OPTIMAL CITING OF DISTRIBUTION GENERATION UNITS IN DISTRIBUTION NETWORKS BASED ON LOAD CENTROID METHOD

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Abstract— 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, which makes the fast decoupled Newton method often not valid. The DSLF methods also exploit the radial nature of the distribution networks. Centroid method of Distribution Load Flow Extensive research has been conducted to identify optimal DG allocation. 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. In this paper an analytical expression to calculate the optimal size and a methodology to identify the corresponding optimum location for DG placement for minimizing the total power losses in distribution systems based on the new concept of load centroid method is presented. The analytical expression and the methodology are based on the exact loss formula. This methodology can only identify the best location for a single DG. Case studies are performed on 12, 22, 33 bus radial distribution systems.

Keywords—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. Distribution system may be defined as a type of system between the transmissions and consumer service points. In general, distribution system is the electrical system between the substation fed by the transmission system and consumers meters. It generally consists of feeders, distributors and service mains. 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'sand 1960's, many methods for solving the load flow problem have been developed. Most of the methods have "grown up" around transmission systems and, over the years, variations of the Newton method such as the fast decoupled method; have become the most widely used. However, distribution networks become the most widely used. However, distribution networks approach for its load flow analysis [3]. 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, which makes the fast decoupled Newton method often not valid. The DSLF methods also exploit the radial nature of the distribution networks. Many programs of real time applications in the area of distribution automation (DA), such as network of distribution automation (DA), such as network so forth, require a robust and efficient distribution system load flow method, which would be able to model the special eatures of distribution systems in sufficient detail. Several load flow algorithms specially designed for distribution systems have been proposed in the literature. Many programs of real time applications in the area of distribution automation (DA), such as network optimization, Var. Planning, switching, state estimation, and so forth, require a robust and efficient distribution system load flow method[1]-[2], which would be able to model the special features of distribution systems in sufficient detail. Distribution system is viewed as a network of lines, shunt capacitors, dispersed generators, loads, and transformers.

II. DISTRIBUTION LOAD FLOW

Power flow analysis is a very important and basic tool for the analysis of any power system as it is used in the planning and design stages as well as during the operational stages. Some applications, especially in the fields of optimization of power system and distribution automation, need repeated fast power flow solutions. In these applications, it is imperative that the power flow analysis is solved as efficiently as possible. With the invention and widespread use of digital computers in 1950s, many methods for solving the power flow problem have been developed such as indirect Gauss-Seidel (bus admittance matrix), direct Gauss-Seidel (bus impedance matrix), Newton-Raphson and its decoupled versions. However, these algorithms have been designed for transmission systems, and therefore their application to the distribution systems usually does not provide good results and very often, the solution diverges. One of the reasons why these methods are unsuitable for distribution systems is that they are mostly based on the general meshed topology of a typical transmission system whereas most distribution systems have a radial or tree structure. Another reason is due to the high R/X ratio of distribution systems. This is a factor which causes the distribution systems to be ill conditioned for conventional power flow methods, especially the fast-decoupled Newton method, which diverges in most cases. Lastly, the active and reactive loads of a distribution system are dependent on the bus voltage. 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. Though considerable efforts has been directed to the development of solution algorithm for power flow analysis of transmission systems with great success , in contrast, comparatively fewer solution algorithms have been developed for power flow analysis of distribution systems. Therefore, the growing need of distribution companies for more complete studies and the increase in system automation have motivated the development of a specialized algorithm for distribution systems that consider all their particular characteristics.

III. IMPORTANCE OF DG LOCATION IN DISTRIBUTION SYSTEM

By definition, the distributed or dispersed generators are small size generators, which can come from traditional or some revolutionary technologies or it is an electric power source connected directly to the distribution network or on the customer side of the meter as mentioned in [2]. DG is expected to play an increasing role in emerging power systems. Studies have predicted that DG will be a significant percentage of all new generation going online. Different resources can be used in DG, such as wind turbines ,photovoltaic, fuel-cells, biomass, micro turbines, small hydroelectric plants, etc., ranging from sub-kW to multi-MW sizes) [3],[4]. Its impact on distribution systems may be either positive or negative depending on the system's operating condition DGs characteristics and location. The potential positive impacts are improving system reliability, loss reduction, and deferment of new generation and improving power quality. To achieve these benefits, DG must be reliable, dispatchable of appropriate size, and at suitable locations. More important, DGs should be properly coordinated with protection systems. The planning of the electric system with the presence of DG requires several factors to be taken into considerations, such as: the best technology to be used, the number and the capacity of the units, the best location, the type of network connection, etc. The impact of DG in system operating characteristics, such as electric losses, voltage profile, stability and reliability needs to be appropriately evaluated. The problem of DG allocation and sizing is of great importance. The installation of DG units at non-optimal places can result in an increase in system losses, implying in an increase in costs and, therefore, having an effect opposite to the desired. For that reason, the use of an optimization method capable of indicating the best solution for a given distribution network can be very useful for the system planning engineer. 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.

IV. DLF ALGORITHMS

The methods developed for the solution of ill-conditioned radial distribution systems may be divided into two categories. The first type of methods is utilized by proper modification of existing methods such as, Newton-Raphson. On the other hand, the second group of methods is based on forward-backward sweep processes using Kirchhoff's Laws or making use of the well-known bi-quadratic equation which, for every branch, relates the voltage magnitude at the receiving end to the voltage at the sending end and the branch power flow for solution of ladder networks. Shirmohammadi et al., have presented compensation-based power flow method for radial distribution networks and/or for weakly meshed structure using a multi-port compensation technique and basic formulations of Kirchhoff's Laws.

V. CENTROID METHOD OF DISTRIBUTION LOAD FLOW

Extensive research has been conducted to identify optimal DG allocation. 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. Many of which can just produce a sub-optimal solution at the end. Others suffer from possible divergence or need good initial solution. Other methods that depend on deterministic closed-form solutions are very rare; an analytical expression to calculate the optimal size and a methodology to identify the corresponding optimum location for DG placement for minimizing the total power losses in distribution systems is presented. The analytical expression and the methodology are based on the exact loss formula. This methodology can only identify the best location for a single DG. Also, the voltage of system nodes is not considered. The concept of load centroid is addressed as a helpful tool in distribution system expansion planning studies. The idea behind which is that if the main source supplies only one load, the best decision is to install prospective DG at the load place. As many loads at different nodes are supplied, it will be the best to install DG at the load center of gravity (centroid) [4]. The load centroid is equivalent to the point of action of the resultant force of a group of forces in mechanics. Alternatively, it is similar to Centre of gravity of a big object formed from a number of parts. The method described in depends on defining a circle of action for a given single DG unit. Then, the load centroid is determined for the loads within that circle. The centroid is selected as the location of the concerned DG unit. The selection is verified by comparing network performance at other possible nodes. The method assumes a simple radial network fed at one end.

VI. DISTRIBUTION SYSTEM LOAD MODELING

In actual power system operation, different categories and types of loads such as; residential, industrial and commercial loads might be present. The nature of these types of loads is such that their active and reactive powers are dependent on the voltage and frequency of the system. Moreover, load characteristics have significant effects on the load flow solutions and convergence ability [1]. The well-known characteristics of an electric distribution system are, Radial or weakly meshed structure, Multiphase and unbalanced operation, Unbalanced distributed load, extremely large number of branches and nodes, Wide-ranging resistance and reactance values.

VII. MATHEMATICAL EQUATIONS

The equivalent aggregated load is

$$P_e = \sum_{n=1}^{N} P_n \text{ and } Q_e = \sum_{n=1}^{N} Q_n$$

Where Pe= the Equivalent active power component of aggregated load, Qe= the equivalent reactive power component of aggregated load, n=bus number index and N= Total number of buses

The voltage at each bus,

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{k=1,\neq i}^{n} Y_{ik}V_k\right], i = 12 \dots n$$

The current flowing in each line

$$I_{ik} = (V_i - V_k)Y_{ik} + V_i Y_{ik0}$$

Total power loss at each 'ik' bus is

$$S_{ik} = V_i I_{ik}^*$$

Total real power losses at each bus is

$$P_{lossik} = \text{Real}\{S_{ik}\}$$

and

$$Q_{lossik} = \text{Imag}\{S_{ik}\}$$

The power system performance index (PI) combines two terms to express both total active power loss (Ploss) and the average node voltage deviation (ANVD). It is always required to minimize PI. It is formed as:

$$PI = Ploss + KANVD$$

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

Where K is selective weighting factor and Vn is voltage of nth node in p.u.

Algorithm

1. Form Ybus from line data.
2. Calculate Performance Index (PI0) value for base case system without any DG placed in the system from any load flow method.
3. $PI = Ploss + KANVD$
4. Where K is selective weighting factor, Vn is voltage of nth node in p.u. and ANVD= Average node voltage deviation.
5. Disconnect all loads.
6. Put a load of Pe and Qe at bus2.
7. $P_e = \sum_{n=1}^{N} P_n$ and $Q_e = \sum_{n=1}^{N} Q_n$
8. Calculate PI and save it in a vector PIE.
9. Move the load Pe and Qe to bus3, and calculate PI.
10. Repeat step-5 for all buses upto N.
11. Determine the absolute difference between PIE of (N-1) and PI0 and save it in a vector DPIE.
12. Determine the order of the element with absolute minimum value in DPIE as 'g'.
13. Centroid for placement of DG is at bus number Bus DG=g+1.

VIII. RESULTS

The proposed load centroid algorithm has been adopted and applied on two test systems i.e., IEEE 12 – bus system and 33 – bus radial distribution systems. The voltage profile is performed based on base case load flow algorithm and the performance index is calculated for each bus by calculating the real and reactive losses and average node voltage deviation for all node voltages. 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 7 is the optimal location and for 33 – bus RDS bus number 26 is identified as the optimal location for the placement of distribution generation unit. The voltage profile, real and reactive power losses and performance index are presented in Table.1 and Table.2 respectively. The variations in the voltage profile at various busses, real and reactive power losses and performance indexes for 12 and 33 – bus RDS are shown in the figures 1 to 8 respectively. The program execution time for this algorithm for IEEE 12-bus RDS is 0.245286 seconds and for 33-bus RDS is 1.199414 seconds.

IEEE 12 bus radial distribution system

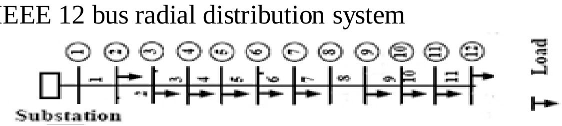

Fig.1 IEEE 12-Bus Radial distribution system

TABLE1. VOLTAGE PROFILE, REAL AND REACTIVE POWER LOSS AND PERFORMANCE INDEX FOR IEEE 12 BUS RDS

(ELAPSED TIME IS 0.245286 SECONDS.)

Bus No	V(p.u)	VD	Ploss	Qloss	PI	DPIE
1	1	0	0.2751	0.1162	3.4634	-
2	0.9946	0.0054	0.2161	0.0904	0.1187	3.3446
3	0.9895	0.0105	0.3073	0.1279	0.3311	3.1322
4	0.9815	0.0185	0.3137	0.1312	2.2216	1.2418
*5	0.9713	0.0286	0.0857	0.0362	4.0684	0.6051
6	0.9682	0.0317	0.0699	0.0286	4.7009	1.2376
7	0.9656	0.0343	0.1673	0.0460	5.285	1.8216
8	0.9577	0.0422	0.1087	0.0308	7.8459	4.3825
9	0.9501	0.0496	0.0241	0.0069	11.1226	7.6592
10	0.9475	0.0523	0.0049	0.0014	12.8057	9.3423
11	0.9466	0.0531	0.0005	0.0001	13.6867	10.2234
12	0.9464	0.0533	Ploss	Qloss	19.0213	15.5579

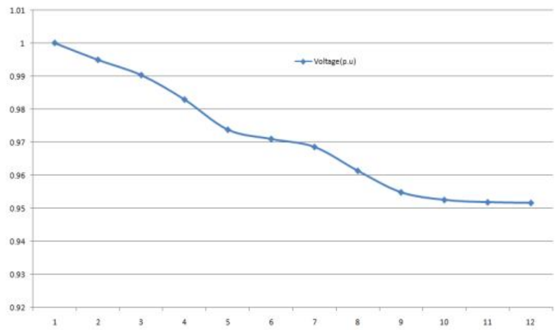

Fig.2 Voltage profile of IEEE 12-Bus RDS

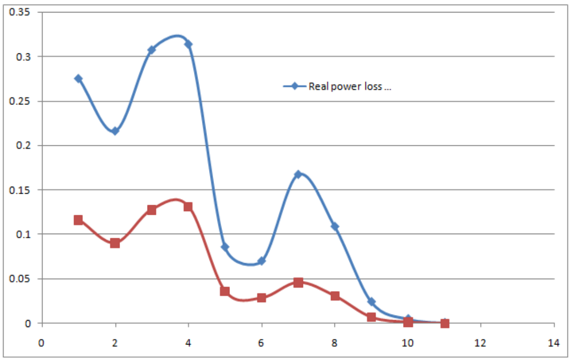

Fig.3 Real and Reactive power loss profile of IEEE 12-Bus RDS

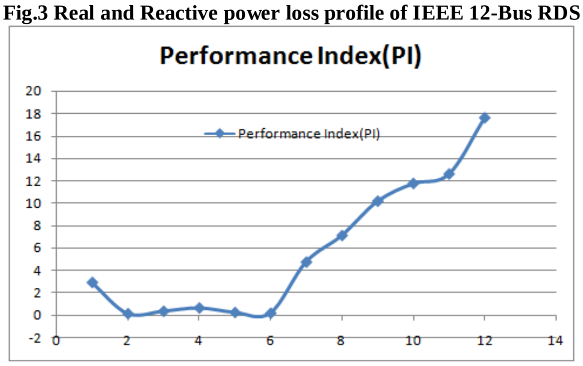

Fig.4 Bus Performance Indexes for IEEE 12-Bus RDS

IEEE 33 bus radial distribution system

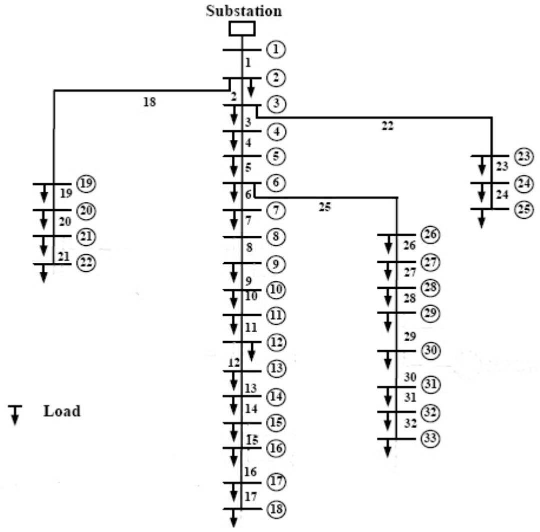

Fig.**5 IEEE 33-bus radial distribution system**

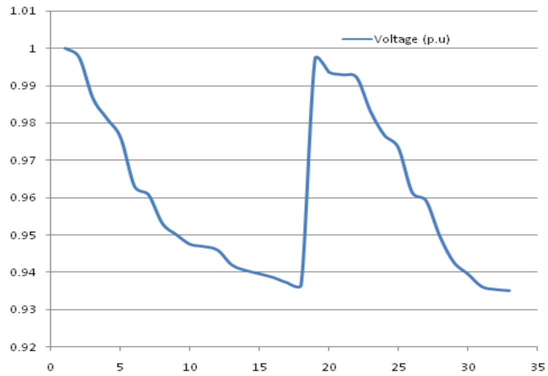

Fig.6 Voltage profile of IEEE 33-Bus RDS

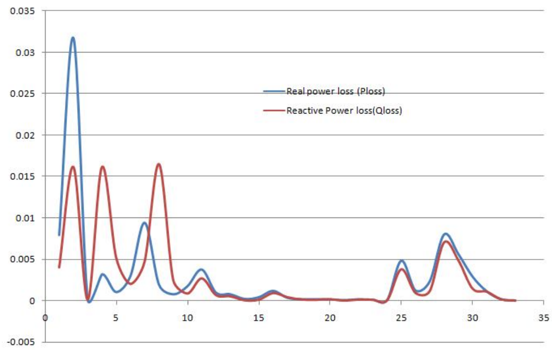

Fig.7 Real and Reactive pow er loss profile of IEEE 33-Bus RDS

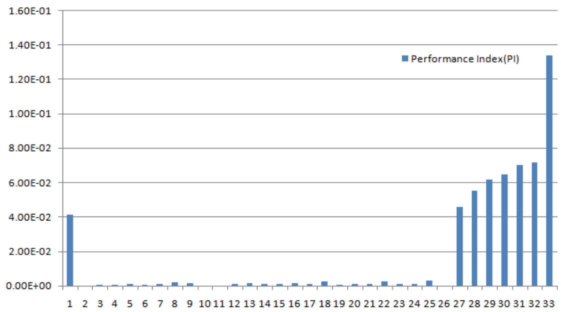

Fig.8 Bus Performance Indexes for IEEE 12-Bus RDS

TABLE2. VOLTAGE PROFILE, REAL AND REACTIVE POWER LOSS AND PERFORMANCE INDEX FOR IEEE 33 BUS RDS ELAPSED TIME IS 1.199414 SECONDS.

Bus No	V(p.u)	VD	Ploss	Qloss	PI	DPIE
1	1	0	0.00791	0.00403	0.0528	-
2	0.9972	0.0028	0.03173	0.01615	0.00023	0.0527
3	0.9842	0.0158	0.0001	0.00015	0.0006	0.0523
4	0.9774	0.0226	0.00317	0.01615	0.00063	0.0523
5	0.9707	0.0293	0.00102	0.00521	0.00098	0.0519
*6	0.954	0.046	0.00297	0.00203	0.0526	0.0002
7	0.9509	0.0491	0.00941	0.00479	0.00098	0.0519
8	0.9389	0.0611	0.00191	0.01650	0.00209	0.0508
9	0.9335	0.0665	0.00076	0.00251	0.00180	0.0511
10	0.9284	0.0716	0.00173	0.00088	0.00047	0.0524
11	0.9277	0.0723	0.00374	0.00270	0.00047	0.0524
12	0.9263	0.0737	0.00095	0.00068	0.00112	0.0518
13	0.9209	0.0791	0.00076	0.00054	0.00157	0.0513
14	0.9189	0.0811	0.00019	0.00006	0.00111	0.0518
15	0.9176	0.0823	0.00039	0.00013	0.00121	0.0517
16	0.9164	0.0835	0.00117	0.00092	0.0018	0.051
17	0.9146	0.0853	0.00034	0.00044	0.00134	0.0515
18	0.9141	0.0859	0.00016	0.00014	0.00250	0.0504
19	0.9967	0.0033	0.00015	0.00011	0.0005	0.0523
20	0.9932	0.0068	0.00013	0.00018	0.0011	0.0517
21	0.9925	0.0075	0.00004	0.00003	0.00105	0.0518
22	0.9918	0.0082	0.00015	0.00015	0.0025	0.0503
23	0.9807	0.0193	0.00009	0.00011	0.00115	0.0517
24	0.9742	0.0258	0.00004	0.00005	0.00146	0.0514
25	0.971	0.029	0.00482	0.00380	0.00306	0.0498
26	0.9523	0.0477	0.00121	0.00094	0.05465	0.0018
27	0.9499	0.0501	0.00233	0.00119	0.0571	0.0043
28	0.9394	0.0605	0.00798	0.00704	0.066	0.0137
29	0.9319	0.0681	0.00562	0.00490	0.0728	0.0199
30	0.9286	0.0713	0.00288	0.00147	0.0759	0.023
31	0.9248	0.0751	0.00110	0.00109	0.0815	0.0287
32	0.924	0.076	0.00016	0.00018	0.083	0.0301
33	0.9237	0.0763	0.00001	0.00002	0.1468	0.094

CONCLUSIONS

The concept of load centroid is addressed as a helpful tool in distribution system expansion planning studies. The idea behind which is that if the main source supplies only one load, the best decision is to install prospective DG at the load place. As many loads at different nodes are supplied, it will be the best to install DG at the load center of gravity. The load centroid is equivalent to the point of action of the resultant force of a group of forces in mechanics. Alternatively, it is similar to Centre of gravity of a big object formed from a number of parts. The method described in depends on defining a circle of action for a given single DG unit. Then, the load centroid is determined for the loads within that circle. The centroid is selected as the location of the concerned DG unit. The selection is verified by comparing network performance at other possible nodes. The method assumes a simple radial network fed at one end. In this paper the load flow analysis id performed based on the simple load centroid method for the optimal location of the distribution generation units. It is proved that it takes less computational time though he number of iterations are more compared to existing DLF methods.

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