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Research on Two-level and Two-stage Scheduling Optimization Model of Distributed Photovoltaic Generation Energy System

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Abstract: Distributed PV (photovoltaic generation) is a distributed PV energy system that uses photovoltaic modules to convert solar energy into electric energy. In this paper, a two-level and two-stage scheduling optimization model and its solution algorithm under distributed PV energy system are constructed. Firstly, based on load forecasting and intermittent energy output forecasting data, this paper establishes a two-stage scheduling optimization model of distributed energy system under active distribution network. Then, the improved PSO (Particle swarm optimization) algorithm is introduced to optimize the scheduling model. Finally, the proposed model is validated by simulation results. The simulation results show that using the double-layer and two-stage scheduling strategy proposed in this paper to optimize the distributed PV energy system can not only optimize the power consumption structure, but also play the role of peak shaving and valley filling, and the state of charge of the battery has been higher than 50%, which can effectively increase its service life. Under the double-level and two-stage scheduling strategy, users get the most benefits, and the revenue growth rate is 20.07%.

Keywords: Two-level and Two-stage Scheduling; Distributed PV; Particle Swarm Optimization.

1. Introduction

Due to the trend of globalization, the world's environmental problems are becoming increasingly serious. On the factors of environmental pollution, it is mainly caused by human factors. In order to protect the environment and promote social development, we must adopt renewable energy to lay the foundation for sustainable development. Among the existing renewable energy technologies, PV (photovoltaic generation), as a power generation technology that directly utilizes solar energy, has the characteristics of green, clean and never-failing, and has great development potential [1-2]. PV uses the principle of photovoltaic effect to convert sunlight into electric energy through solar cells. The distributed PV is connected to the power grid less than 66 kV or even lower through scattered resources and small-scale power generation system. Distributed PV is a distributed PV energy system that uses photovoltaic modules to convert solar energy into electric energy [3-4].

In this paper, a two-level and two-stage scheduling optimization model and its solution algorithm under distributed PV energy system are constructed. Firstly, based on load forecasting and intermittent energy output forecasting data, this paper establishes a two-stage scheduling optimization model of distributed energy system under active distribution network. Then, the improved PSO (Particle swarm optimization) algorithm is introduced to optimize the scheduling model. Finally, the proposed model is validated by simulation results.

2. Research Method

2.1. Two-level and Two-stage Scheduling Optimization Model

At present, small distributed PV energy systems are widely used in various fields of society. It is divided into commercial PV system and household PV system. When using PV system to use electricity during the day, the power provided by PV system can be given priority. If the electric energy provided by PV system cannot ensure the normal operation of load equipment, it can be switched to the public power grid. Can support the electric energy used by the equipment. When you use electricity at night, you can use the electricity stored in the internal battery. When users have problems in using power resources, they can inform maintenance personnel through feedback channels and provide relevant information, which can better help maintenance personnel locate the problems and repair them in time.

The output power of distributed PV is small. Through the modular design, distributed PV can make the power generation scale freely adjustable, and can adjust the photovoltaic capacity system according to different sites. In the process of power generation, the distributed PV energy system can't hear noise, and it won't produce all kinds of pollution to air and water [5]. However, we also need to pay attention to the coordinated development of distributed PV and surrounding urban environment. When we use clean energy, we must consider people's concern for the aesthetic feeling of urban environment. Due to the influence of weather change, the power output of renewable energy generation is random and intermittent, which makes the optimal scheduling of microgrid increasingly complicated [6]. Usually, its active power output is predicted according to weather forecast, and its related uncertainty is simulated by probability distribution curve.

With the increase of user-side flexible load, guiding users to participate in demand response and improving users' income will not only increase the means of economic operation of microgrid, but also improve the economy and reliability of microgrid operation. Therefore, this paper proposes a double-layer and two-stage scheduling optimization method, which can reduce the operation cost of microgrid, improve the user's income and accelerate the optimization speed, and realize the distributed optimal operation of microgrid.

The user side should pay attention to the economic benefits of its participation while participating in the demand response. Flexible load has the advantages of high flexibility and strong schedule ability. In order to describe the benefits of user-side flexible load, assuming that there are m users who have reached an agreement with the load provider, the user-side optimization problem based on maximum benefit can be described as follows:

$$\begin{cases} \min \sum_{i=1}^{m} -P_i\left(l_i^l(t)\right) \\ s.t. \quad \sum_{i=1}^{m} l_i(t) = l_a(t) \end{cases} \tag{1}$$

In the formula, $l_a(t)$ is the total access amount of flexible load on the user side obtained by the load aggregator, and $l_i(t)$ represents the access amount. $P_i(t)$ is the revenue function of flexible load users.

In order to facilitate the distributed solution of the user-side model later, we equivalent the user-side revenue model, invert the user-side revenue function and minimize its negative revenue.

After the objective function of global optimal scheduling of distributed PV energy system is determined, the next step is to determine the corresponding constraints. The charging and discharging process of the battery directly affects its service life, and the discharge degree of the battery can be reflected by the SOC value. Therefore, in order to protect the battery and extend its service life, the SOC value should meet the following requirements:

$$SOC_{\min} \leq SOC \leq SOC_{\max} \tag{2}$$

Where $SOC_{\min}$ is the lowest allowable state of charge in the battery, and it is selected as 20%; $SOC_{\max}$ is the highest allowable state of charge in the battery, and is selected as 100%.

The constraint conditions of microgrid islanding operation are basically the same as those of grid-connected operation, and the difference is that the physical transmission capacity limit of the interconnection line between microgrid and distribution network does not need to be considered when microgrid islanding operation [7]. When the algorithm is implemented, the reserved margin is considered, and 0.2 is taken. The transformed inequality constraint is:

$$P_{load}(t)(1+0.2) \geq \sum_{i=1}^{M} P_i(t) - P_{loss}(t) \geq P_{load}(t) \tag{3}$$

2.2. Model Solving Process

Real-time scheduling is to adjust the current running state of each distributed energy unit in time according to the running state of distributed energy units in the current period and the charging and discharging situation of energy storage, combined with ultra-short-term load forecasting, so as to improve the effective utilization rate of distributed energy in the whole distribution network area. If the centralized optimization algorithm of conventional power management system is adopted, a perfect communication system is needed to transmit these local operation parameters to the central power management system, but the current distribution network does not have such a perfect communication system.

There are many different types and capacities of distributed power sources in microgrid, and their operating characteristics and emission characteristics are different. How to coordinate the output of distributed power sources in microgrid to minimize the operating cost of microgrid system is the problem to be solved in microgrid optimal scheduling. Optimal scheduling model is a multi-stage, discrete and nonlinear optimization problem. Considering the large search space, high efficiency and good robustness of PSO algorithm, this paper adopts the improved PSO algorithm to solve it [8-9].

The process of using PSO algorithm to optimize the problem is actually a process of finding the optimal solution repeatedly. Firstly, the randomly generated particle swarm is initialized, and then the position of the optimal particle in the particle swarm is tracked. During the tracking process, the particle value of itself is constantly updated, and the final optimal solution is determined through repeated iterations.

The dimension of particle search space is determined by specific optimization problems. Generally, the number of particle populations is about 20, and the relatively complex multi-objective optimization problem may take 10-200. A change of the position of all particles in the search space completes an iterative process [10]. Large inertia weight can make particles jump out of local optimum and strengthen global search ability; However, the smaller inertia weight can make particles search accurately in the current region, which is beneficial to convergence. For the phenomenon that the algorithm is premature and the particles oscillate near the global optimal position, the inertia weight which is linear with the number of iterations can be used to solve it:

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{K_{\max}} * k \tag{4}$$

Where ω is the current inertia weight; $\omega_{\max}, \omega_{\min}$ is the maximum and minimum inertia weight, respectively, which is generally taken as $\omega_{\max} = 0.9, \omega_{\max} = 0.4$; k is the current iteration number; $K_{\max}$ is the maximum number of iterations.

Inertia weight decreases linearly with the number of iterations, which is beneficial to determine the approximate range of the optimal solution quickly in the initial stage of the algorithm, while the particle speed slows down in the later stage, which is beneficial to accurate local search.

In order to solve the problems existing in the optimization process of the existing basic PSO algorithm, improve its optimization performance, and reasonably set the three parameters w, c_1, c_2 to avoid premature, local minimum and oscillation, this paper introduces the contraction factor φ on the basis of the basic PSO algorithm, improves the speed calculation formula in the existing PSO algorithm, and updates the running speed of each particle in the particle swarm with the improved speed formula. The improved formula is as follows:

$$\begin{aligned} & v_{ij}(t+1) = \varphi\{v_{ij}(t) + c_{1r1}\lfloor P_{i,j} - x_{i,j}(t)\rfloor + c_{2r2}\lfloor P_{g,j} - x_{i,j}(t)\rfloor\} \\ & \varphi = \frac{2}{\left|2 - C - \sqrt{C^2 - 4C}\right|} \\ & C = c_1 + c_2 \end{aligned} \tag{5}$$

3. Simulation Analysis

In order to test the performance of the proposed two-level and two-stage scheduling optimization method, a microgrid simulation model is established in MATLAB/Simulink. In this paper, the standard IEEE 30-node system is adjusted and reformed accordingly, and microgrids with different topologies are constructed to test the influence of topology changes on the proposed method and ensure the universality of the method. The fault tolerance and robustness of the method proposed in this paper are tested by simulating the broken communication line during operation.

Under isolated island operation, renewable energy is utilized to the maximum extent, and their output power fluctuation is stabilized by the storage battery, so that they can contribute according to the predicted output curve. Secondly, arrange the output of other distributed power sources, and absorb power from the battery when the load demand cannot be met. The battery can be regarded as both a load and a generating unit. The power generation unit of the test system in this paper is mainly composed of distribution network, and the energy storage unit is battery, with the maximum capacity of 400 kW, and the upper and lower limits of state of charge are 100% and 30% respectively. Before islanding operation, the battery state of charge was 40%.

According to the characteristics of distributed power supply, fans and photovoltaic cells are greatly affected by weather conditions, and their output fluctuates. Therefore, in the economic dispatch of microgrid, it is generally considered that wind turbines and PV units are unscheduled units, and their output is treated as negative load. Fig. 1 shows the predicted values of PV power under different weather types.

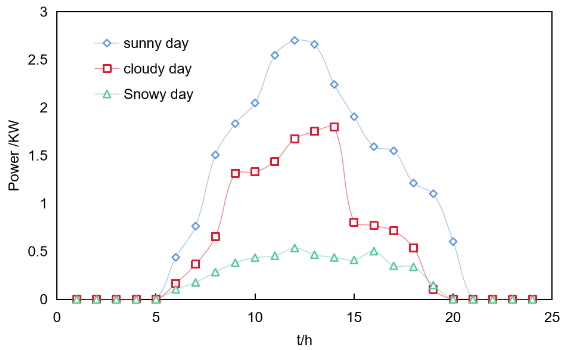

Figure 1. Predictive value of PV power under different weather types

It can be seen that the PV unit has no power output at night, and its output is large at noon during the day. On cloudy days, the power output of the PV unit is greatly reduced compared with that on sunny days, and it only improves at 3 pm, and the power output of the PV unit is very weak all day in snowy days.

Fig. 2 shows the simulation results of optimal scheduling of distributed PV energy system using traditional scheduling strategy. It can be seen that using the double-layer and two-stage scheduling strategy proposed in this paper to optimize the distributed PV energy system can not only optimize the power consumption structure, but also play the role of peak shaving and valley filling, and the state of charge of the battery has been higher than 50%, which can effectively increase its service life.

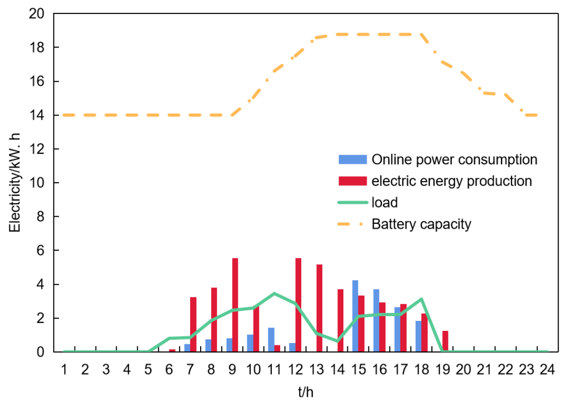

Figure 2. Optimal scheduling results of distributed PV energy system under double-layer and two-stage scheduling strategy

Table 1. Comparison of economic benefits under two dispatching strategies

Scheduling strategy	Daily income/yuan	Income growth rate
Traditional scheduling	28.593	20.07%
Our	35.778	

In addition, the economic benefits obtained by using the traditional scheduling strategy and the two-tier and two-stage scheduling strategy proposed in this paper are compared. The comparison results are given in Table 1. Through analysis, it can be seen that the benefits obtained by users are the largest under the action of the two-tier and two-stage scheduling strategy, and the income growth rate is 20.07%.

4. Conclusion

As a kind of power generation technology using solar energy directly, PV has the characteristics of green, clean and never-failing, and has great development potential. PV uses the principle of photovoltaic effect to convert sunlight into electric energy through solar cells. In this paper, a two-level and two-stage scheduling optimization model and its solution algorithm under distributed PV energy system are constructed. The simulation results show that using the double-layer and two-stage scheduling strategy proposed in this paper to optimize the distributed PV energy system can not only optimize the power consumption structure, but also play the role of peak shaving and valley filling, and the state of charge of the battery has been higher than 50%, which can effectively increase its service life. Under the double-level and two-stage scheduling strategy, users get the most benefits, and the revenue growth rate is 20.07%.

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