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Hybrid optimization implemented for distributed generation parameters in a power system network

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ABSTRACT

This paper presents a novel hybrid optimization algorithm for optimizing the Distributed Generation (DG) parameters in deregulated power system which improves the stability, reduces the losses and also increases the cost of generation. This Hybrid algorithm which includes Fuzzy-Genetic Algorithm (FGA) is used to optimize the various DG parameters simultaneously. The various parameters taken into consideration are their type, location and size of the DG devices. The simulation was performed on a distribution system and modeled for steady state studies. The optimization results are compared to the solution given by another search method like Genetic Algorithm (GA) and Micro Genetic Algorithm (MGA). The results reveal the benefits of the proposed method, for solving simultaneous combinorial problems of DG devices in a power system network.

Introduction

DG means a small-scale power station for the need of satisfying local load different from a traditional or large Central power plant [1]. Right from traditional to non traditional, there are various methodologies used in the application of DG. The DG introductions have technical merits in fuel cells, photovoltaic, biomass, wind, geothermal and gas turbine. It includes voltage profile improvement, loss reduction and improves system reliability.

In a highly congested area the benefit of DG is more predominant [2]. The location of DG should be carried out considering its size and location. The placement should be optimal in order, for maximum customer benefit and minimum congestion of DG implemented in the network. The improper placement will lead to reduction in system losses and sometimes it may even collapse the entire system.

The two broad paradigms for maximizing welfare is cost free and non cost free methods. The marginal cost involved is nominal (not capital cost) in the former method. The later method includes generation rescheduling and prioritization and curtailment of loads/Transactions.

Numerous techniques are proposed so far to address the benefits of DGs in power system. In [3] short term the wind power forecasting is proposed by clustering based bad data detection module and a neural network based forecasting module. This paper deals the maximum amount of wind energy which can be utilized in power sectors. The location of DG placement on the basis of Location Marginal Pricing (LMP) is proposed in [4]. The investment planning strategy of DG devices for reducing the reactive power losses by switching of shunt capacitors is given in [5]. Mithulananthan has used simple and efficient method for placement of DG devices to reduce the losses [6]. Celli has used a penetration level assessment for the placement of DG [7]. Moghadass has modeled different DG units based on power flow studies by using backward/forward algorithm [8]. Zareipour has given current status and challenges in Distributed generation [9]. The author [10] suggests heuristic rules and fuzzy multiobjective approach for optimizing power system network configuration. In the analytical study [11], for various distributed load profiles optimal place of the DGs are determined centrally in radial systems to minimize the total losses. Modeling of distributed generations in a three phase distributed load flow and modeling of wind farms is derived in [12]. GA based optimization technique (which can give near optimal results), suitable for multi-objective problems like DG allocation with optimal power flow (OPF) calculations has been used by [13]. The planning of DG with the reliability index is proposed in [14]. Optimal location and sizing of DG parameters are

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simulated in IEEE system using GA, MGA and Simulated Annealing (SA) in [15–17]. It proves the promising way of placement of DG at the right location using appropriate technology which will solve problems faced in power systems.

The objective of this paper is to develop an algorithm for finding and choosing the optimal location of DG devices, for power loss reduction, which relieves congestion and customer benefit maximization, based on various test cases such as Generation rescheduling, load curtailment and with generation rescheduling with load curtailment with DG devices. Placing the DG devices at the right location is justified using modified IEEE distribution system and in real time India utility system. For the proposed objective function all cases are tested by simultaneous optimization of location, type and size using FGA algorithm which gives faster convergence and can also handle complex optimization problem.

Rest of the paper is organized as follows: mathematical expressions for finding optimal sizes and location are discussed in section 'Mathematical modeling of DG devices'. Section 'Objectives of distributed generation planning' represents the objectives of distributed generation planning with problem formulation. Section 'Hybrid method for optimal placement and sizing of DG' presents Hybrid method implementation for optimal sizing of DG and Section 'Simulation results' gives simulation studies and numerical results obtained. Finally, the major contributions and conclusions are summarized in Section 'Conclusion'.

Mathematical modeling of DG devices

DG devices

The DG size is very important for placing it in a particular bus as the losses decrease to a minimum value and start increasing above the size of DG (i.e. the optimal DG size) at that location [18]. The increase in size leads to maximize the losses value and it may overshoot the values of the losses in the base case. The proper location of DG plays an important role in minimizing the losses, maximizing the customer benefit and minimizing the voltage deviation index. The modeling of DG is very important to achieve the objective.

The Unity power factor modeling is done in PV cell, wind as a variable reactive model and gas turbine is modeled as a constant voltage model. A DG source has a constraint and it can be formulated as

$$P_G^{\min} \leqslant P_G \leqslant P_G^{\max}$$

Considering the output with reactive power of the DG, as it plays a major role, the bus connected to the DG can be modeled in three major cases [19] based on their characteristics in terms of real and reactive power delivering capability as follows:

(1) Type 1: DG which injects Real Power only.
(2) Type 2: DG which injects Reactive power only.
(3) Type 3: DG injecting Real Power but consuming Reactive Power Q.

The primary energy of DG may be injected to grid by a synchronous or asynchronous electric machine which is directly connected to the grid or by means of power electronic interface or a combination of electric machine and power electronic interface. The modeling of different DGs is done as follows:

In general Distributed generation is considered as an electric power source connected directly to the distribution system [20].

Modeling of PV cell

The PV system converts solar energy into electrical energy. The DC power output is converted via an inverter into AC power so that it is compatible with the grid. The DG model depends on control circuit and in general it is designed to control P and V independently which is modeled as a PV node [21]. When P and Q are controlled independently it is modeled as a PQ node.

The power factor is unity and the necessary condition for minimum loss is given by Eq. (2).

$$P_i = P_{\mathrm{DGi}} - P_{\mathrm{Di}} = \frac{1}{A_{ij}} \sum_{\substack{j \neq 1 \\ j \neq i}}^{n} [(A_{ij})P_j - B_{ij}Q_j) \tag{1}$$

From the above equation we obtain the following relationship

$$P_{\mathrm{DGi}} = P_{\mathrm{Di}} - \frac{1}{A_{ij}} \sum_{\substack{j \neq 1 \\ j \neq i}}^{n} [(A_{ij})P_j - B_{ij}Q_j) \tag{2}$$

A_{ij} and B_{ij} = loss coefficients.
P_j = real power injected to bus j.
Q_j = reactive power injected to bus j.
N = number of buses.

Synchronous condensers such as gas turbines

Gas Turbines convert the potential energy saved in fossil fuels from chemical to heat and then heat to mechanical. Synchronous generator is rotated which is directly connected to the grid.

Synchronous condenser DG provides only reactive power to improve voltage profile. To determine the optimal DG placement, the loss equation has to be differentiated on either side with respect to Q_i. The power factor for type 2 will be zero and the optimal DG size for every bus in the system is given by Eq. (3)

$$Q_{\mathrm{DGi}} = Q_{\mathrm{Di}} - \frac{1}{A_{ij}} \sum_{\substack{j \neq 1 \\ j \neq i}}^{n} [(A_{ij})Q_j - B_{ij}P_j) \tag{3}$$

Modeling of wind turbine

The AC output power of these units is converted by a power electronic based rectifier and an inverter to grid compatible AC power. In an induction generator both active and reactive powers are functions of slip.

$$\begin{aligned} P &= P(V, s) \\ Q &= Q(V, s) \end{aligned} \tag{4}$$

where P and Q are the active and reactive produced, the induction generator slip is denoted by 's' and the bus voltage is 'V'. Assuming the dependency of Q is very low and P is constant the expression (5) can be reduced as follows:

$$\begin{aligned} P &= P_s = \text{constant} \\ Q &= f(V) \\ Q &= \sqrt{(E_q|X_d)} - P^2 - \frac{V^2}{X_d} \end{aligned} \tag{5}$$

No load voltage E_q is maintained constant and X_d is the synchronous reactance and V is the generator terminal voltage. The parameters of wind turbine include cut-in wind speed and rated wind speed and typical values of them are 3.5 m/s, 25 m/s and 14 m/s.

$$P_{\mathrm{wind}}(t) = 0.5\alpha\rho(t)A\nu(t)^2 \tag{6}$$

where α is the Albert Betz constant, $\rho(t)$ is air density, A is area swept by turbine rotor, and $\nu(t)$ is the wind speed. Maximum power rating of wind station is fixed by taking averages of all day powers calculated by using the equation. For this type of DG the power factor varies between 0 and 1. The maximum DG capacity for renewable DGs like Solar and Wind is calculated from the average