An analytical method for determining optimal location and size of DGs for real power loss minimization in distribution system

Manish Sharma, SarfarazNawaz, AnkushTandon
Department of Electrical Engineering, Swami Keshvanand Institute of Technology, Management and Gramothan, Jaipur-302017 (INDIA)
***Email*- manishpandya67@gmail.com**
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Abstract: The inclusion of distributed generation (DG) to the distributed network may have an impact on the network losses of the power system. Inappropriate selection of location and size of DG may increase system losses. This paper introduced an effective methodology for optimal distributed generation (DG) allocation to decrease real power loss in radial distribution system. An analytical method has been proposed to get optimal places and corresponding rating of multiple DG units. A new mathematical formulation, Loss Sensitivity Constant (LSC), has been derived in the proposed analytical technique to solve the optimal DG allocation problem. The value of DG penetration is taken up to 30% of total load of this system. The proposed technique has been tested on standard IEEE 33-bus test system. To check the effectiveness of proposed method, the system is tested atthree different type of loading conditions i.e. light load (50% of the rated load), nominal load (rated load condition) and heavy load (160% of the rated load).The results of the proposed analytical technique are compared with the results of the latest optimization techniques in order to show its effectiveness.

Keywords: Radial Distribution System (RDS), Distributed Generation(DG), Real Power Loss(RPL).

1. INTRODUCTION

The classic power system model consists of three important components, namely generation, transmission line and distribution system.The most important and largest part in electrical power network is distribution system. It supplies electric energy to various clients in ready to-use structure at their place ofutilization. Losses in transmission and distribution networks constitute the single largest consumption in any energy system. Because of the rapid growth within the demand for electricity, environmental constraints and competitive energy market situation the transmission and distribution systems are regularly being operated below heavily loaded situations and the distribution system loss has emerge as increasingly of a situation. In general, the 70% of total losses are occurring in the primary and secondary distribution system, while the remaining 30% in transmission and sub transmission lines. Distribution Losses are 15.5% of the generation capacity whereas it should be less than 7.5% as per the grid regulations. Therefore the primary and secondary distribution system must be properly intended to ensure losses within the tolerable limits.

Nowadays, it is univocally acknowledged that the reduction of losses leads to power and energy cheaper than building new capacities of production and transmission especially in the distribution networks. Ideally, losses in an electric system ought to associate with 3 to 6%. In developed nations, it is not more than 10%. In any case, in developing countries, the level of active power losses is around 20%; in this way, utilities in the electric sector are currently interested in diminishing it. In India, the AT&C losses are very much higher than many other developing countries and are close to 25% as per the UjjwalDiscom Assurance Yojana (UDAY).

Distributed generation (DG) is defined as a small scale generation units which are mainly close to load center. It is usually connected to the distribution network &its size may be 50KW to 100MW [1].The integration of the distributed generations (DGs) will help to catch-up with the increasing demand. The optimal allocation of DGs can help in reduction of network active power losses and also provide voltage support. Hence, this loss reduction will also help to meet the increasing demand. A comprehensive literature survey on power loss minimization in distribution system using distributed generation has been presented by the researchers. Kyu-Ho Kim et al. [2] employed a hybridized method (Genetic Algorithm with fuzzy set theory) that determined DG optimal places to be installed concurrently with their sizes in distribution system. N. Acharya et al. [3] suggested an analytical methodology to find out the optimal size of DG. S. Kamalinia et al.[4] presented the solution to optimal DG allocation based on MADM (Multi-Attribute Decision Making) and Genetic algorithm. M. A. Kashem et al. [5] presented a deterministic technique dependent on the SQP algorithm to determine the optimal size as well as optimal location of DG in distribution networks. D. Singh et al.[6] proposed a Genetic Algorithm for optimal allocation of DG in radial distribution network to minimize the power losses. M. Abbagana et al. [7] proposed a Differential Evolution technique for the optimum placement and sizing of a DG in a distribution network. V.V.K. Satyaka et al. [8] proposed discrete particle swarm optimization (DPSO) technique to determine the location of DG in order to minimize the active power loss and to enhance the voltage profile. KomailNekooei et al. [9] employed aneffective method based on Ant colony optimization (ACO) algorithm to find out optimal sites, sizes and number of DGs to decreases power losses in the network. D. Q. Hung et al.[10] proposed an improved analytical (IA) method for optimal placement of multiple DG units to get maximum loss reduction in large-scale primary distribution systems. S. Kaur et al. [11] proposed a methodology based on MINLP (mix-integer non-linear programming) for DG placement in radial distribution system that determined the optimal locations and sizes of multiple DG units to reduce the active power losses. S. sultana et al. [12] implemented the quasi-oppositional teaching learning based optimization (QOTLBO) for getting optimal sizes and capacities of multiple DGs in RDN. R. Ishak et al. [13] proposed a new approach to determine the optimal site and capacity of DG through maximum power stability index (MPSI) with particle swarm optimization (PSO) technique. M. Vatani et al. [14] proposed a method that employs a new hybridized algorithm i.e. a combination of Genetic algorithm with analytical method for the evaluation of optimal allocation of multiple DG units in distribution network. S. sudabattula et al. [15] presented an effective method based on cuckoo search algorithm to find out the optimal allocation of wind based distributed generations in order to reduced real power losses of radial distribution system. M. Dixit et al. [16] presented the solution of optimal location and sizing of multiple DG with different power factor based on Index Vector Method (IVM) and ABC (artificial bee colony) optimized algorithm. M. Majiddi et al. [17] proposed a new application of Cuckoo Search Algorithm for getting optimal location and size of DG in traditional radial distribution network. S. kumar et al. [18] introduced the optimal solution of multiple DG placements using opposition based chaotic differential evolution (OCDE) technique. H. A. mawgoud et al. [19] introduced a new hybrid approach (Loss Sensitivity Factor (LSF) method with Moth-flame optimization (MFO) algorithm) to obtain the optimal sites and sizes of Non-conventional dispersed generation sources (solar and wind turbine) in RDN (radial distribution network).On the basis of real and reactive power delivery, the DGs are classified in four categories are as follows [20, 21]:

Type I DG’s: only supply active power and exchange no reactive power with the grid;

Type II DG’s: only supply reactive power to the grid;

Type III DG’s: feed both active and reactive power to the grid;

Type IV DG’s: generates active power but absorb reactive power from grid.

In this paper, multiple DG (type I) units have been used to locate in distribution system for maximize the percentage loss reduction in real power loss and build up voltage profile. A new analytical technique is estimated to find out the location and rating of multiple DG units. A new mathematical formula has been proposed here that is known as Loss Sensitivity Constant. This constant has been used to find out site and size of any type of DGs at the same time.Up to 30% of total load has been taken into consideration as a penetration level of DGs, so that maximum loss reduction while incorporating less DG size. IEEE 33-bus distribution system has been used as test system.It is significantly observed from the proposed method that it gives better loss reduction as compared to the other latest optimization approaches.

The structure of the remaining part of the paper is follows as: section 2 deals with the formulation of the problem identified and assumptions carried out. Then, section 3 shows the methodology adopted to solve the problem and explains the proposed analytical approach and algorithm for DG sizing and placement. After that, section 4 describes simulation made and obtained results. Finally, section 5 concludes this work with the findings achieved and contribution in the work.

2. PROBLEM FORMULATION

Let’s consider a generic distribution branch connecting two nodes i and j as shown in fig. 1 of two bus system where bus j is connected with a DG unit. The power losses of this distribution network for n bus are calculated by using following formula.

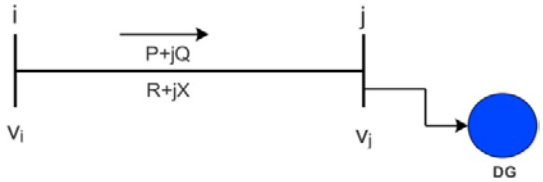

Figure 1: DG Connected Radial Distribution Network of i-j

$$P_{Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} I_{ij}^2 R \quad (1)$$

$$P_{Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} R\left|\frac{V_i - V_j}{Z}\right|^2 \quad (2)$$

$$P_{Loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} R\frac{|V_i|^2 + |V_j|^2 - 2|V_i||V_j|\cos\delta_{ij}}{Z^2} \quad (3)$$

Here, the line impedance and resistance of section (i, j) are Z and R.

The objective of DG placement problem is to determine the size and location of DG units which gives maximum loss reduction.

For n bus radial distribution network, the problem is defined as [22]:

$$\text{Minimize } F_1 = P_{Loss}$$

The constraints, which are considered in the optimization process to ensure all parameters in the distribution network are within allowable limit, are shown below:

(i) For a distribution network, the arithmetical summation of power produced by DG units and power losses together with total incoming and outgoing powers ought to be proportionate to zero.

(ii) The infused power by every DG units is limited under its most extreme and least range as,]

$$P_{DG_j}{}^{min} \le P_{DG_j} \le P_{DG_j}{}^{max}$$

All DG units must operate within the tolerable value where $P_{DG_j}{}^{min}$ and $P_{DG_j}{}^{max}$ are minimum and maximum limit of active power output of DG at bus j.

(iii) Bus voltage limits

$$V_{i,\min} \le V_i \le V_{i,\max}$$

(As per Indian standard ±5%) 0.95 pu ≤ V_i ≤ 1.05 pu

The voltage value for all buses in the network must be within the acceptable limits. Where, $V_{i,\min}$ and $V_{i,\max}$ are minimum and maximum allowable voltage at bus i

(iv) The feeder should not exceed the thermal capacity of the line.

3. PROPOSED APPROACH

A new mathematical formula has been proposed here to calculate the size and site of multiple DG units.

The Loss Sensitivity Constant (LSC) is estimated to find out the rating and position of DG units. The LSC is the sum of two ratios, i.e. ratio of real power loss before and after DG allocation & ratio of rated voltage and minimum bus voltage after DG allocation.

$$LSC = \frac{V_{rated}}{V_{min}} + \frac{P_1}{P_2} \quad (4)$$

Where,
P_1: Active power loss for base case.
P_2: Power loss afterlocating DG at i^{th} bus.
V_{rated}: Rated bus voltage in pu (always be 1 pu).
V_{min}: Value of minimum bus voltage in pu after DGplacement at i^{th} bus.

To obtain the optimal placement of DG units, we have to meet following conditions: (i) the real power losses P_2 after DG placement at i^{th} bus should be at minimum value and (ii) the value of minimum bus voltage V_{min} after DG placement at i^{th} bus should be at maximum value. Both of these conditions will leads to the minimum value of LSC. The LSC value for various specified DG sizes is calculated at each bus. The bus with the minimum value of LSC is the optimal bus for the placement of DG unit. The related DG size value of this minimum LSC at that bus will be the optimal size of the placed DG unit.

The process to compute DG size and site is explained below:

Step 1: Calculate the value of base case real power loss.
Step 2: Start with 1% level of DG penetration & compute real power loss (P_2).
Step 3: Calculate the value of “LSC” for all bus using eq. 4.
Step 4: Now change the level of DG penetration with small variation and compute P_2.
Step 5: Keep the rating of particular DGs that have smallest measure of p2.
Step 6: The optimal location of that DGs will be given by the relating bus.
Step 7: Install the DG of calculated size at particular bus.
Step 8: To determine more location repeat Steps 4 to 7.
Step 9: Adhere the constraint of 30% DG penetration level.

4. TEST RESULTS

The proposed technique has been tested on IEEE standard test system i.e. IEEE 33-bus system. To check the effectiveness of proposed method, the system is tested atthree different type of loading conditions i.e. light load (50% of the rated load), nominal load (100%)and heavy load (160% of load). The proposed method is implemented using MATLAB software. The IEEE 33 bus radial distribution test system [23] has a total active power load of 3.715 MW and reactive power load of 2.30 MVAr. The base values are taken as 12.66 kV and 100 MVA. Figure 2 exhibit the single line diagram of IEEE 33-bus distribution network.

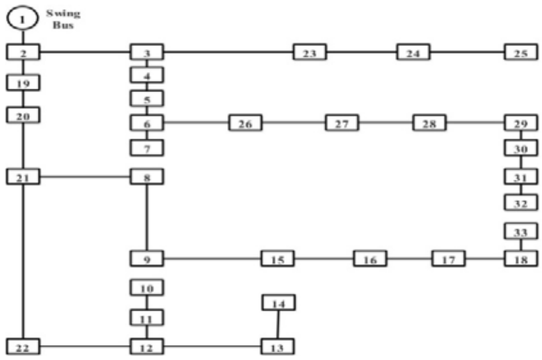

Figure 2: Single Line Diagram of IEEE 33-Bus Distribution System [23]

The base network real power losses are 138.06 kW with minimum bus voltage of 0.9423 pu at nominal loading level. At light and heavy load level, real power losses are 33.15 kW and 377.8254 kW respectively for the same the voltage profile is observed as 0.97 pu and 0.9023 pu respectively.

Table 1: Outcomes of proposed DG placement technique at various loading conditions for IEEE 33-bus distribution system

Case	Items	Different Loading condition		
		50% of load	**100% of laod**	**160% of load**
Base Case[23]	Active Power Loss (kW)	33.15	138.06	377.8254
	V_{min} (pu)	0.97	0.9423	0.9023
After DG Allocation	DG capacity in kW(Location)	120(17) 100(30) 190(31)	310(17) 320(30) 350(31)	950(17) 380(30) 300(31)
	Total capacity of DG (kW)	410	980	1630
	Active Power Loss (kW)	22.08	85.48	236.67
	V_{min} (pu)	0.9806	0.9629	0.9273
	PercentageReduction in Real Power Loss	50.13	38.08	37.36

The value of DG penetration is taken up-to 30% of total load of this system. The optimal size (Capacity) and location of multiple DG (i.e. three DGs) at nominal load level is found to be 310 kW at bus no. 17, 320 kW at bus no. 30 and 350 kW at bus no. 31. At nominal load level, the network real power losses are reduced to 85.48 kW from 138.06 kW for base case which accounts for 38.08% of loss reduction from base case and the value of V_{min} is also increased to 0.9629 pu. It is observed from table 1 that the location of DG units is fixed (17, 30 and 31) for each loading condition. However, the sizes of DG units at these locations are unique for different loading levels. The DG sizes for light load level are 120 kW, 100 kW and 190 kW and for heavy load level are 950 kW, 380 kW and 300 kW. At light and heavy load condition, real power losses are reduced to 22.08 kW and 236.67 kW respectively and for the same percentage loss reduction account for 50.13 % and 37.36 % respectively. The minimum bus voltage is also improved in both (light and heavy) conditions. Hence, it is observed from table 1 that the proposed method yields maximum power loss reduction and better voltage profile for all loading condition.

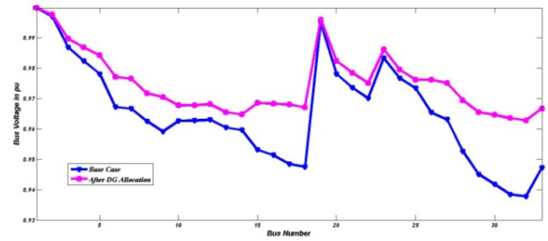

Figure 3: Variation in Voltage Magnitude of the busses of IEEE 33-Bus Radial Distribution System at 100% of Load(Nominal Load)

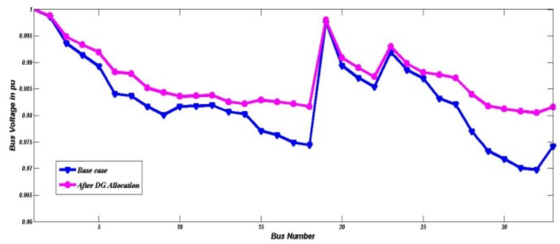

Figure 4: Variation in Voltage Magnitude of the busses of IEEE 33-Bus Radial Distribution System at 50% of Load (Light Load)

The comparison of voltage profile of 33-bus system is shown in fig. 3, 4 and 5 for nominal, light and heavy loading condition. The variation in bus voltages at nominal loading condition is exhibited in fig. 3. It can be observed from figure 3 that the voltage profile is improved as compared with the base case.

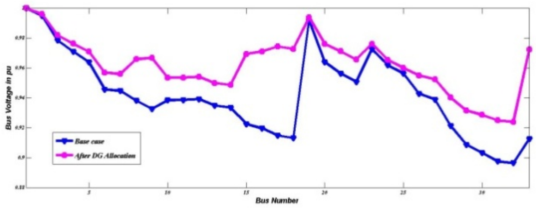

Figure 5: Variation of in Voltage Magnitude of the busses of IEEE 33-Bus Radial Distribution System at 160% of Load (Heavy Load)

Similarly, the voltage profiles at all the nodes are shown in fig. 4 and fig. 5 for light and heavy load levels, respectively. Analogously the voltage profile is also enhanced for light and heavy loading levels.

Table 2 exhibits the comparison of results of proposed technique with other latest optimization approaches such as Modified Plant Growth Simulation Algorithm (MPGSA) [24], Hypercube—Ant Colony Optimization (HC-ACO) [25], Heuristic Search Algorithm (HSA) [26], Refined Genetic Algorithm (RGA) [27], and Genetic Algorithm (GA) [28] at nominal load level to show the effectiveness of the proposed method.

Table 2: Comparative Results of Different Methods for IEEE 33-Bus Distribution System at Nominal Load after DG Placement.

Methods	Total DG Capacity (kW)	Real Power Loss (kW)	Percentage Reduction in Real Power Loss	V_{min} (pu)
Proposed DG Placement	**980**	**85.48**	**38.08**	**0.9629**
MPGSA (2015) [24]	1090	92.87	33.43	0.9482
HC-ACO (2014) [25]	1099	93.45	31.43	0.9556
HSA (2013) [26]	1090	97.13	29.65	0.9479
RGA (2002) [27]	1100	98.23	29.56	0.9479
GA (1992) [28]	1448	98.36	30.57	0.9506

It is significantly observed from the Table 2 that the proposed method gives better loss reduction as compared to the other methods in published literature. It can be observed from above table that proposed technique yields maximum loss reduction while incorporating less DG size in comparison the other technique. Hence, the proposed method is very cost effective also. The voltage profile has been also improved in proposed method. Figure 6 depict the single line diagram of 33 bus system after DG placement at nominal load.

5. CONCLUSION

Conventional distribution systems are passive and radial with the unidirectional power flows in the network. DG integration is increasing at very faster rate in this new era. It changes the power flows into bidirectional. The new DG coming into the distribution network can decrease or increase the network active power losses. Hence, it is very important to optimally place the new DGs coming into the network.

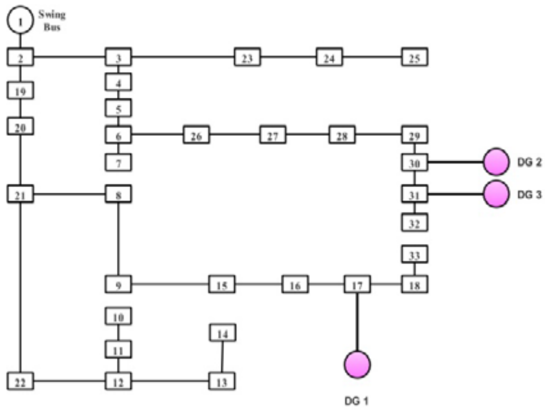

Figure 6: Single Line Diagram of IEEE 33-Bus Distribution System after DG Placement at Nominal Load

This paper proposes a new approach for the DG placement. The optimal location as well as the optimal size of the DG is very important. An analytical method is developed for the determination of the optimal size and location of the dg in the radial distribution network. the new mathematical formulation, LSC, is proposed and explained in this paper.

The proposed algorithm has been implemented on standard IEEE 33-bus distribution system at different loading level i.e., light (50% decrement in load), nominal, and heavy (60% increment in load). The results are compared with other previous work and found better in all cases. DG penetration level is also considered as constraint. The computational results showed that the performance of the proposed approaches is better than other mentioned approaches in all scenarios.

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