ORDERLY CHARGING BASED ELECTRIC VEHICLE CHARGING STATIONS' ON-LINE MONITORING SYSTEM

Minghao AI
China
ai_minghao@126.com

Linhai QI
China
qilinhai@ncepu.edu.cn

ABSTRACT

As a new generation of transport, electric vehicles have incomparable advantages compared with traditional car in the aspects of energy conservation and emissions reduction and reducing human's reliance on traditional fossil energy. However, large-scale electric vehicle access will cause a new challenge to the power grid. Concentrated charging during peak period will seriously aggravate the power grid's load. And the uncertainty of charging behaviour and differences in the type of charge will also increase the difficulty of the power grid operation control. Proper charging strategy is used to control the charging process to achieve orderly charge is imperative. On the basis of analysing the impact of large-scale electric vehicle access on the grid and various ordered charging policy currently, electric vehicles charging station online monitoring system based on ordered charging algorithms is proposed. System created ordered charging method library, chose a kind of considering the safety of power grid, power grid load and user behaviour ordered charging method as a reference and provide dynamic interface to add other methods. The system implemented data importing and acquisition by developing common bus, deployed database server, process control server and Web servers, adopted B/S architecture and released through the Web. It's divided into the data layer, business logic layer and presentation layer in logic. The system implemented online monitoring of the charging station from the function of load forecasting management, battery information management, orderly charging control, load curve analysis, visual monitoring and data statistical analysis. Finally, the main functions were displayed through description of the application of system, and looking to the future development trends and research directions.

INTRODUCTION

Energy and environment problem has become the largest shackles of the current human economic and social development. As a new generation of vehicles, electric vehicles have incomparable advantages than traditional cars on the aspects of **energy conservation**, **reducing human dependence on traditional fossil fuels**.[1] Because of this, the Chinese government is vigorously promoting the electric vehicles industry forward. However, Large-scale electric vehicle access will cause **new challenges to the power grid**.[2][3] **Concentrated charging in peak period** will seriously aggravate grid load. The uncertainty of charging behavior and difference of charge type will also increase the difficulty of the power grid operation control[4]. Therefore, how to adopt appropriate methods to **control the charging process**, in order to achieve the effect of smoothing the load fluctuation, to **ensure the safe operation of the power grid** and to **increase energy efficiency**, is a hotspot of current research.

Adopting the method of **orderly charge** in the charging station is a charging control strategy with more studies at present. The reference [1] set charging stations operating income maximization as the objective function, distribution transformer capacity and maximally meet customers' charging demand as the constraints to establish orderly charging mathematical model. The reference [5] considered the influence of user behavior to charging on the basis of summary of electric vehicle charging influence to power grid. It proposed an electric vehicle orderly charging method according to the measured fitting power curve of charging power data. The reference[6] proposed three orderly charging methods include the optimal charging curve method, the optimal charging cost method and the wind power output fluctuations minimum charging and discharging policies.

Electric vehicle charging station is an indispensable electric vehicles energy services infrastructure as the large-scale commercialization of electric vehicles. How to realize the automation of electric vehicle charging station operation management is the necessary subject of current research [7]. At present, the electric vehicle charging station monitoring system proposed by the industry have the CEV series monitoring system[8][9] and the EVCS2000 system[10]. The existing systems need to be improved in the following two aspects:

(1)**Lack the monitoring function** for electric vehicle orderly charging.

(2) Widely used the **C/S architecture** which has the **poor applicability** and difficult systemmaintenance.

This paper will propose an **B/S architecture** electric vehicle charging stations' on-line monitoring system based on orderly charging method according to charging stations' existing monitoring system functions. It will also integrate orderly charging methods and enhance the **applicability** and **maintainability** of charging station monitoring system.

OVERVIEW OF ORDERLY CHARGING METHOD

The core of orderly charging based electric vehicle charging stations' on-line monitoring system is **orderly charging method**. In order to ensure the **applicability** and **scalability** of the system, we should package the existing orderly charging method into a **method library**

which can be called according to demands. This can achieve **low-cost and dynamic expansion** of new methods.

The paper chose an orderly charging method that considered the power grid safe operation, power grid load and user behaviour as the reference method. Its basic schematic is shown as Figure 1.

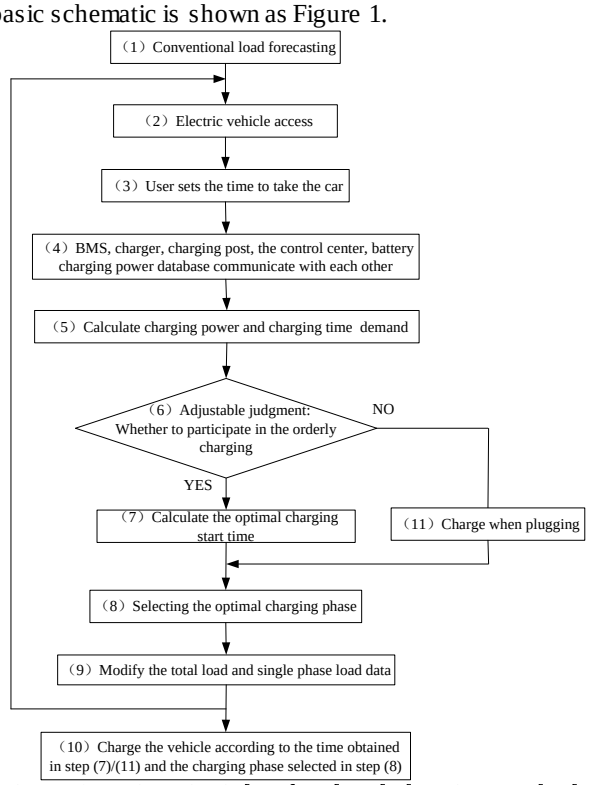

Figure 1 Basic principle of ordered charging method

The method has considered the users' time requirement, used the load curve as the target, sought optimal charging time and optimal charge phase through iteration and forecast the load. The **implementation process** of the method is as follow:

1. Forecast single-phase and three-phase conventional load data.
2. Wait for the electric car access.
3. Users set the charging time requirements.
4. BMS(Battery Manage System), charger, charging pile, orderly charging control center and the battery information database communicate with each other and exchange information.
5. Calculate the charging power and charging time demand.
6. Judge whether the car can be adjusted and to participate orderly charging control. If it has the character of adjustable, go to Step 7, otherwise go to Step 11.
7. Calculate the optimal charging start time.
8. Select the optimal charging phase.
9. Modify the background load data of single-phase and three-phase.
10. Charge the electric vehicle according to the time obtained from Step 7, 11 and the charge phase selected from Step 8. Then go to Step 2.
11. Execute the mode of charge when plug, which choose the access time as EV(electric vehicle) charging start time. Then go to Step 8.

DESIGN OF ORDERLY CHARGING ON-LINE MONITORING AND CONTROL SYSTEM

Design of the system architecture

The physical structure of the system is shown as Figure 2.

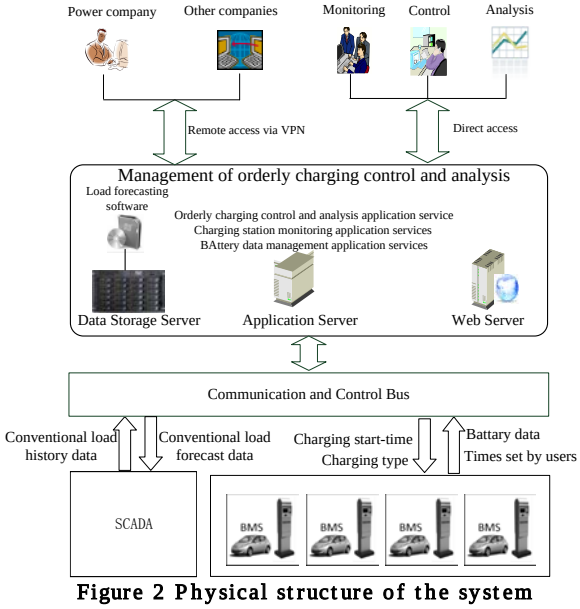

Figure 2 Physical structure of the system

Charging stations orderly online monitoring and control system will be built to a management platform **based on Web**. The platforms will be deployed inside the charging station, the upper management department can access to the platform through the electric power network [11]. Platform includes **data center**, **application service system** and **web service** three parts.

Data in data center comes from the aspects as follows: (1) Load forecasting data from SCADA system. (2) Data from battery pack. (3) Battery power forecasting data. (4) Charging time information. We can acquire and import data by developing the **universal bus**.

Application service system mainly completes the functions of orderly charging control and analysis, charging station monitoring and management and so on [12]. By using a **flexible, modular structure** way, we can easily increase or decrease function modules according to the needs of users. By using flexible permissions management mechanism, we can achieve different levels of orderly charging management according to different users' permissions.

Web Server is used to release application system's each function modules.

The Logical structure of the system is shown as Figure 3.

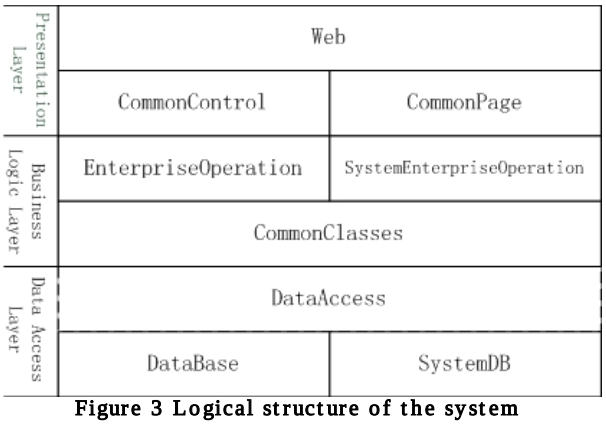

Figure 3 Logical structure of the system

The system uses **B/S three-layer architecture** model, which is divided into **web presentation layer**, **business logic layer** and **data access layer** top-down [13]. The data access layer provides access interface to the upper. The business logic layer is divided into common base class library and logical operation class library. Among them, the common base class library provides public calculation method and logical operation class library provides specific calculation method. The presentation layer includes page public class library and each functional page class library.

Design of the system function

Charging stations' orderly charging online monitoring system mainly includes the following function modules: **Basic data management**, **Orderly charging control**, **Orderly charging visual monitoring** and **Charging data statistics and analysis**. Function modules are shown as Figure 4.

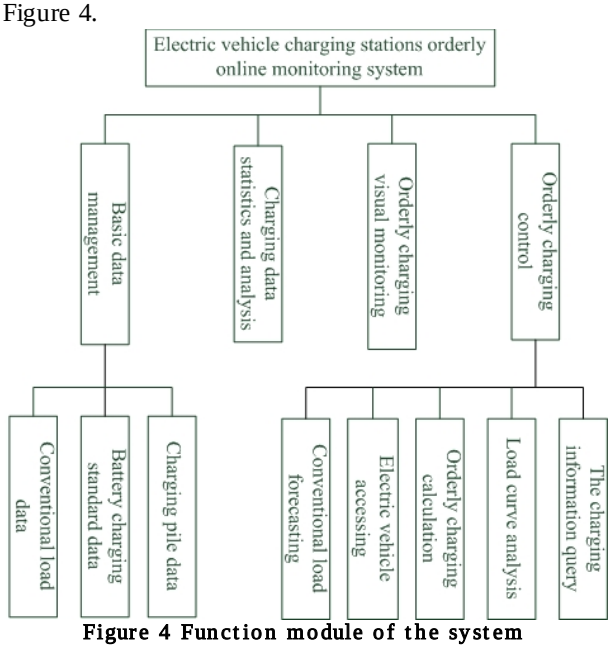

Figure 4 Function module of the system

Basic data management

Basic data management includes the management of conventional load data, battery charging standard data and charging piles data.

Conventional load data is the foundation and power background data of the orderly charging control analysis. In the process of electric vehicle charging, conventional load data will serve as the foundation and new power data will be accumulated on it to form a new load power curve data as the prediction [14]. Load data is from the superior substation **SCADA system** or **PQ monitoring system**, so the **appropriate data interface** should be developed to obtain conventional load data.

Battery charging standard data includes all kinds of battery charging standard power data and charging mode parameter data. Battery charging required time, charging adjustability, the optimal time to start charging, charging phase selection and battery charging power prediction all need use battery charging standard data to be completed.

Electric vehicle charging process is a contact process **between battery and charging pile**. In order to achieve an orderly charging visual monitoring and information query, we need to store the **state of the charging piles**, the charging phase, the charging voltage, current and power and other information.

Orderly charging control

This function module includes conventional load forecasting, electric vehicle access, orderly charging calculation, load curve analysis and charging information query functions.

The initial data of conventional load forecasting is the load on the bus of transformer box in the charging station. The **background load** of the first car each day is the conventional load data. By **superimposing the charging power of the car before**, the load data curve is corrected into a new background load which is as the background load of the next car and by this analogy.

Electric vehicle access is the process of charging parameter data acquisition before electric vehicle charging in the station. Battery type and battery SOC parameters can be automatically acquired into system by **RFID (radio frequency identify technology)** during the car entering the charging station. They can be also acquired into the charging piles by using **CAN communication specification** through the way of **connecting the vehicle battery management system (BMS) and charger with charging piles in charging station**, and be uploaded to the system.

Orderly charging calculation module integrates different orderly charging algorithm libraries such as the orderly charging reference algorithm shown in Figure 1. At the same time of calculating orderly charging, **the system also forced a disorderly charging load calculation** (direct charge without orderly regulation judgment). So that we can contrast the load case of orderly and disorderly charging, and analyze effect of orderly charging.

Load curve analysis function is to show the effect of charging to the current load. The original **background load data**, **data after superposition of orderly charging**

and disordered charging are shown contrastively. At the same time, **Three-phase and single-phase load curve** are also shown contrastively. In addition to display the real-time curve according to vehicle access condition, the system can also **read and display history curve** data according to the input time.

Charging information query function can query charging information on current day or the past. System regards the process of the vehicle enters the charging station for one time charging as a data object and stores it in the database as a record. The data record includes charging date, the optimal charging start time, finish time, charging pile number, etc.

Orderly charging visual monitoring

Orderly charging visual monitoring management is mainly to query and display the operating **status of each charging piles** and the charging status information of batteries in charging station during the operation of the charging station.

System displays the operating status of each charging piles and the charging status information of batteries by an **SVG-based** (Scalable Vector Graphics) Charging station's electrical connect diagram. By clicking pile or battery charging, to achieve drill function, which can track and query details. Using the binding between SVG graphics and background database, we can realize real-time display of the charging piles' status and battery charging process [15]. The change of data value bound to one element in SVG graphics will cause the changes of graphic element's color, shape, location [16].

Charging Data Statistics and Analysis

With the massive charging stations connected to the grid, charging event will inevitably lead to pressure on the grid load. Therefore, grid workers need to **statistical analysis the charging indicators**, **so that adjust power supply strategy.** The system uses graphic way to classify summary and variety show different indicators. For example, access time charts and charging method charts can intuitive display different times' charging events and different charging methods' events.

ORDERLY CHARGING ONLINE MONITORING SYSTEM IMPLEMENTATION AND FUNCTION DISPLAY

System implementation

System architecture implementation

System uses a typical **B/S three-layer architecture** model, which based on enterprise network or VPN network. By setting up database server, control processing server and web display server, the system can be visited by users through browsers.

System is developed by using .NET platform. Each server installs Windows Server 2008 operating system. The database server deploys Sql Server 2008 and web server deploys IIS6.0 (Internet Information Services).

In view of the load data from SCADA system and the information acquired from charging piles, we have developed **universal communication bus** to realize **lossless connection** from data acquisition to the database. System's data layer needs to implement data definition layer and data operation layer, which correspond to each table definitions and various CRUD (Create Read Update Delete) operations in database. Business logic layer needs to implement orderly charging algorithms, data processing and related functions. The presentation layer needs to implement **web pages** as well as **processing classes** of related pages.

The main algorithm implementation

The implementation of orderly charging reference algorithm includes algorithm of calculating the optimal charging start time, algorithm of selecting optimal charging phase and other mainly algorithms.

We use the **traverse** way to calculate of the optimal charging start time. The total load energy after superposition will be obtained by Formula (1). Select the smallest and satisfy Formula (2) background load curve's start time point as the optimal charging start time.

$$\min E = \sum_{t=t_{arrival}}^{t_{arrival}+t_{Charg}} [P_{base}(t) + P_{Charg}(t - t_{arrival})] \cdot \Delta t \quad (1)$$

$$\max_{t \in [t_{arrival}, t_{arrival}+t_{Charg}]} \left[P_{base}(t) + P_{Charg} \cdot (t - t_{arrival}) \right] < P_{smax} \quad (2)$$

Optimal charging phase selection algorithm is similar to the optimal charging time algorithm, which needs to **traverse the background load curve of each phase** to seek to a charging phase with **minimum load energy** as the optimal charging phase.

The main functions implementation

The system provides **function of maintaining battery charging standard information**. Battery charging standard data information is stored in the database and operated through data operation layer, and provides the functions of viewing, adding, editing and deleting battery information to users. Batteries are associated with specific charging station with charging station number and the battery type. Battery information is shows on the page in curve graph form.

Orderly charging control function can receive user input data of battery type, battery SOC(State of Charge), expected charging completion time and Orderly charging adjustable coefficient. Orderly charging algorithm is started through page interaction. System **selects and reads the relevant background load data, battery data and charging pile data** from the database according user input data, **calls the core algorithm** to calculate **the optimal charging start time** and other results, records into a charging event and then updates on the page in real-time. At the same time, the disordered charge calculation module is called in order

to contrast with orderly charging. After calling the algorithm, background load curve will be updated and real-time displayed on the front, so as to analyze the load trend.

Charging station orderly charging visual monitoring function implements the real-time monitoring of current bus status, charging pile working status and battery charging status. The battery charging status and the charging voltage, current, power and other information calculated can be displayed on the web by visual monitoring page handler class. Formula (3) (4) are used for **calculating battery status information** in constant current charging stage and constant voltage charging stage.

$$SOC_{CC} = \frac{SOC_0 + I_{CC} \times (t - t_0)}{Q_N} \quad (3)$$

$$SOC_{CV} = \frac{SOC_{CC} + (1 - SOC_{CC}) \times (t - t_{CV})}{t_A - (t_{Charg} - t_{CV})} \quad (4)$$

Function display

In Figure 5, orderly charging control module is shown in the forms of **table and graph**. In the table, there is all charging events information. In the curve graph, there are load curves of whether adopting orderly charging method and of three-phase load balancing charging.

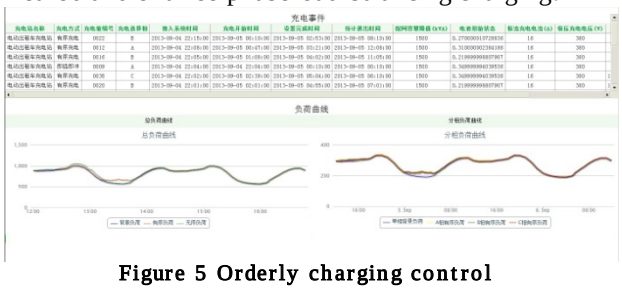

Figure 5 Orderly charging control

Figure 6 is the page of charging stations orderly **visual charging monitoring**. The page provides the display function of all charging piles, batteries and buses status information in charging station.

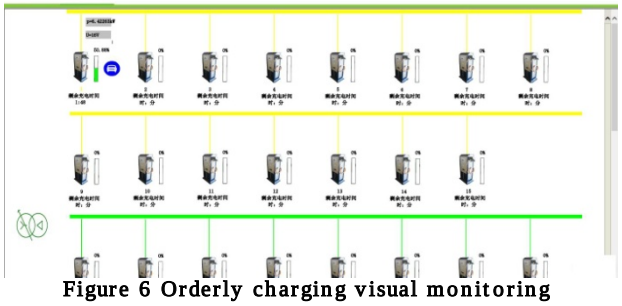

Figure 6 Orderly charging visual monitoring

CONCLUSION

The paper proposed, designed and implemented the online monitoring system of electric vehicle charging stations based on orderly charging algorithm after analyzing the development trends of electric vehicles and electric vehicles orderly charging strategies. The system was designed and implemented in the aspects of system architecture, core algorithm and main functions. At last, system's application and main functions were displayed.

With the development of charging technology and the forward of electric vehicles' industrialization, orderly charging based electric vehicle charging stations' on-line monitoring system needs to study deeply from the following aspects:

1) The study that for the electric vehicle charging users request, **a number of charging stations in an area coordinate** with each other according to their site parking situation and load situation to put forward the most optimal charging scheme. In this way, we can increase the unified control efforts, improve the utilization rate of resources, and maximize the interests.

2) We should consider **the situation of V2G**(Vehicle-to-grid). With the large-scale electric vehicles accessed to the power grid, the electric vehicles not only play the electricity user, but also be used as energy storage devices, which supply power for grid in spare time, to reduce the power grid load and improve resource utilization. So electric vehicle charging stations' on-line monitoring system need to consider relevant V2G controls on function, to ensure the grid's safe and stable operation.

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