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Optimal Scheduling of Microgrid Based on Improved Differential Evolution Algorithm

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Abstract

In order to effectively improve energy efficiency and the reliability of the micro grid, reduce the cost of power generation and pollutant emissions, and ensure the economic, environmental protection and reliable operation of the micro grid system, the optimal scheduling of the micro grid was carried out. Optimization scheduling is a complex nonlinear optimization problem with multiple objectives, constraints and variables. In this paper, considering the economy and environmental protection of the microgrid, a multi-objective function including operation and maintenance cost, electricity reliability and pollution disposal cost is proposed, and a multi-objective differential evolution algorithm based on an index with is used to collect data from a certain region to optimize the operation of the microgrid system.

Keywords

Micro-grid, multi-objective optimization, epsilon indicator, differential evolution algorithm.

1. Introduction

The application of micro-grid is the most important part of China's sustainable development strategy and an indispensable part of energy development research. The characteristics of micro-grid lie in its independence and environmental protection. At present, China has invested a large amount of energy in the research of micro power grid, but from the research results, it still lags far behind the European and American regions, especially in the aspect of optimal control, with great potential for development. More scientific models, more intelligent control algorithms emerge.

In literature [1], the improved genetic algorithm is used to simulate the two states of island operation and grid-connected operation. According to the power output curve of each distributed power source, the parameters of the micro-grid are put into the model for calculation. Compared with the simulation results of the basic genetic algorithm, the cost of pollution treatment and operation decreased by 1.104%, and the power quality was improved to some extent. Of genetic algorithms in the literature [2], the main goal is to dense micro power grid load demand hierarchy, similar to the one to three electricity load standard in our country, the requirement for special user load demand, the optimal supply, at the same time using the adaptive weighting fusion than initial cost, the safe operation of the constraint conditions, considering internal factors, such as transmission loss and micro grid USES different scheduling policies change each DG unit power output. Literature [3] adopts weighted genetic algorithm for different objective functions, taking the island model in northern Europe as an example. The cost of the algorithm includes pollutant treatment costs and the comprehensive benefits of micro-grid. In this paper, the genetic algorithm was optimized and adaptive weights were added to ensure the stable operation of the micro grid under different natural conditions and load demands.

This paper designs a grid-connected island hybrid power grid system, including renewable energy, such as wind and solar energy. Therefore, a well-designed system can be obtained by taking advantage of their respective advantages and combining them to complement each other.

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2. Micro-grid system modeling

The MG model designed in this paper is a small power generation and distribution system composed of a clean energy generating set, a micro gas turbine, a battery and a user. It is a micro power supply system with high controllability and high independence. The structure of the micro power grid is shown in figure 1.

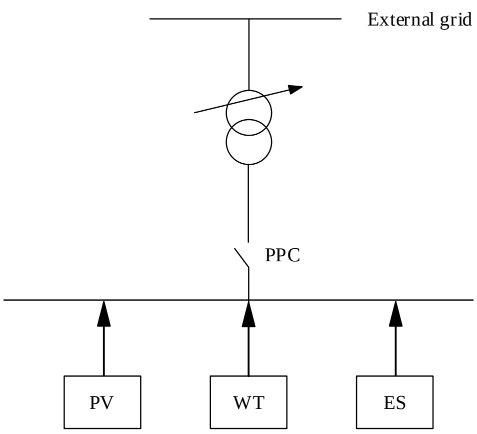

Figure 1. structure diagram of microgrid

2.1 Wind power generation

Wind energy is a typical clean energy source. China has a vast area and extremely rich wind energy reserves. China's new energy strategy plans that the total capacity should reach 20 to 30kMW in the next 15 years. With complete cleanliness; Mature wind turbine technology and flexible installation maintenance cost is low, installation time is short.

The calculation formula of wind power is as follows.

$$P_{WT} = \begin{cases} 0 & v \leq v_{ci} \parallel v \geq v_{co} \\ av^3 - bP_r & v_{ci} < v < v_r \\ P_r & v_r \leq v < v_{co} \end{cases} \tag{1}$$

$$a = \frac{{P_r}^3}{{v_r}^3 - {v_{ci}}^3} \tag{2}$$

$$b = \frac{{v_{ci}}^3}{{v_r}^3 - {v_{ci}}^3} \tag{3}$$

In the formula:

a、b represents operating characteristic parameters.

v represents the actual wind speed (measured at the rotating shaft).

P_{WT}、P_r represents the real–time power and rated power of the wind turbine.

v_{ci}、v_{co}、v_r represents the input wind speed, cutting wind speed and rated wind speed under the working state of the wind generator.

The power characteristic curve of the wind turbine is related to the actual wind speed. Generally speaking, the power frequency of the unit is determined by the input wind speed v_{ci} and the cut wind speed v_{co}. When the actual wind speed is less than the inlet wind speed, that is, the wind speed has not reached the minimum requirement, and the rotation speed of the blade is not enough to output power. When the actual wind speed is higher than the cutting wind speed, in order to be safe, it is necessary to take off the network and stop running immediately to prevent the generator from being damaged by excessively high speed. When the wind speed is between the input wind speed and the

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rated wind speed, the power curve increases linearly, and the output power increases with the increase of the wind speed.

2.2 Photovoltaic power generation

The output power of photovoltaic cells is determined by a number of variables. The decisive factors include daylight and temperature, and it is likely to be affected by the inclination Angle, curved surface shape and impedance of solar photovoltaic panels. It is affected by the fluctuation of light intensity and has the highest weight in the formula.

Expression of surface temperature of photovoltaic cell is

$$T_t = T_a + 0.0138[1 + 0.031T_a](1 - 0.042v)G_t \tag{4}$$

The output power of the photovoltaic panel is as follows.

$$P_{PV} = P_{STC} \times \frac{G_t}{G_{sd}} \times \left(1 + k \times (T_t - T_{sd})\right) \tag{5}$$

Where, T_a represents the actual ambient temperature at time t. T_t is the surface temperature of photovoltaic panel at time t. v is the wind speed in the actual environment. G_t represents the light intensity on the surface of the photovoltaic cell at time t. P_{PV} represents the output power of the photovoltaic panel when the light intensity is G_t. P_{STC} represents the maximum output power of photovoltaic cells under standard test environment. G_{sd} stands for solar radiation illumination intensity. T_{sd} represents the rated temperature of photovoltaic cells.

In order to reduce the light rejection rate, the photovoltaic generator will take the maximum output power, which is generally not suitable for the output adjustment of the work, and will not participate in the power balance scheduling of the micro grid or other adjustments for the stability of the grid.

2.3 Storage battery

Unstable uncontrollable wind and light energy resources, easily led to the decrease of the power system stability, power quality drop, certain economic loss, also brought a lot of difficulties to the optimal operation, micro power grid optimization scheduling, a buffer battery power, can greatly reduce because of the clean energy because of the environmental impact caused by the instability of electric power.

(1) battery capacity refers to all the electricity that can be discharged during the continuous discharge until termination when the battery is fully charged. The capacity is determined by the active material inside the battery.

(2) state-of-charge (SOC) refers to the ratio of the current remaining electric quantity to the total capacity. The general term is SOC. The expression is

$$SOC = \left(\frac{C_r}{C}\right) * 100\% \tag{6}$$

Where, represents the remaining electric quantity.

A SOC of 0% means the battery is no longer charged. The value of SOC of 1 means the battery cannot be charged.

(3) Depth of Charge (DOC) refers to the ratio of the available power after the battery is fully charged to the battery capacity. It reflects the current battery availability. It's normally in DOC. The expression is

$$DOC = (C - Q_e)/C \tag{7}$$

(4) Depth of Discharge (DOD) refers to the ratio between the total Discharge capacity and the battery capacity after Discharge. During use, DOD continues to decline, but the number of times of use increases exponentially. It's normally represented as DOD. The expression is

$$DOD = Q_e/C \tag{8}$$

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The battery can adjust its own output power through micro-grid dispatching, and can effectively output when the load curve fluctuates greatly, so as to optimize the equivalent load curve and ensure the stable operation of the micro-grid power system.

3. Objective functions and constraints

In this paper, a micro-grid model containing distributed power sources such as wind turbines, photovoltaic cells, micro-gas turbines and energy storage batteries is established [4], and a relatively complex, systematic and nonlinear three-objective planning problem is established [5]. The system provides an appropriate balance between economy, reliability and environmental measures.

3.1 Objective function

Goal 1: COST

The total cost (yuan/year) includes the initial cost, operation and maintenance costs of each power supply, in addition, the salvage value of each equipment shall be deducted[6-9].

$$COST = \frac{\sum i=\omega,s,b(I_i - S_{P_i} + OM_{P_i})}{N_P} + C_g \tag{9}$$

ω、s、b Represents wind power, light and energy storage equipment; I_i, S_{P_i} and OM_{P_i} respectively represent the initial cost, present value of residual value and present value of operation and maintenance cost of equipment I; N_P (years) represents the project life; C_g represents the annual cost of purchasing electricity from the public grid, assuming that the service life of the project does not exceed the service life of wind turbines and photovoltaic arrays.

The annual cost of purchasing electricity from the utility grid can be calculated as follows.

$$Cg = \sum_{t=1}^{T} P_{g,t} * \varphi \tag{10}$$

Goal 2: emission of pollutants (PE)

In the world, the requirements for ecological safety have been raised, and the regulations on emissions have become more and more stringent. Because (SO2) and (NOx) are so ecologically destructive, they are considered to be the most urgently needed pollution in the power generation industry. These emissions can be modeled by the function of linking emissions to the amount of electricity produced by a generator set. They depend on fuel consumption and are secondary.

$$PE = \alpha + \beta * \sum_{t=1}^{T} P_{g,t} + \gamma * \left(\sum_{t=1}^{T} P_{g,t}\right)^2 \tag{11}$$

Of which, α、β and γ are the coefficients that approximate the emission characteristics of generators.

Goal 3: power supply quality (EIR)

Reliability is used to evaluate the quality of power supply. Here, the energy reliability index (EIR) is used to measure the reliability of each candidate hybrid design[10]. EIR can be calculated according to the expected unserved energy (EEN) as follows.

$$EIR = 1 - \frac{EENS}{E} \tag{12}$$

$$EENS = \sum_{t=1}^{T} (P_{bmin} - P_{bsoc}(t) - P_{sup}(t)) * U(t) \tag{13}$$

$P_{bsoc}(t)$ is the battery charging level in t hours, $Pbmin$ is the minimum storage level allowed, $P_{bsoc}(t) - P_{bmin}$ represents the available power supply of the battery within t hours.

3.2 Constraint condition

Constraint 1: power balance constraint

At any time t, the total power supply of the hybrid system must provide certain reliability criteria for the total demand P_d. Such a relationship can be expressed in equations (13) and (14).

$$P_\omega(t) + P_s(t) + P_b(t) + P_g(t) \geq (1 - R)P_d(t) \tag{13}$$

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$$P_{\omega}(t) + P_s(t) + P_b(t) + P_g(t) - P_{\text{dump}}(t) \geq P_d(t) \tag{14}$$

In the formula, P_w, P_s, P_b and P_g are the electric energy absorbed and generated by wind power, solar energy and energy storage equipment and purchased from the power grid.

P_{dump} and P_d represent the output power and total load demand, respectively.

R is the ratio of the maximum unmet power and the total load demand at each moment.

The transmission loss is not considered in this paper due to the short distance of microgrid.

Constraint 2: power constraint of each generation unit

$$PG_{min}(t) \leq PG(t) \leq PG_{max}(t) \tag{15}$$

P_{min} and P_{max} is to provide the upper and lower limits of active work at time t.

In order to ensure the stable operation of the micro power supply under the rated state, the active power output must be within a certain range, otherwise it will increase the maintenance cost and affect the stability and power quality of the micro power grid.

Constraint 3: charge and discharge constraint of energy storage battery

$$P_{\text{sb}}\, min(t) \leq P_{\text{sb}}(t) \leq P_{\text{sb}}\text{max}(t) \tag{16}$$

The SOC P_{sb} of the battery shall not exceed the capacity of $P_{\text{sb}}\text{max}$ of the battery, and shall be greater than the allowable minimum storage level $P_{\text{sb}}min$; The total storage capacity of the battery shall not exceed the permitted storage capacity. Generally speaking, $P_{\text{sb}}min$ is 20% of, $P_{\text{sb}}\text{max}$, so as to avoid shortening the life of the battery caused by full charge and discharge.

4. Improved differential evolution algorithm

In this chapter, the optimal scheduling of the microgrid model is carried out by using the binary ε multiple objective differential evolution algorithm (ε-IBDE). Compared with the traditional multi-objective optimization algorithm, the calculation speed is improved and the calculation time is greatly reduced.

Step 1: initialization. Check the algorithm parameters and evaluate the objective function. The function is established to carry out the non-normalization of the population and calculate the target value.

Step 2: perform the mutation in the individual. Mutation is one of the operations that causes random changes in an individual. After the mutation, each parent x will have a new individual, called the test vector u.

To do this, take two random individuals from the population, x_2 and x_3, and create a difference vector $v = x_2 - x_3$. And then, you pick another point, which is called the basis vector x_b.

$$u = x_b + F * v = x_b + F * (x_2 - x_3) \tag{17}$$

Where F is the internal parameter and is called the scale factor.

Step 3: cross recombination. A cross-recombination is performed in the individual, combining information from the parent and the mutated individual (also known as the "experimental carrier") to produce offspring. If x is the i_th parent and u is the i_th test vector (obtained by mutation), then the descendant x_o will have the j_th coordinate of the following formula.

$$\begin{cases} x_{oj} = u_j & if\ rand_j <= CR \\ \quad x_{oj} & \quad otherwise \end{cases} \tag{18}$$

Including $rand_j$ extraction from 0 to 1 the uniform distribution of a number, the CR called interleaving. To prevent duplication, make sure that at least one of the coordinates belongs to the test vector.

Step 4: choose. This is achieved through the use of "non-dominant sorting", i.e. sorting individuals on the non-dominant front, and measuring each Prato non-dominant solution with a crowding distance[11].

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Step 5: calculate the fitness value according to I_ε index.

The multi-objective differential evolution algorithm with indexes can not only guarantee a good initial evolutionary population and make every individual fully evolve, but also reduce the complexity of the algorithm. The orthogonality of the matrix and the quantization of the continuous space, the diversity of the population and the uniformity of the distribution are maintained by the ε-IBDE algorithm with the index of. Moreover, this index-based differential evolution algorithm can approach Pareto frontier well.

5. Simulation results

In this paper, a residential area in a peninsula region is selected. According to the data of wind and solar energy resources per hour on June 5, 2019.The curve of daily light intensity is shown in figure 2. The daily wind speed curve is shown in figure 3. The daily load curve is shown in figure 4.

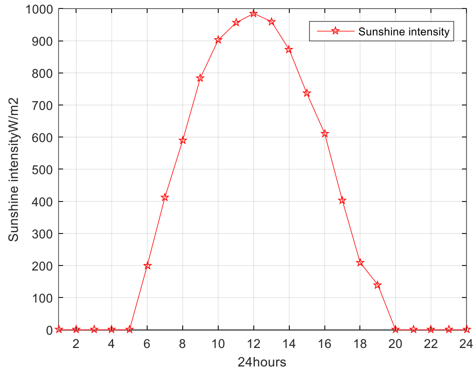

Figure 2. curve of daily light intensity

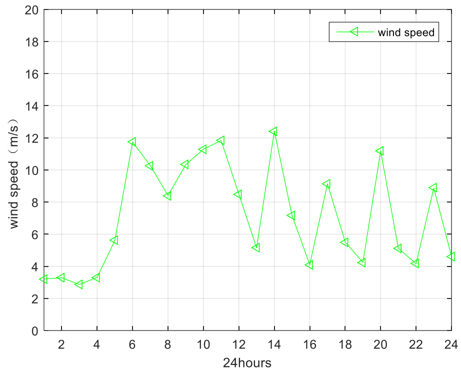

Figure 3. curve of wind speed on day

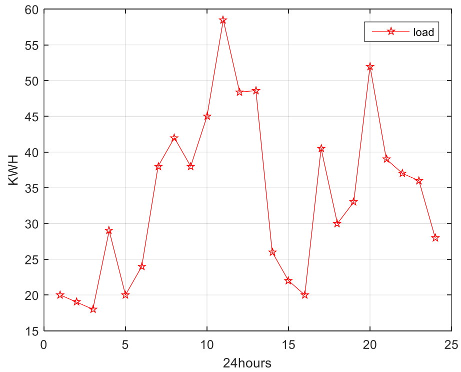

Figure 4. daily load curve

In the algorithm parameters, the population is set to 100, the maximum number of iterations is 300, the scaling factor is $F = 0.5$, and the crossover coefficient is $CR = 0.3$.

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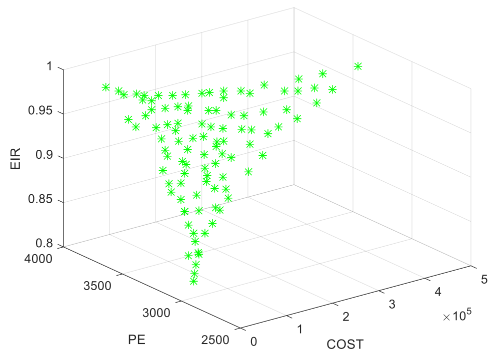

Figure 5. the Prato front of ε-IBDE algorithm

It can be seen from the obtained three-objective equilibrium surface that the non-dominant solution is smooth and uniformly distributed on the surface, and Pareto front is very wide, which can provide a group of representative decision data. Decision makers can choose specific solutions based on system design requirements and local policies or experiences.

6. Conclusion

The essence of the optimal scheduling problem of microgrid is not only a multi-objective programming problem, but also a typical nonlinear optimization problem. In this paper, a grid-connected hybrid power generation system is designed by using the ε-IBDE algorithm. Three design objectives are considered, including operation and maintenance cost, electricity reliability and pollution disposal cost, so as to achieve a balance among the three objective functions. The decision maker can select different non-dominant solutions according to the requirements of different systems. Although the percentage of distributed generation using renewable resources is a small fraction of the world's current electricity supply, it is expected that more and more demonstration projects, more and more talent and money will be invested in this project in the coming years.

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