Research Article

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The structure design of mobile charging piles

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Abstract: The simple instalment of mobile charging piles benefits for its convenient layout, while dynamic arrangements of those charging piles through mobile mode make up for the insufficient number of fixed charging piles, which meets the growing charging demand under the increasing popularity of electric vehicles. According to the application requirements of mobile charging piles, CATIA software was used to model the structure, of which strength and reliability were analysed under four load conditions. Our results have demonstrated that the maximum deformation value of the structure is 3.07 mm, and the maximum stress is 134.41 MPa, which is within the safety range of the selected materials. In addition, the gravity centre of the charging pile is located at the bottom of the structure, and thus the stability meets the requirements. Taken together, our research provided a beneficial reference for future engineering practice.

Keywords: mobile charging piles, structure design, charging demand, engineering practice

1 Introduction

Currently, energy conservation and emission reduction have become the consensus of the whole society. The carbon emission of traditional internal combustion vehicles attracts public attention and has become one of the key areas of carbon emission reduction. Therefore, the electric vehicle market has witnessed rapid development. The new energy vehicle market in China is one of the largest markets worldwide. In 2020, the new energy vehicle sales reached 1.367 million, with 13.3% year-on-year growth. Till the end of 2020, the number of new energy vehicles had reached 4.92 million. Compared with the development of the electric vehicle industry, the development of industry for electric vehicles and its supporting facilities is relatively late in China. In 2006, the first electric vehicle charging pile station was built in Shenzhen, while the accelerated development of the field has been witnessed since 2014. By the end of 2020, the number of public and private charging piles was 1.681 million, while the ratio of vehicle to pile was 3:1. All the data revealed the huge market demand behind the shortage of charging piles. The development of charging facilities, the prerequisite for the operation of electric vehicles, has been identified as the key factor, whose quality, performance, and technological level would directly affect the popularity and development of electric vehicles. Only by increasing the number of charging piles constantly and optimizing the layout, can charging piles match the charging demand of electric vehicles [1,2].

Field research results have shown that existent charging piles are almost fixed and installed in the open-parking ground. For instance, parking spaces are limited at some places, where the set charging pile parking spaces would be occupied by ordinary vehicles, resulting in the idle and low utilization rate of charging piles. In another word, it is a waste of existing charging resources [3,4]. However, in parking lots especially in transfer hubs and large venues, where realistic demands for charging piles emerge due to the aggregation of people. Thus, it is essential to design mobile charging piles for a convenient layout.

2 Modelling of mobile charging piles

The mobile charging pile is mainly composed of the core control module, charging gun group and its interface module, human–computer interaction module, safety protection module, and data communication and monitoring module. Mobile charging piles operate outdoor usually, which means their structure must be able to withstand the requirements of the external environment. At the

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same time, it should sustain the load during the transportation process, to maintain the strength and stability of the structure [5].

2.1 Material selection

The charging pile adopts a frame structure with welding and riveting process. According to environmental requirements, aluminium alloy, steel, and other materials are generally selected. According to the clear and specific provisions on relevant requirements from State Grid Q/GDW485-2010 “Technical Conditions for AC Charging Piles for Electric Vehicles,” considering the cost and manufacturing factors comprehensively, Q235A Profile has been chosen. The basic properties of the material are shown in Table 1.

2.2 Structure modelling of charging piles

CATIA was used to model the pile structure, in which four columns were made of angle steel and the rest brackets were made of square steel. Four wheels were designed at the bottom to facilitate the movement of charging piles. Each functional module of the charging pile is arranged in the modular partition. Moreover, the principle of man–machine engineering was employed in different functional zones for user convenience. The three-dimensional model of pile structure frame design is shown in Figure 1.

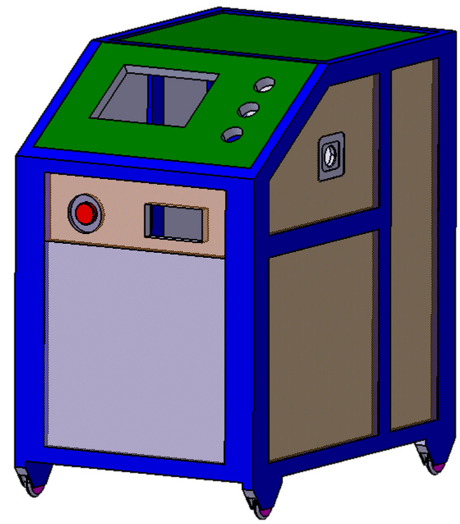

Figure 1: Detailed designed structure model of pile frame.

3 Static analysis of charging pile structure

3.1 Model simplification and network partitioning

The structure and function of the mobile charging pile with detailed sketch of functional modules are shown in Figure 2. As shown in Figure 2, 1 indicates the LCD screen; 2 indicates emergency stop button; 3 indicates the card swiping area; 4 indicates the indicator; and 5 indicates the charging port [6].

In general, the charging pile body is connected by welding and rivets. In the finite element analysis system, considering the complexity of the charging pile structure, the complex parts were simplified under the premise of not affecting the overall strength by following certain simplification principles:

1) In the linear statics calculation of the overall structure of the frame, each connection part has been assumed safe and reliable. And the connection and welding are assumed firm with the strength which is far greater than the yield strength of the component materials.
2) The charging pile body is connected by welding and rivets, so there are a large number of welds and rivet holes on the parts. The size of these weld gaps and holes is very small compared to the overall structure of the box bottom frame; even though, their existence could affect the mesh division of the overall structure of the box bottom frame, resulting in non-convergence of solution. Thus, it needs to be ignored in the mechanical model.
3) The non-bearing parts on the pile skeleton could be ignored as they cannot play a supporting role.

Table 1: Main properties of Q235A

Material	Poisson ratio	Elastic modular (GPa)	Density (kg/m^3)	Yield stress (MPa)	Tension strength (MPa)
Q235A	0.3	200	7,850	235	375

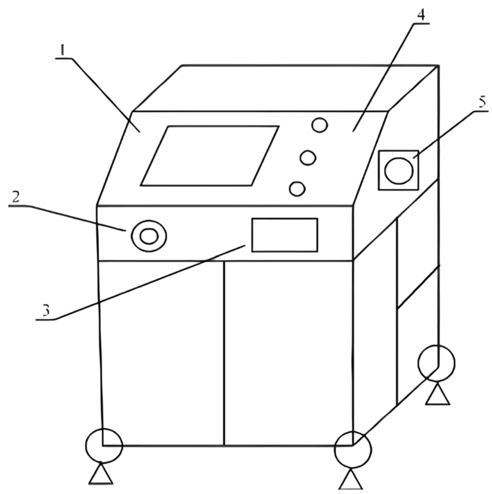

Figure 2: Design sketch of charging post functional module area. 1 indicates the LCDscreen; 2 indicates emergency stop button; 3 indicatesthe card swiping area; 4 indicates the indicator; and 5indicates the charging port.

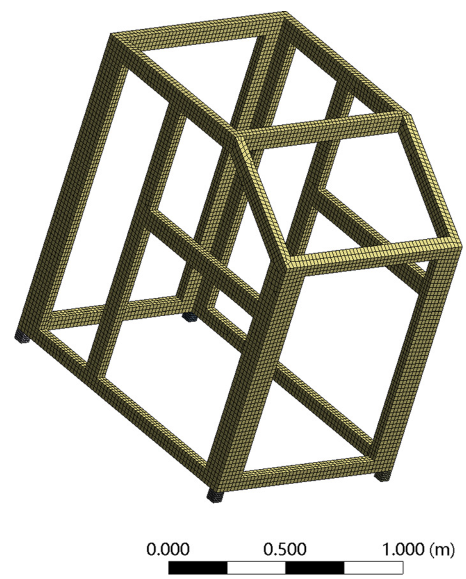

Figure 3: Grid plot of pile framework.

The body of the charging pile was connected by welding and riveting, parts of which had large amounts of weld and rivet holes. Even though those weld gap and hole sizes are too small to influence the whole frame structure, their existence would affect the meshing of the whole frame structure at the bottom of the box, leading to divergence in solution, and thus was ignored in the process of mechanical model analysis. In the statics calculation of the whole structure of the frame, it is assumed that each connection part is safe and reliable, while the connection and welding are firm, whose strength is far greater than the yield strength of the component materials. The non-bearing parts on the pile skeleton have shown no structural support function, which can be ignored. In general, the charging pile works in a static state and is fixed at the bottom during transportation; therefore, we replaced the four wheels with mass blocks for simplification. Furthermore, the overall mesh size of the model has been controlled around 20 mm by mapping mesh division. In details of mesh statistics, the pile skeleton has been divided into 167,714 nodes and 98,883 units, as shown in Figure 3.

3.2 Static analysis under four load conditions (LCs)

Certain load impact has been observed in mobile charging piles during transportation. Generally, in the process of transportation, the charging pile is placed on a special support frame with a fixed bottom, so the LC can be established by referring to the vibration and impact of the train electrical box equipment. Based on the research done by Liu and colleagues, considering that the vertical and lateral impact of the vehicle is higher than the train, and the impact acceleration should be no more than 10*g*, the acceleration value in the longitudinal direction can be assumed by longitudinal value of the train generally. So, the proposed three accelerations are 5*g* in the *X* direction (longitude), 6*g* in the *Y* direction (vertical), and 6*g* in the *Z* direction (horizontal), respectively ($g = 9.80\ \mathrm{m/s^2}$, represents the gravitational acceleration) [7].

The overall weight of the charging pile was approximately 98–100 kg, of which the skeleton was about 40–50 kg. The weight of the safety protection module, human–computer interaction module, charging gun and its interface components, core control module, and data communication and monitoring module of the charging pile were 2, 8, 22, 12, and 6 kg, respectively. In the static analysis, the above-mentioned five parts were applied to the corresponding bearing surface of the charging pile in the form of mass point by mass unit Mass21. The four wheels at the bottom have been simplified to the holder, whose displacement and rotation degrees of freedom have been fully constrained.

1) LC 1: The force and displacement of charging piles were analysed when +5*g* longitudinal acceleration was applied in the *X* direction, +6*g* vertical acceleration in the *Y* direction, and +6*g* transverse acceleration in the *Z* direction. The relevant results of deformation and equivalent stress of the main body of the charging pile under this LC are shown in Figures 4 and 5.

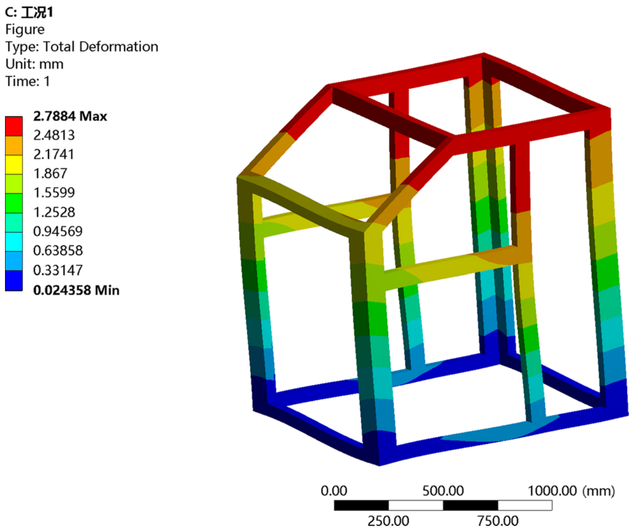

Figure 4: LC1 deformation distribution.

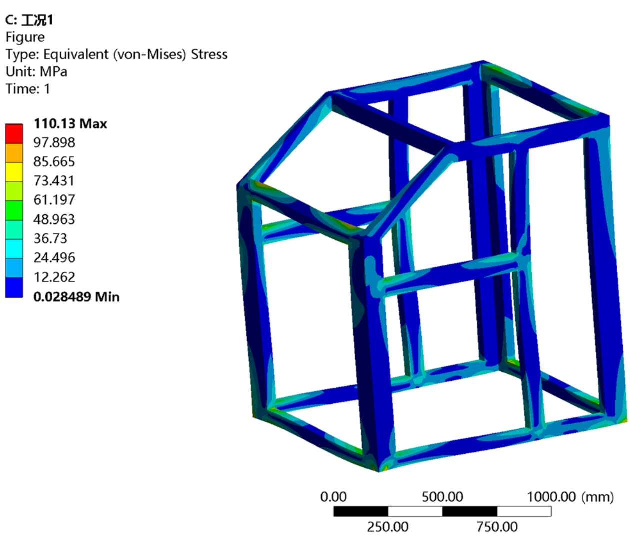

Figure 5: LC1 stress profile.

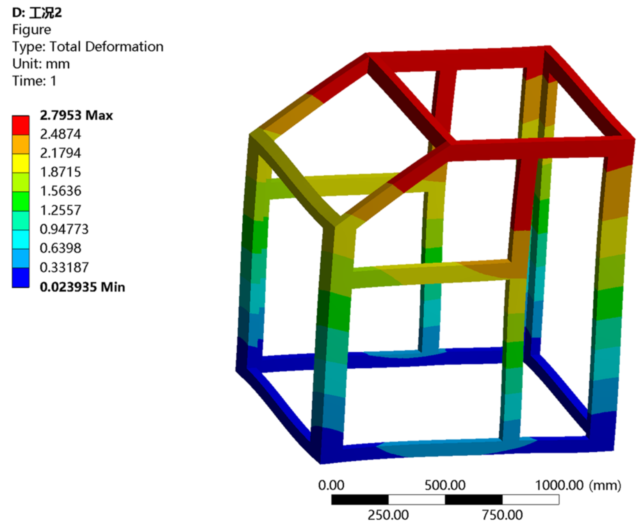

Figure 6: LC2 deformation distribution.

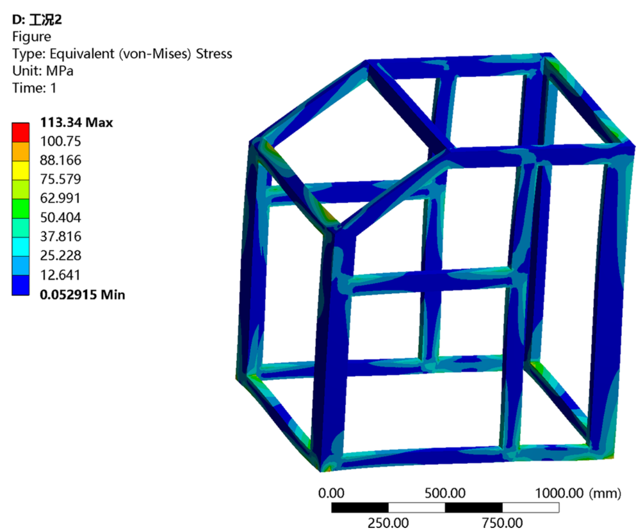

Figure 7: LC2 stress profile.

As shown in Figures 4 and 5, the maximum displacement of the charging pile skeleton was 2.79 mm on the top four steel frames. The maximum stress was 110.13 MPa, which is obviously less than the material yield limit (235 MPa). Thus, the main structure of the charging pile has shown sufficient strength and safety margin under this accelerated LC.

2) LC 2: The force and displacement of the charging pile were analysed when +5g longitudinal acceleration was applied in the X direction, +6g vertical acceleration in the Y direction, and −6g transverse acceleration in the Z direction. The relevant results of deformation and equivalent stress of the main body of the charging pile under this LC are shown in Figures 6 and 7.

From the data, the maximum displacement of the charging pile was 2.80 mm on the top of the skeleton, whose connections were also in the maximum displacement zone. The maximum stress was 113.34 MPa, far less than the material yield limit. Taken together, the main structure of the charging pile exhibited sufficient strength and safety margin under the accelerated LC.

3) LC 3: The force and displacement of the charging pile were analysed when −5g longitudinal acceleration was applied in the X direction, +6g vertical acceleration in the Y direction, and +6g transverse acceleration in the Z direction. The relevant results of deformation and equivalent stress of the main body of the charging pile under this LC are shown in Figures 8 and 9.

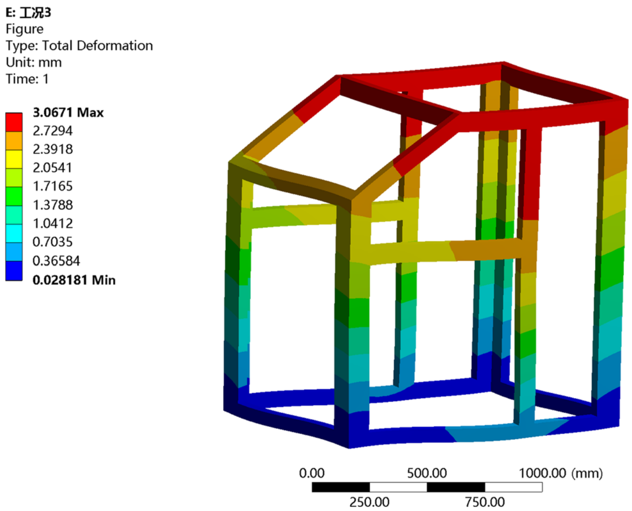

Figure 8: LC3 deformation distribution.

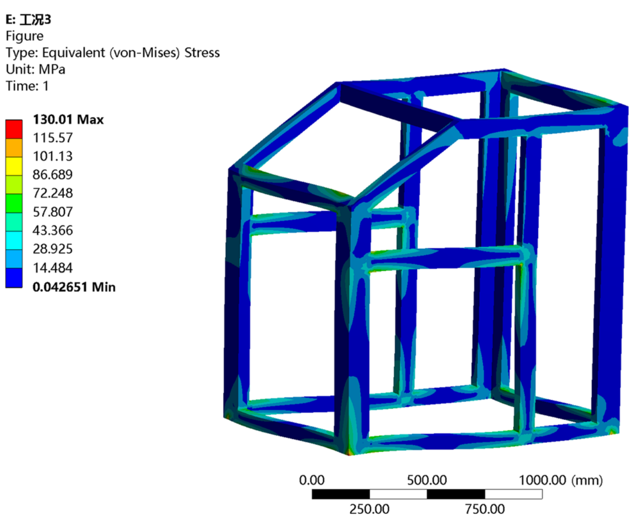

Figure 9: LC3 stress profile.

It has been displayed in figures that the maximum deformation was 3.07 mm, similar to deformation in LC2. The maximum stress was 130.01 MPa, less than the material yield limit, which happened only at the margin of the structure.

4) LC 4: The force and displacement of the charging pile were analysed when −5*g* longitudinal acceleration was applied in the *X* direction, +6*g* vertical acceleration in the *Y* direction, and −6*g* transverse acceleration in the *Z* direction. The relevant results of deformation and equivalent stress of the main body of the charging pile under this LC are shown in Figures 10 and 11.

According to the analysis of LC4, the maximum deformation of charging pile structure was 3.05 mm, close to LC3. The maximum stress was 134.41 MPa.

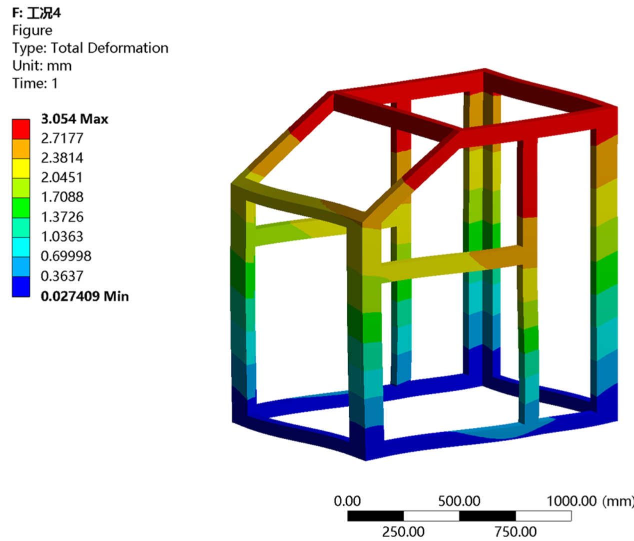

Figure 10: LC4 deformation distribution.

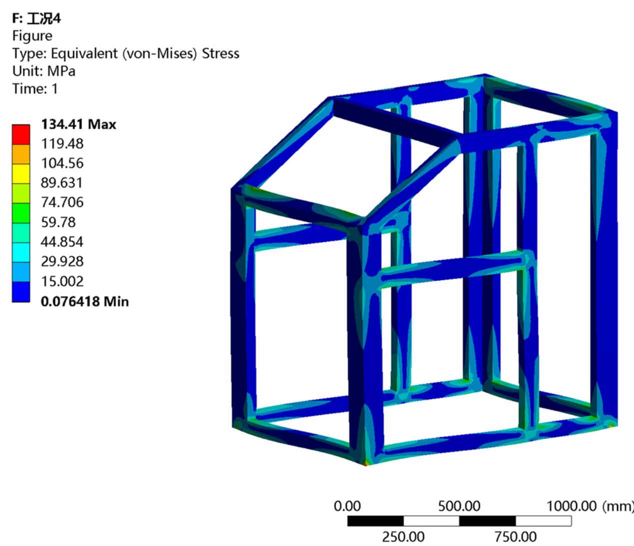

Figure 11: LC4 stress profile.

The analysis results of the above-mentioned four LCs are shown in Table 2. It revealed that the maximum deformation (3.07 mm) occurred in LC3, while the maximum stress (134.41 MPa) happened in LC4, mainly reflected in

Table 2: Results of static analysis under four LCs

LC	Maximum deformation (mm)	Maximum stress (MPa)
LC1	2.79	110.13
LC2	2.80	113.34
LC3	3.07	130.01
LC4	3.05	134.41

each corner. Taken together, the skeleton or main body of the charging pile meets the requirements of strength and safety margin.

4 Anti-dumping property analysis

The anti-dumping stability of the charging pile refers to the ability of the pile with parts to maintain its original equilibrium state in the process of moving. According to the principle of structural stability in mechanics, the structure is stable when the vertical line of gravity centre falls within the range of its bottom. The structured shape of the charging pile is fixed, so the method to improve the stability is mainly to adjust the position of gravity centre of the box, or to increase the size of the bottom support surface of the box, on the premise of not changing the overall structure size. Mobile charging piles are fixed by wheel support. The lower the gravity centre of the object, the better the stability and the anti-dumping ability. The anti-dumping property of the structure was guaranteed by the position of the gravity centre, and thus the stability of the structure can be assessed by calculating the gravity centre of the charging pile.

The calculation principle of the gravity centre is based on the static equilibrium formula, shown in Eqs. (1)–(6):

$$\sum Mi \times Xi = Mo \times Xo, \quad (1)$$

$$Xo = \sum Mi \times Xi/Mo, \quad (2)$$

$$\sum Mi \times Yi = Mo \times Yo, \quad (3)$$

$$Yo = \sum Mi \times Yi/Mo, \quad (4)$$

$$\sum Mi \times Zi = Mo \times Zo, \quad (5)$$

$$Zo = \sum Mi \times Zi/Mo, \quad (6)$$

where Mi represents the quality of each component; Mo represents the total mass of charging pile. Xi, Yi, and Zi represent coordinate values of the gravity centre of each component in the X, Y, and Z direction in the three-dimensional Cartesian coordinate system of the pile, respectively. Xo, Yo, and Zo represent the coordinate value of the overall centre of gravity of the charging pile in the X, Y, and Z direction in the three-dimensional Cartesian coordinate system, respectively, as shown in Table 3.

The calculated gravity centre positions of the overall charging pile skeleton were roughly 0, 59.48, and 718.78 mm as calculated by the software. The vertical line of the gravity centre fell within the range of the bottom surface of the structure, so the skeleton structure of the designed charging pile was stable [7].

Table 3: Calculated gravity centre data

Coordinate	Data
X axis	-2.7471×10^{-16} m
Y axis	5.9484×10^{-2} m
Z axis	0.71878 m

5 Conclusion

After modelling the mobile charging pile, analysis has demonstrated that the structural strength of the charging pile meets the requirements under four LCs. Simultaneously, the gravity centre of the structure fell perpendicular within the bottom surface of the charging pile, which indicates that its stability meets the requirements. However, structure materials, including composite environment-friendly materials, deserve more attention in future studies for weight-lightening and cost reduction, under the requirements of strength and stability [8]. In the meantime, ergonomic factors should be fully considered in structural design, in which innovative color material finishing design methods could be employed for the improvement of users' convenience [9–12].

Furthermore, the layout of mobile charging piles is based on users' demands. Mobile charging piles impact the power grid of the access system when charging, which indicates the possibility of new installation and layout rearrangement of the original power gird should be taken into consideration. Furthermore, the investigation of the intelligent regulation function of the power grid remains challenging. To date, the real-time intelligent metering method has been adopted to further optimize the power grid frequency regulation and peak regulation power of charging piles, for better controllability and load flexibility. Furthermore, the development of wireless mobile charging piles calls for great concerns, whose structure meets the requirements of electromagnetic and network environment are worthy of deeper study [13,14].

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