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# Architecture and performance analysis of a smart battery charging and swapping operation service network for electric vehicles in China

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**Abstract** In recent years, the Chinese government and State Grid Corporation of China (SGCC) have paid great attention to the technical development and infrastructure construction for electric vehicles (EVs). This paper focuses on the mechanism of Smart Battery Charging and Swapping Operation Service Network for EVs including its overall architecture and operational mode. The overall architecture based on the internet of things is analyzed and clarified through terminal device, station management and management center layers. Then two different types of demonstration projects are presented which expound on the condition of EV's infrastructure construction. Lastly, performance analysis of the charging behaviors of electric taxis in fast charging station based on the Queuing theory is proposed. The simulation results show that the service time and the number of generators has an influence on the average waiting time and the length of queue.

**Keywords** Demonstration project, Electric vehicles, Data analysis, Smart charging and swapping operational network, Queuing theory

## 1 Introduction

As an important prerequisite and conditions for grid large-scale integrations electric vehicles (EVs), the battery charging and swapping technologies and related infrastructure facilities for EVs have attracted widespread attention [1–7]. State Grid Corporation of China (SGCC) attaches great importance for the operational requirements of EVs, and has carried out a series of research programs and demonstration projects in this field. According to the National Eleventh Five-year Plan for the development of renewable energy vehicles, SGCC has taken a series of measures to promote the construction of EV charging facilities, in order to deal with the potentially increased load demand from grid integrations of EVs. Currently, a number of promising breakthroughs in key technologies such as efficient charging facilities, standardization, demonstration projects associated with gird infrastructure, operational service models and so on, have been achieved. In addition, many enterprises such as China Southern Power Grid have carried out the research on key technologies of EV charging facilities and engineering applications, facilitating the development of domestic EV industry.

This paper firstly introduces the overall architecture and functions of smart battery charging and swapping operational service network for EVs, and related demonstration projects in China, and then evaluates their performances and benefits. A model used for battery management is also proposed in this paper.

## 2 Smart battery charging and swapping operation service network for EVs

In this section, the smart battery charging and swapping operational service network of EVs developed in China are presented firstly. Operational service network of EVs is comprised of battery identity, power cells, charging facilities, user owner, smart grid and so on, which are linked through GPRS/3G, Wi-Fi, Internet, using technologies such as radio frequency identification devices (RFID), sensors, image recognition. In

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this way, the automatic operation and management of the service network of EVs are implemented based on the Internet of Things. The overall architecture is shown in Fig. 1.

The architecture of operational service network can be divided into three layers from bottom to top, i.e. terminal device, station-level management, and management center

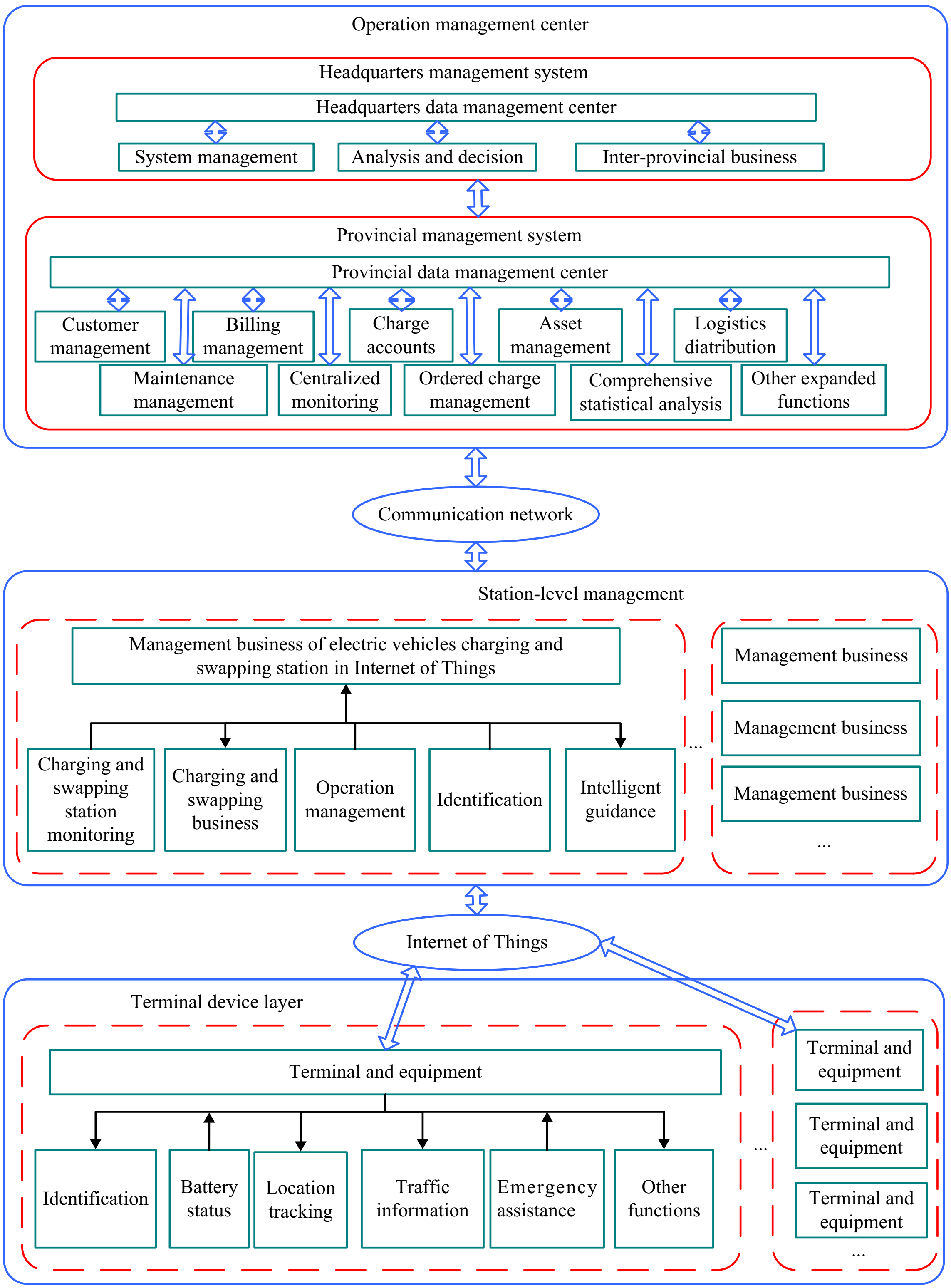


**Fig. 1** Overall architecture of smart battery charging and swapping operational service network

layers. Management center can be further divided into the provincial and headquarters management as needed.

### 2.1 Terminal device layer

Terminal device layer contains the equipment and terminals which are mainly used to identify, collect and process base data related to the system operation, including power batteries, EVs, and vehicle terminals. It uses technologies such as RFID to monitor and recognize based on the unified coding standard. It can collect current work status of vehicles and batteries, such as power, current, voltage, temperature, location, etc. Furthermore, it can exchange data with the station management layer through wired or wireless communications. The basic functions include battery identification, battery location tracking, battery status information acquisition and processing, vehicle identification, vehicle running dynamic positioning and so on.

### 2.2 Station management layer

Station management is responsible for the integrated monitoring and operation management of EV charging and swapping stations through a series of technological means. Its key features include basic functions, such as real-time monitoring of charging and swapping stations, swapping business management and operation management, and enhanced functions, such as EV identification, self-direction, as well as a series of business applications available to the provincial management [8]. The management functions of a standard station mainly include monitoring and management of the charging and swapping stations, with local applications such as operation, swapping management and specific business functions that can be deployed in the provincial management layer.

### 2.3 Management center layer

Management center layer is deployed on the top of the station management layer, and is used to manage the operation of the related charging business in a specific geographic region. Management center layer provides the information interaction interface with the grid operation management system. Management center layer is further divided into provincial management and headquarters management.

The provincial management is responsible for monitoring and managing the operation of charging business distributed in the province or geographic area, including information collection, billing, and customer services. In addition, it is in charge of regional overall business decisions and scheduling based on detailed analysis, including billing, operation management, asset management, logistics deployment and customer services. The provincial management is also responsible to submit macro-statistics information including operational status and assets condition to headquarters management. In addition, it also provides value-added services, for example, charging load forecast, traffic flow forecast, emergency rescue command and dispatch, optimal route hint, nearby charging and swapping station condition hint, traffic information hint, and dynamic charging scheme.

Headquarters management is the only central monitoring management within the areas under the jurisdiction of state grid. However, headquarters management in principle does not take part in specific operational decisions about charging and swapping business. Headquarters management collects and aggregates macro-statistics information such as operational status and assets condition from each provincial management for development and construction planning. Headquarters management is responsible for transferring and coordinating inter-provincial business information, and managing trans-provincial business billing and asset relationship.

## 3 Demonstrations of EV operational service network

In this section, two different types of demonstration projects will be presented. The smart battery charging and swapping service network in Hangzhou is a typical EV service network. And the intercity operational service network within the region of Suzhou-Shanghai-Hangzhou is a large cooperative network involving three big cities in China.

### 3.1 Construction of a smart battery charging and swapping service network

Hangzhou Power Company developed ‘planning program for EVs charging stations in Hangzhou’, in accordance with the principle of employing unified standard, regulations and common identifier with optimized distribution that takes into account of safety and reliability and having appropriate advance in design and concept. The project involves building a three-tier service network consisting of large-scale centralized, standard and distribution stations, facilitating efficient transshipment and distribution of the standard battery packs, which allows users to access battery swapping services easily and quickly. It achieved this by carefully considering urban complex and where possible, utilizing existing complex such as supermarkets, stadiums and public parking. It also employs the advanced technologies and resources such as modern logistics, services, and Internet of Things. It is illustrated in Fig. 2.

The three-tier service network is arranged to facilitate centralized charging and classification distribution. It charges the standard batteries through the concentrated charging stations, and transfers the fully charged battery packs to charging/swapping stations and distribution stations in a hierarchical manner through logistics. Finally, users spend only 2–5 min to replace their battery in a distribution substation. In addition, the design with optimally located charging stations of varying capacity and employing standard batteries and building blocks allows the build of a low cost, broad coverage service network. It also facilitates charging flexibly over a wide geographical area to smooth out grid load and reduce logistics cost.

Hangzhou project has built 8 EV charging stations and 130 standard charging poles and initially formed a unified service network with Gucui station as the base, complemented by other stations, AC charging poles and battery distribution stations. Among them, Gucui and Chengbei stations are constructed by utilizing 110 kV substation subsidiary space, and Xixi station is constructed at the site of the public parking and two distribution stations are constructed in the express highway service zone. Gucui 500 kW station is directly connected to the grid.

### 3.2 Construction of intercity operational service network within the region of Suzhou-Shanghai-Hangzhou

The demonstration project of intercity operational service network for EVs in the region of Suzhou, Shanghai, and Hangzhou was fully completed at the end of November in 2011 and has been in operation. It is China's first trans-provincial and intercity EV charging and swapping facility. It involves 5 service zones located at the junctions of motorways and 9 smart charging and swapping stations in Shanghai, Suzhou and Hangzhou area. Among the 9 smart charging and swapping stations built, 3 plants were in Jiangsu province, 2 in Shanghai city, and 4 in Zhejiang province.

The operation management system of smart charging and swapping service network for EVs has covered all links of EVs charging and swapping service, including customer service, metering and billing, maintenance management, centralized monitoring. Through the information fusion of smart grid, IOT and transportation network, the operation management system can meet EV users' cross-city and cross-regional requirements, and provide commercial operation of charging and swapping service network with the support of information system.

## 4 Data analysis of electric taxis in smart battery charging and swapping operational service network

According to the policy of SGCC, smart battery charging and swapping operational service network for EVs should, where possible, follow the principle of providing battery swapping as the primary service, supplemented by charging where necessary, aided by concentrated charging and classification distribution. It should charge and maintain the standard batteries in a concentrated manner, and swap the batteries of EVs. Meanwhile, to satisfy different needs of EVs and customers, AC and DC charging is provided as supplement service. The principle of the service network is to provide a first class service to all the

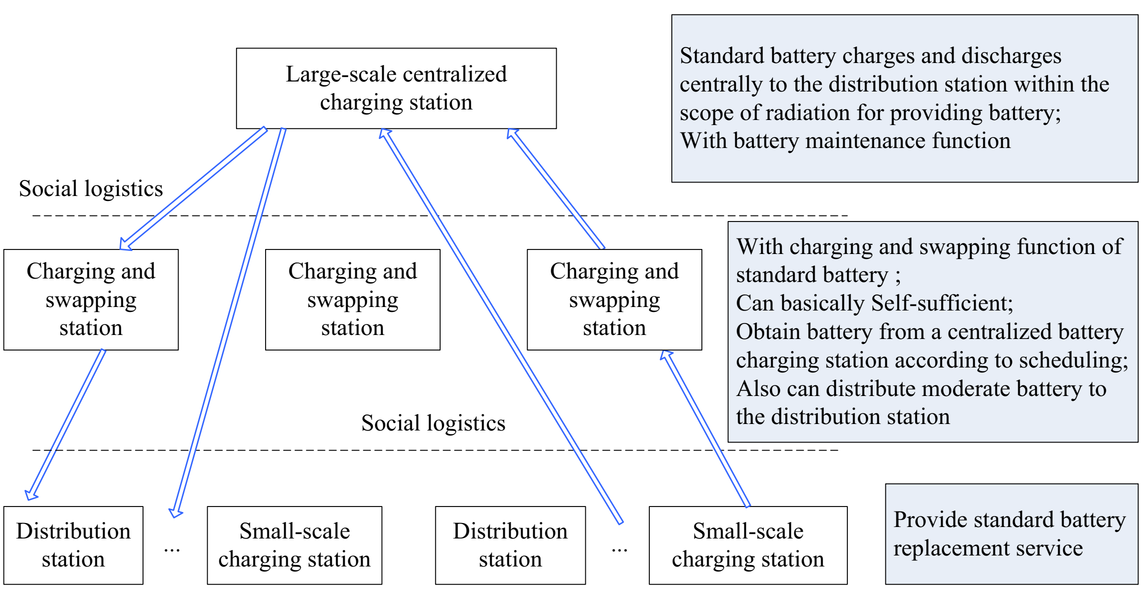


**Fig. 2** Architecture diagram of three-tier service network

customers and make full use of the grid capability without bringing harmful load pressure or fluctuation to it [9–12].

In this part, the performance of the developed network will be exhibited and studied through a real case study of electric taxies in Hangzhou, China. Then data analysis of charging behaviors of electric taxis in fast charging station based on the Queuing Theory is proposed to show the performance of the network.

### 4.1 A demonstration scenario of electric taxies in Hangzhou

Smart battery charging and swapping operational service network can provide an open interface to adapt the development of technology and market. There are many operation modes in China to stimulate the development of EV market.

Hangzhou has launched an 'EV private rental project'. Customers can rent an EV costing less than 1000 yuan (USD $1 is approximately equal to 6.1 yuan) per month. A normal electric taxi has an operating income of about 450 yuan over 15 h. The whole 200 km mileage needs to swap batteries 3–4 times. Each swapping takes about 2–5 min.

Besides, Hangzhou Electric Power Company of SGCC has launched a charging infrastructure construction and operation project of EVs. The project has two kinds of charge modes.

1) Because of the battery subsidies from the Chinese government, the EV customers can choose to rent the batteries charged according to mileage. Per kilometer only costs 0.5 yuan.
2) For the customers who purchase the batteries themselves, it costs them 2.24 yuan/kWh (approximately 0.2 yuan per kilometer).

Figure 3 shows the real case of 90 electric taxies operating at a charging and swapping station in Hangzhou. It is showed that the fast-charging data in one typical day. In the figure, every line in the same color stands for one taxi. The short line shows the beginning and the end time of every fast-charging taxi. Most of the taxis need to charge 3–4 times per day. The average fast-charging time is about 46 min. What's more, we can see from the figure that the fast-charging behaviors of electric taxies have their own regular pattern which can be divided into four time periods. The first period is from the midnight to eight o'clock in the morning. During this period, the taxi drivers are facing a stable business condition as it is late for travel. They usually don't choose to charge until the state of charge of the battery is too low. Another three time periods are mainly around the taxi drivers' shift changing time. They will meet at the charging station and at the same time charge the EV.

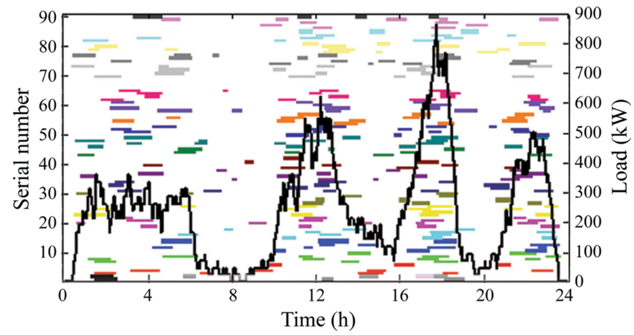


**Fig. 3** A real case of 90 electric taxies operating at a charging and swapping station in Hangzhou

Although there are only 90 taxies, the overall charging load can be large since the fast charging load for every EV is much larger than regular slow charging [13]. What's more, the EVs' charging load fluctuates along with the stochastic access. The characteristic is especially harmful for the distribute network [14–16]. The overall load of the 90 taxies is shown as the black line in Fig. 3.

### 4.2 Arrival flow of electric taxis in different time scales

In order to study the charging behaviors of electric taxis, it is the most important to analyze the arrival time of them. For electric taxis, most of them will charge only when their batteries is low except for meal time. So the state of charge is always low when taxis arrive at the station. Hence the charging time is similar to each other. The arrival time alone decides the charging load requirement. With the arrival time, charging strategy can be planned before the coming peak time.

The arrival time of 90 taxis is shown in Fig. 4. The data is counted and shown in different time scales from 1 to 10 min. From Fig. 4, the distribution of arrival time is found to be different in different time scales. It is because that the sample in the above scenario is too small to show the accurate charging behaviors of electric taxis, but the statistic law is still hidden in the data.

It is generalized that the arrival behaviors of EVs form a Poisson flow [17]. So the arrival behaviors can be described through Poisson distribution. The probability of Poisson distribution is

$$P_n(t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t} \qquad (1)$$

where $n$ is the frequency of the events that happen in the time $t$; $\lambda$ is the average frequency.

With the help of the Poisson flow, Queuing theory can be applied for studying the performance of the electric taxis in fast charging station.

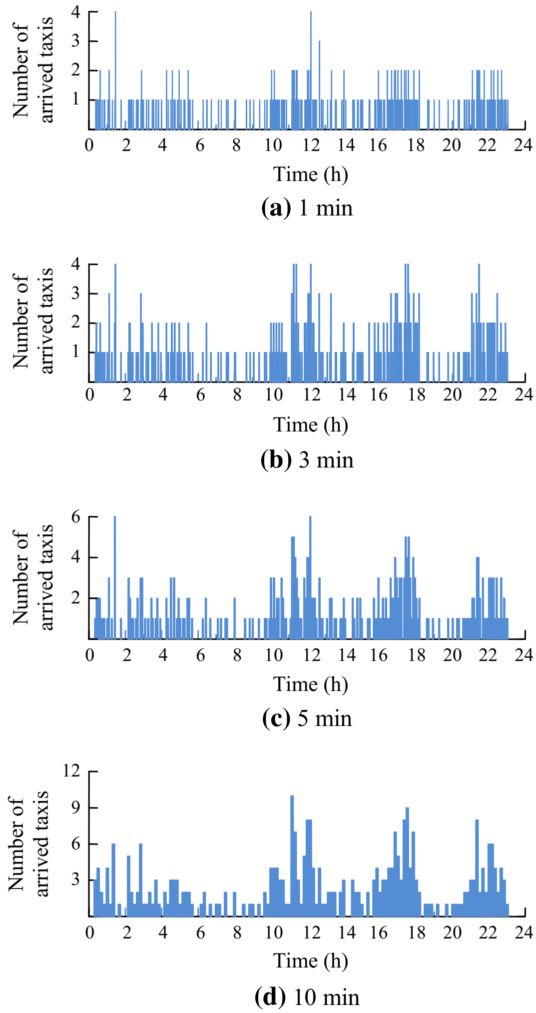


**Fig. 4** Arrival time of electric taxis in different time scales

## 5 Performance analysis on charging behaviors of electric taxis in fast charging station

### 5.1 Principle of Queuing theory

Queuing theory, as a branch of operational research, is used to study the congestion phenomenon and stochastic process. Based on the hard work of researchers all over the world, Queuing theory is now a mature theory mainly used to research on the regular pattern of queuing behavior, optimal operational questions and analysis of queuing systems. Many classical queuing models has been invented for queuing theory. The models provide many useful formulas and indexes which is able to solve most queuing problems [18].

Queuing theory mainly consists of three parts: arrival pattern, service time and service equipment. It uses three letters to represent different kinds of queuing systems, such as *X*/*Y*/*Z*. *X* stands for the distribution of arrival time. *Y* stands for the distribution of service time. And *Z* stands for the number of service equipment.

A *M*/*M*/*c* queuing model is suitable for describe the charging process in fast charging station in this paper [17].

The first *M* indicates that the time interval between two taxis arrived in succession, which is represented by $T$, follows an negative exponential distribution with rate $\lambda$. Actually, $T$ will follow negative exponential distribution as long as the arrival behavior follows the Poisson distribution.

The arrival time interval between two taxis can be expressed as

$$F_T(t) = P\{T \le t\} = 1 - P\{T > t\} = 1 - P_0(t) \tag{2}$$

Putting $n = 0$ in (1),

$$P_0(t) = e^{-\lambda t} \tag{3}$$

So, the cumulative distribution function of negative exponential distribution can be expressed as

$$F_T(t) = 1 - e^{-\lambda t}(t \ge 0) \tag{4}$$

where $\lambda$ is the number of customers arrived in one time period and becomes the most important parameter in both negative exponential distribution and Poisson distribution; $n$ is the number of customers arrived in time $t$; $P_n(t)$ is the probability of the event that $n$ customers arrive at the charging station in time $t$.

The second *M* assumes that the time taking for charging service also follows the negative exponential distribution with the parameter of $\mu$ [19]. $1/\mu$ is the average service time for each EV.

The other letter $c$ represents the number of charging equipment in the station.

In a small time period $[t, t + \Delta t)$, there are some conclusions.

1) The probability that one EV will arrive at the station: $\lambda \Delta t + o(\Delta t)$.
2) The probability that no EV will arrive at the station: $1 - \lambda \Delta t + o(\Delta t)$.
3) The probability that one EV will be fully charged: $n\mu\Delta t + o(\Delta t)$ $(n < c)$ or $c\mu\Delta t + o(\Delta t)$ $(n \ge c)$.
4) The probability that no EV will be fully charged: $1 - n\mu\Delta t + o(\Delta t)$ $(n < c)$ or $1 - c\mu\Delta t + o(\Delta t)$ $(n \ge c)$.
5) The probability of other situations: $o(\Delta t)$.

The conclusions above can be shown in Fig. 5.

Use $P_n$ to represent the probability of $n$ EVs in the station. So the equilibrium equation of *M*/*M*/*c* queuing model is deduced as

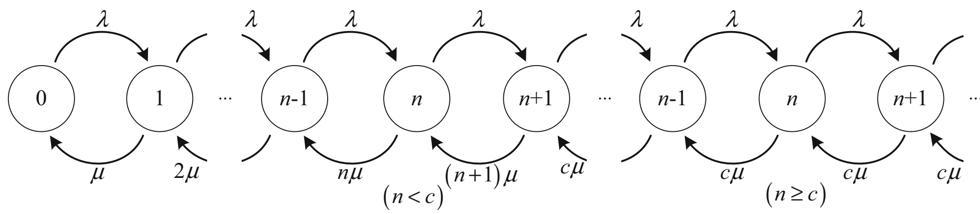


**Fig. 5** State transition diagram of *M/M/c* queuing model

$$\begin{cases} \mu P_1 = \lambda P_0 \\ (n+1)\mu P_{n+1} + \lambda P_{n-1} = (\lambda + n\mu)P_n & 1 \leq n \leq c \\ c\mu P_{n+1} + \lambda P_{n-1} = (\lambda + c\mu)P_n & n > c \end{cases} \quad (5)$$

where $\lambda$ is the rate of negative exponential distribution of arrival time interval; $\mu$ is the rate of negative exponential distribution of service time; $c$ is the number of charging equipment; $n$ is the number of EVs in the station; $\sum_{n=0}^{\infty} P_n = 1$ and $\rho = \frac{\lambda}{c\mu}$. Then $P_n$ can be obtained by

$$P_0 = \left[ \sum_{k=0}^{c-1} \frac{1}{k!} \left(\frac{\lambda}{\mu}\right)^k + \frac{1}{c!} \frac{1}{1-\rho} \left(\frac{\lambda}{\mu}\right)^c \right]^{-1} \quad (6)$$

$$P_n = \begin{cases} \frac{1}{n!} \left(\frac{\lambda}{\mu}\right)^n P_0 & n \leq c \\ \frac{1}{c!} \frac{1}{c^{n-c}} \left(\frac{\lambda}{\mu}\right)^n P_0 & n > c \end{cases} \quad (7)$$

Then some important indexes can also be obtained.

The average length of the queue $L_q$ is

$$\begin{aligned} L_q &= \sum_{n=c+1}^{\infty} (n-c)P_n = \sum_{k=1}^{\infty} kP_{k+c} \\ &= \sum_{k=1}^{\infty} \frac{k}{c!c^k} (c\rho)^{k+c} P_0 = \frac{(c\rho)^c \rho}{c!(1-\rho)^2} P_0 \end{aligned} \quad (8)$$

The average waiting time $W_q$ is

$$W_q = \frac{L_q}{\lambda} = \frac{(c\rho)^c \rho}{c!(1-\rho)^2 \lambda} P_0 \quad (9)$$

## 5.2 Charging station based on Queuing theory

Charging station is built to manage the charging behaviors of EVs. The station should minimize the overall cost of station operation as well as completely meet all the service needs of EV drivers. For the station concerned, it only provides service for the electric taxis mentioned above and all the taxis will only come to this station for fast charging. The research scenario is effective and simply for research on the charging behaviors of electric taxis.

Electric taxis are different from electric buses and electric cars as the main charging mode is fast charging. With fast charging mode, charging strategy is meaningless because the taxies drivers are waiting beside their taxis and they want their taxis to be fully charged as soon as possible. So as long as there are spare charging generators, the taxis will be charged immediately. If the number of charging generators cannot meets the needs of taxis, there taxis form a queue waiting for charging. The station will follow the rule of first-come-first-served. The taxis drivers will wait until their taxis is fully charged so the station do not concern about losing its customers.

Queuing Theory researches on the property of queuing phenomenon, such as the length of queue, the waiting time and busy time periods. With the help of optimal algorithm, Queuing Theory is able to solve the problem between good quality of service and economy. When applying for fast charging station, Queuing Theory focuses on the number of taxis waiting in line, customers' average waiting time, charging load and the needs number of charging generators which is parameter $c$ in *M/M/c* queuing model. The customers' waiting time is the only thing that customers concern about. The number of charging generators affects the property of queue. The more generators, the less waiting time there will be. But more generators raise the total investment of the station [20]. So it is important to find the proper number of generators. For a station that has already constructed, the cost of equipment is sunk cost. So the maximum number of generators is fixed. But the station can adjust the number of generators in use.

While the required waiting time for customers in China is actually short as the stations should ensure that there are enough generators for charging to give the customer a wonderful service experience. The queue of the taxis in the fast charging station is shown in Fig. 6.

## 5.3 Maximum likelihood estimation for electric taxi flow

In this section, the relation between $c$ and indexes of queue in fast charging station is studied through *M/M/c* queuing model. The indexes refer to $L_q$ in (8) and $W_q$ in (9). $\lambda$ is acquired from the data of the station based on Maximum likelihood estimation. It is a classical method to estimate the parameters in probability problems.

$X$ is a research population whose distribution is

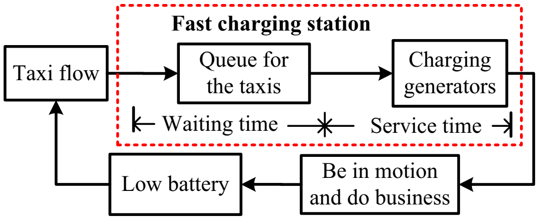


**Fig. 6** Queue for taxis in fast charging station

$$f(x,\lambda)=\frac{\lambda^x}{x!}e^{-\lambda} \tag{10}$$

If $(X_1, X_2, \cdots, X_n)$ are samples from the population, $X$ the likelihood function is

$$L(\lambda)=\prod_{i=1}^{n} f(X_i,\lambda)=\prod_{i=1}^{n}\frac{\lambda^{X_i}}{X_i!}e^{-\lambda} = \lambda^{\prod_{i=1}^{n} X_i} e^{-n\lambda}\frac{1}{\prod_{i=1}^{n} X_i!}=\lambda^{n\bar{X}}e^{-n\lambda}\frac{1}{\prod_{i=1}^{n} X_i!} \tag{11}$$

And the log-likelihood function is

$$\ln L(\lambda)=n\bar{X}\ln\lambda-n\lambda-\ln\prod_{i=1}^{n} X_i! \tag{12}$$

The derivation of (12) is

$$\frac{\mathrm{d}\ln L(\lambda)}{\mathrm{d}\lambda}=\frac{n\bar{X}}{\lambda}-n=0 \tag{13}$$

$$\hat{\lambda}=\bar{X} \tag{14}$$

So $\bar{X}$ can be used to estimate $\lambda$.

Then hypothesis testing is used for testing the accuracy of maximum likelihood estimation. Usually, test statistic formula is used for testing Poisson distribution

$$\chi^2=\sum_{i=1}^{r}\frac{(\gamma_i-np_i)^2}{np_i} \tag{15}$$

where all the data of the samples are divided into $r$ parts according to the number of possible events and in this research, the number equals to the maximum number of arrived EVs in one time scale; $\gamma_i$ and $p_i$ are the frequency number and probability of different events, respectively; $n$ is the number of all the samples.

$$\text{If } \chi^2<\chi^2_\alpha(r-1) \tag{16}$$

the hypothesis testing is accepted.

Obviously, the arrival time of electric taxis has its own temporal characteristic. Not all the arrival behaviors are following the Poisson distribution. So the data should be divides considering the pattern of taxi drivers. In Sect. 4.1, the data are divided into four time periods. The first period experiences a steady flow of taxis. The other three periods respectively experience a peak time. In fact, only when peak time will the queuing phenomenon appear to be serious problem. The research should focus on the performance of the station in peak time.

**Table 1** Results of electric taxi flow in peak time based on maximum likelihood estimation

| $\Delta T$ (min) | Peak time period | $\lambda$ | $\lambda/\Delta T$ (min$^{-1}$) | $\chi^2$ |
|---|---|---|---|---|
| 3 | 11:09–12:15 | 2.0 | 0.667 | 0.5114 |
| | 16:53–18:06 | 2.0 | 0.667 | 1.2426 |
| 5 | 11:15–12:35 | 3.0 | 0.600 | 1.5912 |
| | 16:00–18:25 | 2.5 | 0.500 | 1.2415 |
| 10 | 11:10–11:30 | 8.5 | 0.850 | 3.3042 |
| | 11:50–12:30 | 5.7 | 0.570 | 3.8934 |

**Table 2** Simulation results of average waiting time and length of queue in different service time ($\Delta T = 5$)

| $c$ | $1/\mu = 36$ min | | $1/\mu = 30$ min | |
|---|---|---|---|---|
| | $W_q$ (min) | $L_q$ | $W_q$ (min) | $L_q$ |
| 28 | 104.9 | 2.2 | 62.9 | 1.1 |
| 30 | 10.7 | 0.8 | 6.4 | 0.3 |
| 32 | 3.4 | 0.3 | 2.0 | 0.1 |

Based on the maximum likelihood estimation and hypothesis testing, the results are shown in Table 1 according to different time scales. Firstly, the maximum likelihood estimation confirms that the peak time period of different time scale is around 11:00. Among the time period, the taxis coming for charging follows the Poisson distribution. The results could be useful for the daily operation because the workers in the station could prepare for the coming peak time ahead Secondly, the value of $\lambda$ means the average number of EVs arrived in one time scale. So the number of EVs per minute can also be calculated. At last, the value of $\chi^2$ shows the accuracy of the maximum likelihood estimation. All the results have passed the hypothesis testing according to (16). The smaller $\chi^2$ is, the more accurate the testing will be.

The results indicate that the behaviors will express different in different statistical time scale. The data for time scales of 3 min and 5 min are all following Poisson distribution. But for time scale of 10 min, the data follows two different Poisson distribution at noon and does not fit maximum likelihood estimation in the evening. The statistical time scale of 10 min is not suitable for the research.

Then the two indexes are simulated through *M/M/c* queuing model. The results shown in Table 2 have two

**Table 3** Simulation results of average waiting time and length of queue in different statistical time scale ($1/\mu = 36$ min)

| $c$ | $\Delta T = 5$ min | | $\Delta T = 3$ min | |
|---|---|---|---|---|
| | $W_q$ (min) | $L_q$ | $W_q$ (min) | $L_q$ |
| 32 | 3.4 | 2.0 | 25 | 17.1 |
| 35 | 0.8 | 0.5 | 3.7 | 3.7 |
| 38 | 0.2 | 0.1 | 0.9 | 0.6 |

values of different service time and different number of generators. The results indicate that more generators will reduce the average waiting time. If the number of generators is chosen properly, the average waiting time could be tolerated. As in Table 2, when the value of $c$ adds up to 30, the waiting time is greatly reduced by nearly ten times. But it is not effective if $c$ adds up to 32. In the other hand, the service time also influences the waiting time and the length of queue. The shorter the service time is, the less the waiting time will be.

Table 3 shows the simulation results in different time scales. Although the simulation has the same parameters $c$ and $\mu$, the performance of the station varies. In different time scales, the data follows different Poisson distribution. The station should consider the coping strategy when facing the peak time. If the station wants to simulate the extreme peak time, the time scale should be small. The data in big time scales will help the station to facing the long term operation.

## 6 Conclusions

Uncontrolled charging of large scale EVs could have a major adverse impact on the grid, requiring particular attention to the management of EVs. This paper firstly analyzed and built the overall architecture of the smart battery charging and swapping operational service network for EVs in China based on the research of SGCC. The architecture described the operational mode of EVs in China and explained the function of its three layers. Then, the paper introduced the technologies, business modes and operational data of the demonstration projects, which are currently in operation in Hangzhou city and also in Suzhou-Shanghai-Hangzhou intercity areas of eastern China. At last, a demonstration scenario was introduced to study the performance of charging behaviors in the operation network. Based on the data analysis, the charging behaviors were confirmed to follow the Poisson distribution. Then the performance analysis was proposed based on the Queuing theory. With the analysis results, a method was proposed to find out the peak time of the charging station and the most suitable number of charging equipment for the fast charging station.

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