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Optimal wind turbine sizing to minimize energy loss

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ABSTRACT

The integration of renewable distributed generation (DG) in power systems has been increasing day by day. One of the most promising DG technologies is wind turbine among the renewable sources. Therefore, the optimization of DG whose the output power is varying with time is very crucial for the future power systems. However, it is difficult to establish a suitable objective function by taking into account of time varying characteristics. In this paper, a methodology based on weighting factors is proposed in order to minimize energy loss by finding the optimal sizes of wind turbines. The optimization is carried out by using the genetic algorithm with utilizing power flow analysis. The contribution of this paper is to allow considering the time varying characteristics of both load and wind-generation profile in a pairwise manner without violating the harmony of correspondence between load and generation profile. In addition, the proposed methodology is merged with the fuzzy-c means clustering to reduce execution time and allow long term planning due to the fact that the computational burden of the genetic algorithm is substantially high. The proposed methodology is applied to the IEEE-30 bus test system for 4 days and annual energy loss minimization scenarios. The results show that energy loss can be reduced significantly by using the proposed methodology.

1. Introduction

Distributed generation (DG) concept has been emerged as a promising solution to meet the increasing power demand in power systems. One of the most promising DG technologies is wind turbine (WT) among the renewable resources owing to the environmental friendly characteristics. Developing technologies make WTs more viable in power system. Integration of wind-based DG into the power systems offers a number of technical, environmental, and economical advantages [1]. To make these advantages available in terms of power system operation, optimal sizing and allocations of DGs has become an essential issue for power system planners [2]. Reducing line loss is one of the most important planning issues because of the regulatory policies, so that power system operators can be penalized or stimulated according to threshold level of the predefined line loss [3]. For this reason, non-optimal allocations of DGs can result in increasing line loss and thus increasing penalization cost for system operators. For this reason, there are many efforts to develop new and simple methodologies in order to minimize line loss. In addition, annual load and generation profiles should be considered as a whole instead of an instant in profiles while looking for optimum size of DGs.

The line loss studies have generally focused on the power loss minimization [4–11]. It means that losses are investigated for a single load and generation case. Analytical methods have constituted the center of proposed methodologies due to their non-iterative and less time-consuming approaches [4,5]. These approaches are available to find the location and size of only a single DG unit. On the other hand, the integrations of multiple DGs have nonlinear impacts on power system operation [6,7]. Therefore, different techniques have been developed for the problem of multiple DGs' integrations [8]. Nevertheless, it is very difficult to find an analytical equation to be used in the optimization of multiple DGs problem. Hence, search based optimization tools such as genetic algorithm (GA), particle swarm optimization, artificial bee colony, and ant colony have been widely used [9–11]. A bee colony method is developed to minimize power loss by determining the size, location, and power factor of DGs [9]. Another study proposes a hybrid method to minimize power loss and it is assumed that the power factors of DGs are unity [10]. In [11], optimal placement of multiple-DG units including different load models is investigated by using particle swarm optimization. Different assumptions, objective functions, and constraints in these studies result in different contributions into the literature.

The power loss minimization is useful if the firm DG generations are considered in the planning phase. Nevertheless, most of the DGs are based on the renewable resources which are highly dependent on the weather conditions, so their output powers are time-varying. To include time-varying characteristics

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of both load and wind generation profiles, planning criteria should be energy loss instead of power loss due to the uncontrolled power output. The total penetration level of DGs has a great impact on energy loss [12]. Thus, energy loss should be considered in planning of DGs' integrations. There are some studies on the energy loss optimization by considering time-varying characteristics of DGs and loads [13–19]. A GA based method is developed to minimize energy loss with considering only load profile [13]. In terms of the energy loss minimization concept, more comprehensive problem is stated including simultaneous distributed generation, reactive sources, and network configuration without considering the time-varying characteristic of DGs [14]. In [15], energy loss reduction is investigated by including the smart operation such as coordinated voltage control and dispatchable power factor of DG. Analytical approaches are also developed to minimize energy loss by integrating renewable energy sources considering the varying load and possible operating conditions of DG units [16]. Rotaru et al. presents a two-stage iterative approach to obtain the optimal size of DG sources in electrical distribution systems, taking into account the time-dependent evolution of generation and load and selecting a set of candidate nodes through a clustering-based approach based on normalized loss sensitivity factors and normalized node voltages [17]. In [18], optimal mixed of renewable energy resources are investigated to minimize energy loss using probabilistic based method. They also propose a method for wind-based DG integration by using the similar approach [19]. In [18,19], the load and generation profiles are clustered separately for a given period and the all combinations of obtained clusters are considered. Because of the specific characteristics of wind speed and load profiles in each hour, the annual load and wind speed data should be dealt with in a pairwise manner without violating the harmony of correspondence between load and generation profile. Other important point for the planning problems is to reduce the computational burden of problem formulation [20]. If the search space is exceptionally large, some techniques should be developed to explore search space effectively. For this reason, a clustering method based GA is used to reduce the computational effort in this study. And also, it is clear that there is still need for a simple method to minimize energy loss because of the complexity of this optimization problem.

In this paper, a GA-based methodology is developed to find optimal sizes of WTs to minimize energy loss. This methodology is based on weighting factors. The contribution of this paper is to allow considering the time varying characteristics of both load and wind generation profile in a pairwise manner. On the other hand, since GA is time-consuming tool [21,22], fuzzy-c means (FCM) clustering is used to reduce the execution time of the optimization process by grouping the pairwise load and wind-generation data with considering the correspondence of both profiles. The proposed methodology is tested on the mostly used IEEE-30 bus test network for different scenarios.

2. Discussion on power and energy loss minimization

Line loss minimization can be divided into two groups in the literature: power loss and energy loss minimizations. The evaluations and formulations of them are quite different. The difference between power and energy loss minimization problems is shown in Fig. 1. Power loss minimization is well developed in the literature. There are two ways to handle this problem: based on analytical and power flow analysis. One of them is the calculation of exact loss formula as mentioned in [5,23]. The second way is to use a heuristic method with simple power flow analysis.

By using exact loss formula, the power loss can be expressed in terms of generations as follows:

$$\textit{Minimize} \quad P_{LOSS} = f(X) \tag{1}$$

where P_{LOSS} is the active power loss and X is a vector that consists of the design variables as

$$X = [P_{\mathrm{DG}-1}, P_{\mathrm{DG}-2}, \ldots, P_{\mathrm{DG}-n}] \tag{2}$$

where P_{DG} is the active power of DG at an instant and n is the number of candidate buses at which DGs are located. If this analytical equation is used to minimize power loss, the power balance should be considered by using the following constraints in the optimization problem [23]:

$$P_{CG} + P_{TDG} = P_{LOSS} + P_{TL} \tag{3}$$

$$P_{CG} + P_{TDG} = P_{LOSS} + P_{TL} \tag{4}$$

where P_{CG}, Q_{CG}, P_{TDG}, Q_{TDG}, P_{TL}, and Q_{TL} are total active and reactive powers of conventional generators, DGs, and loads, respectively. Q_{LOSS} denotes the reactive power loss. This problem can be solved easily using any optimization tool [24]. Exact loss formula is given as follows:

$$P_{LOSS} = \sum_{i=1}^{N_{bus}} \sum_{j=1}^{N_{bus}} [\alpha_{ij}(P_i P_j + Q_i Q_j) + \beta_{ij}(Q_i P_j - P_i Q_j)] \tag{5}$$

$$\alpha_{ij} = \frac{R_{ij}}{V_i V_j} \cos(\delta_i - \delta_j) \quad \text{and} \quad \beta_{ij} = \frac{R_{ij}}{V_i V_k} \sin(\delta_i - \delta_j) \tag{6}$$

where P_i and Q_i are the real and reactive power injection in bus i, respectively. V_i and δ_i are the magnitude and angle of bus i, respectively. R_{ij} is the resistance of ijth element of bus impedance matrix and N_{bus} denotes the number of buses. However, it needs to execute the power flow analysis in order to form this formula [5]. To extend

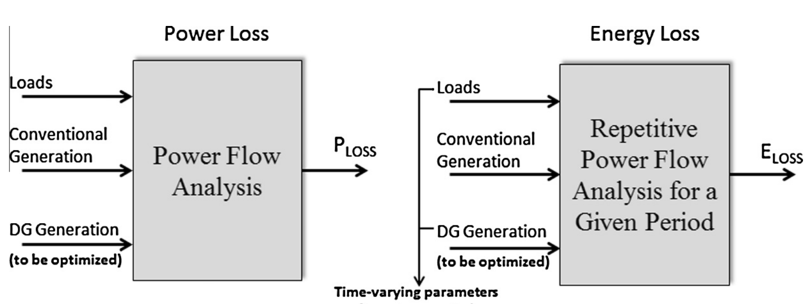

Fig. 1. Schematic of power and energy loss minimization.