Research on Multi-Objective Optimal Dispatch of Microgrid Containing Electric Vehicles Based on Improved NSGA-II Algorithm

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Abstract. In this society where resources are increasingly scarce, the microgrid is developing rapidly in anticipation, due to the random energy storage characteristics of electric vehicles, the integration of electric vehicles in the microgrid is of great significance to suppress the volatility of new energy. In this paper, a microgrid model of renewable energy, energy storage equipment, micro-turbine and electric vehicles is established, and the impact of time-sharing electricity prices on system operation is fully considered. With the operating cost of the microgrid system and the cost of environmental pollution control as the goal, use the improved NSGA-II to solve. The effectiveness of the proposed microgrid optimization model is verified through analysis of examples, and compared with the standard genetic algorithm algorithm to solve the model. The results show that the improved algorithm can effectively improve the algorithm's operation efficiency and optimization ability, and in the microgrid Access to electric vehicles can also reduce environmental pollution and reduce the cost of operating microgrid systems.

1. Introduction
The microgrid network is of great significance for achieving renewable energy development and building a low-carbon society. The current rapid development of the microgrid has changed the status of energy consumption. According to the IEA’s Global Electric Vehicle Outlook report, global sales of electric vehicles exceeded 2.1 million in 2019. It is estimated that by 2020, the number of electric vehicles in the world will be close to 10 million. Safe, reliable, flexible, economical, energy-efficient microgrids and green, environmentally friendly, and low-noise electric vehicles are gradually gaining attention from all walks of life [1]. Therefore, the efficient and economical operation of electric vehicles and microgrids has become a popular research direction.

At present, domestic and foreign scholars have achieved a lot of research results on the optimization dispatch of microgrids. Literature [2] established a microgrid optimization model that considers the cost of power generation and pollutant emissions, and uses fuzzy decision-making to give economic and environmental costs. Different weight coefficient values are solved by improved particle swarm optimization algorithm. Literature [3] proposed a multi-objective scheduling model of microgrid with the goal of operation and maintenance cost and environmental pollutant cost, introduced variable inertia weight and chaos theory to improve the particle swarm optimization algorithm, and proposed a dynamic fuzzy multi-objective chaos particle swarm optimization algorithm (FCPSO). The literature [4] proposes
a microgrid energy optimization scheduling strategy aiming at maximizing operator purchase and sale revenue and minimizing demand response compensation costs, through the internal generation side and users of the microgrid in the market environment. The interaction of side resources enables demand response resources to participate in all levels of scheduling, realizing the coordination and optimization of day-to-day-real-time scheduling. Literature [5] proposed a microgrid scheduling method that considers the electric vehicle load of time-sharing electricity price, and uses weighted particle swarm optimization (PSO) to obtain the optimal scheduling strategy.

In this paper, a microgrid model containing electric vehicles is established, and a scheduling model with the lowest system operating cost and the least environmental pollution is established. In view of the shortcomings of the current heuristic algorithm, the improved genetic algorithm is used to simulate the proposed model to prove the effectiveness of the proposed model algorithm. Other paragraphs are indented.

2. Construction of multi-objective optimization model for connecting electric vehicles in microgrid

2.1. Wind turbine model

A wind turbine is a power generation device that converts wind energy into electrical energy. Its output power is related to factors such as wind speed and installed capacity. The mathematical model of the output power of the wind turbine is as follows:

$$P_{WT}(t) = av^3(t) + bv^2(t) + cv(t) + d; v_{in} \leq v(t) \leq v_{out}$$  \hspace{1cm} (1)

In the formula: $v_{in}$ and $v_{out}$ are the unit's cut-in, cut-out wind speed; $a$, $b$, $c$, and $d$ are polynomial coefficients, which can be obtained according to the power wind speed curve fitting.

2.2. Photovoltaic power generation system model

In this paper, the solar light intensity is used to represent the output power of the photovoltaic power generation panel. The mathematical model is as follows:

$$P_{pv} = P_{ST} G_T \left[1 + k (T_C - T_R) \right]/G_{ST}$$  \hspace{1cm} (2)

In the formula: $G_{ST}$ is the solar radiation intensity under standard test conditions; $k$ is the temperature coefficient, approximately -0.0047 degrees Celsius; $T_C$ is the battery surface temperature; $T_R$ is the reference temperature; $P_{ST}$ is the maximum test power under standard test conditions.

2.3. Miniature gas turbine model

$$P_{EMT} = P_{gas} * \eta_{EMT}$$  \hspace{1cm} (3)

$$V_{MT}(t) = \frac{P_{gas}}{LNG} \Delta T$$  \hspace{1cm} (4)

In the formula: $P_{EMT}$ is the output electric power of MT (KW); $P_{gas}$ is the natural gas power consumed by MT (KW); $\eta$ is the power generation efficiency of MT; $V_{MT}(t)$ is the consumption of natural gas at time $t$ (m$^3$); $\Delta T$ is the unit dispatch Time; LNG is the low heating value of natural gas, generally taken as 9.78 (KWh)/m$^3$.

2.4. Battery model

$$E_{BT}(t) = E_{BT}(t-1) \cdot (1 - \sigma_{bt} + \eta_{bt-c} P_{bt-c}(t) - \frac{P_{bt-d}(t)}{\eta_{bt-d}}) \cdot \Delta t$$  \hspace{1cm} (5)

$$E_C-SOC_{min} \leq E_{BT}(t) \leq E_C-SOC_{max}$$  \hspace{1cm} (6)
In the formula: $E_{BT}(t)$, $E_{BT}(t-1)$ are the storage capacity (KWh) of the battery at time $t$ and $t-1$; $P_{br-c}(t)$, $P_{br-d}(t)$ are the battery The charge and discharge power at time $t$, $\Delta t$ is the time interval; $\sigma_{bt}$, $\eta_{bt-c}$, $\eta_{bt-d}$ are the energy loss rate, charging efficiency and discharge efficiency of the battery; $SOC_{min}$, $SOC_{max}$ is The minimum and maximum state of charge of the battery.

2.5. Electric car model

It is assumed that the battery capacity of the daily rechargeable electric vehicle, the average charging power of the electric vehicle and the average power consumption per kilometer are fixed values, and there is no limit to the charging time [6].

$$Sc = \sum_{n=1}^{N} \int_{t_0}^{t_0+T_c} P_c(t)dt$$

In the formula: $S_c$ is the total charging capacity; $N$ is the number of electric vehicles connected to the microgrid; $t_0$ is the charging start time; $T_c$ is the connection duration; $P_c(t)$ is the average charging power.

Under the average charging power, the charging connection duration meets the following formula:

$$T_c = \frac{S_c - dW}{P_c(t)}$$

In the formula: $S_i$ is the battery capacity; $d$ is the daily mileage; $W$ is the average power consumption per kilometer.

3. Objective function of economic-environmental benefit optimization model for microgrid access to electric vehicles

In this paper, the multi-objective optimal scheduling of micro-grids connected to electric vehicles is to reasonably allocate the output of each micro-source under the condition of meeting load requirements and all constraints to achieve the purpose of the lowest operating cost of the micro-grid system and the smallest environmental pollution. Objective function C For the system operating cost $C1$ and the total environmental cost $C2$.

3.1. Objective function

(1) The system operation cost includes: fuel cost, equipment operation and maintenance cost, equipment start-stop cost, energy storage equipment depreciation cost, and total cost of electrical energy interaction between the system and the power grid:

$$\min C1 = \sum_{t=1}^{T} \left[ C_{F}(t) + C_{OM}(t) + C_{GE}(t) + C_{SS}(t) + C_{BW}(t) \right]$$

In the formula: $C_{F}(t)$, $C_{OM}(t)$, $C_{GE}(t)$, $C_{SS}(t)$ and $C_{BW}(t)$ are the system operation fuel cost, system operation and maintenance cost, two-way power interaction cost with the grid, system equipment start-stop costs and system storage Energy equipment depreciation cost; $T$ is a scheduling cycle.

(2) The total cost of environmental treatment to control sulfur dioxide, carbon dioxide, carbon and nitrogen oxides and other gas emissions:

$$\min C2 = C_g + C_s$$

In the formula: $C_g$ is the degree of harmfulness of gases such as sulfur dioxide, carbon dioxide and carbon and nitrogen oxides to the atmosphere, and $C_s$ is the converted amount of various pollutants generated for each micro-source.
3.2. Restrictions

The constraints of the model mainly include power balance constraints, equipment capacity and operation constraints, battery power constraints and grid interaction constraints.

(1) Power balance constraints

\[
P_{WT}(t) + P_{PV}(t) + P_{MT}(t) + P_{\text{grid}}(t) = P_L(t) \quad (11)
\]

\[
Q_{MT} + Q_{\text{GB}} - Q_{\text{HE}} + H_{EH} + H_{TS} = Q_{L-H} \quad (12)
\]

\[
\sum_{i=1}^{N} P_i + P_g = P_{\text{LOAD}} + P_{EV} \quad (13)
\]

\[
SOC^{\text{min}}_{EV} \leq SOC_{EV}(t) \leq SOC^{\text{max}}_{EV}, \forall t \quad (14)
\]

In the formula: \( P_{WT}(t), P_{PV}(t), P_{MT}(t) \) are the power generated by wind turbines, photovoltaic arrays and micro gas turbines; \( P_{\text{grid}}(t) \) is the interactive power between the microgrid and the large power grid; \( P_L(t) \) is the load prediction power; \( Q_{MT}, Q_{\text{GB}}, Q_{\text{HE}}, H_{EH}, H_{TS} \) is the thermal power required by the micro gas turbine, gas boiler, waste heat recovery boiler, electric boiler and heat storage tank, \( Q_{L-H} \) is the predicted power of the load; \( P_i \) is the total power of all micro sources in the micro grid; \( P_g \) is the grid-connected power, positive The value indicates that the microgrid absorbs power from the large grid, and the negative value represents the output power of the microgrid to the large grid; \( P_{\text{LOAD}} \) is the power absorbed by the load in the microgrid; \( P_{EV} \) is the electric vehicle charging power, and the positive value indicates that the electric vehicle absorbs power from the microgrid, negative The value represents the output power of the electric vehicle to the microgrid; \( SOC^{\text{min}}_{EV} \) and \( SOC^{\text{max}}_{EV} \) respectively represent the minimum state of charge and the maximum state of charge of the battery of the electric vehicle.

(2) Equipment capacity and operation output constraints

\[
P^{\text{min}}_i \leq P_i \leq P^{\text{max}}_i \quad (15)
\]

\[
P^{\text{min}}_g \leq P_g \leq P^{\text{max}}_g \quad (16)
\]

\[
0 < P_{WT} \leq P_{\text{fore}}^{\text{WT}} \quad (17)
\]

\[
0 < P_{PV} \leq P_{\text{fore}}^{PV} \quad (18)
\]

\[
P^{\text{MT, min}} \leq P_{MT} \leq P_{\text{MT, max}} \quad (19)
\]

\[
P_{\text{MT, down}} \leq P_{MT}(t) - P_{MT}(t-1) \leq P_{\text{MT, up}} \quad (20)
\]

In the formula: \( P_i \) is the actual total power of each microsource in the microgrid; \( P^{\text{min}}_i, P^{\text{max}}_i \) is the upper and lower power limits of the i-th microsource; \( P_g \) is the interactive power of the microgrid and the large grid; \( P^{\text{min}}_g, P^{\text{max}}_g \) is the upper and lower limits of the interactive power of the microgrid and the large grid; \( P_{\text{fore}}^{\text{WT}}, P_{\text{fore}}^{PV} \) is the predicted power of the wind turbine and photovoltaic; \( P^{\text{MT, min}} \) and \( P^{\text{MT, max}} \) are the minimum and maximum output power of the micro gas turbine; \( P_{\text{MT, down}} \) and \( P_{\text{MT, up}} \) are the climbing power of the micro gas turbine.
4. Fast non-dominated sorting genetic algorithm II optimization model based on enhanced crossover operator

(1) Solution

In the field of multi-objective optimization, NSGA-II [7] (Non-Dominated Sorting Genetic Algorithm, NSGA) is a classic algorithm, a multi-objective optimization strategy based on the basic genetic algorithm, because it is in the field of multi-objective optimization The advantages. The main technology of the non-dominated sorting genetic algorithm is [8]: First, for the characteristics that the fitness of the multi-objective problem is difficult to determine directly, the non-dominated sorting algorithm is used to carry out non-dominated stratification of the population, and the virtual fitness value is assigned. The next genetic operation; second, the shared niche technology is used to reassign the virtual fitness on the same non-dominated layer, maintaining the uniform distribution of Pareto's optimal solution set. Its main functions are reflected in two strategies, namely non-dominated sorting and crowding distance. The non-dominated sorting strategy is to divide the population individuals into multiple non-dominated fronts. The essence is to distinguish individuals (collections) with different degrees of evolution through the dominant relationship. The crowding distance is an index used to measure the crowding degree between an individual and an adjacent individual. Its main concern is the uniformity between individuals.

Let P1, P2, and P3 be the individuals selected using the tournament strategy, then the standard crossover algorithm can be expressed as follows [9]:

\[ Q1 = \frac{(P1 + P2)}{2} + \beta \times \frac{(P1 - P2)}{2} \]  
\[ Q2 = \frac{(P1 + P2 + P3)}{3} + \beta \times \frac{(P1 - P2 - P3)}{3} \]  

For the multi-objective optimal dispatch model of microgrid in this paper, the process of fast non-dominated sorting genetic algorithm with enhanced crossover operator is shown in the figure

![NSGA-II flow chart](image-url)
(2) Example analysis

The calculation period of the example is one day, divided into 24 periods [10]. The load data and time-sharing electricity price of the microgrid are predicted based on historical data as shown in Figure 2 and Figure 3. Among them, the maximum output power of the photovoltaic array is 400 kW and the fan. The rated output power is 200 kW, the total output power of the micro gas turbine is 300, the battery uses a lead-acid battery, which $SOC_{\text{max}} = 200 \text{ kW} \cdot \text{h}$, $SOC_{\text{min}} = 50 \text{ kW} \cdot \text{h}$, the maximum charge and discharge power is 30 kW, the charge and discharge efficiency is 0.85, energy storage. The initial battery = 50 kW·h. The microgrid is connected to 100 electric vehicles, the total capacity of the on-board lithium battery is $SOC_{EV} = 2000 \text{ kW} \cdot \text{h}$, the maximum charge and discharge power is 80 kW, $SOC_{EV}^{\text{min}} = 80 \text{ kW} \cdot \text{h}$, and other loads in the microgrid are 600 kW.

Table 1. Time-of-use electricity prices.

| Status | Period       | price (yuan/(kW·h)) |
|--------|--------------|---------------------|
| Peak   | 17:00~22:00  | 0.870               |
| Level  | 9:00~16:00   | 0.621               |
| Valley | 1:00~8:00, 23:00~24:00 | 0.434               |

Table 2. Environmental pollution control costs

| Pollutant | FC/MTemission/ (g·(kW·h)$^{-1}$) | Grid connection/ (g·(kW·h)$^{-1}$) | Processing fee/ (yuan·kg$^{-1}$) |
|-----------|---------------------------------|----------------------------------|---------------------------------|
| NO$\text{x}$ | 0.014                           | 0.2                              | 0.5095                          | 8                               |
| SO$\text{2}$ | 0.003                           | 0.004                            | 0.2575                          | 6                               |
| CO$\text{2}$ | 489.4                           | 724.6                            | 852.79                          | 0.3                             |

Figure 2. 3 kinds of load curve.

(3) Result analysis

As can be seen from Figure 3, the fast non-dominated sorting genetic algorithm II with enhanced crossover operator is used to solve the optimal dispatching operation problem of microgrids connected
to electric vehicles, with better results and lower costs. The algorithm has high computational efficiency and its solution time is the fastest, and the solution time is much shorter than the standard genetic algorithm. From the final result, we can see that the algorithm has the best optimization effect, and the operation and maintenance cost and the total cost are the lowest. In meeting load demand, grid-connected power constraints, micro-source output under the conditions of the upper and lower limits and the climbing rate, the fast non-dominated sorting genetic algorithm II algorithm with enhanced crossover operator solves the economic-environmental optimization model of microgrid access to electric vehicles, and outputs the optimal plan.

Table 3. Comparison of the cost of electric vehicles and non-electric vehicles.

|                      | System operating cost/ten thousand yuan | Environmental cost/ten thousand yuan | Total cost/ten thousand yuan |
|----------------------|----------------------------------------|--------------------------------------|-----------------------------|
| Without electric vehicles | 2253                                    | 390.13                               | 2643                        |
| Including electric vehicles | 2108                                    | 382.88                               | 2491                        |

Figure 3. Contrast graph of 2 algorithms convergence

5. Conclusion
This paper comprehensively considers the two objective functions of system operating cost and environmental cost, combines the constraints of each device in the system and the mathematical model of the device, establishes a simulation model to optimize the economic-environmental efficiency optimization model, and performs optimization with the standard genetic algorithm algorithm. Data comparison. While verifying the effectiveness of the model, it is also concluded that the algorithm's operation efficiency and optimization ability are improved, and that the microgrid connected to the electric vehicle is effective in reducing environmental pollution and total system cost.

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