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Research on optimal schedule strategy for active distribution network using particle swarm optimization combined with bacterial foraging algorithm

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ABSTRACT

Comparing with the traditional distribution network, a significant feature of the active distribution network (ADN) is that the performance of distributed generation (DG) units, energy storage units and micro-grid (MG) in the network is controllable for the distribution network operator. Considering the characteristics of the distributed power supply and micro-grid, and giving full play to the advantages of distributed generation technology in the economic, environmental and energy aspects, this paper highlights an environmental protection and energy saving optimal schedule model for ADN. The scheduling model focuses on the minimum network loss, minimum voltage deviation and minimum difference between peak and valley load. In addition, the two stage algorithm is presented to solve the proposed multi-objective scheduling model of ADN. First, a set of Pareto solutions are obtained by using the proposed particle swarm optimization combined with bacterial foraging algorithm (PSO-BFO) to solve multi-objective optimization problems, then the optimal schedule strategy of ADN is gained through evaluating the Pareto solutions with entropy weight decision-making method. To avoid the search falling into local optimal solution, the two-value crossover operator is introduced to exchange the information among subpopulations and update the position of related particles. Meanwhile, the adaptive adjusting inertia constant strategy is used to improve the algorithm convergence speed. Finally, the case study results demonstrate the rationality of the proposed optimal schedule model and the validity of its solution algorithm for ADN.
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Introduction

The basic definition of active distribution network (ADN) which proposed by CIGRE C6.11 project team in 2008 is a distribution system which can realize the active control and active management on local distribution generation (DG) by using the flexible network topology to manage flow [1].

The main scheduling units of AND are distributed generation (DG), micro grid (micro-grid, MG) or micro network and load [2,3], where the hot topic of current research is on the MG and DG [4–6] scheduling.

Lots of research on ADN optimal operation has been conducted in Europe, the United States and Japan. In papers [7–9] an ADN optimized operation model was proposed based on optimal power flow algorithm. It aimed at an economic operation with minimum total cost in distribution network operation and meeting the various technical constraints, by means of finding the optimal combination of various control options. Document [10] achieved reduction of distribution network investment in infrastructure by optimizing the scheduling of DG. In [11], optimal dispatching of load on demand side was proposed to meet maximum environmental benefit using the method adjustment on heat load, electric cars and other demand side load.

China is eager to carry out research in the field of ADN and its related technology. Document [12] established distributed generation scheduling models, such as wind turbine generator scheduling model, photovoltaic cell scheduling model, and micro gas turbine scheduling model. The scheduling strategy gave priority adoption on semi controllable or uncontrollable distributed generations which were mainly based on renewable energy, then the energy supplied by those controllable distributed generations is used. Besides, it established a price oriented comprehensive optimization objective function. Document [13] built a scheduling model based on the coordination of the micro grid and the grid, along with the objective function that minimized total generation cost on MG and gird. This was a coordination scheduling model with

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an economic benefit objective function, and it achieved a coordinate dispatching over MG and the grid without considering the technology influence (i.e. voltage and network loss) when AND was dispatching DG and MG. Document [14] gave a technology target model of the distribution network interaction schedule, which established minimum voltage deviation objective function through controlling of DG output power. This model did not give the affection on power supply cost of electric company due to voltage quality improvement. Document [15] put forward to an energy saving generation dispatching by coordinating between centralized dispatching and power generation enterprises' self-scheduling, as well as an user side interactive optimization scheduling based on the peak load marginal energy consumption It showed a preliminary analysis on the development of interactive energy saving scheduling optimization model and algorithm, however, further expansion and in-depth study on contents like specific mechanism, procedure, model, algorithm, technical support and application was not discussed.

Therefore, the foundation of interactive and coordinative scheduling of the AND among the grid, DG and load is that ADN offer an optimal schedule on DG and demand side load and MG. Nevertheless, the existing distribution network scheduling method is still unable to accurately reflect the random factors' affections of intermittent distributed power and load. Furthermore, a multi-objective optimization problem considering the electrical parameters, network loss and power quality while ADN is operating has not been effectively solved, under the conditions that wind or photovoltaic power prediction and complementary characteristics of MG units are involved [16,17].

Comparing with the traditional distribution network, a significant feature of the active distribution network (ADN) is that the performance of distributed generation (DG), energy storage units and micro-grid (MG) is controllable for the distribution network operator. DG will participate in the schedule of network operation, unlike the simple connection at previous time. It gives the active distribution network dispatching operation richer content, not just the tie-open switches in the traditional distribution network adjustment [18]. However, the inherent uncertainty of intermittent renewable energy power output, the different time section on coupling correlation in energy storage system caused by its own energy constraints, and the flexible position of tie-open switches in distribution network, making the optimization scheduling strategy for ADN very complex [19]. Therefore, the study on the optimization of scheduling strategy of ADN has a very important significance for the implementation of active management of distributed power and realization of economic and safe operation of the network [4,20,21].

Scheduling model of ADN

ADN dispatching can realize the resources coordination and interaction between generation side and demand side by means of data exchanging between dispatch department of electric power company and controllable DG and MG, which is under the condition that distribution network, DG and MG have complete systems over measurement, control and communication. This paper just takes into account the mathematical model of day-ahead dispatching strategy for ADN.

No matter from the control variables, constraints and the objective function, the optimal scheduling model of ADN has changed deeply compares to traditional distribution network. The control variables of ADN optimal scheduling not only include the controllable distributed generation units, such as fuel cells and diesel generators, but also consist of micro-grid units which contain energy storage units with both charge and discharge characteristics and tie-open switches in the distribution network [22,23]. It is the embodiment of core value on maximum using renewable energy by ADN that intermittent renewable generation units, such as wind power and photovoltaic power generation, does not participate in active distribution network optimization scheduling, in other words, they are uncontrollable units with maximum power point tracking (MPPT) control mode usually [24].

The objective function of ADN optimal scheduling strategy aim at optimal network loss through entire scheduling period which is unlike the traditional power flow optimal purposed on the minimum network loss or generating cost in a moment [25]. The reason is that the upper and lower limits on power generation units in traditional power grid has been a constant, it is determined by the parameters of the equipment and does not change with time. However, due to its energy restricts, the upper and lower limits of DG and MG units' output power are real-time change variables in ADN. For example, available energy of energy storage units containing in MG at the present moment completely depends on the charge and discharge strategy at the previous moment, thus the traditional optimization scheduling strategy aiming at optimal power flow in a moment goes against to energy constraints of energy storage and becomes meaningless.

Based on the above background, here focuses on the research of optimization scheduling model of active distribution network. The model takes the minimum network loss, minimum voltage deviation and minimum difference between peak and valley load as objective function with a complete scheduling period, and gives consideration of the influence on objective function by adjustment of output power of DG and MG units and changing position on tie-open switches. Besides, its control methods are DG units, MG units and tie-open switches, and the system ensures the low of energy conservation and capacity constraints during the whole dispatching period.

Objective function

The essence of ADN optimization scheduling is co-ordinate all the control methods involved to active management and achieve the minimum run loss on the premise to ensure the maximum utilization of green renewable energy. The contents of control methods covered 3 aspects: source, network and load, in other words, including the adjustment on DG' power as the representative of source control, the transformation on tie-open switches position as the representative of network control and the changing of MG' power as the representative of flexible load control. Therefore, the control vector of ADN optimization scheduling can be expressed as $[P_{DG1},\ldots,P_{DGn},P_{MG1},\ldots,P_{MGm},O]$. Where, the first n components are the output power of controllable distributed generation units, the middle m components are the power output of micro-grid units, and the last component represents scheme of tie-open switches position.

The objective function of ADN optimal scheduling can be expressed as follows:

(1) Chose the minimum power loss of the system as objective function of optimization, which is:

$$\min f_1 = P_{loss} = \min \sum_{t=1}^{T} \left(\sum_{z=1}^{z_L} G_{ij}(U_i^2 + U_j^2 - 2U_i^2 U_j^2 \cos\theta_{ij}) \right) \quad (1)$$

where T is the number of stages divided by a complete dispatching period, for each stage can be considered the distributed generation units' output power, micro-grid units' output power and load as unchanged; P_{loss} is the active power loss; z_L is the total number of system branches; U_i, U_j are node voltage amplitude for node

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