Research on the Operation of Electric Vehicle Charging Stations

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Abstract. As the number of electric vehicles continues to grow, the demand for charging infrastructure continues to expand, and the construction of charging facilities is significantly accelerated. However, after the completion of large-scale construction, problems such as low utilization, low operating profit, and extended investment payback period have emerged, which has become a bottleneck for the development of the electric vehicle industry. Based on the actual operating data of a charging station, this article analyses the operating characteristics of the charging station from the three aspects of charging power, charging time, and utilization. According to its characteristics, this article analyses the relationship with the local economic operation trend, the reasonable length of time for charging parking spaces, and the efficiency of manual maintenance. The article proposes corresponding improvement opinions for existing operational shortcomings.

1. Introduction
Under the severe situation of increasingly scarce traditional energy sources and increasingly serious pollution emissions, the country is speeding up the development and promotion of transportation using clean fuels. As a new type of transportation with no pollution and diversified energy configuration, electric vehicles have an energy conversion efficiency of more than 90%, and have gradually become the main substitute for fuel vehicles[1]. However, as a key link and basic guarantee in the industry chain for the promotion and application of electric vehicles, the development of charging facilities is facing huge challenges[2]. According to the charging method of electric vehicles, charging facilities can be divided into three types: charging piles, charging stations, and swap stations[3]. Among them, charging piles because of the low construction cost and small footprint has become the main way to charge electric vehicles. In the early stage of the construction of charging piles, there was a situation of "enclosing the land" and seizing the market. As a result, the site selection, the ratio of fast and slow charging are unreasonable, the quality of charging piles is uneven, and there is a lack of effective management and maintenance, which makes construction companies that invest a lot of money face huge financial pressures, and dampens the enthusiasm for capital investment.

In order to promote related technological innovations, achieve orderly construction of charging facilities, and improve the effectiveness of charging facilities operations, this article discusses the charging transaction records of eight charging piles at a charging station from May 2019 to April 2020. Analysis the operating characteristics of charging piles from the three perspectives of charging
capacity, charging time, and utilization, and study possible operational shortcomings of charging stations in actual operation. It also proposes targeted improvement suggestions to provide a theoretical basis for achieving sustained profitability.

2. Analysis of charging station operation data
The research object of this paper is a charging station with 8 120kW DC fast charging piles. According to the statistics of the existing operating platform, there were 33,920 charging transaction records in the 12 months from May 2019 to April 2020, of which 27,193 orders had a transaction power greater than 1kWh. The following will quantitatively analyse the operating characteristics of the charging station from three aspects. The first is the relationship between the amount of charge and economic operation. And the characteristics of power loss. The second is the impact of manual inspection room on charging frequency and revenue. Finally, analysing the current status of the charging pile utilization rate and set a reasonable charging pile reasonable occupation time.

2.1. Analysis of charging capacity and economic operation
According to the order information of the trading platform, the total transaction power for the year is 490882.52 kWh, and the total charging time is 36645 h. A gateway meter is set at the box-type substation of the charging station to measure the power consumption of all loads connected to the box-type substation. The total electricity consumption calculated by the gateway meter is 571216kWh, and the average monthly electricity consumption is 47601kWh. The calculation shows that the annual power consumption is 80333.48KWh, and the average monthly power consumption is 6694.46kWh. The monthly charge, power loss and percentage of loss are plotted as follows[4]:

![Figure 1. The monthly charging capacity and the proportion of power loss.](image-url)

It can be seen from the figure that from May to December 2019, the monthly charging capacity showed a synchronous and steady increase with small fluctuations. Due to the obvious abnormal fluctuations in the charging capacity from January to April 2020, the year is divided into two time periods from May to December 2019 and January to April 2020 for analysis. From May 2019 to April 2020, the average monthly charging capacity of charging stations was 40906.88kWh, the average monthly charging capacity of each charging station was 5113.4kWh, and the charging time was 381.17h. From May to December 2019, the average monthly charging capacity of charging stations was 42514.22kWh, and the average monthly charging capacity of each charging station was 5314.28kWh, and the charging time was 393.63h. From January to April 2020, the average monthly charging capacity of charging stations is 37692.20kWh, the average monthly charging capacity of each charging pile is 4711.53kWh, and the charging time is 356.25h. In the four months of 2020, there was a dramatically drop in the monthly charging capacity in February, but the monthly charging
capacity increased rapidly in March and April, basically returning to the previous level. Compared with the previous 8 months, the average monthly charging capacity has been reduced by 4,822.02kWh, and the average monthly charging time has been shortened by 37.38h. Based on the above analysis, the following inferences can be made:

- From May 2019 to December 2019, the monthly charging capacity is generally stable and has an upward trend. It shows that during this time period, people in the radiation area of the charging station travel normally, and the travel demand has increased or the number of new energy vehicles has increased. That is, the economic operation is relatively stable, and the overall development situation of the new energy automobile industry is rising.
- The charging capacity in January 2020 has a slight decrease compared to December 2019. The 10 days from January 24 to February 2 are the Spring Festival holiday. In addition, due to the impact of the COVID-19, the flow of people during the entire Spring Festival is not large, and the demand for work and travel is reduced. That is, the economic slowdown.
- There was a cliff-like decline in charging capacity in February 2020. Since February is the most severe period of the COVID-19, the whole nation is concentrated at home and the travel rate has dropped significantly. That is, the economic shutdown.
- In March 2020, the charging capacity began to rise, and which was basically returned to average level before the epidemic in April. It can be seen that residents’ travel in the radiation area of the charging station gradually returns to normal. The side verified the decision to resume work and production in March after the province where the charging station is located has no new confirmed cases of the COVID-19 for 11 days from February 18 to February 29. That is, the economy is gradually recovering, showing a positive situation.

To sum up, it is reasonable to believe that the monthly change in the amount of charge can reflect the economic operation of the area radiated by the charging station. The operation of the charging pile can be used as a data reference for analysing the economic operation.

In the loss dimension, the calculation formula of the loss rate is:

\[ \alpha = \frac{P_g - P_c}{P_g} \times 100\% \]  

\( \alpha \) is the loss rate, \( P_g \) is the statistics of electricity by gateway meter, \( P_c \) is the transaction power.

It can be seen from the Figure 1 that in the months when the charging capacity is basically stable, the proportion of power loss is basically stable, maintaining at about 14%. However, in February 2020, when the trading power is low, the proportion of power consumption has increased, reaching 17.26%. From the perspective of loss, the average monthly loss of electricity for the remaining 11 months is 6927.5kWh, except for February. The monthly loss in February also reached 4529.4kWh. This shows that in addition to the variable power loss caused by charging transactions, there is also a relatively large proportion of fixed power loss. Therefore, efforts should be made to reduce the fixed loss of charging stations.

In the statistical year, the total power consumption of charging stations was 80333.48KWh. Calculated according to the electricity price of 0.66 yuan for large industrial level section, the annual loss is 53,000 yuan. The loss expenses accounted for 9.88% of the total annual income. Therefore, further study the causes of loss. The charging station gateway meter in this study is installed on the high-voltage line side of the 10kV transformer. It includes not only the power loss of the charging pile and other load losses, but also the transformation loss of the transformer.

Transformer loss includes active loss and reactive loss. When calculating the annual loss of the transformer, it is assumed that the reactive power compensation of the transformer participating in the calculation is qualified, so the reactive power loss is not included in it. The relevant calculation formula of active power loss is [5]:

\[ P_F = P_N + P_L \]  
\[ P_N = P_0 \times T \]
\[ P_L = \frac{P_T}{T} \cdot \left( \frac{K \cdot P_P}{\varphi} \right)^2 \]  

(4)

\( P_F \) is the active power loss of the transformer, \( P_N \) is the no-load active power loss, \( P_L \) is load active loss, \( P_0 \) is the rated iron loss, \( P_T \) is the rated copper loss, \( P \) is the transformer rated capacity, \( P_p \) is the total electricity consumption, their units are all kWh. \( T \) is the time, which units is h. \( K \) is the root mean square current coefficient. \( \varphi \) is the power factor.

After the simplified transformer operation energy consumption formula can be simplified as:

\[ P_t = P_0 \times T + P_T \times T \times K^2 \times \lambda^2 \]  

(5)

\( P_t \) is the operating loss, \( \lambda \) is the load factor.

The rated capacity of the transformer used in this charging station is 630kVA, the rated iron loss is 0.81kW, and the rated copper loss is 6.2 kW. The load rate is calculated as the effective occupancy time described in section 2.3, the utilization rate is 26.8%. Root mean square current coefficient table according to different load rates:

| Load factor | \( K \) | Load factor | \( K \) |
|-------------|--------|-------------|--------|
| 0.1         | 2.06   | 0.7         | 1.07   |
| 0.3         | 1.05   | 1.0         | 1.00   |
| 0.5         | 1.20   |             |        |

The load rate is approximately 0.3 according to the effective utilization rate of the charging pile. Then \( K \) takes 1.50. A rough estimate is that the annual loss of a 10kV transformer is about 18093.78kWh, which accounts for about 22.52% of the annual loss of the charging station. The generation of other losses requires more data for further analysis and calculation, so as to reduce the corresponding cost expenditure according to the actual situation. In turn, increase operating income.

2.2. Analysis of charging frequency and maintenance cycle

The busyness of charging stations and the utilization effect of charging piles can be reflected by the charging frequency characteristics to a certain extent. When counting the order information, it is found that there are 6727 records of transaction electricity less than 1kWh, which can basically be regarded as a failed transaction. Therefore, delete these failed transaction records before doing the following analysis. According to the calculated transaction data after screening, the average daily charging frequency of the eight charging piles is 74.5 times/day. And each pile will generate 9.31 transaction orders per day. Draw the daily charging frequency chart of the charging pile as shown below:

![Figure 2. Charging frequency and daily average frequency of a charging station.](image)
It is worth noting that the 11 abnormal points in the rectangle appearing in Figure 2. Its value is significantly lower than the average daily charging frequency line shown by the dashed line. After checking the original order data, it is found that on the last day of each month, the total number of transaction orders for all charging piles is not greater than 8. The occurrence of abnormalities is obviously periodic, fixed at the end of the month. It is preliminarily judged that the cause of the special value is the routine maintenance of charging facilities. The average daily charging frequency of abnormal points is 6.3 times/day, indicating that the overhaul has greatly affected the number of transactions. Based on the charging price of 1.3 yuan/kWh, the estimated annual loss is about 15102.72 yuan. The long-term existence of this phenomenon will affect operating income. Therefore, try to reduce the number of days or length of time that the charging service cannot be provided, and improve the efficiency of routine maintenance. It will significantly increase the revenue of charging stations and improve the operating efficiency of charging stations.

2.3. Analysis of utilization and reasonable occupation time
During the transaction process, the transaction duration of different orders varies greatly. It is difficult to fully describe the operation of the charging station only from the dimension of the number of transactions. The utilization of charging piles will be further analysed from the perspective of the time occupied by charging piles. According to the start and end time of the transaction order data record, the daily utilization of the eight charging piles of the charging station can be calculated, and the result is shown in Figure 3:

![Figure 3. Daily utilization and annual average utilization of charging piles in a charging station.](image)

As can be seen in the figure, the average annual utilization of the eight charging piles in the charging station reached 48.8% during the statistical year. The overall operational effect is relatively satisfactory. However, comparing Figure 2 and Figure 3, it can be found that the abnormal daily utilization is not as obvious as the daily charging frequency. By screening the transaction records of abnormal trading days, it was found that out of 69 records, 42 were terminated due to fullness. Accounted for 60.9% of total transactions on abnormal trading days. The transaction lasts for a long time, the average duration is 5h54min, which seriously exceeds the normal charging time. As the charging station is located in the urban area, the main charging model is minibus. The current battery capacity of minibus is up to 90kWh. The charging time is estimated to be 45 minutes using a 120kW charging pile. So 5h54min has seriously timed out.

Then, further calculating the reasonable duration of charging for the problem of overtime occupation. Without upgrading the hardware conditions, simply calculating the required charging time based on the theoretical charging power and battery capacity will reduce the user experience. Therefore, analysing reasonable parking space occupancy time based on existing data, in order to
improve the actual utilization of charging piles. The data characteristics of the duration of a single charge are shown in the following table:

Table 2. Statistical characteristics table of single charge time.

| Statistical Features | Minimum | Quartile | Median | Third quarters | Average value | Maximum |
|----------------------|---------|----------|--------|----------------|---------------|---------|
| Single charge time(min) | 1.92    | 29.25    | 49.10  | 76.12          | 79.74         | 1406.50 |

It can be seen from the table that 75% of the transaction records have a single charging time within 76.12 minutes. 50% of the single charge time is within 49.10min. Classify the duration at an interval of 40 minutes, and draw the classification chart as shown in Figure 4:

![Figure 4. Diagram of the proportion of the duration of a single charge.](image)

It can be seen from the figure that orders with a single charge time of less than 80 minutes accounted for 77.12%, and orders within 120 minutes accounted for 88.1%. It shows that most vehicles can be fully charged within 120 minutes. Therefore, the part of a single charge that exceeds 120min is the overtime occupation time. Further divide the charging time into two categories with the limit of 120min, and calculate the total time occupied by the two categories respectively, as shown in the Figure 5:

![Figure 5. The proportion of charging time.](image)

It can be seen from the figure that the effective occupation time accounts for 62.25% of the total charging time. Although the charging station can reach the utilization of 48.8% without considering
overtime occupation, which is much higher than the national average of 10%, there is 37.75% of invalid occupation. If only the effective occupancy time is calculated, the average utilization of the charging station will drop to 26.8%. It can be said that there is a serious parking space occupation problem, which will affect the utilization of charging stations and customer experience. Therefore, limiting the length of time that charging vehicles occupy parking spaces will further enhance the actual use value of charging stations. Setting the free charging time of the charging station at 1.5-2 hours is more reasonable. And it meets the actual use of the charging station.

3. Conclusion
This article analyses the characteristics of the charging station operation from three perspectives of charging capacity, charging time, and utilization. Proposing corresponding improvements based on the existing problems. According to the change of the charging capacity, the relationship with the economic operation state is analysed, and the idea of using the charging station operation data as a reference for analysing the economic development is proposed. According to the data characteristics of charging frequency, the shortcomings of regular large-scale manual maintenance are found. In order to further improve the efficiency of charging station operation and maintenance, the fault situation of charging station can be analysed. The paper carries out targeted, short-time and efficient maintenance, thereby reducing operation and maintenance costs. It also analyses the utilization and the data characteristics of the single charging time. A serious parking problem was found in the charging station. It provides a scientific reference basis for stipulating reasonable charging time. The above analysis provides analysis ideas and quantitative methods for data to help improve the operating efficiency of charging stations.

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