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A Novel Approach for Optimal Location and Size of Distribution Generation Unit in Radial Distribution Systems Based on Load Centroid Method

G.Rajyalakshmi, N.Prema Kumar

***Abstract*— Optimum DG placement and sizing is one of the current topics in restructured power system. Almost All known methods model the task as an optimization problem based on certain objective function(s) and constraints. The formulated optimization problem is commonly solved using various versions of heuristic techniques like SA, GA, PSO, ABC, etc. All these techniques are iterative methods that form a heavy computational burden and are very time consuming especially for fairly big networks. This paper presents a load centroid method for placement and sizing of Distributed Generation (DG) in radial/meshed distribution networks. Backward/Forward sweep method is used for Distribution load flow calculation due to their computational efficiencies and solution accuracies. The objective function is of performance index includes power system total real power loss and average node voltage deviation based on power handling capacity at each load. Results confirm stability, efficacy of the proposed approach.**

Index Terms— *Distribution load flow, Optimal location, Distribution Generation Units, Load Centroid*

I. INTRODUCTION

Distribution Generation is expected to become more important in future generation system. In distribution system, due to load uncertainties the load exceeds the generating capacity which leads to power loss and unreliable operation of the system. To overcome this problem DG units are incorporated into the distribution system to meet the excess demand which results in power loss minimization, improvement of voltage profile, power quality improvement, reliable operation, etc. Distribution systems hold a very significant position in power system since it is the main point of link between bulk power and consumers. Distribution System has been growing rapidly due there potential solution for issues, like the deregulation in power systems, to meet power demand and the shortage of transmission capacities.

Load flow analysis is a very important and basic tool in the field of power system engineering. This is used in the operational as well as planning stages. Since the invention and widespread use of digital computers, beginning in the 1950's and1960's, many methods for solving the load flow problem have been developed. The Distribution System Load Flow (DSLF) methods take special care to overcome the ill- conditioned nature arising due to high R/X ratios of the feeders.

Newton method and fast decoupled load flow (FDLF) are the most preferred method in power flow calculation. But in the distribution network, because of the high ratio of R/X, it is hard for the FDLF to converge [1]. When the distribution network is overloading, the voltages drops seriously, which may influence the convergence of Newton-Raphson method [2], and these methods diverges in most of cases. However, most of the conventional power flow methods for both transmission and distribution systems, consider power demands as specified constant values. The constant power load model is highly questionable and it is so especially for a distribution system because the bus voltages are not controlled. Therefore, there is a need for a power flow method that takes this aspect into consideration to obtain better and more accurate results. In the past, many approaches for distribution system load-flow analyses have been developed [3]–[5]. Among these approaches, the ladder network theory and the backward/ forward (BW/FW) sweep methods are commonly used due to their computational efficiencies and solution accuracies [6][7-review]. In the backward/forward sweep, Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law (KVL) are used to calculate voltage for each upstream bus of a line [8]. After performing each backward sweep, the mismatch of the calculated and specified voltages at the substation is checked. The solution algorithm repeats until the convergence tolerance of the substation voltage is satisfied. This can be applied for radial as well as weakly meshed distribution systems.

II. OPTIMAL LOCATION AND SIZE OF DISTRIBUTION GENERATION

Size and location of DG are crucial factors in the application of DG for its maximum benefits and minimization of real power losses in radial distribution network and its monetary benefits [10].

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G.Rajyalakshmi, *Electrical Engineering, Andhra University College of Engineering, Guntur, India, 9849003731.*

N.Prema Kumar, *Associate Professor, Electrical Engineering, Andhra University College of Engineering, Visakhapatnam, India,9490193294.,*

Optimal placement of DG units is determined exclusively for the various distributed load profiles to minimize the total losses. They have iteratively increased the size of DG unit at all buses and then calculated the losses; based on loss calculation they ranked the nodes. Top ranked nodes are selected for DG unit placement [11]. Its impact on distribution systems may be either positive or negative depending on the system's operating condition DGs characteristics and location. The selection of the best places for installation and the preferable size of the DG units in large distribution systems is a complex combinatorial optimization problem [12].

All the known methods are of iterative methods and time consuming methods for optimal placement of distribution generation. The load centroid method is based on centroid and center of gravity. The concept of load centroid is the place were total load is concentrated same as the point of action of the resultant force of a group of forces in mechanics. Alternatively it is similar to center of gravity of a big object formed from a number of parts. Distribution system supplies power to different loads and each node has different characteristics, power handling capacities and different requirements. Based on these load requirements if we know the load which has high power handling capacity or the highest load concentration or load centroid based on that we can place distribution generation. In this method based on center of gravity or centroid optimal location of distribution generation is calculated by placing equivalent

III. DISTRIBUTION LOAD FLOW

The development of distributed generation (DG) has a great influence on the traditional power systems and received considerable attention in recent years. After interconnected DG, the voltage maybe to rise along the feeder, and has serious potential impacts on distribution system. In this method Backward/ Forward sweep method is used for the voltage profile and line currents calculation using Kirchhoff's voltage and current laws.

Bus currents of an 'N' distribution system using Kirchhoff's voltage law,

$$I_i = \sum_{k=1}^{n} (Y_{ik} V_k) \quad k = 1,2,\ldots N$$

Where Y_{ik} (i≠k) = $-y_{ik}$ = Negative of the total admittance connected between i^{th} and k^{th} bus

Y_{ik}(i≠k)=0 if there is no transmission line between i^{th} and k^{th} bus.

Complex power injected by the source into the i^{th} bus of a power system is

$$S_i = P_i + j\,Q_i = V_i\, I_i^*$$

$$P_i - j\,Q_i = V_i^{\,*} I_i$$

Bus Voltages at each bus of an 'N' bus distribution system is

$$V_i = \frac{\frac{(P_i - j\,Q_i)}{V_i^*} - \sum_{j=1}^{n} V_j Y_{ij}}{Y_{ii}}.$$

IV. OBJECTIVE FUNCTION

In centroid method we considered the performance index as the objective function for optimal location of distribution generation. The performance index is a combination of equivalent total real power losses and average node voltage deviation and the DG is placed at which the performance index value is minimum.

$$PI = Ploss + K\ ANVD$$

$$ANVD = \left|1 - \frac{\sum_n V_n}{N}\right|$$

Where K is selective weighting factor and V_n is voltage of n^{th} node in p.u.

The equivalent real power losses are calculated by placing equivalent load P_e and Q_e at each bus by removing all loads of a distribution system. In centroid method by placing equivalent loads at each bus the power handling capacity of a distribution system known by this the optimal location is calculated.

This method is simple and effective avoiding the complicated calculation process and over many assumptions of the traditional heuristic optimization methods. [14]

V. ALGORITHM FOR OPTIMAL PLACEMENT OF DISTRIBUTION GENERATION

1. Form the bus admittance matrix Y_{bus} from the distribution network data of the test system.
2. Calculate the voltage profiles at all buses based on the forward sweep approach.
3. Determine the deviation in voltage profiles at all buses and check for error limits.
4. Perform forward sweep to obtain the new voltage profile if the deviation in voltage profile is beyond specified tolerances.
5. Calculate branch currents using simple KVL equations.
6. Perform the load studies of the distribution network to obtain power losses i.e., real and reactive at all buses using the previously calculated voltage and current profiles of buses.
7. Calculate Performance Index (PI0) value for base case system without any DG placed in the system by using already calculated load flow values.

$$PI = Ploss + K * ANVD$$

Where

K is selective weighting factor

V_n is voltage of n^{th} node in p.u.

ANVD= Average node voltage deviation.

8. Disconnect all loads and put a load of $P_e = \sum_{n=1}^{N} P_n$ and $Q_e = \sum_{n=1}^{N} Q_n$ at bus2. Then calculate PI again and save it in a vector called PIE.
9. Move load P_e and Q_e to bus3, calculate PI and repeat the process for all buses upto N.
10. Determine the absolute difference between PIE of (N-1) buses and PI0 (Base case PI) i.e., DPIE.
11. Identify the bus (g) with absolute minimum value of DPIE.
12. Centroid for placement of DG is at bus number g+1.

VI. RESULTS

12-bus, 33-bus and Radial Distribution test systems are considered for the study to show the effectiveness of the proposed method that is based on load centroid method and to simulate the problem. At each system the optimal location of contribution generation as centroid is calculated without the distribution generation unit installed. The DG size at the optimally located bus is obtained by placing the 60% of the total real power loss, which is the maximum possible DG size for reliable system operation.

The bus with worst performance index is identified using the sweep algorithm and is attributed to be as the optimal location for the placement of the DG unit. For the 12 – bus RDS, bus number 5 is the optimal location and for 33 – bus RDS bus number 6 is identified as the optimal location for the placement of distribution generation unit. The voltage profile, performance index with and without distribution generation is presented in Table.1 and Table.2 respectively. The variations in real and reactive power losses with and without distribution generation for 12 and 33 – bus RDS are shown in the figures 2 and 4. The program execution time for this algorithm for IEEE 12-bus RDS is 0.245286 s and for 33-bus RDS is 1.199414 s.

IEEE 12 bus radial distribution system

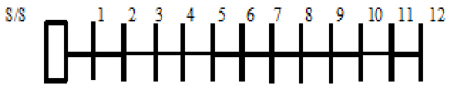

Fig.1 IEEE 12-Bus Radial distribution system

Table.1 Voltage p.u, performance index and DPIE for 12-bus RDS with and without DG unit

	Without DG unit			With DG unit	
Bus No	Voltage (p.u)	PI	DPIE	Voltage (p.u)	Voltage Deviation
1	1	3.4634	-	1	0
2	0.9946	0.1187	3.3446	0.9947	0.0053
3	0.9895	0.3311	3.1322	0.9898	0.0102
4	0.9815	2.2216	1.2418	0.9821	0.0179
5	**0.9713**	**4.0684**	**0.6051**	**0.9724**	**0.0275**
6	0.9682	4.7009	1.2376	0.9695	0.0305
7	0.9656	5.285	1.8216	0.967	0.0329
8	0.9577	7.8459	4.3825	0.959	0.0408
9	0.9501	11.1226	7.6592	0.9515	0.0483
10	0.9475	12.8057	9.3423	0.9489	0.0509
11	0.9466	13.6867	10.2234	0.948	0.0517
12	0.9464	19.0213	15.5579	0.9478	0.0519

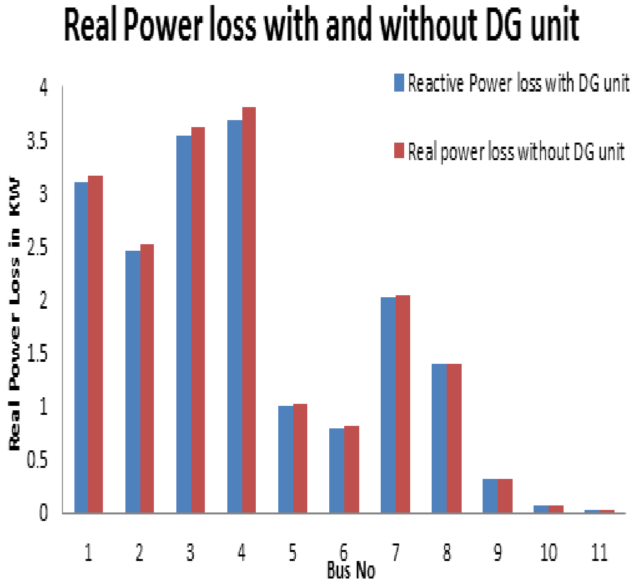

Figure.2 Plot between real power loss with and without DG unit for 12 bus RDS

Table.2 Voltage p.u, performance index and DPIE for 33-bus RDS with and without DG unit

	Without DG unit			With DG unit	
Bus No	Voltage (p.u)	PI	DPIE	Voltage (p.u)	VD
1	1	0.0528	-	1	0
2	0.9972	0.00023	0.0527	0.9973	0.0027
3	0.9842	0.0006	0.0523	0.9849	0.0151
4	0.9774	0.00063	0.0523	0.9786	0.0214
5	0.9707	0.00098	0.0519	0.9724	0.0276
6	**0.9541**	**0.0526**	**0.0002**	**0.9568**	**0.0432**
7	0.9509	0.00098	0.0519	0.9537	0.0463
8	0.9389	0.00209	0.0508	0.9417	0.0583
9	0.9335	0.0018	0.0511	0.9362	0.0638
10	0.9284	0.00047	0.0524	0.9312	0.0688
11	0.9277	0.00047	0.0524	0.9304	0.0696
12	0.9263	0.00112	0.0518	0.9291	0.0709
13	0.9209	0.00157	0.0513	0.9237	0.0763
14	0.9189	0.00111	0.0518	0.9217	0.0783
15	0.9176	0.00121	0.0517	0.9204	0.0796
16	0.9164	0.0018	0.051	0.9192	0.0808
17	0.9146	0.00134	0.0515	0.9174	0.0826
18	0.9141	0.0025	0.0504	0.9168	0.0831
19	0.9967	0.0005	0.0523	0.9968	0.0032
20	0.9932	0.0011	0.0517	0.9933	0.0067
21	0.9925	0.00105	0.0518	0.9926	0.0074
22	0.9918	0.0025	0.0503	0.9919	0.0081
23	0.9807	0.00115	0.0517	0.9814	0.0185

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24	0.9742	0.00146	0.0514	0.975	0.025
25	0.971	0.00306	0.0498	0.9718	0.0282
26	0.9523	0.05465	0.0018	0.955	0.045
27	0.9499	0.0571	0.0043	0.9527	0.0473
28	0.9394	0.066	0.0137	0.9422	0.0578
29	0.9319	0.0728	0.0199	0.9347	0.0653
30	0.9286	0.0759	0.023	0.9314	0.0686
31	0.9248	0.0815	0.0287	0.9276	0.0724
32	0.924	0.083	0.0301	0.9267	0.0732
33	0.9237	0.1468	0.094	0.9265	0.0735

IEEE 33 bus radial distribution system

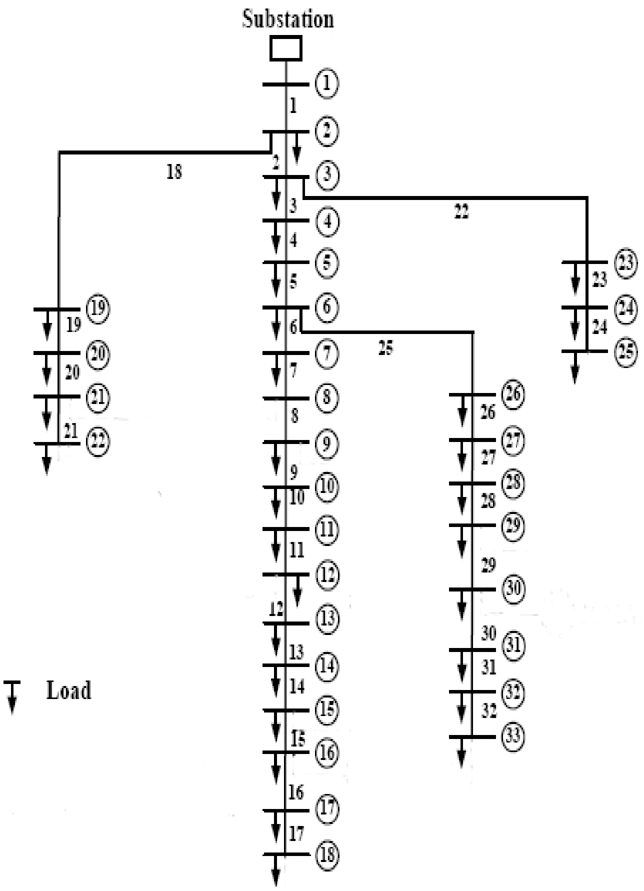

Figure 3 33-bus radial distribution system

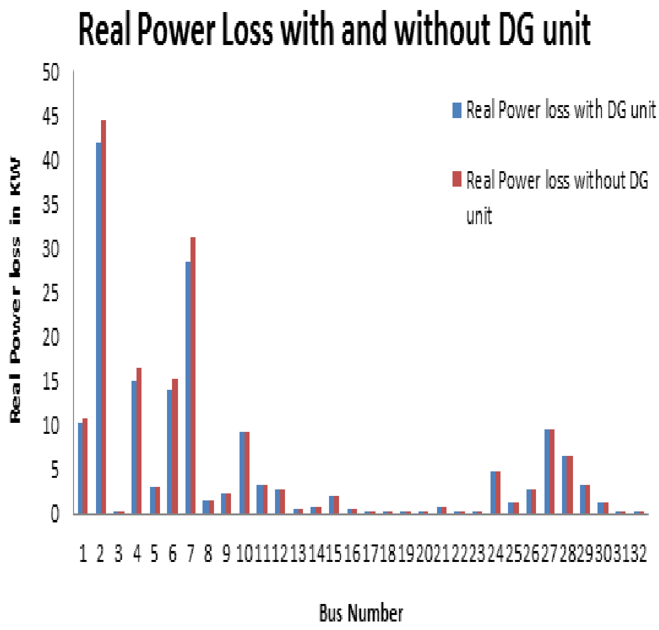

Figure 4 Plot between real power loss with and without DG unit for 33-bus RDS

VII. CONCUSION

The concept of load centroid is addressed as a helpful tool in distribution system expansion planning studies. The DLF method considered in this work is of forward and backward sweep method. The optimal location of distribution generation is calculated by based on load centroid method by using the indices PI, DPIE. This method is a systematic simple to allocate distribution generation in any distribution system. The concept of equivalent aggregated load is introduced to identify the load centroid precisely. An algorithm is proposed for optimal location of distribution generation. Size of distribution generation is taken as 60% of the total power losses of distribution system which is the maximum size. The allocation of DG unit based on this method improves the voltage profile, stability in terms of losses and reliability of the distribution system.

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G. Rajyalakshmi is a PG scholar in Department of Electrical Engineering, Andhra University college of Engineering, her research interests includes Distribution Generation and Power system stability analysis.

Dr. **N.Prema Kumar** is an associate professor in Department of Electrical Engineering, Andhra University College of Engineering. His research interests include Distribution Generation and Electrical drives.