Energy Efficiency Optimization Management for Industrial Enterprises with Electric Vehicle Charging Stations

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Abstract. Most industrial enterprises only have extensive production mode and lack of certain economy. Combined with the characteristics of renewable energy power generation system and electric vehicles, a mathematical model of electric vehicles with wind power and photovoltaic power generation station was firstly built, and then an industrial enterprise energy efficiency optimization management model with electric vehicles charging station was built on this model. Improved adaptive genetic optimization algorithm is programmed based on MATLAB 7.0. Then taking a certain system as an object, we optimize the energy efficiency of industrial enterprises in 5 typical scenarios. The results show that the reasonable utilization of renewable energy power generation and electric vehicle charging load can significantly improve the energy efficiency of industrial enterprises.

1. Introduction
In the 21st century, energy and environmental issues have been standing in the way of human development. Traditional coal-based thermal power generation will not only consume a lot of petrochemical resources, but also generate a large number of greenhouse gases which accelerate global warming. With the continuous development of renewable energy technology and the popularization of electric vehicles, most of the countries begin to focus on renewable energy and electric vehicles to alleviate the energy and environmental crisis. Common renewable energy of power generation includes wind power, solar photovoltaic power generation, tidal power generation, geothermal power generation, etc. Electric vehicles include pure electric vehicles and hybrid vehicles. At present, most industrial enterprises use electricity as the driving force for their production activities, and their electricity expenses account for about 5% -70% of their total production costs. For enterprises with a high proportion of electrical energy consumption, we call them high-energy-consuming enterprises. High-energy-consuming enterprises are major consumers of electricity in the power system. Therefore, the improvement of the energy-efficiency level of high-energy-consuming enterprises will not only reduce the total power consumption of the society, but also promote the thorough implementation of Chinese energy policy.

The promotion of renewable energy power generation technology has made microgrid research the focus of attention [1-4]. Traditional microgrids combine various distributed power sources, loads, energy storage devices, and control units to form an organic unit in order to provide electricity to users. In terms of microgrid optimized dispatching operation, reference [3], taking the influence of uncertain factors such as wind turbines, solar photovoltaic cells and sodium-sulfur batteries on economic dispatch into consideration and the minimum cost of microgrid operation as the optimization goal, proposes
Dynamic economic dispatching model of microgrid. Reference [4] takes the wind-light-storage microgrid system as a research object, taking into account the operating cost of energy storage devices and establishes an economic operation optimization model of the microgrid. Reference [5] establishes the economic operation optimization model of the microgrid system with cold-heat-electricity cogeneration, and determines the optimal unit combination and the best electricity trading plan of the microgrid under different operating modes. In [6], a combined study of electric vehicles and photovoltaic power generation was carried out, and a study was performed on the scheduling problem in the operation of photovoltaic charging stations. Literature [7] takes the reduction of investment costs as an optimization goal to optimize the capacity allocation of electric vehicle replacement stations with wind-light power generation. Reference [8] establishes a mathematical model of centralized charging stations for electric vehicles with photovoltaic power generation, with the minimum active network loss as the optimization goal.

The above literatures have studied the optimized operation of microgrids and electric vehicle charging and replacing stations with wind-photovoltaic power generation systems, which have certain reference significance and value. Based on the above research and combining the energy consumption characteristics of industrial enterprises, this paper explores how to establish an electric vehicle charging station with wind and photovoltaic power generation and then build an energy efficiency optimization management model for industrial enterprises. Furthermore, based on improved adaptive genetic algorithm, this paper also tries to solve the model, and carry a simulation analysis of five typical scenarios.

2. Mathematical model of electric vehicle charging station with wind-photovoltaic generation

2.1. Electric vehicle charging station structure

The structure of an electric vehicle charging station with wind power and solar photovoltaic power generation systems is shown in Figure 1. The figure includes wind turbines, solar photovoltaic generators, and electric vehicle charging facilities. The dashed box is the microgrid unit, which establishes an electromagnetic connection with the main grid through a 0.4 / 10kV boost transformer.

![Figure 1: The EVs charging station with WT-PV](image)

2.2. Wind power output model

Wind energy is currently recognized as the most potential renewable energy source in the world. Wind power is a power generation technology that converts wind energy into electricity. The output power model of wind power is [9]:

\[
P_{wind} = C_D \frac{1}{2} \rho A v^3 \eta
\]
In the formula, $v_{ci}$, $v_{co}$, and $v_r$ represent the cut-in wind speed, cut-out wind speed, and rated wind speed of the fan; $P_N$ represents the rated output power of the fan.

2.3. Photovoltaic power output model

The principle of solar photovoltaic power generation is the photovoltaic effect, which uses solar cells to directly convert light radiation into electrical energy. The output power model of solar photovoltaic power generation is:

$$P_{sol} = \alpha \cdot \sum_{n=1}^{N} B_n \cdot \beta_n$$  \hspace{1cm} (2)

In the formula: $\alpha$ indicates the solar light intensity, and its value can be determined according to historical weather data; $N$ indicates the number of photovoltaic cells; $B_n$ and $\beta_n$ indicate the area of the nth module and the photoelectric conversion efficiency, respectively.

2.4. Electric vehicle battery model

The battery provides driving force for the electric vehicle. The electric vehicle is connected to the grid as a mobile load. The battery power model can be approximated as:

$$P_{EV} = \eta \cdot P_{charge}$$  \hspace{1cm} (3)

In the formula, $P_{charge}$ represents the rated charging power of the electric vehicle; $\eta$ represents the charging correction coefficient, and its value is different in different charging periods.

3. Energy efficiency optimization management model and solving algorithm for industrial enterprises

Industrial enterprises are major consumers of electricity, and their electricity consumption can account for 50% or more of the total electricity consumption of the local power grid. If it is possible to reasonably arrange the electricity consumption plan of high-energy-consuming industrial enterprises and combine with renewable energy power generation systems, effectively improving the energy efficiency of enterprises and reducing the demand for traditional energy sources can be possible, thus reducing greenhouse gas emissions. This not only reduces the operating costs of enterprises, but also improves the environment.

This article combines the electric vehicle charging station with wind-photovoltaic power generation unit with industrial high energy consumption enterprises, meaning choosing the appropriate location around the enterprise to arrange the electric vehicle charging station. When the output power of wind-solar power is greater than the charging power of electric vehicles, the charging station will sell electricity to industrial enterprises, reducing the amount of electricity purchased by the enterprise from the power grid, and reducing its costs. When the output power of wind-solar power is smaller than the charging power of electric vehicles, its operating strategy will be based on real electricity prices.

3.1. The objective function

The energy efficiency optimization management model of industrial enterprises with electric vehicle charging stations is as follows:

$$\min C = \sum_{t=1}^{24} \left[ Q_{ep}(t) + Q_{evs}(t) - Q_{evs}(t) \right] \cdot P(t)$$  \hspace{1cm} (4)
In the formula, $Q_e(t)$ represents the electricity consumption of industrial enterprises in t period; $Q_{EV}(t)$ represents the charging load of charging stations in t period; $Q_{WPs}(t)$ represents the wind and solar power generation in t period; $P_{grid}$ represents t period Grid real-time electricity prices.

This article divides a day into 24 periods, assuming that wind power, photovoltaic power, and charging power meet the following conditions in each time period:

1) The output power of wind power, solar photovoltaic power generation, and electric vehicle charging power are kept constant.

2) The exchange power between the enterprise and the main network remains constant.

3.2. Restrictions

The energy efficiency optimization management model for industrial enterprises with electric vehicle charging stations needs to consider the following constraints: including system power balance constraints, line transmission power constraints, power generation volume constraints, and electric vehicle battery constraints, as follows:

3.2.1. Power balance constraint

$$\sum_{i=1}^{m} P_{L}^i + \sum_{i=1}^{n} P_{EV}^i = \sum_{i=1}^{n} P_{DG}^i + P_{grid}$$ (5)

In the formula: $P_{L}^i$ represents the active power required by the i-th production workshop in the enterprise, $m$ represents the number of enterprise workshops; $P_{EV}^i$ represents the charging power of the i-th charging facility in the electric vehicle charging station, and $n$ represents the number of charging facilities in the charging station; $P_{DG}^i$ represents the active power from the i distributed power source (wind power or photovoltaic power), $n$ represents the number of DG in the system; $P_{grid}$ represents the exchange power between the industrial enterprise and the grid connection line.

3.2.2. Transmission line power exchange constraints

$$S_{grid} \leq S_{line,max}$$ (6)

In the formula, $S_{grid}$ indicates the exchange power on the connection line between the industrial enterprise and the power grid; $S_{line,max}$ indicates the maximum allowable exchange power on the connection line.

3.2.3. Wind and photovoltaic power constraints

$$P_{DG} \leq P_{DG,max}$$ (7)

In the formula, $P_{DG}, P_{DG,max}$ represent the actual output power and maximum output power of the wind and photovoltaic power generation units, respectively.

3.2.4. Constraint of electric vehicle battery state of charge

$$SOC_{min} \leq SOC \leq SOC_{max}$$ (8)

In the formula, $SOC$ represents the state of charge of the electric vehicle battery.

3.3. Solving Algorithm

Genetic Algorithm (GA) is a random search algorithm based on the principles of genetics and natural selection. It is an efficient algorithm that can help find the global optimal solution without relying on any original information.

In the basic genetic algorithm, the crossover rate $P_c$ and the mutation rate $P_m$ are the key factors affecting the performance of the algorithm. The larger the crossover rate is, the faster the new individuals in the population are generated, but it may cause the genetic model to be destroyed. If the crossover rate is small, the search efficiency of the algorithm will be reduced. For the mutation rate, if the value is small, it will not be easy to generate new individuals in the population. If the value is big, the algorithm will become a completely random search algorithm.
In response to the above-mentioned shortcomings, M. Srinivvas proposed an adaptive genetic algorithm [12], the cross rate $P_c$ and the mutation rate $P_m$ can automatically change with the change of fitness. The method in reference [1] of this paper makes the following improvements to the crossover rate and mutation rate:

\[
P_c = \begin{cases} 
  P_{c1} - \frac{(P_{c2} - P_{c3})(F - F_{avg})}{F_{max} - F_{avg}}, & F \geq F_{avg} \\
  P_{c1} - \frac{(P_{c1} - P_{c2})(F - F_{min})}{F_{avg} - F_{min}}, & F < F_{avg} 
\end{cases}
\]

\[
P_m = \begin{cases} 
  P_{m1} - \frac{(P_{m2} - P_{m3})(F - F_{avg})}{F_{max} - F_{avg}}, & F \geq F_{avg} \\
  P_{m1} - \frac{(P_{m1} - P_{m2})(F - F_{min})}{F_{avg} - F_{min}}, & F < F_{avg} 
\end{cases}
\]

In the formula, $F_{max}$, $F_{min}$, and $F_{avg}$ respectively represent the maximum, minimum, and average fitness in the population; $F$ represents the larger fitness in the two individuals that need to be crossed. The other parameters in the formula are as follows: $P_{c1}=0.85$, $P_{c2}=0.5$, $P_{c3}=0.2$, $P_{m1}=0.09$, $P_{m2}=0.05$, $P_{m3}=0.01$.

4. Example analysis

In this paper, simulation analysis is performed on an industrial enterprise with an electric vehicle charging station, as shown in Figure 2. In the figure, the electric vehicle charging station is composed of a wind turbine, a photovoltaic generator and an electric vehicle charging facility. The charging station is connected to an industrial enterprise through a 0.4 /10kV step-up transformer to realize a two-way flow of power.

![Figure 2 Diagram of industrial enterprises with EVs charging station](image)

The maximum load of industrial enterprises is 3MW. 20 electric turbines with a rated power of 100kW and 40 photovoltaic generators with a rated power of 50kW are installed in the electric vehicle charging station. There are 20 electric vehicle charging facilities and the rated charging power of electric vehicle charging facilities is 40kW. Assume that an optimization cycle is one day and is divided into 24 periods, the real-time grid purchase / sale price is shown in Table I.
**TABLE I. THE BUY/SELL PRICE OF REAL TIME**

| Period     | Time                | Electricity purchase price | Electricity sale price |
|------------|---------------------|-----------------------------|------------------------|
| Peak time  | 11:00-15:00, 19:00-21:00 | 0.83                        | 0.65                   |
|            | 08:00-10:00, 16:00-18:00 | 0.49                        | 0.38                   |
| Ordinary   | 22:00-24:00         | 0.17                        | 0.13                   |
| Valley time| 00:00-07:00         |                             |                        |

The predicted output power of wind power and solar photovoltaic power generation [13] is shown in Figure 3.

![Figure 3](image)

(a) No wind and cloudy optimization results of wind
(b) No wind and cloudy optimization results of photovoltaic power

**Figure 3** Predicted output power of wind and photovoltaic power

In order to analyze the energy consumption of industrial enterprises under different climate conditions, the following five typical scenarios are taken into consideration:
- Scenario 1: No wind and solar power access;
- Scenario 2: Cloudy weather;
- Scenario 3: sunny day;
- Scenario 4: cloudy and windy;
- Scenario 5: Windy and sunny;

A genetic algorithm optimization program was written based on Matlab 7.0, and the optimization results of the industrial enterprise in the above scenarios were obtained, as shown in Figure 4.

![Figure 4](image)

**Figure 4** The optimization result in different scenarios

In Scenario 1, no renewable energy power generation system is included, and the power flow on the communication line between the industrial enterprise and the main network is large. Some of the power is used for enterprise production, and the rest is provided to the electric vehicle charging station. In
Scenario 2 to 5, wind and solar renewable energy power generation units are connected. Among them, scenario 2 is a small windy cloudy day, with a total purchase of 48.80MW in one day, and scenario 3 is a small windy sunny day. The total amount of electricity purchased in the day is 40.10MW. Scene 4 is a cloudy and cloudy day. The total amount of electricity purchased in a day is 34.92MW. The scene 5 is a windy day. The net purchase of electricity in a day is 26.22MW. During the entire scheduling cycle, the operating costs and power purchases and sales of industrial enterprises in different scenarios are shown in Table II.

As can be seen from Table II, the operating costs of industrial enterprises have been significantly reduced after the wind and solar power generation units were connected. In Scenario 5, both wind turbines and solar photovoltaic power generation are close to the rated output power, so their operating costs are further reduced. At 12:00 and 13:00, industrial enterprises sell electricity to the grid through communication lines, and the transmission power is 0.2MW and 0.12MW respectively, with a certain income.

5. Conclusion
This paper takes the energy efficiency management of industrial high energy-consuming enterprises as the research object, and establishes an energy efficiency optimization management model for industrial enterprises with electric vehicle charging stations. The optimization model is solved based on an improved adaptive genetic algorithm. The case studies discuss the power purchase and sale requirements of industrial enterprises in five typical scenarios. Simulation results show the accuracy of the model proposed in this paper. By installing a renewable energy power generation system with a certain capacity, the economic efficiency and energy efficiency level of industrial enterprises can be improved. This research offers a high-energy-saving measure for industrial high energy-consuming enterprises. In addition, how to coordinate the relationship between renewable energy power generation, electric vehicles, and industrial enterprise energy consumption will be the focus of follow-up research.

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