Power loss and Reliability optimization in Distribution System with Network Reconfiguration and Capacitor placement

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ABSTRACT

Network Feeder Reconfiguration is the process of altering the topological structure of distribution feeders by changing the open/closed status of the tie and sectionalizing switches. In this paper, the Network Reconfiguration problem will be formulated as multi objective optimization problem with equality and inequality constraints. The proposed solution is based on optimization algorithms known as Network Reconfiguration Algorithms and Cutset Approach. The proposed Algorithms have been implemented on IEEE 33-Bus Radial Distribution System using MATLAB/ETAP. The comparison of various Network Reconfiguration Algorithms is also considered with respect to power loss and Reliability Indices. Optimal Placement of Capacitor has been considered for loss reduction.

Keywords*–*Radial Distribution System, Distribution Load Flow, Network Reconfiguration, Voltage Stability Index, Performance Indices, Optimal Capacitor Placement.

I. INTRODUCTION

The networks are reconfigured to reduce system real power losses and accomplish load balancing to relieve network overloads. The Voltage Stability of the Electrical Distribution Systems (EDS) can be enhanced if the loads are rescheduled by network reconfiguration [1], which also allows smoothing the peak demands, improves the voltage profile and Reliability.

Reliability evaluation can be used to evaluate past performance and predict future performance of the EDS. It also identifies the problematic components in the system that can impact Reliability. It can also help to predict the reliability performance of the system after any expansion and quantify the impact of adding new components to the system. Reliability evaluation techniques developed by [2] are applied in EDS planning studies and operation.

A method which applies an artificial Bee Colony algorithm (ABC) for determining the sectionalising switch to be operated in order to solve EDS loss minimization problem[3]. A Tabu search algorithm for the Reconfiguration of EDS for minimizing the real power loss is proposed in [4].

An approach using Distribution Load Flow solution and a Network Reconfiguration Algorithm (NRA) is considered in [5, 6] which improves voltage profile, Reliability and Voltage Stability Index (VSI) besides minimising losses. A method was proposed to operate EDS at its optimum performance with Network Reconfiguration in [7]. A method to reduce the Active Power Loss (APL) and Reactive Power Loss (RPL) and to improve the Voltage Stability in EDS with installation of capacitor banks is proposed in [8, 9]. A simple modification to the Binary Particle Swarm Optimization (BPSO) called selective particle swarm optimization (SPSO) [10].

The main objective of this paper is to conceptualize and realize EDS with improved Reliability and Voltage Stability that will contribute to the substantial reduction in the EDS loss by using Network Reconfiguration.

II. PROBLEM FORMULATION

It is considered that the voltage should be within the specified tolerance limits. Radial Distribution System is only considered, Feeder reconfiguration is performed by selecting among all possible configurations, the one that gives minimum failure indices and incurs the smallest power losses, and satisfies a group of constraints. The objective function is to minimize the Active power losses of distribution system P_L and reliability indices, considering the following constraints.

1. Node voltage constraint:

$$|V_i|_{\min} \le |V_i| \le |V_i|_{\max}$$

where V_{imin} and V_{imax} are the minimum and maximum permissible RMS voltages of node i respectively.

2. Load connectivity: Each load bus should be connected via one path to the feeder.
3. Radial Network structure: No loops are allowed in the network.

4. Power losses and Reliability indices:
$0<P_L, Q_L \leq P_{Lb}, Q_{Lb}$;
$0<SAIFI \leq (SAIFI)_b$;$0<SAIDI \leq (SAIDI)_b$;
$0<CAIDI \leq (CAIDI)_b$;$0<ASUI \leq (ASUI)_b$;

III. LOAD FLOW AND NETWORK RECONFIGURATION ALGORITHMS

1. Load Flow Analysis

The formation of Bus Injection Branch Current (BIBC) and Branch Current Bus Voltage (BCBV) matrices are explained in [6]. These matrices explore the topological structure of distribution system.

2. Reliability Evaluation

Basic Probability Indices (BPI) to evaluate system reliability are given by
Average failure rate (λ)

$$\lambda_{sys,i} = \sum_{k \in S} \lambda_k \quad \text{f/yr} \qquad (1)$$

Average annual outage time (U)

$$U_{sys,i} = \sum_{k \in S} \lambda_k r_k \quad \text{hrs / yr} \qquad (2)$$

Average outage time (r)

$$r_{sys,i} = \frac{U_{sys,i}}{\lambda_{sys,i}} \quad \text{hrs} \qquad (3)$$

Where $\lambda_{sys,i}$ is the system failure rate at i^{th} load point, $U_{sys,i}$ is system annual outage duration at i^{th} load point, λ_k, r_k are the failure rate and average repair time of k^{th} distributor segment, S is the set of distributor segments connected in series up to i^{th} load point. The Customer orientated Performance Indices that are most commonly used are defined in [2] as:

$$SAIFI = \frac{\sum \lambda_{sys,i} N_i}{\sum N_i} \quad \text{f / customer} \qquad (4)$$

$$SAIDI = \frac{\sum U_{sys,i} N_i}{\sum N_i} \quad \text{hr / yr} \qquad (5)$$

$$CAIDI = \frac{\sum U_{sys,i} N_i}{\sum \lambda_{sys,i} N_i} \quad \text{hr} \qquad (6)$$

$$ASAI = \frac{\sum N_i \cdot 8760 - \sum U_{sys,i} N_i}{\sum N_i \cdot 8760} \qquad (7)$$

$$ASUI = 1 - ASAI = \frac{\sum U_{sys,i} N_i}{\sum N_i \cdot 8760} \qquad (8)$$

N_i is number of customers at load point i.

3. Network Reconfiguration Algorithms

The Network Reconfiguration Algorithms (NRA) with the following conditions have been considered.
1. With VSI condition, considering only adjacent sectionalizing switch with Maximum VSI difference.
2. Without VSI condition, considering only adjacent sectionalizing switch with Maximum VSI difference.
3. With VSI condition, considering only adjacent sectionalizing switch with Minimum VSI difference.
4. Without VSI condition, considering only adjacent sectionalizing switch with Minimum VSI difference.
5. With VSI condition, considering the sectionalizing switch gives minimum losses with Maximum VSI difference.
6. Without VSI condition, considering the sectionalizing switch gives minimum losses with Maximum VSI difference.
7. With VSI condition, considering the sectionalizing switch gives minimum losses with Minimum VSI difference.
8. Without VSI condition, considering the sectionalizing switch gives minimum losses with Minimum VSI difference.

The Network Reconfiguration Algorithms with the above conditions have been applied to 33-bus Radial Distribution System and results are analysed and it is found that NRA with 6^{th} Condition gives better improvement in voltage profile, Reliability and reduction in power loss and hence it has been explained in the next subsection.

4. Optimal Network Reconfiguration Algorithm(NRA with 6^{th} condition)

The proposed Network Reconfiguration Algorithm is used to search the better switching combination that improves the voltage stability, voltage profile and Reliability and reduces losses by considering a tie switch and its adjacent sectionalised switch, one at a time, and continues the search process until there is no further improvement in voltage stability and there is no further reduction in power loss and reliability Indices. Before the reconfiguration is accepted, a load flow analysis is needed to make sure the losses, performance indices are decreased. If the result is negative, the reconfiguration network must reset to previous network condition.
The algorithmic steps for Network Reconfiguration of Distribution System are given as follows:

Step 1: Read Line data, bus data, Probability of the distribution system and set the flag equal to zero for all tie switches.
Step 2: Run the Distribution Load Flow using BIBC, BCBV matrix approach and compute voltages, VSI, real and reactive power losses, performance indices SAIFI, SAIDI,CAIDI and ASUI.
Step 3: Check whether all the bus voltages are within the specified tolerance limits or not. $|V_i|_{\min} \le |V_i| \le |V_i|_{\max}$ i.e. within 6% of the rated voltage; $0.94 \le |V_i| \le 1.06$, If so, go to step 10.
Step4: Find the VSI difference between the end nodes k and m of tie switches with zero flag. Choose the tie-switch with largest VSI difference.
Step 5: Check whether VSI at k^{th} node is larger than VSI at m^{th} node, if so, go to step 7
Step 6: Open the sectionalizing switch between k and k-1 or k-1 and k-2 or any switch that gives minimum losses and performance Indices and go to Step 8.
Step 7: Open the sectionalizing switch between m and m-1or m-1 and m-2 or any switch that give minimum losses and performance Indices (PI).
Step 8: Connect the tie switch and set flag equal to 1.
Step 9: Calculate power losses if not $0 < P_L$, $Q_L \le P_{Lb}$, Q_{Lb}, open tie switch and close sectionalizing switch and go to step 2.
Step 10: Calculate reliability indices: SAIFI, SAIDI, CAIDI and ASUI
If not $0 < SAIFI \le (SAIFI)_b$; $0 < SAIDI \le (SAIDI)_b$; $0 < CAIDI \le (CAIDI)_b$; $0 < ASUI \le (ASUI)_b$, open tie switch and close sectionalizing switch and go to step 2.
Step 11: Check the tie switches flag equal to 1 or not, If not go to step 2.
Step 12: Print $|V_i|$, $(VSI)_i$, P_L, Q_L, SAIFI, SAIDI,CAIDI and ASUI.
The algorithmic steps are shown as Flowchart in Figure 1.

IV. RESULTS AND ANALYSIS

Consider a 33-bus RDS shown in Fig.2. Line, bus and reliability data of 33-bus RDS are given in [5]. The NRA is implemented in MATLAB, applied to 33-bus RDS and analysis is done. The converged values of Voltage magnitudes, phase angle and VSI for the Base configuration shown in Fig. 2 are given in Table 1. Active power loss (APL) of the system is 202.6650 kW.
The VSI difference between two sides of the tie switch in between 22-12 is larger so this tie-switch is to be closed first. As VSI of 22 is greater than VSI of 12, the switch in the branch 12-11 is opened. Now the APL is 156.7283 kW which is smaller than the initial value so keep on searching in the direction. Finally when the switch in between 9-10 closed, APL is 154.07 kW which is minimum for this loop with tie switch in between 22-12 is closed.
For this reconfiguration, next tie switch is to be closed is in between 25-29, and then repeat the procedure andsolution is to open the switch in between 28-29 with APL 145.88 kW. Next tie switch to be closed in between 9-15, and the switch to open in between 14-15, with APL 142.56 kW. The procedure is repeated until the final optimal configuration is achieved.
Thus the APL is 140.00 kW after reconfiguration and the final optimal configuration is shown in Fig. 3, the tie switches are in between 9-10, 28-29, 33-32, 14-15 and 7-8.

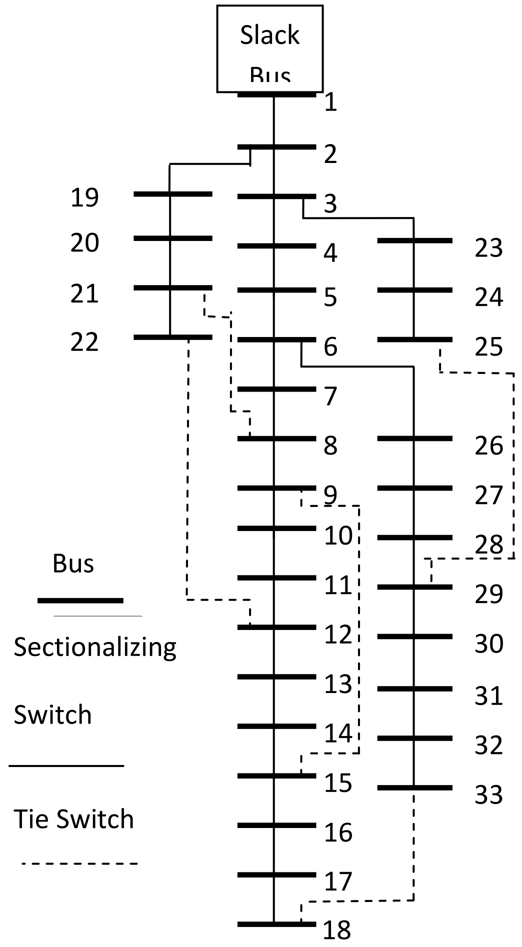

Fig. 2 Line Diagram of 33-bus RDS for Base Configuration

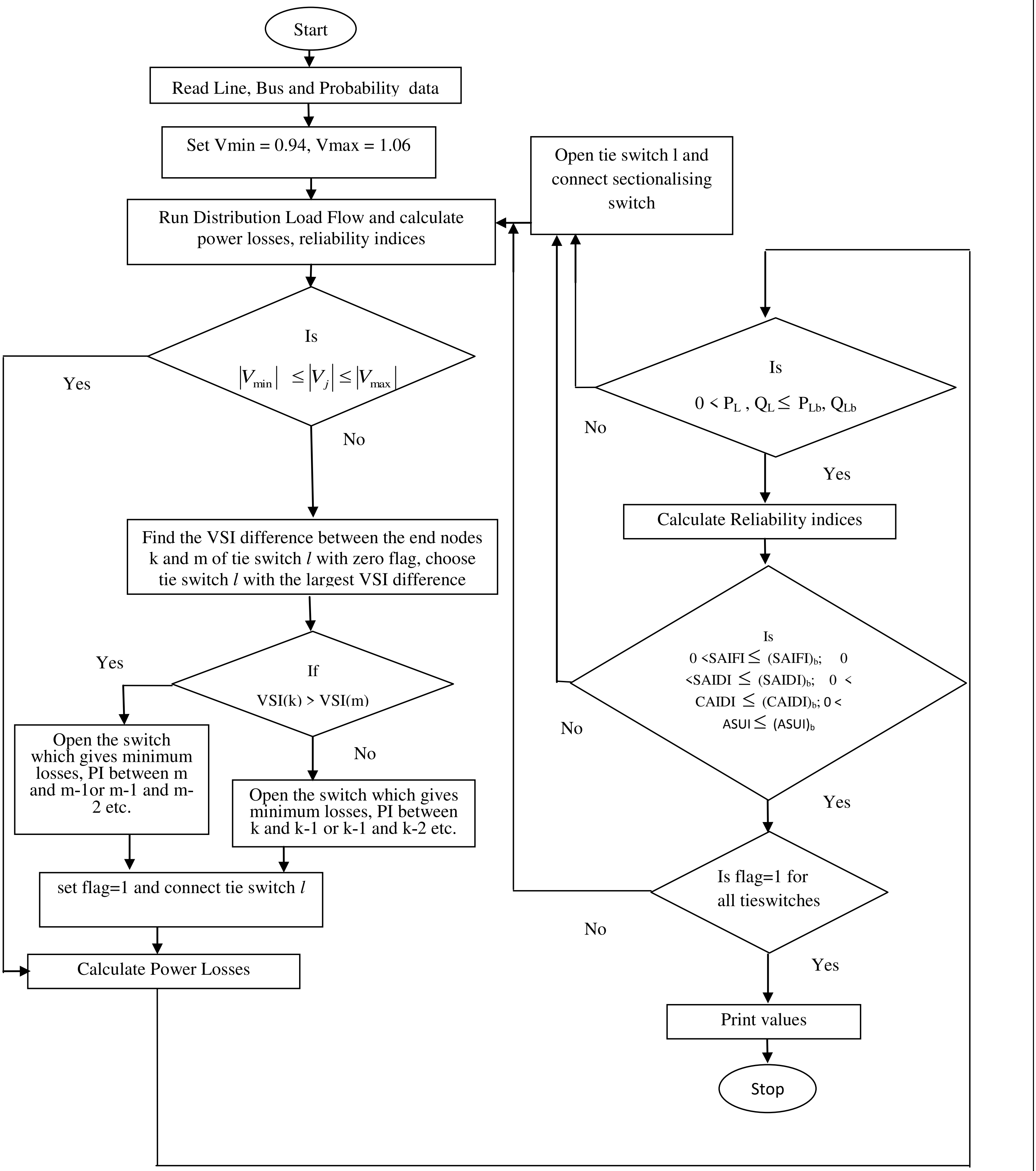

Fig. 1 Flow chart for Network Reconfiguration of 33-bus RDS

Table 1

Converged values of bus voltages magnitude, phase angle and VSI Before Reconfiguration

Bus No.	Voltage Magnitude (p.u.)	Phase Angle (p.u.)	VSI (p.u.)	Bus No.	Voltage Magnitude (p.u.)	Phase Angle (p.u.)	VSI (p.u.)
1	1	0	1	18	0.9131	-0.0086	0.6951
2	0.997	0.0003	0.9882	19	0.9965	0.0001	0.6934
3	0.9829	0.0017	0.9331	20	0.9929	-0.0011	0.9720
4	0.9755	0.0028	0.9053	21	0.9922	-0.0014	0.9692
5	0.9681	0.004	0.8781	22	0.9916	-0.0018	0.9668
6	0.9497	0.0023	0.8127	23	0.9794	0.0011	0.9529
7	0.9462	-0.0017	0.8014	24	0.9727	-0.0004	0.8950
8	0.9413	-0.0011	0.7851	25	0.9694	-0.0012	0.8829
9	0.9351	-0.0023	0.7644	26	0.9477	0.003	0.8761
10	0.9292	-0.0034	0.7456	27	0.9452	0.004	0.7980
11	0.9284	-0.0033	0.7429	28	0.9337	0.0055	0.7599
12	0.9269	-0.0031	0.7381	29	0.9255	0.0068	0.7336
13	0.9208	-0.0047	0.7187	30	0.922	0.0086	0.7225
14	0.9185	-0.0061	0.7117	31	0.9178	0.0072	0.7095
15	0.9171	-0.0067	0.7074	32	0.9169	0.0068	0.7067
16	0.9157	-0.0071	0.7032	33	0.9166	0.0066	0.7058
17	0.9137	-0.0085	0.6970				

Table 2

Converged values of bus voltages magnitude, phase angle and VSI After Reconfiguration

Bus No.	Voltage Magnitude (p.u.)	Phase Angle (p.u.)	VSI (p.u.)	Bus No.	Voltage Magnitude (p.u.)	Phase Angle (p.u.)	VSI (p.u.)
1	1.00000	0.00000	1.00000	18	0.98874	-0.00453	0.94004
2	0.99732	0.00027	0.98933	19	0.99583	-0.00018	0.94322
3	0.98724	0.00172	0.94971	20	0.98357	-0.00351	0.97016
4	0.98544	0.00169	0.94301	21	0.98027	-0.00488	0.93333
5	0.98395	0.00160	0.93734	22	0.97724	-0.00616	0.92235
6	0.98081	0.00060	0.92538	23	0.97987	0.00229	0.91105
7	0.98017	-0.00008	0.92302	24	0.96515	0.00252	0.91995
8	0.97438	-0.00723	0.91743	25	0.95385	0.00361	0.94172
9	0.97339	-0.00755	0.85607	26	0.98053	0.00057	0.82179
10	0.97290	-0.00770	0.88562	27	0.98027	0.00054	0.91378
11	0.97112	-0.00750	0.88476	28	0.97974	0.00031	0.91967
12	0.97125	-0.00754	0.86744	29	0.94883	0.00416	0.92025
13	0.96869	-0.00780	0.88051	30	0.94564	0.00587	0.79032
14	0.96791	-0.00808	0.87767	31	0.94223	0.00461	0.79632
15	0.99420	-0.00251	0.85023	32	0.94156	0.00429	0.78651
16	0.99251	-0.00287	0.91922	33	0.98842	-0.00459	0.78547
17	0.98972	-0.00435	0.92630				

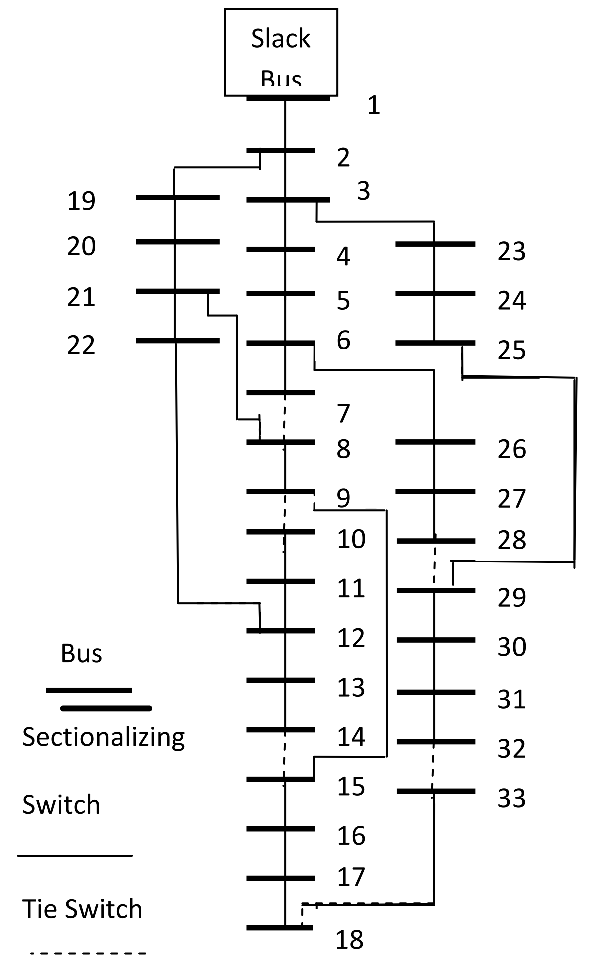

Fig. 3 Reconfigured 33-bus RDS

1. Comparison of Voltage Magnitudes

Comparison of voltage magnitudes for base case and reconfigured network of 33-bus RDS is shown in Fig.4.

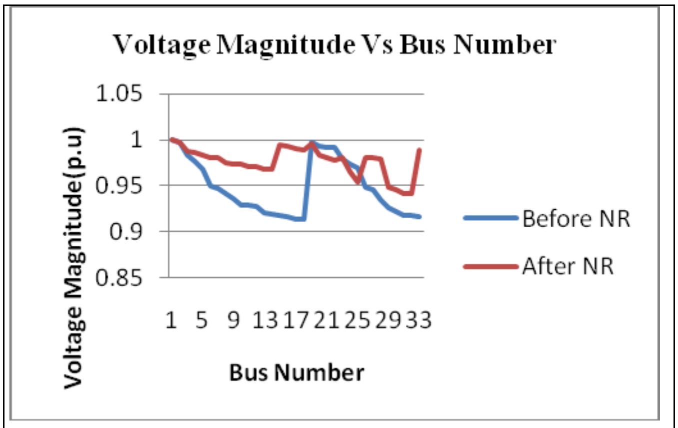

Fig.4 Comparison of voltage magnitudes for Base Case and Reconfigured Network

2. Power Loss Analysis

The APL, RPL and Total Power Losses (TPL) of the 33-bus RDS, before and after reconfiguration are given in Table 3 and its comparison is shown in Fig.5.

Table 3

Variation in the power loss of 33-bus RDS

Power loss	Before NR	After NR	%Decrease
Active Power Loss(kW)	202.67	140.00	30.92
Reactive Power Loss (kVar)	135.13	104.09	22.97
Total Power Loss (KVA)	243.59	174.4	28.40

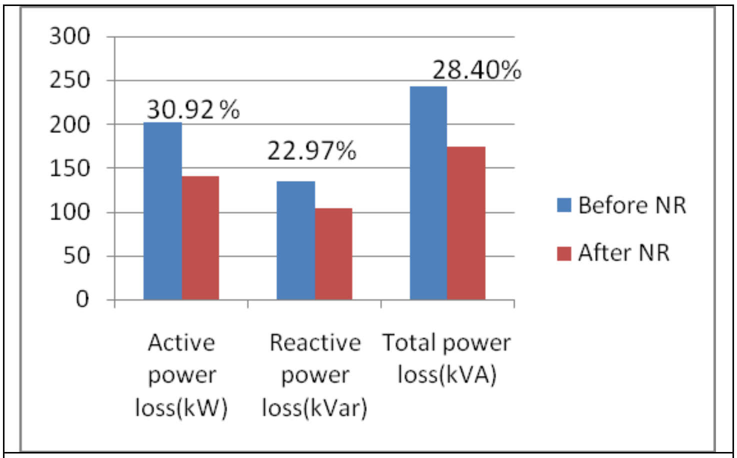

Fig. 5 Comparison of Power loss for Base Case and Reconfigured Network

3. Performance Indices

The Performance Indices SAIFI, SAIDI, CAIDI, and ASUI of the 33-bus RDS are evaluated by considering cutsets of various load points using cutset approach [5]. The values of performance indices before and after Network Reconfiguration are given in Table 4 and its comparison is shown in Fig. 6.

Table 4

Variation in the Performance Indices of Distribution System

Index	Before NR	After NR	%Decrease
SAIFI (f/customer)	2.41	2.31	4.14
SAIDI (hrs/ yr)	2.04	1.48	27.4
CAIDI (hr)	0.85	0.64	24.7
ASUI	$2.33e^{-4}$	$1.66e^{-4}$	28.75

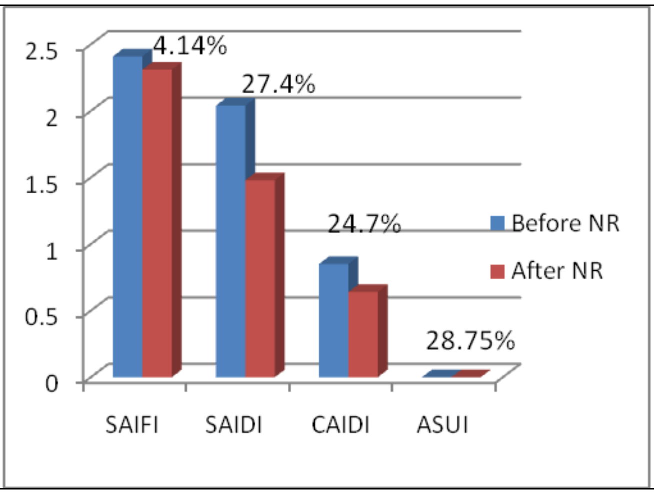

Fig. 6 Comparison of Performance Indices for Base Case and Reconfigured Network

V. OPTIMAL CAPACITOR PLACEMENT

Capacitor placement in distribution network is one of the most common methods that used in the distribution network to reduce the power loss and improving the voltage profile. ETAP software is used for Optimal Capacitor placement. A capacitor of 0.3MVAR is placed optimally at bus 3 of 33-bus RDS. The comparison of power loss values for base case and Reconfigured network of 33-bus RDS with Optimal Capacitor placement is given Table 5.

Table 5
Comparison of Power loss for Base Case and Reconfigured Network with Optimal Capacitor Placement

Power loss	Base Case		Reconfigured Network with NRA 6	
	Without Capacitor	With Capacitor	Without capacitor	With Capacitor
APL (kW)	202.66	197.9	140.00	136.3
RPL (kVar)	135.13	132.7	104.9	103.0
TPL (kVA)	243.58	238.27	174.9	170.8

VI. COMPARISON OF POWER LOSS WITH EXISTING METHODS

The comparison of Power loss with existing methods is given in Table 6.

Table 6
Comparison of Power loss with existing methods

Method	Active Power Loss With Network Reconfiguration and without capacitor (kW)	Active Power Loss with Network Reconfiguration with Capacitor (kW)
ABC method [2]	139.5	-
GA method[11]	140.2	-
PSO method [10]	139.7	-
GSO [9]	-	143.76
Proposed method	140	136.3

From Table 6, it can be concluded that with the proposed algorithm and OCP the losses are further reduced and also it is proved that Reliability is also improved.

VII. CONCLUSIONS

A Network Reconfiguration scheme for Voltage Stability enhancement of Radial Distribution Systems has been developed. This algorithm is based on VSI and improves voltage profile, Reliability Indices, enhance the voltage stability and reduce the system power losses. The proposed algorithm is applied to 33-bus RDS and the obtained results from MATLAB are analyzed and compared with existing methods. With the Optimal Capacitor Placement the losses are further reduced.

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