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Optimal allocation of microgrid considering economic dispatch based on hybrid weighted bilevel planning method and algorithm improvement

Hongbin Wu *, Huaidong Zhuang, Wei Zhang, Ming Ding

School of Electrical Engineering and Automation, Hefei University of Technology, Hefei 230009, China

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ABSTRACT

During the microgrid search process, optimal allocation and economic dispatch are very important and are interrelated, having interaction and mutual checks. In this paper, we adopt a bilevel planning method to search for the multi-objective optimal allocation of a microgrid, considering economic dispatch. The upper level is the optimal allocation, which aims at minimizing the daily fixed cost of investment (DFCI), load loss probability (LLP), and excess energy rate (EER), with which it determines the capacity of each power supply. The lower level is the economic dispatch, which aims at minimizing the cost of operation and management (COM) and cost of pollutant disposal (CPD), with which it determines the output power of each distributed generator (DG). Considering the different dimensions of multi-objective functions of the upper level, a hybrid weighted method based on the judgment matrix method and variation coefficient method is proposed. For the objective function of the lower level, the penalty function method is adopted to handle the unbalanced active power. We propose an improved adaptive genetic algorithm (IAGA), which can avoid premature phenomena and local convergence and can find the global optimal solution more quickly and stably. We also discuss the two different scheduling strategies of the microgrid. With the example system, the correctness and effectiveness of the model and algorithm are verified. The simulation results show that the hybrid weighted bilevel planning model can efficiently realize the optimal allocation of DGs, reasonably schedule the output power of DGs, and eventually achieve optimal multiple objectives, considering optimal allocation and economic dispatch. The presented research can provide some reference information for microgrid applications.

Introduction

With the rapid development of the world economy, energy demand is increasing dramatically, and the energy crisis and environmental problems are constantly emerging. Power generation by distributed generators (DGs), especially renewable energy power generation such as wind turbine generators (WTGs) and photovoltaic arrays (PVs), has become the focus of current study worldwide. Microgrid systems can integrate distributed generation units, storage units, and loads, achieve a variety of types of energy complementation, improve energy efficiency, and flexibly access and withdraw from the distribution network by operating in grid-connected or island mode, which are the important part of a smart grid [1–4].

When operating in island mode, the microgrid system can only rely on the internal power to supply the load. As wind and solar are intermittent and random, this is done primarily through the use of additional batteries (BS) and diesel generators (DE) to balance the supply in the microgrid; thus these power sources constitute the wind–PV–battery–diesel system. The way to implement the optimal allocation of each generator's capacity, reasonably schedule the output power according to the climate resource conditions and load demand, and maximize the maintenance of system power balance is not only related to the power supply reliability of the whole system, but also determines the economy and reliability of the system to a large extent. Therefore, it is of great significance to study the optimal allocation of DGs.

In [5], the social welfare maximization and profit maximization were taken as the objective functions for the optimal allocation of DGs. The research in [6,7] took the total cost of the power supply company as the optimization objective, and gave the planning model of DGs based on market conditions. Ref. [8] proposed a

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* Corresponding author. Tel.: +86 13856013658; fax: +86 055162903929.
E-mail address: hfwuhongbin@163.com (H. Wu).

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novel method based on harmony search algorithm to find the optimum locations of energy storage systems in a specified microgrid, which will minimize the cost of microgrid amount of energy which should be purchased from the main network. But it only studied the optimal allocation of energy storage systems. The research in [9,10] studied the optimal allocation of renewable energy generation systems by analyzing the mathematical model and the economy of a wind–PV–battery system. In [11], the optimal allocation of two types of DGs was studied with the objective function which is adapted with weighting factor to reduce the network real loss and enhance the voltage profile. But in all these studies, they just considered the optimal allocation of one or two kinds of DGs, and the objective function was relatively simple. The research in [12,13] studied the optimal allocation of a single objective and multi-objectives by matching the relationship between the DGs and the load in a microgrid. In [14], a methodology for optimal DG allocation and sizing in distribution systems was presented to minimize the electrical network losses and to guarantee acceptable reliability level and voltage profile. These studies considered multi-objectives.

The authors in [15] explained the background to the technical constraints faced by embedded generation projects, and developed a new methodology using linear programming to determine the optimal allocation of embedded generation with respect to these constraints. Ref. [16] proposed a two-layer simulation-based optimization approach to determine the optimal allocation and capacity of DGs in a power distribution system. The second layer which is the optimal allocation is based on the outputs of the first layer which is a dynamic optimal power flow routine to optimize the location and capacity of DGs. But this study took into account the economic dispatch in the optimal allocation using simple linear additivity when considering the optimal allocation and the economic dispatch of DGs at the same time. Such treatment of the objective was relatively simple and could not fully reflect the relationship and effectiveness between optimal allocation and economic dispatch. The linear additivity method is not applicable especially in dealing with the multi-objectives problem. So the weighting approach is significant to determining the weight coefficients of multi-objective functions.

Many different optimization algorithms have been employed to solve optimal allocation. Such as genetic algorithm (GA) [12–14], particle swarm optimization (PSO) [12,16], harmony search algorithm (HSA) [8] and backtracking search optimization algorithm (BSOA) [11]. Also these algorithms can be used to handle economic dispatch problems [17–20]. But each kind of optimization algorithm has both superiority and shortages. So it is important to select an optimization algorithm.

Therefore, considering optimal allocation and economic dispatch of microgrid at the same time, this paper establishes a mathematical model of hybrid weighted bilevel planning. The upper level is the optimal allocation, which aims at minimizing the daily fixed cost of investment (DFCI), load loss probability (LLP), and excess energy rate (EER) in order to consider economy, reliability, and resource utilization. The lower level is the economic dispatch, which aims at minimizing the cost of operation and management (COM) and cost of pollutant disposal (CPD), with which it determines the output power of the DGs. For the objective functions of the upper level, a hybrid weighted method based on the judgment matrix method and variation coefficient method is proposed. For the objective functions of the lower level, the penalty function method is adopted to handle the unbalanced active power. After establishing the mathematical models of hybrid weighted bilevel planning, an improved adaptive genetic algorithm (IAGA) is proposed to solve the problem. Finally, with the example system, the proposed model and algorithm are validated. Also, we discuss the various influences on optimal allocation and economic dispatch of microgrid.

Mathematical models of DE and BS

Mathematical model of DE

The actual output power of the DE can be changed in the range from 0 to the rated power, and the characteristic expression of energy consumption and power output of DE is shown as follows:

$$F(t) = F_0 P_{gen}(t) + F_1 Y_{gen}(t) \tag{1}$$

where $F(t)$ indicates the fuel consumption of DE (L), $P_{gen}(t)$, and $Y_{gen}(t)$ are respectively the rated power and actual output power (kW), and F_0 and F_1 are respectively the intercept coefficient and slope of the fuel curve (L/kW h).

Mathematical model of the BS

This paper chooses BS to adjust the energy. The energy storage system of the BS can be modeled by the state of charge (SOC) and the charging and discharging power. The electricity recurrence relation is shown as follows:

(1) Charging process:

$$\mathrm{SOC}(t) = (1-\delta)\mathrm{SOC}(t-1) - P_c \Delta t \eta_c / E_C \tag{2}$$

(2) Discharging process:

$$\mathrm{SOC}(t) = (1-\delta)\mathrm{SOC}(t-1) - P_d \Delta t / (E_C \eta_d) \tag{3}$$

where SOC(t) and SOC($t-1$) are the SOC of BS at the end of the periods t and $t-1$, respectively, δ is the self-discharge rate of BS (%/h), P_c and P_d are the charging and discharging power of BS, respectively, which is negative under charging and positive under discharge (kW), η_c and η_d are the charging and discharging efficiency (%), respectively, and E_C is the rated capacity (kW h).

The hybrid weighted bilevel planning method

Introduction of bilevel planning method

Bilevel planning is the mathematical model of bilevel decision-making problems, which are a kind of optimization problem with a bilevel hierarchical structure. Besides, the upper and lower levels all have different objective functions and different constraint conditions. The objective functions and constraints of the upper level are not only related to the decision variables of the upper level, but also depend on the optimal solution of the problem of the lower level. The optimal solution of the problem of the lower level is also affected by the decision variables of the upper level. The model [21–23] is shown as below:

$$\begin{cases} & \min\limits_{x} F(x,y) \\ s.t. & g_1(x,y) \leqslant 0 \\ & g_2(x,y) = 0 \\ & \min\limits_{y} f(x,y) \\ s.t. & h_1(x,y) \leqslant 0 \\ & h_2(x,y) = 0 \end{cases} \tag{4}$$

where $x \in R^{n_x}$ and $y \in R^{n_y}$ are the decision variables of the upper and lower levels, respectively. F, f: $R^{n_x+n_y} \to R$ are the objective functions of the upper level and the lower level respectively, and g_i: