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A NEW TECHNIQUE TO SOLVE DG ALLOCATION PROBLEM FOR DISTRIBUTION POWER LOSS MINIMIZATION

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Abstract. *Distributed Generation (DG) units are widely used to reduce the power losses in distribution system. To optimize the benefits of DGs it is essential to determine its appropriate size and position. In the paper two types of DG units (PV module & shunt capacitor) are anticipated for power loss minimization. A simple analytical technique is proposed to solve the allocation problem. A new mathematical expression, Power Voltage Sensitivity Constant (PVSC), has been formulated to determine its size and position. The size of DG units is restricted up to 50% of total system load. The proposed approach is validated on standard 69 bus test system at three load levels (nominal, light & heavy). The results obtained from standard systems are compared with latest optimization techniques to show the effectiveness and robustness of the proposed approach.*
Keywords: Radial Distribution Systems (RDS), Real power loss, PVSC, Distributed Generation (DG), Shunt capacitors

1. **Introduction.** The operation and control of distribution systems have become more complex due to variation of loads on feeders. Electrical power distribution systems generally work in radial configuration. Due to high R/X ratio, radial distribution systems cause a huge voltage drop and considerable power losses. As per Indian scenario, distribution losses constitute a significant part of the system losses (around 21%). Nowadays DG technologies are widely used to minimize power losses in RDS. In Distributed Generation (DG) technology, the small generating units (1 kW to 50 MW) are connected near the load side. DG units came into picture from last two decades due to the development in DG technologies and deregulation of electricity market in addition to other factors like economical and regulatory changes in distribution system. DG can utilize the power of both renewable and non-renewable energy sources. Sources like wind, solar, geothermal, small hydro and biomass and cogeneration come in the category of renewable energy, while reciprocating engines, fuel cell, gas turbines and micro turbines are the part of non-renewable energy sources. Optimal DG Allocation (OPDG) can enhance the system performance with the point of view of voltage stability, minimal system losses and flows, better power quality and improved reliability of power supply. The problem of DG allocation is to find the optimal location and optimum size of DG units to be installed into existing distribution networks that can satisfy all the operating constraints of electrical network, constraints of operation of DG, and constraints of cost. Various researchers applied different approaches to solving the DG allocation problem. G. Levitin [1] presented a solution by combining genetic algorithm and fast energy loss method. K.-H. Kim et al. [2] adopted hybridized method to determine optimal location of DGs along with their capacities in distribution networks. The authors combined the genetic algorithm with theory of fuzzy set. M. Gandomkar et al. [3] suggested a method that works as a new hybridized

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algorithm for deciding the optimal DG site and size in medium voltage systems. The GA was correlated to Simulated Annealing (SA) metaheuristic methods and employed for DG allocation. N. Acharya et al. [4] presented an analytical method to calculate the optimal capacity of DG. A direct equation derived from the sensitivity factor equation calculates the optimal size of DG corresponding with each network bus. S. Kamalinia et al. [5] proposed a solution for the problem of optimal DG placement developed by using a technique of MADM (Multi-Attribute Decision Making) and genetic algorithm. To determine the optimal capacity and location of DG units, authors used Analytic Hierarchy Process (AHP) along with Data Envelopment Analysis (DEA) as the technique of multi attribute decision-making. A. D. T. Le et al. [6] established a deterministic methodology that was based on the SQP algorithm for determining the optimal location and size of DG in distribution network systems. D. Singh et al. [7] introduced a technique using GA for placement of distributed generation. Three types of loading conditions (peak, medium and low) were examined. M. Abbagana et al. [8] derived a methodology based on the technique of differential evolution to calculate the size and location of DG in distribution network while meeting all the constraints of optimality. The authors presented decision making techniques to find the solution for OPDG. M. Sedighi et al. [9] evaluated the optimal location and capacity of single and multiple DGs by adopting PSO method. S. Nawaz et al. [10] presented sensitivity analysis technique and tested it on 33 bus system at different loading conditions. R. Viral and D. K. Khatod [11] proposed an analytical approach to determine the best position and size of DG units in balanced distribution system to reduce real power. S. Nawaz et al. [12] proposed a new analytical technique to solve DG allocation problem in RDS. K. R. Devabalaji and K. Ravi [18] proposed bacterial foraging optimization algorithm for optimal allocation of DG & STATCOM.

The various types of DG units are [13]:

Type-I: Generate active power (ex. PV module)

Type-II: Generate reactive power (ex. Capacitors)

Type-III: Generate both active and reactive power (ex. synchronous generator)

Type-IV: Generate active power but consume reactive power (ex. induction generators used in wind farms)

In this paper a new approach has been presented for optimal DG allocation in RDS. Type-I (PV module) and type-II (Capacitors) are used for placement. The aim of this paper is to minimize distribution power loss. A new mathematical expression is formulated that is called PVSC (Power Voltage Sensitivity Constant). The sensitivity constant determines the optimal size and gives the best location of DG simultaneously. Up to 50% penetrate on level of DG units is also taken into consideration, so that less size of DG units produces maximum loss reduction. The proposed method is tested on standard IEEE 69 at three load levels (nominal, light & heavy). The obtained results of standard test system are compared with other approaches and found superior. The rest of the paper is organized as follows. Section 2 gives the portrayal of problem statement. Section 3 gives the proposed approach for feeder reconfiguration and DG placement problem. Section 4 portrays the simulation results of test distribution systems used in this paper. A brief summary of the obtained results is also included in this section and the conclusions of the papers are summarized in Section 5.

2. **Problem Statement.** The objective of the paper is the minimization in active power loss of radial distribution system to its lowest value. This is achieved by installing the DG units (Solar PV Module & Capacitors) of appropriate size at optimal location. The operating constraints of the problem are divided into equality and inequality constraints.

Mathematically, the DG placement problem can be formulated as a constrained nonlinear optimization model [14]:

$$Minimize\,(P_{\mathrm{Loss}}) \tag{1}$$

$$\text{Subjected to: } k1(x,z) = 0$$
$$k2(x,z) \le 0$$

$k1(x,z)$ and $k2(x,z)$ are the set of equality and inequality constraints, respectively, where x is the state variables and z is the control variables. The control variables are power outputs of DG (P and Q). The state variables are bus voltage and line power flows.

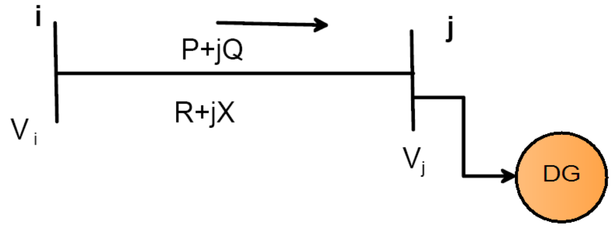

FIGURE 1. DG connected radial distribution network of i-j bus

Figure 1 shows the line diagram of two bus (i and j) system. The DG unit is connected at bus j. The voltages of bus i and j are V_i and V_j respectively. The line power $(P + jQ)$ is flowing from bus i to j and line impedance is $R + jX$. The distribution network power loss of above system for n bus is calculated by using:

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

(a) Equality Constraints:

The arithmetical summation of all incoming and outgoing powers together with power losses for distribution system and power generated by DG units should be equal to zero.

(b) Inequality Constraints:

(i) The injected power by each DG unit is restricted by its maximum and minimum limits as,

$$P_{\text{DG}j}^{\min} \le P_{\text{DG}j} \le P_{\text{DG}j}^{\max}$$
$$Q_{\text{DG}j}^{\min} \le Q_{\text{DG}j} \le Q_{\text{DG}j}^{\max}$$

(ii) Bus voltage limits (As per Indian standard ±5%)

$$0.95\,\text{pu} \le V_i \le 1.05\,\text{pu}$$

(iii) The feeder should not go beyond the thermal limit of the line.

Here,

R: Line resistance between buses i and j;
X: Line reactance between buses i and j;
Z: Line impedance;
V_i: Magnitude of voltage at bus i;
V_j: Magnitude of voltage at bus j;
$V_{\min}$: Minimum bus voltage
δ_i: Angle of voltage at bus i; δ_j: Angle of voltage at bus j; P and Q: Active and reactive power flow from bus i to j.

3. **Proposed Approach.** A new analytical approach has been proposed in the paper to solve optimal DG placement problem. Other optimization techniques have large number of iterations, so the computational time is large. However, in the proposed analytical technique the processing time is less. In most of the techniques, the candidate bus is determined by sensitivity analysis and size is determined by other optimization methods. However, in proposed technique, single mathematical formula gives size and location both.

The proposed method for optimal placement of DG units is based on a new mathematical formulation. The Power Voltage Sensitivity Constant (PVSC) is projected to determine the size and location of DG units. This constant takes active power loss and voltage limits of individual buses into account and suggests optimal location and size of the DG units.

$$\text{PVSC} = \frac{V_{\text{max}}}{V_{\text{min}}} + \frac{P_{\text{dgloss}}}{P_{\text{realloss}}} \tag{3}$$

where,

P_{realloss}: base case real power loss.

P_{dgloss}: active power loss after DG placement at the ith bus.

V_{max} is rated bus voltage in pu after DG placement at the ith bus (always be 1 pu).

V_{min} is minimum bus voltage in pu after DG placement at the ith bus.

For optimal placement of DG units the value of P_{dgloss} should be minimum and value of V_{min} should be maximum. Hence, the value of PVSC should be minimum. To obtain the optimal location and size of DG units, PVSC value at each bus for specified DG size is calculated. The bus, which has least PVSC value, will be the candidate bus for allocation and the corresponding DG's size would be optimum.

Computational process for the proposed analytical technique is explained below.

Step 1: Run the load flow program and calculate value of P_{realloss}.

Step 2: Start with 5% DG penetration level and run load flow program.

Step 3: Compute P_{dgloss} of the system and "PVSC" values for each bus using Equation (3).

Step 4: Now vary DG penetration in small step and compute P_{dgloss}.

Step 5: Store the size of DGs which gives least amount of P_{dgloss}.

Step 6: The bus, which has least "PVSC" value, will be the optimal position of DG unit.

Step 7: Repeat Steps 4 to 6 to find more location of DGs.

4. **Test Results.** The proposed method has been tested on standard IEEE 69 bus distribution system. The standard IEEE 69 bus distribution system has 12.66 kV and 100 MVA base values. The total system load is 3.802 MW and 2.694 MVAr [15]. The base case real power loss of 69 bus system is 225 kW and minimum bus voltage is 0.9092 pu.

The results for simultaneous placement of DGs & capacitor bank are presented in Table 1. The real power loss is reduced to 11.74 kW from 225 kW. The optimal locations of DG units are bus no. 21, 61, 64. The total size of DG (PV module) and shunt capacitor

Table 1. Results of 69 bus systems after simultaneous placement of DGs and capacitors

Case	Item	Results
Base Case	Real Power Loss (kW)	225
	Reactive Power Loss (kVAr)	102.15
	Minimum Bus Voltage (pu)	0.9092
DG and Capacitor allocation	DG size in kW (bus no.)	310 (21); 950 (61); 550 (64)
	Total DG size (kW)	1810
	Capacitor size in kVAr (location)	700 (61); 230 (21); 350 (64)
	Total Capacitor size (kVAr)	1280
	Real Power Loss (kW)	11.74
	% Real Power Loss reduction	95.72%
	Reactive Power Loss (kVAr)	10.38
	% Reactive Power Loss reduction	90%
	Minimum Bus Voltage (pu)	0.99

units are 1810 kW and 1280 kVAr respectively. This yields to percentage loss reduction of 95.72% and the minimum bus voltage is also improved to 0.99 pu from 0.9092 pu. The reactive power losses are also reduced from 102.15 kVAr to 10.38 kVAr.

The results are compared with the result of latest optimization techniques in Table 2. It has been observed that the proposed approach gives maximum loss reduction as compared to other techniques.

Table 2. Comparison of results of 69 bus systems after DGs allocation

Item	**PSO [16] (2013)**	**IMDE [17] (2016)**	**Proposed**
Total DG size in kW	1820	2217	**1810**
Total Capacitor size in kVAr	1300	1301	**1280**
Total Real Power Loss	23.17	13.83	**11.74**
% Loss Reduction	89.70%	93.85%	**94.12%**
Min. Voltage	0.98	0.99	**0.99**

The comparison of bus voltage profile is presented in Figure 2. In the comparison, four cases are considered, i.e., base case, after DG allocation only, after capacitor allocation only and after simultaneous allocation of DG & capacitor. As it can be depicted from the figure that the minimum voltage is 0.9092 at bus number 67 for base case. After placing DG, capacitor and combination of both it leads to improvement of voltage profile. It can be seen that minimum voltage profile is 0.931 pu at bus number 67 (in case of capacitor placement), 0.970 pu at bus number 67 (in the case of DG placement) and 0.99 pu at bus no. 28 (in the case of capacitor and DG placement both).

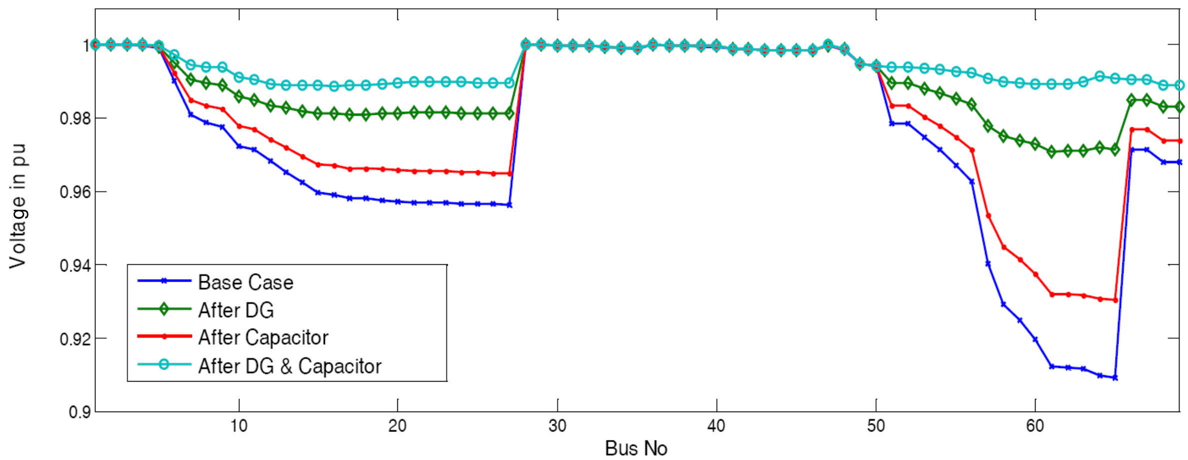

Figure 2. Bus voltage profile of 69 bus systems for Case-I, II & III

5. **Conclusion.** In the paper a new approach has been proposed in order to minimize active power loss of radial distribution system by maintaining several operating conditions. The objective has been achieved by allocation of DG units (type-I and II). A new analytical technique has been proposed to solve optimal DG placement problem. A new mathematical formulation, Power Voltage Sensitivity Constant (PVSC), has been proposed for determining candidate bus location and size. The level of DG penetration is also considered in a range of 0-50% of total system load. To examine the performance of the proposed approach, it has been tested on standard IEEE 69 bus distribution systems. The results are compared with the latest optimization techniques. The result obtained shows that the proposed approach yields maximum loss reduction percentage, while optimizing the size constraint of DGs. The state electricity boards are motivated to install

renewable base DG units after reviewing the results. The proposed approach can be easily implemented on large scale distribution system and real distribution system also.

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