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Loss Minimization by Optimal DG Placement on Radial Distribution Network

Nikunj Lad[1], Prof. Arun Pachori[2]
[1,2]Department of Electrical Engineering, Jabalpur Engineering College, Jabalpur (M.P), India

Abstract: With the increase in load demand and efforts to reduce distribution system losses, to increase the efficiency of the distribution system maintaining proper voltage profile and for the future expansion of the distribution network optimal distribution system planning is therefore very important and this important task must be solved in an optimal way. In this paper, IEEE-33 bus system is considered for optimally allocating the distributed generation source at some of the buses. The following effort explains that by placing distributed generation at most sensitive buses the real power losses in the system can be reduced drastically and voltage profile can also be improved. The sites for distributed generation are selected on the basis of sensitivity and the amount of real power source at that bus is decided by applying Local Search Method.
Keywords: Load flow analysis, Radial distribution system, Backward/forward sweep method, Local Search Method, Distributed Generation [DG].

I. INTRODUCTION

The load flow study of radial distribution system is of prime importance for effective planning of load scheduling and for analyzing the voltage profile of the system. By carrying out load flow analysis in any electric supply system, the real power and reactive power losses in the system can also be calculated. But in any system it is desirable to have minimum losses and by carrying out only the load flow analysis the losses cannot be minimized. So to minimize the real power losses methods like distributed generation can be used. In this paper, a technique to improve the voltage profile by effectively placing distributed generation is presented using local search algorithms. These algorithms are non-exhaustivein the sense that they do not guarantee finding an optimal solution but they search non- thoroughly until a specific criterion is fulfilled.

A. Radial Distribution System

Radial distribution system has feeders which are connected to many loads and each load has a unique path from its location to the source. Radial distribution system can also be modeled as a network of buses connected by distribution lines, switches and transformers. Effective planning of radial distribution network is required to meet the present rising demands of commercial, industrial and domestic loads step-by-step as this type of distribution system is most economical to deploy in the case of rural electrification and the load located far from the source.

B. Distributed Generation [DG]

In DG electricity is contributed to the grid from a variety of decentralized locations through various sources of electrical power. DG has turned out to be a main requirement of the modern power system as it can reduce losses occurring in transmission, distribution of electricity. DG can provide benefits in gaining faster response to new electrical power demand, improved supply reliability and improved power quality. DG can increase the possibility of better load management and optimal use of accessible electricity resources. Typical installation of DG through micro, mini, small, medium and large generation systems according to the capacity of photovoltaic cell, fuel, biomass, wind and other resources is given in Table 1.

Classification	Technical Definition	Typical Installation
Macro	Less than 2 kw and connected to low voltage network	Roof Top Solar PV
Mini	More than 2 KW and up to 10 KW 1- phase and 3-phase	Fuel Cells
Small	More than 10 KW and up to 1 MW	Biomass
Medium	More than 1 MW and up to 5 MW	Wind Generation
Large	Greater Than 5 MW	Hydra , Thermal and Solar

Table 1: Typical Installation of DG through Different Systems

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C. Local Search Method

Local search techniques are widely used to obtain approximate solutions to a variety of combinatorial optimization problems. Two important categories of local search methods are neighborhood search and genetic algorithms. The local search techniques are based on the way of iterative exploration of solution spaces at all iterations, a local search algorithm makes his way from a solution to the solution lying in the neighboring or nearby area. Local search based algorithms regulates from one solution to other nearby available solution in the space of candidate solutions by applying small difference in local changes in the previously obtained solution, this process continues until an optimal solution is found or if the time decided for the completion of process is over. So it can be said that the local search methods works simply on the idea of navigating a solution space by moving from one solution to the solution kept in its neighbors this process is done in number of iterations.

II. PROBLEM IDENTIFICATION

The load flow analysis of distribution systems to calculate the values of voltage, power angle real power and reactive power flow in the system cannot be carried out accurately using conventional methods like Newton Raphson method. However this conventional method gives sufficiently accurate result in analysis of transmission systems. Problem with the distribution system analysis using conventional methods is due to the following reasons.

A. In the case of load flow analysis of distribution systems, the simplifying assumptions like taking line impedance to be purely reactive as in case of transmission system, cannot be considered as in distribution system the X/R ratio is very small.
B. X/R ratio is very small due to low reactance of distribution transformers so as to keep low voltage regulation in the distribution system.
C. High resistance of the distribution line conductors because of low cross-sectional area.
D. Low reactance because of less geometric mean distance between the conductors and less geometric mean radius of the conductors.

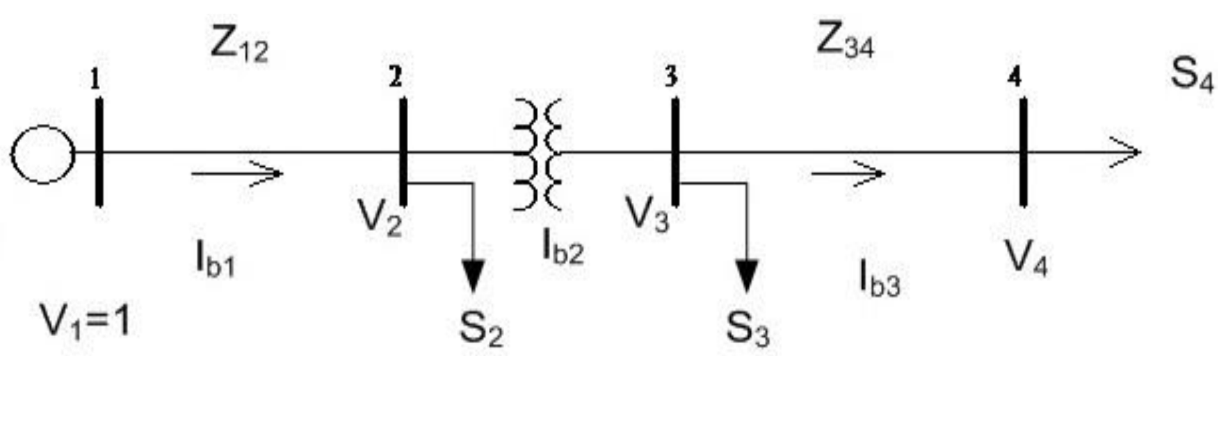
III. SOLUTION METHODOLOGY

The algorithm of forward backward sweep method is simple as it is based on application of KCL and KVL equations and for minimizing the system real power losses, DG is applied in the system. Optimal placement and optimal site allocation for the DG sources is done using the local search method which is an iterative method that checks each and every possible solution and further checks that whether the solution is optimal. If the solution obtained by local search method in iteration is not found to be optimal then the method restarts to find optimal solution by considering next iteration.

IV. FORWARD BACKWARD SWEEP METHOD

A. System Modeling

For the purposes of power flow studies, we model a radial distribution system as a network of buses connected by distribution lines, switches, or transformers to a voltage specified source bus. Each bus may also have a corresponding load, shunt capacitor or cogenerator connected to it. The model can be represented as shown in Figure 1.



Forward → ← Backward

Fig. 1 Radial Distribution System

A. Input Data

1) Active power, reactive power, sending end and receiving end node voltage and Positive
2) Sequence impedance model of all branches are needed.
3) Assume rated voltages at end nodes only for 1st iteration.
4) Voltage at end node equals the value of voltage computed in the forward sweep for the
5) subsequent iterations

This method includes two steps: The Backward Sweep & The Forward Sweep.

a) In backward sweep, voltage and currents are computed using KVL and KCL from the farthest node to the source node.
b) In forward sweep, the downstream voltages are calculated starting from source node.

Steps:
Start with end node and compute the node current using equation

$$\mathbf{I_i = (S_i / V_i^*)} \text{ ----- } \textbf{Equation 1}$$

Apply KCL to determine the current flowing from node i towards node i+1 using equation

$$\mathbf{I(i, i+1) = I_{i+1} + \sum(\text{Currents in branches emanating from node i+1})} \text{--}\textbf{Equation 2}$$

With the current calculated in equation 1 calculate the voltage at i_{th} node using equation 2 Continue this step till the junction node is reached. At junction node the voltage computed is stored.

$$\mathbf{V_i = V_{i+1} + I(i, i+1) * Z(i, i+1)} \text{-----------}\textbf{Equation 3}$$

Start with another end node of the system and compute voltage and current as in above step

Start further computation with the most recent voltage at the junction node and the current using equation 1.
Similarly compute till the source node.
Compare the calculated magnitude of the rated voltage at source node with specified source voltage.
Stop if the voltage difference is less than specified criteria, otherwise begin forward sweep.

B. Sensitivity Based Bus Allocation for DG

Selection of buses for placing DG can be done on the basis of sensitivity of the buses. Here sensitivity is calculated with respect to the change in total real power losses of the system when a particular amount of real power source is applied at each bus separately.

C. Basic Procedure for Sensitivity Based Selection of Buses

1) Choose a particular value of real power source that can be used as DG source.
2) Apply the chosen real power source at any of the buses and then perform the load flow analysis of the system to get the total real power losses in the system.
3) Remove the real power source from the previously selected bus and now apply it to some other bus again perform load flow analysis and get the values of real power losses.
4) Repeat the above procedure for all the buses in the system.
5) Prepare graph for change in power losses with respect to the bus number.
6) Then the buses which provide maximum reduction in the real power losses can be used for the placement of DG source.

$$\text{Percentage sensitivity} = \{(\mathbf{P_{Lold} - P_{Lnew}}) / \mathbf{P_{DG}}\} * \mathbf{100}$$

Where,

$\mathbf{P_{Lold}}$ = Original real power losses of the system.
$\mathbf{P_{Lnew}}$ = Real power losses of system with DG at a particular bus.
$\mathbf{P_{DG}}$= Amount of real power source applied at the bus as DG.

D. Single Line Diagram of IEEE-33 Bus System

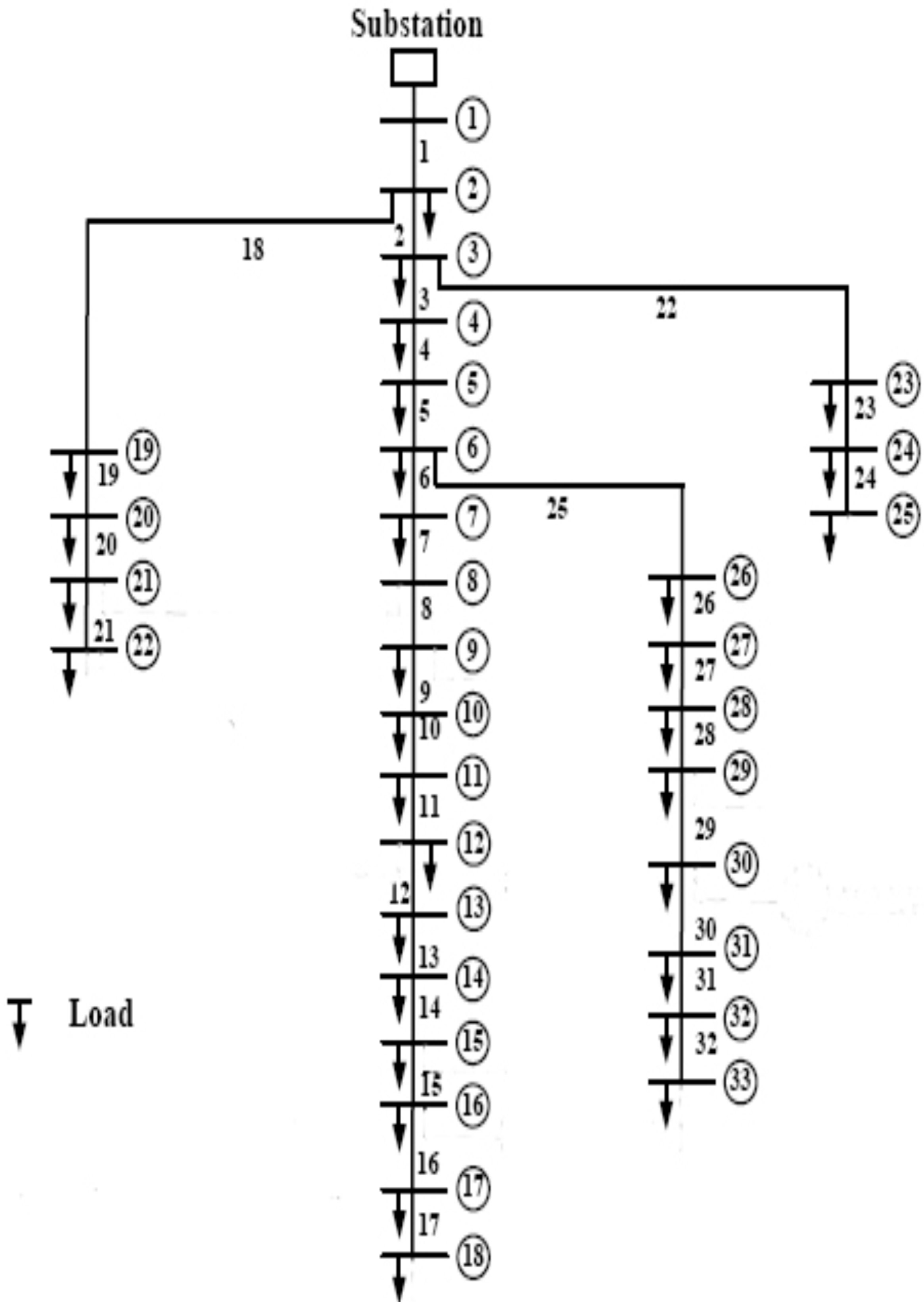


Fig 2: SLD of IEEE-33 Bus system

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S.No	From Bus	To Bus	R+jX	S.No	From Bus	To Bus	R+jX
1	1	2	0.0922+j0.0470	17	17	18	0.7320+j0.5740
2	2	3	0.4930+j0.2511	18	2	19	0.1640+j0.1565
3	3	4	0.3660+j0.1864	19	19	20	1.5042+j1.3554
4	4	5	0.3811+j0.1941	20	20	21	0.4095+j0.4784
5	5	6	0.8190+j0.7070	21	21	22	0.7089+j0.9373
6	6	7	0.1872+j0.6188	22	3	23	0.4512+j0.3083
7	7	8	0.7114+j0.2351	23	23	24	0.8980+j0.7091
8	8	9	1.0300+j0.7400	24	24	25	0.8960+j0.7011
9	9	10	1.0440+j0.7400	25	6	26	0.2030+j0.1034
10	10	11	0.1966+j0.0650	26	26	27	0.2842+j0.1447
11	11	12	0.3744+j0.1238	27	27	28	1.0590+j0.9337
12	12	13	1.4680+j1.1550	28	28	29	0.8042+j0.7006
13	13	14	0.5416+j0.7129	29	29	30	0.5075+j0.2585
14	14	15	0.5910+j0.5260	30	30	31	0.9744+j0.9630
15	15	16	0.7463+j0.5450	31	31	32	0.3105+j0.3619
16	16	17	1.2890+j1.7210	32	32	33	0.3410+j0.5302

Bus No	Load		Bus No	Load		Bus No	Load		Bus No	Load	
	In KW	In KVAR		In KW	In KVAR		In KW	In KVAR		In KW	In KVAR
2	100	60	10	60	20	18	90	40	26	60	25
3	90	40	11	45	30	19	90	40	27	60	25
4	120	80	12	60	35	20	90	40	28	60	20
5	60	30	13	60	35	21	90	40	29	120	70
6	60	20	14	120	80	22	90	40	30	200	600
7	200	100	15	60	10	23	90	50	31	150	70
8	200	100	16	60	20	24	420	200	32	210	100
9	60	20	17	60	20	25	420	200	33	60	40

Table 3 Load Data of IEEE-33 Bus system

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Flow Chart for the Solution Methodology

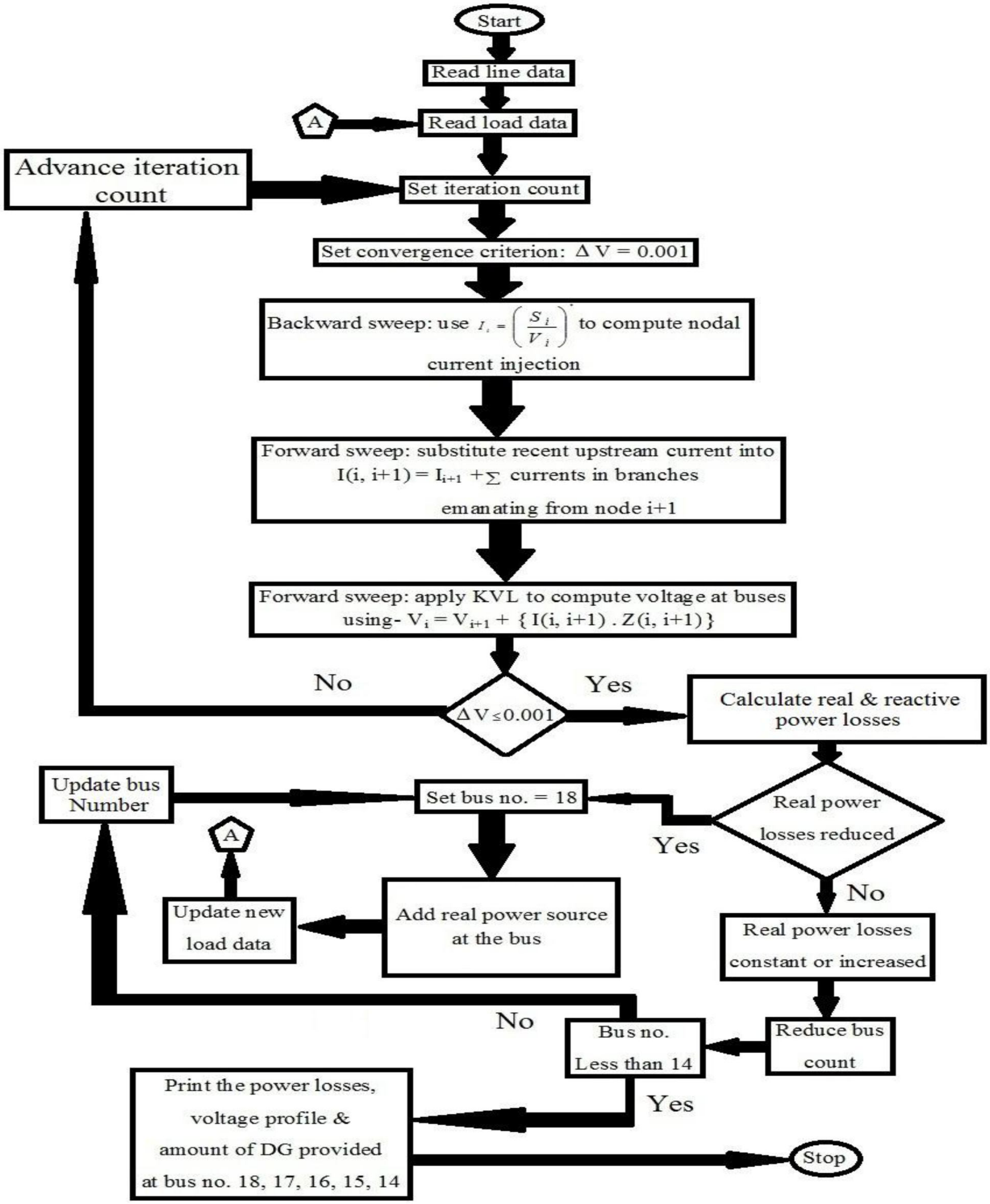

Fig 3 Flow Chart for Solution Methodology

V. RESULTS AND DISCUSSION

Load Flow Analysis using Forward Backward Sweep Method without DG bus voltages, real power losses and reactive power losses of the system are calculated using Load Data and Line Data of IEEE-33 Bus System given in Table No 2 & 3.

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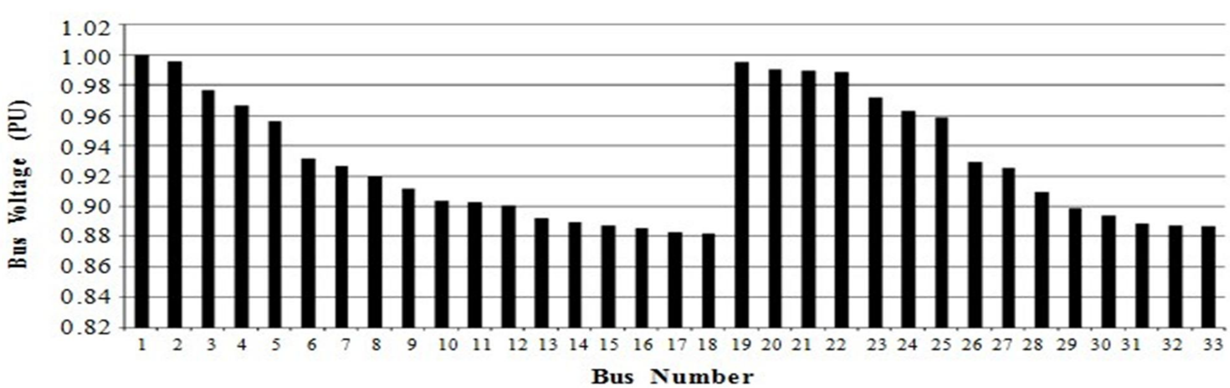
Line Number	Real Power Losses (KW)	Reactive Power Losses(KVAR)
1	16.8042	8.5661
2	71.3939	36.3631
3	27.6696	14.0918
4	26.0406	13.2629
5	53.2996	46.0108
6	2.6787	8.8546
7	6.7909	2.2442
8	5.8918	4.2329
9	5.023	3.5604
10	0.7815	0.2584
11	1.2449	0.4116
12	3.7715	2.9674
13	1.0322	1.3586
14	0.5062	0.4505
15	0.3993	0.2916
16	0.3571	0.4768
17	0.0754	0.0591
18	0.2142	0.2044
19	1.1081	0.9985
20	0.1342	0.1568
21	0.0581	0.0769
22	4.2998	2.938
23	6.9559	5.4927
24	1.7431	1.364
25	3.6496	1.859
26	4.6773	2.3814
27	15.8975	14.0165
28	11.0276	9.607
29	5.4873	2.795
30	2.2543	2.2279
31	0.3017	0.3516
32	0.0186	0.029
Total	281.5877	187.9595

Table No 4 Real and Reactive Power Losses without DG

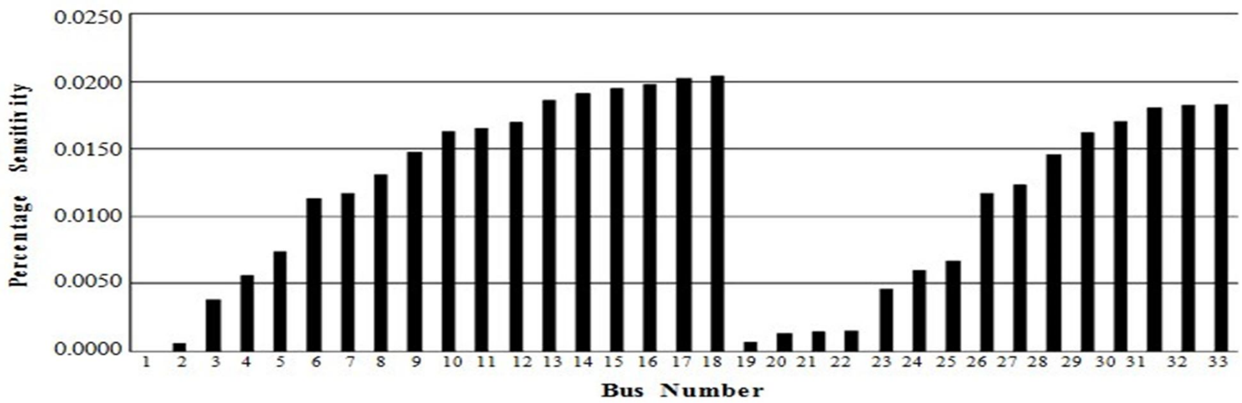


Graph No1 Between Bus Voltage (pu) and Bus Number without DG

From the graph no 1 it can be concluded that the bus number 18 has the minimum voltage, approximately 0.88 PU. Bus number 1 has the healthiest voltage of 1 PU, as it is the bus connected directly to the substation, the farthest bus (bus no.18) in the system has the lowest voltage because of the voltage drops across the line impedance. The bus number 18, 22, 25 and 33 are the farthest buses in their respective buses and hence they have very low voltages.

A. Selection of Buses for Placement of DG Sources

Now Real power source is applied once at every bus and then the change in total real power losses is observed. On the basis of calculations for sensitivity of the buses allocations for DG sources will be decided.



Graph No 2 Between Percentage Sensitivity and Bus Number

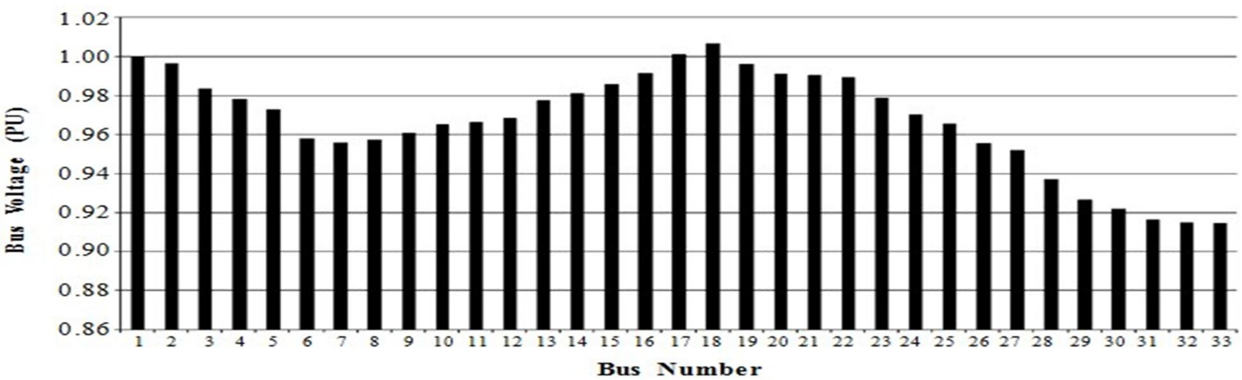
From above graph no 2 it can be seen that the bus number 18 has the highest sensitivity. Sensitivity of buses from bus number 14 to 18 can be arranged in descending order as 18> 17 > 16 > 15 > 14. As per this graph, it is clear that the buses located farthest from the substation have the highest sensitivity because the real power flowing through line gets reduced. So DG sources will be applied at buses 14, 15, 16, 17 and 18.

Local search method is applied to get the value of real power source at the buses chosen for DG allocation. Firstly the local search method is applied at the most sensitive bus, when the value of real power source is obtained at the most sensitive bus, then that bus is fixed at that value of DG source. After this local search method is applied similarly to next sensitive buses respectively.

B. Load Flow Analysis Using Forward Backward Sweep Method with DG

After carrying out load flow analysis on the IEEE-33 bus system with DG sources at the buses selected as highly sensitive buses, bus voltages, real power losses and reactive power losses of the system are calculated.

Graph between the bus voltages and bus number has shown that the bus number 18 has the maximum voltage approximately 1.008 PU which is higher even than the substation voltage. Bus number 17 also has voltage slightly greater than rated voltage of 1 PU. Bus number 1 has the rated voltage of 1 PU as it is the bus connected directly to the substation.



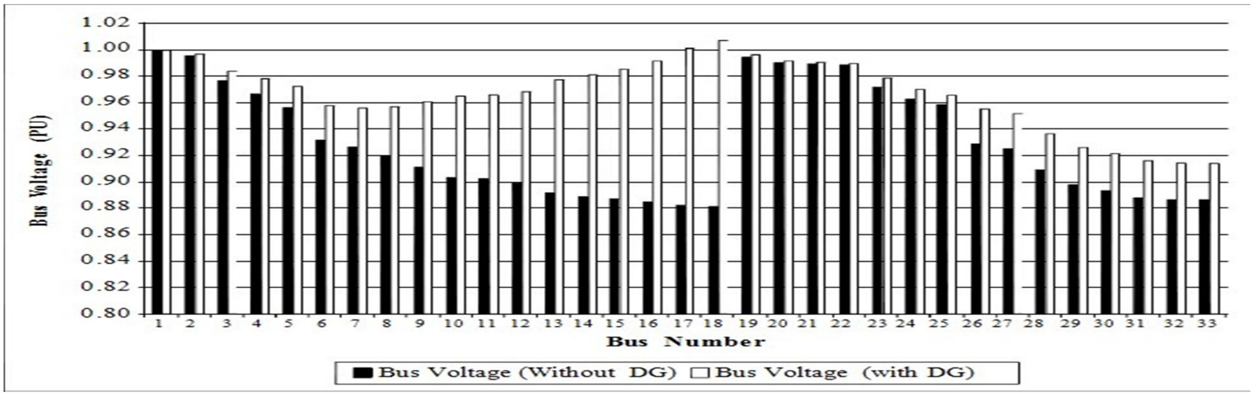
Graph No 3 Between Bus Voltage (pu) and Bus Number with DG

Line Number	Real Power Losses (KW)	Reactive Power Losses(KVAR)
1	9.3447	4.7636
2	37.0888	18.8904
3	11.7035	5.9605
4	10.5858	5.3915
5	21.3424	18.4238
6	0.4022	1.3296
7	1.6595	0.5484
8	3.5149	2.5253
9	4.1239	2.9231
10	0.8952	0.296
11	1.8703	0.6185
12	8.3351	6.5579
13	3.4833	4.585
14	4.2129	3.7496
15	5.0822	3.7114
16	7.6255	10.1812
17	4.3191	3.3868
18	0.2137	0.2039
19	1.1056	0.9962
20	0.1339	0.1564
21	0.058	0.0767
22	4.2358	2.8943
23	6.8521	5.4107
24	1.717	1.3435
25	3.4333	1.7488
26	4.3993	2.2399
27	14.9501	13.1812
28	10.3695	9.0337
29	5.1594	2.628
30	2.1183	2.0935
31	0.2835	0.3304
32	0.0175	0.0272
Total	190.6362	136.2068

Table No 5 Real and Reactive Power Losses with DG

C. Comparison of Values Obtained Before and After DG Placement

1) *Comparison of Voltage Profiles*: From the graph no 4 it is visible that the voltage profile of the system has improved. Voltage at the buses of those feeders where DG is not applied has also improved.



Graph No 4 Comparison of Voltage Profile

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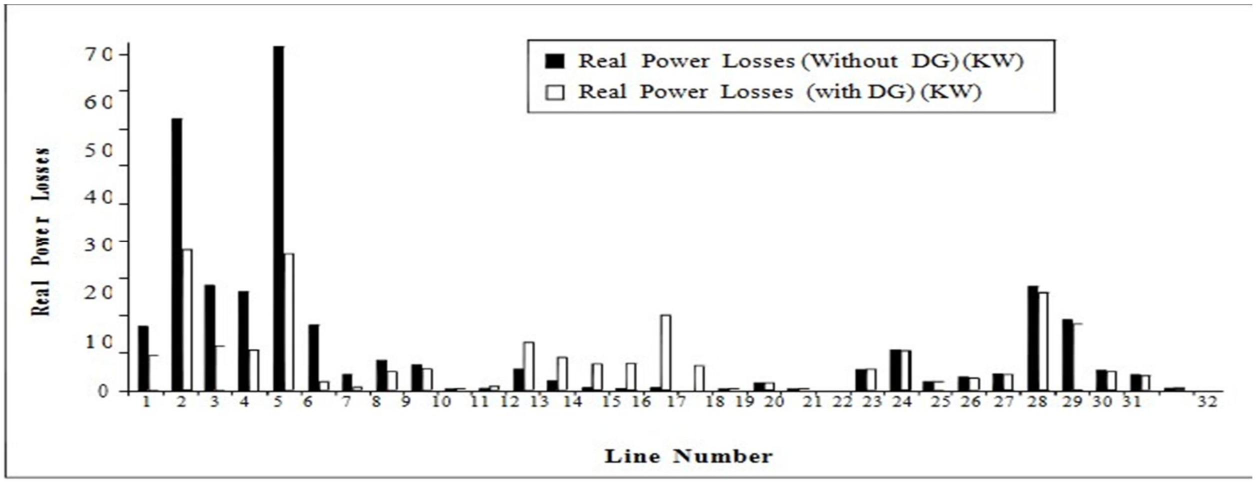
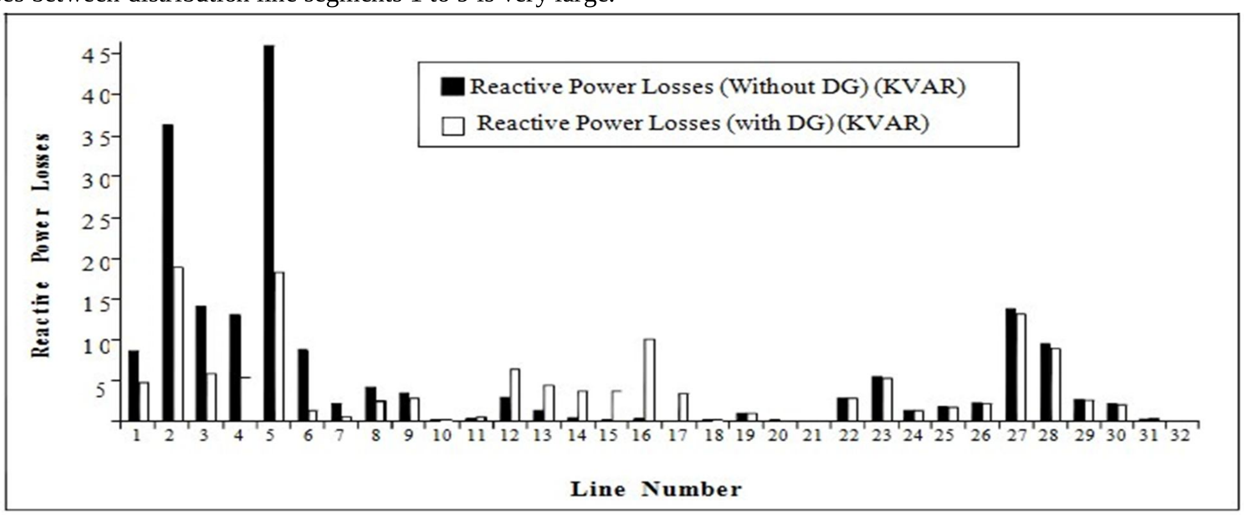
2) *Comparison of Real Power Losses* Due to DG placement in the system it can be clearly seen from the graph no 5 that real power losses have drastically reduced in distribution line section number 1 to 10, but the real power losses have increased slightly in the distribution line sections 11 to 18 & the real power losses are almost constant from distribution line section 19 to 32.



Graph No 5 Comparison of Real Power Losses

3) *Comparison of Reactive Power Losses* Due to DG placement in the system it can be clearly seen from the graph no 6 that reactive power losses have drastically reduced in distribution line section number 1 to 9 but the reactive power losses have increased slightly in the distribution line sections 12 to 18 and the reactive power losses are almost constant for distribution line sections 10, 11 and 19 to 32. Although the reactive power losses are increased in distribution line section 12 to 18 due to power flow from DG source to other feeders but still the total reactive power losses are reduced as the reduction in reactive power losses between distribution line segments 1 to 9 is very large.



Graph No 6 Comparison of Reactive Power Losses

VI. CONCLUSION

This paper presented a comparison of real power and reactive power loss with and without DG.

A. Total real power losses

Before applying DG = 281.5877KW
After applying DG = 190.6362 KW

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B. Total reactive power losses

Before applying DG = 187.9595 KVAR

After applying DG = 136.2068KVAR

The present study based on a load flow analysis for radial distribution system using forward backward sweep method gives the values of voltages at all the buses and real and reactive power losses of the system. These calculated values can be used further for the planning of DG and thus increasing the efficiency and voltage profile of the system. For DG planning, the most important fact to be consideredis that not all the buses can be provided with real power support as the cost of overall system is also to be kept low. In the considered IEEE 33-bus radial distribution system, it is found that real power support should be provided at those buses where the change in total power losses of the system is largest when each of the buses is separately provided with a specified active power source. It can be concluded that in the case of radial distribution system, the DG should be deployed at the farthest buses from the source to have minimum losses as these buses give very high sensitivity. The optimum value of active power source at a bus can be calculated efficientlyby using local search method.

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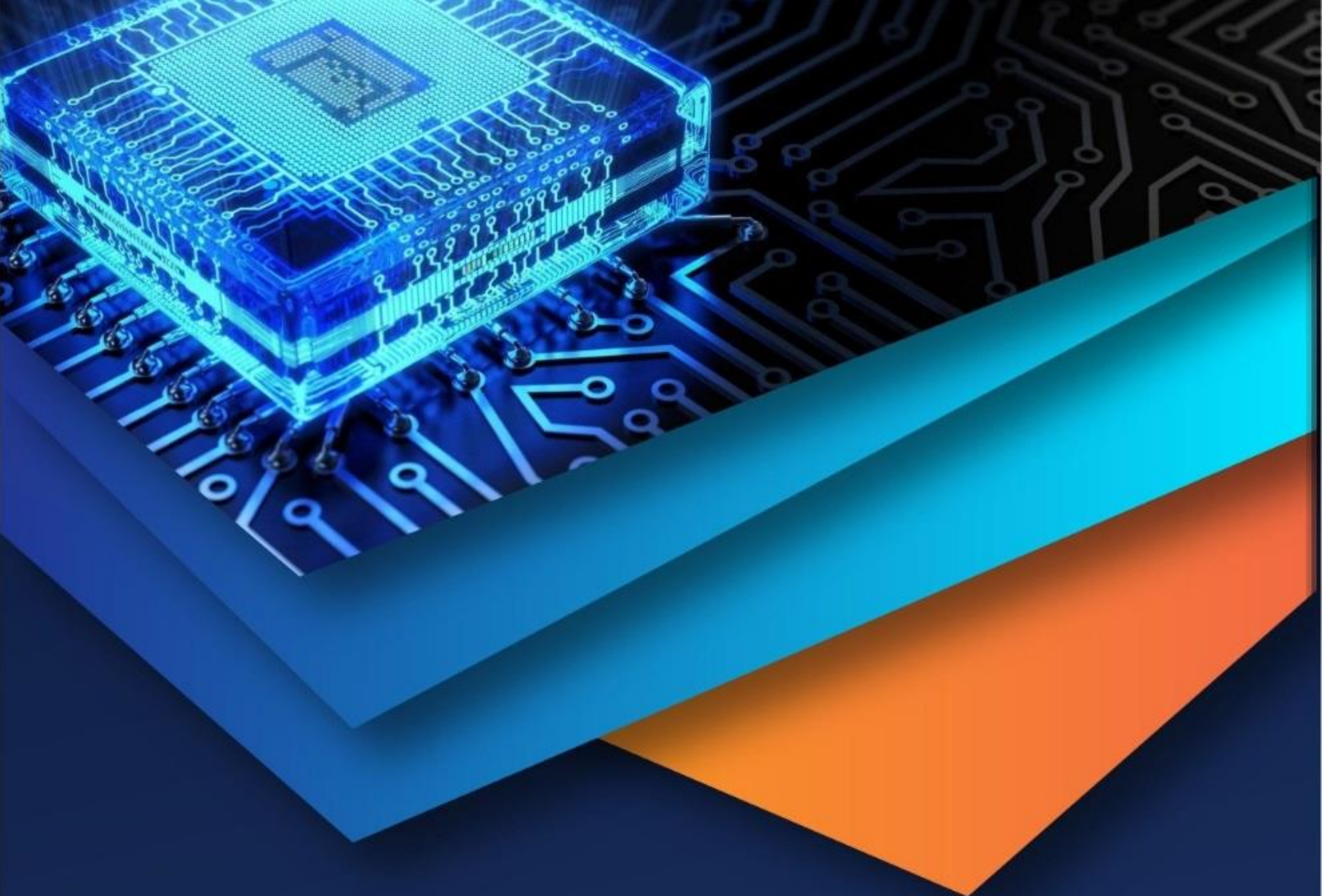

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