Energy 159 (2018) 774–785

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Coordinated DG-Tie planning in distribution networks based on temporal scenarios

Yue Xiang [a], Lili Zhou [a], Yunche Su [b], Jichun Liu [a, *], Yuan Huang [a], Junyong Liu [a], Xia Lei [c], Zhang Sun [c], Weiting Xu [b], Wentao Zhang [b]

[a] College of Electrical Engineering and Information Technology, Sichuan University, Chengdu, 610065, China
[b] State Grid Sichuan Economic Research Institute, Chengdu, 610041, China
[c] School of Electrical Engineering and Electronic Information, Xihua University, Chengdu, 610039, China

ARTICLE INFO

Article history:
Received 9 April 2017
Received in revised form
16 May 2018
Accepted 23 June 2018
Available online 27 June 2018

Keywords:
Distributed renewable generation
Tie lines
Temporal scenarios
Chance constrained
Genetic algorithm

ABSTRACT

Optimal planning of distributed generation (DG) in distribution networks is key for improving energy utilization efficiency and system operation benefits. Considering the uncertainties and temporal correlations of DG output and load demand, a multi-scenario chance-constrained economic model for DG planning is established in this paper. The model considers the comprehensive benefits of environmental, reliability and other aspects, as well as the active curtailment management of DGs. Thereafter, the model is extended to the coordinated planning of both DGs and tie lines, which is formulated as a multi-objective model. An improved genetic algorithm based solving strategy integrated with game multi-objective decision method is proposed. The feasibility and effectiveness of the proposed models are verified on the IEEE 33-bus distribution system. The impacts of natural resource distribution, confidence level, unit environmental cost and other parameters are investigated as well. The case studies also prove the integration of complementary DG generation could help improve the maximum capacity of DG and indicate the environmental benefit is the vital incentive to introduce DG into the distribution network.

1. Introduction

The objective in decreasing carbon emissions and depletion of energy resources are promoting an evolution in the power industry. Clean energies, such as distributed wind generation and photovoltaic, are encouraged to the distribution network. The integration of distributed generation (DG) has changed the state of one-way direction of the power flow and affected voltage, power loss, and system reliability [1]. To maximize the benefits of DG and alleviate its negative impacts [2], optimal allocation of DGs in the distribution network at the planning stage is important [3].

The siting and sizing of DGs have been investigated by many scholars. An overview of the optimal DG placement models was presented in Ref. [4]. Specifically, a planning model aiming at maximizing DG penetration was proposed in Ref. [1]. The penetration level of DG is an important index to describe the capability of distribution systems to accommodate renewables. Besides, power loss and voltage deviations are also important indicators of DG planning [5]. Furthermore, to achieve the trade-off between different performance goals, multi-objective models aiming at improving topology performance [6], economics [7], reliability [8], etc. were developed and investigated. In practice, the economic factor plays the most important role in planning, and some research focuses on economic aspects. The reinforcement cost, power loss cost, purchasing electricity cost and outage cost were considered in Ref. [9]. In Ref. [10], DG's investment and operating costs, total payments toward compensating for system losses are minimized along the planning period, as well as different costs according to the available alternative scenarios. Besides the above cost type, DGs' maintenance and capacity adequacy cost are considered in the uncertain environment [11] as well as the management cost [12]. In fact, one truly important incentive for promoting DGs into the distribution network is the environmental benefits of emission reduction. Therefore, the environmental cost was integrated into the planning model [13]. In addition, active management may be necessary for DG operation, which was also integrated in planning phase. To evaluate the maximum wind power capacity that can be connected to a distribution network, the active management

* Corresponding author.
E-mail address: jichunliu@scu.edu.cn (J. Liu).

https://doi.org/10.1016/j.energy.2018.06.159
0360-5442/

methodology was designed and applied to a 38 kV Irish distribution network in Ref. [14]. In the active management strategy [15], the "active" characteristics of DGs are reflected by the reasonable curtailment of outputs according to the forecasted values and the operation states of the distribution system.

The planning of DGs is closely related to power network planning, where the tie line planning is also important, and thus DG-tie planning can be simultaneously considered as it also fits the present conditions in China. As most China's urban residents live in apartments, they are not able to invest in DG in their own premises because the installation space is limited. As a result, not only tie-lines but also most DGs are mainly invested by local electrical power companies (Of course, there are a few utilities in China, e.g., electricity retail companies, investing DGs too, but the number is fairly small and are not considered in the planning framework yet). The economic benefits of such coordinated investment mainly come from twofold. First, the local electrical power companies do not need to pay for the power generated by DGs (otherwise it needs to purchase the power from the upper electrical grid) while customers still pay the electricity bills. The revenue is usually higher than DG operation costs that electrical companies need to afford. Second, as renewable DGs are contributing to the environment, investors can obtain environmental subsidies provided by the government [16]. In several studies, e.g. [17], it is also assumed that the operation of renewable energy does not need to cover the environment cost, while that should be included for conventional generations. it is also an economic incentive for investing DGs [18]. In terms of specific methods for dealing with the coordinated DG-tie planning, there are several studies. For example, in Ref. [19], a two-level model was proposed to solve the coordinated planning problem. Game theory was used in Ref. [20] by gaming the investment between DGs and tie lines to coordinate their locations and capacities. The coordinated planning model was extended to multiple time periods in Ref. [21] so that the load growth during the planning years could be considered.

The intermittent and uncertain features of renewable generation, such as wind power and solar power, also greatly impact distribution system operation. Thus, the uncertainty issues need to be handled at the planning phase. Weibull probability functions [22] are used to describe the wind speed, while fuzzy probability methods [23], multi-state probability models [24], Copula method [25], clustering methods [26] etc. are used to model wind output. However, the probabilistic methods are easily affected by parameters. Scenario technology [27] is an effective method for dealing with uncertainty by integrating several uncertain conditions. A multi-scenarios approach was proposed in Ref. [28] in order to represent the uncertainties of wind, load and energy prizes. However, the final set of uncertainty states was obtained by a simple probabilistic combination, which means different uncertainty factors were handled independently. Additionally, in current study, the typical notional or peak points of uncertain parameters are selected as the worst-case scenarios for planning DGs [29]. It is rather conservative and cannot reflect the temporal correlations of multi-type uncertain parameters. In the real operation of some specific area, the load demand and DG generation output exists correlations [25]. However. The existing scenario methods could not handle the situation well or too complicated and rely on the pre-setting probability of the corresponding resources. On the other hand, it is also challenging to generate a limited number of representative scenarios with corresponding probabilities. Therefore, the design of multi-scenarios for planning is important and challenging.

As mentioned above, there are plenty of DG planning investigations at present, which lead to several exiciting achievements. However, the temporal correlation between the different types of DGs and load demand in the specific area is considered clear or modelled practically in the majority of them, as well as the environmental incentives brought by the DGs. Furthermore, the topology impact and its reliable performance of the distribution network in the DG planning are not well modelled and integrated in the comprehensive optimization. Besides, studies on planning DGs or tie lines are mainly implemented independently and seldom is realized in a coordinated way, in which the power company is regarded as the invest majority. Considering the above problems, this paper studies the optimal planning of distributed renewable generation in the distribution network and extends it to the coordinated planning with tie lines. The main contributions of this paper include as follows:

- A joint probability method is presented to handle the uncertainties of DG output and load demand. Compared to conventional multiple scenario approaches, it further considers the "temporal simultaneity and correlation" between different factors, e.g. renewable generation's output and load demand, so that the uncertainty and correlation features can be modelled more accurately.
- A coordinated two-stage DG-Tie planning model is established. It is very suitable for the practical distribution network planning when DGs and tie lines are both invested by the same utility, e.g., the local electrical power company, where the assessment of investment costs and economic profits is different from the case where DGs are highly distributed and invested by customers. The coordination between the two will improve the comprehensive performance.
- Reliability enhancement and environment sustainability functions are emphasized in the planning model. On one hand, most DGs are relatively in large scale so that they have the ability to back-up generation after failures appear in distribution networks. On the other hand, as electrical power companies in some countries, e.g., China, are not only a profitable enterprise, but also a social service agency, they are also responsible for the environmental conservation.
- By using the bargaining function integrated decision algorithm to deal with the multi-objective trade-off between economic and reliability objectives, effective planning candidates can be made investors according to their practical needs.

The rest of the paper is organized as follows. The process for obtaining temporal scenarios and corresponding joint probability is proposed in section 2. In Section 3, the basic planning optimal model for DGs is proposed, which is then extended to the coordinated DG-tie planning model. Section 4 presents the solving process based on the improved genetic algorithm. The application is shown in Section 5. Finally, conclusions are given in Section 6.

2. Design of temporal scenarios

The temporal correlation between renewable generation output and load demand in the same area is considered in scenario generation. Based on the historical data of wind speed, solar intensity and load demand curves, the operational state intervals are discretized, and the corresponding joint probability of each scenario is obtained.

2.1. Output modelling of wind turbine and photovoltaic

The wind turbine (WT) and photovoltaic (PV) are regarded as the representative DG in this paper. The relation between WT output and wind speed is formulated as: