder Reconfiguration is used. The algorithm takes into consideration the voltage levels at both ends of the switches deployed in the prospective tie links, but the magnitude of the currents being transferred is considered independently in every element of the loops involved, by means of a procedure that remarkably increases the accuracy of the results without demanding excessive amount of computing time. The procedure is accomplished with a simple coding number for nodes, which can be used also in other applications within Distribution Automation. The algorithm is very fast since it does not require further load flow solutions except for the base case and gives consistent results. On the other hand the method allows to consider loads either concentrated at the ends or distributed along the feeders. A further advantage of the algorithm is that the loads of those nodes that are not included in the loop or main path, are considered within the equivalent at the corresponding node from the loop where they are tapped and not individually as some previous algorithms suggested. This saves calculations and improves the accuracy of results.

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