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Network Reconfiguration for Electric Power Loss Reduction in a Distribution Network

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ABSTRACT

In this paper work, an IEEE 33 bus radial distribution system has been chosen as the test system. Reconfiguration of this system is done by changing the status of normally closed sectionalizing switches and normally open tie-switches. Initially, power loss for original network is obtained and the same is checked for the reconfigured network and a comparative study has been done of the feeder system on the basis of power loss and other constraints including voltage regulation, capacity limit and power balance. The topology complexity of real distribution networks requires searching through many possible configurations.

The paper presents two different methods of loop cutting technique for reconfiguration. The first method is minimum branch current based reduction which gives a power loss of 0.1296MW with a 38.60% reduction with respect to the power loss in the original network of 0.211MW, the second method being the minimum voltage difference based reduction with a power loss of 0.1265MW with a 40.05% also with respect to the power loss in the original network of 0.211MW. A comparison has been done for power loss reduction and voltage profile in these. Also, the applicability of BIBC has been discussed for weakly meshed radial distribution networks.

Keywords: Electrical Distribution System, Network Reconfiguration, Loss Reduction, BIBC, Loop Cutting Techniques.

INTRODUCTION

There are three main parts in an electric power system; generation, transmission and distribution. Distribution systems hold a very significant position in the power system since it is the main point of link between bulk power and consumers. Effective planning of radial distribution network is required to meet the present growing domestic, industrial and commercial load day by day. Distribution networks have gained an overwhelming research interest in the academics as well as in the industries community nearly from last three decades. The examples of prominent distribution networks that affect domestic/residential users and industrial personals are water distribution networks, electricity distribution networks, data/voice communication networks, and road traffic networks etc. Electricity is an essential commodity and its absence for short-while creates annoyance and discomfort in everybody's life. Typical voltage levels for distribution networks in Nigeria are 33kV and 11kV. Even though distribution systems only deal with low voltages, distribution network plays important part in linking transmission lines with retail customers.

As customers keep increasing day by day, the distribution network has become more complex. Hence, it is important to improve the reliability of the system. Reliable electric power system serves customer loads without interruptions in power supply, and has the ability to deliver uninterrupted services to customers. Subsequently, a reliable network should allow the utility company to deliver the power at a minimum cost.

However, a perfect power system may seem almost impossible to achieve due to some obstacles during power dispatch. Technical losses occur due to current that flows through the conductor. This means that, a power utility company has to generate more power to fulfill customer demand.

One of the important ways to reduce technical losses is through reconfiguration of distributions systems. Hence, a proper planning is crucial in ensuring that the distribution network is in an efficient condition.

Distribution network needs proper planning during system configuration where then objective of planning is to find the most reliable system that fulfils the need of minimum losses and meet the system constraints.

CLASSIFICATION OF DISTRIBUTION NETWORK

All distribution of electrical energy is done by constant voltage system. In practice, the following three classes of distribution circuits are generally used in distribution system.

1. Radial Distribution System

In this system, primary feeders take power from the distribution substation to the load areas by way of sub feeders and lateral-branch circuits. This is the most common system used because it is the simplest and least expensive to build. It is widely used in sparsely populated areas. A radial system has only one power source for a group of customers. Radial feeders are characterized by having only one path for the power to flow from the source (distribution substation) to each customer. The major disadvantage of radial system is its lack of security of supply.

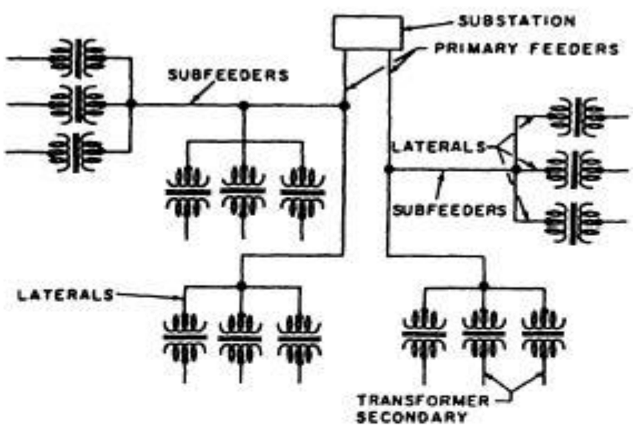

Figure 1 : Radial distribution system

2. Ring Main System

The loop (or ring) distribution system is one that starts at a distribution substation, runs through or around an area serving one or more distribution transformers or load centre, and returns to the same substation. A fault in the primary loop is cleared by the breakers in the loop nearest the fault, and power is supplied the other way around the loop without interruption to most of the connected loads. If a fault occurs in a section adjacent to the distribution substation, the entire load can be fed from one direction over one side of the loop until repairs are made. The ring main system has the following advantages:

- There are very less voltage fluctuations at consumer’s terminals.
- The system is very reliable as each distributor is fed with two feeders.

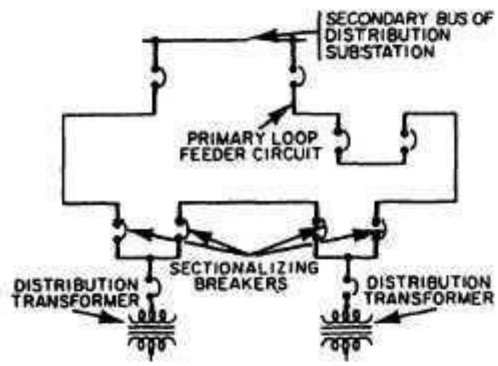

Figure 2 : Ring main system

1.2.3 Interconnected system

The network system shown is the most flexible type of primary feeder system. Power can flow from any substation to any distribution transformer or load centre in the network system. The network system is more flexible about load growth than the radial or loop system. Service can readily be extended to additional points of usage with relatively small amounts of new construction. When the feeder ring is energized by two or more than two generating stations or sub stations, it is called inter-connected system.

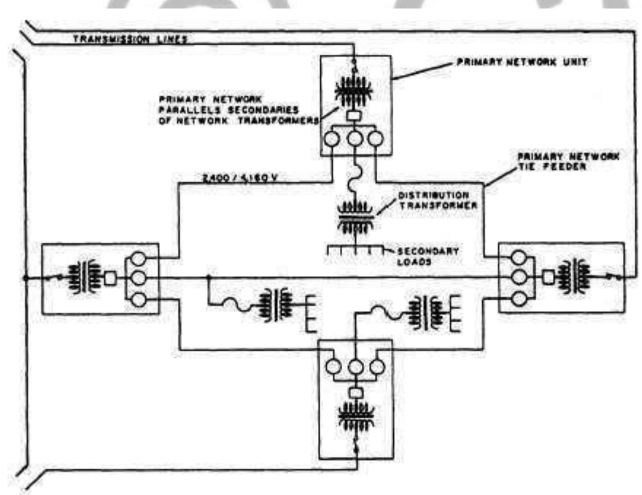

Figure 3: Interconnected system

REQUIREMENTS OF DISTRIBUTION NETWORK

It is mandatory to maintain the supply of electrical power within the requirements of many types of consumers. Following are the necessary requirements of a good distribution system:

(a) Availability of power demand: Power should be made available to the consumers in large amount as per their requirement. This is very important requirement of a distribution system.

(b) Reliability: As we can see that present day industry is now totally dependent on electrical power for its operation. So, there is an urgent need of a reliable service. If by chance, there is a power failure, it should be for the minimum possible time at every cost. Improvement in reliability can be made up to a considerable extent by

a) Reliable automatic control system.

b) Providing additional reserve facilities.

(c) Proper voltage: Furthermost requirement of a distribution system is that the voltage variations at the consumer terminals should be as low as possible. The main cause of changes in voltage variation is variation of load on distribution side which has to be reduced. Thus, a distribution system is said to be only good, if it ensures that the voltage variations are within permissible limits at consumer terminals.

(d) Loading: The transmission line should never be over loaded and under loaded.

(e) Efficiency: The efficiency of transmission lines should be maximum say about 90%.

Distribution network reconfiguration is an important tool to reduce the system's power loss, and to do the load balancing in distribution system. This operation is to transfer load from one feeder to another, which will significantly improve the overall system operating conditions. Configuration must be done from time to time, since the line distribution shows different characteristics as each distribution feeder consists of residential, commercial and industrial type, load. Some sections of the light distribution system loaded at specific times of the day and many loaded at other times. The configuration management is done at the time of service maintenance or service testing. The configuration of this radial distribution system can be changed by changing the status of switches. Here the normally close sectionalizing switches are opened and same numbers of normally open tie-switches are closed. This is called reconfiguration. In new topological structure, the tree shape of radial distribution is maintained. The procedure can be said as the part of “Distribution Management”. Here, reconfiguration is done to obtain minimum loss path for the load feeding. An early work on loss reduction through network reconfiguration was presented by Civanlar et al. [1] which described a formula to estimate the loss change resulting from the transfer of a group of loads from one feeder to another feeder. This is done through the closing of a single tie switch and the opening of a single sectionalizing switch. Baran et al. [2] described a reconfiguration methodology for loss reduction and load balancing based upon considering branch exchange type switching. Shirmohammadi et al. [3] described a technique for the reconfiguration of distribution networks to decrease their resistive line losses and included results pertaining to large scale system examples. Lubkeman et al. [4] presented an expert system using heuristic rules to shrink the search space for reducing the computation time. However, only a feasible solution can be obtained for knowledge based methods. Chiang et al. [5], [6] proposed new solution methodologies using the simulated annealing algorithm for the network reconfiguration. Goswami et al. [7] presented a heuristic algorithm for the reconfiguration of feeders. Kochi Nara et al. [8] proposed network reconfiguration techniques for minimum loss configuration using genetic algorithm (GA). Kim et al. [9] proposed a neural network based method with mapping capability to identify various network configurations corresponding to different load levels. Borozan et al. [10] proposed an algorithm for calculating Zloop matrix using the ordered network elements. Taleski et al. [11] proposed a method to determine the network reconfiguration with minimum energy losses for a given period. Jeon et al. [12] presented the simulated annealing algorithm with Tabu search for loss reduction. The Tabu search attempted to determine a better solution in the manner of a greatest - descent algorithm, but it could not give any guarantee of the convergence property. Chin et al. [13] presented a ranking index method to determine the distribution network reconfiguration problem for loss reduction. Morton et al. [14] presented a brute force solution for determining a minimal-loss radial configuration. The graph theory involving semi sparse transformations of a current sensitivity matrix was used, which guaranteed a globally optimal solution but needed an exhaustive search. Lin et al. [15] presented a refined genetic algorithm (RGA) to reduce losses. In RGA, the conventional crossover and mutation schemes were refined by a competition mechanism. Veerareddy et al. [17] presented a two stage approach for determining the network reconfiguration, which involves determining the loop for maximum loss reduction and distance center technique. Prasad et al. [18] presented a fuzzy mutated genetic algorithm for optimal reconfiguration of radial distribution systems.

This method involves a new chromosome representation of the network and a fuzzy mutation control for an effective search of solution space. Hong et al. [16], [19] presented a method based on genetic algorithms (GA) and fuzzy multi objective programming for determining the network reconfiguration in distribution systems. Shirmohammadi et al. [20] presented a reconfiguration of electric distribution system for resistive power loss reduction using loop cutting technique.

PROBLEM FORMULATION

Radial distribution system reconfiguration is done by opening/closing two types of switches, tie switches and sectionalizing switches. A feeder may be served from another feeder by closing a tie switch linking the two while a particular sectionalizing switch must be opened to maintain radial structures. In case of loss reduction, the problem here to be addressed is to identify tie and sectionalizing switches that should be closed and opened, respectively, to achieve a maximum reduction in losses. Theoretically, it is a straightforward matter to determine whether or not, the new system obtained through a feeder reconfiguration would incur lower losses. The reduction in losses can easily be computed from the results of two load flow studies of the system configurations before and after the feeder reconfiguration.

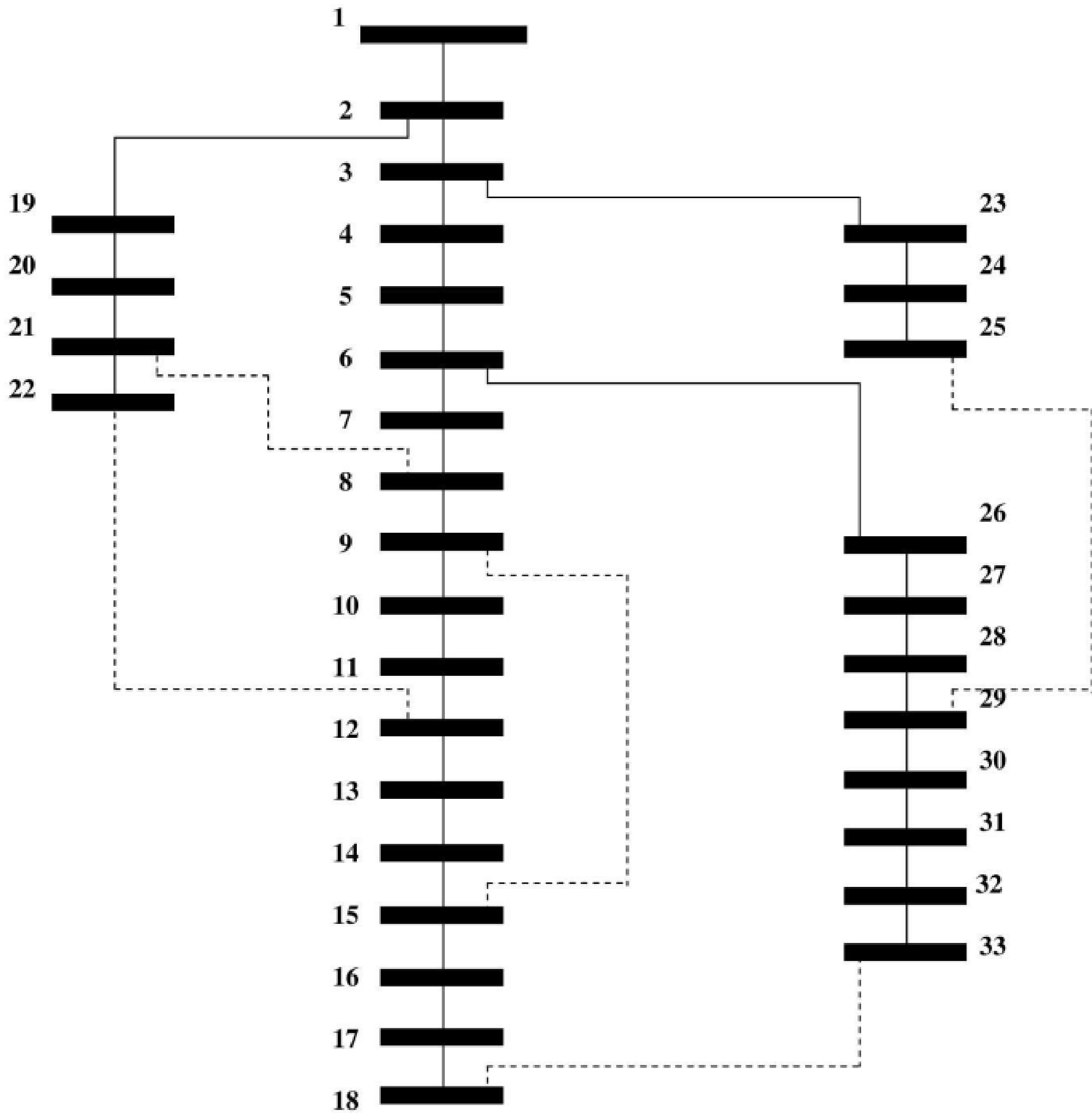

FIGURE 4: IEEE 33- Bus Radial Distribution System

STATEMENT OF THE PROBLEM:

The statement of the DSR problem can be given as:

$$Minimize P_L = \sum_{i=1}^{(N_{br}+N_{ts})} x_i I_i^2 R_i$$

Subject to:

- $V_{imin} \leq V_i \leq V_{imax} i \epsilon \{1,2,3, \dots \dots \dots, N_b\}$
- $|I_t| \leq I_{imax} i \epsilon \{1, 2, 3, \dots \dots \dots \dots (N_{br} + N_{ts})\}$
- $\sum_{i=1}^{(N_{br}+N_{ts})} x_i = N_b - 1$
- $\sum P_{i_{GEN}} = P_L + \sum P_{i_{Load}}$ and $\sum Q_{i_{GEN}} = Q_L + \sum Q_{i_{Load}}$

BIBC LOAD FLOW METHOD

The BIBC load flow method depends on branch currents. Three matrices are formed in order to calculate the bus voltages. The entire method has been summarized as under:

- Computation of voltage at buses : If Vk is the voltage of buses at kth iteration, then Vk+1 is the voltage at buses at (k+1)th iteration is given by :

$V_{k+1} = V_k - \Delta V_k$ (1)

Where ΔV_k is the change in bus voltages after two successive iterations.

Real and reactive power flow: If Pij and Qij be the real and reactive power flowing between ith and jth bus, Vi and Vj are bus voltages of ith and jth bus, yij is the admittance between ith and jth bus then:

P_{ij} = Real $\left[V_i\{(V_i - V_j)y_{ij}\} *\right]$ (2)

Q_{ij} = Imag $\left[V_i\{(V_i - V_j)y_{ij}\} *\right]$ (3)

Real power loss: If Vss and Vj refers to the voltages at main substation and bus j, respectively, yss, j refers to the line admittance between the main substation bus and bus j, PDss,j refers to the real power load at bus j and N the number of buses in the radial distribution system (RDS), then real power loss can be given by:

P_{loss} = Real $\left\{V_{ss} \sum_{j\epsilon ss}\left[(V_{ss} - V_j)\ yss, j\right] * - \sum_{j=1}^{N} PDj\right\}$ (4)

Now the current injection at the kth iteration of the solution is:

$$I_{i_{k=}} I_{i_k}\left(V_{i_k}\right) + jI_{i_k}\left(V_{i_k}\right) = \left(\frac{P_i+jQ_i}{V_{ik}}\right)^* \quad (5)$$

Where Vik and Iik are the respective bus voltage and equivalent circuit injection of bus I at kth iteration. The loop cutting or sequential switch opening method starts with all tie switches closed. The typical distribution system would be "weakly meshed" in this state, compared to the transmission system. A load flow of the meshed system will provide a minimum-loss solution (in the absence of any control action). However, the system must be brought into a radial configuration. This is done by opening switches that carry the least current, voltage or voltage differences on the premise that these will least disturb the meshed load flow solution. After each switch opening, the meshed load flow is solved again before selecting the next switch to open. The algorithm stops when the system is radial.

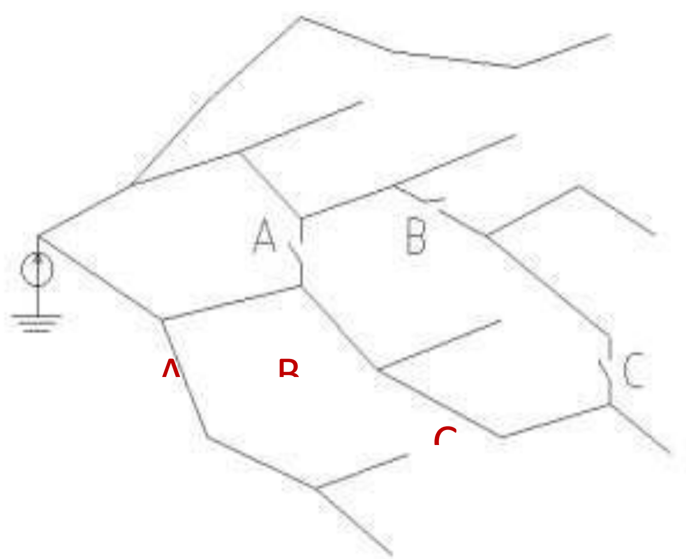

Figure 5 : A weakly meshed distribution network.

Method 1: Minimum branch current based reduction

1) Calculate active power loss for initial 33- bus radial distribution system.
2) Now consider fully meshed configuration. Calculate the power loss for the fully meshed network; this will be the least power loss the system can have. Our aim is to reach the most feasible radial state in terms of power loss by opening sectionalizing switches in each loop such that radiality is maintained and none of the loads is isolated.

3) After the power flow in base case, sort all the branch currents. The branch with the minimum current will be opened. In this way minimum current will be redistributed in the new configuration and increase in power loss will be very small.
4) Repeat load flow and open the switch with the next minimum branch current, such that it lies in a different loop, no load is isolated and radial structure is maintained.
5) The number of tie switches created due to the open loop, must be counterbalance by the same number of opened sectionalizing switches corresponding to each loop. Repeat step (4) till the network is radial and note down final configuration power loss.

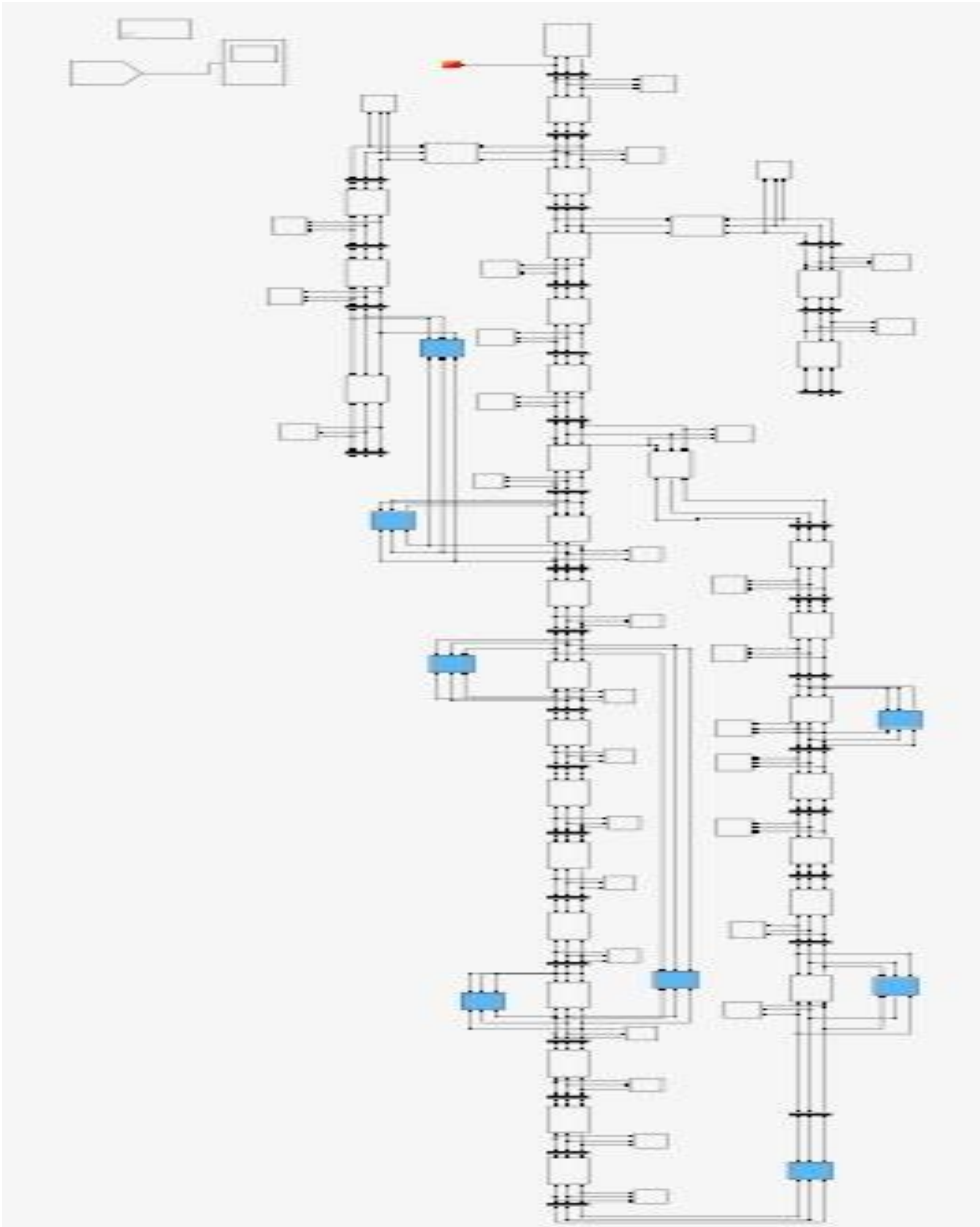

Figure 6 : Simulink Model of Final Radial Configuration using Method 1

Method 2: Minimum voltage difference based reduction

1) Calculate active power loss for initial 33- bus radial distribution system.

2) Now consider fully meshed configuration. Calculate the power loss for the fully meshed network; this will be the least power loss the system can have. Our aim is to reach the most feasible radial state in terms of power loss by opening sectionalizing switches in each loop such that radiality is maintained and none of the loads is isolated.
3) After the power flow in base case, sort voltage differences between all buses. The branch with the minimum voltage difference between the buses will be opened.
4) Repeat load flow and open the switch with the next minimum voltage differences, such that it lies in a different loop, no load is isolated and radial structure is maintained.
5) The number of tie switches created due to the open loop, must be counterbalance by the same number of opened sectionalizing switches corresponding to each loop. Repeat step (4) till the network is radial and note down final power loss.

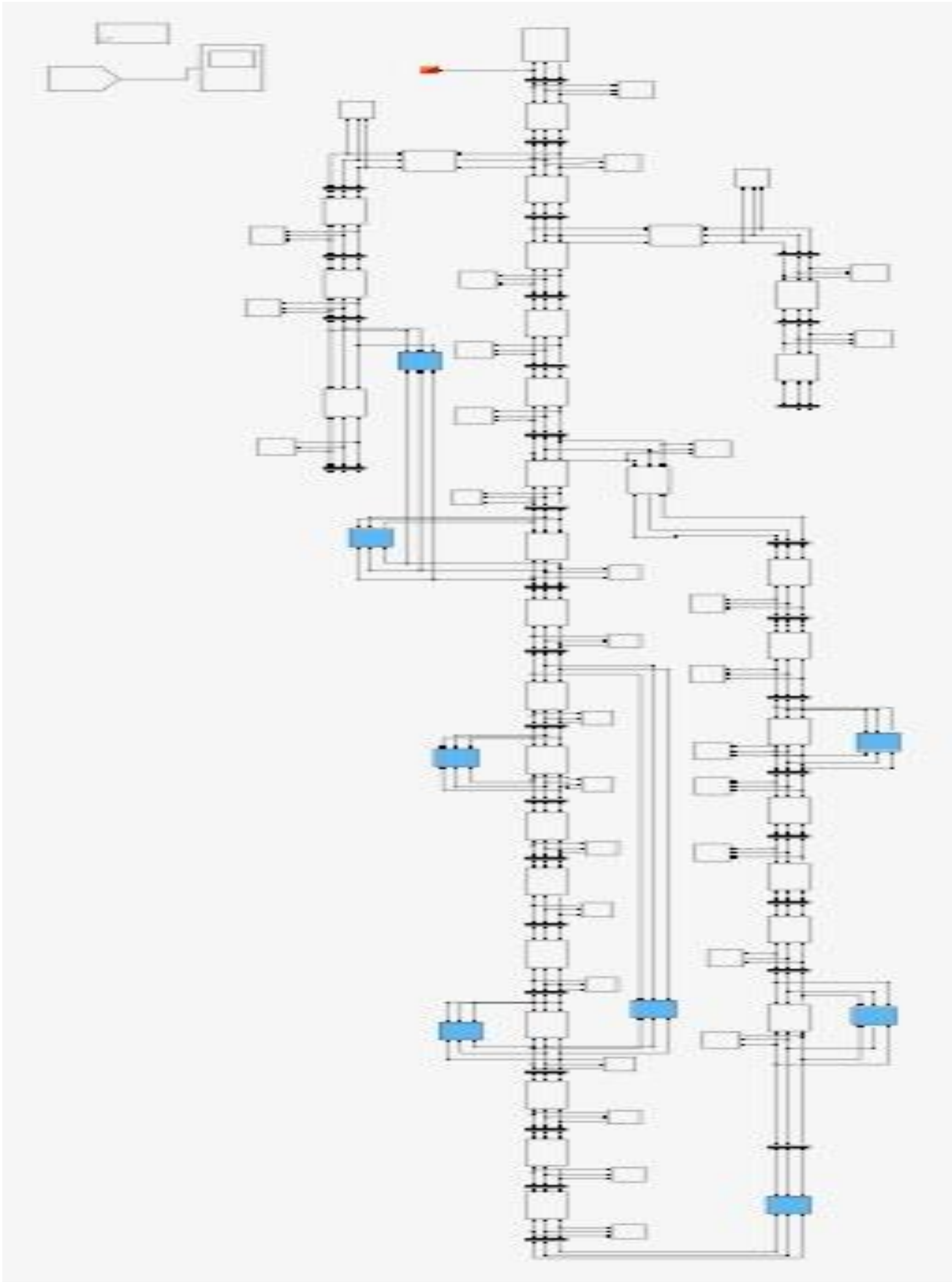

Figure 7 : Simulink Model of Final Radial Configuration using Method 2

RESULT

To illustrate the efficiency of the loop cutting technique idea for network reconfiguration, 33 IEEE bus distribution systems with an initial power loss of 0.211MW is used as test system. The numerical data for 33 bus distribution system is tabulated in appendix. The simulation studies are carried out on Intel Pentium -IV, 8.0 – GHz system in MATLAB environment. The percentage power loss reduction in these methods and their respective voltage profiles will be compared. The best method will be the one which gives maximum power loss reduction.

Table 1

S. NO	METHOD	INITIAL ACTIVE POWER LOSS (MW)	SWITCHES OPENED	FINAL ACTIVE POWER LOSS (MW)	% LOSS REDUCTION
1	Minimum branch current based reduction	0.1159 (Fully meshed state)	14 – 15, 9 – 10, 32 – 33, 28 – 29, 7 – 8.	0.1296	38.60%
2	Minimum voltage difference based reduction	0.1159 (Fully meshed state)	10 – 11, 14 – 15, 32 – 33, 28 – 29, 7 – 8.	0.1265	40.05

CONCLUSION

In this paper, distribution systems loss minimum reconfiguration methodology using loop cutting techniques was adopted. The solution methodology employs a search over different radial configurations by considering minimum branch current based reduction and minimum voltage difference based reduction. From the numerical example, it was seen that the estimation method is computationally efficient and the loss-reduction of 38.60% for minimum branch current based reduction and 40.05% for minimum voltage difference based reduction is achieved by this technique. This result demonstrates the validity and effectiveness of the methodology, and shows that the minimum voltage difference based reduction is the most efficient.

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APPENDIX

PARAMETERS FOR 33-BUS DISTRIBUTION SYSTEM

Branch Number	Bus (From)	Bus (To)	R (ohm)	X (ohm)	P-load (kW)	Q-load (kVar)
1	1	2	0.0922	0.047	100	60
2	2	3	0.493	0.2511	90	40
3	3	4	0.366	0.1844	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.819	0.707	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.03	0.74	60	20
9	9	10	1.044	0.74	60	20
10	10	11	0.1966	0.065	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.468	1.155	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.591	0.526	60	10
15	15	16	0.7463	0.545	60	20
16	16	17	1.289	1.721	60	20
17	17	18	0.732	0.574	90	40
18	2	19	0.164	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50

23	23	24	0.898	0.7091	420	200
24	24	25	0.896	0.7011	420	200
25	6	26	0.203	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.059	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.963	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.341	0.5302	60	40
33	21	8	0	2		
34	9	15	0	2		
35	12	22	0	2		
36	18	33	0	2		
37	25	19	0	2		

Base kV= 12.66, Base MVA= 0.1

Tie switches = 21-8; 9-15; 12-22; 18-33; 25-19