The Journal of CPRI,
Vol. 11, No. 2, June 2015 pp. 259-268

Loss reduction and reliability optimization in electrical distribution systems using network reconfiguration

Ravi Kumar D* and Sankar V**

Network reconfigurationis an operation strategy, which alters the topological structure of the distribution feeders by rearranging the status of switches in order to obtain an optimal configuration, minimise system losses and to improve reliability. In this paper, an approach using Distribution Load Flow(DLF) solution and a reconfiguration algorithm that enhances voltage profile, reliability and voltage stability index besides minimising losses is developed. The proposed algorithm has been implemented on33 bus Radial Distribution System (RDS) in the MATLAB™ environment.

Keywords: *Radial distribution system, distribution load flow, Voltage Stability Index(VSI), Network Reconfiguration (NR), performance indices.*

1.0 INTRODUCTION

Reliability evaluation can be used to evaluate past performance and predict future performance of the distribution system. It also identify 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 [1, 3, 9] are applied in distribution system planning studies and operation.

The input data of algorithm [4] is the bus-branch oriented data used by most utilities. Two developed matrices, the Bus-Injection to Branch-Current matrix (BIBC) and the Branch-Current to Bus-Voltage matrix (BCBV), and a simple matrix multiplication are utilized to obtain load flow solutions [4]. Method to obtain an acceptable voltage profile under increasing load demand and / or configuration changes is proposed in [7]. By changing the open/close status of the sectionalising and tie switches NR is done [2].

The method proposed [6] started with a power flow solution of the system with all its switches closed, thus forming a meshed system. A branch exchange procedure is applied to the above method to refine the solution. The process of solving Distribution Network Reconfiguration (DNR) problem based on Selective Particle Swarm Optimization (SPSO) [8] is developed. A Meta-heuristics Fire Works Algorithm (FWA) [10] is proposed to optimize the RDS while satisfying the operating constraints. A fuzzy genetic approach [5] for reconfiguration of RDSso asto maximize the voltage stability of the network for a specific set of loads is proposed.

In the literature so far methods have been developed for improving voltage profile, VSI, mitigating losses etc. However, it appears that not much attention has been made to evaluate performance indices of RDS together with the above objectives. Moreover, the limits

*VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad-500090, India. E-mail:ravi44d@gmail.com
**JNTU Anantapur, College of Engineering, Anantapur-515 002, India. E-mail:vsankar.eee@jntua.ac.in

for voltages, real, reactive power and probability performance indices such as SAIDI, SAIFI, CAIDI and ASUI have not been considered in the earlier studies. In this paper, a reconfiguration algorithm is developed which enhances voltage profile, reliability performance indices and voltage stability index besides minimising losses. About problem formulation is discussed in Section 2. The proposed Algorithm and Flow chart have been explained in Section 3. A case study with 33 bus RDS is considered and the results are presented and analysed in Section 4. Conclusions are presented in Section 5.

2.0 PROBLEM FORMULATION

In this paper, it is considered that the voltage should be within the specified tolerance limits of minimum and maximum values. There shall be a unique path from feeder to the consumer and Radial Distribution Systems are only considered. Power losses and performance indices should be improved with network reconfiguration. Feeder reconfiguration is performed by selecting among all possible configurations, the one that incurs the smallest power losses, gives minimum failure indices and that satisfies a group of constraints. The objective function is to minimize the real power losses of distribution system PL and reliability indices, considering the following constraints.

1. Node voltage constraint:

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

   where Vimin and Vimax 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 P_{Lb}, Q_{Lb};

   0<SAIFI $(SAIFI)_b$; 0<SAIDI $(SAIDI)_b$;

   0<CAIDI $(CAIDI)_b$; 0<ASUI $(ASUI)_b$;

3.0 PROPOSED ALGORITHM

3.1 Load Flow Analysis

The formation of BIBC and BCBV matrices are explained in [4]. These matrices explore the topological structure of distribution systems. The BIBC matrix is responsible for the relations between the bus current injections and branch currents. The BCBV matrix is responsible for the relations between the branch currents and bus voltages.

3.2 Reliability Evaluation

Load point indices to evaluate system reliability given by [3]

Average failure rate (λ)

$$\lambda_{sys,i} = \sum_{k \in S} \lambda_k \quad ....(1)$$

Average annual outage time (U)

$$U_{sys,i} = \sum_{k \in S} \lambda_k r_k \quad ....(2)$$

Average outage time (r)

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

Where λ_{sys}, i is the system failure rate at ith load point, Usys, i is system annual outage duration at ith load point, λ_k, r_k are the failure rate and average repair time of kth distributor segment,S is the set of distributor segments connected in series upto ith load point. The Customer oriented performance indices that are most commonly used are defined as[1]

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

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

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

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

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

N_i is number of customers at load point i.

3.3 Network Reconfiguration

A reconfiguration algorithm is proposed which enhances voltage stability and improves the voltage profile besides minimizing losses and improve network reliability. The algorithmic steps for network reconfiguration of distribution system are given as follows:

Step1: 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.

$|V_i|_{\min} \leq |V_i| \leq |V_i|_{\max}$ i.e. within 6% of the rated voltage; 0.94 |≤| Vi ≤ 1.06 ,If so, go to step 10.

Step 4: 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 mth node, If so, go to step 7

Step 6: Open the sectionalized switch between k and k-1 and go to Step 8.

Step 7: Open the sectionalized switch between m and m-1.

Step 8: Connect the tie switch and set flag equal to 1.

Step 9: Check the tie switches flag equal to 1 or not, If not go to step 2.

Step 10: Calculate power losses

If not 0 < P_L, Q_L, P_{Lb}, Q_{Lb}, go to step 2.

Step 11: Calculate reliability indices: SAIFI, SAIDI, CAIDI and ASUI

If not 0< SAIFI≤ $(SAIFI)_b$; 0< SAIDI≤ $(SAIDI)_b$; 0 < CAIDI≤ $(CAIDI)_b$; 0 < ASUI≤ $(ASUI)_b$, go to step2.

Step 12: Print |V|, $(VSI)_i$, P_L, Q_L, SAIFI, SAIDI, CAIDI and ASUI.

The algorithmic steps are shown as Flow chart in Figure 1.

4.0 RESULTS AND ANALYSIS

The algorithm given in Section 3 is applied to a 6-bus distribution system using MATLAB™ programming and the obtained results are validated with theoretical calculations but not presented in this paper. Consider 33-bus RDS [5] shown in Figure 1.

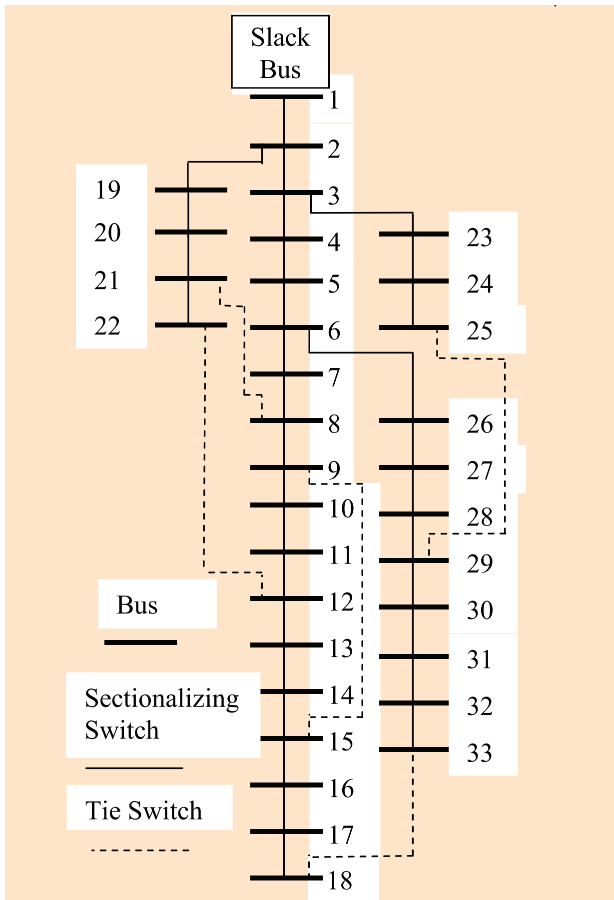

FIG. 1 LINE DIAGRAM OF 33-BUS RDS

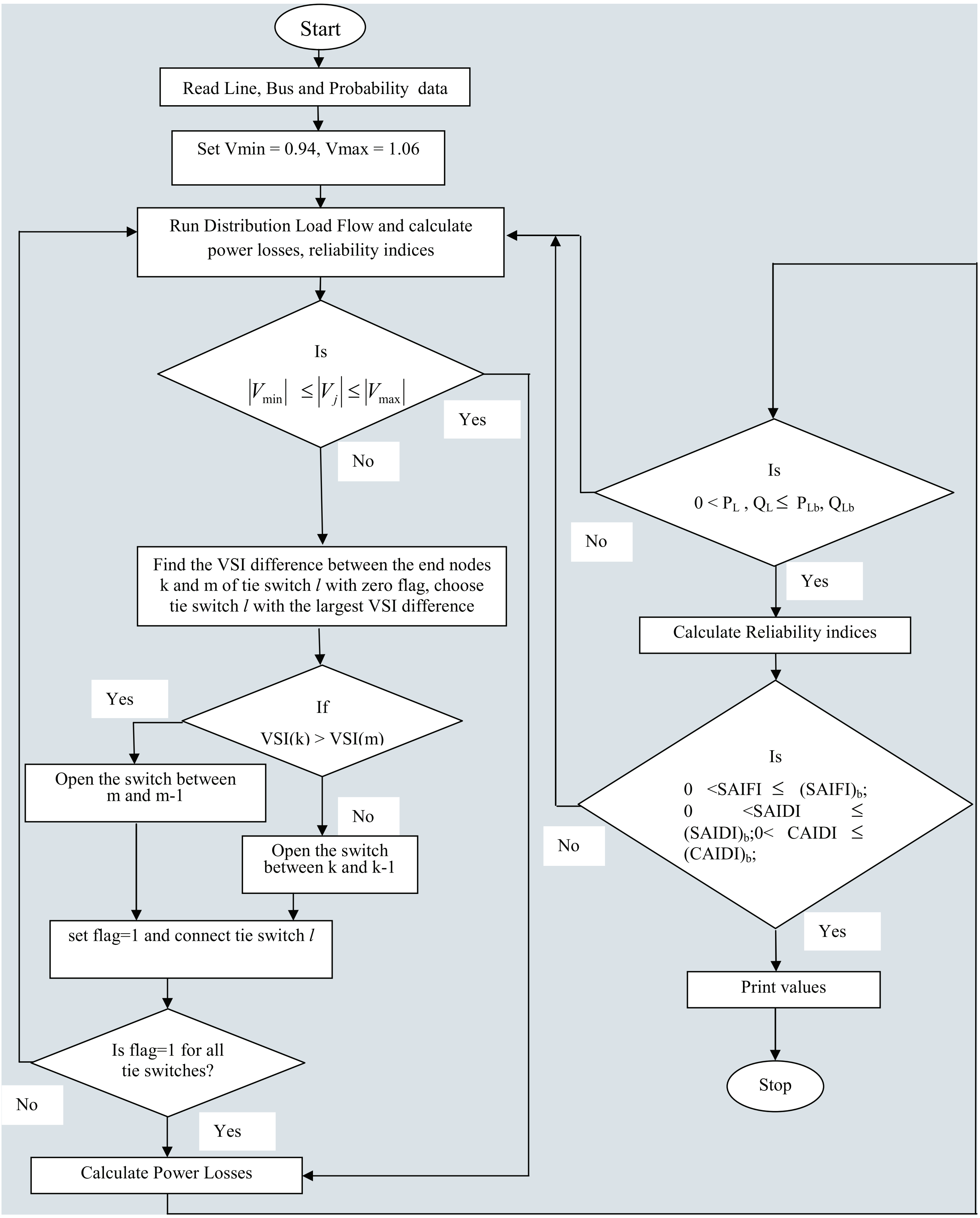

FIG. 2 FLOW CHART FOR NETWORK RECONFIGURATION OF RDS

Line, bus and reliability data of 33-bus RDS [5] are given in Appendix A. The Algorithm is implemented in MATLAB™ for 33 bus RDS and analysis is done. The Converged values of Voltage magnitude, phase angle and VSI for the Base Configuration shown in Figure 2 are given in Table 1. Total Real power loss of the system is 202.6650 kW.

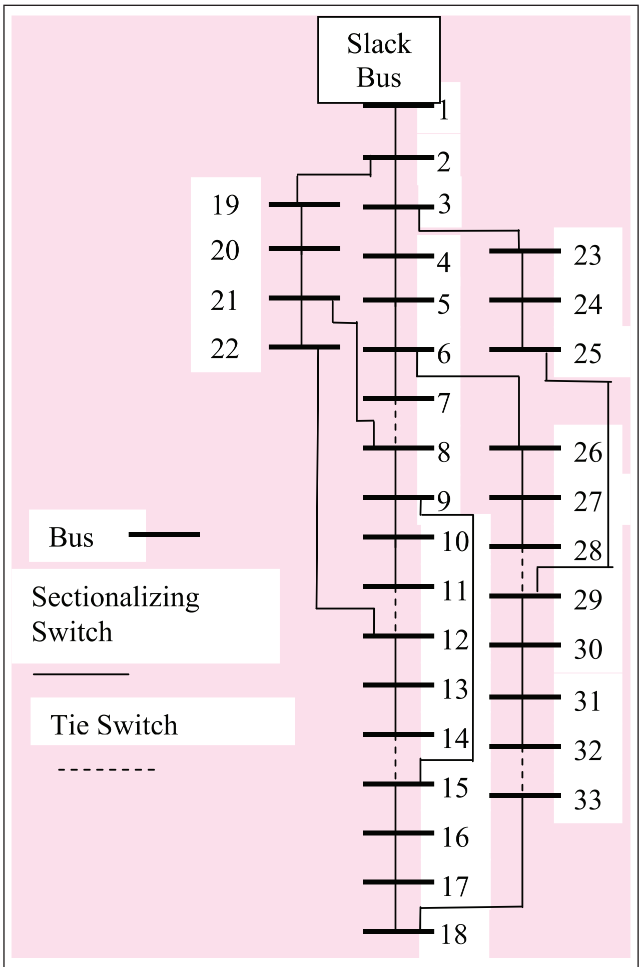

FIG. 3 RECONFIGURED 33-BUS RDS

The VSI difference between two sides of the tie switch in between 22 - 12 is largest 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 total real power loss is 156.7283 kW. For this reconfiguration, next tie switch to be closed is 25 – 29, then repeat the procedure and the solution is to open the switch in branch 28-29 with total real power loss 146.0039 kW. Next tie switch to be closed is 18 – 33, and the switch to open is 33 – 32, with total real power loss 143.679 kW. The procedure is repeated until final optimal configuration is achieved. Thus, final total real power loss is 141.6001 kW after reconfiguration and the final optimal configuration is shown in Figure 3, the tie switches are 12–11,29–28,33–32,14–15,7–8.

4.1 Comparison of Voltage Magnitudes

Comparison of Voltage magnitudes for the base case and reconfigured network of 33 bus RDS is shown in Figure 4.

4.2 Power Loss Analysis

The real power, reactive power and total power loss of the 33-bus RDS, before and after reconfiguration are given in Table 3 and comparison of power loss for the base case and reconfigured network is shown in Figure 5.

4.3 Reliability Indices

The reliability indices SAIDI, SAIFI, CAIDI and ASUI of the 33-bus RDS are evaluated by considering cutsets of various load points. The values of reliability indices before and after reconfiguration are given in Table 4 and comparison of reliability indices for the base case and reconfigured network is shown in Figure 6.

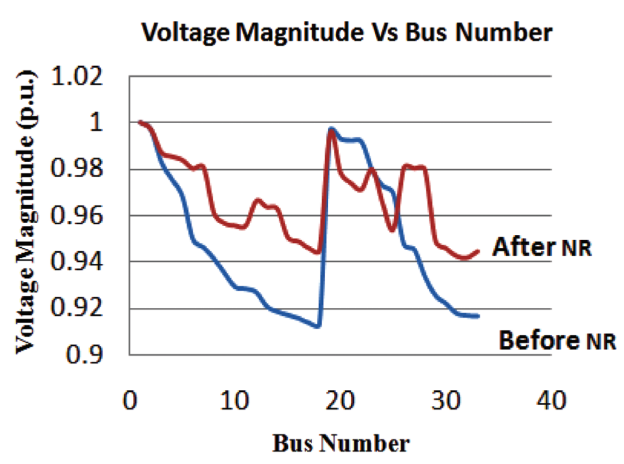

FIG. 4 COMPARISON OF VOLTAGEMAGNITUDES FOR BASE CASE AND RECONFIGURED NETWORK

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				

The Converged values of Voltage magnitude, phase angle and VSI after reconfiguration are given in Table 2.

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	0.94440	-0.01874	0.79871
2	0.99708	0.00025	0.98834	19	0.99507	-0.00039	0.76932
3	0.98699	0.00171	0.94875	20	0.97822	-0.00534	0.92337
4	0.98519	0.00167	0.94204	21	0.97358	-0.00742	0.87352
5	0.98370	0.00159	0.93638	22	0.97091	-0.00858	0.87992
6	0.97992	0.00058	0.92443	23	0.97962	0.00227	0.87680
7	0.98055	-0.00010	0.92206	24	0.96489	0.00251	0.90831
8	0.96052	-0.01270	0.91470	25	0.95359	0.00360	0.86441
9	0.95619	-0.01379	0.79180	26	0.98027	0.00055	0.82591
10	0.95523	-0.01396	0.81979	27	0.98001	0.00052	0.92242
11	0.95516	-0.01394	0.82333	28	0.97949	0.00030	0.92045
12	0.96586	-0.00978	0.81455	29	0.94857	0.00415	0.89814

13	0.96329	-0.01004	0.86104	30	0.94537	0.00586	0.80359
14	0.96250	-0.01032	0.85822	31	0.94197	0.00459	0.78879
15	0.95012	-0.01653	0.81226	32	0.94129	0.00428	0.78385
16	0.94836	-0.01693	0.80010	33	0.94407	-0.01881	0.78395
17	0.94543	-0.01855	0.80563				

TABLE 3

VARIATION IN THE POWER LOSS OF 33 BUS RDS

Power Loss	Before NR	After NR	% Decrease
Real Power Loss (kW)	202.67	141.60	30.13
Reactive Power Loss (kVar)	135.13	106.12	21.47
Total Power Loss (kVA)	243.59	176.95	27.36

TABLE 4

VARIATION IN THE RELIABILITY INDICES OF DISTRIBUTION SYSTEM

Index	Before NR	After NR	% Decrease
SAIDI	2.04	1.51	25.91
SAIFI	2.41	2.35	2.64
CAIDI	0.85	0.64	23.91
ASUI	2.33e-4	1.73e-4	25.92

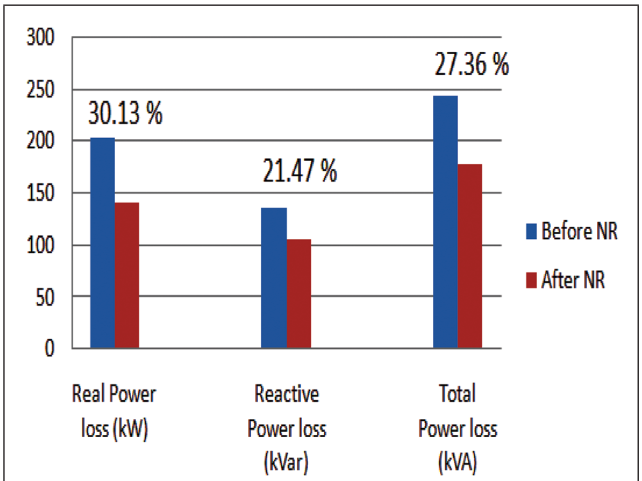

FIG. 5 COMPARISON OF POWER LOSS FOR BASE CASE AND RECONFIGUREDNETWORK

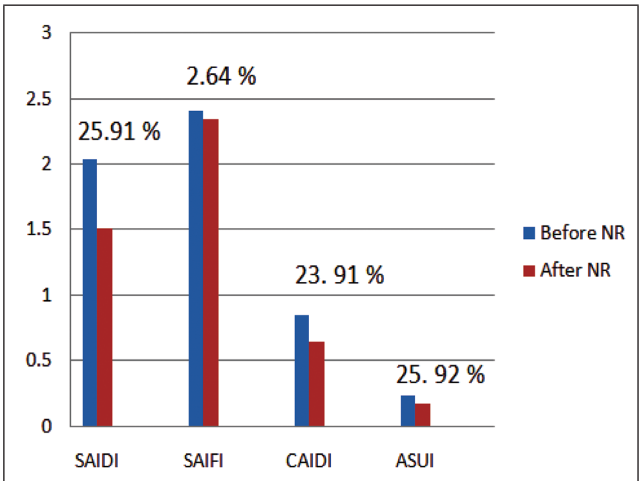

FIG. 6 COMPARISON OF RELIABILITY INDICES FOR BASE CASE AND RECONFIGURED NETWORK

5.0 CONCLUSIONS

A reconfiguration scheme for voltage stability enhancement of radial distribution systems has been developed. This algorithm is based on a simple VSI has been found to improve voltage profile, enhance the voltage stability, reduce the system power losses and improve the reliability indices without any additional equipment cost. The proposed algorithm is applied to 33-bus RDS and the obtained results from MATLAB™ are analyzed.

REFERENCES

[1] R Billinton, R N Allan, Reliability Evaluation of Power Systems, Second Edition, Springer International Edition, Reprinted in India, BS Publications pp. 229-231, 2007.

[2] M K Khedkar, G M Dhole, A Textbook of Electric Power Distribution Automation, Laxmi Publications Ltd., pp. 78-80 ,2010.

[3] V Sankar, System reliability concepts, Himalaya Publishing house, pp. 239-275, 2015.

[4] Jen Hao Teng, A Direct Approach for Distribution System Load Flow Solutions, IEEE Trans. PD, Vol. 18, No.3, pp. 882-887, 2003

[5] N C Sahoo, K Prasad, A fuzzy genetic approach for network reconfiguration to enhance voltage stability in radial distribution systems, Energy Conversion and Management, Vol. 47, Issues 18-19, pp. 3288–3306, 2006

[6] G K Viswanadha Raju, P R Bijwe, Efficient reconfiguration of balanced and unbalanced distribution systems for loss minimisation, IET Proceedings of Generation, Transmission, Distribution, Vol. 2, No. 1, pp. 7-12, 2008

[7] M Arun, P Aravindhababu, A New Reconfiguration Scheme for Voltage Stability Enhancement of Radial Distribution System, Energy Conversion and Management, Vol. 50, pp. 2148-2151, 2009

[8] M Tamer, Khalil, Alexander V Gorpinich, Reconfiguration for Loss Reduction of Distribution Systems Using Selective particle Swarm Optimization, International Journal of Multidisciplinary Sciences and Engg., Vol. 3, No. 6, pp. 16-21, 2012

[9] T Lantharthong, N Phanthuna, Techniques for Reliability Evaluation in Distribution System Planning, World Academy of Science, Engineering and Technology, Vol. 64, pp. 392-395, 2012

[10] A Mohamed Imran, M Kowsalya, A New Power System ReconfigurationScheme for Power Loss Minimizationand Voltage Profile Enhancement Using Fireworks Algorithm, Electrical Power and Energy Systems, pp. 312-322, 2014

APPENDIX - A

TABLE. A.1

LINE AND RELIABILITY DATA OF 33-BUS RDS

Line Number	Sending end Node	Receiving end Node	R (Ω)	X(Ω)	Failure rate(f/yr)	Repair time(hrs)
1	1	2	0.092	0.047	0.05	1
2	2	3	0.493	0.251	0.3	1
3	3	4	0.366	0.186	0.22	1
4	4	5	0.381	0.194	0.23	1
5	5	6	0.819	0.707	0.51	1
6	6	7	0.187	0.619	0.11	1
7	7	8	0.711	0.235	0.44	1
8	8	9	1.03	0.74	0.64	1
9	9	10	1.044	0.74	0.65	1
10	10	11	0.197	0.065	0.12	1
11	11	12	0.374	0.124	0.23	1
12	12	13	1.468	1.155	0.91	1
13	13	14	0.542	0.713	0.33	1
14	14	15	0.591	0.526	0.36	1
15	15	16	0.746	0.545	0.46	1
16	16	17	1.289	1.721	0.8	1
17	17	18	0.732	0.574	0.45	1
18	2	19	0.164	0.157	0.1	0.5
19	19	20	1.5042	1.3554	0.93	0.5
20	20	21	0.41	0.478	0.25	0.5
21	21	22	0.709	0.937	0.44	0.5
22	3	23	0.451	0.308	0.28	0.5
23	23	24	0.898	0.709	0.56	0.5
24	24	25	0.896	0.701	0.55	0.5
25	6	26	0.203	0.103	0.12	0.5
26	26	27	0.284	0.145	0.17	0.5
27	27	28	1.059	0.934	0.66	0.5
28	28	29	0.804	0.701	0.5	0.5
29	29	30	0.508	0.259	0.31	0.5
30	30	31	0.974	0.963	0.6	0.5
31	31	32	0.311	0.362	0.19	0.5
32	32	33	0.341	0.53	0.21	0.5
33	8	21	2	2	1.24	0.5
34	9	15	2	2	1.24	0.5
35	12	22	2	2	1.24	0.5
36	18	33	0.5	0.5	0.31	0.5
37	25	29	0.5	0.5	0.31	0.5

TABLE. A.2

LOAD AND NO. OF CUSTOMERS DATA OF 33 BUS RDS

Bus No.	Active power (kW)	Reactive power (kVAr)	No. of Customers	Bus No.	Active power (kW)	Reactive power (kVAr)	No. of Customers
1	-	-	-	19	90	40	450
2	100	60	500	20	90	40	350
3	90	40	400	21	90	40	450
4	120	80	600	22	90	40	550
5	60	30	350	23	90	50	450
6	60	20	350	24	420	200	1500
7	200	100	1000	25	420	200	1300
8	200	100	1000	26	60	25	300
9	60	20	550	27	60	25	500
10	60	20	550	28	60	20	300
11	45	30	400	29	120	70	600
12	60	35	300	30	200	600	900
13	60	35	400	31	150	70	800
14	120	80	550	32	210	100	1050
15	60	10	300	33	60	40	300
16	60	20	450				
17	60	20	300				
18	90	40	400				