Design of Electric Vehicle Charging Station Based on Genetic Algorithm

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Abstract. Aimed at the design problem of electric vehicle (EV) charging station, this paper proposes an optimization algorithm based on genetic algorithm (GA) to explore the optimal design scheme. The proposed algorithm is verified by using a charging station equipped with distributed energy as an example. At the same time, the example is divided into three cases for comparison. The results show that the construction of distributed generation for charging station will have better economic benefits.

1. Introduction
With the gradual depletion of fossil energy and the increasing environmental pollution, the development of new energy sources is imminent. At the same time, EV as a kind of zero-pollution vehicle, has gradually replaced fuel vehicles in recent years and has played a pivotal role in people's lives. It is expected that the number of EVs will increase exponentially in the next few years [1]. However, there are still many problems in the development of EVs, of which the charging problem is the most urgent. At present, fast charging is the main solution to the charging problem. Fast charging means that the charging process of the battery is completed in a short time by high voltage and high current, which means that the charging power is very large. So, when there is a huge charging load, it will affect the grid. In order to solve this problem, current EV charging stations often choose to build distributed generation (DG) and energy storage systems to reduce grid load, such as wind power generation and photovoltaic (PV) power generation. Aimed at the construction and operation of EV fast charging station, considering the cost and profitability, this paper proposes a design method based on genetic algorithm, which is used to explore the optimal construction scheme of EV charging station.

2. Algorithm model
2.1 Objective function
The goal of this paper is to maximize the profitability of the EV charging station. Establish a mathematical model with the objective function of maximizing the net present value (NPV):
\[ NPV = \sum_{t=1}^{8760} \left( \sum_{h=1}^{n(h)} \left( E_{ev_h} \cdot C_{ev_h} + E_{sal_e_h} \cdot C_{sal_e_h} - E_{buy_h} \cdot C_{buy_h} \right) - \frac{\sum_{h=1}^{n(h)} E_{sto_h}}{Esto} \cdot C_{sto} \cdot S_{sto} + C_m \right) \cdot (1+i)^t \]

where \( i \) is annual interest rate; \( E_{ev_h} \) is the energy of EV station charging to EV at hour \( h \); \( C_{ev_h} \) is the price of EV charging at hour \( h \); \( E_{sal_e_h} \) is the energy that EV charging station sales to grid at hour \( h \); \( C_{sal_e_h} \) is the unit price of energy that EV charging station sales to grid at hour \( h \); \( E_{buy_h} \) is the energy that EV charging station buys from grid at hour \( h \); \( C_{buy_h} \) is the unit price of energy that EV charging station buys from grid at hour \( h \); \( E_{sto_h} \) is the energy throughput of energy storage unit at hour \( h \); \( Esto \) is the total energy throughput of energy storage unit in its life cycle; \( C_{sto} \) is the cost of energy storage unit; \( S_{sto} \) is the installed capacity of energy storage system; \( C_m \) is cost of energy storage system maintenance at year \( t \); \( C_c \) is the cost of a charger; \( N_c \) is the number of chargers; \( C_w \) is the cost of a wind generator; \( N_w \) is the number of wind generator; \( C_{pv} \) is the cost of PV panel; \( S_{pv} \) is the area of PV panel.

2.2 EV demand model

2.2.1 Time of EV arrive at the charging station.
The number of EVs arriving at charging station in a period is consistent with the Poisson distribution [3]. The interval between two EVs arriving is exponentially distributed, and the probability distribution model is established as follows:

\[ T = \frac{1}{\mu} \cdot e^{-\lambda_h T} \]

where \( \lambda_h \) is the average number of EVs arriving at charging station.

Simulate the arriving time by Monte Carlo simulation method. The simulated result is shown in figure 1.

![Figure 1. Simulation of arrival times of EVs in 1 day](image)

2.2.2 Energy for EV charging.
The energy required to EV charging is related to battery capacity and state of charge (SOC). The probability distribution of the SOC conforms to the lognormal distribution and establishes a mathematical model [4]:

\[ P(E;m,s) = \frac{1}{E \sigma \sqrt{2\pi}} e^{-(lnE-m)^2/2\sigma^2} \]

where \( E \) is the initial SOC; \( \sigma \) is the typical deviation; \( \mu \) is the average.

2.3 DG model

2.3.1 Wind power generation model.
Wind speed distribution is modeled by Weibull distribution [5]:

\[ P(v) = \frac{k}{c} \left( \frac{v}{c} \right)^{k-1} \cdot e^{-\left( \frac{v}{c} \right)^k} \]  

(4)

where \( k \) is a scale factor; \( c \) is a shape factor; and they both are determined by the position.

By introducing the [0,1] random number sequence into the inverse of the distribution function model [6], we can get the change of wind speed at hourly:

\[ v = -c \left[ \ln \left( 1 - P \right) \right]^{\frac{1}{k}} \]  

(5)

After determining the wind speed, the generation power can be known from the power-wind speed curve.

2.3.2 PV generation model

The generation power of PV system can be calculated by the following formula [7]:

\[ P_{pv_h} = G \cdot S_{pv} \cdot h \eta \]  

(6)

where \( P_{pv_h} \) is generation power of PV system at hour \( h \); \( G \) is the solar irradiance on PV panel; \( S_{pv} \) is the area of PV panel; \( \eta \) is efficiency of PV system, and in this design the efficiency is 18%.

3. Algorithm flow

3.1 Chromosome structure

This paper uses GA to design the construction scheme of EV charging station. In this GA, the number of chargers \( N_c \), the number of wind generators \( N_w \), the installed area of PV panel, the charging power \( P_{ch} \), the installed capacity of the energy storage system \( Esto_{ins} \), the transmission power between the charging station and the grid \( P_g \) are used as genes on the chromosome [8]. The values of the six genes on the chromosome have certain limitations, and the range of values can be judged according to the actual construction situation of the EV charging station. Chromosome structure as shown in figure 2.

| \( N_c \) | \( N_w \) | \( S_{pv} \) | \( P_{ch} \) | \( Esto_{ins} \) | \( P_g \) |
|---------|---------|---------|---------|-------------|---------|

Figure 2. Chromosome structure

3.2 Fitness function

The fitness function determines the effect of GA. In this paper, the net present value NPV in the objective function is used as the fitness function to evaluate the individuals. The calculation process of the fitness function is as follows:

Step1: calculate the EV demand for the current individual;

Step2: calculate the DG situation for the current individual;

Step3: calculate the energy flow between charging station and the grid for the current individual;

Step4: determine whether the value of the decision variable satisfies the constraint; if yes, proceed to step 5; if not, discard this individual;

Step5: calculate the objective function NPV.

3.3 GA flow

It can be seen from the chromosome structure that there are two integer genes, and four real-type genes. For the two integer genes, crossover can be realized by generating a random two-dimensional binary vector. A vector of 1 indicates gene is inherited from parent1, and a vector of 0 indicates gene is inherited from parent2. Four real-type genes use the following function to realize crossover [9]:

\[ \text{child} = \text{parent1} + a \cdot (\text{parent2} - \text{parent1}) \]  

(7)

where \( a \) is a scale factor, and it’s equal to 0.8 in this case.

Mutation can be achieved as follows: First, generate a random number in [0, 1]. If the random
number is less than 0.001, the individual is judged to apply mutation, and vice versa. For the individual judged to apply mutation, a random integer of [1,6] is generated, and the random number represents the gene in which the mutation applied [10].

\[
\begin{align*}
gene = \text{rand} (\text{min}, \text{max}) & \quad \text{gene is integer} \\
gene = \text{min} + (\text{max} - \text{min}) \cdot \text{rand}() & \quad \text{gene is real}
\end{align*}
\] (8)

4. Case study

4.1 Case introduction
In this paper, a EV charging station combining wind power, photovoltaic power generation and energy storage system is taken as an example to study the proposed algorithm. And the case is divided into three cases to study the operation of the EV charging station under different conditions.

Case 1: The charging station is connected to the grid and is only powered by the grid.
Case 2: The charging station is isolated from the grid and is only powered by DGs.
Case 3: The charging station is connected to the grid and can powered by grid and DGs.

4.2 Results
The case is calculated by using the algorithm proposed in this paper, and the construction scheme under three cases is obtained. The optimal configuration for each case is shown in table 1, and the economics of each case is shown in table 2.

| Case | 1    | 2    | 3    |
|------|------|------|------|
| Number of chargers | 4    | 5    | 5    |
| Charging power (kW) | 44.26 | 44.25 | 46.11 |
| Number of wind generator | 0    | 4    | 4    |
| Area of PV panel (m²) | 0    | 1456.38 | 1871.95 |
| Transmission power (kW) | 128.33 | 0    | 298.36 |

| Case | 1        | 2        | 3        |
|------|----------|----------|----------|
| NPV (yuan) | 1264622 | 5981405 | 7527382 |
| Investment (yuan) | 672843 | 2676834 | 2970817 |
4.3 Result analysis
The optimal construction of the EV charging station calculated by the algorithm shows that the number of chargers in case 1 is a little less than it in case 2 and case 3, it may mainly because that, the energy needs to be purchased from the grid in case 1, so the increase in the number of chargers will lead to an increase in cost.

In terms of DG construction, it can be seen that the installed area of the PV system in case 3 is a little more than that of case 2. This is mainly because more power generation will result in waste of energy, while in case 3, charging station can sell excess energy to the grid, so building more DGs will generate certain capital gains.

From the economic situation in table 2, it can be seen case 3 has the biggest NPV. It mainly because the EV charging station can sell energy to the grid and gain great economic benefits. However, there is also the biggest investment cost in case 3 as is shown in figure 4. Because a large amount of DGs are built in case 3, but these costs can be quickly compensated.

5. Conclusion
In this paper, an optimization algorithm is proposed for the construction scheme of EV charging station. The algorithm is based on GA and uses Monte Carlo method to simulate the EV demand and DG supply, and optimize the design of EV charging station from economic and technical aspects. Then through three cases, the optimal construction of the EV charging station is proposed, which shows that the construction of DG will effectively improve the profit level.

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