Multi-objective optimal dispatching of microgrid based on improved genetic algorithm

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Abstract. Aiming at the optimization problem of micro-grid energy dispatch, the environmental benefit, system operation and maintenance cost, start-stop cost and main grid electricity price are proposed as the objective function, and the influence of the actual operation constraints of micro-grid system and the distributed non-scheduled new energy are taken into account at the same time. The multi-objective optimal dispatching model of microgrid is constructed, and the model is solved based on improved genetic algorithm. The numerical simulation results show that compared with the traditional single-target scheduling method of microgrid, the optimal scheduling method of this paper is beneficial to the micro-grid in the process of scheduling decision-making to achieve the overall coordination of economic, environmental and social benefits of microgrid.

1. Introduction
With the increasing emphasis on energy and environmental issues worldwide, renewable distributed generation (DG) is receiving increasing attention from all countries. As a controllable unit of the distribution network[1], the microgrid can schedule and adjust the internal power supply[2]. At the same time, the microgrid must meet the local load demand and power quality, optimize the power supply plan, and ensure the stability, reliability and economy of the microgrid operation[3].

In reference [4], a safe economic dispatching method based on Tabu search algorithm for source / load of micro grid is proposed. In reference [5], a method for economic dispatch of microgrid considering energy storage benefit is proposed. In reference [6], based on the difference of electricity price in microgrid, a multi-agent bidding method was proposed to optimize the operation of micro-grid, and the benefit distribution model of distributed generation was established. In reference [7], a model of microgrid optimization based on chaotic particle swarm optimization algorithm is proposed. By introducing the inertial weight of linear differential decrement and the learning factor of linear adjustment, we can avoid falling into local optimum and improve the global searching ability.

In this paper, energy consumption cost, environmental benefit, system operation and maintenance, starting and stopping cost and main network price are considered as decision variables, and the influence of the actual operation constraints of micro-grid system and distributed non-schedulable new energy are considered. A multi-objective optimal dispatching model for micro-grid is constructed. The objective function and constraint conditions of the established model are simplified and processed by penalty function method, and the improved genetic algorithm is applied to solve the objective function. The results are analyzed to verify the correctness and accuracy of the model and algorithm.
2. Microgrid dispatching model

2.1. Scheduling objective function

The objective of this paper is to minimize the comprehensive cost of microgrid in a typical day. The start-up and shutdown state and unit output of dispatchable generators in microgrid are taken as decision variables, and various constraints are taken into account to optimize the calculation. Among them, the comprehensive cost includes the operation cost of diesel generators and fuels, start-up and shutdown costs, maintenance costs of all microgrid units including distributed wind and photovoltaic power generation, environmental benefits of microgrid itself and the cost of purchasing electricity from the main network. The objective functions are:

\[
\min C(S_i(t), P_i(t)) = \sum_{i=1}^{24} (C_1 + C_2 + C_3 + xC_4 + yC_5 + C_6) \tag{1}
\]

Where \(C_1\) is the fuel consumption cost of the micro-grid system in time period \(t\). \(C_2\) is the operation and maintenance cost of the system. \(C_3\) is the cost of environmental effects. \(C_4\) is the starting and stopping cost of the unit. \(C_5\) is the cost of interacting with the main network. \(C_6\) is the converted cost of the energy storage device. When the system is connected to the grid, \(x=1\), \(y=0\). When the system is running in an isolated network, \(x=0\), \(y=1\). \(P_i(t)\) is the active power output of the DG in the micro-grid system in time period \(t\).

\[
C_1 = C_{DE}(P_i(t)) + C_{FC}(P_i(t)) = a_i P_i^2(t) + b_i P_i(t) + c_i + C_{\text{fuel}} \sum_{i=1}^{n} \frac{P_i(t)}{\eta_i(t)} \tag{2}
\]

In the form: \(C_{DE}(\cdot)\) is the energy cost of diesel generators; \(a_i\), \(b_i\), \(c_i\) are the fuel cost factors of diesel generators; \(C_{FC}(\cdot)\) is the energy cost of fuel cells; \(C_{\text{fuel}}\) is the price of gaseous fuel; \(\eta_i(t)\) is the fuel utilization rate of the fuel cell, that is, the ratio of the output electrical energy to the input fuel.

\[
C_2 = K_{\text{omt}} P_i(t) + K_{\text{ormv}} P_w(t) + K_{\text{ompp}} P_{pv}(t) \tag{3}
\]

Where \(K_{\text{omt}}\) is the cost coefficient of the i-th DG operation management in the microgrid system; \(P_w(t)\) and \(P_{pv}(t)\) are the output of wind turbines and photovoltaics at time \(t\).

\[
C_3 = C_{K} \gamma_i P_i(t) \tag{4}
\]

Where \(C_K\) is the cost of treating pollutants; \(\gamma_i\) is the pollutant coefficient corresponding to different power production methods.

\[
C_4 = C_{i,\text{su}} S_i(t)(1-S_i(t-1)) + C_{i,\text{sd}} S_i(t-1)(1-S_i(t)) \tag{5}
\]

Where \(C_{i,\text{su}}\), \(C_{i,\text{sd}}\) is the start-up and shutdown cost of the diesel generator set; \(S_i(t)\) is the working state of the i-th DG in the micro-network system during t period, 0 means stop, 1 means run.

\[
C_5 = C_G(t) C_{gp}(t) - C_S(t) C_{sp}(t) \tag{6}
\]

Where \(C_G(t)\) is the purchase price of the microgrid system to the main network system during the \(t\) period; \(C_{gp}(t)\) is the power purchased by the microgrid system to the main network system during the \(t\) period; \(C_S(t)\) is the price of electricity sold by the microgrid system to the main network system during the \(t\) period; \(C_{sp}(t)\) is the electricity sold by the microgrid system to the main network system during the \(t\) period. When \(C_{gp}(t) = C_{sp}(t) = 0\), it is established for each \(t\) period, then the microgrid is in an independent operation state.
\[ C_n(t) = \frac{1}{P_c} \times C_{cap} \times \frac{r(1 + r)^n}{(1 + r)^n - 1} \times \sum_{i=1}^{24} P_i(t) \]  

Where \( r \) represents the depreciation rate, \( n \) indicates the service life of the energy storage device; \( T_a \) represents the number of hours of annual operation of the energy storage unit; \( P_{an} \) indicates the rated output power of the energy storage device; \( C_{cap} \) is the actual power of the energy storage device in the \( t \) period.

2.2. Constraint condition

(1) Power balance constraint:
\[ \sum_{i=1}^{24} S_i P_i(t) = P_c(t) - P_{pv}(t) - P_{wt}(t) \]  

(2) Distributed generation unit output power constraint:
\[ P_{min}^i \leq P_i(t) \leq P_{max}^i \]  

(3) Storage capacity constraint:
\[ 0 \leq P_i(t) \leq P_{max}^i \]  
\[ S_{OC_{max}} \leq S_{OC}(t) \leq S_{OC_{min}} \]  

(4) The transmission capacity constraints between the microgrid and the main network:
\[ P_{GRID}^{min} \leq P_{GRID}(t) \leq P_{GRID}^{max} \]  

(5) Spinning reserve constraint:
\[ \sum_{i=1}^{24} S_i P_i(t) \geq P_c(t) + R_L \]  

In the formula: \( P_{max}^i, P_{min}^i \) is the upper and lower limit of the power output of the DG unit in the microgrid; \( P_{BAT}(t) \) is the charge and discharge power of the energy storage battery, positive when charging, negative when discharging; \( P_{max}^i \) is the maximum charge and discharge power of energy storage battery; \( S_{OC}(t) \) is the state of charge of the energy storage during the \( t \) period; \( S_{OC_{max}}(t), S_{OC_{min}}(t) \) is the maximum and minimum residual capacity of the energy storage unit; \( P_{GRID}^{max}, P_{GRID}^{min} \) is the upper and lower limits of the capacity between the microgrid system and the main network system can be allowed to interact; \( R_L \) is the spinning reserve capacity..

3. Model solution

3.1. Improvements in selection, crossover, and mutation processes

In order to effectively prevent local optimality, this paper adopts the tournament selection method, that is, each time randomly selects \( r_1 \) individuals from the previous generation population (the probability of each individual being selected is the same) and compares the fitness values of each body to select the adaptation. For the individual with the largest value, the above method is repeated \( R \) times, and the obtained individual constitutes a new generation of population. Compared to the roulette selection method, the tournament selection method does not have to convert the fitness function value.

In the process of crossover, a single-point crossover method is adopted, that is, a certain number of individuals are randomly selected from the population according to a certain intersection rate, and these individuals are randomly paired, and then each genetic position is randomly selected as an intersection point for each pair of individuals. The intersections begin to exchange the chromosomes of two individuals, resulting in two new individuals.
In order to strengthen the local search ability and improve the convergence speed, the mutation process adopts the method of single-point Gaussian variation. The mutated sub-individual can be expressed as:

\[
x_{r2} = x_{r1} + \sigma_{r2} N(0,1)
\]

\[
\sigma_{r2} = \sigma_{r1} \exp\left(\tau N(0,1) + \tau N'(0,1)\right)
\]

\[
\tau = \left(2(N+1)\right)^{1/2}, \quad \tau = \left[2(N+1)^{1/2}\right]^{1/2}
\]

In addition, in order to preserve the optimal solution of the problem to be optimized in the iterative process, an elite retention strategy can be adopted, that is, the current optimal individual directly enters the next generation.

The improved genetic algorithm flow chart is shown in Figure 1.
3.2. Treatment of constraint conditions

For constrained optimization problems, the constraints increase the complexity of the model solution. In order to reduce the difficulty of solving, the penalty function method is used to transform the existing constrained optimization problem into an unconstrained problem.

In the model of this paper, the constraints involved are (9)–(13), which are treated by penalty function:

$$\min F = C + \sigma|\Delta P|$$

In the form: $\sigma$ is the penalty factor; $\Delta P$ is the exceedance threshold of power.

Searching in the coding space using genetic algorithms inevitably leads to illegal individuals, i.e., infeasible solutions. Here, the penalty method is used to deal with the constraint, and the penalty for the infeasible solution converts the constraint problem into an unconstrained problem. Can be expressed as:

$$\min f(x) = f(x) + \sum_k P_k(P_k(t))$$

The penalties are defined as:

$$P_k(P_k(t)) = \begin{cases} 0 & \text{if } P_k(t) \text{ satisfies the condition } k \\ M_k & \text{otherwise} \end{cases}$$

In the form: $M_k$ is a large constant, and its size is determined by the importance of the importance of the constraint conditions.

4. An example Analysis of optimal dispatching in Microgrid

4.1. Example parameter

Taking the typical spring and autumn days of a microgrid in northwest China as an example, its structure is shown in Figure 2. Set 24 time periods of 1 day as the scheduling period, and optimize the daily scheduling of the micro network. The microgrid includes a fuel cell (FC) and four sets of diesel generator sets (DE), a wind farm (WT), a photovoltaic power station (PV) and a set of batteries (BT). The upper and lower limits of the state of charge of the battery are 100% and 20%, respectively. The upper limit of the transmission capacity of the communication line between the microgrid and the distribution network is 60 kW. The operating parameters and operational management coefficients of each DG are shown in Table 1 to Table 4. Time-of-use price are shown as Figure 3. The population size of the genetic algorithm is set to 20, the number of iterations is 200, and the crossover efficiency and mutation probability are 0.05 and 0.8, respectively.

![Figure 2 Typical structure of the microgrid](image)

![Figure 3.time-of-use price](image)

| Table 1 Operation parameter and management coefficient of micro sources |
|------------------|---|---|---|---|---|---|
| DG Type | PV | WT | FC | DE | BS |
| --- | --- | --- | --- | --- | --- |
| --- | --- | --- | --- | --- | --- |

| DG Type | PV | WT | FC | DE | BS |
| --- | --- | --- | --- | --- | --- |
| 0.17 | 0.49 | 0.65 | 0.13 | 0.38 | 0.83 | 0.83 |

yuan/kWh
| Lower power limit (kW) | 0 | 0 | 0 | 0 | -30 |
|-----------------------|---|---|---|---|-----|
| Power upper limit (kW) | 6 | 12 | 30 | 30 | 30 |
| Operation management coefficient $K_{OM}$ (yuan/kWh) | 0.0096 | 0.0296 | 0.0293 | 0.088 | - |
| CO₂ Emission coefficient | 0 | 0 | 490 | 650 | - |
| SO₂ Emission coefficient | 0 | 0 | 0.0028 | 0.21 | - |
| NOₓ Emission coefficient | 0 | 0 | 0.0098 | 9.9 | - |

Table 2 Fuel cell Parameters

| $C_{fuel}$ (yuan/m³) | $\eta$ | $LHV_f$ (kWh/m³) |
|----------------------|--------|------------------|
| 4.375 | 80% | 9.7 |

Table 3 Battery Parameters

| Rated capacity (Ah) | Rated power (kW) | Number of running hours per year (h) | Useful life (years) | Annual depreciation rate | Total investment cost (yuan) |
|---------------------|------------------|--------------------------------------|--------------------|-------------------------|----------------------------|
| 100                 | 30               | 8760                                 | 15                 | 6.3%                    | 40000                      |

Table 4 Diesel generator Parameters

| Parameters | 1  | 2  | 3  | 4  |
|------------|----|----|----|----|
| a          | 0.168 | 0.168 | 0.0505 | 0.0674 |
| b          | 2.105 | 1.68 | 1.263 | 2.739 |
| c          | 0.04 | 0.04 | 0.03 | 0.03 |
| Maximum force/MW | 80 | 55 | 55 | 55 |
| Minimum force/MW | 20 | 10 | 10 | 10 |

Figure 4. Undistributable unit output prediction and electric load forecasting

4.2. Optimization result
A. The optimization results of Grid-connected operation:
Figure 5. Power optimization results of microgrid under grid-connected operation

As can be seen from Figure 5, in the typical spring and autumn days, power generation of WT and PV is preferentially used. The power generation cost of FC and DE during 0:00-11:00 is higher than the purchase price, while the total output power of wind power and photovoltaic power generation is small, so the power is purchased from the main network to meet the power shortage. The power generation costs of FC during 12:00-14:00 and 17:00-23:00 are lower than the price of electricity purchase and electricity sales, so it works at rated power, and the remaining power shortage is provided by the main network. Among them, BT is not involved in regulation during periodic charge and discharge, and the charge and discharge cycle is 6 hours.

B. The optimization results under isolated network operation

As can be seen from Figure 6, wind power and photovoltaic power generation are preferred in the typical spring and autumn days when the microgrid is running on isolated islands. When BT is in discharge state, the BT device is preferred. From 0:00 to 6:00, although the total output of WT and PV is low, but the load demand is small, so the load demand can be met by FC power generation and BT discharge with lower generation cost; From 7:00 to 13:00, the output of WT and PV increases. In order to meet the increased load demand, the output of FC increases, and DE starts to generate electricity gradually, and as the peak period of electricity consumption enters, more DE units participate in power generation; From 13:00 to 17:00, the output of WT and PV increases. Load decreases, BT starts to discharge after charging to supply load; From 17:00 to 20:00, load begins to increase, BT continues to discharge, 1-3 DE output, FC gradually reaches the rated power, all DE participate in power generation if necessary; From 20:00 to 24:00 load decreases, all units’ output decrease, BT enters the charging state.

4.3. Optimization result analysis

In order to verify the effectiveness of the optimized scheduling method, combined with the typical data of spring, autumn, summer and winter, the comprehensive cost before and after optimization is compared. Before the optimization, all WT and PV generations in the microgrid will generate electricity as much as possible. In the grid-connected operation mode, DE and FC will all generate electricity as much as possible. If there is still a shortage, the electricity from main network will be purchased to meet the load demand and if there is a surplus of electricity they will be sold to the main network; When it is in the island mode of operation, FC is preferred to meet the load demand, and DE is started to generate...
electricity if it is not satisfied. Comparisons of daily combined costs before and after optimization are shown in Table 5.

Table 5 Comparison of daily comprehensive cost of system before and after optimization

|            | Grid-connected | Grid-isolated |
|------------|----------------|---------------|
|            | before | after | decline | before | after | decline |
| Spring&Autumn | 645.32 | 605.02 | 6.24%   | 677.51 | 656.9 | 3.05%   |
| Summer     | 698.74 | 652.72 | 6.59%   | 710.42 | 664.3 | 6.50%   |
| Winter     | 702.24 | 672.31 | 4.26%   | 714.75 | 673.5 | 5.78%   |

It can be seen from Table 5 that in the two modes of grid-connected and isolated networks, the micro-store optimization scheduling method proposed in this paper can meet the typical load requirements of each season and can effectively reduce the comprehensive cost of the micro-grid.

5. Summary

In this paper, environmental benefit, system operation and maintenance, start-stop cost and main grid price are taken as objective functions. Considering the actual operation constraints of micro-grid system and the influence of distributed unschedulable new energy, a multi-objective optimal scheduling model of micro-grid is constructed. The improved genetic algorithm is used to solve the model. Compared with the traditional single-target scheduling method of microgrid, the optimal scheduling method is beneficial to the micro-grid in the process of scheduling decision-making to realize the overall coordination of economic, environmental and social benefits of microgrid.

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