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An Analytical Approach for DG Placement in Reconfigured Distribution Networks

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ABSTRACT

A novel approach is proposed in this paper for optimal placement of DG units in reconfigured distribution system with the aim of reduction of real power losses while satisfying operating constraints. The proposed analytical method for optimal DG placement is developed based on a new mathematical formulation. Type-I and type-II DG units are used here. The results of the proposed technique are validated on IEEE 69 bus distribution system. The level of DG penetration is also considered in a range of 0–50% of total system load. A novel index is also proposed which incorporates level of DG penetration and percentage reduction in real power losses. The results are promising when compared with recently proposed algorithms.

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1. INTRODUCTION

Now days, electrical power generation systems in all parts of the world are shifting from big centralized power plants to small distributed power generation sources located near the load, which is generally known as distributed generation (DG). DG technology is the concept of generation of electrical power by connecting small generation units (1 kW to 50MW) to the distribution system. Distributed generation (DG) devices can be deliberately sited to reduce real or reactive power losses, to enhance bus voltage profile, to improve load factors, reliability and efficiency in power systems. The DG units may be both renewable (PV solar, wind, geothermal, mini-hydro, biomass, etc.) and nonrenewable (fuel cell, gas turbines, etc.) energy sources. The renewable based distributed generation units become a leading choice due to limitation of fossils fuels in power systems. To optimize the benefits of DGs, it is essential to find out the optimum size and location of DG; otherwise, it could give adverse effects like increased line losses and degraded voltage profile. To solve the problem, distributed generation (DG) placement is continuously being considered by researches. Various researchers applied different approaches and optimizing various objective functions. Such optimization methods can be classified into deterministic methods such as analytical methods and heuristic methods (like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC) etc.) or into single- and multi-objective, based on the number of objectives. To solve the problem of distributed generation placement is continuously being considered by researches. The various researchers have applied different approaches to optimize various objective functions. Wang and Nehrir [1] reported an analytical technique to place DG units at optimum location in radial and meshed distribution system. Acharya et al. [2] solve DG placement problem by analytical method in radial distribution system. Gozel and Hocaoglu [3] also used analytical approach to solve the DG placement problem in a quicker way. They did not use admittance, impedance & Jacobian matrices. The approach was only suitable for radial

systems. In [4,5], the optimal size and location is determined by using Genetic algorithm (GA) based method. Moradi M.H. [6] combined GA and PSO technique to determine the optimal size and location of DG units. Optimal location is determined by GA technique and size of DG units is calculated by PSO technique. Soo-Hyoung et. al. [7] proposed classical Kalman Filter algorithm to calculate DG size and location. In [8], author presented Tabu Search (TS) technique to solve the problem of optimal DG allocation. Borges et.al [9] presented Genetic Algorithm (GA) technique to solve allocation of DG placement problem in distribution systems. Abu-Mouti ET. al. [10] determined the size and location of DG and shunt capacitors by using artificial bee colony algorithm. In [11] a modified voltage index method is proposed to solve the DG sizing and siting problem. Authors improved the voltage stability margin, without violating system operating constraints. In [12] a Meta heuristic Harmony Search Algorithm (HSA) is used to find out locations and size of DG units in a distribution system. *Seyed Abbas Taher et.al.* [13] Formulated a multi objective function to reduce line losses by using the feeder reconfiguration in the presence of DG units. Author proposed GA method to solve the problem. Sayyid Mohssen Sajjadi et.al. [14] Presented Memetic algorithm to determine the size and location of DGs and capacitors in radial distribution system. Su Hlaing Win [15] used exact loss formula method to determine optimal DG size and its location. Author tested his approach on 36-bus distribution system in Belin Substation in Myanmar. Mohammad Sedaghat et.al. [16] Proposed biogeography-based optimization (BBO) algorithm for optimal placement and sizing of DG units in the distribution system. The results were promising when compared with recently proposed algorithm.
The various types of DG units are [17]:

Type-I: Generate real power (e.g. Solar cell etc.)

Type-II: Generate reactive power (e.g. Shunt capacitor etc.)

Type-III: Generate both real and reactive power (e.g. synchronous machine)

Type-IV: Generate real power but consuming reactive power (e.g. induction generators used in wind farms)

The researchers proposed various model to solve allocation of DG units problem. Authors did not consider any DG penetration level. In many practical cases along with economic constraints the size of DG (type-I) units are not pragmatic. The high size of DG units gives high cost of the system. This paper presents an analytical technique to solve DG allocation problem by considering DG penetration level. The level of DG penetration (only type-I) is considered in a range of 0-50%. The DG type-I and type-II are considered here. A new mathematical expression is formulated for minimizing the line losses in radial distribution system. In this paper a novel index, DG penetration index (DGPI) is also proposed. The proposed approach is experimented on IEEE 69-bus distribution network and obtained results are discussed.

The rest of the paper is organized as follows: section 2 gives the description of problem formulation. Section 3: gives the solution methodology for 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 FORMULATION

The aim of the paper is the reduction in active power loss of radial distribution system to its minimum value. This is achieved by installing the DG units of appropriate size at optimal location. Figure 1 shows the single diagram of DG connected distribution network. The operating constraints are divided into two parts (equality and inequality constraints).

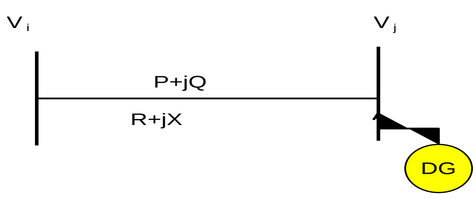

Figure 1. DG connected radial distribution network of i–j bus

Mathematically, the DG placement problem can be formulated as a constrained nonlinear optimization model [18]:

$$\textit{Minimize}\ (P_{Loss}) \qquad (1)$$

Subjected to:

g1(x, z) =0
g2(x, z) ≤ 0

g1(x,z) and g2(x,z) are 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 voltage of buses and line power flows.

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

(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 units is restricted by its maximum and minimum limits as,

$$P_{DGj}^{min} \leq P_{DGj} \leq P_{DGj}^{max}$$

$$Q_{DGj}^{min} \leq Q_{DGj} \leq Q_{DGj}^{max}$$

(ii) Bus voltage limits $0.95\ pu \leq V_i \leq 1.0\ pu$

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

Where,

R : Line resistance between bus i and j;
X : Line reactance between bus i and j
Z : Line impedance;
V_i : Magnitude of voltage at bus i ;
V_j: Magnitude of voltage at bus j;
δ_i: Angle of voltage at bus i;
δ_j: Angle of voltage at bus j ;
P and Q: Real and reactive power flow from bus i to j;

3. PROPOSED METHODOLOGY

3.1. Analytical Approach

An analytical approach has been proposed for DG placement problem here. The Power Voltage Sensitivity Constant (PVSC) is proposed to determine the size and location of DG units. This constant takes active power loss and voltage limits of individual buses in account and suggest the optimal location of the DG.

$$PVSC = \frac{V_{max}}{V_{min}} + \frac{Pdgloss}{Prealloss}) \quad (4)$$

Where,
$P_{realloss}$: base case real power loss.
P_{dgloss} : active power loss after DG placement at i^{th} bus.
V_{max} is maximum bus voltage in pu after DG placement at i^{th} bus.
V_{min} is minimum bus voltage in pu after DG placement at i^{th} bus.
For optimal placement of DG units the value of PVSC should be minimum. Computational process for proposed analytical technique is explained below:
Step 1: Run the base case load flow program and calculate real power loss $P_{realloss}$.
Step 2: Set any DG penetration level and run load flow program.
Step 3: Calculate the real power loss of the system and "PVSC" values for each bus using eq. 4.
Step 4: Now vary the penetration of DG in minute step and compute real power loss by running load flow program.

Step 5: Store the size of DGs which gives least amount of real power loss.
Step 6: The bus, which has least "PVSC" value, will be the optimal location of DG unit.
Step 7: Repeat Steps 4 to 6 to find more location of DGs.

3.2. DG penetration Index (DGPI)

Most of the researchers did not consider DG penetration in their research. In many practical cases along with economic constraints the size of DG (type-I) units are not pragmatic. In their paper the size of DG unit is very high. But the high size of DG unit will lead to high cost of the system.

In this paper a novel index, called DG penetration index, is proposed. The DGPI gives the % power loss reduction for unit size of DG.

$$\text{DGPI} = \frac{(\%\ \text{power loss reduction})}{\text{Total type}-\text{I DG size}} \tag{5}$$

Hence, for improvement of network performance the value of the DGPI should be maximum.

4. TEST RESULTS AND DISCUSSION

4.1. Test Results

The proposed analytical method has been tested on IEEE 69 bus system. The proposed method is implemented using MATLAB 10 software. Four cases are considered here:

Case I: Base Case
Case II: Only type-I DG placement
Case III: Only type-II DG placement
Case IV: Simultaneous placement of DG type-I and type-II

Case I: Base Case

The IEEE 69 bus system has 12.66 kV and 100 MVA base values. It consists of 68 sectionalizing switches (normally closed) and 5 tie switches (normally open) [18]. The open switches are 69,70,71,72,73 respectively. The total system load is 3.802 MW and 2.694 MVAr. The base case real power loss and minimum bus voltage are 225 kW and 0.9092 pu. The results of reconfigured system are used from [19]. Table 1 shows the results of reconfigured system:

Table 1. Results of IEEE 69 bus reconfigured system [17]

Tie Switch	Real Power Loss in kW	Minimum Bus voltage in pu	% loss reduction from base case
69,18,13,56,61	99.35	0.9428	55.85%

Case II: Only type-I DG p*lacement*

The proposed analytical method is used to find optimal location and size of type-I DG units for 69 bus system. The level of DG (type-I) penetration is considered in a range of 0–50% of total load of this system.

Table 2. Results of 69 bus system for case II

DG size (bus no.) in kW	Total DG size in kW	Power Loss (kW)	Minimum bus Voltage (p.u.)	% loss reduction (from base case)
1330 (61) 310 (64) 210 (27)	1850	38	0.98	83 %

The obtained results for 69 bus system are organized in Table 2. DGs are connected to the nodes 27, 61 and 64 of total 1850 kW size, which reduces the real power loss to 38 KW. The % loss reduction is 83 % as compared with base case. The minimum bus voltage is also enhanced to 0.98 pu.

Case III: Only type-II DG placement

The proposed method is also used to determine the optimal size and location of capacitors (type-II DG) for 69 bus radial distribution system. The size of capacitors, their positions and the impact of optimal placement of capacitors on the real power loss and voltage profile are given in Table 3.

Table 3: Results of 69 bus systems for case III

Capacitor size (bus no.) in kVAR	Total Capacitor size in kVAR	Power Loss (kW)	Minimum bus Voltage (p.u.)	% loss reduction (from base case)
350 (50) 1050 (61) 390 (64)	1790	66.74	0.97	70.3 %

Case IV: Simultaneous placement of DG type-I and type-II

The enhancement in the system performance after optimal placement of DG and capacitor units is shown in table 4. The table shows the results of power loss, minimum bus voltage and percentage power loss reduction achieved for 69 bus system using proposed analytical method. It is observed that simultaneous placement of DG and capacitor in reconfigured distribution system leads the percentage power loss reduction to 95.72%. The minimum bus voltage is also enhanced from 0.90 pu to 0.99 pu.

Table 4: Summary of results of 69 bus system for case IV

Total DG size in kW	Total Capacitor size in kVAR	Real Power Loss in kW	Minimum bus Voltage (p.u.)	% loss reduction (from base case)
1850	1790	9.63	0.99	95.72 %

4.2. Comparison of Results

Now the results of proposed approach are compared with latest optimization techniques. From table 5, it is concluded that in [20] value of DG penetration is very high; in many practical cases along with economic constraints these results are not pragmatic. However, in our case these values are low, which advocates the suitability of the proposed approach in a real power system.

Table 5: Comparison of Results for 69 bus system

Technique	Total Capacitor size in kVAR	Total DG size in kW	%loss reduction	Min. bus Voltage (pu)	DGPI
IGA [20]	1800	2409	98.04	0.99	0.040
IPSO [20]	1800	2550	98.17	0.99	0.038
ICSO [20]	1800	2689	98.07	0.99	0.036
Proposed	*1790*	*1850*	*95.72*	*0.99*	*0.051*

From the table 5, it is observed that the proposed method give more % loss reduction for unit size of DG (Type-I). But in the recently proposed technique (IGA, IPSO, ICSO) [20] the value of DGPI is less, this gives the high cost and size of DG.

5. CONCLUSION

In this paper, the optimal allocation of two types of DG units in reconfigured distribution system is modeled. An analytical technique has been proposed to solve the DG (type-I and type-II) placement problem. A new mathematical expression is formulated. The effectiveness of proposed approach has been experienced on standard 69-bus radial distribution network. The level of DG (type-I) penetration is considered in a range of 0–50% of total load of this system. A novel index, DG penetration Index (DGPI), has been also proposed to incorporate the level of DG penetration and % loss reduction. The obtained results shown that the proposed approach gives more % power loss reduction in less DG size. It gives economical benefits to the distribution network.

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