Multi-Objective Optimal Allocation Of DG-EV Charging Station Considering Space-Time Characteristics Model

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Abstract. With the promotion and development of new energy in the country, Distributed Generation (DG) and electric vehicle (EV) are welcoming development opportunities. The paper proposes a DG-EV charging station that considers space-time characteristics. Multi-objective coordination optimization configuration method, by extracting the road network topology in the city, monitoring the road network traffic, using the traffic planning software TransCAD to carry out the OD matrix back-pull, establishing the travel probability matrix to describe the user travel characteristics, considering the timing characteristics of EV, DG and conventional load, taking into account the grid side and the user side, and establishing a multi-objective joint planning model for the DG-EV charging station with the sub-goal of comprehensive benefit, system load fluctuation and charging time-consuming cost. Finally, the simulation analysis of the IEEE-33 node distribution network and the main road in a certain urban area is carried out to verify the validity and feasibility of the model.

Keywords: DG, EV charging station, OD matrix, Multi-objective.

1. Introduction
Nowadays, the research on DG and EV is mainly to plan the two separately, and less consider the coordinated planning of the two. Literature [1] designed a new type of regional electric vehicle charging station system including wind power, photovoltaic and energy storage systems, whichever is better the effect fully shows that the joint planning of DG-EV charging stations is beneficial to promote the complementary timing characteristics of intermittent DG output and charging load. Literature [2] considers the dispersion of electric vehicles, and uses the short-term interaction between electric vehicles and microgrids to stabilize Load fluctuations. It realizes the local consumption of DG by electric vehicles and improves the penetration rate of intermittent DG.

2. Construction of typical operating scenarios of "wind-light-load"
This paper selects the historical data of wind speed, light intensity and conventional load in each hour during a period of time in the planned area as the original samples, and generates the "wind-light-load" daily operation scenario in a unit of 24 hours to avoid substituting all data into the model. For the
problem of excessive calculation, the original data is reduced by the K-Means algorithm \[^3\], and the typical daily operation scenario is extracted one of that as shown in Fig. 1.

![Figure 1. Typical operating scenario.](image)

3. **EV charging demand forecast**

Predicting the user’s charging demand is a prerequisite for charging station planning. This chapter will combine electric vehicle parameters and user travel characteristics to simulate the user’s travel process and predict the charging demand.

3.1. **Electric vehicle type and battery parameters**

Electric vehicles mainly include four types of buses, taxis, urban functional vehicles and private cars. The parameters of different types of electric vehicles are shown in Table 1.

| Types of electric vehicles | Daily mileage/km | charging method | Parking position | battery capacity/ (kW·h) | Slow charging power | Fast charging power |
|----------------------------|------------------|-----------------|-----------------|--------------------------|---------------------|---------------------|
| Taxi                       | 350–500          | Fast            | Not fixed       | 64                       | 7                   | 90                  |
| City functional car        | 60–100           | Fast /Slow      | Work area       | 32                       | 7                   | 45                  |
| Private car                | 20–60            | Fast /Slow      | Home/Unit       | 32                       | 7                   | 45                  |

According to the battery capacity of different types of electric vehicles, the battery power at the time of travel is obtained. The remaining power $Cap$ during driving can be obtained by equation (1).

$$Cap_{t+1} = Cap_t - d_t \cdot \Delta Cap$$

$Cap_t$: The remaining power of the vehicle at $t$;

$d_t$: The distance traveled by the vehicle from time $t$ to time $t+1$;

$\Delta Cap$: Fuel consumption per 100 kilometers.

3.2. **TransCAD-based inverse model of OD matrix**

TransCAD is a professional traffic planning software for traffic data management and analysis. It provides a single path allocation and multi-path allocation OD matrix inversion program. The OD inversion program provides All-or-Nothing and capacity limitation methods, and other traffic distribution models. Researchers can select the traffic distribution model based on the imported road network map information, combined with the actual situation, enter the prior OD matrix, and use the
"OD Matrix Estimation" module in TransCAD to estimate the OD matrix. Fig. 2 shows the process of OD matrix inversion based on TransCAD.

3.3. Temporal and Spatial Distribution of Electric Vehicle Charging Demand
The Monte Carlo method is used to simulate and generate the initial operating power $Cap_0$ and the initial travel time $t_c$ of private cars, taxis, and urban function vehicles. For vehicle $k$, according to the vehicle's initial position $Oi$ and the initial travel time, call the travel probability and OD probability matrix corresponding to time $t_c$, and use the stratified random sampling method to generate the destination $D_j$ corresponding to vehicle $k$, assuming that the driver will choose the shortest path. The shortest path search algorithm of Floyd is used to get the shortest path to the destination $D_j$. The vehicle passes through the roads in the set-in turn, and the remaining power $Cap_k$ of vehicle $k$ is updated for each road section, corresponding to time $t$, if If the remaining power of the vehicle is lower than the charging threshold, the information of the electric vehicle that generates the charging demand is recorded, including the type of electric vehicle, the remaining power $Cap_k$, the time $t$ of the charging demand, and the location.

4. Planning model of DG-EV charging station considering time-space distribution
The Monte Carlo method is used to simulate and generate the initial operating power $Cap_0$ and the initial travel time $t_c$ of private cars, taxis, and urban function vehicles. For vehicle $k$, according to the vehicle’s initial position $Oi$ and the initial travel time, call the travel probability and OD probability matrix corresponding to time $t_c$, and use the stratified random sampling method to generate the destination $D_j$ corresponding to vehicle $k$, assuming that the driver will choose the shortest path. The shortest path search algorithm of Floyd is used to get the shortest path to the destination $D_j$. The vehicle passes through the roads in the set-in turn, and the remaining power $Cap_k$ of vehicle $k$ is updated for each road section, corresponding to time $t$, if If the remaining power of the vehicle is lower than the charging threshold, the information of the electric vehicle that generates the charging demand is recorded, including the type of electric vehicle, the remaining power $Cap_k$, the time $t$ of the charging demand, and the location.

4.1. Mathematical Model of Multi-Objective Optimal Allocation
When optimizing the configuration of DG-EV charging stations, the grid-connected location and installation capacity of DG and EV charging stations should be determined from both the power grid and the user. Based on this, the establishment is established with the largest comprehensive benefit,
the smallest system load fluctuation, and the smallest charging time and cost. Multi-objective coordination planning model.

Distribution company annual comprehensive income $F_1$

$$\text{max } F_1 = I_S - O_{CO} - O_{MA} - C_{loss}$$

(2)

$I_S$: Electricity sales income;
$O_{CO}$: Construction expenditure of the EV charging station and DG;
$O_{MA}$: maintenance fee of the EV charging station and DG;
$C_{loss}$: Distribution system network loss cost.

System load fluctuation index $F_2$

$$\text{min } F_2 = \sum_{z=1}^{N_z} \frac{d_z}{365} \sqrt{\frac{\sum_{t=1}^{24} (P_{z,t,e} - P_{z,ave})^2}{24}}$$

(3)

$P_{z,t,e}$: The equivalent load of the system at time $t$ in scene;
$P_{z,ave}$: The average load of the system at scene $z$;

Charging time-consuming cost $F_3$

$$\text{min } F_3 = 365p \sum_{k \in N_{ev}} \sum_{j \in h_{nodes}} \Delta T_{jk}$$

(4)

$p$: Driver’s cost per unit time;
$\Delta T_{jk}$: The length of the journey between two nodes.

4.2. Case analysis

This paper combines the IEEE-33 node system and 29-node road network transportation network to carry out the simulation analysis of the DG-EV charging station joint planning. The system parameters are shown in Reference [4]. 29-node traffic road network diagram 3, the coupling relationship between road network parameters and road network and distribution network see reference [5].

The travel probability matrix is used to simulate the travel trajectory of electric vehicles to obtain the time distribution of electric vehicle charging requirements as shown in Fig. 3. It can be seen from Figure 3 that the charging load has two peaks of charging demand at 13:00-14:00 and 17:00-18:00.

![Figure 3. Flowchart of OD matrix reverse push.](image)

In order to verify the superiority of the joint planning of DG-EV charging stations, the number of charging stations is set to 5, and two schemes are established for simulation analysis. Option 1) First carry out DG independent planning, and carry out EV charging station planning on the basis of the DG planning scheme. Option 2) Joint planning of DG-EV charging stations.
In the DG planning scheme, 13(6) indicates that 6 DGs are installed at node 13, and 20(690) in the charging station planning scheme indicates that the installed capacity of the charging station at node 20 of the road network is 690kW. Comparing scheme 1 and scheme 2, it can be found that compared with the independent planning of DG and EV, the planned capacity of DG and charging station is improved because the joint planning considers the mutual absorption capacity of EV charging load and DG.

### Table 2. Optimal allocation results of different schemes

| Program | Optimize configuration results | capacity/kW |
|---------|-------------------------------|-------------|
| DG      | 13(6),23(8),31(9),7(5)        | 2800        |
| Charging station | 20(690),13(360),5(290).24(503),17(296) | 2199        |
| DG      | 13(9),23(6),31(6),7(5).21(7),28(6) | 3900        |
| Charging station | 20(754),13(410),5(350).24(597),17(360) | 2471        |

### Table 3. Optimal allocation results of different schemes

| Program | Program.1 | Program.2 |
|---------|-----------|-----------|
| Comprehensive benefit index/10,000 yuan | 1843.45   | 2098.12   |
| System load fluctuation index/kW       | 530.48    | 506.77    |
| Annual charging time cost/10,000 yuan  | 45.57     | 45.57     |
| Comprehensive evaluation index          | 0.895     | 0.922     |

### 5. Conclusions

This paper proposes a DG-EV charging station joint planning method that considers the timing and spatial characteristics of the charging load of electric vehicles. The effectiveness of the method is demonstrated by combining the IEEE-33 node and the main road in a certain urban area. The peak demand of charging load and the output of DG are highly complementary, which can effectively achieve the effect of "peak cutting and valley filling" and increase the system's consumption of DG.

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