

DG Placement in Distribution Systems for Loss and Reliability Optimization with Network Reconfiguration

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Abstract

This paper presents a method to improve the reliability and minimize losses in a radial distribution system by using network reconfiguration method. The methodology adopted to enhance reliability uses Cut set approach and historical data of the network such as reliability data, voltage profile etc. The optimal location for the placement of DG units is followed by using sensitivity analysis. Various network reconfiguration algorithms are simulated for the study of effectiveness of the method proposed. This method has been applied to a 33-bus radial distribution system to demonstrate that the objective of loss reduction and reliability improvement has been achieved to a significant level.

I. Introduction

Electrical distribution systems are facing the problem of ever increasing load. In addition to supplying power to the increased load, there is a necessity of improving distribution system reliability, and overall efficiency. When compared and reducing losses to the transmission system efficiency due to the low operation voltage and there is a need for a new method to improve efficiency. Distributed generations is a promising solution for the improvement of efficiency and reliability of a distribution system. Feeder Reconfiguration is another method to improve the overall system reliability further.

The trend followed by the power system engineers was to install a bulk generation plant at suitable places and expand the capacity of those plants in order to meet increasing demands. This method of bulk generation of power has its own advantages such as lower investment, operation and maintenance cost. There are, but, inherent disadvantages too for this system which are the need for an extensive transmission system, which requires huge investments. The cumulative losses of the power system i.e., generation, transmission, distribution losses add up to a significant amount. A power system with distributed generation overcomes many of these setbacks. DG also paves a path for privatization and deregulation of the power system which is much needed. It is estimated that about more than 25% of the total power generation in India will be from DG station by 2020. The feeder of a distribution system are loaded in real time arbitrarily in real time. This makes controlling and operating the distribution system very complex. This problem is more pounced in areas where the load density is more. The power losses in a distribution system will not be minimum for a fixed configuration under all conditions. Therefore network reconfiguration is required from time to time.

There are many methods for reducing active power losses, such as, increasing of conductor size, decreasing line lengths, installation of power factor correction equipment i.e., shunt capacitors. Feeder reconfiguration is also a reliable method for decreasing power losses in a distribution system. Feeder reconfiguration refers to the placement of sectionalizing switches and tie switches between the buses of a distribution system. Sectionalizing switch is present between buses n, n+1 and normally closed.

Tie switches are switches that are placed strategically between certain buses of the system so as to facilitate power flow when required. They are normally opened. The advantages of network reconfiguration are reduction of losses in real power, balancing the

load on the system, improvement of bus voltage profile and increasing the reliability and security of the system.

Network reconfiguration is a real time complex with dynamic nature. Therefore it demands new and more complex methods of solutions. Many algorithms are proposed in the past to solve this optimization problem. An optimization technique is known as branch-and-bound type to solve the reconfiguration problem [1]. A heuristic algorithm in which for the determination of change in power losses with branch exchange was proposed in [2]. A heuristic method for network reconfiguration is proposed in [3].

II Methodology

A. Problem Formulation

In this paper the system constraints such as voltage limits, power flows and line loading capabilities are considered. Radial distribution system is considered for the simulation. A reduction in power losses and increase in performance indices is expected after network reconfiguration.

i) Node voltages:

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

Here V_{imin} and V_{imax} are the permissible RMS voltage limits at i^{th} node.

ii) Reliability indices and power losses

$$\begin{aligned} 0 < P_L, Q_L &\leq P_{Lb}, Q_{Lb}; \\ 0 < SAIFI &\leq (SAIFI)_b; 0 < SAIDI &\leq (SAIDI)_b; \\ 0 < CAIDI &\leq (CAIDI)_b; 0 < ASUI &\leq (ASUI)_b; \end{aligned}$$

The power flow analysis is carried out by Distribution load Flow Algorithm[1]. The power flows and voltages constraints have to be satisfied while minimizing the power losses and maximizing the reliability. To obtain load flow analysis a simple matrix multiplication and the Branch-Current to Bus voltage matrix (BCBV) and the Bus-Injection to Branch-current matrix (BIBC) are utilized in[5].

2. Reliability evaluation

Reliability analysis also plays a key role in planning for up-gradation of the distribution network, thus meeting new and ever increasing demands. The principle of series system is applied to this system. To evaluate reliability of system, load point indices are used.

i) Average failure rate(λ_s)

$$\lambda_s = \sum_{i=1}^N \lambda_{if/yr} \quad (1)$$

ii) Average annual outage (U_s)

$$U_s = \sum_{i=1}^N \lambda_i r_i \text{hrs/yr} \quad (2)$$

iii) Average outage time (r_s)

$$r_s = \frac{U_s}{\lambda_s} \text{hrs} \quad (3)$$

Where (λ_i) is the failure rate of a component i, and (r_i) is the repair time of component i. In order to consider the significance of a system outage, costumer orientated indices can be evaluated, they are given by

(i) System Average Interruption Frequency Index (SAIFI):

$$\text{SAIFI} = \frac{\text{TOTAL NO. OF CUSTOMER INTERRUPTIONS}}{\text{TOTAL NO. OF CUSTOMERS SERVED}}$$

$$\text{SAIFI} = \frac{\sum \lambda_i N_i}{\sum N_i} \text{ interruptions/customer} \quad (4)$$

Where λ_i is the failure rate and N_i is the no. of customers at load point i.

(ii) System Average Interruption Duration Index (SAIDI):

$$\text{SAIDI} = \frac{\text{SUM OF CUSTOMER INTERRUPTION DURATIONS}}{\text{TOTAL NO. OF CUSTOMERS}}$$

$$\text{SAIDI} = \frac{\sum U_i N_i}{\sum N_i} \text{ Hours/ Customer} \quad (5)$$

Where U_i is the annual outage time of i^{th} load point.

(iii) Customer Average interruption Duration Index:

$$\text{CAIDI} = \frac{\text{SUM OF CUSTOMER INTERRUPTION DURATIONS}}{\text{TOTAL NO. OF CUSTOMER INTERRUPTIONS}}$$

$$\text{CAIDI} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \text{ Hours/interruption} \quad (6)$$

Where λ_i is the failure rate, U_i is the annual outage time and N_i is the number of customers at load point i.

(iv) Average service availability Index (ASAI):

$$\text{ASAI} = \frac{\text{CUSTOMER HOURS OF AVAILABLE SERVICE}}{\text{CUSTOMER HOURS DEMANDED}}$$

$$\text{ASAI} = \frac{\sum N_i (8760) - U_i N_i}{\sum N_i (8760)} \quad (7)$$

(v) Average service unavailability Index:

$$\text{ASUI} = \frac{\text{CUSTOMER HOURS OF UNAVAILABLE SERVICE}}{\text{CUSTOMER HOURS DEMANDED}}$$

$$\text{ASUI} = 1 - \text{ASAI}$$

$$\text{ASUI} = \frac{\sum U_i N_i}{\sum N_i (8760)} \quad (8)$$

Where 8760 is the number of hours in a calendar year.

C. Network Reconfiguration Algorithm

Network reconfiguration is one of the feasible methods in which power flow is altered by opening or closing the switches on the feeders. It is implemented by opening a sectionalizing switch and closing a tie switch to conserve radial structure of the feeders.

The algorithm steps for network reconfiguration of radial distribution system are as follows

Step 1: Read the Bus data, Line data, the probability of distribution system and set the flag to zero for all the tie switches.

Step 2: Run the distribution load flow by using BIBC, BVBC matrices and compute the node voltages, real power losses, reactive power losses, and reliability indices.

Step 3: The voltage should be within the specified limits

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

i.e. within the 6% of rated voltage; $0.94 \leq V \leq 1.06$, if yes then go to step 11.

Step 4: Calculate the VSI difference between end node k and m of the tie switches with zero flag. The tie switch with maximum VSI difference is chosen.

Step 5: Check if the VSI at k^{th} node is greater than that at the m^{th} node. If yes go to step 7.

Step 6: The sectionalizing switch between k and k-1 should be opened.

Step 7: The sectionalizing switch between m and m-1 should be opened.

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

Step 9: Check if the ties switch with flag equal to 1 else then go to step 10.

Step 10: Calculate the power losses

If not $0 < P_L, Q_L \leq P_{Lb}, Q_{Lb}$; then go to step 2

Step 11: Calculate reliability indices: SAIFI, SAIDI, ASUI & CAIDI.

If not

$0 < \text{SAIFI} \leq (\text{SAIFI})_b; 0 < \text{SAIDI} \leq (\text{SAIDI})_b;$

$0 < \text{CAIDI} \leq (\text{CAIDI})_b; 0 < \text{ASUI} \leq (\text{ASUI})_b;$

Then go to step 2.

Step 12: Print the values of |V|, VSI, PL, QL, SAIDI, SAIFI, ASUI and CAIDI.

The flow chart for the above algorithm is shown figure 1.

D. Optimal placement of a DG

There are several benefits by installing a DG unit at an optimal location. These include minimising of line losses, enhancement of voltage profile, peak demand shaving, relieving overloaded lines,

improvement of the overall system efficiency. DG is placed at three optimal locations in 33-bus radial distribution system with 0.1070 MW (18) and 0.5724 MW (17), 1.0462 MW (33). Single line diagram of 33-bus radial distribution system with DG installation is shown in figure 4.

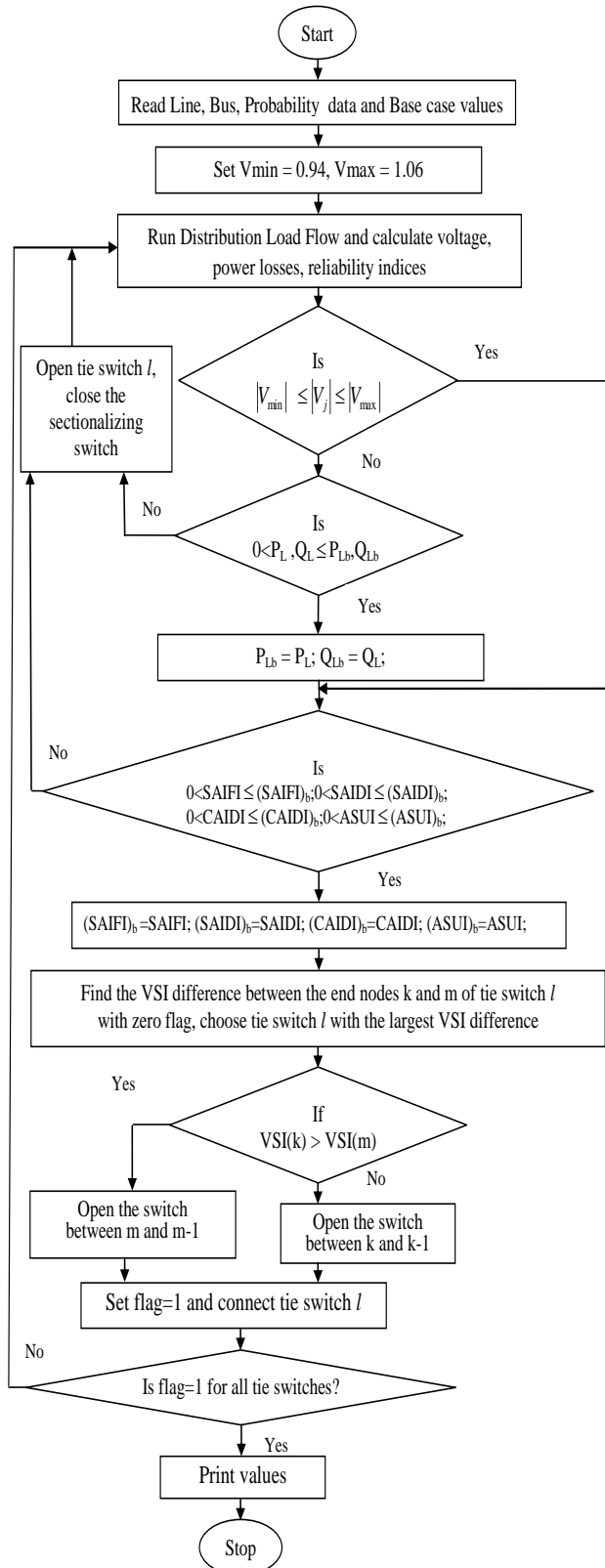


Fig.1: Flow Chart for network reconfiguration of 33-bus RDS

III Result analysis and Discussions

33-Bus radial distribution system having voltage of 12.66 KV is shown in fig.2 and the relevant data for this system are taken from [6,7].

Following are 5 cases that are considered for analysis of this test system.

Case 1: The test system is without placement of DG and without Reconfiguration

Case 2: The test system with Reconfiguration only

Case 3: The test system with DG placement only

Case 4: The test system simultaneous operation of Reconfiguration & DG placement.

Case 5: Network Reconfiguration Algorithm [6]

The Network reconfiguration algorithm in section C is applied to a 33-bus Radial distribution system using MATLAB™ programming and the results are evaluated and validated.

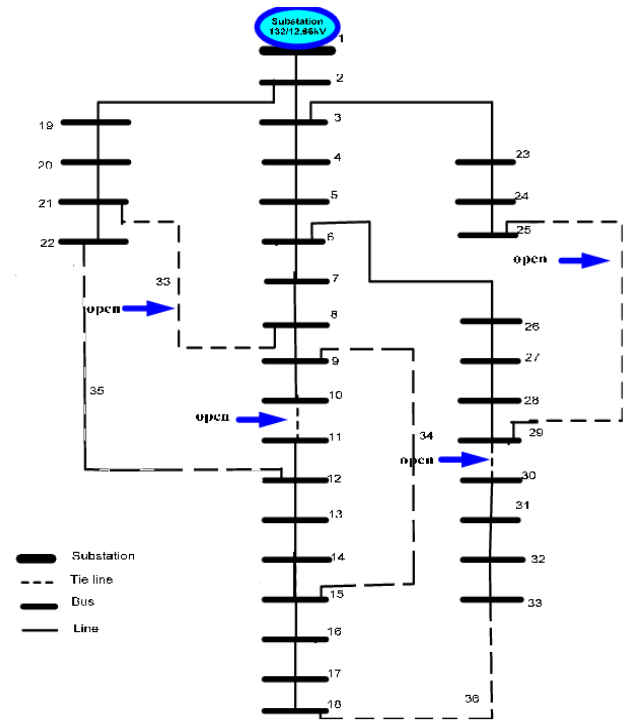


Fig.2: Single line diagram of 33-bus RDS base Configuration

Table 1 shows the Converged values of VSI, Voltage magnitude and Phase angle for the Base Configuration as shown in figure 2. The VSI difference between the tie switches 22-12 is highest. Hence this tie switch is to be closed first. As the VSI of 22 is more than the VSI of 12, the switch in the branch 10-11 should be open. The total real power loss is 153.93 KW. Now, the next tie switch which is to be closed is 25-29, the procedure is repeated and the solution is to open the switch 28-29 having a total real power loss of 145.88KW. Now, the next tie switch should be closed is 18-33, and the switch to be opened is 33-32 with a total real power loss 142.12 KW. The procedure has to be repeated until the final optimal configuration is achieved. Thus, a total power loss of 140.00 KW has been observed after Reconfiguration. The final optimal configuration can be seen in figure 4 and the tie switches are 10-11, 28-29, 33-32, 14-15, 7-8.

3.1 Power Loss Analysis

The single diagram of 33-bus Radial Distribution System with Reconfiguration is shown in figure 3. The Converged values of Voltage stability index, Voltage magnitudes and Phase angle after reconfiguration are shown in Table 2. The decrease in the power losses of a 33 bus RDS for base case and reconfiguration have been tabulated in Table 3. It can be observed from Table 3 that, after applying a network reconfiguration the real power losses have been

reduced to 140.00 KW. The switches that have been opened in this reconfiguration are 7, 14, 9, 32, and 37. The variation in the power losses of a 33-bus Radial Distribution System for Base case and DG installation are shown in Table 4. The Base Case real power loss without network reconfiguration is observed to be 202.66 KW. It can be observed from Table 4 that, after placement of DG the real power losses have been reduced to 96.76 KW. The switches that have been opened in this DG Case are 33, 34, 35, 36 and 37.

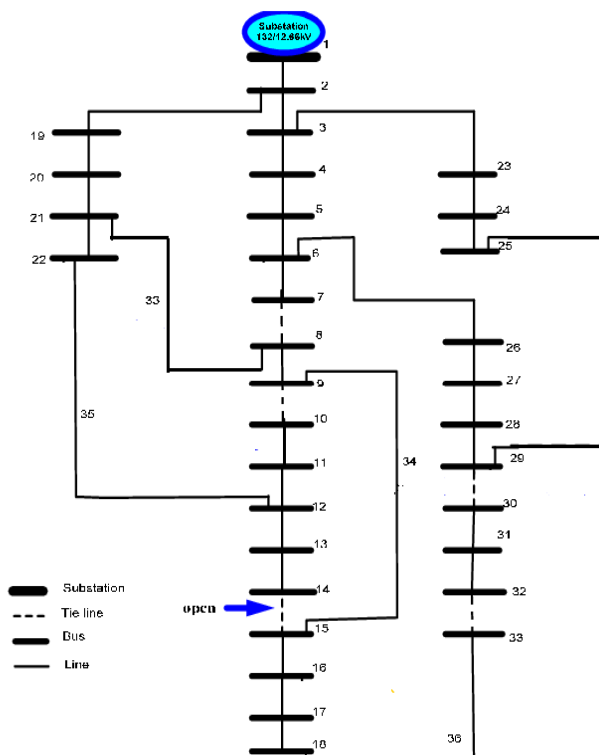


Fig.3: Single line diagram of 33-bus RDS with Reconfiguration

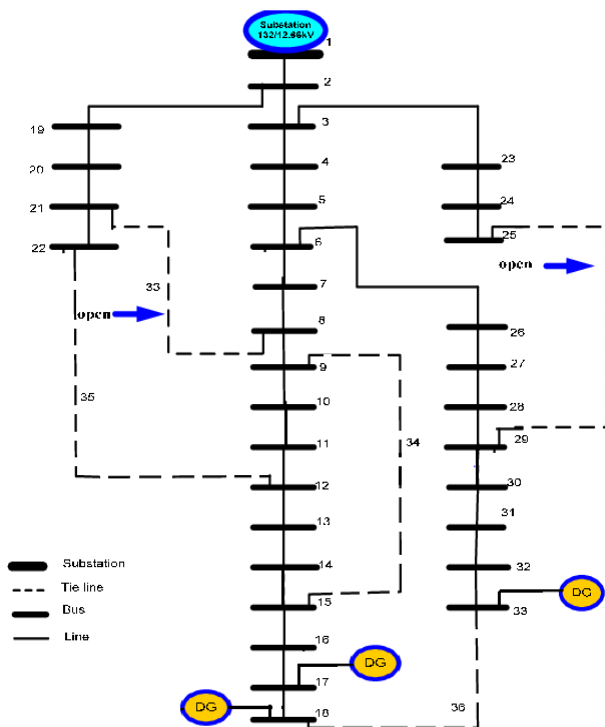


Fig.4: Single diagram of 33-bus RDS with DG installation

It can be observed from Table 5 that, after applying network reconfiguration with simultaneous DG placement the real power losses have been reduced to 73.50 KW. The switches that have been opened in this DG Case are 7, 14, 10, 32 and 37, and the line diagram for reconfiguration with simultaneous DG Case is shown in fig 5.

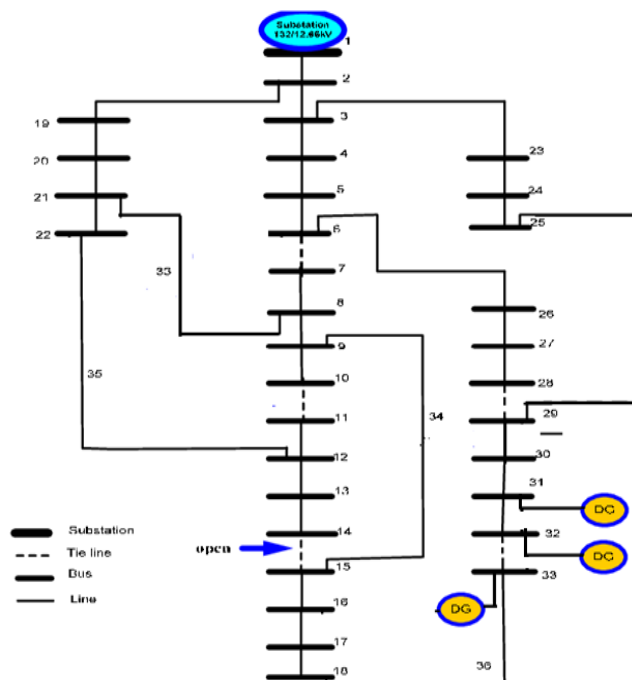


Fig.5: Single line diagram of 33-bus RDS with simultaneous Reconfiguration with DG installation.

TABLE.1 CONVERGED VALUES OF BUS VOLTAGES MAGNITUDE, VSI, PHASE ANGLE 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	0.972
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	0.895
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	0.798
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	0.697				

TABLE.2: CONVERGED VALUES OF VSI, VOLTAGE MAGNITUDE AND PHASE ANGLE 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	0	1	18	0.9396	-0.0204	0.777
2	0.9971	0.0003	0.9883	19	0.9954	-0.0003	0.769
3	0.9862	0.0017	0.9456	20	0.9813	-0.0045	0.9776
4	0.9838	0.0017	0.9367	21	0.9775	-0.0062	0.926
5	0.9817	0.0016	0.9287	22	0.9712	-0.0095	0.9033
6	0.977	0.0002	0.9111	23	0.9788	0.0023	0.8868
7	0.9757	-0.0012	0.9064	24	0.9641	0.0025	0.8906
8	0.9747	-0.001	0.9025	25	0.9528	0.0036	0.8116
9	0.9515	-0.0154	0.8964	26	0.9767	0.0002	0.7839
10	0.9549	-0.0145	0.771	27	0.9765	0.0001	0.8914
11	0.9556	-0.0145	0.8182	28	0.976	-0.0001	0.8972
12	0.9569	-0.0146	0.8119	29	0.9477	0.0041	0.8949
13	0.9543	-0.0149	0.7885	30	0.9445	0.0059	0.8045
14	0.9535	-0.0152	0.8247	31	0.9411	0.0046	0.795
15	0.9454	-0.0182	0.8245	32	0.9404	0.0043	0.7836
16	0.9436	-0.0186	0.7871	33	0.9393	-0.0205	0.7805
17	0.9406	-0.0202	0.7723				

COMPARISION OF POWER LOSSES

TABLE 3: VARIATION IN THE POWER LOSSES OF 33-BUS RDS FOR CASE 1, CASE 2

Power loss	Before NR	After NR	%Decrease
Real power loss(KW)	202.6650	140.00	30.92
Reactive power loss(kVar)	135.1327	104.9	22.37
Total power loss(kVA)	243.5856	174.9	28.19

TABLE 4: VARIATION IN THE POWER LOSSES OF 33-BUS RDS FOR CASE 1, CASE 3

Power loss	Base Case	DG	%Decrease
Real power loss(KW)	202.6650	96.76	52.256
Reactive power loss(kVar)	135.1327	69.7426	48.38
Total power loss(kVA)	243.5856	119.2577	51.04

TABLE 5: VARIATION IN THE POWER LOSSES OF 33-BUS RDS FOR CASE 2, CASE 4

Power loss	After NR	NR with DG units	%Decrease
Real power loss(KW)	140.00	73.50	47.5
Reactive power loss(kVar)	104.9	55.72	46.88
Total power loss(kVA)	174.9	92.16	47.30

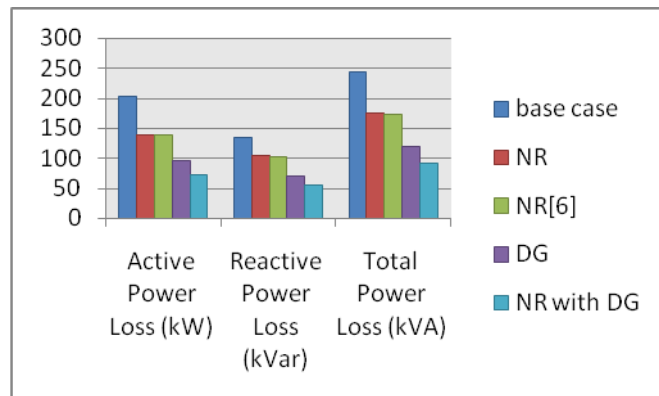


Fig.7: Comparison of power losses for all five cases

3.2 Reliability Analysis

The Reliability indices SAIFI, SAIDI, ASUI and CAIDI of the 33-bus RDS have been calculated. The Reliability indices of the system before and after reconfiguration are compared in table 6. The Reliability indices of the system Base Case and after DG case are compared in table 7. The Reliability indices of the system with four cases can be comparatively seen in table 8. Figure 6 shows the Voltage Magnitudes for all the four cases.

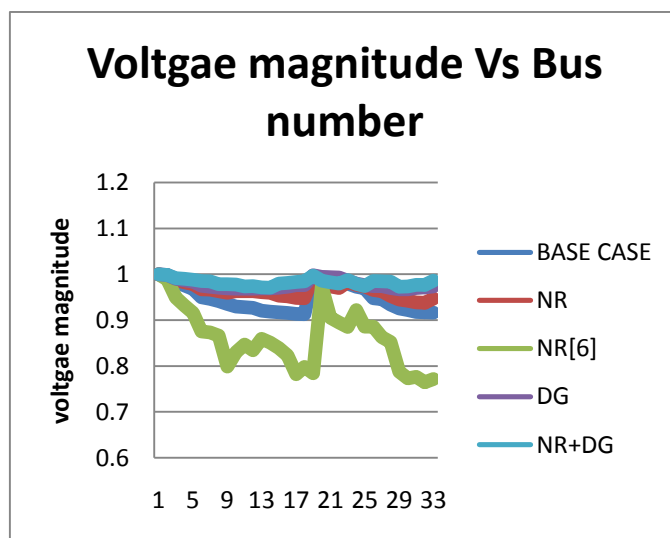


Fig.6: Comparison of Voltage Magnitudes for all five cases

COMPARISION OF RELIABILITY INDICES FOR BASE CASE AND AFTER RECONFIGURATION:

TABLE 6: VARIATION IN THE RELIABILITY OF 33-BUS RDS FOR CASE 1, CASE 2

Index	Before NR	After NR	%Decrease
SAIFI (f/yr)	2.4126	2.135	11.6
SAIDI (hr/yr)	2.0436	1.4357	29.5
CAIDI (hr)	0.8470	0.6722	20.63
ASUI	2.3328e-04	1.6389e-04	29.74

TABLE 7: VARIATION IN THE RELIABILITY OF 33-BUS RDS FOR CASE 1, CASE 3

Index	Base Case	DG placement	%Decrease
SAIFI (f/yr)	2.4126	2.368	2.180
SAIDI (hr/yr)	2.0436	2.001	2.08
CAIDI (hr)	0.8470	0.8449	0.247
ASUI	2.3328e-04	2.284e-04	2.099

TABLE 8: VARIATION IN THE RELIABILITY OF 33-BUS RDS FOR CASE 2, CASE 4

Index	After NR	NR with DG units	%Decrease
SAIFI (f/yr)	2.135	1.967	7.86
SAIDI (hr/yr)	1.4357	1.293	9.79
CAIDI (hr)	0.6722	0.657	2.261
ASUI	1.6389e-04	1.4767e-04	9.89

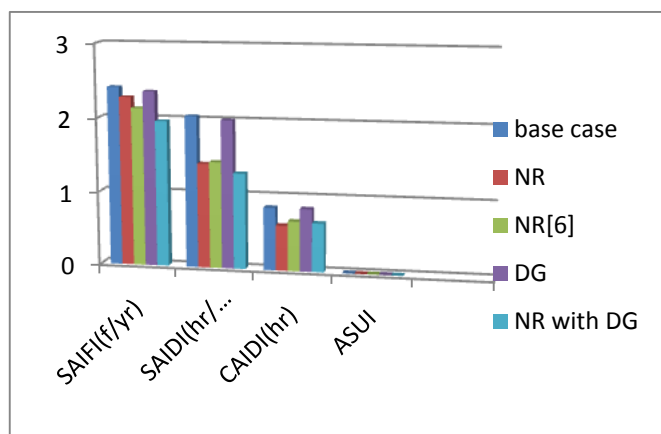


Fig.8: Comparison of reliability indices for all five cases

IV CONCLUSION

In this paper, a new approach has been developed to reconfigure a 33-bus Radial distribution system. In this approach an algorithm is developed to reconfigure the 33-bus RDS to enhance the stability. This algorithm is based on VSI that has been found to improve the voltage stability and to enhance the voltage profile, to reduce the power losses in the system and to improve reliability of the system. Network Reconfiguration, DG Installation only, Reconfiguration with simultaneous DG Installation are also simulated in MATLAB Programming to establish the superiority of the proposed method. The results show that with the installations of DG and Network reconfiguration simultaneously show the best results. The results show that the power loss reduction percentage is improving as the numbers of DG installation location are increase.

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