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Optimal coordinate operation control for wind–photovoltaic–battery storage power-generation units

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ABSTRACT

An optimal coordinate operation control method for large-scale wind–photovoltaic (PV)–battery storage power generation units (WPB-PGUs) connected to a power grid with rated power output was proposed to address the challenges of poor stability, lack of decision-making, and low economic benefits. The "rainflow" calculation method was adopted to establish the battery cycle life model and to calculate quantitatively the life expectancy loss in the operation process. To minimize unit cost of power generation, this work optimized the output period of the equipment and strategy of battery charging and discharging with consideration of working conditions, generation equipment characteristics, and load demand by using the enhanced gravitational search algorithm (EGSA). A case study was conducted on the basis of data obtained using WPB-PGU in Zhangbei, China. Results showed that the proposed method could effectively minimize the unit cost of a WPB-PGU under different scenarios and diverse meteorological conditions. The proposed algorithm has high calculation accuracy and fast convergence speed.

1. Introduction

Large-scale, centralized, wind–photovoltaic–battery storage power generation is one of the most popular topics in the field of new energy power system research. Such aspect is also an important part of smart grids. With the development of battery energy storage systems, the installed capacity of wind turbines and PV panels increased, and equipment performance improved [1–2]. WPB-PGUs connected to the power grid as a power generation unit with rated capacity has broad application prospects, and many experts and scholars around the world have focused on developing this field [3,4]. During the operation process of connecting to the power grid, WPB-PGUs exhibit low economic benefits and poor stability because of their high installation price, battery energy storage system with short life cycles, unpredictable meteorological conditions, and the lack of an operation strategy. Therefore, formulating reasonable coordinate operation strategies to reduce operation costs is necessary to satisfy the demand for power dispatch. Such condition is conducive to the development of new energy power plants and power grids that use renewable energy.

Existing studies related to hybrid wind–photovoltaic–battery power generation are mainly focused on modeling [5,6], capacity allocation [7,8], optimal design [9–11], economic evaluation [12], reliability evaluation [13], and optimal operation aspects [14,15]. Coordinate operation controls for wind–photovoltaic–battery power generation mainly adopt intelligent algorithms to solve operation optimization models on the basis of the output complementary characteristics of wind turbines and PV arrays. For example, to minimize electrical active power losses, voltage deviations, total electrical energy cost, and total emissions of RESs and substations, Taher et al. presented a new multi-objective modified honey bee mating optimization algorithm to optimize the operation management of wind/photovoltaic/fuel cell power generation units connected to distribution networks. Moreover, the authors adopted a fuzzy-based decision maker to select the "best" compromised solution among non-dominated optimal solutions [16].

To ensure load supply in all cases, Yumurtaci et al. selected the artificial neural network controller to examine and evaluate the performance of the hybrid renewable energy system [17]. To achieve fast charging, energy saving, power source protection, and system stability assurance, Wai et al. designed an intelligent optimal energy management system for hybrid power sources, and the fuzzy control method was adopted to manipulate the system stably [18].

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To satisfy the load demand with the least possible cost, Mohamed et al. proposed an effective algorithm for hybrid renewable energy systems connected to a smart grid. Moreover, the authors designed a smart energy commitment technique for controlling batteries to achieve better economic gains [19]. Feroldi et al. presented an energy management strategy for hybrid systems on the basis of wind–solar energy and bioethanol. They used a genetic algorithm to design a stand-alone system that enhances the efficiency of hydrogen production [20].

Previous studies on the optimal operation of wind–photovoltaic–battery units have mainly focused on how to maximize the use of renewable energy. Few studies consider the battery life characteristics of energy storage systems, and no studies quantitatively calculate the cost of battery life lost during the operation process. Reducing the cost of large-scale WPB-PGUs is difficult. In this study, a constant output strategy of WPB-PGUs was first presented to ensure the reliability of renewable energy utilization and to reduce the effect of large-scale grid-connected renewable power system operation to the security and stability of power grid. Second, an optimal coordinate operation control model for large-scale WPB-PGUs was proposed to minimize the unit cost of power generation on the basis of constant output constraints. The optimal model adopted the enhanced gravitational search algorithm to calculate the output value of all power generation equipment, as well as the charge and discharge sequence of batteries with consideration of battery life expectancy loss in the process of each cycle. Finally, a simulation based on the measured data of WPB-PGU in Zhangbei, China was conducted to verify the superiority of the optimization model and the validity of the proposed algorithm. Further analyses of the optimization model indicators were conducted under different scenarios to guarantee the adaptability of the optimization model under different weather conditions.

2. System structure

Typical of WPB-PGUs are shown in Fig. 1. The unit mainly consists of several wind farms, PV arrays, energy storage buildings for battery banks, and a combined coordinate operation control system. Wind farms and PV arrays are primarily responsible for generating power from wind and solar energy and are the main generating equipment of WPB-PGUs. The equipment can be divided into groups with the use of a van-type converter connected to the feeder and a summary connected to the DC bus. The energy storage buildings are mainly used as storage battery banks under a constant temperature. Several battery cabinets connect to a battery pack series and to another battery pack series connected in parallel to form a battery energy unit that is connected to the DC bus through a power convert system (PCS). The bus accesses the power grid through the inverter. The combined coordinate operation control system formulates the power generation strategy for equipment according to the scheduling instruction from the power grid and meteorological data from monitoring stations.

3. Proposed optimization model

Improving the power grid acceptance of renewable energy for renewable energy power plants is necessary to stabilize the process of connecting to the grid. Moreover, the economic benefits of power plants should be considered by reasonably arranging unit power outputs and the charging and discharging strategy for battery storage, such that the overall operation costs are reduced. In this study, optimal operation involves optimizing the unit power output value and charging and discharging strategy of battery storage under constant WPB-PGU output, which is similar to the output characteristics of conventional thermal power units. On one hand, optimization should be conducive to operational stability and power grid scheduling plans to reduce the spinning reserve capacity of the system while improving the quality of renewable energy. On the other hand, optimization should also make the coordinated control of WPB-PGUs convenient to decrease the instances of unit start-stop as well as decrease the charging and discharging required by battery storage. This work will use an enhanced gravitational search algorithm to calculate the problem model.

3.1. Optimization objective

The objective function of WPB-PGUs is to minimize the unit cost of power generation C during the research period T, which can be expressed as follows:

$$minC = \left[C_{OM}(P_{ref}) + C_{dep} + C_{equ} + C_{pun}\right] \Big/ \int_T P_{ref}dt \tag{1}$$

where P_{ref} is the reference value of the constant output of power generation units; C_{OM}, C_{dep}, and C_{pun} are operation maintenance costs, equipment depreciation costs, and the penalty costs attributed to the incapability to ensure constant output during the research period, respectively. These values can be calculated as follows:

$$C_{OM}(P_{ref}) = \sum_{t=1}^{T}\left[C_{WT}^{OM}(P_{WT}(t)) + C_{PV}^{OM}(P_{PV}(t)) + C_{BAT}^{OM}(P_{BAT}(t))\right] \tag{2}$$

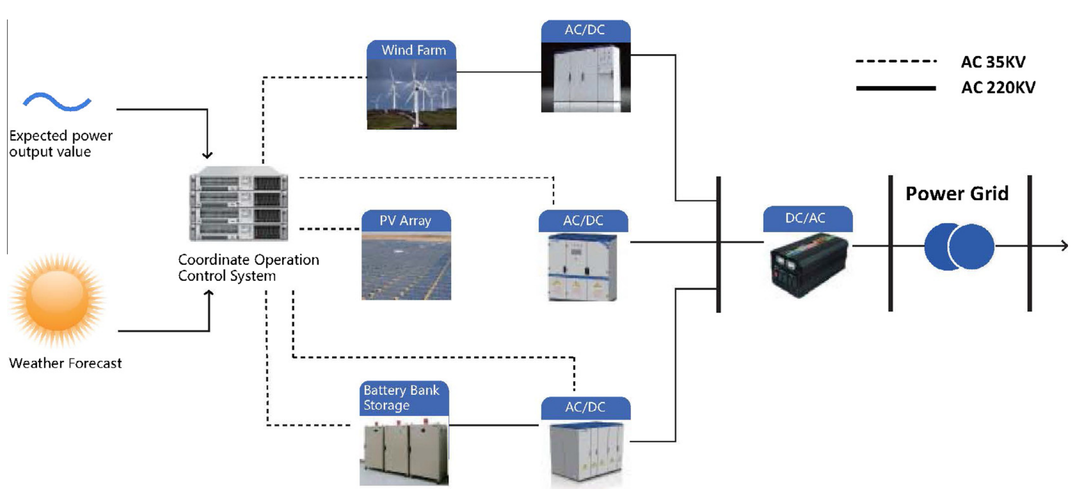

Fig. 1. Typical WPB-PGUs structure.