A Fuzzy Multi Objective Approach For Reconfiguration of Radial Distribution Systems

A Project Report

Submitted by

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BONAFIDE CERTIFICATE

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ABSTRACT

This project presents a way for network reconfiguration of radial distribution systems based on fuzzy multi-objective approach.

Among various types of distribution systems, radial distribution systems are the most commonly used one in our country, because of low initial cost of this system. But end customers might face the problem of large voltage drop. There will be increased power loss, voltage drop, current flow beyond capacity in the branches and feeder imbalance when load varies. To avoid these problems, reconfiguration of distribution system is done.

Tie line switches (which are normally open switches) will be present between feeders; they are used to reconfigure loads to a different feeder depending on certain objectives. This is called network reconfiguration. To reconfigure the system, initially a tie line switch is selected and closed so that a loop is formed and any one of the branches (which are normally closed switches) present between the loads in the loop is opened to maintain radial structure in which all loads must be energized. Load flow solution process is used to find node voltage, line flows, losses, line and feeder current flow for each configuration. These are used to validate the best configuration.

Multiple objectives are considered for determining which branch should be opened. Load balancing among the feeders, minimization of real power loss, minimization of deviation of node voltage, and minimization of branch current constraint violation are the four objectives considered. These four objectives are modeled with fuzzy sets to evaluate their nature and the above objectives are converted to membership functions. After each reconfiguration, membership values are noted and the best among

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LIST OF SYMBOLS

	SYMBOLS	ABBREVIATION
1.	NB	Total number of nodes
2.	LNI	Total number of branches
3.	B	Branch no B=1,2,3…..LN1
4.	PL(i)	Real power load at i^{th} node
5.	QL(i)	Reactive power load at i^{th} node
6.	V(i)	Voltage of i^{th} node
7.	R(B)	Resistance of B^{th} branch
8.	X(B)	Reactance of B^{th} branch
9.	Z(B)	Impedance of B^{th} branch
10.	I(B)	Current that flows through branch B
11.	IL(B)	Load current of node i
12.	LP(B)	Real power loss of branch B
13.	LQ(B)	Reactive power loss of branch B
14.	IS(B)	Sending end node of branch B
15.	IR(B)	Receiving end node of branch B
16.	DVMAX	Maximum voltage difference

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION FOR THE WORK BEING CARRIED OUT

Network reconfiguration is done in radial distribution system to handle problems during distribution. But most of the work carried out so far focuses only on loss reduction as the objective for network reconfiguration. Other factors like reducing voltage drop across end customers and feeder load balancing are not considered for reconfiguration. In our work multiple objectives like, minimization of real power loss, minimization of deviation of node voltage, minimization of branch current constraint violation and load balancing among various feeders are considered for performing the reconfiguration process.

1.2 STATEMENT OF THE PROBLEM

In India most distribution networks are configured radially, because of low initial cost of this system. But end customers might face the problem of large voltage drop. There will be increased power loss, node voltage deviation, current flow beyond capacity in the branches and feeder imbalance when load varies. To avoid these problems, reconfiguration of distribution system is done.

1.3 OBJECTIVE OF THE WORK

- To develop nodes beyond branches algorithm for load flow analysis.
- To develop load flow algorithm for radial distribution network.
- To reconfigure the radial distribution system with the following multi objectives.
  They are:

1.4 ORGANIZATION OF THE REPORT

This report is organized in 7 chapters including this chapter. They are described in what follows.

Chapter 2 of the report gives a brief insight into distribution networks. The components of a distribution network, radial and ring main systems, their advantages and disadvantages are explained.

Chapter 3 explains the process of network reconfiguration. Its purpose, methodology, objectives considered and how heuristic rules are incorporated in the process.

Chapter 4 explains the method adopted for radial load flow solution. The solution methodology is stated and the entire process is explained with the help of flowcharts and algorithms. A sample 28 node distribution system is considered and the results of the solution methodology are presented.

In chapter 5 introduction is given to fuzzy set theory, how the membership functions for the multiple objectives are framed in fuzzy environment and how each option is validated in fuzzy environment using deterministic approach is explained.

Chapter 6 explains the network reconfiguration process using fuzzy validation and an algorithm is given for the entire process.

Chapter 7 explains the entire simulation process and the results obtained. A 3 feeder sample system consisting of 13 branches, 16 nodes and 3 tie line switches is considered for the simulation process and the results are presented. Improvement in the objectives of the reconfiguration process is also explained in this chapter.

1.5 METHODOLOGY

In our work, network reconfiguration of radial distribution system is

CHAPTER 2

DISTRIBUTION SYSTEM

CHAPTER 2

DISTRIBUTION SYSTEM

2.1 DISTRIBUTION SYSTEM

A distribution system is a network of conductors consisting of

(1) Feeders

(2) Distributors and

(3) Service lines

A feeder is a conductor joining sub-station with the locality, where power is to be distributed. Generally no tappings are taken from the feeder hence the current remains the same throughout. The conductor used as a feeder should have the required current carrying capability.

A distributor is a conductor from which tappings are taken for supplying the power to the individual consumers. Therefore, it causes voltage drop and current varies throughout the length of the distributor. For designing a distributor, voltage drop is the main consideration.

A service line is a piece of small conductor, which joins the energy meter of the consumer with the distributor.

2.2 RADIAL DISTRIBUTION SYSTEM

If the distributor is connected to the supply system on only one end with help of feeder, then the system is a radial system of distribution. The simple radial structure is given in the figure 2.1. The direction of power flow in a radial system is unambiguous and always flows away from the source. Where each component has a unique path to the

- Distribution system typically has a radial architecture, a tree that branches from highest voltage to successively smaller sub transmission lines
- Radially operated system is highly interconnective, but radial conditions are satisfied by the use of normally open switches.

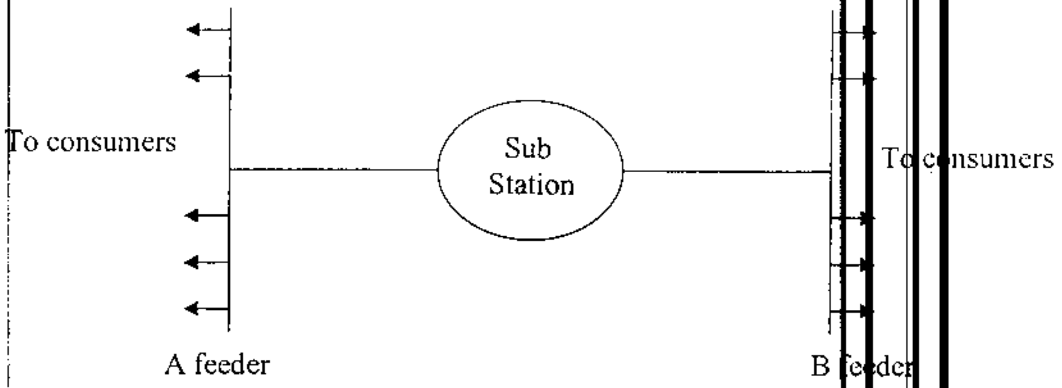


Figure 2.1 Simple Radial structure

2.2.1 Advantages

- Simplest, since it is fed only at one end.
- The initial cost is low.
- Useful when the generation is at low voltage.
- Preferred when the station is located at the centre of the load.

2.2.2 Disadvantages

- In this type of system, the end of the distributor nearest to the generating station would be heavily loaded.

- This can be remedied to some extent if the distributor is fed at a number of points as shown in figure 2.2.

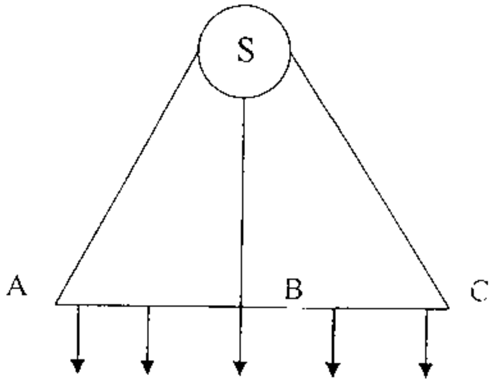
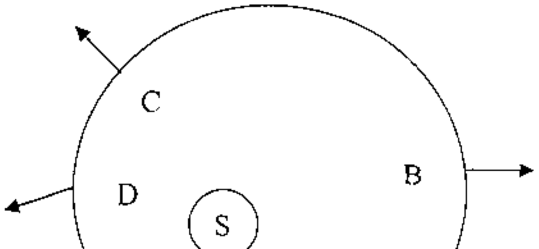


Figure 2.2 Radial distribution system

In this figure, three feeders SA, SB and SC from a generating station S are shown feeding a distributor AC at points A, B and C.

2.3 RING MAIN SYSTEM

- A ring main distribution system employs a feeder which covers the whole area of supply finally returning to the generating station.
- The feeder is closed on itself.
- This arrangement is shown in figure 2.3 where the feeder ABCDEFA forms complete ring.
- This arrangement is similar to two feeders in parallel on different routes.



CHAPTER 3

NETWORK RECONFIGURATION OF RADIAL DISTRIBUTION SYSTEMS

CHAPTER 3

NETWORK RECONFIGURATION OF RADIAL DISTRIBUTION SYSTEMS

3.1 NEED OF NETWORK RECONFIGURATION

In India most of the distribution networks are configured radially, because initial cost is low in this system. But end customers might face the problem of large voltage drop. There will be increased power loss, node voltage deviation, current flow beyond capacity in the branches and feeder imbalance when load varies. To avoid these problems, reconfiguration of distribution system is done.

3.2 METHODOLOGY

The configuration can be varied with manual or automatic switching operations, so that all of the loads are supplied but power loss is reduced and power quality is enhanced. Reconfiguration also relieves the overloading of network components. The change in network configuration is performed by closing tie (normally open) switches and opening sectionalizing (normally closed) switches of the network. These switching are performed in such a way that the radiality of the network is maintained and all the loads are energized. Obviously, the greater the number of switches is, the greater the possibilities are for reconfiguration and better the effect are. In recent years, considerable research has been conducted for loss minimization in the area of network reconfiguration of distribution systems.

The present work considers network reconfiguration problem as a multiple objectives problem subject to operational and electric constraints . The problem formulation proposed here considers four different objectives related to

At the same time, a radial network structure must be maintained after network reconfiguration in which all the loads must be energized. The branch to be opened after closing tie switch is validated based on the four objectives. These four objectives are modeled with fuzzy sets to evaluate their precise nature. Heuristic rules are also incorporated in proposed algorithm for minimizing the number of tie switch operations. There are multiple objectives to be satisfied simultaneously, a compromise must be made to get the best solution. One solution methodology for multiple objective validation in fuzzy framework is based on max-min principle.

3.3 MULTIPLE OBJECTIVES

There will be certain real power loss when a sub-station is feeding loads. Total real power loss of the system can be reduced when the system is reconfigured. Reconfiguration is done by selecting the configuration which has minimum real power loss. Thus, minimization of system real power loss is one of our objectives.

In case of radial distribution system, consumers at end are often affected by large voltage drop. To avoid huge voltage drop, not many loads should be connected to a single sub-station. If such a case occurs, reconfiguration should be done by finding which configuration's maximum value of deviation of node voltage from sub-station voltage is the least. Thus, minimization of deviation of node voltage is one of our objectives.

When many loads are fed by a single sub-station, large value of current flows through the branches, so reconfiguration has to be done by checking whether the current carried by each branch is within permissible limits. Thus minimization of branch current constraint violation is one of our objectives.

To avoid a single sub-station feeding many loads, we should check feeder current of all feeders not vary to great degree. This objective is called load balancing among

3.4 HEURISTIC RULES

Heuristic rules are incorporated in the proposed algorithm for minimizing the number of tie switch operations.

The optimum switching strategies for network reconfiguration proposed by most of the researches need to consider every candidate switch to evaluate the effectiveness of loss reduction and extensive numerical computation is often required. In the present work, heuristic rules are considered, which minimize the number of tie-switch operations. These heuristic rules are explained below.

In the first iteration, compute the voltage difference across all of the open tie switches and detect the open tie switch across which the voltage difference is maximum. If this maximum voltage difference is greater than some specified value (έ), then this tie switch is considered first. It is expected that because of the largest voltage difference, this switching will cause maximum loss reduction, improve minimum system voltage, and will provide better load balancing. In the next iteration, the same procedure is repeated for the remaining tie – switches and so forth. If, in any iteration, this maximum voltage difference is less than the specified value (έ) then this tie-switch operation is discarded because the voltage difference across all other open tie switches is less than (έ).

CHARTER-4

LOAD FLOW ANALYSIS FOR RADIAL DISTRIBUTION NETWORK

CHARTER-4

LOAD FLOW ANALYSIS FOR RADIAL DISTRIBUTION NETWORK

4.1 INTRODUCTION

The choice of a solution method for a practical distribution system is often difficult. Generally, distribution networks are radial and the X/R ratio is very high. For this reason, conventional Newton-Raphson (NR) and fast decoupled load-flow methods do not converge.

This method of load-flow involves only the evaluation of a simple algebraic expression of receiving-end voltages. This method is very efficient. It is also has good and fast convergence characteristics. This method can easily include composite load modeling, if the composition of the loads is known. Several radial distribution feeders have been solved successively by using this method.

It is assumed that the three-phase radial distribution networks are balanced and can be represented by their equivalent single-line diagrams.

4.1.1 Sample distribution network

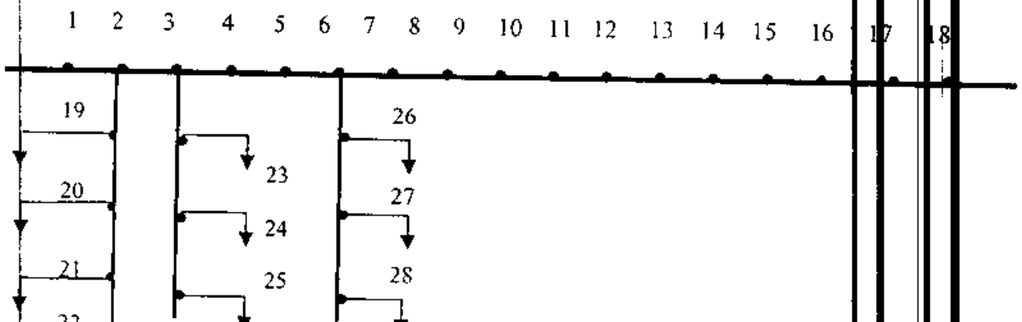


TABLE 4.1: LINE DATA AND LOAD DATA FOR 28 BRANCH SAMPLE DISTRIBUTION NETWORK

Branch Number	Sending End	Receiving end	R (Ω)	X(Ω)	PL of receiving-end node (kw)	QL of receiving-end) node (kVAr)
1	1	2	1.8216	0.7580	140.00	90.00
2	2	3	2.2270	0.9475	80.00	50.00
3	3	4	0.9180	0.5685	80.00	60.00
4	4	5	1.3662	0.3790	100.00	60.00
5	5	6	3.6432	1.5160	80.00	50.00
6	6	7	2.7324	1.1370	90.00	40.00
7	7	8	1.4573	0.6064	90.00	40.00
8	8	9	2.7324	1.1370	80.00	50.00
9	9	10	3.6432	1.5160	90.00	50.00
10	10	11	2.7520	0.7780	80.00	50.00
11	11	12	1.3760	0.3890	80.00	40.00
12	12	13	4.1280	1.1670	90.00	50.00
13	13	14	4.1280	0.8558	70.00	[illegible]0.00
14	14	15	3.0272	0.7780	70.00	[illegible]0.00
15	15	16	2.7520	1.1670	70.00	[illegible]0.00
16	16	17	4.1280	0.7780	60.00	[illegible]0.00
17	17	18	2.7520	0.7780	60.00	[illegible]0.00
18	2	19	3.4400	0.9725	70.00	40.00
19	19	20	1.3760	0.3890	50.00	30.00
20	20	21	2.7520	0.7780	50.00	30.00
21	21	22	4.9536	1.4004	40.00	20.00
22	3	23	3.5776	1.0114	50.00	30.00

4.2 SOLUTION METHODOLOGY

4.2.1 Receiving end voltage

First consider branch 1, the receiving-end node voltage can be written as

$$V(2) = V(1) - I(1)Z(1) \quad \ldots (4.1)$$

Similarly for branch 2,

$$V(3) = V(2) - I(2)Z(2) \quad \ldots (4.2)$$

As the substation voltage V(1) is known, so if I(1) is known, i.e. current of branch 1, it is easy to calculate V(2) from equation (4.1).

Once V(2) is known, it is easy to calculate V(3) from equation (4.2), if the current through branch 2 is known. Similarly, voltages of nodes 4, 5...NB can easily be calculated if all the branch currents are known. Therefore, a generalized equation of receiving-end voltage

$$V(m2) = V(m1) - I(B)Z(B) \quad \ldots (4.3)$$

$$m2 = IR(B) \quad \ldots (4.4)$$

$$m1 = IS(B) \quad \ldots (4.5)$$

where B is the branch number. B=1,2,3,………NB-1

4.2.2 Branch Current

Current through branch 1 is equal to the sum of the load currents of all the nodes beyond branch 1.

$$I(1) = \sum_{i=2}^{LNI} IL(i) + \sum_{i=2}^{LNI} IC(i) \quad \ldots (4.6)$$

The current through branch 2 is equal to the sum of the load currents of all the nodes beyond branch 2 i.e.

4.2.3 Load Current

The load current of the node *i* is

$$IL(i) = (PL(i) - jQL(i))/V^*(i) \quad i = 2,3,\ldots NB \qquad \ldots(4.8)$$

Load current is calculated iteratively. Initially, a flat voltage of all the nodes is assumed and load current of all the loads are computed using equation 4.8. A detailed load flow calculation procedure is described in section 4.5.

4.2.4 Real Power Loss

The real and reactive power loss of branch Bare given by:

$$LP(B) = |I(B)|^2 R(B) \qquad \ldots(4.9)$$

$$LQ(B) = |I(B)|^2 X(B) \qquad \ldots(4.10)$$

4.3 IDENTIFICATION OF NODES BEYOND ALL BRANCHES

To run the load flow for the distribution network, the load currents of all the nodes beyond each branch should be found. This is possible only if the nodes beyond all the branches are identified. Therefore if it is possible to identify the nodes beyond all the branches, it is possible to compute all the branch currents. Identification of nodes beyond all the branches is realized through the algorithm as explained below.

Before the detailed algorithm is given, the details of the methodology of identifying the nodes beyond all branches has been discussed. This will help in finding the exact current flowing through all the branches.

1. B=1,2,3,..............................LN1(B indicates branch)
2. k is the node count
3. Node(k) is the total number of nodes beyond branch B; and

beyond branch 2. This will help to find the exact current flowing through branch 2.

- For each node identification beyond a particular branch, 'k' will be increased by 1. Note here that before identification of nodes beyond a particular branch k has to be reset to 1.
- For B=1 (branch 1) IR(B)=IR(1)=2; check whether IR(1)=IS(i) or not for i=2,3,4,.......LN1. It is seen that IR(1)=IS(2)=2, IR(1)=IS(18)=2; the corresponding receiving end nodes are IR(2)=3 and IR(18)=19.
- Therefore, IE(1,1)=2, IE(1,2)=3, IE(1,3)=19.
- From the above discussion, it is seen that node 2 is connected to nodes 3 and 19. Similarly the proposed logic will identify the nodes which are connected to nodes 3 and 19.
- First it will check whether node 3 appears in left hand column of table 1. It is seen that node 3 is connected to node 4. Therefore IE(1,4)=4. Then it will check whether node 19 appears in the left-hand column of table 1. It is seen that node 19 is connected to 20. Therefore, IE(1,5)=20.
- Similarly, the proposed logic will check whether nodes 4 and [illegible] are connected to any other nodes. This process will continue unless all nodes are identified beyond branch 1.
- Similarly for B=2. The processes will continue unless all nodes are identified beyond branch 2.
- It is continued by considering the receiving end node of branch 3, branch4, ..., branch LN1 and in a similar way to that discussed above, the nodes have to be identified beyond these branches.
- Note that, if the receiving end node of any branch in Figure 4.1 is an end node of

- This concept of identifying the nodes beyond all the branches, which helps in computing the exact current flowing through all the branches, has been realized using an algorithm (Figure 4.2) and applied in the load flow technique as shown in the flowchart in Figure 4.2.

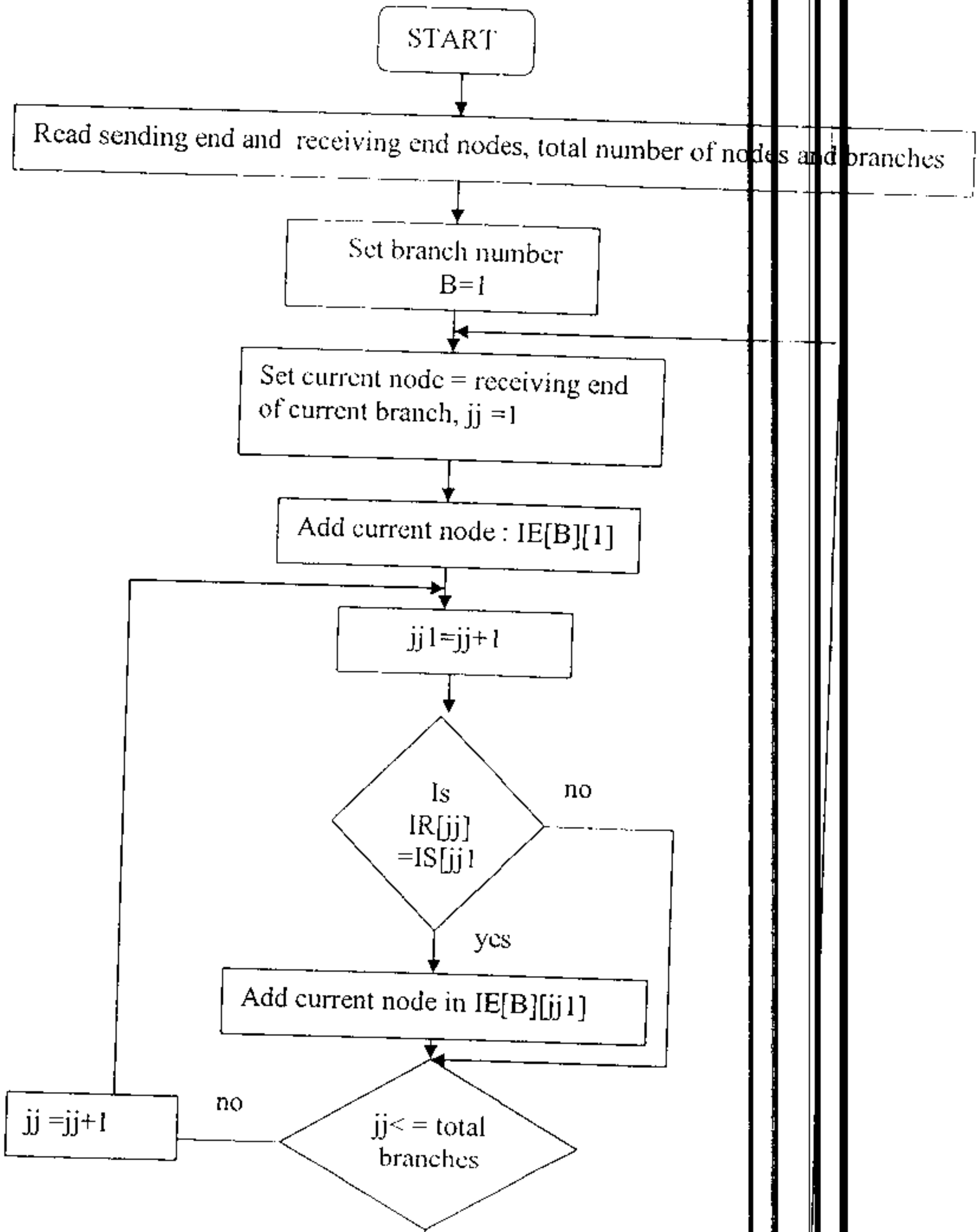

START
Read sending end and receiving end nodes, total number of nodes and branches
Set branch number B=1
Set current node = receiving end of current branch, jj =1
Add current node : IE[B][1]
jj1=jj+1
Is IR[jj] =IS[jj1
no
yes
Add current node in IE[B][jj1]
jj =jj+1
no
jj< = total branches

TABLE 4.2: NODES BEYOND EACH BRANCH FOR 28 BRANCH SAMPLE DISTRIBUTION NETWORK

Branch No(jj)	Sending End m1=IS(jj)	Receiving end m2=IR(jj)	Nodes beyond Branch jj	Total no of Nodes beyond Branch jj
1	1	2	2,3,19,4,20,23,5,21,24,6,22,25,7,26,8,27,9,28,10,11,12,13,14,15,16,17,18	27
2	2	3	3,4,23,5,24,6,25,7,26,8,27,9,28,10,11,12,14,15 16,17,18	22
3	3	4	4,5,6,7,26,8,27,9,28,10,11,12,13,14,15,16,17,18	18
4	4	5	5,6,7,26,8,27,9,28,10,11,12,13,14,15,16,17,18	17
5	5	6	6,7,26,8,27,9,28,10,11,12,13,14,15,16,17,18	16
6	6	7	7,8,9,10,11,12,13,14,15,16,17,18	12
7	7	8	8,9,10,11,12,13,14,15,16,17,18	11
8	8	9	9,10,11,12,13,14,15,16,17	10
9	9	10	10,11,12,13,14,15,16,17,18	9
10	10	11	11,12,13,14,15,16,17,18	8
11	11	12	12,13,14,15,16,17,18	7
12	12	13	13,14,15,16,17,18	6
13	13	14	14,15,16,17,18	5
14	14	15	15,16,17,18	4
15	15	16	16,17,18	3
16	16	17	17,18	2
17	17	18	18	1
18	18	19	19,20,21,22	4
19	19	20	20,21,22	3
20	20	21	21,22	2
21	21	22	22	1

4.4 LOAD FLOW

Once all nodes beyond each branch are identified, it is very easy to calculate the current flowing through each branch as described in section 4.3. For this purpose, the load current of each node is calculated using equation 8. Once the nodes are identified beyond each branch, the expression of branch current is given as

$$I(B)=\sum_{i=1}^{Node(B)} IL\ \{IE(B,i)\}$$

Initially, a constant voltage of all the nodes is assumed and load currents are computed using equations 8. After load currents and charging currents have been calculated, branch currents are computed using equation 12. The voltage of each node is then calculated by using equation 3. Real and reactive power loss of each branch is calculated by using equations 9 and 10 respectively. Once the new values of the voltages of all the nodes are computed, convergence of the solution is checked. If it does not converge, then the load and charging currents are computed using the most recent values of the voltages and the whole process is repeated. The convergence criterion of this proposed method is that if, in successive iterations the maximum difference in voltage magnitude (DVMAX) is less than 0.0001p.u, the solution has then converged.

This method for distribution load-flow algorithm for solving radial distribution networks is given in the form of a flowchart and algorithm given below.

4.4.1 ALGORITHM FOR LOAD FLOW

Step 1: Start

Step 2: Read the no of branches, starting bus IS(jj) and ending bus IR(jj) of each branch and the substation voltage V(1)

Step 3: Assume a flat voltage start, i.e. V(i) = V(1) = 1+j0 for i=2,3,……,NB and Set VV(i)=V(i) for i=2,3,……..,NB

Step 4: Read line data R + jX and load data PL – jQL in p.u value

Step 5: Start a loop for continuous iteration until a specific condition satisfied set iteration count k=0, set DVMAX=0

Step 6: Calculate load current IL (i) for all nodes i=2,3,..NB. By using eqn

$$IL(i) = \frac{PL(i) - jQL(i)}{V^*(i)}$$

Step 7: For the first branch get the no of nodes and all the nodes beyond the branch

Step 8: Calculate the branch current which the sum of the load current of all the nodes beyond that branch

Step 9: Calculate the receiving end voltage for the branch using formula

$$V(m2) = V(m1) - I(jj)Z(jj)$$

Step 10: Calculate voltage deviation at receiving end node m2,

$$DV(m2)=ABS[V(m2)-VV(m2)]$$

Step 11: if DV (m2)>DVMAX then DVMAX = DV(m2)

Step 12: Repeat steps 7,8,9,10,11 for all branches

Step 13: Check condition is DVMAX<e if not satisfied set k=k+1 and VV(m2)=V(m2) For m2=2,3,…..,NB and continue the loop

Step 14: If satisfied, the solution has converged. calculate line losses and print the

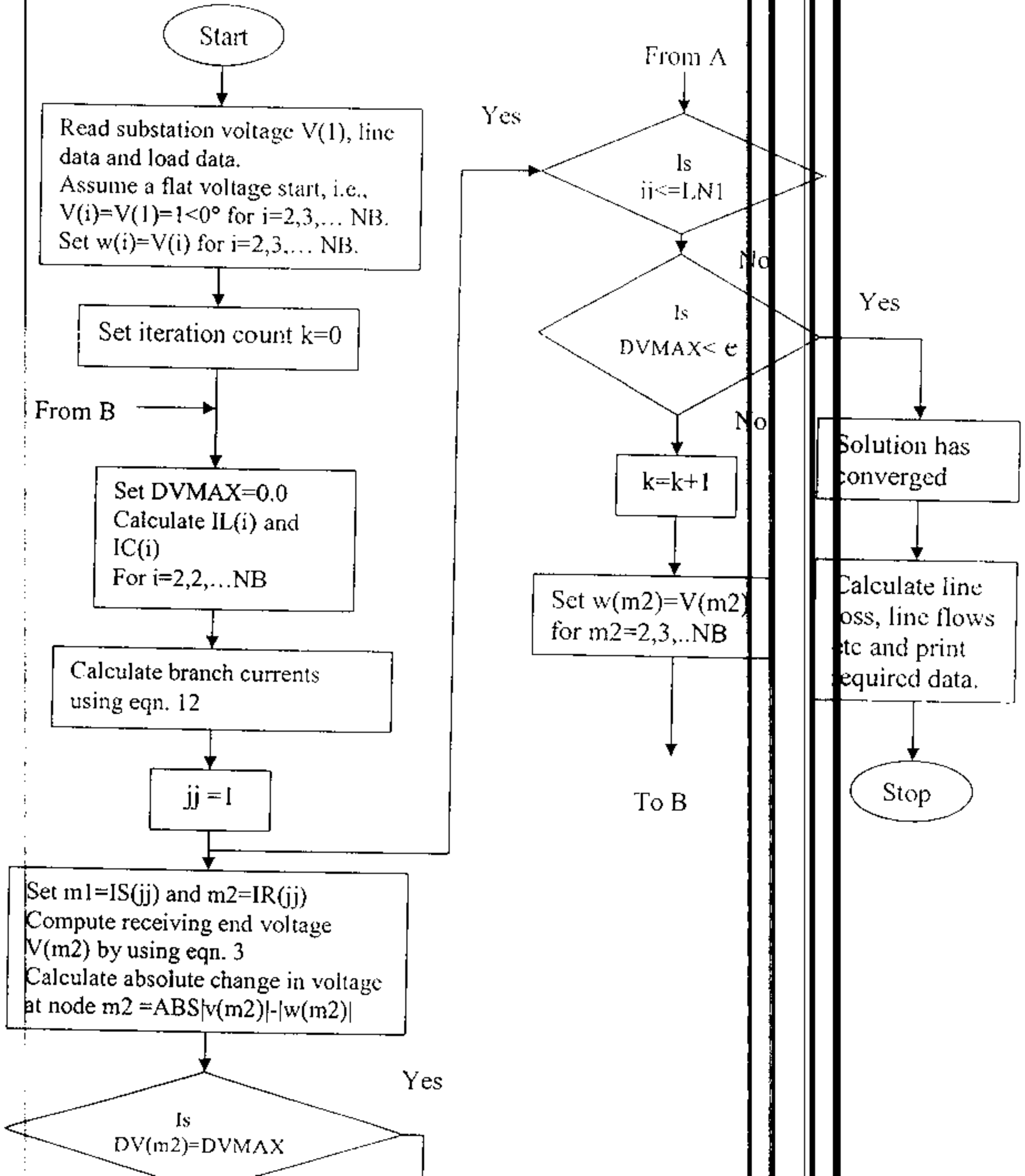

Start
Read substation voltage V(1), line data and load data.
Assume a flat voltage start, i.e., V(i)=V(1)=1<0° for i=2,3,… NB.
Set w(i)=V(i) for i=2,3,… NB.
Set iteration count k=0
From B
Set DVMAX=0.0
Calculate IL(i) and IC(i)
For i=2,2,…NB
Calculate branch currents using eqn. 12
jj =1
Set m1=IS(jj) and m2=IR(jj)
Compute receiving end voltage V(m2) by using eqn. 3
Calculate absolute change in voltage at node m2 =ABS|v(m2)|-|w(m2)|
Yes
Is DV(m2)=DVMAX
From A
Yes
Is jj<=LN1
No
Is DVMAX< e
Yes
No
k=k+1
Set w(m2)=V(m2)
for m2=2,3,..NB
To B
Solution has converged
Calculate line loss, line flows etc and print required data.
Stop

TABLE 4.3: LOAD FLOW RESULTS FOR 28 BRANCH SAMPLE DISTRIBUTION NETWORKS

Node number	Voltage magnitude(p.u)		Node number	Voltage magnitude(p.u)	
1	1.00000		15	0.565887	∠4.07695
2	0.952547	∠0.237877	16	0.556402	∠4.15615
3	0.903954	∠0.462133	17	0.548293	∠4.39566
4	0.877864	∠0.602502	18	0.545453	∠4.45247
5	0.86124	∠0.689426	19	0.943331	∠0.356132
6	0.799474	∠1.00981	20	0.941367	∠0.385785
7	0.759775	∠1.22681	21	0.938848	∠0.421985
8	0.740213	∠1.34838	22	0.936857	∠0.445165
9	0.706714	∠1.58672	23	0.898012	∠0.533519
10	0.666162	∠1.87992	24	0.894546	∠0.567268
11	0.640667	∠2.35193	25	0.891064	∠0.609898
12	0.629537	∠2.55791	26	0.795698	∠1.06197
13	0.601048	∠3.1267	27	0.794392	∠.07989
14	0.579045	∠3.75607	28	0.793739	∠.08888

CHAPTER 5

FUZZY SET THEORY AND VALIDATION IN FUZZY ENVIRONMENT

CHAPTER 5

FUZZY SET THEORY AND VALIDATION IN FUZZY ENVIRONMENT

5.1 INTRODUCTION

The concept of fuzzy logic was conceived by Lotfi Zadeh, a professor at the university of California at Berkley, and presented not as control methodology but as a way of processing data by allowing partial set membership rather than crisp set membership or non-membership. It is derived from fuzzy set theory dealing with reasoning that is approximate rather than precisely deduced from classical predicate logic.

Fuzzy logic is a problem solving control system methodology that lends itself to implementation in the systems ranging from small, simple embedded micro-controllers to large, networked, multi-channel PC or work station based data acquisition and control systems. It can be implemented in hardware, software or combination of both. It provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information.

5.2 MEMBERSHIP FUNCTION

In the fuzzy domain, each objective is associated with a membership function. The membership function indicates the degree of satisfaction of the objective. In the crisp domain, either the objective is satisfied or it is violated, implying membership values of unity and zero, respectively. On the contrary, fuzzy sets entertain varying degrees of membership function values from zero to unity. Thus, fuzzy set theory is an extension of standard set theory. The membership function consist in the given set, 1 describes a fully included member. The values between 0 and 1 characterize fuzzy members.

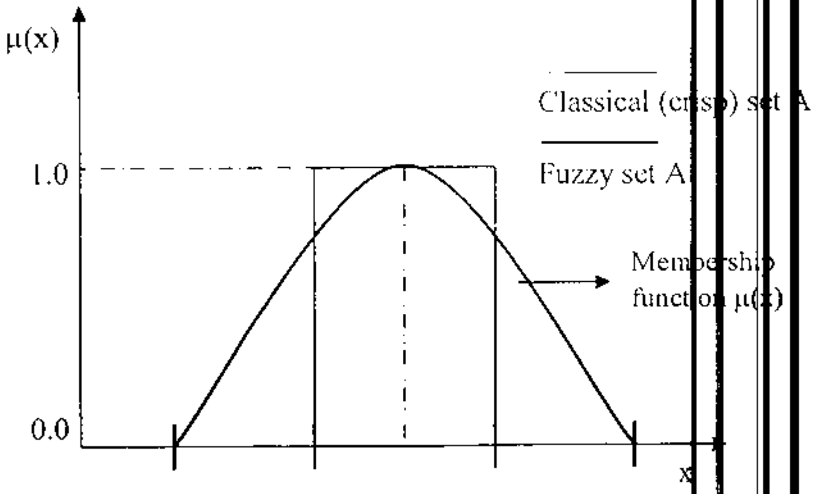


Figure 5.1 Fuzzy set and crisp set

5.3 MEMBERSHIP FUNCTIONS OF DIFFERENT OBJECTIVES FOR RECONFIGURATION

There are four objectives which determine which branch should be opened in the loop to maintain radiality. Fuzzy set theory is used to validate all the options. In the fuzzy logic, each objective is associated with membership function. The membership function indicates the degree of satisfaction of the objective. In the crisp set, either the objective is satisfied or it is violated, implying membership values of unity and zero, respectively. On the contrary, fuzzy sets entertain varying degrees of membership function values from zero to unity. The membership function consists of a lower and upper bound values together with a strictly monotonically decreasing and continuous function for different objectives which are described below.

5.3.1 Membership Function for Real Power Loss Reduction (μL_i)

The basic purpose of this membership function is to reduce the real power loss of the system.

$$X_i = PLOSS\,(i)/PLOSS^0 \quad \text{for } i=1, 2, 3\ldots N_k \text{ ------------ } (5.1)$$

Where,

N_k = Total number of branches in the loop including the Branch, when k^{th} tie-switch is closed

PLOSS (i) = Total real power loss of radial configuration of the System when i^{th} branch in the loop is opened.

$PLOSS^0$ = Total real power loss before network reconfiguration

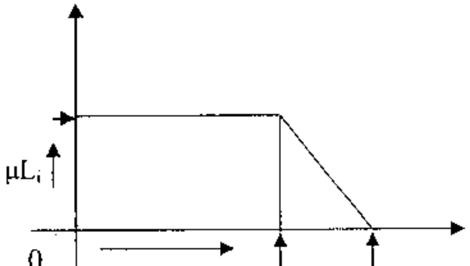
Equation (5.1) indicates that if Xi is high, power loss reduction is low and hence a lower membership value is assigned and if Xi is low, the power loss reduction is high and hence a higher membership value is assigned.

The membership function for real power loss reduction is given in Figure 5.2. From Figure μL_i can be written as:

$$\mu L_i = (X_{max} - X(i))/(X_{max} - X_{min}), \quad X_{min} < X(i) < X_{max}$$

$$\mu L_i = 1 \quad \text{for } X_i <= X_{min}$$

$$\mu L_i = 0 \quad \text{for } X_i >= X_{max}$$



5.3.2 Membership Function for Maximum Node Voltage Deviation (μV_i)

The basic function of this membership function is that the deviation of nodes voltage should be less.

$$Y_i = \max |V_{i,j} - V_s| \quad \text{for } i = 1,2,\ldots, N_k \quad j = 1, 2\ldots\ldots, NB$$

N_k = Total number of branches in the loop including the tie Branch, when the kth tie switch is closed

NB = Total number of nodes of the system

V_s = Voltage of substation (in per unit)

$V_{i,j}$ = Voltage of node j corresponding to the opening of the ith branch in the loop (in per unit)

If the maximum value of nodes voltage deviation is less, than a higher membership value is assigned and if the deviation is more, then a lower membership value is assigned.

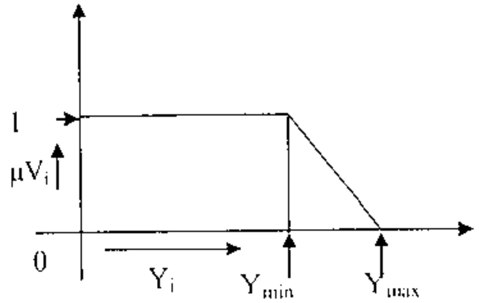
The membership function for Maximum Node Voltage Deviation is given in figure5.3.

From figure 5.3 μV_i can be written as:

$\mu V_i = (Y_{max} - Y(i)) / (Y_{max} - Y_{min}),\ Y_{min} < Y(i) < Y_{max}$

$\mu V_i = 1$ for $Y(i) <= Y_{min}$

$\mu V_i = 0$ for $Y(i) >= Y_{max}$



and if the minimum system voltage is less than or equal to 0.90 p.u, the zero membership value is assigned.

5.3.3 Membership Function for Maximum Branch Current Loading Index (μA_i)

The basic purpose for this membership function is to minimize the branch current constraint violation.

Branch current loading index $Z(i) = |I\ (i, m)| / I_c\ (m)$

For $i = 1, 2 \ldots N_k$

$m = 1, 2 \ldots NB-1$

N_k = Total number of branches in the loop including the tie branch when the i th tie switch is closed

$I(i,m)$ = Magnitude of current of branch-m when its i th branch in the loop is opened

$I_c\ (m)$ = Line capacity of branch-m

NB = Total number of the nodes of the system.

When the maximum value of branch current loading index exceeds unity, a lower membership value is assigned and as long as it is less than or equal to unity, the maximum membership value is assigned (i.e., unity).

The membership function for Maximum Branch Current Loading Index is given in fig5.4.

From figure 5.4 μA_i can be written as:

$$\mu A_i = (Z_{max} - Z\ (i)) / (Z_{max} - Z_{min}),\quad Z_{min} < Z\ (i) < Z_{max}$$

$$\mu A_i = 1 \quad \text{for } Z_i <= Z_{min}$$

$$\mu A_i = 0 \quad \text{for } Z_i >= Z_{max}$$

In this case, Zmin =1.0 and Zmax =1.15 have been considered. Zmin =1.0 indicates that as long as the branch currents of the system are less than or equal to their respective line capacity, unity membership value is assigned and Zmax =1.15 indicates that 15% overloading is allowed for each branch and if in any branch, the current is greater than or equal to 1.15 times the line capacity, a zero membership value is assigned.

5.3.4 Membership Function for Feeder Load Balancing (μB_i)

Load balancing is one of the major objectives of feeder reconfiguration. An effective strategy to increase the loading margin of heavily loaded feeders is to transfer part of their loads to lightly loaded feeders. Feeder load balancing index may be given as

$$FLB_{i,j} = (IFF_i^{max} - IF_{i,j}) / IFF_i^{max}$$

$$\text{for } i = 1, 2 \ldots N_k$$
$$j = 1, 2 \ldots NF$$

Where,

N_K = Total number of branches including the tie branch in the loop when k th tie switch is closed

NF = Total number of feeders

$IF_{i,j}$ = Current of feeder j corresponding to the opening of i th branch in the loop

IFF_i^{max} = The maximum of all the feeder currents corresponding to the opening of the i th branch in the loop

U_i = max ($FLB_{i,j}$),

for i = 1, 2 ... N

The membership function for Feeder Load Balancing is given in figure 5.5. From figure 5.5 μB_i can be written as:

$$\mu B_i = U_{max} - U(i) / U_{max} - U_{min}\ ,\ U_{min} < U(i) < U_{max}$$
$$\mu B_i = 1 \quad \text{for } U_i <= U_{min}$$
$$\mu B_i = 0 \quad \text{for } U_i >= U_{max}$$

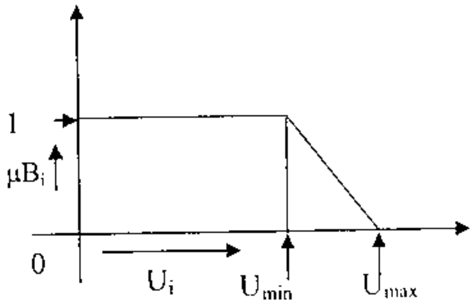


Figure 5.5: Membership Function for Feeder Load Balancing

In this case, Umin = 0.10 and Umax =0.70 have been considered. Umin =0.10 indicates that the maximum deviation of feeder currents will be 10% with respect to the maximum value of feeder current and if this deviation is less than or equal to 10%, the unity membership value is assigned and Umax =0.70 indicates that if this deviation is greater than 70%, a zero membership value is assigned

5.4 VALIDATION IN FUZZY ENVIRONMENT

(DETERMINISTIC APPROACH)

The required switching operation producing best results is found using this approach. When there are multiple objectives to be satisfied simultaneously, a compromise has to be made to get the best solution. One solution methodology for the multi-objective optimization in fuzzy framework is based on max-min principle. Steps to be proceeded are:

Step 1) For each option considered, the membership values of all the different objectives are evaluated.

For example, when the k^{th} tie switch of a distribution system is closed, a loop is formed with N_k number of branches in the loop. Now, opening each branch in this loop is an option. After opening the i^{th} branch in this loop (radial structure is retained), the load-flow run was carried out to compute

$$\mu L_i, \mu V_i, \mu A_i \text{ and } \mu B_i, \text{ for } i = 1, 2 \ldots\ldots\ldots N_k$$

Step 2) The degree of overall satisfaction for this option is the minimum of all the above membership values.

Now, a fuzzy decision for overall satisfaction may be defined as the choice that satisfies the entire objective and if we interpret this as a logical "and", we can model it with the intersection of the fuzzy sets. In the present work, classical fuzzy set intersection is used and the fuzzy decision for overall satisfaction is given by,

$$D_{k,i} = \min\{\mu Li, \mu V_i, \mu A_i, \mu B_i\} \text{ for } i = 1, 2 \ldots\ldots\ldots N_k$$

Step 3) The optimal solution is the maximum of all such overall degrees of satisfaction. Now, a fuzzy decision for an optimal solution may be defined as the choice that maximizes all such overall degrees of satisfaction and if we interpret this as a logical "or"

CHAPTER 6

NETWORK RECONFIGURATION USING FUZZY VALIDATION

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NETWORK RECONFIGURATION USING FUZZY VALIDATION

6.1 ALGORITHM FOR NETWORK RECONFIGURATION

In the present work, heuristic rules are considered which minimize the number of tie-switch operations. A complete algorithm for the proposed method of the network reconfiguration process is given below.

1. Read system data;
2. Run the load-flow program for radial distribution networks;
3. Compute the voltage difference across the open tie switches (i.e., ΔV_{tie} (i) for i = 1, 2…n_{tie});
4. Identify the open tie switch across which the voltage difference is maximum and its code k (i.e., ΔV_{tie}, max = ΔV_{tie} (k));
5. If ΔV_{tie}, max< ΔV_{tie}, go to Step 6; otherwise go to step 10;
6. Select the tie switch “k” and identify the total number of loop branches (N_k) including the tie branch when the tie switch “k” is closed;
7. Open one branch at a time in the loop and evaluate the memberships value for each objective and also evaluate the overall degree of satisfaction i.e., for i=1 to N_k compute μLi, μVi, μAi and μBi using equations 4.2, 4.4, 4.7, 4.10 in chapter 5,respectively and evaluate: $D_{k,i} = \min\{\mu Li, \mu Vi, \mu Ai, \mu Bi\}$;
8. Obtain the optimal solution for the operation of tie-switch “k”, (i.e., for $OS_k = \max\{D_k, i\}$ for i = 1, 2, N_k).
9. $n_{tie} = n_{tie} - 1$ and rearrange the coding of the rest of the tie switches and go to Step 2.
10. Print output results.
11. Stop

6.2 A DETAILED ALGORITHM FOR NETWORK RECONFIGURATION USING FUZZY VALIDATION

1. Enter the number of substations in the distribution system
2. For each substation enter the number of branches and find the number of nodes
3. For each branch enter all essential details like Branch No, Starting node, Ending node, Resistance, Reactance, Real Power Load and Reactive Power Load
4. Give index value as 0 for all branches; To be used to find branches not involved in tie loop
5. Assign input details to array SS1 which is sent to load flow algorithm; To be used to find load flow details before reconfiguration
6. Enter the number of tie line switches involved in the distribution system
7. For each tie line switch enter essential details like Tie No, Start SS, End SS, Branch No, Start node, End node, Resistance and Reactance
8. Call load flow algorithm before tie line switching
9. Print all the load flow details (current, losses, voltage) of all SS's and find total real power loss of system, maximum node voltage deviation and deviation from maximum feeder current.
10. Find voltage difference between all tie line switches
11. Find the tie line which has greatest voltage difference and assign that tie to be tie to be closed
12. Find the number of SS's which are not involved in tie line switching
13. Print all the SS's which are not involved in tie line switching
14. Add the details of all branches involved in the loop to their respective loop array's
15. First add details of branches which are present in left of the tie line switch
16. Then requires arrangement of the branches in left in top to bottom order
17. Add the tie line switch details in the loop arrays

21. To find lead branch; If the branch's starting node is present in loop then the branch's previous branch which is present in loop becomes lead branch but if starting node is not present in loop then previous branch's lead branch becomes its lead branch
22. The branch (normally closed switch) to be opened is stored in variable q
23. SS is a multi-dimensional array to store all SS details after respective switching operation is done
24. Initialize all values for SS's involved in loop to 0
25. Store details of SS's not involved in loop in SS
26. Call tie algorithm; Finds which branch is present in which SS after opening the normally closed switch (go to step 43)
27. Run a loop for all branches not involved in loop
28. Find; to which substation the branches not involved in loop should be relocated to
29. Run a loop for both substations; run a loop for all branches in that SS; If lead branch is available in that SS then assign the branch to that SS else to the other SS.
30. The entire reconfigured system is stored in other array SS1 so that it can be sent to Load flow algorithm.
31. b1 is used to count the number branches in the SS after reconfiguration; b2 is used to store the details in SS to SS1 in ascending order
32. Print SS details after reconfiguration
33. Call the load flow algorithm after reconfiguration for all SS
34. Print all the load flow details(current, losses, voltage) of all SS's
35. Fuzzification process is done
36. Find total real power loss for all receiving nodes; find feeder current for all SS; Find difference b/w voltage of all nodes and SS volt; Find the maximum volt diff

39. Print the details of all SS after optimal switching operation
40. Reassign system details after reconfiguration;
41. Reassign tie line switches after reconfiguration; Tie line previously closed is neglected so reduce the number of tie line switches by 1.
42. If number of tie line switches is 0 exit the program otherwise repeat the same steps from 8 to 41

Tie algorithm

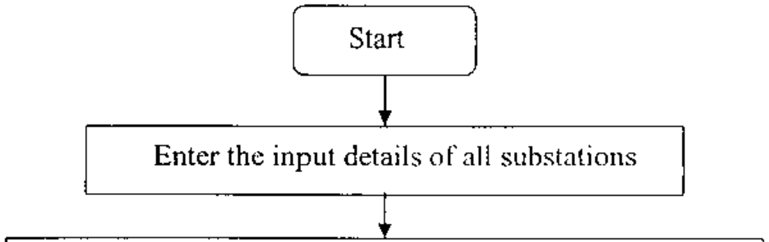
43. Run the loop for all branches until switch opened is found
44. The branches to the left of the branch to be opened are added to the left SS
45. The branches to the right of the branch to be opened are added to the right SS but in this case starting branch is changed to ending branch and vice versa

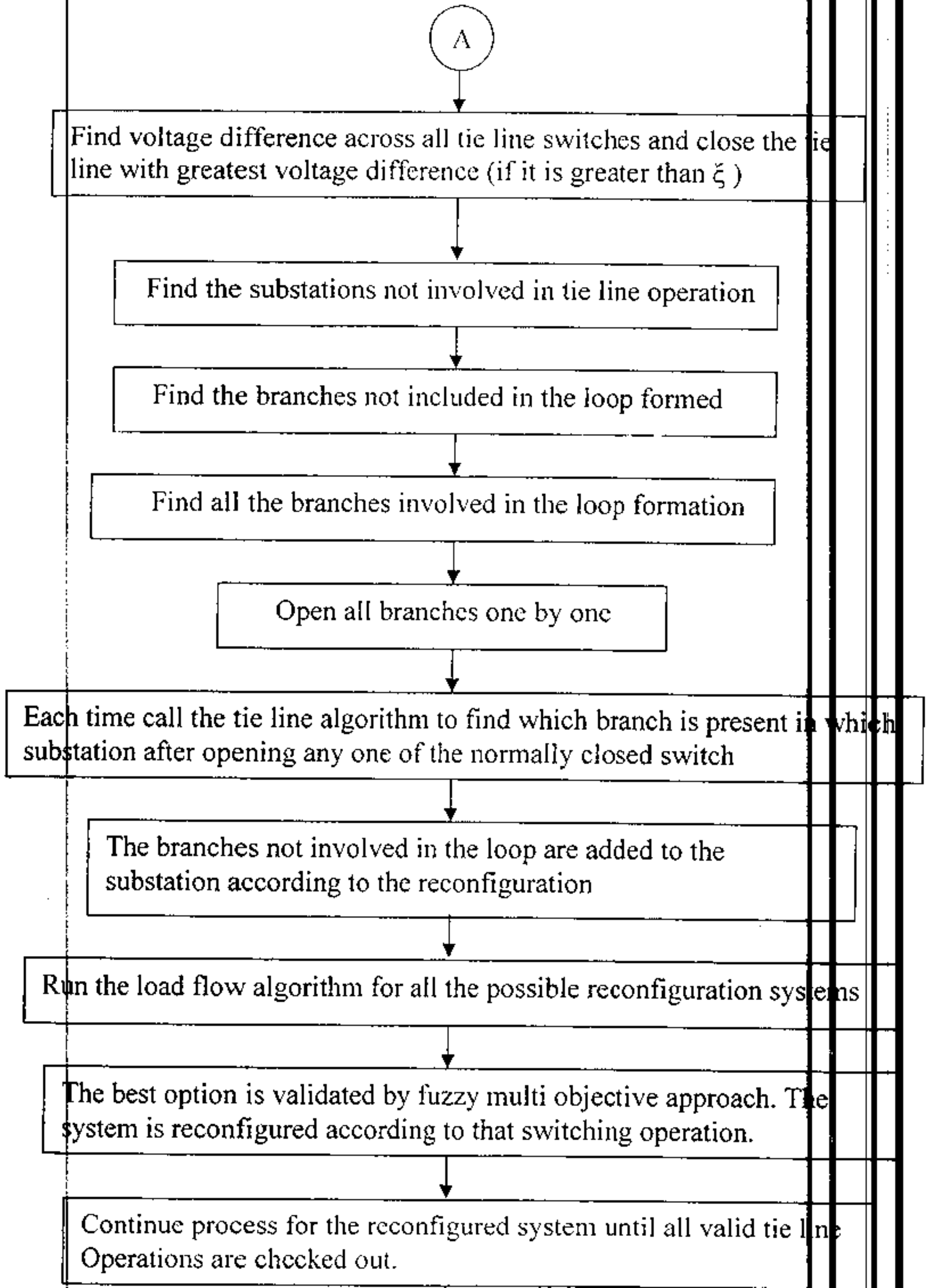
Load flow algorithm

It is explained in chapter 4.

Fuzzification algorithm

Fuzzy membership functions are found for all four objectives, and optimal membership value is found using max-min principle as explained in chapter 5.




A
Find voltage difference across all tie line switches and close the tie line with greatest voltage difference (if it is greater than ξ)
Find the substations not involved in tie line operation
Find the branches not included in the loop formed
Find all the branches involved in the loop formation
Open all branches one by one
Each time call the tie line algorithm to find which branch is present in which substation after opening any one of the normally closed switch
The branches not involved in the loop are added to the substation according to the reconfiguration
Run the load flow algorithm for all the possible reconfiguration systems
The best option is validated by fuzzy multi objective approach. The system is reconfigured according to that switching operation.
Continue process for the reconfigured system until all valid tie line Operations are checked out.

CHAPTER 7

WORK AND RESULTS

CHAPTER 7

WORK AND RESULTS

7.1 SAMPLE SYSTEM USED FOR SIMULATION

Figure 7.1 shows the 3 feeder sample distribution system used for simulation and validation of results

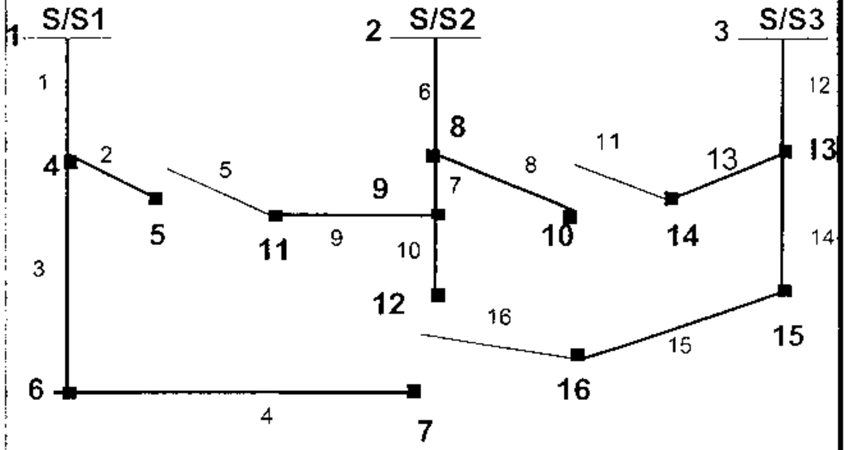


Figure 7.1: The 3 feeder sample system consist of 13 branches, 16 nodes and 3 tie line switches

TABLE 7.1 LINE AND LOAD DATA FOR 3 FEEDER SYSTEM IS GIVEN BELOW:

Branch no	Sending end	Receiving end	Resistance (p.u)	Reactance (p.u)	PL of receiving end node (MW)	QL of receiving end node (MVAR)
1	1	4	.075	.10	2.0	1.6
2	4	5	.080	.11	3.0	1.5
3	4	6	.090	.18	2.0	0.8

14	13	15	.080	.11	1.0	0.9
15	13	16	.040	.04	2.1	1.0
5 (Tie)	5	11	.040	.04	--------	------
11 (Tie)	10	14	.040	.04	--------	------
16 (Tie)	7	15	.090	.12	--------	------

Base: 100 MVA and 23 kV

- Total real power of all receiving end nodes PL (total) = 28.7 MW
- Total reactive power of all receiving end nodes QL (total) = 17.3 MVAR

We follow the algorithm for reconfiguration of the radial distribution system.

We run the load flow program for the 3 feeders separately. After running the load flow program we find:

- The total real power loss = 0.00613741 p.u. = 0.613741 MW
- Maximum voltage deviation = 0.045511 p.u. = 1.046753 kV
- Maximum deviation of feeder current = 0.222517 p.u. = 0.96746 kA
- Maximum value of branch current in system = 0.17427 p.u. =0.757695 kA

Tie - Line	**Voltage Difference**
1	0.0249971
2	0.0170465
3	0.00409079

The greatest voltage difference between tie line switches is: 0.0249971

TIE LINE CLOSED: is between 5 and 11

7.2 TIE LINE SWITCHING OPERATIONS

7.2.1 Tie line to be closed: 1

Tie line switch 1(branch 5) between feeders 1 and 2 is closed, the system becomes as shown in fig 7.2

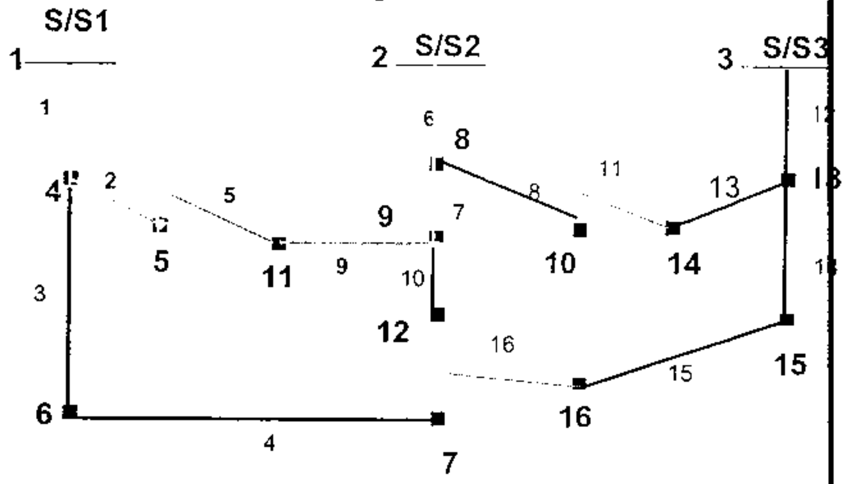


Figure 7.2: Tie line switch 1(branch 5) between feeders 1 and 2 is closed

After closing the tie line switch a loop is formed. The branches in the loop are 1,2,5,9,7,6. Here to maintain radiality any one of the branches (normally closed switches) must be opened. The switches are opened one by one from 1,2,5,9,7 to 6 and their respective fuzzy membership functions are found for validation and best switching operation is found.

When Branch 1 Is Opened:

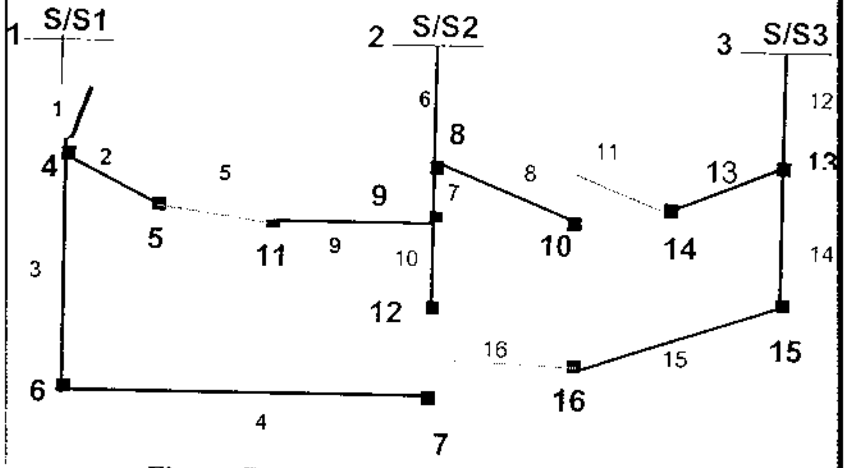


Figure 7.3: When Branch 1 is opened system configuration

Max deviation of feeder current from max feeder when switch opened is 1: 0.91231 p.u.

Maximum voltage difference when switch opened is 1 : 0.109652 p.u.

Maximum branch current in the system when switch opened is 1 : 0.219576 p.u.

Total loss when switch opened is 1: 0.0154888 p.u.

Fuzzy Membership values

Membership Function for Feeder Load Balancing μBi: 0

Membership Function for Real Power Loss Reduction μLi : 0

Membership Function for Maximum Node Voltage Deviation μVi: 0

Membership Function for Maximum Branch Current Loading Index μAi: 0

D_k value for switch 1is: 0

Here after reconfiguration loss and voltage deviation increases hence

When branch 2 is Opened :

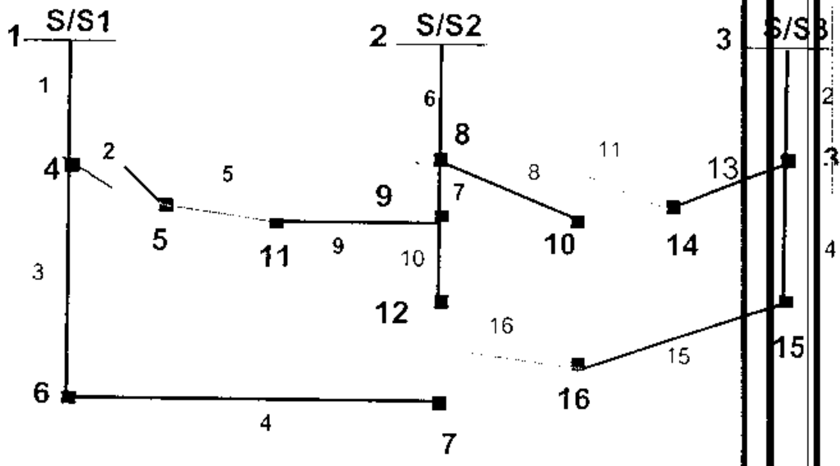


Figure 7.4: When Branch 2 is opened system configuration

Max deviation of feeder current from max feeder when switch opened is 2: 0.366343 p.u.

Maximum voltage difference when switch opened is 2 : 0.0562923 p.u.

Maximum branch current in the system when switch opened is 2 : 0.208475 p.u.

Total loss when switch opened is 2 : 0.00798097p.u.

Fuzzy Membership values

Membership Function for Feeder Load Balancing μBi : 0

Membership Function for Real Power Loss Reduction μLi : 0

Membership Function for Maximum Node Voltage Deviation μVi : 0.37416

Membership Function for Maximum Branch Current Loading Index μA : 0.374154

D_i value for switch 2 is: 0

When branch 5 is opened:

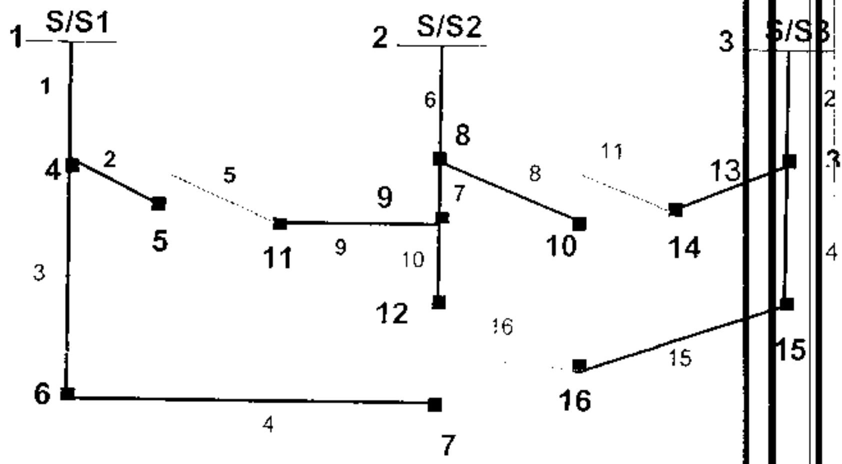


Figure 7.5: When Branch 5 is opened system configuration

Max deviation of feeder current from max feeder when switch opened is 5: 0.222517 p.u.

Maximum voltage difference when switch opened is 5 : 0.045511 p.u.

Maximum branch current in the system when switch opened is 5 : 0.17427 p.u.

Total loss when switch opened is 5 : 0.00613741p.u.

Fuzzy Membership values

Membership Function for Feeder Load Balancing μBi : 0.125497

Membership Function for Real Power Loss Reduction μLi : 0

Membership Function for Maximum Node Voltage Deviation μVi : 1

Membership Function for Maximum Branch Current Loading Index μAi : 1

D_i value for switch 5is:0

When Branch 9 is opened:

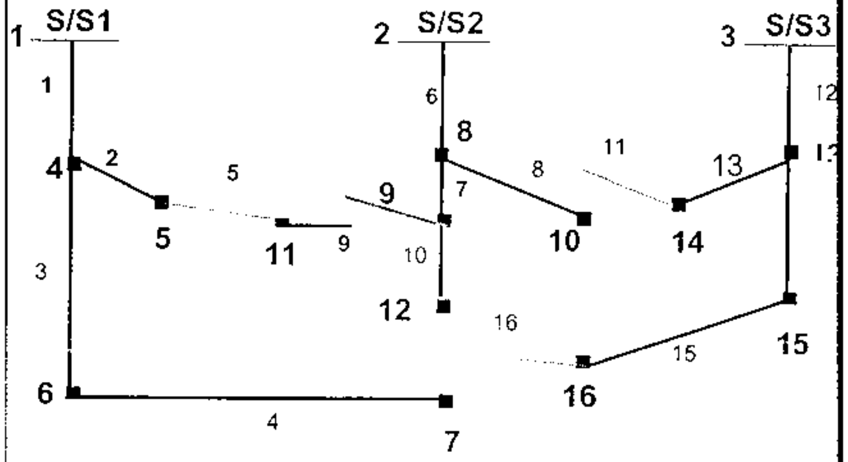


Figure 7.6: When Branch 9 is opened system configuration

Max deviation of feeder current from max feeder when switch opened is 9: 0.204958 p.u.

Maximum voltage difference when switch opened is 9: 0.0441712 p.u.

Maximum branch current in the system when switch opened is 9: 0.168585 p.u.

Total loss when switch opened is 9: 0.00594819 p.u.

Fuzzy Membership values

Membership Function for Feeder Load Balancing µBi: 0.15793

Membership Function for Real Power Loss Reduction µLi: 0.0616633

Membership Function for Maximum Node Voltage Deviation µVi: 1

Membership Function for Maximum Branch Current Loading Index µAi: 1

D_k value for switch 9is: 0.0616633

When Branch 7 is Opened:

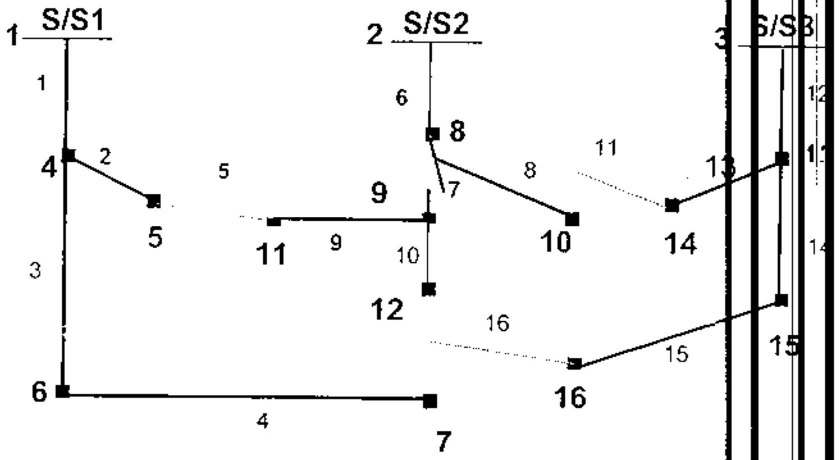


Fig 7.7: When Branch 7 is opened system configuration

Max deviation of feeder current from max feeder when switch opened is 7 : 0.631105 p.u.

Maximum voltage difference when switch opened is 7 : 0.0713336 p.u.

Maximum branch current in the system when switch opened is 7 : 0.216891 p.u.

Total loss when switch opened is 7 : 0.00858854 p.u.

Fuzzy Membership values

Membership Function for Feeder Load Balancing μBi : 0

Membership Function for Real Power Loss Reduction μLi : 0

Membership Function for Maximum Node Voltage Deviation μVi : 0.573328

Membership Function for Maximum Branch Current Loading Index μAi: 0.573328

D_k value for switch 7is :0

When Branch 6 is Opened:

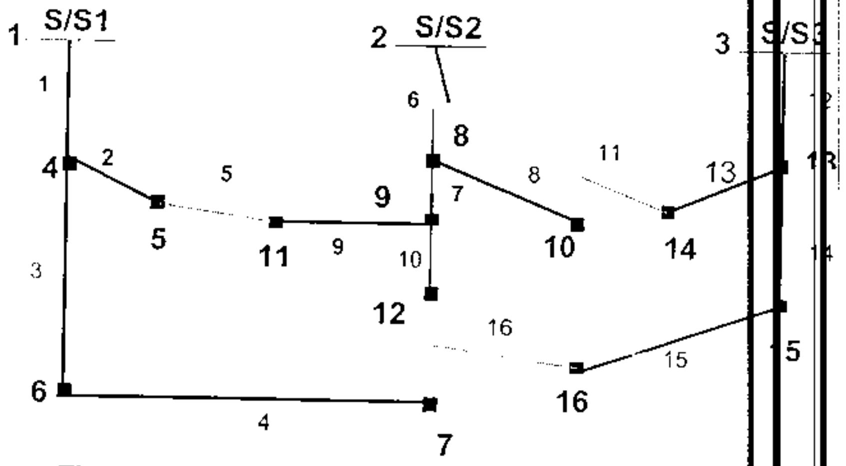


Figure 7.8: When Branch 6 is opened system configuration

Max deviation of feeder current from max feeder when switch opened is 6: 1.07147 p.u.

Maximum voltage difference when switch opened is 6 : 0.108658 p.u.

Maximum branch current in the system when switch opened is 6 : 0.27058 p.u.

Total loss when switch opened is 6 : 0.0163649 p.u.

Fuzzy Membership values

Membership Function for Feeder Load Balancing μBi : 0

Membership Function for Real Power Loss Reduction μLi : 0

Membership Function for Maximum Node Voltage Deviation μVi : 0

Membership Function for Maximum Branch Current Loading Index μAi : 0

D_k value for switch 6 is: 0

Now all switching operations are checked out completely

- Greatest value of μLi : 0.0616891
- Greatest value of μVi : 1

Optimal switching operation for real power loss reduction: 9

Optimal switching operation for maximum node voltage deviation: 5

Optimal switching operation for maximum node feeder load balancing: 9

Optimal switching operation for maximum branch current loading index: 5

The final optimal solution value is: 0.0616891

The optimal switching operation is: 9

7.2.2 The Reconfigured System :

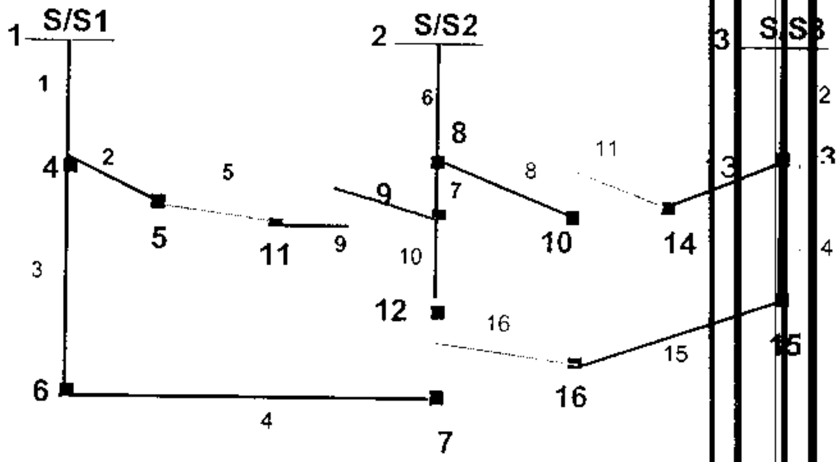


Figure 7.9: reconfigured system after tie line switch 1 is closed

Continue the reconfiguration process with tie line switches 2 and 3.

Voltage difference between nodes of tie line 2is:0.0162804

Voltage difference between nodes of tie line 3is:0.0047701

The greatest voltage difference between tie line switches is: 0.0162804

TIE LINE CLOSED: is between 10 and 14

7.2.3 Tie line to be closed: 2

Tie line switch 2 (branch 11) between feeders 2 and 3 is closed, the system becomes as shown in fig.

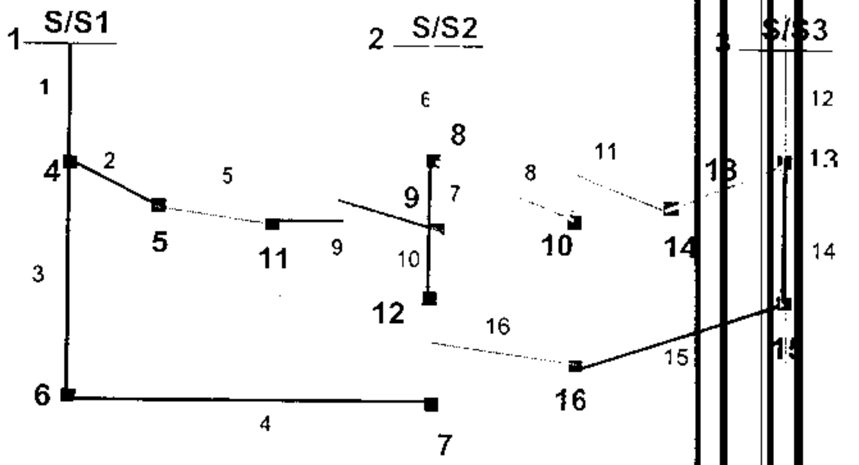


Figure7.10: Tie line switch 2 (branch 11) between feeders 2 and 3 is closed

After closing the tie line switch a loop is formed. The branches in the loop are 6,8,11,13,12. Here to maintain radiality any one of the branches (normally closed switches) must be opened.

The switches are opened one by one from 6,8,11,13 to 12 and their respective fuzzy membership functions are found for validation and best switching operation is found.

After all switching operations are checked out completely

- Greatest value of μLi: 0.0790156
- Greatest value of μVi:
- Greatest value of μAi :
- Greatest value of μBi: 0.428899

7.2.4 The reconfigured system is:

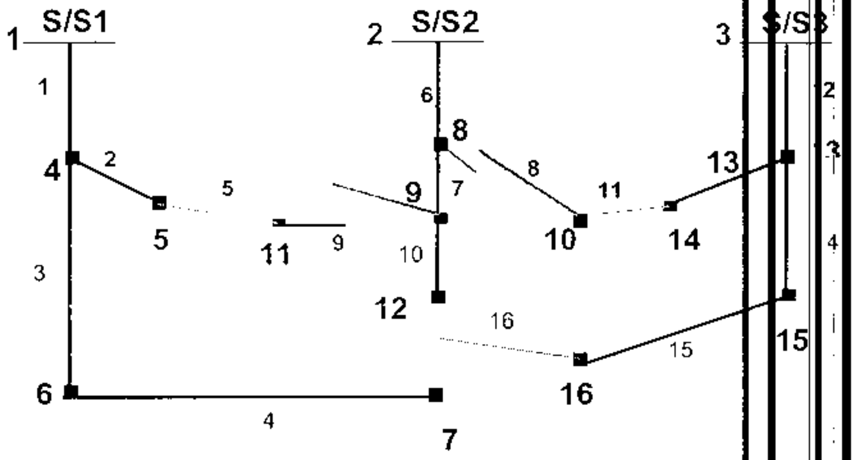


Figure 7.11: reconfigured system after tie line switch 2 is closed

Continue the reconfiguration process with tie line switch 3.

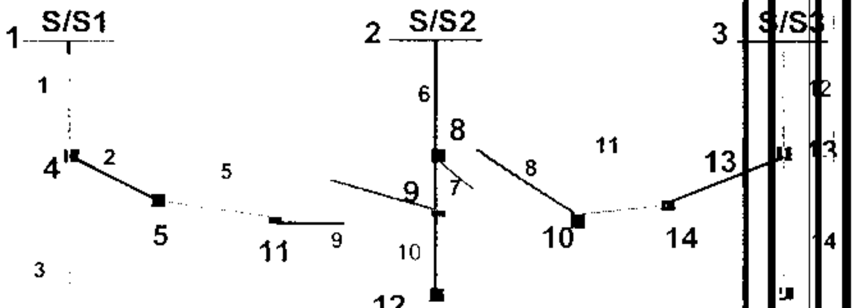
Voltage difference between nodes of tie line 3 is:0.00268161

The greatest voltage difference between tie line switches is: 0.00268 6

TIE LINE CLOSED: is between 7 and 16

7.2.5 Tie line to be closed: 3

Tie line switch 3 (branch 16) between feeders 3 and 1 is closed, the system becomes as shown in fig. :



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