frontiers | Frontiers in Energy Research

ORIGINAL RESEARCH
published: 05 July 2022
doi: 10.3389/fenrg.2022.922766

Research on Restrictive Factors and Planning of Charging Piles for Electric Vehicles in the Park Based on the Interpretative Structural Model

*Chao Zhang[1], Yihang Zhao[1], Huiru Zhao[1] and Qiang Wang[2]**

[1]School of Economics and Management, North China Electric Power University, Beijing, China, [2]Institute of Grassland Research of CAAS, Inner Mongolia Academy of Grassland Science, Hohhot, China

At present, the world is vigorously promoting the innovative development concept of "green development, park first," prompting the park to vigorously promote the construction of electric vehicle charging stations and charging pile projects. However, the development of the construction is not satisfactory due to a series of restrictive factors. Under this background, this article studies the constraints of EV charging stations in the park and further studies the impact on park planning. First, this article outlines the constraints of charging piles in the park based on the field research. Then, interpretive structural modeling (ISM) is adopted in this article for in-depth analysis of the restrictive factors. Finally, the impact on the industrial park's planning is analyzed as a case study. The improved countermeasures provide a basis for the scientific planning and design of electric vehicle charging stations in industrial parks.

Keywords: park charging pile, restrictive factors, interpretative structural model, countermeasures, planning

OPEN ACCESS

Edited by:
Yiyi Zhang,
Guangxi University, China

Reviewed by:
Linfeng Zheng,
Jinan University, China
Haoran Zhao,
Beijing Information Science and Technology University, China

Correspondence:
Qiang Wang
1162106025@ncepu.edu.cn

Specialty section:
This article was submitted to Smart Grids, a section of the journal Frontiers in Energy Research

Received: *18 April 2022*
Accepted: *09 June 2022*
Published: *05 July 2022*

Citation:
Zhang C, Zhao Y, Zhao H and Wang Q (2022) Research on Restrictive Factors and Planning of Charging Piles for Electric Vehicles in the Park Based on the Interpretative Structural Model. Front. Energy Res. 10:922766. doi: 10.3389/fenrg.2022.922766

1 INTRODUCTION

1.1 Background and Motivation

The green and low-carbon development concept facilitates the wider application of electric vehicles (EVs), which are increasingly favored by the market for their clean and environmentally friendly characteristics (Zhang et al., 2020). According to the report from EV Volumes, the global sales of electric vehicles in 2021 were about 6.75 million, with an increase of 108% compared with 2020 (Roland, 2021). In view of the limitation of battery capacity and endurance mileage, at present, electric vehicles are mainly used for driving in cities, especially for daily commuting to places of residence and work. As the main work gathering place, the park is the main area where electric vehicles are distributed. Hence, it is urgent and of great practical significance to plan the charging facilities for electric vehicles in the park reasonably.

Simultaneously, compared with traditional infrastructure projects, the construction of charging pile projects can stimulate new consumption patterns and promote the development of new energy vehicles (Ding et al., 2018). The New Energy Automobile Industry Development Plan (2021–2035) issued by the Ministry of Industry and Information Technology of the People's Republic of China in 2020 points out that the gap of charging piles in China reaches 63 million, which seriously does not match the development speed of new energy vehicles and requires investment and construction with a vehicle pile ratio of 1:1. However, some practical reasons, such as difficulty in charging, low utilization rate, and unbalanced layout, directly restrict the orderly development of the charging pile market in

China. Therefore, it is urgent to analyze the restrictive factors affecting the charging pile project and propose corresponding development countermeasures accordingly.

1.2 Literature Review

Due to the characteristics of cleanliness and environmental protection, the number of EVs has increased year by year, which has also attracted widespread attention from scholars. The existing research on EVs mainly includes the following: EV load forecasting (Buzna et al., 2021), EV charging and discharging strategies (Liu et al., 2016; Apostolaki-Iosifidou et al., 2017), EV energy storage systems (Amjadi and Williamson, 2010), and EV business models (Yan et al., 2017).

At present, some scholars have also carried out research on charging piles. Hong et al. (2021) detected electricity stealing behavior of charging piles based on support vector machine. By constructing a recognition model of the electricity stealing behavior of a charging pile, the purpose of anti-stealing electricity from a charging pile is achieved. Tan et al. (2020) proposed an integrated weighting-Shapley method to allocate the benefits of a distributed photovoltaic power generation vehicle shed and energy storage charging pile. Zhao et al. (2020) employed a non-cooperative game model to determine a charging pile sharing price considering EV consumers' charging behaviors. Chen et al. (2022) proposed a hierarchical scheduling model of EVs considering shared charging piles, which can address the mismatch between charging facilities and electric vehicles. Shuohan Liu et al. (2021) proposed an Urgency First Charging (UFC) scheduling policy, which orders EVs via their charging urgency (calculated by their charging demand and remaining parking duration). In addition, some scholars have carried out research on the site selection planning of charging piles. Dang et al. (2021) proposed a multi-criteria decision-making (MCDM) framework for site selection of an island photovoltaic charging station. Ju et al. (2019) proposed an effective comprehensive framework to evaluate and select the optimal EVCS site under a fuzzy environment. Guo and Zhao (2015) employed a multi-criteria decision-making (MCDM) method to consider some subjective but important criteria for electric vehicle charging station site selection.

The aforementioned research studies have been carried out in the aspects of planning and layout optimization and site selection of charging piles, but they focus more on the traffic behavior and charging habits of electric vehicle users and lack consideration of the construction demands, influencing factors, and limiting conditions of charging piles for electric vehicles. Although some scholars have studied the constraints of EV charging piles, the constraints considered are mostly related to the capacity, voltage, number of charging stations, and EV charging services (Chen et al., 2014; Shahraki et al., 2015; Liu J. et al., 2021). The restrictive factors considered are not comprehensive, and the mechanism of the logical relationship between the various factors is not clear.

1.3 Contributions and Article Organization

Based on the previous study, this study takes the park as a specific application scenario. First, the restrictive factors of charging pile development in the park are obtained through a field survey. Then, the interpretative structural model (ISM) of the restrictive factors of charging pile development in the park is built, and the hierarchical relationship among different factors is clarified. Next, the case study is carried out, and the optimal charging pile planning scheme is designed based on a 25-node traffic system and a 27-node power distribution system. Finally, the improvement countermeasures are proposed accordingly, which provides the basis for the sustainable development of charging piles in industrial parks. The main contributions and innovations of this study are as follows:

1) Twelve restrictive factors of EV charging piles planning are considered in this study, and ISM is introduced to clarify the hierarchical relationship and transmission logic between various factors.
2) The effectiveness of ISM is verified by the case studies of a 25-node traffic system and a 27-node power distribution system.

The other sections of this research are structured as follows. Following the introductory section, **Section 2** analyzes the construction demands and influencing factors of charging piles for electric vehicles. **Section 3** mainly builds the interpretative structural model of the restrictive factors of charging piles in the park. **Section 4** analyzes the calculation results, and **Section 5** presents the conclusions and policy suggestions.

2 ANALYSIS ON CONSTRUCTION DEMANDS AND INFLUENCING FACTORS OF EV CHARGING PILES

In order to clarify the construction demands and influencing factors of EV charging piles, we distributed questionnaires to several practitioners, scholars, and professors in the electric vehicle field. The result shows that charging capacity, operating mode, and business operation mode are considered the main influencing factors of EV charging piles.

1) Charging capacity of electric vehicles

The overall demand for charging capacity of EVs is the key factor affecting the layout of EV charging piles (Fernández et al., 2013). Only after the charging capacity reaches a certain scale, the large-scale distribution can be realized in the construction. Furthermore, the charging capacity of EVs is related to the vehicle holdings, the average daily mileage of vehicles, and the energy consumption level per unit mileage.

2) Operating mode

Under operating modes in different scenarios, EVs have different requirements for their endurance and charging time, which will affect the charging mode and power consumption (Chen and Duan, 2015). Meanwhile, the construction mode and power demand of EV charging piles will also be directly affected. According to different types of users, there are different classes of

TABLE 1 | Main restrictive factors of charging piles in the park.

Number	Restrictive factor	Description
C_1	Policy promotion	Policies related to charging piles formulated by people's governments at all levels and their relevant departments
C_2	Technological advance	Technological advance related to charging pile construction
C_3	Technical standard	Technical standards related to charging pile construction
C_4	Intelligence of charging piles	Intelligent development of charging piles
C_5	Operation and maintenance personnel of charging piles	Charging pile operation and maintenance personnel
C_6	Hardware facilities of charging piles in the park	Hardware facilities such as charging piles in the park
C_7	Software platform of charging piles in the park	Software platform that provides positioning and settlement services for charging piles in the park
C_8	Charging compatibility	Compatibility of charging piles in the park for different brands and different types of vehicles
C_9	Charging safety	Safety of charging piles in the park
C_{10}	Charging convenience	Location and identification of charging piles in the park
C_{11}	Comprehensive charging price	Including the charging price for charging piles in the park and the parking price related to it
C_{12}	Charging pile operation mode	Distribution mode of interests of related parties in charging pile operation

EVs—vehicles for demonstration areas, vehicles for group business, and general vehicles. As each type of vehicle is different in terms of daily power consumption, traffic routes, schedule and rest, and charging time, it is necessary to consider the influence of their respective characteristics on the construction of EV charging piles.

3) Business operation mode

Commercialization is one of the important indicators to judge the rationality of the construction mode of EV charging piles (Zeng et al., 2019). Generally, the business operation mode usually needs to consider the cost of EV charging piles (including construction costs and charging costs), operation safety and capability, charging port standards, and relevant development policy. Meanwhile, the construction of charging piles should not only consider the cost of power grid reconstruction, land acquisition, and environmental management but also consider the social benefits after the EV charging piles are built. Different locations and construction scales of EV charging piles will directly affect the vehicle running cost and time cost of drivers waiting for charging. Therefore, the location and scale of EV charging piles shall be determined in consideration of the interests of both charging companies and users.

3 ISM CONSTRUCTION AND ANALYSIS

Research on the restrictive factors of charging piles and countermeasures is a systematic problem involving many factors. Different factors interact directly and jointly to affect the development of charging piles in the park (Ju et al., 2019). Based on the influencing factors of EV charging pile construction mentioned in **Section 2**, this section further determines the restrictive factors of charging piles in the park. Then, the restrictive factors of charging piles in the park are analyzed by ISM, so as to obtain the hierarchical relationship between different factors, which is conducive to further proposing corresponding countermeasures.

3.1 Methodology

ISM was first adopted by Warfield in 1973, and it can analyze complex problems in the social economy (Jahangoshai Rezaee et al., 2019). The basic theory is to construct a multi-level hierarchical structure by analyzing the mutual influence paths of various factors in the system so that the complex relationships of various factors in the system can be clearly displayed. The steps are as follows:

1) Determining the restrictive factors of charging piles in the park
2) Determining the correlation between restrictive factors and constructing the adjacency matrix

In the adjacency matrix, 1 indicates that the restrictive factor has a direct impact on the other restrictive factor, and 0 indicates that the risk factor has no direct impact on the risk factor.

3) Constructing the reachable matrix

According to the basic theory of ISM, MATLAB software is adopted to perform auxiliary operations according to Boolean algebra operation rules. The reachable matrix can be obtained by $M = (A + I)^{n+1} = (A + I)^{n} \neq (A + I)^{n-1} \neq \ldots \neq (A + I)^{2} \neq (A + I)$.

4) Constructing the reachable set, antecedent set, and their intersection table to determine the level of each factor

The reachable set $A(C_i)$ and antecedent set $B(C_i)$ can be obtained according to the reachable matrix M, where $A(C_i)$ represents the set C_i that can affect all other factors, $B(C_i)$ represents all the sets C_i that can affect, analyzes the common set $C(C_i)$, and represents the set $C(C_i)$ that can affect or can be affected by both $A(C_i)$ and $B(C_i)$, namely $C(C_i) = A(C_i) \cap B(C_i)$. When $A(C_i) = C(C_i)$, $A(C_i)$ is the first-level factor, then remove the row and column of the first level factor in the reachable matrix K, and then obtain the second-level factor in the same way, and so on, until the series of all factors is obtained.

TABLE 2 | Relationship between the restrictive factors of charging piles in the park.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
C_1	0	1	1	1	1	1	1	1	1	1	1	1
C_2	1	0	1	1	1	1	1	1	1	1	0	0
C_3	0	1	0	1	1	1	1	1	0	1	0	0
C_4	0	0	0	0	0	1	1	0	1	0	0	0
C_5	0	0	0	0	0	1	1	0	0	0	0	1
C_6	0	0	0	0	0	0	1	1	1	1	1	1
C_7	0	0	0	0	0	1	0	1	1	1	1	1
C_8	0	0	0	0	0	0	0	0	1	0	0	0
C_9	0	0	0	0	0	0	0	1	0	0	0	0
C_{10}	0	0	0	0	0	0	0	0	0	0	1	0
C_{11}	0	0	0	0	0	0	0	0	0	1	0	1
C_{12}	0	0	0	0	0	0	0	0	0	0	1	0

5) Constructing the interpretative structural model

According to the relationship between the restrictive factors and the series of each element, the hierarchical interpretative structural model can be obtained.

3.2 Analysis of the Restrictive Factors for EV Charging Piles in the Park Based on the ISM

Under the background of the general trend of new infrastructure construction, the ISM discussion group conducted discussions and expert argumentation on the restrictive factors of charging piles in the park. The ISM discussion group is composed of EV owners, employees in charge of charging piles in the park, charging technicians, employees of the electric power company, and park government staff. Then, the group conducted in-depth research on the constraints and complex relationships of charging piles in the park by reviewing relevant literature, conducting consultation and research on charging piles in the park, investigating personal feelings of customers, and understanding government support policies. **Table 1** lists the main restrictive factors for charging piles in the park.

The relationship between the restrictive factors of charging piles in the park is shown in **Table 2**.

The adjacency matrix A can be expressed as follows:

$$A = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}.$$

The reachable matrix M can be obtained as follows:

TABLE 3 | Series of restrictive factors for charging piles in the park.

Number	Level	Factor
1	First level	C8, C9, C10, C11, and C12
2	Second level	C6 and C7
3	Third level	C4 and C5
4	Fourth level	C1, C2, and C3

$$M = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}.$$

The series of restrictive factors for EV charging piles in the park is listed in **Table 3**.

The hierarchical ISM is shown in **Figure 1**.

Figure 1 is a four-level hierarchical structure model of the restrictive factors for EV charging piles in the park. The first level is the most direct factor affecting the system, and the fourth level is the most important factor affecting the mode. The higher the level, the deeper the influence is.

1) The first level factors mainly include the charging compatibility, charging safety, charging convenience, comprehensive charging price, and the operation mode of charging pile.

➢ Due to the respective protection strategies, different EV brands have inconsistent charging ports and poor compatibility.

➢ The charging process is affected by the maturity of EVs and charging technology, and there are certain potential safety hazards.

➢ The improper location of charging piles in some parks is far away from the office area, resulting in a long distance for EV owners to send and pick up their vehicles. In addition, the identification of some charging piles is not obvious, which makes them difficult to find.

➢ Affected by the different charging prices of parking fees in different regions and different electricity prices in different periods, the comprehensive charging fees of the same vehicle will vary greatly at the same charging time.

➢ The business model of the charging pile in the park is not mature. At present, many enterprises are in the exploratory stage. After the initial investment enthusiasm, most of the subsequent capital is in a wait-and-see state, which further restricts the construction of charging piles in the park.

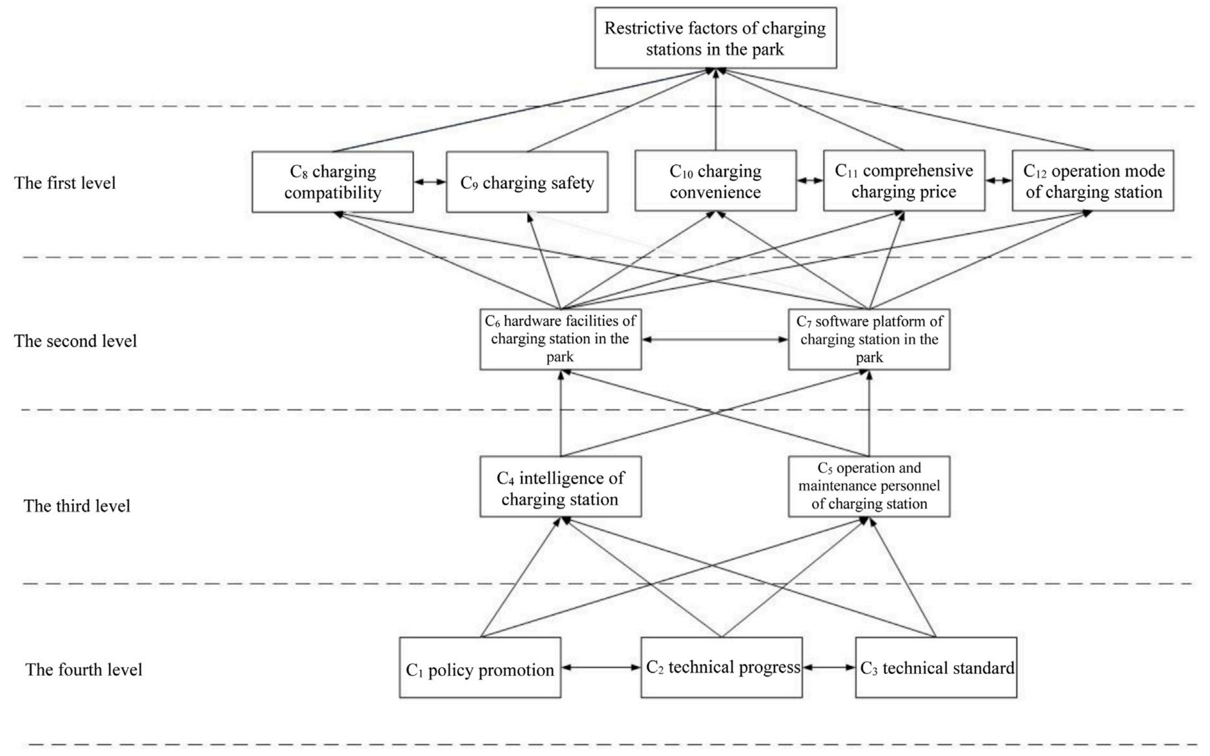

FIGURE 1 | ISM of restrictive factors for EV charging piles in the park.

2) The second level factors mainly include the intelligence of the charging pile and the operation and maintenance personnel of the charging pile.
   ➢ The intelligence of the charging pile is low, especially in the location and status queries of the charging pile. The real-time information interaction between charging pile owners and charging facilities cannot be realized, and the charging pile can be found difficultly and cannot be used when found.
   ➢ There is a serious shortage of the operation and maintenance personnel of charging piles, especially the operation and maintenance personnel of charging piles with special operation certificates. Due to the high voltage and high risk involved in the EV charging pile, the personnel shortage also restricts the development of the charging pile in the park.
3) The third level factors mainly include the hardware facilities and software platform of the charging pile in the park, which will be a deep influencing factor.
   ➢ The good level of the hardware facilities of the charging pile in the park directly affects the use of EV users. Through field survey, some charging facilities cannot be charged in their normal state or be repaired for a long time in their damaged state in the actual operation process.
   ➢ The service function for the software platform of the charging pile in the park is not perfect. Many software functions of the charging pile platform in the park have simple function design and poor interactivity. Some can only provide a telephone reservation function. At present, consumers are used to using mobile apps, which limits the development of the charging pile in the park.
4) The fourth level factors mainly include policy promotion, scientific and technological advance and technical standards. It is the biggest influencing factor for the development of charging piles in the park, which directly reflects the positive role of the government, scientific and technological advancements and technical standards in the development of charging piles in the park.
   ➢ The development of charging piles in the park involves many departments and links, mainly land use approval and power use approval. The introduction of charging pile related policies is conducive to the development of charging piles, but it is affected by the implementation of specific supporting policies. Therefore, the government should strengthen the formulation of supporting policies and supervise and urge the implementation of these policies.
   ➢ Technological advances have a direct impact on mileage and charging efficiency of EVs, both of which will further drive the development of charging piles in the park. Technical standards will help to achieve uniformity in charging ports for different types of vehicles and facilitate the reduction of charging piles in the park. At the same time, technical standards should be continuously improved according to the development of technology to eliminate outdated charging piles and develop advanced ones.

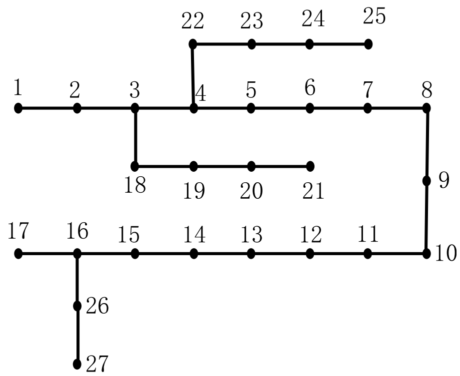

FIGURE 2 | 27-node distribution system.

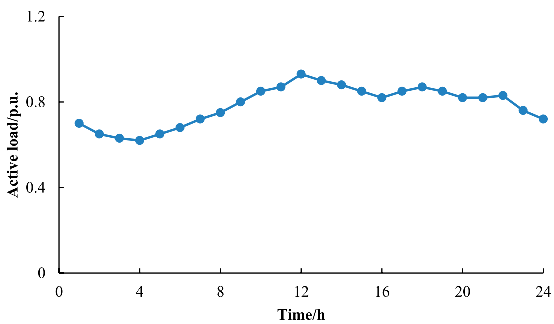

FIGURE 3 | Daily active load curve.

4 CASE STUDY AND DISCUSSION

To verify the validity of the models proposed in this study, a case study is carried out in this section based on a 25-node traffic system and a 27-node distribution system.

The topology of the 27-node distribution system of a park is shown in **Figure 2**. For the probabilistic power flow calculation of the distribution system, a typical planning day is planned to be divided into 24 power flow analysis periods, and the length of a single power flow analysis period is 1 h. The active load during a typical planning day for each node is shown in **Figure 3**. In addition, the load power factor is assumed to remain constant over the typical planning day. The maximum allowable current for each distribution line is derived from a 10% increase in the load current at base load.

The traffic system is shown in **Figure 4** and consists of 25 traffic nodes and 43 roads. It is assumed that traffic nodes overlap with distribution nodes 1 to 25 in the distribution system as candidate addresses for charging stations. In the traffic system, no more than five charging stations are to be built, with a total of no more than 120 charging piles, each with a maximum of 50 piles, and each pile can operate in either fast or slow charging mode, with a corresponding charging power of 20 and 5 kW, respectively. The allowable percentage of voltage excursion at the distribution node is 10% and the confidence level for both voltage violation and line power flow violation is 0.05.

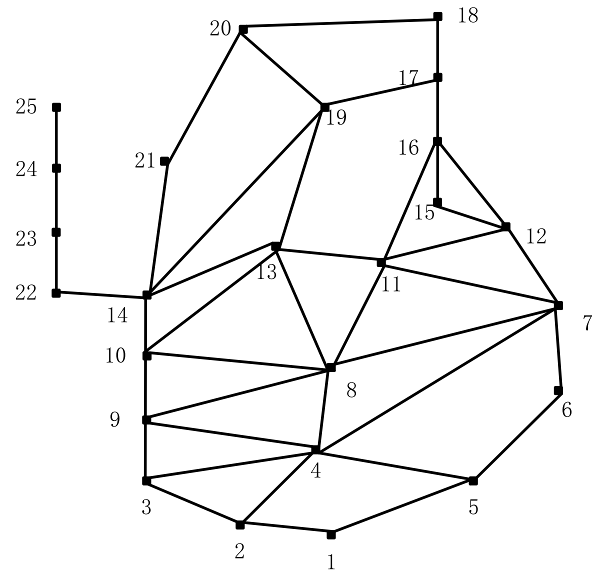

FIGURE 4 | Schematic diagram of the calculation example of the traffic system.

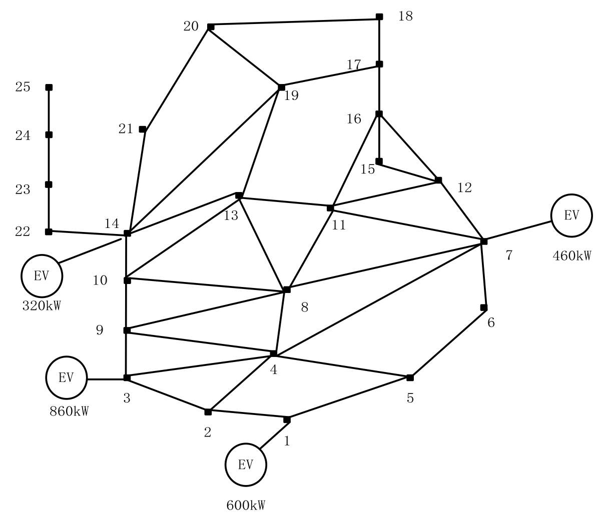

FIGURE 5 | Charging network planning scheme (considering the minimum network loss of a distribution system).

This study addresses the planning of a charging network that minimizes network losses in the distribution system and takes into account all restrictive factors. The planning scheme, taking into account the network losses of the distribution system, is shown in **Figure 5**, including four charging stations at traffic nodes 1, 3, 7 and 14 with 30, 43, 23, and 16 charging piles, respectively (with the capacities of 600, 860, 460, and 320 kW, respectively). Under this planning scheme, network losses reach a theoretical minimum of 2958.45 kWh in a typical planning day,

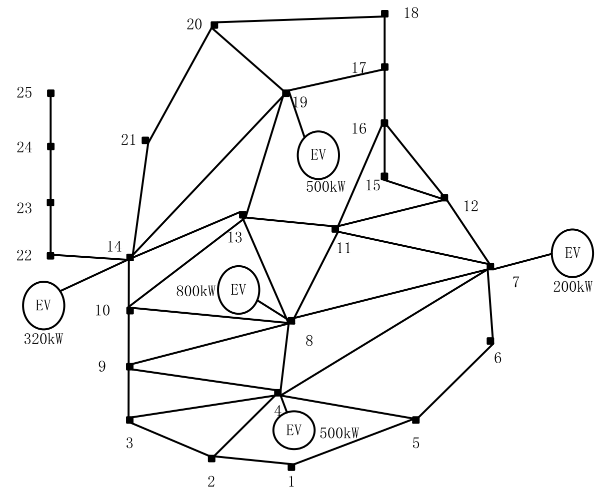

FIGURE 6 | Charging network planning scheme (based on the interpretative structural model).

and only line 20 experiences power flow violations, but only with a 3.5% probability. In operation, minor violation, of power flow in the lines can be eliminated by measures such as demand-side management, without the need to modify the current distribution system. However, the charging network service capacity corresponding to the aforementioned planning scheme decreases severely. The intercepted traffic volume has declined from 0.174 to 0.0799, a drop of 54.08%. In other words, the planning scheme given in **Figure 5** is also not reasonable.

The charging network planning based on ISM is shown in **Figure 6**. In this planning scheme, five charging stations are constructed at traffic nodes 4, 7, 8, 14, and 19, respectively, and the number of charging piles is 25, 10, 40, 16, and 25, respectively (with the capacities of 500, 200, 800, 320, and 500 kW, respectively).

The planning scheme given in **Figure 6** differs significantly from that given in **Figure 5** since multiple constraints for charging stations have been taken into account. With reference to **Figure 6**, the construction locations of two charging stations are changed from the traffic nodes 1 and 3 to 4, 18 and 19. Moreover, the number of charging piles at each charging stations has been changed accordingly. For a charging network, the location of charging station is a key factor in determining the charging service capacity. For the planning scheme given in **Figure 6**, the traffic volume intercepted by the charging network decreases from 0.174 to 0.132. The satisfaction of planning personnel for this planning objective is 0.788. For the distribution system, charging load is only a part of its total load. The network load within a typical planning day only increased from 2958.45 kW h to 3256.77 kW h. The satisfaction of planning personnel for this optimization objective is up to 0.97.

According to the aforementioned analysis and overall consideration of restrictive factors for ISM-based charging stations in the park, a more reasonable EV charging network planning scheme is needed while the distribution system has been maintained in a favorable operational state. This planning scheme will not only provide a strong charging service capacity but also require a lower operation cost of the distribution system. It does not need to expand and reconstruct the distribution system.

5 CONCLUSION AND POLICY SUGGESTIONS

5.1 Conclusion

In this study, the restrictive factors for EV charging piles in the park are analyzed and ISM is applied to the restrictive factors of charging piles in the park. In addition, hierarchical analysis is performed on these factors, and the charging network planning model is also established in this study. The result proves that the charging network planning based on ISM does not improve the network loss and improves the satisfaction of planning personnel for this scheme. In conclusion, this scheme provides an effective reference for solving the problems related to charging pile planning.

5.2 Policy Suggestions

1) Strengthening the formulation of supporting policies and supervision of the implementation for these policies

For the development of charging piles in parks, the policy support of the government and its management departments plays a decisive role. While implementing specific policies, the local governments should strengthen the formulation of supporting policies and supervise the implementation of these policies, in particular the policies on land use and power utilization for charging piles. Reasonable supporting policies on the construction land of charging piles and on the efficient power utilization of charging piles will remarkably promote the development of charging piles in parks and help solve the short-term problems about the quantity of charging piles.

2) Increasing the investment in charging technology R&D

Higher investment in charging technology R&D is essential to the improved safety and charging efficiency of charging piles in the park. In the context of new infrastructure construction, key-charging technology R&D and construction projects have turned into the key investment projects of many local governments and enterprises. With the support of AI, big data, and other technologies, EV users will be provided with custom charging services according to mobility data, and the location of charging piles will be reasonably recommended by analyzing consumption data. Therefore, it needs to increase not only the investment in key and core technologies with hard facilities as the main item but also the investment in soft technologies with software service platforms as the main item.

3) Strengthening the development of personnel for charging pile operation and maintenance

Technical personnel who are proficient in modern science and technology will significantly guarantee the development of charging piles in the park. For the charging pile operation personnel, they should learn about the technical knowledge of charging piles. For example, provide corresponding charging services and derivative services based on the actual needs of customers, such as EV washing and maintenance. Meanwhile, they should grasp the new online service mode and marketing mode in the context of "Internet+", closely follow the development of the times, constantly refresh their ideas and enrich their operation channels. They should also extend and improve the operation mode of charging piles. Once being fully proven, the operation mode should be disseminated after the summarization of experience. For the charging pile maintenance personnel, they should not only have solid knowledge and practical ability of charging equipment maintenance but also obtain corresponding technical qualification certificates. Furthermore, they should adapt to the development of the new era. With the development of online monitoring technology, charging equipment can also realize online monitoring. The maintenance personnel will be able to monitor and know about the operation status of charging equipment online in real time, thus facilitating daily maintenance and troubleshooting. Therefore, the state should strengthen the development of charging pile operation and maintenance personnel in terms of specialty setup in universities and colleges and qualification certification examinations to ensure the future development of the charging pile industry. Meanwhile, local governments should formulate relevant incentive mechanisms, encouraging the personnel engaged in park operations and social institutions to conduct technical training on charging piles.

4) Accelerating the formulation of technical standards for charging piles

In the process of charge pile construction and development, the consistency of technical standards directly affects the construction cost of charging piles and the compatibility of charging facilities. In the early development period, EVs encountered a situation similar to that with mobile phone chargers. Different enterprises have their own standards for the purpose of personal protectionism. New standards are often adopted by the new manufacturers in the market, resulting in poor compatibility of charging facilities. Mobile phone charging stations are mostly provided with several types of ports to meet diverse charging needs. Therefore, the Standardization Administration of China or industry associations should conduct in-depth surveys and accelerate the formulation of national and industry standards to guide the construction of charging piles and avoid repeated and inefficient investment.

5) Accelerating the construction of charging pile projects and the promotion of proven modes

While developing the charging piles in the park, we should accelerate the pilot project of charging piles in the park and accumulate experience for the subsequent charging pile construction based on the construction and operation of pilot projects. In addition, we should refer to domestic and foreign business models based on actual park development.

The development of charging piles in the park is undoubtedly a systematic project. It will face both new opportunities and challenges with the progress in science and technology in the future. In this sense, the analysis of restrictive factors for charging piles in parks and relevant measures against these restrictive factors in this study should be further updated and improved according to actual situations.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

Conceptualization, CZ. Methodology, QW. Software, CZ and YZ. Validation, HZ. Resources, CZ. Writing—original draft preparation, CZ. Writing—review and editing, YZ and QW. Visualization, QW. Supervision, HZ. Project administration, QW. All authors have read and agreed to the published version of the manuscript.

FUNDING

This research was funded by the National Natural Science Foundation of China, grant number 71973043.

ACKNOWLEDGMENTS

The authors are grateful to the editor and reviewers for their work.

REFERENCES

Amjadi, Z., and Williamson, S. S. (2010). A Novel Control Technique for a Switched-Capacitor-Converter-Based Hybrid Electric Vehicle Energy Storage System. *IEEE Trans. Ind. Electron.* 57 (3), 926–934. doi:10.1109/tie.2009.2032196

Apostolaki-Iosifidou, E., Codani, P., and Kempton, W. (2017). Measurement of Power Loss during Electric Vehicle Charging and Discharging. *Energy* 127, 730–742. doi:10.1016/j.energy.2017.03.015

Buzna, L., De Falco, P., Ferruzzi, G., Khormali, S., Proto, D., Refa, N., et al. (2021). An Ensemble Methodology for Hierarchical Probabilistic Electric Vehicle Load Forecasting at Regular Charging Stations. *Appl. Energy* 283, 116337. doi:10.1016/j.apenergy.2020.116337

Chen, C., and Duan, S. (2015). Microgrid Economic Operation Considering Plug-In Hybrid Electric Vehicles Integration. *J. Mod. Power Syst. Clean. Energy* 3 (2), 221–231. doi:10.1007/s40565-015-0116-0

Chen, G., Mao, Z., Li, J., Wang, D., Zhou, H., and Sun, K. (2014). Multi-objective Optimal Planning of Electric Vehicle Charging Stations Considering Carbon Emission. *Automation Electr. Power Syst.* 38 (17), 49–53. 136. doi:10.1007/s40565-018-0493-2

Chen, J., Huang, X., Cao, Y., Li, L., Yan, K., Wu, L., et al. (2022). Electric Vehicle Charging Schedule Considering Shared Charging Pile Based on Generalized Nash Game. *Int. J. Electr. Power & Energy Syst.* 136, 107579. doi:10.1016/j.ijepes.2021.107579

Dang, R., Li, X., Li, C., and Xu, C. (2021). A MCDM Framework for Site Selection of Island Photovoltaic Charging Station Based on New Criteria Identification and a Hybrid Fuzzy Approach. *Sustain. Cities Soc.* 74, 103230. doi:10.1016/j.scs.2021.103230

Ding, D., Dai, K., Zhang, X., Gu, J., Zhou, H., and Qian, K. (2018). Network Planning for EV Charging Based on Fuzzy Multi-Objective Optimization. *Power Syst. Prot. Control* 46 (3), 43–50. doi:10.7667/PSPC170006

Fernández, I. J., Calvillo, C. F., Sánchez-Miralles, A., and Boal, J. (2013). Capacity Fade and Aging Models for Electric Batteries and Optimal Charging Strategy for Electric Vehicles. *Energy* 60, 35–43. doi:10.1016/j.energy.2013.07.068

Guo, S., and Zhao, H. (2015). Optimal Site Selection of Electric Vehicle Charging Station by Using Fuzzy TOPSIS Based on Sustainability Perspective. *Appl. Energy* 158, 390–402. doi:10.1016/j.apenergy.2015.08.082

Hong, H., Su, Y., Zheng, P., Cheng, N., and Zhang, J. (2021). A SVM-Based Detection Method for Electricity Stealing Behavior of Charging Pile. *Procedia Comput. Sci.* 183 (2), 295–302. doi:10.1016/j.procs.2021.02.062

Jahangoshai Rezaee, M., Yousefi, S., and Hayati, J. (2019). Root Barriers Management in Development of Renewable Energy Resources in Iran: An Interpretative Structural Modeling Approach. *Energy Policy* 129, 292–306. doi:10.1016/j.enpol.2019.02.030

Ju, Y., Ju, D., Santibanez Gonzalez, E. D. R., Giannakis, M., and Wang, A. (2019). Study of Site Selection of Electric Vehicle Charging Station Based on Extended GRP Method under Picture Fuzzy Environment. *Comput. Industrial Eng.* 135, 1271–1285. doi:10.1016/j.cie.2018.07.048

Liu, D., Wang, Y., and Shen, Y. (2016). Electric Vehicle Charging and Discharging Coordination on Distribution Network Using Multi-Objective Particle Swarm Optimization and Fuzzy Decision Making. *Energies* 9 (3), 186. doi:10.3390/en9030186

Liu, J., Peper, J., Lin, G., Zhou, Y., Awasthi, S., Li, Y., et al. (2021). A Planning Strategy Considering Multiple Factors for Electric Vehicle Charging Stations along German Motorways. *Int. J. Electr. Power & Energy Syst.* 124, 106379. doi:10.1016/j.ijepes.2020.106379

Liu, S., Xia, X., Cao, Y., Ni, Q., Zhang, X., and Xu, L. (2021). Reservation-based EV Charging Recommendation Concerning Charging Urgency Policy. *Sustain. Cities Soc.* 74 (2), 103150. doi:10.1016/j.scs.2021.103150

Roland, I. (2021). Global EV Sales for 2021. Available at: https://www.ev-volumes.com/.

Shahraki, N., Cai, H., Turkay, M., and Xu, M. (2015). Optimal Locations of Electric Public Charging Stations Using Real World Vehicle Travel Patterns. *Transp. Res. Part D Transp. Environ.* 41, 165–176. doi:10.1016/j.trd.2015.09.011

Tan, Q., Wu, P., Tang, W., Cao, C., Wang, C., and Zhang, Y. (2020). Benefit Allocation Model of Distributed Photovoltaic Power Generation Vehicle Shed and Energy Storage Charging Pile Based on Integrated Weighting-Shapley Method. *Glob. Energy Interconnect.* 3 (4), 375–384. doi:10.1016/j.gloei.2020.10.009

Yan, C., Xiao, Q., and Yang, L. (2017). "Electric Vehicle Business Model Innovation Study from the Perspective of the Energy Internet," in 2017 IEEE Conference on Energy Internet and Energy System Integration (EI2), Beijing, China, 26-28 November 2017 (IEEE).

Zeng, X., Li, M., Abd El-Hady, D., Alshitari, W., Al-Bogami, A. S., Lu, J., et al. (2019). Commercialization of Lithium Battery Technologies for Electric Vehicles. *Adv. Energy Mat.* 9 (27), 1900161. doi:10.1002/aenm.201900161

Zhang, L., Liu, W., and Qi, B. (2020). Energy Optimization of Multi-Mode Coupling Drive Plug-In Hybrid EVs Based on Speed Prediction. *Energy* 206, 118126. doi:10.1016/j.energy.2020.118126

Zhao, Z., Zhang, L., Yang, M., Chai, J., and Li, S. (2020). Pricing for Private Charging Pile Sharing Considering EV Consumers Based on Non-cooperative Game Model. *J. Clean. Prod.* 254, 120039. doi:10.1016/j.jclepro.2020.120039

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.