Research on Optimization Scheduling Simulation System of Electric Vehicle Charging Station Based on CPLEX Model Technology

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Abstract. The construction of intelligent charging and replacement grids for electric vehicles, such as centralized charging stations, charging and replacement stations, and charging piles, is a more reasonable business model for the large-scale development of electric vehicles in densely populated areas. For the charging mode of centralized charging and unified scheduling, it is necessary to consider the influence of the FM capacity service decision to ensure the orderly charging of the charging station under the power market situation. Based on this background, the thesis aims at maximizing the revenue of electric vehicle charging stations. Based on the CPLEX simulation model for the charging period optimization of electric vehicle charging stations, the paper fully considers the synergistic scheduling of the energy market and the current FM market. The rod optimization model uses three methods of disordered charging, centralized control charging, and distributed charging to compare its influence on the daily load curve. The final paper validated the versatility and reliability of the policy system and helped to complete the orderly scheduling of the electric vehicle charging station.

1. Introduction

Electric vehicles enter the network with two-way and two-way energy transmission modes. The former can provide services to the system by changing the charging power of the electric vehicle, such as smoothing the load curve; the latter cannot only change the charging power, but also can reversely transmit power to the system when necessary to provide auxiliary services such as frequency modulation and rotating standby. In fact, in the electricity market environment, the clearing prices of the energy market and FM service market have obvious uncertainties. In this way, it is an important issue worth studying to study how to properly formulate the charging plan of the centralized charging station and the frequency modulation capacity provided to the system to meet the scheduling requirements of the centralized charging station under the premise of meeting the power supply requirements of the subordinate distribution stations. Sensitivity analysis does not provide a control mechanism for uncertain parameters for results, while stochastic programming requires a probability density distribution function for random variables.

In the problem [1] that the working process of the microcomputer protection experiment cannot be directly observed by the experimenter, the simulation system based on EMTP and MATLAB relay protection is established. In [2], the simulation models of sub-modules such as Inverter Bridge and photovoltaic module are built respectively, and the user interface is designed for this system. The
characteristic curves of any component can be viewed, the effects of different algorithms can be simulated and the parameters can be debugged. The GUI in MATLAB is a simple and fast simulation software. In [3], starting from the graphical user interface (GUI), combined with the specific software graphical interface, the basic method of making graphical user interface using GUI is given. The Simulink model simulation test system based on GUI interface is established, and different motors are obtained. Different characteristic curves. Based on the model predictive control, the literature [4] proposes a method of joint participation in load frequency control by electric vehicles, controllable loads, and cogeneration units. Based on the dynamic programming method, the literature [5] proposed an optimal scheduling model for electric vehicle dealers to participate in FM services. Literature [6] established a large number of electric vehicles participating in the system load frequency control model and demonstrated the rationality and effectiveness of the constructed model through MATLAB/ Simulink simulation.

2. Introduction to CPLEX features
CPLEX is a software that is reliable, fast, and flexible, and can solve many large-scale problems. Its high level of functionality relies on a component library that seamlessly integrates the CPLEX engine, the flexibility of optimized applications, and various functions for supply chain planning, network design, logistics, utilities, and more. In the industry. Specifically, linear programming problems, quadratic programming problems, quadratic constrained programming problems, and mixed integer programming problems can be solved. It can handle problems with millions of variables and constraints, and it always refreshes the highest performance records for mathematical programming. More importantly, it can also be used as a solver in conjunction with MATLAB for mixed programming.

3. Establishment of Simulation Model for Electric Vehicle Charging Station Scheduling
The charging mode specifically refers to the charging mode of the whole vehicle, that is, the electric vehicle directly obtains electric energy by accessing the charging pile or using the in-vehicle charging device, and the charging pile is generally small in size and low in price, and can be installed in a residential area, an office building or a commercial area. The advantage of the whole vehicle charging mode is that the charging operation process is simple, does not involve the process of battery replacement, storage, etc., and the equipment cost is low; the disadvantage is that the charging time of the vehicle occupies a part of the driving operation time, the vehicle utilization rate is low, and it is not conducive to maintaining the balance of the battery pack. Sex and extend the life of the battery.

The power-change mode refers specifically to the battery replacement charging mode, that is, the electric vehicle enters the battery replacement area of the power station, and then the battery is removed from the vehicle by replacing the battery pack, and the full battery of the power station is replaced to meet the endurance demand, and the battery is unloaded. The battery is uniformly charged by the substation charging device. The operation of the battery replacement charging mode can be completed in 10 minutes, which is roughly equivalent to the fueling time of the existing fuel vehicle. The power-changing mode is beneficial to improve the vehicle usage rate, improve the service life of the battery, and provide the electric energy supplement service to the user in time, but puts higher requirements on the vehicle and the battery replacement device, and has higher equipment and management costs, how to unify different cars. The manufacturer's battery standard is also a tricky issue.

3.1. Upper target function setting
In 1973, Bracken. J first proposed the concept of multi-level planning to solve multi-level planning/optimization problems. Two-tier planning is a special case of multi-level planning. As the name suggests, the two-tier plan consists of two levels. The upper-level decision results generally affect the lower-level goals and constraints, while the lower-level feedbacks the decision-making results to the upper-level, thus realizing the interaction of the upper-level decision-making. Double-layer planning has been reported in the fields of transmission system planning and reactive power optimization. In the charge and discharge scheduling of the coordinated operation of the power station and the power grid,
considering that the time-of-use price information will effectively reflect the original load fluctuations, the introduction of the time-of-use electricity price means that the smaller the load fluctuation, the greater the operating income of the power station, so this paper temporarily The target of charging and discharging revenue of the power station is not considered. The upper grid scheduling is based on the minimum total load fluctuation of the grid and the minimum deviation of the upper and lower layers, and the power network trend is used as the constraint to obtain the following multi-objective model:

### 3.1.1. Minimum total load fluctuation of the power grid

\[
\begin{align*}
\min_{P_{s,t}} F_1 &= \frac{1}{T^{(i)}} \sum_{i \in W^{(i)}} \left( P_{s,t} + \sum_{z \in Z} P_{z,t} - P_{w} \right) \\
\end{align*}
\]

\[
\begin{align*}
P_{w} &= \frac{1}{T^{(i)}} \sum_{i \in W^{(i)}} \left( P_{s,t} + \sum_{z \in Z} P_{z,t} \right) \\
\end{align*}
\]

Where: \( Z \) is the set of power stations; \( P_{s,t} \) is the original load of the grid during \( t \) period; \( P_{z,t} \) is the overall power of the power station \( z \) during the \( t \) period, positive power means that the power is obtained from the power grid, negative power means that the power is supplied to the power grid; \( W^{(i)} \) is the time-optimized time window of the power station \( z \) at time \( i \), that is \( W^{(i)} = \left\{ t \mid t \leq i + T^p_z, z \in Z \right\} \); \( T^p_z \) is the length of the time period of the power-reduction prediction of the power-changing station \( z \); \( T^{(i)} \) is the number of time periods included in the optimization time window \( W^{(i)} \); \( P_{w} \) is the average system load over \( T^{(i)} \) time periods.

### 3.1.2. The upper and lower scheduling plans have the smallest deviation

\[
\min_{P_{s,t}} F_2 = \sum_{z \in Z} f \left( P_{s,t} \right) 
\]

Where: \( t \in W^{(i)} \) and \( f \left( P_{s,t} \right) \) are the deviations between the actual dispatching results of the lower-level power station \( z \) and the upper-level power grid dispatching plan.

### 3.2. Upper constraint

#### 3.2.1. Multi-time exchange trend constraints

\[
\begin{align*}
P_{Gm,t} &= P_{Lm,t} + P_{Em,t} + U_{n,t} \left( G_{mn} \cos \theta_{mn,t} + B_{mn} \sin \theta_{mn,t} \right) \\
Q_{Gm,t} &= Q_{Lm,t} + U_{n,t} \left( G_{mn} \sin \theta_{mn,t} + B_{mn} \cos \theta_{mn,t} \right) \\
\end{align*}
\]

Where: \( t \in W^{(i)} \); \( P_{Gm,t}, Q_{Gm,t} \) are the injected active and reactive power of the access node \( m \) in the \( t \)-time; \( P_{Lm,t}, Q_{Lm,t} \) are the injected active and reactive power of the node \( m \) in the \( t \)-time; \( P_{Em,t} \) is the \( t \)-time access The scheduling plan of the power station of the node \( m \); \( U_{n,t} \) is the voltage value of the node \( m \) in the \( t \) period; \( N_m \) is the system node set; \( G_{mn}, B_{mn} \) are the real and imaginary parts of the node admittance matrix; \( \theta_{mn,t} \) is the phase of the \( t \) period branch \( mn \) Angle difference.
3.2.2. Node voltage constraint

\[ U^\text{min}_{m,t} \leq U_{m,t} \leq U^\text{max}_{m,t} \]  (5)

Where: \( t \in W \);  \( U^\text{min}_{m,t} \) and \( U^\text{max}_{m,t} \) are the upper and lower limits of the voltage of node \( m \), respectively.

3.2.3. Line transmission power constraints

\[ |P_{l,t}| \leq P^\text{max}_{l} \]  (6)

Where: \( t \in W \);  \( P_{l,t} \) is the transmission power of line \( l \) in time \( t \);  \( P^\text{max}_{l} \) is the upper limit of the transmission power allowed by line \( l \).

3.2.4. Generator output upper and lower limit constraints

\[
\begin{align*}
    P^\text{min}_{\text{Gm,t}} & \leq P_{\text{Gm,t}} \leq P^\text{max}_{\text{Gm,t}} \\
    Q^\text{min}_{\text{Gm,t}} & \leq Q_{\text{Gm,t}} \leq Q^\text{max}_{\text{Gm,t}}
\end{align*}
\]  (7)

Where: \( t \in W \);  \( P^\text{min}_{\text{Gm,t}}, P^\text{max}_{\text{Gm,t}} \) are the upper and lower limits of the active output of the generator \( m \);  \( Q^\text{min}_{\text{Gm,t}}, Q^\text{max}_{\text{Gm,t}} \) are the upper and lower limits of the reactive output of the generator \( m \), respectively.

3.2.5. Scheduling constraints for each period of the power station

\[
- \sum_{k \in H^T_{s}} P^\text{NC}_{s,k,t,I_{s,k,t}} \alpha \leq P_{s,t} \leq \sum_{k \in H^T_{s}} P^\text{NDC}_{s,k,t,I_{s,k,t}} \alpha
\]  (8)

Where: \( t \in W \);  \( P^\text{NC}_{s,k,t}, P^\text{NDC}_{s,k,t} \) are the rated charging power and rated discharge power of the \( k \)th charging and discharging device of the power station \( z \) respectively;  \( I_{s,k,t} \) is the connection state of the \( k \)th charging and discharging device of the power station \( z \) in the \( t \) period;  \( I_{n,0} \) means no access;  \( \alpha \) is the available coefficient, that is, the upper limit of the actual chargeable and dischargeable amount of the cluster will decrease as the cluster charge and discharge amount increases.  \( H^T_{s} = \{ k \in N_{s} | t^r_{s,k} \leq t + T^p_{s} \} \) is the set of network charging and discharging devices in the optimization time window side \( W^r_{s} \) of the power station \( z \), including the current time network charging and discharging device set and the remaining time period predicting network charging and discharging device set;  \( N_{s} \) is the power station \( W^r_{s} \) charging and discharging device set; The battery on the \( t^r_{s,k} \) charging and discharging device of the power station \( z \) starts to access the time.

3.3. Lower objective function

In the lower model, each agent minimizes the deviation between the actual load/output of the agent and the scheduling plan given by the dispatching organization by controlling the state of charge and discharge of the electric vehicle under various jurisdictions.

For the \( k \)th agent, its objective function can be expressed as:

\[
\min_{Y_{k,t}} f_{k}(X_{k,t}, Y_{k,t}) = \sum_{t=1}^{T_p} \left( \sum_{m=1}^{N_{m}} P_{k,m,t} - x_{k,t} \right)^2
\]  (9)
\[ P_{k,m,j} = \begin{cases} P_{k,m,ch} & y_{k,m,t} = 1 \\ 0 & y_{k,m,t} = 0 \\ -P_{k,m,dc} & y_{k,m,t} = -1 \end{cases} \]  

(10)

Where: \( P_{k,m,j} \) is the actual dispatch result of the mth electric vehicle belonging to agent k.

### 3.4. Lower layer constraint function

#### 3.4.1. Electric vehicle battery charging and discharging equation constraints

\[ S_{k,m,t+1} = \begin{cases} S_{k,m,t} + \frac{\eta_{ch} P_{k,m,ch} \Delta t}{\beta_{k,m}} & y_{k,m,t} = 1 \\ S_{k,m,t} & y_{k,m,t} = 0 \\ S_{k,m,t} - \frac{P_{k,m,dc} \Delta t}{\beta_{k,m} \eta_{dc}} & y_{k,m,t} = -1 \end{cases} \]  

(11)

Where: \( S_{k,m,t} \) is the SOC of the mth electric vehicle belonging to the agent k at the end of the time period \( t \); \( \eta_{ch}, \eta_{dc} \) are the charging efficiency and the discharging efficiency respectively; \( \beta_{k,m} \) is the battery capacity of the mth electric vehicle belonging to the agent k; \( \Delta t \) is the length of a time period. In equation (11), the self-discharge rate of the battery is not considered.

#### 3.4.2. Battery safety constraints

\[ S_{min} \leq S_{k,m,t} \leq S_{max} \]  

(12)

Where: \( S_{max} \) and \( S_{min} \) are the upper and lower limits of the SOC of the electric vehicle battery, respectively.

#### 3.4.3. Unschedulable time constraint

\[ y_{k,m,t} = 0 \quad t < t_{k,m,r} \text{ or } t < t_{k,m,o} \]  

(13)

Where: \( A, B \) are the moments of the mth electric vehicle access system belonging to agent k and leaving the system.

#### 3.4.4. Next day driving demand constraint

\[ S_{k,m,j} \geq S_{k,m} \quad \text{and} \quad S_{k,m,e} \geq S_{k,m} \]  

(14)

Where: \( S_{k,m,r}, S_{k,m}, S_{k,m,e} \) are the actual SOC and the required SOC of the mth electric vehicle belonging to agent k when leaving the system.
4. System simulation model establishment

4.1. Basic Information Module
The basic information includes time-of-use electricity price (grid selling electricity price, charging station selling electricity price), electric vehicle quantity, electric vehicle charging rated power, charging efficiency, battery capacity, local daily original load, all of which are given by the model in advance.

4.2. Basic Data Module
The basic data includes the access time of all electric vehicles, the time of leaving the grid, and the daily mileage. These data generally conform to the normal probability density function or the lognormal probability density function, by obtaining their expectation and variance two parameters, often according to the existing literature [1] or foreign official website, and get more accurate basic data.

4.3. Running the main interface
In the basic information column, the functions of the four control buttons in the m file are win open. For example, the "centralized control model" button corresponds to the input win open ('centralized control model.pdf') that is, after clicking and opening the specified picture. In the basic data column, the time when the electric vehicle is connected to the grid, the time of leaving the grid, and the mileage of the day can be calculated by entering "run" (subprogram file name) in the current m file to run another corresponding subroutine. And use the load instruction to call the variables obtained by the subroutine into the current m file. And each time you run a subroutine; the latest updated variables are automatically saved. In the three modes of operation: disordered charging, decentralized control optimization, and centralized control optimization, the functions of the corresponding "running program" and "load curve" buttons are all obtained through the running method in the basic data column; The maximum gain of the charging station can be represented by the variable obtained by the corresponding program, such as Profit1. Enter set (handles. edit10, 'string', Profit1), that is, input the target function value into the specified edit text box when the program finishes running. Figure 1 shows the electric vehicle simulation dispatching platform.

![Electric vehicle dispatching simulation platform](image-url)

Figure 1. Electric vehicle dispatching simulation platform.
5. Case analysis

The test environment for this operation is an Intel I5 processor with a 4 GB desktop. The VNS/TS algorithm is implemented in single-threaded JAVA. The example is a random construction. The meaning of the name is the customer point-charging station. Take K50-6 as an example, it is a network of 50 customer points and 6 charging stations. The six constructed examples were solved using the CPLEX and VNS/TS algorithms. Among them, the VNS/TS algorithm performs 20 times for each study and takes the optimal result. According to common practice, the upper limit of 2 h is set for the operation time of CPLEX. The experimental data obtained are shown in Table 1. It can be seen from the table that the accuracy of the VNS/TS algorithm is good, and the calculation result and the optimal solution obtained by the CPLEX algorithm have no error on the small-scale problem. At the same time, the VNS/TS algorithm is much better than CPLEX in terms of operation speed. When CPLEX cannot complete the calculation of K75-10 and K100-10 within the upper limit of 2 h operation time, VNS/TS can find a feasible solution within 2s. As shown in Table 1, the results of the test study are shown. At the same time, there is a corresponding simulation map for the vehicle running time after optimization scheduling, as shown in Figure 2.

| Study name | CPLEX Optimal solution | Calculation time / s | actual Optimal solution | Calculation time / s | error |
|------------|------------------------|----------------------|-------------------------|----------------------|-------|
| K50-6      | 199.16                 | 49.32                | 199.16                  | 0.44                 | 0     |
| K75-6      | 68.19                  | 63.04                | 68.19                   | 0.42                 | 0     |
| K100-6     | 194.31                 | 134.39               | 194.31                  | 0.39                 | 0     |
| K75-10     | -                      | 7200                 | 403.11                  | 1.39                 | -     |
| K100-10    | -                      | 7200                 | 482.93                  | 2.03                 | -     |
| K1000-100  | -                      | 7200                 | 42                      | 425346.7             |       |

![Figure 2. Simulation of driving time of electric vehicles after optimal scheduling](image)

6. Results

After a large number of electric vehicles are widely used, if they are allowed to be disorderly charged, they will pose a threat to the safety and economic operation of the power system. On the other hand, the energy storage characteristics of electric vehicle batteries help to improve the safety and economy of system operation. In this way, how to optimally dispatch and control the charging and discharging...
process of electric vehicles to maximize their positive effects and minimize negative impacts becomes an important issue worthy of study. The model constructed in this paper develops an appropriate electricity price incentive mechanism, guides electric vehicles to provide frequency modulation and rotation backup services for the system, and fully exerts the role of CPLEX technology, which is an important issue to be further studied.

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