Renewable and Sustainable Energy Reviews 35 (2014) 304–310

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Optimal load distribution model of microgrid in the smart grid environment

Kaile Zhou*, Shanlin Yang, Zhiqiang Chen, Shuai Ding

School of Management, Hefei University of Technology, Hefei 230009, China

A R T I C L E I N F O

Article history:
Received 27 September 2013
Received in revised form
18 March 2014
Accepted 7 April 2014
Available online 25 April 2014

Keywords:
Microgrid
Smart grid
Distributed generation
Optimal load distribution
Optimization model

A B S T R A C T

In the smart grid environment, the flexible and diverse distributed generation (DG) and microgrid (MG) are attracting considerable attention. There are many key management and optimization issues involved in smart grid. As an important part of smart grid optimizations, the optimal load distribution of MG contributes to the efficient operation of MG in the smart grid environment. However, traditional optimal load distribution models of large-scale power generation systems are not fully applicable to MG for their distinct characteristics. In this paper, we first introduce the MG in smart grid and analyze its characteristics. Then, we present a review of the optimal load distribution models of MG in the smart grid environment, and point out the deficiencies of the existing models. Finally, a comprehensive optimal load distribution model of MG both in objective functions and constraints is established and discussed.

Contents

1. Introduction . . . 304
2. Optimal load distribution of MG in the smart grid environment . . . 305
   2.1. MG in the smart grid . . . 305
   2.2. The characteristics of MG optimal load distribution . . . 305
3. Optimal load distribution models of MG . . . 306
   3.1. Single-objective models . . . 306
   3.2. Multi-objective models . . . 307
4. A comprehensive model of MG optimal load distribution . . . 307
   4.1. Objective function of MG optimal load distribution . . . 307
   4.2. Constraints of MG optimal load distribution . . . 308
      4.2.1. Power supply and demand balance constraints . . . 308
      4.2.2. Operation constraints of energy storage devices . . . 308
      4.2.3. Power generation constraints of renewable energy . . . 308
      4.2.4. CHP system constraints . . . 308
      4.2.5. Other constraints . . . 308
5. Conclusion . . . 309
Acknowledgments . . . 309
References . . . 309

1. Introduction

With the rapid development of power generation technologies and the increasing demand for electricity, large-scale centralized power generation systems were widely implemented, in which thermal power is the major power generation method. However,

* Corresponding author.
E-mail addresses: kailezhou@gmail.com, zhoukaile@mail.hfut.edu.cn (K. Zhou).

http://dx.doi.org/10.1016/j.rser.2014.04.028
1364-0321/

the disadvantages of large-scale centralized thermal power generation, such as disadvantages in the aspects of economic efficiency, environmental protection, security and reliability, and control agility, were gradually emerging. People began to re-evaluate the large-scale centralized power generation methods, and the idea of small-scale distributed generation was presented [1]. After the late 1990s, increasing research efforts have focused on the distributed generation (DG) and its economic benefits [2–5]. DG, also known as dispersed generation or distributed energy supply, is a new energy production and supply model [6–8]. In DG, relatively small power generation units are arranged near the user load sites. Therefore, compared with the large-scale centralized power generation, the main advantages of DG are its dispersion in locations and flexibility in power supply. In addition, DG can also improve the reliability of power supply system when collaborating with large-scale power generation systems [9]. However, DG also has some disadvantages. The main power grid always employs methods like restriction and isolation to reduce the impact from DG. With the development of smart grid, the concept of microgrid (MG) [10–12] was proposed in order to coordinate the contradictions between DG and the main power grid. MG is an important power generation mode in smart grid [13–15].

Currently, MG is primarily in the experimental research stage [16–18]. There are still many obstacles in terms of technology, control and management that needs to be overcome before MG can be widely applied [19–21]. The economic optimization of MG is one of the key management issues which can affect its operating efficiency and user acceptance [22–24]. Three aspects of MG economics were summarized in [25]. Solar power, wind power and other renewable energy power generation methods are widely adopted in MG, which makes its environmental benefits apparent [26]. Also, power generated in MG can be supplied in a safer, more reliable, and more personalized way by means of electricity users division and load classification [27,28]. Currently, there have been some research efforts in the economic optimization of MG [29–32].

The various optimization issues are the key parts of MG economics, such as the location optimization [33–35] and capacity optimization [36–38] of distributed generators in order to determine the location and capacity of each generator. The optimal load distribution is an important optimization problem to support the efficient operation of MG [39]. The optimal load distribution of MG is to achieve multi-objectives, including low operating cost, low emissions, high reliability, high power quality, and low line loss, etc., while meeting various system operating constraints. In this paper, we will review some existing optimal load distribution models of MG, and point out the deficiencies of the existing models. Then a general and comprehensive model of MG optimal load distribution is proposed and discussed.

The remainder of this paper is structured as follows. A brief introduction of smart grid and MG, as well as the optimal load distribution of MG are described in Section 2. Then, the optimization mathematical models of MG optimal load distribution, both single-objective and multi-objective, are reviewed in Section 3. In Section 4, we propose a comprehensive model of MG optimal load distribution, including different objective functions and various constraints. Finally, conclusions are drawn in Section 5.

2. Optimal load distribution of MG in the smart grid environment

2.1. MG in the smart grid

To achieve the goal that the operation of power systems becomes safer, more reliable, more environmentally friendly, more flexible, more controllable, and more cost-effective, the United States and some European countries proposed the concept of "smart grid" [40–42]. Currently, many countries have put smart grid as one of the national strategies, and considerable research work have been carried out [43–45]. Smart grid [46–48] can be generally considered as an intelligent power grid system which integrates the energy flow and information flow by advanced information technology, sensor technology, automatic control technology and scientific management methods, etc.

MG is an important part of smart grid implementation and application. A variety of distributed generators and energy storage devices can assess to the main power grid in the smart grid environment. They can form a "virtual power plant" through the interconnection on all voltage levels by electrical communication systems. Many researchers studied the roles of distributed generators and energy storage devices in smart grid. Zhang [49] described a framework for the operation and control of smart grid with DG and Flexible AC Transmissions (FACTS), and proposed a global coordinated strategy for voltage control. Mohd et al. [50] pointed out that distributed energy storage systems with advanced power electronics can play an important role in power supply systems and lead to many financial benefits. They also studied the topologies, control and flexibility of the main power grid with energy storage systems. Chowdhury et al. [51] studied the operation and control of distributed generators in power islands by simulation, and an appropriate bus controller was designed. They also analyzed the flexibility, safety and power quality of DG. These research efforts mainly focused on the technical and control perspective of DG operation in the smart grid environment.

2.2. The characteristics of MG optimal load distribution

MG is a kind of small power distribution and consumption system, which overcomes the deficiencies of DG in terms of intelligence and flexibility [52]. MG provides power energy for users by modern power techniques, such as fast power electronic switches, advanced converting techniques, efficient new energy sources and various energy storage devices. Many kinds of distributed generators and energy storage devices, including photovoltaic (PV) arrays, wind turbines (WTs), microturbines (MTs), fuel cells (FCs), and energy storage batteries, are widely adopted in MG.

MG is a controllable power system that provides thermal and electricity for users by combining the power generation equipment, energy storage devices, control equipment and load [53]. The basic structure of MG has been presented by the America Consortium for Electric Reliability Technology Solution (CERTS) [54]. MG can operate in both grid-connected mode by collaborating with main power grid and independent isolated mode. As an effective supplement of main power grid, MG has attracted considerable attention in recent years due to its characteristics of low cost, low pollution, high reliability and easy to control.

The optimal load distribution of MG is to achieve multiple goals, including minimizing cost, minimizing pollution emissions, and maximizing reliability, etc., while satisfying various constrains. Fig. 1 shows the basic structure of MG optimal load distribution.

There are many differences between the MG and traditional large-scale thermal power generation. First, power generation of various distributed generators in MG usually follows the maximum power-point tracking mode [55,56], and cannot be controlled through manual scheduling. The output characteristics of these distributed generators of renewable energy power generation are sensitive to the natural conditions, such as the intensity of sunlight and the velocity of wind. Second, the power