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A New Method for Placement of DG Units in Radial Distribution Networks

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Abstract
Distributed Generation (DG) can help in reducing the cost of electricity to the costumer, relieve network congestion and provide environmentally friendly energy close to load centers. Its capacity is also scalable and it provides voltage support at distribution level. Hence, DG placement and penetration level is an important problem for both the utility and DG owner. The Optimal Power Flow (OPF) has been widely used for both the operation and planning of a power system. The OPF is also suited for deregulated environment. Four different objective functions are considered in this study: (1) Improvement voltage profile (2) minimization of active and reactive power. The site and size of DG units are assumed as design variables. The results are discussed and compared with those of traditional distribution planning and also with Partial Swarm Optimization (PSO).

Key words: Distributed generation, distribution network planning, multi-objective optimization, Partial Swarm Optimization.

I. Introduction

The Distributed generations (DGs) are small-scale power generation technologies of low voltage type that provide electrical power at a site closer to consumption centers than central station generation. It has many names like Distributed energy resources (DER), onsite generation, and decentralized energy. DGs are from renewable and artificial models. DGs are the energy resources which contain Renewable Energy Resources such as Wind, Solar and Fuel cell and some artificial models like Micro turbines, Gas turbines, Diesel engines, Sterling engines, Internal combustion reciprocating engines[1]. In the present vast load growing electrical system, usage of DG have more advantages like reduction of transmission and distribution cost, electricity price, saving of the fuel, reduction of sound pollution and green house gases. Other benefits include line loss reduction, peak shaving, and better voltage profile, power quality improvement, reliving of transmission and distribution congestion then improved network capacity, protection selectivity, network robustness, and islanding operations [2-3]. The impact of DG on power losses is not only affected by DG location but also depends on the network topology as well as on DG size and type [1].

Distributed Generation (DG) can help in reducing the cost of electricity to the costumer, relieve network congestion and provide environmentally friendly energy close to load centers. Its capacity is also scalable and it provides voltage support at distribution level. The placement and size of the DG should be optimal in order to maximize the benefits of it[4]. For optimal placement of the DG in Distribution system, evolutionary methods have been used, as they can allow continuous and discrete variables [5-6]. Many analytical approaches [7-9] are available for optimal DG, but they cannot be directly applied, because of the size, complexity and the specific characteristics of distributed systems [1]. In [7, 8, 10-12] the optimal placement and size of single DG was considered and in[9,13-15] optimal placement and size for multi DGs were determined. In all these papers the bus available limit is not considered for placement of DG. The main objective of this paper is to optimize the power system modeled multi DGs location and size, while minimizing system real, reactive losses and to improve voltage profile and line loading and reliability by considering the bus available limit of the units DGs.

II. Optimal DG allocation

Real and Reactive Loss Indices (ILP and ILQ)

The active and reactive losses are greatly depending on the proper location and size of the DGs. The indices are defined as

$$ILP = \left(\frac{TP_{loss}^{wit\,hDG}}{TP_{loss}^{wit\,houtDG}}\right)$$

$$ILQ = \left(\frac{TQ_{loss}^{wit\,hDG}}{TQ_{loss}^{wit\,houtDG}}\right)$$

Where, $TP_{loss}^{wit\,hDG}$ and $TQ_{loss}^{wit\,hDG}$ are the real and reactive power losses of the distribution system with DG. $TP_{loss}^{wit\,houtDG}$ and $TQ_{loss}^{wit\,houtDG}$ are the real and reactive power losses of the system without DG.

Voltage Profile Index (IVD)

The voltage profile of the system is depending on the proper location and size of the DGs. The IVD is defined as

$$IVD = max_{i=2}^{n}\left(\frac{|V_1| - |V_i|}{|V_1|}\right)$$

Where n is the number of busses in system. V_1 is the substation bus voltage (reference voltage). V_i is the i th bus voltage.

III. Objective Function

The main objective of this paper is to study the effect of placing and sizing the DG in all system indices given previously. Also observe the study with renewable bus avail-able limits. Multi objective optimization is formed by combining the all indices with appropriate weights. The multi objective function is defined as

$$Objective\ Function = (w1 * ILP + w2 * ILQ + w3 * IVD)$$

In this paper the weight are considered as W1=0.4, W2=0.2, W3=0.25 fallowing the constraint

$$\sum_{k=1}^{3} w_k = 1 \qquad w_k \in [0,1]$$

The weights are indicated to give the corresponding importance to each impact indices for the penetration of DGs and depend on the required analysis. In this analysis, active power losses have higher weight (0.4), since the main importance is given to active power with integration of DG. The least weight is given to the IVD, since the IVD is normally small and within permissible limits. Equality constraint is

$$p_{gs} + \sum_{DG=1}^{m} P_{DG} = p_{load} + p_{loss}$$

In equality constraint is

$$V_{imin} \leq V_i \leq V_{imax}$$

IV. Power Flow Analysis Method

The methods proposed for solving distribution power flow analysis can be classified into three categories: Direct methods, Backward-Forward sweep methods and Newton-Raphson (NR) methods. The Backward-Forward Sweep method is an iterative means to solving the load flow equations of radial distribution systems which has two steps. The Backward sweep, which updates currents using Kirchhoff's Current Law (KCL), and the Forward sweep, which updates voltage using voltage drop calculations [12].

The Backward Sweep calculates the current injected into each branch as a function of the end node voltages. It performs a current summation while updating voltages. Bus voltages at the end nodes are initialized for the first iteration. Starting at the end buses, each branch is traversed toward the source bus updating the voltage and calculating the current injected into each bus. These calculated currents are stored and used in the subsequent Forward Sweep calculations. The calculated source voltage is used for mismatch calculation as the termination criteria by comparing it to the specified source voltage. The Forward Sweep calculates node voltages as a function of the currents injected into each bus. The Forward Sweep is a voltage drop calculation with the constraint that the source voltage used is the specified nominal voltage at the beginning of each forward sweep. The voltage is calculated at each bus, beginning at the source bus and traversing out to the end buses using the currents calculated in previous the Backward Sweep [20].

V. DG Modeled as PQ Node

A DG unit can be modeled as three different ways in PQ node mode as illustrated below:

- DG as a 'Negative PQ Load' Model of PQ Mode

In this case the DG is simply modeled as a constant active (P) and reactive (Q) power generating source. The specified values of this DG model are real (PDG) and reactive (QDG) power output of the DG. It may me noted that Fuel cell type DGs can be modeled as negative PQ load model. The load at bus-i with DG unit is to be modified

$$P_{load,i} = P_{load,i} - P_{DG,i}$$
$$Q_{load,i} = Q_{load,i} - Q_{DG,i}$$

- DG as a 'Constant Power Factor' Model of PQ Mode

The DG is commonly modeled as constant power factor model [16,20]. Controllable DGs such as synchronous generator based DGs and power electronic based units are preferably modeled as constant power factor model. For example, the output power can be adjusted by controlling the exciting current and trigger angles for synchronous generator based DGs and power electronic based DGs, respectively [16]. For this model, the specified values are the real power and power factor of the DG. The reactive power of the DG can be calculated and then the equivalent current injection can be obtained by

$$Q_{DG} = P_{i,DG} \times \tan(\cos^{-1}(PF_{i,DG}))$$

$$I_{iDG} = I_{iDG}^{'}(V_{iDG}) + jI_{iDG}^{'}(V_{iDG}) = \left(\frac{(P_{iDG} + Q_{iDG})}{V_{iDG}}\right)^{*}$$

- DG as 'Variable Reactive Power' Model of PQ Mode

DGs employing Induction Generators as the power con-version devices will act mostly like variable Reactive Power generators. By using the Induction Generator based Wind Turbine as an example, the real power output can be calculated by Wind Turbine power curve. Then, its reactive power output can be formulated as a function comprising the real power output, bus voltage, generator impedance and so on. However, the reactive power calculation using this approach is cumbersome and difficult to calculate efficiently. From a steady-state view point, reactive power consumed by a Wind Turbine can be represented as a function of its Real Power [17], that is

$$Q_{iDG}^{'} = -Q_0 - Q_1 P_{iDG} - Q_2 P_{iDG}^2$$

Where $Q_{iDG}^{'}$ is the Reactive Power function consumed by the Wind Turbine. The Q_0, Q_1 and Q_2 are usually obtained experimentally. The reactive power consumed by the load cannot be fully provided by the distribution system, and therefore capacitor banks are installed for power factor correction where induction generator based DGs are employed.

VI. Method

1. Produce an initial population *P* and create the empty external non-dominated set *Q*.
2. Paste non-dominated members of *P* into *Q*.
3. Remove all the solutions within *Q*, which are covered by any other members of *Q*. If the number of externally stored non-dominated solutions exceeds a given maximum *N'*, prune *Q* by means of clustering.
4. Calculate the fitness of all individuals in *P* and *Q*.
5. Use binary tournament selection with replacement and select the individuals from *P* and *Q* until the mating pool is filled.
6. Apply crossover and mutation operators as usual.
7. If the maximum number of generations is reached, then stop, else go to step 2.

VII. Particle swarm optimization (PSO)

In the present paper, as mentioned, particle swarm optimization algorithm is the second EA which is used to solve the DG allocation problem. Its key concept is that potential solutions are flown through hyperspace and are accelerated towards better or more optimum solutions. It lies somewhere on between evolutionary programming and the genetic algorithms. Some of the features of PSO are adaptability, diverse response, proximity, quality, and stability (Clerk and Kennedy, 2002). There are three versions of PSO: real, binary and discrete codifications. As the decision variables of the present problem are of discrete type, hence, Discrete Particle Swarm Optimization (DPSO) method is used in this paper.

1. Tests and Results

Simulations are carried out on 69-bus radial distribution network using PSO approaches in order to show the accuracy as well as the efficiency of the proposed solution technique. The single line diagram for proposed radial distribution systems is shown in Fig. 1. Length of all branches is considered to be equal to 60m. The properties of the three conductors used in the analysis of this system are given in Table 1.

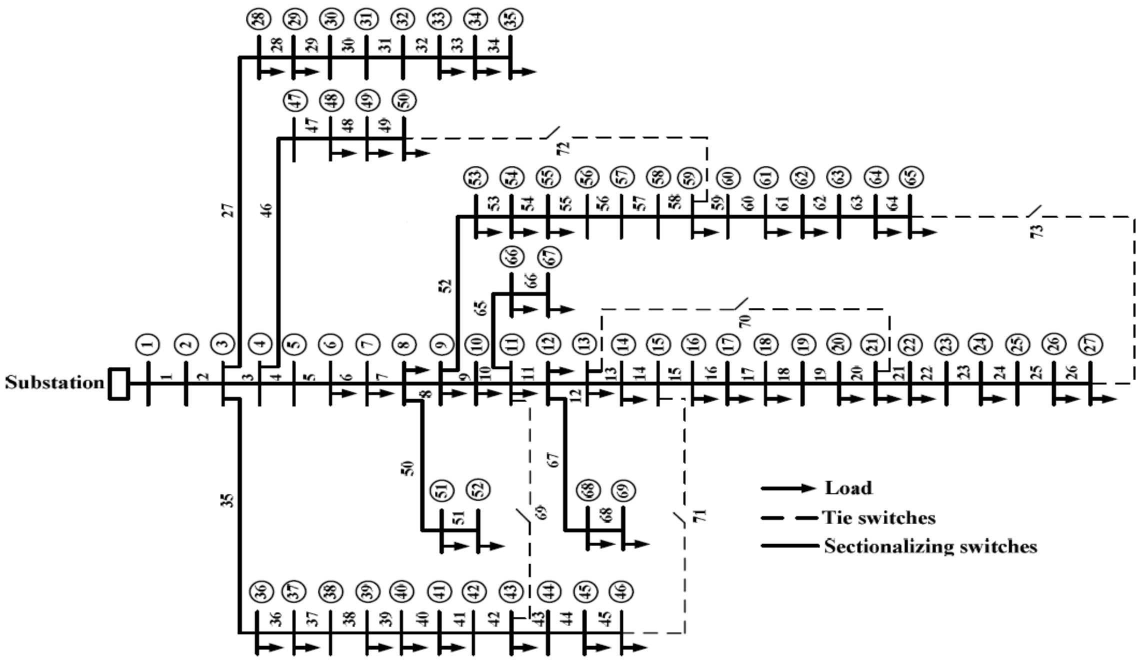

Fig 1. Single line diagram for a 69-bus radial distribution system

Table 1: Conductor properties

Type	R [Ω/km]	X [Ω/km]	Cmax [A]	A [mm2]	Cost [Toman/m]
Hyena	0.1576	0.2277	550	126	2075
Dog	0.2712	0.2464	440	120	3500
Mink	0.4545	0.2664	315	70	2075

The Table 2 shows the methods which are compared, location (bus number), DG capacity, and real power loss in fig 4 shows which are basic columns. After installing DG, the voltage level for that bus is improved. Furthermore, the voltage levels at all nodes for RDS have improved. The voltage profile is given in Fig. 5. It can be seen that the voltage profile achieved by PSO optimization algorithms are almost the same while having better improvement in compare with no DG state.

Table 2: Optimal Place and Size of the DG in 69 Bus systems using Genetic Algorithm

Bus Location	Capacity [MW]
3	0.47
17	1.035
26	1.52
33	0.345
49	0.5
64	1.5

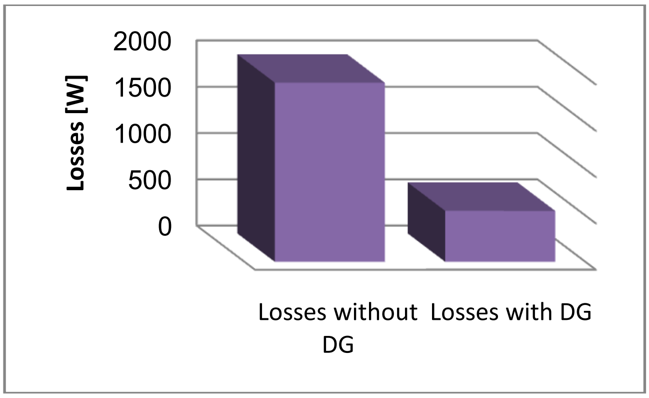

Fig 4. Bar Losses profile with & without DG in 69 bus system

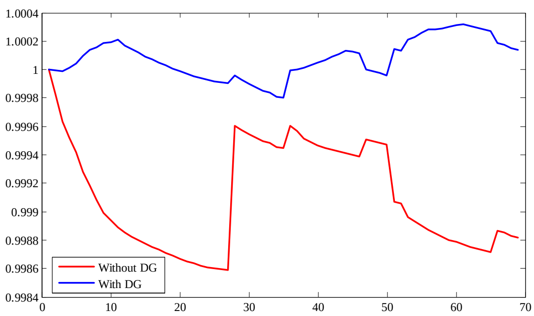

Fig 5. Voltage profile with and without DGs in 69 bus system using PSO

VIII. Conclusion

The optimization location of distribution generation in distribution must meet some objective functions in order to enhance the quality of network. The placement and capacity of the DGs in a 69 bus distribution system was presented. The objective function, which contains the different objectives combined with weights, is optimized with and without considering the DG available bus limit constraints. The different impact indices, losses and voltages profile at all busses are studied at all cases.

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