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ALLOCATION OF MULTIPLE DISTRIBUTED GENERATORS IN RADIAL DISTRIBUTION FEEDER FOR LOSS MINIMIZATION

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Abstract—This paper presents a methodology for multiple distributed generator (DG) placement in primary distribution network for loss reduction. Optimal location for distributed generator (DG) is selected by Analytical expressions and the optimal DG size calculated by IA method and loss sensitivity factor (LSF). These two methods are tested on two test systems 33-bus and 69-bus radial distribution systems. The final results showed that LSF gives same loss reduction and minimum voltage in the system with less DG size than obtained in IA method.

Index Terms—IA method, Loss Sensitivity Factor, optimal location, Optimal DG size, Multiple DG, Analytical Expressions, Distributed generation.

I. INTRODUCTION

The central power plants are thermal, nuclear or hydro powered and their rating lies in the range of several hundred MW's to few GW's [2]. central power plants are economically unviable in many areas due to diminishing fossil fuels, increasing fuel costs, and stricter environmental regulations about acid deposition and green house gas emission[3].smaller power plants with a few dozens of MW's, instead of few GW's, became more economical[2]. Also, generators with renewable sources as wind or solar energy became more economically and technically feasible. This has resulted in the installation of small power plants connected to the distribution side of the network, close to the customers and hence referred to as "embedded" or "distributed" generation (DG). Sometimes it is also called "dispersed generation" or "decentralized generation". [4].

Distributed generation technologies are renewable and nonrenewable. Renewable technologies include solar, photovoltaic or thermal, wind, geothermal, ocean. Nonrenewable technologies include internal combustion engine, ice, combined cycle, combustion turbine, micro turbines and fuel cell. [5] Most of the DG energy sources are designed using green energy which is assumed pollution free [6].

Installing DGs at the load centers will prevent the new transmission lines extension to energize new substation, DG is capable of providing some or all of the required power without the need for increasing the existing traditional generation capacity or T&D system expansion. DG capital cost is not large due to its moderate electric size and modular behavior as it can be installed incrementally unlike installing new substations and feeders, which require large capital cost to activate the new expanded distribution system [12].

The technical benefits include improvement of voltage, loss reduction, relieved transmission and distribution congestion, improved utility system reliability and power quality [6] and increasing the durability of equipment, improving power quality, total harmony distortion networks and voltage stability by making changes in the path through which power passes [9].These benefits get the optimum DG size and location is selected. Distributed system planning using distributed generation [12]. If the DG units are improperly sized and allocated leads to real power losses increases than the real power loss without DG and reverse power flow from larger DG units**.** So, the size of distribution system in terms of load (MW) will play important role is selecting the size of DG. The reason for higher losses and high capacity of DG can be explained by the fact that the distribution system was initially designed such that power flows from the sending end (source substation) to the load and conductor sizes are gradually decreased from the substation to consumer point. Thus without reinforcement of the system, the use of high capacity DG will lead to excessive power flow through small sized conductors and hence results in higher losses.[7]

Different techniques are proposed by authors the techniques are, a technique for DG placement using "2/3 rule" which is traditionally applied to capacitor allocation in distribution systems with uniformly distributed loads has been presented. Although simple and easy to apply, this technique cannot be applied directly to a feeder with other types of load distribution or to a meshed distribution system. The genetic algorithm (GA) based method has been presented to determine the size and location of DG. GA is suitable for multi-objective problems and can lead to a near optimal solution, but demand higher computational time.

An analytical approach based on an exact loss formula has been presented to find the optimal size and location of single DG. A probabilistic-based planning technique has been proposed for determining the optimal fuel mix of different types of renewable DG units (i.e., wind, solar, and biomass) in order to minimize the annual energy losses in the distribution system [1]

II. PROBLEM FORMULATION

This section describes to find the optimum size and location of distributed generator.

A. Selection of Location:

Find the best bus for the placement of DG, The DG sizes at each bus is calculated by using (2).The DG's are placed at each bus and calculate the real power loss by (1).The bus which has minimum real power loss is selected as best location for placement of DG.

The real power loss in a system can be calculated by (1). This is also called as "Exact loss formula" [13].

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) \quad + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)] \qquad (1)$$

Where

$$\alpha_{ij} = \frac{r_{ij}}{v_iv_j}\cos\left(\delta_i - \delta_j\right);$$

$$\beta_{ij} = \frac{r_{ij}}{v_iv_j}\sin\left(\delta_i - \delta_j\right);$$

$r_{ij} + jx_{ij} = Z_{ij}$ ij^{th} element of $[Z_{bus}]$ impedance matrix;

N is number of buses

Where P_i and Q_i are Real and Reactive power injections at node 'i' respectively.

Real power injection is the difference between Real power generation and the real power demand at that node.

$$P_i = (P_{DGi} - P_{Di})$$

$$Q_i = (Q_{DGi} - Q_{Di})$$

Where, P_{DGi} and Q_{DGi} is the real power injection and reactive power injection from DG placed at node *i* respectively. P_{Di} and Q_{Di} are load demand at the node *i* respectively [14].

$$P_{DGi} = \frac{\alpha_{ii}(P_{Di} + aQ_{Di}) - X_i - aY_i}{a^2\alpha_{ii} + \alpha_{ii}} \qquad (2)$$

$$Q_{DGi=} \pm (\tan(\cos^{-1}(PF_{DG}))) \qquad (3)$$

Where

$$X_i = \sum_{\substack{j=1 \\ j\neq i}}^{n}\left(\alpha_{ii}P_j - \beta_{ij}\,Q_j\right)$$

$$Y_i = \sum_{\substack{j=1 \\ j\neq i}}^{n}\left(\alpha_{ii}Q_j + \beta_{ij}\,P_j\right)$$

'+' sign for injecting Reactive power

'- 'sign for consuming Reactive power

The exact loss formula is a function of loss coefficients α and β.These coefficients depends on magnitude of voltage and voltage angle at each bus. So for every DG placement at each bus the α and β changes so for that every time requires load flow calculation. But the results show that with and without updating the α and β the results are same [1].

B. Optimal DG size selection:

The Distributed generator is placed at the optimum location. The optimum DG size is selected by varying the DG in small steps up to the point where real power loss is minimum. The real power loss is calculated by "back ward forward sweep" load flow algorithm.

III. IA METHOD

The computational procedure of IA method is as follows:

Step 1: Enter the number of DG units to be installed.

Step 2: Run load flow for the base case and find losses using (1).

Step 3: Find these optimal location of DG using the following steps.

a) Calculate the optimal size of DG at each bus using (2) and (3).
b) Place the DG with the optimal size as mentioned earlier at each bus, one at a time. Calculate the approximate loss for each case using (1).
c) Locate the optimal bus at which the loss is at minimum.

Step 4: Find the optimal size of DG and calculate losses using the following steps.

a) Place a DG at the optimal bus obtained in step 4, change this DG size in small step, and calculate the loss for each case using "Back ward forward" load flow.
b) Select and store the optimal size of the DG that gives the minimum loss.

Step 5: Update load data after placing the DG with the optimal size obtained in step 5 to allocate the next DG.

Step 6: Stop if either the following occurs

a) the voltage at a particular bus is over the upper limit
b) The total size of DG units is over the total plus loss
c) The maximum number of DG units is unavailable
d) The new iteration loss is greater than the previous iteration loss. The previous iteration loss is retained otherwise, repeat steps 2 to6.

IV. LSF METHOD

Loss Sensitivity Factor (LSF) method is employed to find the optimal location to place DG units which supplies active power only. The sensitivity factor method is based on the principle of linearization of original nonlinear equation around the initial operating point, which helps in reduction of the number of solutions. The LSF at i^{th} bus is derived from equation (1) is given as

$$\alpha_i = \frac{\partial PL}{\partial Pi} = 2\sum_{j=1}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) \qquad (3)$$

The procedure to find the optimal locations and sizes of multiple DG units using the loss sensitivity factor is described in detail as follows.

Step 1: Enter the number of DG units to be installed.

Step 2: Run load flow for the base case and find losses using (1).

Step 3: Find the optimal location of DG using the following steps

(a) Find LSF using (4). Rank buses in descending order of the values of their LSFs to form a priority list.
(b) Locate the highest priority bus.

Step 4: Find the optimal size of DG and calculate losses using the following steps:

(a) Place a DG at the bus with the highest priority obtained in step 3, change this DG size in "small" step, update the values α and β , and calculate the loss for each case using (1) by running load flow.
(b) Select and store the optimal size of the DG that gives the minimum loss.

Step 5: Update load data after placing the DG with the optimal size obtained in step 4 to allocate the next DG.

Step 6: Stop if either the following occurs:

(a) The voltage at a particular bus is over the upper limit;
(b) The total size of DG units is over the total load plus loss;
(c) The maximum number of DG units is unavailable;
(d) the new iteration loss is greater than the previous iteration loss.

The previous iteration loss is retained; otherwise, repeat steps 2 to 5.

V. RESULTS AND ANALYSIS

In this paper IA method and Loss Sensitivity Factor method are tested on 33-bus [10] and 69-bus [11] radial distribution system. Here Type 3 [1] DG is considered

A. Assumptions

The assumptions for this paper are as follows:

1. The maximum number of DG units is three, with the size each from 250KW to the total load plus loss.
2. The maximum voltage at each bus is 1.0 p.u.

B. 33-Bus system

The simulation results of the optimal location and optimal sizing of DG is shown in Table-I. The real power loss of 33-bus system is 211kW without DG. In single DG placement by LSF method the DG size is 850 kW, the real power loss is 145.7kW and in case of IA is 2600 kW, the real power loss is 105.21 kW. In case of 2 DG's placement the DG size by LSF method 710 kW, 1010 kW the real power loss is 100.20 kW and in case of IA is2310kW,710kW the real power loss is 94.78kW. In case of 3 DG's placement by LSF Method is 610 kW, 910 kW, 910 kW the real power loss is 84.11 kW and by IA Method is 1710 kW,710 kW,610 kW the real power loss is 76.93kW.

TABLE-I
COMPARISON OF DIFFERENT TECHNIQUES ON 33-BUS SYSTEM

Cases	DG schedule	With out DG	With DG		
			1 DG	2 DG's	3 DG's
LSF Method	optimum bus	----	18	18,33	18,33 ,25
	DG Size (kW)		850	710 1010	610 910 910
	Loss (kW)	211	145.7	100.2	84.11
IA method	Optimu m bus	---	6	6,25	6,25, 15
	DG Size (kW)		2600	2310 710	1710 710 610
	Loss (kW)	211	105.20	94.78	76.93

C. 69-Bus system:

The simulation results of the optimal location and optimal sizing of DG shown in Table-II .The real power loss of 69-bus system is 224 kW without DG. In single DG placement by LSF method the DG size is 1440kW the real power loss is 112.11kW and in case of IA Method the DG Size is 1900 kW the real power loss is 81.26 kW.

In case of 2 DG's placement the DG size by LSF method 1410 kW, 410 kW the real power loss is 100.51 kW and in case of IA method 1810 kW, 510 kW the real power loss is 70.36 kW. In case of 3 DG's placement the DG size by LSF method 210 kW, 410kW, 1610kW the real power loss is 73.62kW and by IA method 1810kW, 510kW, 710kW the real power loss is 68.87kW.

TABLE-II
COMPARISON OF DIFFERENT TECHNIQUES ON 69-BUS SYSTEM

Cases	DG schedule	With out DG	With DG		
			1 DG	2 DG's	3 DG's
	Optimum Bus	-----	65	65,27	65,27, 61
LSF Method	DG size (kW)	-----	1440	1410 410	210 410 1610
	Loss (kW)	224	112.11	100.51	73.62
IA Method	Optimum Bus	-----	61	61,22	61,22, 49
	DG size (kW)	-----	1900	1810 510	1810 510 710
	Loss (kW)	224	81.26	70.36	68.87

VI. CONCLUSION

In this paper Loss Sensitivity Factor method is proposed for multiple DG placement. The DG location is finding by IA expressions and the optimum DG size is finding by IA method and LSF method. The results are compared with IA method. Results shows that LSF method gives nearly same real power loss and voltage with less DG size occurred in IA method.

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