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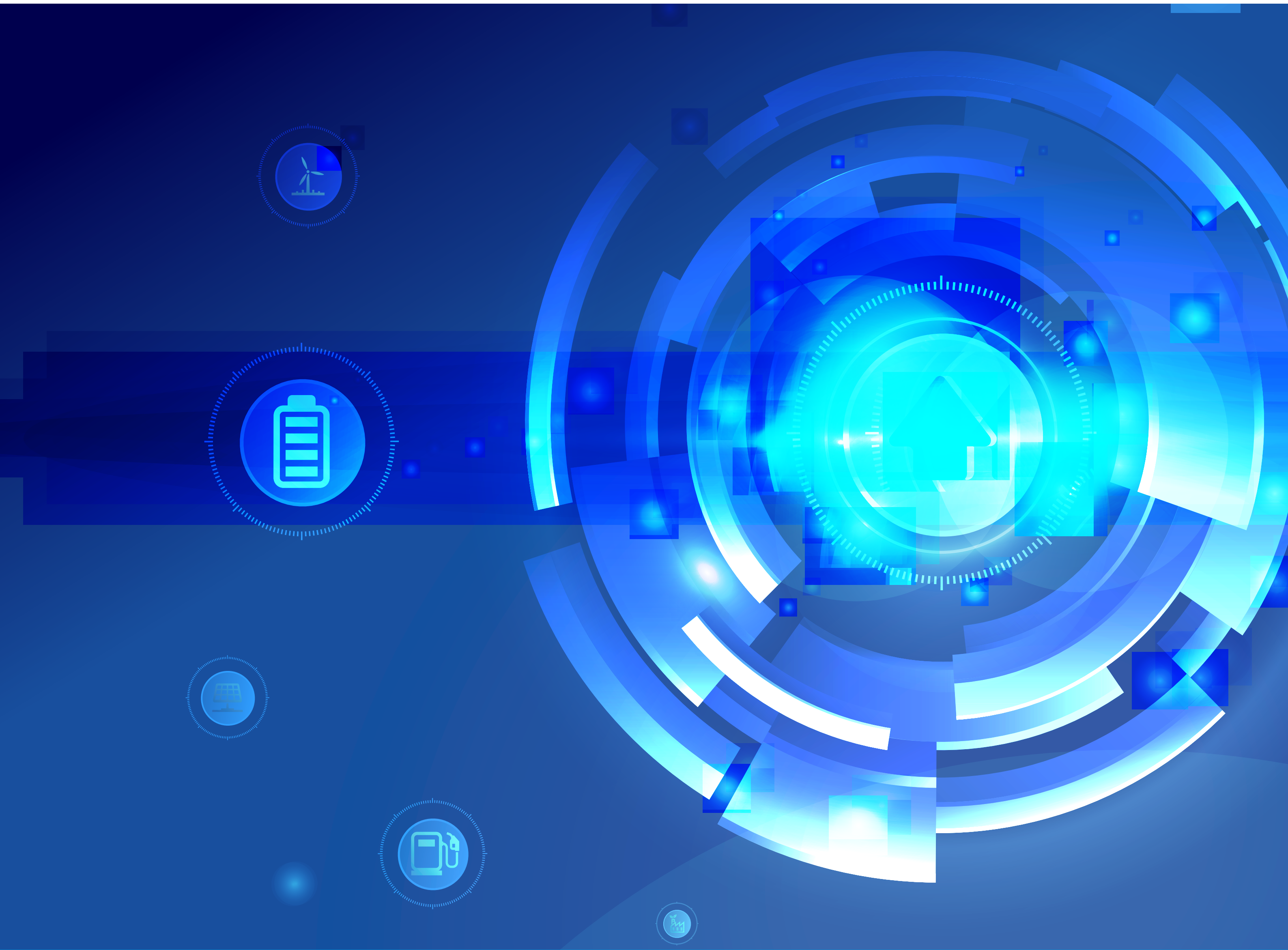

TECHNICAL GUIDELINES FOR INTEGRATED APPLICATION OF ELECTRIC VEHICLES AND RENEWABLE ENERGY

BEST PRACTICE IN CHINA

GLOBAL ENVIRONMENT FACILITY
INVESTING IN OUR PLANET

TECHNICAL GUIDELINES FOR INTEGRATED APPLICATION OF ELECTRIC VEHICLES AND RENEWABLE ENERGY

United Nations Industrial Development Organization
China Society of Automotive Engineers

With Special Support from Global Environment Facility

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Preface

Our global community continues to face an unprecedented convergence of challenges, many of which are disproportionally impacting the world's most vulnerable people. Developing countries, which have contributed the least to global greenhouse gas emissions and climate change, continue to grapple with record heat waves, flooding and drought, even as they attempt to grow their economies, create jobs and recover from the COVID-19 pandemic. Moreover, rising fuel and energy prices place increasing pressure on families and small businesses.

At the heart of these crisis is our global "economies" reliance on fossil fuels for energy and the urgent need to transition to clean and sustainable energy. Although the challenge is great, many of the solutions we need to achieve a just and inclusive energy transition already exist. This is particularly the case in the transportation sector where electric vehicle adoption has emerged as a key strategy for countries to meet ambitious climate targets in line with the Paris Agreement.

There is reason to be optimistic. The last decade has seen tremendous growth in electric vehicle use, especially in China. Advances in battery technology and manufacturing have helped reduce costs while forward thinking government policy has helped make electric vehicles more affordable and accessible to the public. Investment by governments and the private sector in necessary charging infrastructure has also helped accelerate adoption by reducing potential owners concerns related to finding a place to charge their new vehicle.

While current growth in electric vehicle use is encouraging, we know that adoption is not enough. To realize the full benefits of electrifying our transportation system, the energy infrastructure and related supply chains supporting electric vehicles must also be clean and sustainable.

The *Technical Guidelines for Integrated Application of Electric Vehicle and Renewable Energy* is an outcome of the innovative project, *Integrated Adoption of New Energy Vehicles in China*, led by UNIDO in partnership with China's Ministry of Industry and Information Technology, the China Society of Automotive Engineers and the Global Environment Facility. The project has been instrumental in piloting different applications of renewable energy integrated with charging infrastructure within China. The Technical Guidelines build on the success of these demonstrations and provide an outline for how electric vehicle and renewable energy integration can be accomplished and thereby scaled-up in China and around the globe.

My sincere thanks and gratitude to our partners and the stakeholders that contributed to this publication. UNIDO remains fully committed to supporting countries accelerate their adoption of low carbon mobility and I am certain the Technical Guidelines will be a valuable resource for advancing electric vehicle use that is truly sustainable.

Gerd Müller
DIRECTOR GENERAL, UNIDO

Climate change is a universal challenge for all mankind. Accelerating the innovation, promotion, and application of green and low-carbon science and technology have become the choice of an increasing number of countries. The integrated development of New Energy Vehicles (NEV) and Renewable Energy (RE) is the main path of low-carbon transformation in the transportation sector, and it is also an important engine to enhance the economical sustainability. As the world's largest NEV market, the total stock of China's NEV has exceeded 10 million this year. Such a large-scale market has become a vital driving force for accelerating the green and low-carbon energy transformation and increasing the proportion of clean energy consumption, which will in turn promote the development of green and low-carbon society.

Under the guidance and support of the Global Environment Facility, the Ministry of Industry and Information Technologyof the People's Republic of China, and the United Nations Industrial Development Organization (UNIDO), the China Society of Automotive Engineers (China-SAE) implementedthe project "*Integrated Adoption of New Energy Vehicles in China*". By focusing on fusion technologies such as unidirectional smart charging, vehicle-to-grid bidirectional smart charging, integrated microgrid powered by PV with energy storage system and EV charging facilities, and downcycing utilization of retired EV power batteries etc., the project has carried out a two-year demonstration of multi-scenario applications in nine cities including Shanghai, Qingdao, Yancheng, Beijing, Shenzhen, Baoding, Zhenjiang, Tianjin, Lianyungang, and Shanxi Province.

In order to fully summarize the project progress and achievements, China-SAE and UNIDO jointly compiled the "Technical Guidelines for Integrated Application of Electric Vehicles and Renewable Energy". The Guidelines systematically sorts out the application of various fusion technologies in different scenarios from ten typical demonstration projects and condenses the relevant fusion technical requirements and guidelines from the perspectives of technical solutions, construction requirements, business models, and operational effects. It is our hope that it will provide relevant data, experience, and practical reference for the integrated application of EV and RE across the globe.

As the integrated application of NEV and RE is a new trend and new opportunity for future industrial development, we expect that the Technical Guidelines can provide a Chinese solution for the development of the global new energy automobile industry. We also hope that international exchanges and cooperation will be further strengthened in the future, and more suitable regions around the world will be promoted to carry out demonstration and applications of EV-RE integration. This will contribute to the green and low-carbon development in the fields of transportation and energy, and to the goal of global carbon neutrality.

ZHANG Jinhua
Secretary General of China Society of Automotive Engineers

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We are also grateful to many other organizations for providing inputs whom we are unable to mention individually.

Abbreviations and Acronyms

BMS	Battery Management System
BSS	Battery Swapping Station
CA	Certification Authority
CO_2	Carbon Dioxide
C-V2X	Cellular Vehicle-to-Everything
DOD	Depth of Discharge
EMC	Electromagnetic Compatibility
EMS	Energy Management System
ESS	Energy Storage System
EV	Electric Vehicle
GEF	Global Environment Facility
IEC	International Electrotechnical Commission
IOV	Internet of Vehicle
LTE	Long Term Evolution
NDRC	National Development and Reform Commission
NEA	National Energy Administration of China
NIST	National Institute of Standards And Technology
PCS	Power Conversion System
PHEV	Plug-in Hybrid EV
PKI	Public Key Infrastructure
PMU	Power Management Unit
PV	Photovoltaic
R&D	Research and Development
RE	Renewable Energy
SAE	Society of Automotive Engineers
SOC	State of Charge
SOH	State of Health
UNIDO	United Nations Industrial Development Organisation
UPS	Uninterruptible Power Supply
V1G	Unidirectional Smart Charging
V2B	Vehicle-to-Building
V2G	Vehicle-to-Grid Bidirectional Smart Charging
V2H	Vehicle-to-Home
V2X	vehicle-to-Everything
VSC-HVDC	Voltage-sourced Converter Based High Voltage DC Devices

Executive Summary

The power and transportation sectors play a critical role in achieving net-zero emissions by 2050 globally and electric vehicles (EVs) are the nexus of these two critical sectors. EVs can act as a massive mobile energy storage, complementing renewable energy (RE)'s distributed and intermittent nature and therefore realizing smart connections between RE generation and consumption, as well as integration with electrical grid. This consequentially enables coordinated energy operation across a range of industries, including transportation, urban green building parks, and smart cities, and accelerates the transition to smart and green energy. Against this backdrop, EV-RE integration is attracting more and more nations' interest and investment.

Among the issues that policymakers and practioners must address in EV-RE integration is how to demonstrate, deploy and eventually diffuse a wide range of relevant technologies. China has showcased its leadership in pouring money, research and development (R&D) resources, and a combination of incentives and regulatory levers, into RE-EV integration, and also demonstrated the EV-RE integration applications in different scenarios.

Chapter 1 provides an array of specific industry development plans, policies and regulations being released to guide the research and development (R&D), demonstration and investment centered on EV-grid-RE integration in China. This chapter also summarizes some of the key flagship projects around the world and identifies the challenges in technology, standards, and business models respectively, which we are facing in further technological advances and large-scale application of EV-RE integration.

Ten Case Studies in China

Chapter 2 examines how the EV-RE integration technologies are applied in various scenarios through ten case studies in China, covering four key technologies, i.e. the unidirectional smart charging (V1G), vehicle-to-grid bidirectional smart charging (V2G), integrated microgrid powered by RE with energy storage system (ESS) and EV charging facilities (hereafter referred to as the integrated microgrid) and downcycling utilization of retired EV power batteries.

The V1G cases demonstrate the centralized V1G applied in urban neighborhoods and the large-scale V1G application based on transactions responding to large electric systems demands, which demonstrated transaction mechanisms and execution modes for EVs to be engaged with the demand side response under the non-electricity spot market.

The V2G case applies large-scale V2G in **the industrial park**. The operator develops vehicle models and charging piles with V2G functions, finalizes mass-production of V2G vehicles and verifies the business model of large-scale application of V2G in an industrial cluster.

The integrated microgrid technology is demonstrated in different scenarios, covering **commercial cluster, industrial cluster, public EV charging infrastructure, university campus and rural area**.

There are five cases further verifying the value of various technical solutions that are applicable to combining RE with microgrid system and charging EVs in different scenarios.

As for **the downcycling utilization of retired EV power batteries**, two operators provide their case studies in this field. One utilizes the downcycled EV power batteries in large scale for **energy storage in industrial cluster**, and the other demonstrates the utilization of downcycled EV power **in micro communication base station as emergency power supply**.

Five technical guidelines

Chapter 3 proposes the technical guidelines for five technologies in China, with the technology for network information system and communication security as a supplement to the four technologies above mentioned. This chapter provides a detailed account of technical framework and standardization framework for EV-RE integration, technical requirements, existing technical standards and future development demand related to each of the five technologies in China. Some of them are technologically forward-looking, which helps readers to gain a more comprehensive understanding of EV-RE vehicle-grid integration technologies and development trends.

Conclusions

Chapter 4 suggests some important building blocks for deployment and diffusion of EV-RE integration technologies that are fundamental and universal.

Findings

(1) Role of domestic policy: incentive policy and deliberate plan are the keys to the EV-RE integration.

(2) Technical pathways: there are four pathways to the EV-RE integration from the technical perspective.

(3) An operation platform: a three-layer operation platform forms the base for the EV-RE integration.

(4) Inter-sectoral standards: designing national-level and inter-sectoral standards is the key to further development.

(5) New market and promising business opportunities: lucrative business opportunities are to be materialized as key V2X technologies are being rapidly commercialized, and a suite of sharing-economy business models is being explored.

Recommendations

(1) For the automobile manufacturers: to establish interoperable interfaces among V1G, V2G and charging facilities.

(2) **For the charging infrastructure service providers:** to construction new charging facilities with bidirectional charging functions and develop effective business models.

(3) **For the information service providers:** to accelerate data interconnection, cross-platform data sharing, accelerated application of internet of things, and expansion of C-V2X integrated application and extended development with smart infrastructure.

(4) **For the power sector:** to coordinate development of smart EVs and smart grid, improve pricing system for EVs charging and create a transaction mechanism for load aggregators to participate in spot market transactions.

(5) **For the regional planners:** to construction integrated microgrid powered by RE with ESS and EV charging facilities based on local context.

(6) **For the EV battery producers:** to make great efforts in safety protection and control technology of power batteries' life cycle application.

In summary, China has accelerated its deployment of RE-EV integration in recent years, indicating its commitment to becoming a global player in the low-carbon economy, and contributing to the goal of global carbon neutrality by 2050. While reflecting on China's success and lessons-learnt, it is important not to lose sight of China's unique advantages – the sheer size of the Chinese market and governments' policy design and enforcement capacity. Nevertheless, the decisive role of the government in providing clear and lasting signals for all low-carbon technologies and the central role that government-funded pilots and demonstrations can play give some clear instances of success from which other countries can benefit. Such lessons are critically important to global efforts to scaling up low-carbon technology deployment to tackle climate change.

CONTENTS

1 Introduction

1. Introduction

The power and transportation sectors play a critical role in achieving net-zero emissions by 2050 globally. There are complementarities between renewable energy (RE)'s distributed and intermittent nature and electric vehicles (EVs)[1]'s mobility and flexibility. EVs can act as a massive mobile energy storage, and therefore realize complementary connections between RE generation and consumption, as well as integration with electrical grid. This consequentially enables coordinated energy operation across a range of industries, including transportation, urban green building parks, and smart cities, and accelerates the transition to smart and green energy. Against this backdrop, EV-RE integration is attracting more and more nations' interest and investment.

1.1 Overview of relevant policies in China

To tackle global climate change, the Chinese Government pledged in 2020 to strive to peak carbon emissions by 2030 and achieve carbon neutrality by 2060. The *Action Plan for Carbon Dioxide Peaking Before 2030* issued in 2021 laid out the prerequisites for actions in the energy and transportation sectors from the perspective of overall national strategy. It proposed to actively pursue the development of new energy resources and advance the transition towards low-carbon automobiles and other transportation equipment. It also required to speed up the development of new electric power systems, incorporate EV charging infrastructure networks and virtual power plants into the regulation of power systems, and actively develop the model with new energy plus energy storage, promote the coordination of power source, grid, load, and storage, use multiple energy sources to supplement each other, and support the deployment of appropriate energy storage systems for distributed new energy sources.

Guided by this strategic vision, specific industry development plans have been established to support EV-RE integration and to increase the degree of EV-grid-RE synergy. An array of industrial policies and regulations have accordingly been released to guide the research and development (R&D), demonstration and investment centered on EV-grid-RE integration.

1 In this Guidelines, electric vehicles (EVs) mainly refer to battery electric vehicles (BEVs), but also applies to plug-in hybrid electric vehicles (PHEVs) and range extended electric vehicles (REEVs).

Table 1-1 Summary of China's main EV-RE promotion policies

Sector	Document Title	Issued on	Issued by	Related Policies
Automobiles	**New Energy Vehicle[2] Industry Development Plan (2021–2035)**	October 2020	Office of the State Council	● **To strengthen the energy interaction between EVs and Grid via the vehicle-to-grid bi-directional smart charging (V2G).** To further the R&D in high-cycle-life power battery technologies and promote the application of low-power direct-current technology. To encourage V2G local demonstrations and consolidate EV's charging and discharging needs with power dispatching needs via flexible pricing and EV incentive policies, aiming to reduce the charging costs of EV owners, and to improve power grid's peak load capacity and emergency response capacity. ● **To promote efficient integration between EVs and RE.** To enable the information sharing between EVs and meteorology and RE power forecasting and prediction systems, harmonize the energy consumed by EVs and the power generated from wind and solar, so as to increase the utilization of RE. To encourage the construction of multi-functional power stations that integrate distributed photovoltaic (PV) power generation, energy storage, charging and discharging. ● **To speed up the infrastructure construction of charging and battery swapping stations (BSS).** To actively promote the charging service model in neighborhood with emergency fast-charging as support to unidirectional smart slow-charging. To strengthen the research and development of new charging technologies such as unidirectional smart charging (V1G), high power charging, and wireless charging, so as to improve charging convenience and reliability.
	Innovation and Development Strategy for Intelligent Vehicles	February 2020	11 ministries and commissions	By 2025, the infrastructure centered on smart cities and intelligent transportation systems will advance positively. The vehicle-to-everything (V2X) network (such as LTE-V2X) will achieve full coverage in certain regions. The next-generation wireless communication network for vehicles (5G-V2X) will be gradually adopted in some cities and highways. And high-precision spatiotemporal benchmark services will be completely accessible.

2 New energy vehicles in China mainly include EVs and hydrogen fuel cell vehicles (HFCVs).

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Sector	Document Title	Issued on	Issued by	Related Policies
Automobiles	**Implementation Opinions on Further Improving the Service Guarantee Capability of Electric Vehicle Charging Infrastructure**	January 2022	National Development and Reform Commission (NDRC)	● **To promote the innovation and demonstration of V2G technologies.** To support grid companies in collaboration with automobile manufacturers and other upstream and downstream stakeholders along the value chain to build platforms for the innovative integration of EVs and smart energy, carry out cross-industry joint innovation and technology research and development, and accelerate the construction of V2G interactive test and standardization system. To speed up pilot projects and demonstrations to explore the implementation pathways to involve EVs in the electricity spot market, and study and improve the transaction and dispatching mechanism for green power consumption and storage by EVs. To explore pilots of distributed PV power generation-energy storage system-charging-discharging integration for charging facilities in campuses and industrial parks. ● **To encourage application of V1G.** To guide the public to participate in V1G mode, and gradually increase the number of V1G piles. To encourage the integration of V1G function into charging piles and EVs and accelerate the sectoral standardization.
	Measures for the Administration of Traction Battery Downcycling for New Energy Vehicles	August 2021	Five ministries	● To encourage battery downcycling companies to develop downcycled products that are suitable for base station backup, energy storage, charging and battery swapping, and other fields. To encourage innovative business models facilitating battery downcycling, such as leasing and large-scale utilization. ● To take performance testing on downcycled battery products to ensure that they meet the requirements of the applicable standards for the application field in terms of electrical performance, safety, and reliability.

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Sector	Document Title	Issued on	Issued by	Related Policies
Energy	**Modern Energy System Planning during the 14th Five-Year Plan Period**	January 2022	NDRC and National Energy Administration (NEA)	● To encourage user-side energy storage units such as EVs and uninterruptible power supplies (UPS) to take part in peak shaving and frequency regulation. ● To carry out virtual power plant demonstrations of various resource aggregation including industrial adjustable load, building air conditioning load, big data center load, user-side energy storage and V2G energy interaction. ● To optimize the layout for charging infrastructure, support the coordinated development of EVs and charging piles across the board, promote the bidirectional interaction of energy and information between EVs and smart grids, and conduct pilot projects and demonstrations for new power stations that integrate distributed PV power generation, energy storage, charging and battery swapping. ● To actively develop smart microgrids powered by new energy sources to achieve compatibility and complementarity with the grid.
	Implementation Plan for Development of New Energy Storage during the 14th Five-Year Plan Period	January 2022	NDRC and NEA	● To explore EV applications in distributed energy supply systems to improve energy quality and reduce energy costs. ● To actively push the construction of user-side distributed energy storage units such as UPS and charging and battery swapping facilities, explore and promote the use of bidirectionally interactive smart charging technologies, such as EVs and smart power consumption facilities, and increase the ability of users' flexible adjustment and utilize power more intelligently and efficiently. ● To encourage the aggregate utilization of user-side distributed energy storage units such as UPS, EVs, and charging and battery swapping facilities.

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Sector	Document Title	Issued on	Issued by	Related Policies
Energy	**Opinions on Improving the Institutional Mechanisms and Policy Measures for Green and Low-Carbon Energy Transition**	January 2022	NDRC and NEA	● To support the application of energy trading platforms to enable nearby transactions between electricity customers and distributed generation facilities (including electricity storage, electric ships and EVs) in the same distribution network and improve the pricing policies and market regulations to support market-based transactions of distributed power generation. To refine electricity pricing policies to better support energy storage applications. ● To support user-side adjustable resources such as user-side energy storage, charging facilities, and distributed power generation systems, as well as load aggregators, virtual power plant operators, and comprehensive energy service providers to participate in electricity market transactions and system operation adjustment. ● To clearly define the standards and requirements for the safe development of user-side energy storage and strengthen safety supervision. To accelerate the market-oriented development of demand response and create a demand response market-based compensation mechanism. To investigate and assess all available demand response resources to compile a graded and classified list and build a dynamic and demand responsive resource library.
Transport	**Development Plan for Modern Comprehensive Transportation System during the 14th Five-Year Plan Period**	January 2022	State Council	● To plan and construct a convenient, efficient, and moderately advanced charging and battery swapping network, and encourage a reasonable layout of PV power generation and energy storage facilities in transportation hubs and stations, and along roads and railways. ● To push forward the use of low-carbon and diversified energy development for transportation, actively promote clean and energy-efficient vehicles and further reduce vehicle energy consumption.

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Sector	Document Title	Issued on	Issued by	Related Policies
Transport	**Development Plan for Integrated Transportation Services during the 14th Five-Year Plan Period**	November 2021	Ministry of Transport	● To vigorously develop clean transportation equipment. To promote the clean, low-carbon, and efficient development of the transportation energy system, and optimize the transportation energy structure. ● To accelerate the planning, deployment and construction of infrastructure such as charging and battery swapping, and hydrogen refueling. In the national pilot zones for ecological civilization and the priority regions for the prevention and management of air pollution, EVs must make up at least 80% of new or renewed public transportation, taxies, logistics and distribution vehicles each year.
Housing construction	**Opinions on Strengthening the Green and Low-carbon Development of County Seats**	May 2021	15 Ministries and commissions	To build a green and low-carbon energy system at the county level by facilitating the application of clean energy such as distributed wind power and PV, and smart PV power to improve the level of clean energy for production and living, promoting comprehensive smart energy services, and increasing the construction of energy infrastructures such as distribution networks, energy storage systems (ESS) and EV charging piles.

1.2 International experiences

Globally, there is an increasing understanding that the energy and transportation challenges we currently confront require more comprehensive and integrated solutions, particularly solutions that can integrate EV charging with grid, renewable energy, stationary storage, and other energy management systems. Against this backdrop, many demonstration projects were launched by governments in conjunction with corporations and academia. Table 1-2 summarizes some of the key flagship projects around the world[3–12].

Table 1–2 Demonstrations of cutting-edge EV-RE integration technology around the world

Project	i-rEzEPT	Virtual Power Plant Demonstration	EV-Grid Integration	Scirius Domestic V2G Demonstration
Country	Germany	Japan	USA	UK
Funder	German Ministry of Transport and Digital Infrastructure	Japan Ministry of Economy, Trade, and Industry	US Department of Energy	Innovate UK
Technology providers	Nissan LEAF Bosch Software Innovations GmgH Fraunhofer Institute for Industrial Engineering	Toyota Tsusho Corp. Chubu Electric Power Nuvve Corp.	National Renewable Energy Laboratory (NREL)	Cenex Nissan LEAF Kaluza OVO Energy Indra
Description	The project includes installing solar systems and a local energy management controller in 13 homes, 15 bidirectional charging stations, and 13 Nissan LEAFs, technology for vehicle-to-home (V2H), vehicle-to-building (V2B), and vehicle-to-grid (V2G)	Through a V2G control system that groups together multiple in-vehicle storage batteries, distributed energy resources, and bi-directional chargers at parking facilities in Toyota City, the project tested the charge and discharge of stored electricity to grids	The research investigated how each system synchronizes with one another using an EV charging station, an emulated power source, efficient buildings, monitoring systems, and community energy storage systems.	The project includes 320 homes with installed V2G units and 750MWH of energy offset through V2G. Participants who own or lease a Nissan Leaf provided electrical support to grid operators during peak energy demand times

3 Intelligent Mobility for Energy Transition Final Report.https://smart-cities-marketplace.ec.europa.eu/sites/default/files/2020-12/IMET FINAL REPORT.pdf
4 Electric Vehicle Smart Charging at Scale. https://www.nrel.gov/transportation/managed-electric-vehicle-charging.html
5 The Highly Integrated Vehicle Ecosystem: A Platform for Managing the Operations of On-Demand Vehicle Fleets. https://www.nrel.gov/transportation/hive.html
6 Electric Vehicle Charging at China and the United States. https://energypolicy.columbia.edu/sites/default/files/file-uploads/EV_ChargingChina-CGEP_Report_Final.pdf
7 PEV Grid Integration Research: Vehicles, Buildings, and Renewables Working Together. https://www.nrel.gov/docs/fy14osti/62244.pdf
8 Nissan Global Sustainability Report 2021. https://www.nissan-global.com/EN/SUSTAINABILITY/LIBRARY/SR/2021/
9 First V2G Project Defined for Japan. https://nuvve.com/first-v2g-project-defined-for-japan/
10 Toyota Tsusho Demonstration Project Explained. https://www.toyota-tsusho.com/english/press/upload_files/201806011300en.pdf
11 Using Renewables for Electric Vehicle Demand: A Review of Utility Program Designs and Implementation Strategies. https://www.wri.org/research/using-renewables-electric-vehicle-demand-review-utility-program-designs-and-implementation
12 Sciurus: Domestic V2G Demonstration. https://www.cenex.co.uk/projects-case-studies/sciurus/

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Project	i-rEzEPT	Virtual Power Plant Demonstration	EV-Grid Integration	Scirius Domestic V2G Demonstration
Results	The project demonstrated the high flexibility of the entire EV-RE integration system. The project maximized the self-sufficiency of the participant fleet and households.	The project verified the feasibility of V2G to balance power and shift the supply capacity of renewable energy and confirmed the functionality of virtual power plants. The project improved and stabilized electrical power at a single frequency without building new power plants.	The project assessed the functionality and value of load management to reduce charging costs and contribute to the development of standards. The project developed and evaluated integrated V2G systems, which can reduce local peak-power demand and access grid service value potential.	The project collected data in 320 V2G homes over 12 months. The project validated the business case of residential customers participating and benefiting from V2G service provision. The project demonstrated the value of V2G to vehicle manufacturers.
Experiences and implications	From the perspective of EV owners and charging infrastructure operators, it is necessary to make a business case for EV-RE integration technology. Legal restrictions of V2G services by the German government are the main impediment to progress: Customers are not allowed to sell back to the grid.	Balancing control power in response to short-term fluctuations is critical to the commercialization of the EV-RE integration technology. V2G technology will enable further diversification of energy resources, and facilitate the integration of relatively small, distributed energy sources (DER) such as solar equipment, batteries, and plug-in hybrid EVs (PHV/EV) with other power sources in homes and factories.	The project raised two practical questions: Can functionality be added without significantly affecting the battery and the vehicle performance? How is information shared and protected within the systems architecture?	V2G enables intelligent charging of EVs and allows EVs owners to sell surplus energy back to the grid, effectively converting households into mini green power stations. Further commercialization is dependent on policy and technology standards. Only a small number of vehicles are V2G compatible at the moment, and the major charging standard in Europe is still working to make V2G accessible.

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Project	i-rEzEPT	Virtual Power Plant Demonstration	EV-Grid Integration	Scirius Domestic V2G Demonstration
Scaling-up potential	The experiment received a lot more applications than was anticipated, and the final participants were selected by drawing.	Nuvve has acquired patents for the core V2G technology and started operating the world's first commercial V2G hub in Denmark.	NREL has partnered with some utilities to install bi-directional charges across the country.	Compared to normal EV charging trials, this experiment attracted far more user participation, with the majority of participants plugging in daily as compared to twice per week.

The above demonstrations and pilots bespoke the importance of EV-RE integration to reducing the consumption of conventional fossil energy and increasing the use or integration of RE, and thereby cutting energy costs and mitigating carbon dioxide (CO_2) emissions.

Regarding integration scenarios, most demonstrations have so far focused on the interaction between EVs and surrounding power infrastructure, especially user-side microgrid system. The application scenarios cover neighborhood, parking lots, homes, office buildings, etc. EVs as a flexible load and energy storage unit interact with the microgrid or the distribution network and take part in peak shaving and valley filling, electricity market transactions, etc.

Regarding integration technology, V1G, V2G, and microgrids that integrates optical storage and charging, represent the predominant technological means to enable EV-RE integration.

1.3 Challenges

Despite the profound significance of EV-RE deep integration and coordinated development, there are challenges and bottlenecks yet to be tackled. Further technological advancement and large-scale application will come from big strides in technology, standards, and business models[13]:

In terms of technology, the existing distribution networks have weakness such as not supporting balanced regulation between local loads, and lacking data communication or creating communication redundancy. There is currently no V2G network support system in place, and the cross-platform business collaboration capacity is insufficient. In addition, the immaturity of V2G technology dampens the construction and expansion of new energy microgrids.

13 Smart Cities Marketplace: Intelligent Mobility for Energy Transition, European Commission, December 2020, Available athttps://smart-cities-marketplace.ec.europa.eu/sites/default/files/2020-12/IMET%20FINAL%20REPORT.pdf

In terms of standards, the V2G standards for EV-RE integration are yet to be refined. Original technical standards established by different sectors have their limitations, and cannot be easily adapted to fulfill the needs for RE-EV integration.

In terms of business models, EV-RE integration is an emerging industry that involves multiple industries and various stakeholders. It is important to explore business models that take into accounts of input cost, benefit distribution, and market acceptance. Continuous demonstration and verification are required to drive technology iteration and large-scale application and thus accelerate the deployment and diffusion of core technology. They are also essential to a quick adoption V2G technology by automobile manufacturers, an improvement in the grid-side's ability to regulate V2G interaction, increased ability to adapt to large-scale RE access and to mitigate consumers' anxiety.

2 Practices in China

2. Practices in China

Among the issues that policymakers and practioners must address in integrating electric vehicles (EVs) and renewable energy (RE) is how to demonstrate, deploy and eventually diffuse a wide range of relevant technologies, such as unidirectional smart charging (V1G), vehicle-to-grid bidirectional smart charging (V2G), integrated microgrid powered by RE with energy storage system (ESS) and EV charging facility, and downcycling of retired power batteries for energy storage. The speed and scale of technology demonstration and diffusion are greatly correlated with income level. Despite being a middle-income country, China has defied this trend, showcasing its leadership in pouring money, research and development (R&D) resources, and a combination of incentives and regulatory levers, into RE-EV integration. Table 2-1 presents a summary of China's representative EV-RE integration applications in different scenarios.

Table 2-1 Typical demonstration projects in China

Demonstrated technology	Application scenario	Location	Characteristics
V1G	Urban neighborhood	Xibalizhuang Neighborhood, Beijing	A centralized V1G system has been promoted in urban neighborhood and perform grid-load integration, which verified the feasibility of the V1G strategy in neighborhood where the charging costs of users were taken into consideration.
	Power transactions responding to large electric systems demands	Shanxi Province	Province-wide multi-location charging aggregation services based on the V1G mode have been provided. And factors affecting the response improvement have been explored by adjusting demand distribution, load declaration, real-time response and cost settlement.
V2G	Industrial clusters	Baoding Great Wall Motor Industrial Park	Vehicle models and charging piles with V2G functions have been developed, charging & discharging tests and compatibility tests have been conducted, the V2G vehicles for mass-production have been finalized, and the influencing factors and potential of commercial operation in V2G park scenarios have been explored.

(Continued)

Demonstrated technology	Application scenario	Location	Characteristics
Integrated microgrid powered by RE with ESS and EV charging facilities	Commercial clusters	Shanghai Auto Expo Park	A small off-grid system powered by PV has been established to realize the complementary mode of integrated stations with battery swapping and fast-charging. Electricity was supplied for EVs by replacing power batteries, and electricity interaction was realized between battery holders and fast-charging facilities.
	Public charging facilities	Gongmingnan Charging Station, Shenzhen, Guangdong	The contribution of the energy storage optimization regulation algorithm to improving the system economy has been verified. The status of the connector and power battery in the charging process has been monitored. And the system operation efficiency has been improved.
	Industrial clusters	Qingdao TGOOD Industrial Park	The direct current (DC) distribution and consumption microgrid system powered by PV with ESS and EV charging facilities has been adopted in the industrial park, which realized the bidirectional interaction in the microgrid in the park. And the smart charging pile cluster has the functions of group control and flexible charging management.
	Campus	Shanghai University of Electric Power	The self-production and self-use of renewable energy have been achieved through the intelligent energy management and control platform; and the shared E-bus fleet services and more green electricity for customized travel routes have further promoted the realization of green travel.
	Rural area	Chongming District, Shanghai	The integrated microgrid system has been built in the rural area, where the local power supply is self-generated and self-consumed, and the surplus-power is transmitted to gird, so as to achieve multi-win results for farmers, collectives and the grid. The charging piles in the parking lots use 100% green electricity to charge EVs and electric bicycles.

(Continued)

Demonstrated technology	Application scenario	Location	Characteristics
Downcycling of retired power batteries for energy storage	Industrial clusters	BAIC Blue Park Zhenjiang Base	A rapid battery pack consistency screening method and a safety risk assessment model for life evolution of power battery downcycling have been established, and the downcycling of the whole battery pack has been adopted, which reflected the importance of assessing the battery history data. Good economic benefits have been achieved through such business models as peak-valley arbitrage and peak-shaving response.
	Communication base stations	Tianjin Iron Tower Micro Communication Base Station	The technical method of downcycling of retired power batteries for storage system at the communication base station has been proposed, and the scenario of retired power batteries as uninterruptible power supply (UPS) for wireless base stations and the corresponding technical solutions have been verified.

2.1 Cases of unidirectional smart charging (V1G)

Disorderly charging of EVs can generate negative impact on the power distribution network and restrict the charging service capacity of transformers in the station area. As a countermeasure, V1G, using effective economic or technical measures to control when and where EVs charging takes place, is able to cut the peak and fill the valley of the grid load curve to reduce the variance of the load curve, thus reducing the peak load of transformers and relieving the load pressure of EVs on the grid. Typical cases include the centralized V1G applied in urban neighborhoods and the large-scale V1G application based on transactions responding to large electric systems demands, which demonstrated transaction mechanisms and execution modes for EVs to be engaged with the demand side response under the non-electricity spot market.

Case 1: Centralized V1G in urban neighborhood—Beijing Xibalizhuang Neighborhood

Basic Information

Application scenario: Urban neighborhoods

Applied technology: V1G

Demonstration site: Xibalizhuang Neighborhood, Haidian District, Beijing

Operator: State Grid Beijing Electric Power Company

Description: There are 54 V1G piles installed in the underground parking lot of the neighborhood to meet the charging needs of more than 80 EVs in the neighborhood.

Operation time: 2019 January to present

(1) Technology and equipment solutions

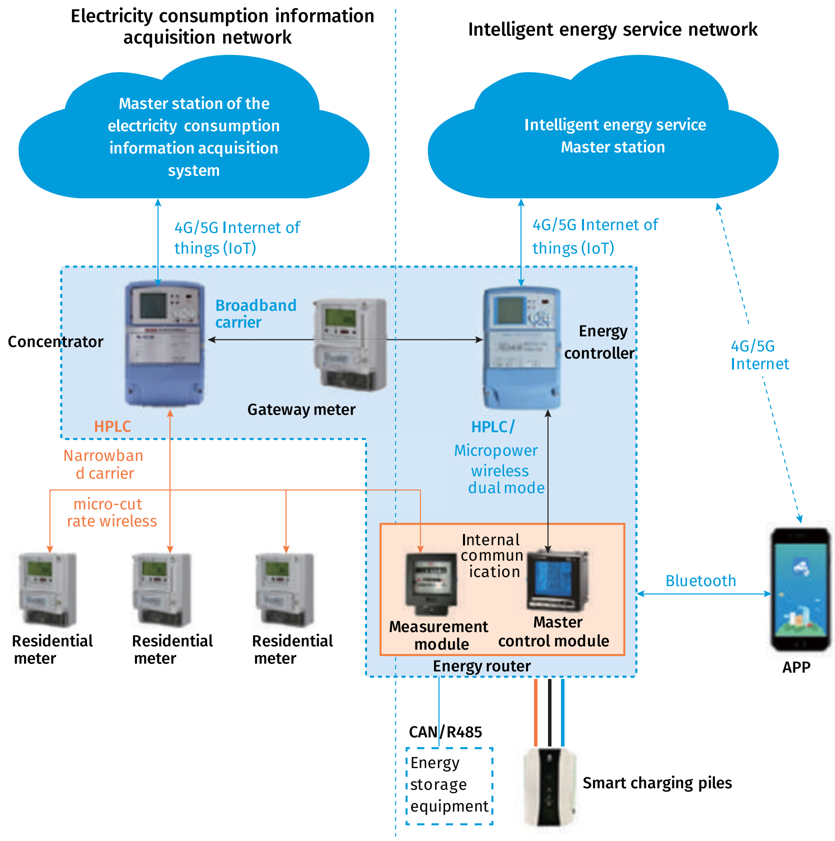
The centralized V1G system is constructed according to an energy controller solution, which is a part of the local distribution network.

On the platform side of the system, there are two systems for the internal and external networks. The electricity consumption information acquisition system of the internal network communicates with the concentrator on the transformer side through 4G or 5G to collect the real-time electricity load in the neighborhood; the external intelligent energy service system of the external network collects users' charging demands, interconnects with the energy controller, generates smart charging control strategies according to the characteristics of the electricity load in the neighborhood, and provides the user-side operation function of smart charging service through a mobile application.

On the transformer side in the neighborhood, a gateway watt-hour meter is installed to collect the transformer load through the local concentrator and send it to the electricity consumption information acquisition system of the internal network; the energy controller is interconnected with the gateway meter to collect the transformer load and issue the smart charging control command to the charging pile according to the change in charging load and the charging demand of users.

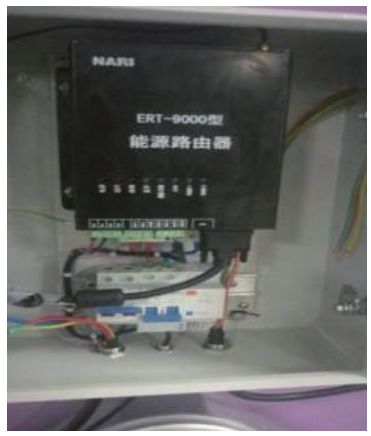
On the charging pile side, there are functions of protocol conversion and metering, and the V1G load control command is executed.

Figure 2-1 Energy controller solution system and main equipment



Architecture diagram of energy controller scheme system deployment

Energy controller



Energy router

1) Energy controller

The energy controller is installed on the low-voltage side of the low-voltage distribution transformer, and collects the data of alternating current (AC) V1G piles through power line carrier communication. As the main equipment in the V1G station area, the energy controller plays a key role in communication, strategy processing, charging plan distribution, and station area information collection, and thus manages charging piles and realizes the V1G control.

2) Energy router

The energy router is a new smart meter integrated device with the functions of data collection, storage, communication, power control and strategy execution. It can collect real-time data of the watt-hour meter connected with the corresponding charging pile, and receive and store the charging plan issued by the energy controller. It can realize real-time power regulation or control of EV charging by executing the charging plan and giving instructions to the charging pile at specified time points.

3) Intelligent energy service platform

The intelligent energy service platform is deployed at the cloud. It collects users' charging demands through a supporting application, and interconnects with the energy controller, so as to generate and issue control strategies according to the characteristics of the electricity load in the neighborhood. The charging power is set at 15-minute intervals according to the charging plan. The station area load line-crossing control strategy is adopted to judge whether the threshold-crossing condition is met. If the station area load crosses the line, the control command will be issued immediately to stop charging to ensure the stable operation of the transformer in the station area by reducing the load in real time.

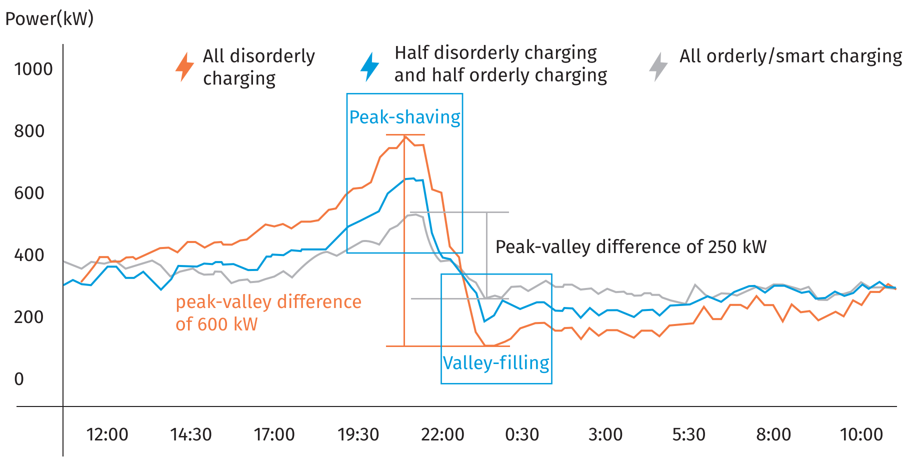
(2) Business model

Smart transformation of distribution facilities in the neighborhood is carried out through the extension of an investment interface, and smart charging control, settlement and load aggregation are implemented directly for private vehicle owners. The engagement potential of property and vehicle owners is tapped by means of incentives and rewards. Based on the cost-benefit analysis of the V1G cases in the neighborhood, the investment is guaranteed to be paid back under the condition of a service fee of CNY 0.3/kWh.

(3) Results

Through centralized V1G, the electricity consumption during the valley period has been greatly increased, and the peak-valley charging load difference in the neighborhood has been reduced. From 2019 January to 2021 November, a total of 2,942 V1G orders were received and implemented, with V1G of 49,107.39 kWh, accounting for 25.32% of the total charging quantity in the neighborhood. The share of charging quantity in the valley section in the total charging quantity has increased from less than 48% in the case of disorderly charging to about 75%. According to the test, with the engagement of more than 30 EV owners, if all of them adopt disorderly charging, the peak-valley charging load difference in the neighborhood will reach 600 kW; if all of them adopt V1G, the peak-valley charging load difference will reduce to 250 kW, with a reduction of 58%.

Figure 2-2 Comparison of V1G effects on peak-shaving and valley-filling



In the process of expansion and promotion, Beijing Electric Power Company has carried out a four-month incentive verification experiment involving 10,066 private pile users in Beijing. These users were encouraged to participate in V1G mainly through kilowatt subsidy, supplemented by cash back, extended warranty and other diversified incentives. With the deepening of incentive activities, the number of users participating in V1G has increased from 804 to 3,338, the total amount of electricity by V1G has increased from 36,000 kWh to 191,100 kWh, and the single charge has reached 22.20 kWh. During the activity period, the proportion of V1G users increased from 13.77% to 48.92%, the proportion of V1G times increased from 8.31% to 27.58%, the V1G electricity quantity increased to 29.18%, and the willingness of users to be engaged with V1G increased significantly. The experiment suggested that the price difference of CNY 0.4/kWh should be promoted on a larger scale, the residential electricity price for households with a shared electricity meter should be taken as the valley price, and the peak charging price in neighborhoods should be set. It lays a good foundation for advancing the government to introduce the peak-valley electricity price policy for neighborhoods and stimulating users to be engaged in V1G.

The experiment also generated other impactful results. For users, after the implementation of V1G, a total of 13,259 kWh of electricity is transferred to the valley section for charging. By adopting the peak-valley price difference (CNY 0.6/kWh), CNY 7,955 can be saved in an extreme scenario.

For grid companies, the cost of investment and transformation of existing power distribution networks can be greatly reduced. For 1.2 million family electric passenger vehicles, in the case of disorderly charging, Beijing Electric Power Company would have to invest CNY 6.4 billion in the transformation of the power distribution network; in the case of V1G, however, only a few distribution transformers need to be upgraded, with a total investment of CNY 2.2 billion, saving CNY 4.2 billion compared with that of disorderly charging.

(4) Lessons learned

It is predicted that 80% of EVs in China will be charged in neighborhoods in the future, so it is of great significance to provide large-scale charging services in urban neighborhoods.

To ease inconvenience of EVs charging in urban neighborhood, all EV-pile AC charging connectors should be equipped with V1G functions. In addition, public parking space should be fully utilized to provide shared smart DC fast-charging services.

Case 2: Large-scale application of VIG for power transactions responding to large electric systems demands—State Grid Shanxi Electric Power Company

Basic Information
Application scenario: Power transactions responding to large electric systems demands
Applied technology: V1G
Demonstration site: Shanxi Province
Operator: State Grid EV (Shanxi) Service Co., Ltd.
Description: The project utilizes a demand-side response transaction and execution in the electricity wholesale market in Shanxi by means of monthly listed pre-clearing price, demands for and responses to recently determined curtailed and limited electricity demands, intra-day measurement of the demand-side response effects, and daily clearing and monthly settlement of interactive electricity.
Implementation time: 2020 December to present

(1) Technology solution

The State Grid EV (Shanxi) Service Co., Ltd. carried out an interactive demonstration of new energy and EVs based on transactions responding to large electric systems demands, aggregated EV load to be engaged with electricity transactions based on the Internet of vehicles (IoV) platform, and improved the RE consumption level through V1G for EVs.

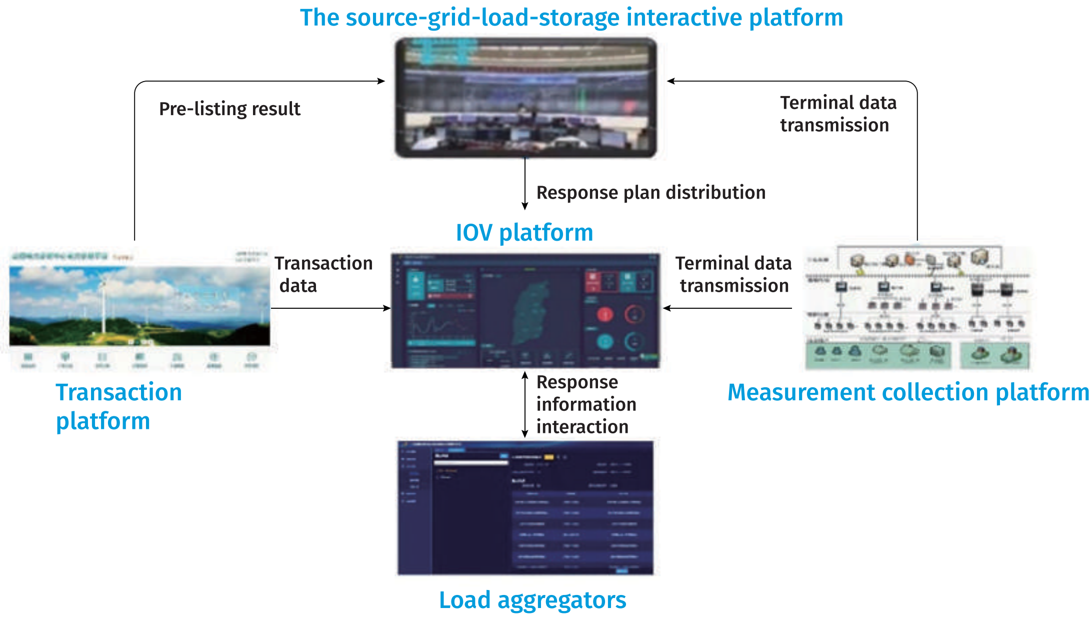
1) Demand response transaction model

The market players involved in demand response transactions mainly include load aggregators, load operators, EV users, electricity transaction centers and grid dispatching agencies. The transaction targets mainly include interactive electricity of demand response and non-interactive electricity of daily charging. Among them, the non-interactive electricity is traded by load aggregators and power generation enterprises in the wholesale market according to the current mode of electricity users' engagement with direct electricity transactions within the province; the interactive electricity is traded by load aggregators in accordance with the power system's response to demands and market rules. Transaction centers determine the prices of curtailed and limited electricity by listing and delisting before the current month, and control centers complete the whole transactions by recently determined curtailed and limited electricity load.

2) Multi-platform information interaction framework

The IoV platform is responsible for real-time detection of the use of charging piles, and can display the charging quantity of each period in real time. If there are a large number of unused charging piles during the electricity curtailing and limiting periods, the platform will issue coupons to users to encourage them to charge at charging stations, so as to consume as much electric energy as possible and mitigate wind power curtailment and PV power curtailment.

Figure 2-3 Diagram of the multi-platform information interaction framework

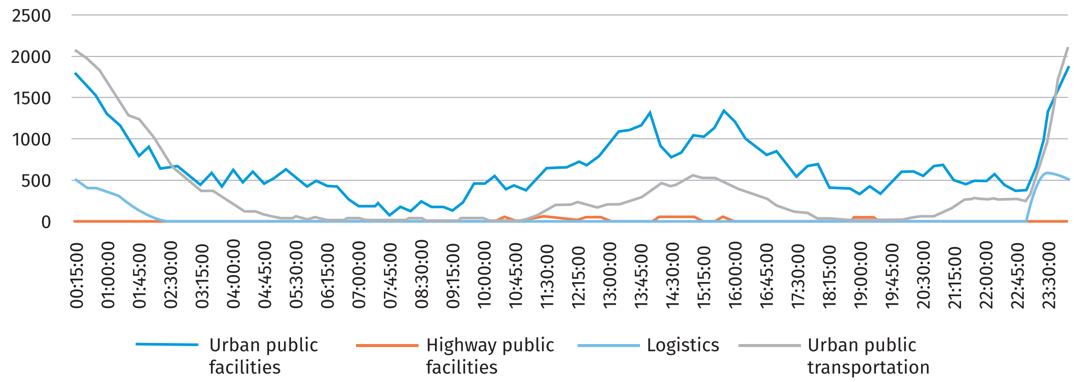


The source-grid-load-storage interactive platform is mainly responsible for information exchange between aggregators and operators. Its core functions include demand response invitation, benchmark curve calculation, user-side demand response capacity declaration, real-time monitor and electricity consumption statistics. In addition, a micro interactive response WeChat mini program has been developed.

(2) Business model

According to the aggregated load type, the aggregated charging stations can be divided into dedicated stations and public stations. Among them, dedicated stations include charging stations for buses and for logistics vehicles, while public stations include urban public stations and expressway public stations. There are great differences in demand response effect and response space of different types of charging stations. Both urban public charging stations and bus charging stations feature obvious peak-valley differences, high total charging quantity, and good response capacity and effect, so they can serve as major participants in demand response. Charging at urban public charging stations is mainly concentrated between 11:00 and 16:00 in the day, while the curtailing and limiting of renewable energy electricity in the day is mainly concentrated between 11:00 and 15:00 in the day. There is a good response relationship between the two, so urban public charging stations can serve as major electricity demand responders in the day. Charging at bus charging stations is mainly concentrated at night, and electricity demands can be responded to at night by adjusting the charging time and the number of vehicles to be charged.

Figure 2-4 Comparison of the baseline power changes in the typical charging stations



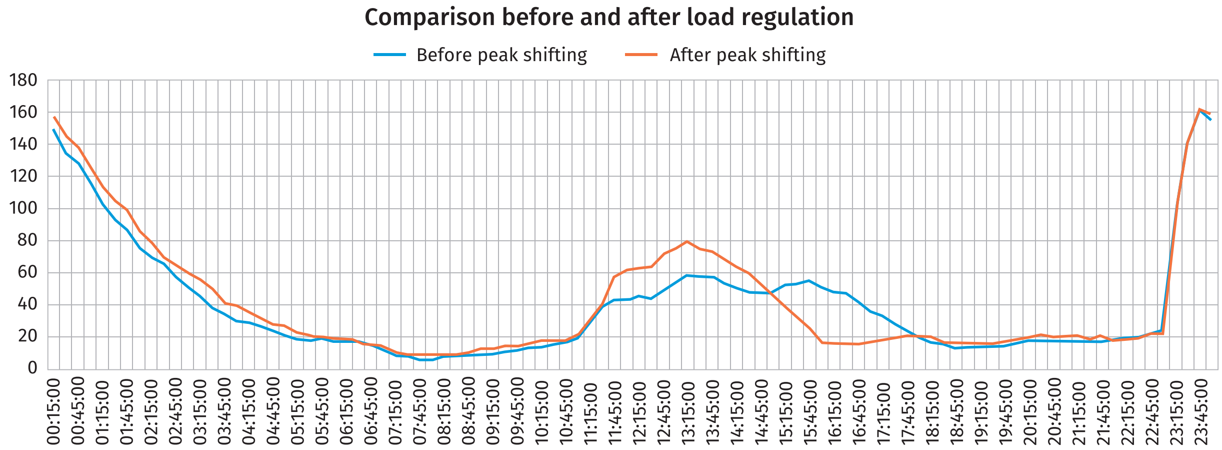
The benefits obtained from demand response are distributed based on the actual response electricity quantity and response results according to rules. Priority is given to the dedicated public service providers such as public transport, logistics and sanitation, and their share of the benefits is not less than 70%. For public charging stations that mainly serve end users such as taxis and online car-hailing vehicles, their share of the benefits is not less than 60%. The benefit distribution method for load aggregators and load operators shall be subject to the agreement between both parties.

(3) Results

As of 2021 December, State Grid EV (Shanxi) Service Co., Ltd. aggregated 88 charging pile operators and 179 charging stations in Shanxi Province. In order to promote renewable energy consumption and responses to curtailed and limited electricity, incentive mechanisms for operators and end users such as coupons and preferential electricity prices have been launched. There are more than 8,000 charging facilities for buses, logistics vehicles and online car-hailing vehicles, with an aggregate capacity of 374MW. A single response can charge 600 EVs, with a maximum response load of 37.4MW. The actual monthly power consumption of all aggregated charging facilities is about 30GWh, and the annual electricity consumption reach 300GWh.

Load aggregators actively organize and guide charging operators to respond to the grid regulation demand. As of 2021 October, load aggregators had organized the operators to conduct online and offline centralized training twice, organized 56 times of demand responses, consumed 152.3mWh of electricity generated from renewable energy sources, and distributed total electricity benefits of CNY 27,109.4 (KWH price cut of CNY 0.178). The response time was about 2.5h/time. The Figure 2-5 below shows that the loads after peak shifting are more concentrated in the period of renewable energy consumption.

Figure 2-5 Comparison before and after the load regulation



(4) Lessons learned

In the case of a substantial increase in RE generation in the future, EVs, as flexible and mobile energy storage loads, can effectively aggregate EV users to carry out electricity transactions via V1G technology. EVs represent an attempt to match the generation and use of a new electric power system, which can reduce the charging cost of users and increase the consumption of renewable energy.

Incentivizing participation and level of engagement is the premise of ensuring high-quality demand response. First, users' load characteristics is necessary to be considered to study electricity price fluctuation signals of electricity transaction's incentive effects on users' charging characteristics and participation intention, and the choices of user groups. The differences in time flexibility of different vehicles as demand response resources is the key factor to improve the accuracy and effectiveness of demand response. Second, the transaction mechanism should be constantly improved, and the functions of the support system should be optimized. In particular, stakeholders pay more attention to the transparency and real-time push of price fluctuation information on the electricity demand side.

2.2 Cases of vehicle-to-grid bidirectional smart charging (V2G)

EVs are not only energy consumers, but also energy containers. For more than 90% time of a day, the majority of EVs remain parked, thus making a beneficial interaction between parked EVs and the grid possible. V2G technology, by utilizing charging piles, is critical to the bidirectional flow between EVs and the grid. From vehicle to grid, with highly flexible EVs functioning as mobile energy containers, power load adjustment, power quality improvement, and renewable energy adsorption are realized through means of charging and discharging via charging piles. Through V2G application in an industrial park, this case has verified V2G system's technical framework, providing vital referential information for applying V2G technology on a large scale.

Case 3: Demonstration of V2G application in industrial parks——Baoding Great Wall Motor Industrial Park

Basic Information

Application scenario: Industrial clusters

Applied technology: V2G

Demonstration site: Great Wall Motor Industrial Park, Baoding, Hebei

Operator: Great Wall Motor (GWM) and State Grid EV Service Co., Ltd.

Description: There are 35 Great Wall Ora vehicle models equipped with V2G function, and 50 sets of 15 kW V2G DC charging piles being built, with the main scenario of vehicle scenarios for employees.

Operation time: 2021 April to present

(1) Technology and equipment solutions

The V2G DC charging solution is adopted. 8 sets of 0.4kV electricity distribution boxes are newly built at the pile side, and 50 sets of 15 kW column V2G charging piles developed by State Grid EV Service are newly installed. V2G charging piles are connected to the local grid of the GWM Dynamic Test Center, and 7 sets of MF/ABC 5 fire extinguishers are equipped according to the principle that the interval should not be less than 15m.

Figure 2-6 V2G DC charging solution

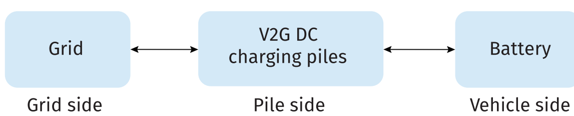


Table 2-2 Pile parameters

	Parameter	Three phases plus protecting earthing (PE)
AC port	Voltage range	260Vac ～ 530Vac
	Maximum static voltage in the non-operating state	600Vac
	Rated voltage	400Vac
	Rated current	23A
	Rated frequency	50Hz/60Hz
	THD	≤5％ @50％ ~100％ full-load output power
DC port	Voltage range	Rectifier mode: 150Vdc~750Vdc Inverter mode: 300Vdc ～ 750Vdc
	Current range	0~25A (the current limit point can be set)
	Rated current	20A @750V
	Voltage stabilization precision	＜ ±0.5％
	Current stabilization precision	≤±1％ (rated range of output load of 20% ~ 100%)

On the vehicle side, the battery system has a quantity of electricity of more than 40 kWh in order to provide a warranty of 1500 times of V2G discharges in 8 years or within 150,000km of mileage. Based on the discharge of 30 kWh at every time, the total discharge quantity should be ensured to reach 45,000 kWh.

Table 2-3 Vehicle parameters

Vehicle model	Length * width * height (mm)	Wheelbase (mm)	Electricity quantity (kWh)	Battery type	Discharging current (A)
Ora Good Cat Standard mile range of 400km	4235*1825*1596	2650	47.8	Lithium iron phosphate	0-25

(2) Business model

The EV users are mainly GWM's employees working in the park. According to their driving habits, the charging and discharging behaviors on weekdays are as follows: during the valley hours from 0:00 to 6:00, they charge their EVs at home; from 7:00 to 8:00, they drive to work; during peak hours and flat hours from 8:00 to 18:00, they discharge electricity from EVs to the grid in the industrial park; from 18:00 to 21:00, they go home from work. Users can benefit from the peak-valley difference (CNY 0.47 / kWh).

In order to recruit vehicle owners, GWM has also set up a number of incentive policies, including but not limited to providing an additional warranty for V2G discharge; setting multi-level operation subsidies respectively at the price of CNY 3.5/kWh, CNY 3/kWh, CNY 2 /kWh and CNY 0.76 /kWh; setting an employee purchase discount of 15%; providing a charging subsidy of CNY 100 /month for three years; giving priority to vehicle pick-up and exclusive discharge parking spots for vehicle owners participating in the activity; and carrying out contracted subsidy activities to provide lump-sum subsidies for contracted vehicle owners. In summary all benefits were given to participants.

Table 2-4 The contracted subsidy scheme

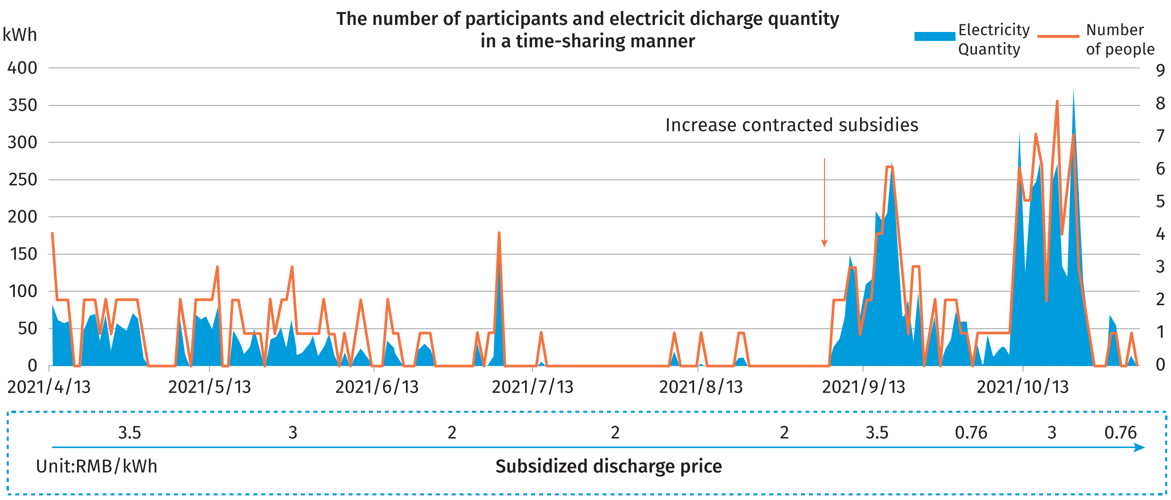
Range of activity	Scheme	Lump-sum subsidy standard	Contracted V2G discharging requirements	Quota	Vehicle model
Pre-order vehicle owner	Scheme I	Lump-sum subsidy of CNY 10,000	Discharge of 3,600 kWh within one year	5	400kM (LFP)
	Scheme II	Lump-sum subsidy of CNY 5,000	Discharge of 1,800 kWh within half a year	5	
	Scheme III	Lump-sum subsidy of CNY 3,000	Discharge of 1,000 kWh within three months	10	400 kM (LFP) 500 kM (NCM)
Other vehicle owners	Scheme IV	Monthly subsidy of CNY 500	Discharge of 300 kWh	15	

(3) Results

As of 2021 November 16, a total of 30 vehicle owners had signed up to participate in the activity, and 5 test vehicles had been involved in the activity. There were 53 employees working within 500 meters of the charging piles, and 21 of them signed up, with an engagement rate of 39.6%. The main reasons for not participating in the activity included inconformity with the scenario (44%), concern about the service life of EVs (40%), and disinterest (16%); and 9 employees working over 500 meters away from the charging piles signed up.

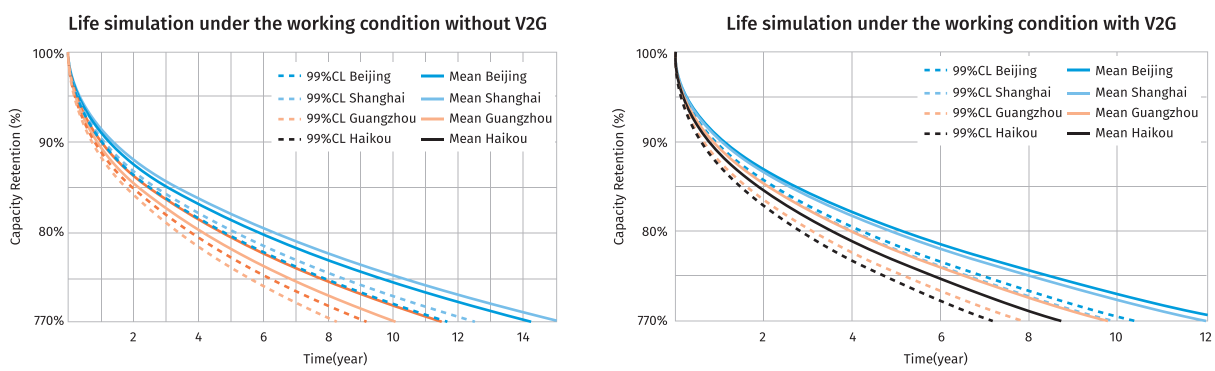
As of 2021 November 16, through V2G EV-grid interaction, peak-hour electricity had been transferred for a total of 483 times, with a cumulative electricity transfer of 12,353 kWh. Four vehicles had discharged more than 1,000 kWh, with the discharge times and discharge quantity being 76 times and 2,630.31 kWh, 126 times and 2,297 kWh, 39 times and 1,294 kWh, and 30 times and 1,040 kWh, respectively. According to the incentive discharge price, users got a total income from discharging of CNY 30,950.65, with the highest income of CNY 6,820 and the average income of CNY 884.30 among 35 vehicle owners.

Figure 2-7 The number of participating EVs and electricity discharged in a time-sharing manner



The working conditions V2G with depth of discharge (DOD) of 60% and current of 25A (discharge rate of about 0.2C) were coupled with the original working conditions of private vehicles, and the battery life was analyzed by comparative simulation. The stimulation was conducted based on the characteristics of current power batteries. The 99% confidence level (99% CL) under the original working condition was 12.6 years or 236,000 km. After adding in the V2G, 99% CL was 10.5 years or 197,000 km with 81,000 kWh of electricity discharged, 2.1 years or 39,000 km earlier than that under the original working condition. The simulation suggests there is a need to develop long-life batteries to ease the range anxiety of EV owners.

Figure 2-8 Life simulation of lithium iron phosphate batteries with and without V2G



As of 2021 November, the participants had engaged in V2G for 105 times, discharged electricity of 1,823 kWh (based on the electricity consumption of 13 kWh/100km, the equivalent mileage of about 14,000 km), and driven 1,960 km, with an equivalent mileage of about 16,000 km; vehicle owners not participated in the activity had driven mileage of 3,485 km. Both categories of the EVs in the project have the same age of one year, with the state of health (SOH) attenuation of 3% for all of them and without any significant difference. A comprehensive analysis of battery life requires the validation of a larger amount of data for a longer period of time.

(4) Lessons learned

In terms of technology, the low-power DC charging solution can be realized in the development and application of V2G in GWM Ora. During the first 10 months since this vehicle model being put onto the market, more than 20,000 vehicles had been sold, with no problems found. However, the battery data, vehicle travel data and charging data of the charging piles are not completely connected at present, which makes it difficult to monitor and analyze the battery life of EVs.

In terms of policy, how EVs can get involved in the operation of the electricity market is the main challenge encountered in the development of V2G. It is necessary to establish a perfect electricity spot market and auxiliary service market to allow consumers directly participate in the market transaction.

In terms of standards, V2G standards are comprehensive, including but not limited to EV batteries, charging pile equipment and operation control system. However, there is currently no clear technical specification for these standards, and the upstream and downstream of the industry need to discuss together to promote the establishment of sound standards.

In terms of user participation, the main reason for low participation rate is inconvenience caused by a lack of applicable V2G scenarios, followed by vehicle owners' concern about the negative impacts on battery lifespan.

Here are four suggestions for promoting the commercial application of V2G: to improve market mechanism design and policy formulation to boost V2G engagement, to formulate and advance technical standards by joining hands with all relevant industries; and to encourage operators to aggregate V2G charging pile resources by further widening the price differences between peak and valley electricity prices. Finally, battery enterprises, pile enterprises, vehicle enterprises and operators should be encouraged to accelerate the launch of V2G products, reduce equipment costs and increase the coverage of V2G products.

2.3 Cases of the integrated microgrids powered by RE with ESS and EV charging facilities

The penetration rate of renewables represented by wind and solar energy in the power system has been increasing. Their intermittent and spontaneous feature, however, has been a bottleneck for their further expansion. As a kind of distributed energy storage, EVs fleet can greatly improve the flexibility of the power system and realize the distributed utilization of renewable energy. The following cases demonstrate the integrated model of charging and battery swapping stations combined with the microgrid system, the integrated microgrid system models in industrial clusters, university campuses and rural areas, which further verify the referential value of these technical solutions of combining RE with microgrid system and charging EVs in different scenarios.

Case 4: Integrated power station powered by PV with ESS, charging and battery swapping - Shanghai Automobile Expo Park

Basic Information

Application scenario: Commercial clusters

Applied technology: Integrated power station powered by PV with ESS, charging and battery swapping

Demonstration site: Shanghai Automobile Expo Park, Jiading District, Shanghai

Operator: NIO Co., Ltd.

Description: One flexible and integrated power station has been constructed, including one 20 kWp distributed PV power generation system, one 300 kW intensive battery swapping station (five power batteries of 70 kWh can be configured), and three 60 kW DC charging piles, equipped with smart load management systems.

Operation time: 2019 January to present

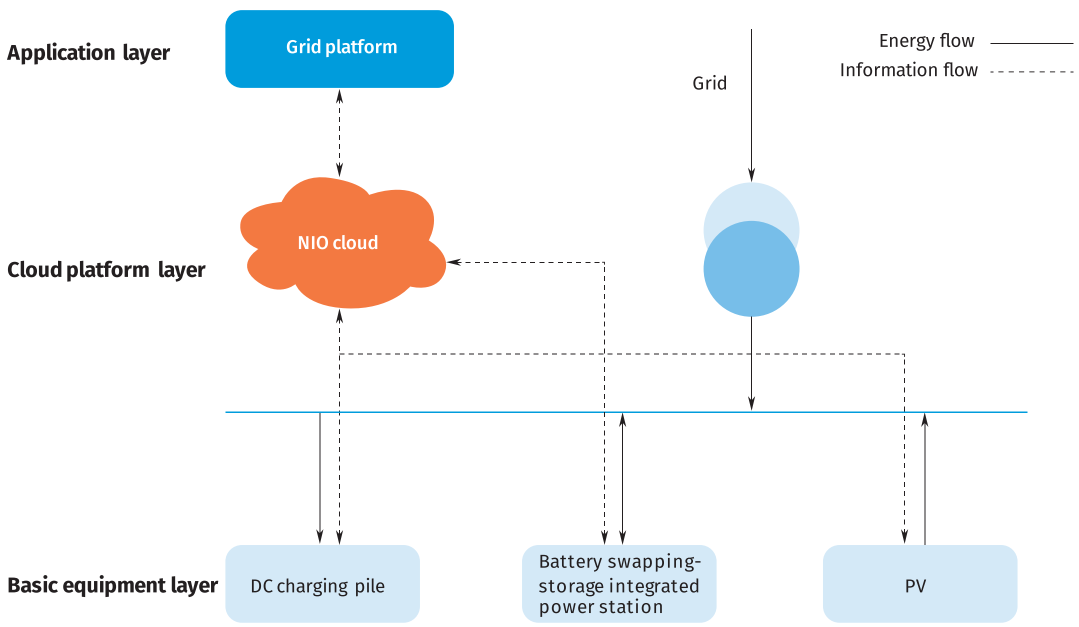
Total investment: CNY 5,505 million

(1) Technology and equipment solutions

Through the integrated power station in the Shanghai Automobile Expo Park, the project aims to demonstrate an innovative EV refueling mode from multi energy sources. The station is equipped with a smart load management system to distribute the power of real-time charging piles effectively and evenly, battery swapping stations and PV to maximize the utilization of available power capacity, improve the capacity utilization rate of the distribution network, thus realizing the coordinated operation, smart charging and smart energy utilization of the whole station.

The station's infrastructure consists of three components. First, the basic equipment, including PV, EV charging and battery swapping systems, and local load control system, can realize data collection and coordinated local control; second, the cloud platform. It can manage and dispatch all information on the equipment layer, and connect with other external platforms; third, the application, which realize energy efficiency management in accordance with policies, and cooperate with the transaction of grid auxiliary services.

Figure 2-9　Technical framework of the project



Battery swapping technology, as a feature of this project, is a form of electricity supply for EVs by swapping the power batteries. The battery swapping system can carry out centralized storage, centralized charging and unified deployment of batteries, as well as integrated monitoring and control of the operating status.

The main equipment and technical parameters of the integrated power station are as the follows:

Table 2-5 Main equipment and technical parameters

No.	Equipment name	Parameters
1	Intensive energy storage battery swapping stations	With the AC input of 300V, a total capacity of 300 kW, and the three-minute extremely rapid battery swapping can be achieved
2	60 kW DC charging piles	The output power is 60 kW, and the voltage is 200-500 V
3	Distributed PV system	A total of 76 battery panels are laid on the roof of the shed, and the total PV module of the system is about 20 kW

(2) Business model

The integrated power station follows the concept of providing accessible charging, battery swapping and upgrading services in the EV energy refueling sector. The battery swapping stations, charging piles and PV form a small and integrated off-grid power generation–electricity consumption system. The station has served more than 500 vehicles in total.

NIO puts the innovative concepts of separation of vehicle and electricity, battery rental, charging and battery swapping, and downcycling into practice, realizing the separation of vehicle and electricity physically and in ownership, and achieving the shared use of battery packs, so as to maximize the economic benefit of battery assets.

The battery swapping function currently only serves NIO users, and the supporting fast-charging piles can serve all EV users. The sources of income of battery swapping stations include charging service fees and the money saved on electricity bills after adopting PV power generation.

(3) Results

The accumulative PV power generated from the project had reached 48,718 kWh, with the CO2 emissions decreasing by 33.66 t (calculated according to the CO2 factor of the grid in East China) by2020 December 31. The PV power generation is mainly used for daytime peak energy consumption of battery swapping stations, accounting for 2.7% of the total electricity consumption. During the operation period, the accumulative energy consumption of battery swapping stations was 1,366 MWh, the accumulative refueled energy of battery swapping stations was 1,168 MWh, and the accumulative times of battery swapping reached 28,900. In addition, battery swapping stations have been engaged with the peak-shaving and valley-filling project of State Grid Shanghai Electric Power Company for over 10 times, and reduced the load by nearly 100kW in response to the grid demands during peak hours.

Figure 2-10 Operation data of the integrated power station with ESS, charging and battery swapping

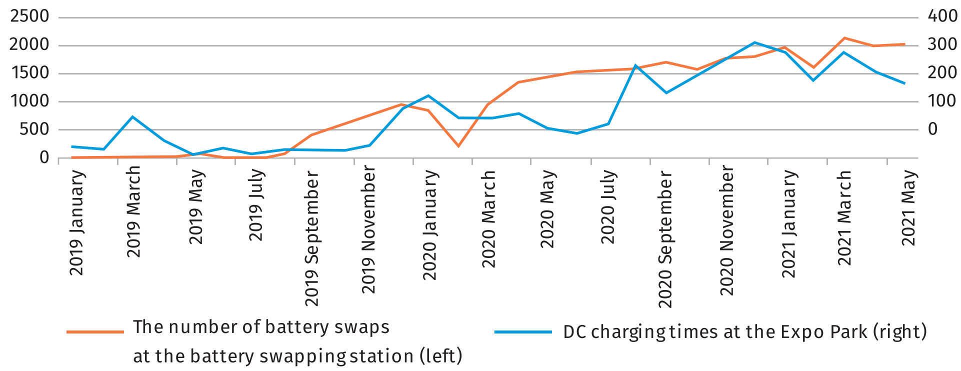
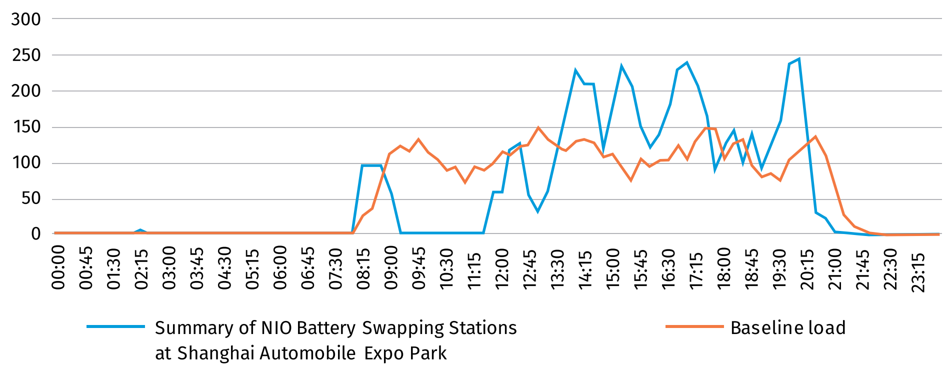


Figure 2-11 Peak-shaving response power curve (2020 December 5, 9:00-12:00)



In terms of economic benefits, the annual operating equivalent revenue of this project is about CNY 322,000. Among them, the annual PV power generation is about 21,000 kWh, equivalent to saving electricity costs of CNY 273,000; the project is engaged with peak-shaving responses and valley-filling responses for four times on average, with cumulative income of about CNY 4,000; and the income from the charging service fees is about CNY 45,000.

Built on this successful project, NIO plans to build 3,000 such stations nationwide by 2025, and already has carried out strategic cooperation with China Petroleum & Chemical Corporation (Sinopec) to jointly build the integrated power stations in a large-scale at their existing gas stations and surrounding areas.

(4) Lesson learned

The construction of integrated power stations is conducive to the ready-to-use power generated from new energy sources, the shared capacity of charging stations and battery swapping stations, and the reuse of charging and distribution equipment, to improve the utilization efficiency of electricity distribution equipment. There are some problems in the process of comprehensive promotion such as small arbitrage space of peak-valley electricity prices, high costs of selecting suitable sites and equipping with adequate security measures for energy storage stations, and a lack of flexible metrological authentication methods for EVs' engagement in V2G as distributed energy storages.

Suggestions: First, in view of the high initial investment cost, supporting policies should be formulated to ensure that the time-of-use electricity price is effectively carried out at the operating terminal, improve the economy of the stations, and mobilize the initiative of the operating enterprises; second, the fire safety and other standards and regulations of energy storage stations should be clarified.

Case 5: Integrated EV charging and battery inspection station powered by PV with ESS——Gongmingnan EV Charging Station in Shenzhen, Guangdong Province

Basic Information

Application scenario: Public EV charging stations

Applied technology: Integrated microgrid powered by PV with ESS, EV charging and battery inspection services

Demonstration site: Gongmingnan EV Charging Station of Southern Power Grid, Shenzhen City, Guangdong Province

Operator: Southern Power Grid Electric Vehicle Co., Ltd.

Description: There are 128 DC charging piles with 160 charging guns, power of 9600kW in total, 7 sets of 1600kVA container electricity distribution rooms, installed capacity of 11,200kVA, and PV power generation capacity of 444.15kWp by using the parking canopy and configured with a storage energy system of 516kWh. The charging piles are equipped with battery inspection terminals, which can realize the EV battery inspection function.

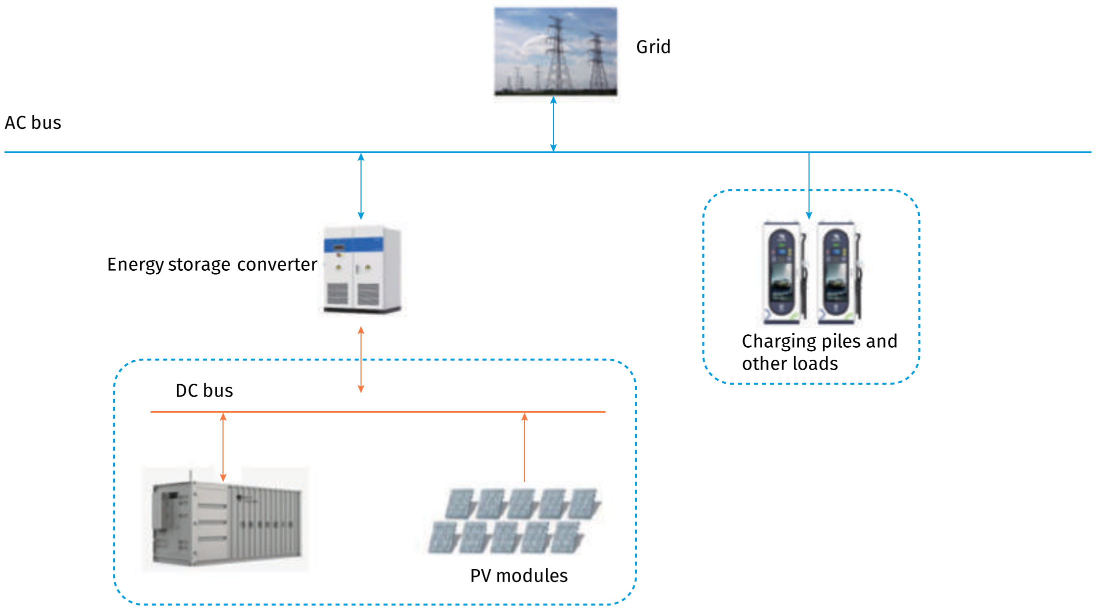
Operation time: September 2020 to present

Total investment: About CNY 15 million

(1) Technology and equipment solutions

The integrated microgrid consists of a PV sub-system, lithium battery energy storage sub-system, and charging piles sub-system, including a power conversion system (PCS), DC-DC converter (DCDC), and PV inverter and other vital parts. The entire PV-ESS system, and charging pile are respectively connected to the AC/DC hybrid bus.

Figure 2-12 The integrated microgrid system powered by PV with ESS, EV charging and battery inspection



The PV storage system adopts the common DC bus solution, the charging pile system adopts the AC bus solution, and the energy supplementary decoupling is controlled independently. As the main energy source, the grid directly supplies power to the charging pile system, and the PV storage system acts as a supplementary energy source to supplement the charging pile to improve system efficiency.

The battery inspection system uses an intelligent edge controller installed at the charging pile to read the battery management system (BMS) data of the EVs, upload it to the battery testing platform, and apply algorithm models such as SOH status estimation, average difference model, and consistency analysis to calculate the battery system data and form a battery health diagnosis report.

Table 2-6 Main equipment and parameters

No.	Equipment	Parameters
1	PV system	The charging pile canopy area of 2,200m^2, with the deployment of a total of 987 pieces of PV modules, PV device installed capacity of 444.15kWp, of which 226.8kWp was connected to the ESS, self-generated and self-consumed, and 217.35kWp of surplus-power-to-grid.
2	ESS	The ESS specification is 250kW/516kWh.
3	Charging system	Build 19 charging stacks with a total of 128 charging terminals.
4	Battery inspection system	Algorithmic models such as SOH status estimation, average difference model, and consistency analysis are used to have a comprehensive assessment of the battery health status of EVs.

(2) Business model

Currently, the total revenue is mainly generated from PV power generation, energy storage charging-discharging (the difference between discharge benefits and charging cost), and charging service.

PV power generation revenue is from local consumption (including supply to charging facilities, ESS absorption and transfer) benefits, and revenue from surplus-power-to-grid.

Energy storage charging-discharging benefits mechanism: the main source of energy storage benefits is the difference between discharge benefits (charging electricity fee and service fee) and charging cost (valley section or flat section charging electricity fee to cover up the PV cost).

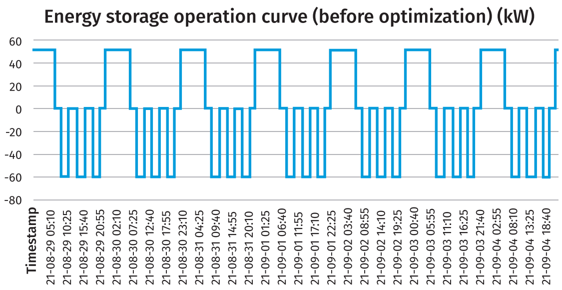
In addition, the project site can further increase revenue by engaging the grid demand-side response and carrying out value-added services such as battery inspection.

(3) Results

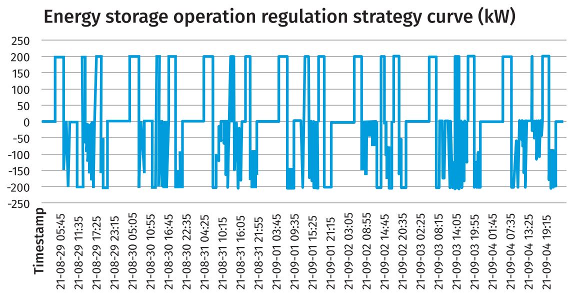
Taking the demonstration period from August 29 to September 28, 2021, as an example, the PV power generation of the project system is 53,260.42kWh, the number of charging & discharging is about 90 times, and the cumulative charging is 482,277.07 kWh, among which the total PV power generation accounts for about 11% of the total charging.

In timed charging-discharging mode, the energy storage facilities are charging during the valley period and discharging during the peak period. The energy storage SOC operating range is 20%-100%. Using the local energy management controller, the ESS is optimized and adjusted according to the electricity price and service fee data, charging power forecast data, and PV power generation forecast data. After optimization, the energy storage and discharge revenue saw a significant increase.

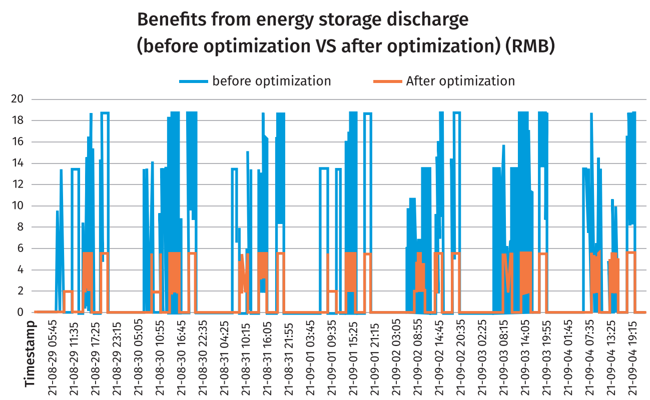
Figure 2-13 Comparison of operating curves and revenue before and after ESS's optimization



Energy storage operation curve (timed charging-discharging)



Energy storage optimization regulation strategy



Comparison of energy storage and discharge income before and after optimization (5 min/point)

In terms of economic and social benefits, according to statistics from August 29 to September 28, 2021, the total power generation of the PV system was 53,260.42 kWh, resulting in a reduction of 34.97t CO_2 emissions (calculated according to the CO_2 emission factor of the southern regional grid), and savings of electricity charge at CNY 49,262.10. Combined with the energy storage revenue, the total economic benefit was CNY 49,192.62. Based on this calculation, the total annualized revenue rate of the PV storage system is 17.8%. Considering equipment aging and maintenance costs, the payback period is about 6 to 8 years.

(4) Lessons learned

In the initial stage of the station's construction, the system structure should be rationally planned and designed, and the optimal configuration should be carried out according to the actual operation objective. In view of the dual revenue of electricity fees and service fees, the installation of PV equipment in the station has a high investment value. It is recommended to fully install PV equipment in areas with suitable conditions, such as carports, open spaces, and monitor room roofs. For energy storage equipment, due to the large peak-valley difference between the electricity fee and service fee and the valley electricity price (more than CNY 1), there is good room for profit from peak-valley arbitrage, but the investment in energy storage equipment is large. In practice, the size of the charging load and the price period of the station should be fully considered, and appropriate capacity and power equipment should be selected to ensure that the reasonable annualized revenue of energy storage can be met under the simple strategy of regular charging-discharging.

In terms of battery inspection, the battery inspection function is integrated into the charging terminals of large public charging stations to realize fault warning and battery health inspection during EV charging. On the one hand, it can provide a reference for the safe operation and maintenance of the station; on the other hand, it can also become a potential value-added service for the users.

In terms of demand-side response, on the basis of local optimization and regulation at the station, it can further expand engagement and power interactive regulation to enlarge revenue by participating in grid auxiliary services, virtual power plants, demand-side response and other businesses.

Case 6: Integrated microgrid powered by PV with ESS and EV charging in industrial park—Qingdao TGOOD Park

Basic Information

Application scenario: Industrial clusters

Applied technology: Integrated microgrid powered by PV, V2G, DC power distribution system

Demonstration site: TGOOD Industrial Park, Laoshan District, Qingdao

Operator: Teld New Energy Co., Ltd.

Description: A smart microgrid system powered by PV with ESS has been built. Equipment such as rooftop PV, ESS, and charging piles are centrally connected to the DC bus. The DC bus is divided into two sections, each section includes 500kW rooftop PV and two sets of 9 DC charging piles of 10kW each. Among them, 5 charging piles support V2G, and each group of charging piles is equipped with an ESS of 80kW/80kWh.

Operation time: January 2021 to present

Total investment: CNY 11.75 million

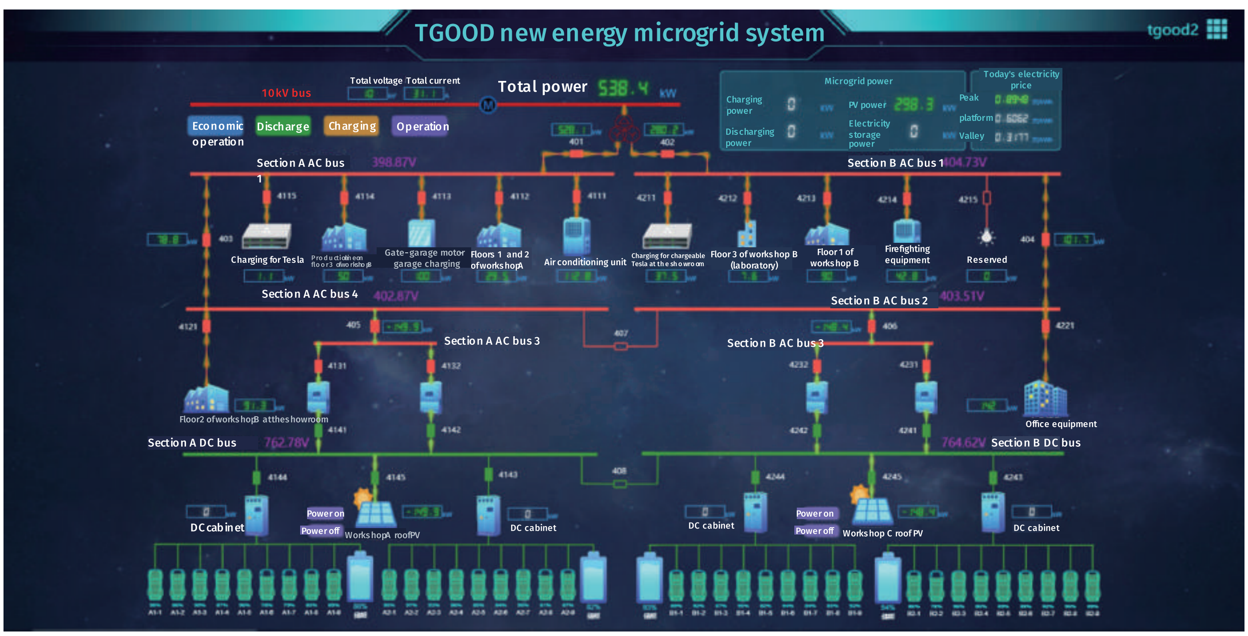



(1) Technology and equipment solutions

The microgrid system of this project integrates four sub-systems of EV charging & discharging, distributed power generation, ESS, and V2G energy feedback, and they are dispatched and monitored by a smart energy control unit, with the capacity of a bidirectional energy flow regulation. The system framework includes a rooftop PV system, energy storage and V2G charging piles, and other equipment that are centrally connected to the DC bus. The DC bus is divided into two sections, A and B, which are respectively connected to the A and B sections of the AC bus through two AC/DC inverters. DC charging piles in Zone A are divided into two groups. Each group of charging piles and a set of 80KW/80kWh ESS are integrated into the DC cabinet and are connected to the Section A DC bus together with the 500kW roof PV of the Zone A workshop. The bus in Section B is connected to the 500kW rooftop PV in the Zone C workshop and the two sets of charging piles and the corresponding ESS in Zone B.

This system has functions such as real-time data monitoring, equipment status monitoring, PV monitoring and forecasting, load monitoring and forecasting, energy storage monitor, charging monitor, etc. It can monitor the source, load, storage, vehicle, and other equipment in the system in real-time, make maximum use of the distributed power source and provide auxiliary response dispatching services to the power distribution network. For off-grid operation, the system can match with the considerable time scale balance of the load according to the power supply of each power source and energy storage equipment.

Figure 2-14　Overall structure of the microgrid system



The main feature is the application of a DC power distribution network system in the integrated microgrid. Compared with the AC power distribution network, the line loss of the DC power distribution network can be reduced by more than 15% under the same voltage level and cable parameters, and the same investment cost.

Table 2-7 Main equipment and parameters

No.	Equipment	Parameters
1	PV controller	PV controller HPPCU160-16, IP65 protection grade, maximum efficiency 99.7%, MPPT voltage range 300-820V, rated input voltage 600Vdc, rated output voltage 820V.
2	Energy storage converter	With input over-voltage, over-temperature, output over-voltage, output over-current, battery side short circuit, and other protection functions. Dynamic response <20ms, peak efficiency ≥98% at 25°C, efficiency ≥95% when the load is greater than 50% at 25℃ .
3	Battery &BMS	The energy storage batteries have a total of 320kWh and are located near 4 sets of DC charging piles, each with a capacity of 80kWh. BMS (Battery Management System) functions include real-time monitoring of physical parameters of the battery, battery status assessment, online diagnosis and alarm, fault management and protection, etc.

(2) Business model

In terms of PV power generation, the city of Qingdao currently implements a policy of full electricity subsidy for distributed PV power generation, at a subsidy level of CNY 0.42/kWh (tax included). Among these, the distributed PV power generation system itself uses the surplus electricity that can be transmitted to the grid, which is purchased by the grid company according to the benchmark electricity price of the local coal-fired desulfurization unit.

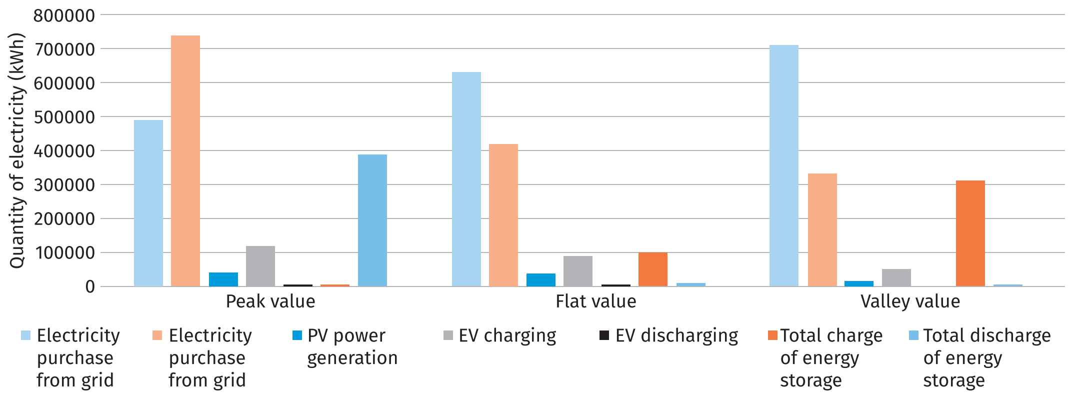
In the microgrid, EV users can set the running time of the vehicle to engage in V2G and the minimum battery SOC value when the vehicle leaves the field according to subsequent driving needs. The system signs a short-term service contract with the users without affecting the use of the vehicle so that the vehicle owners can choose to exchange part of the vehicle use in exchange for some of the economic returns, increasing the discharging revenue of the vehicle owners to make up for the cost of battery aging.

The entire microgrid system integrates a variety of energy equipment and can engage in the demand-side grid response. In-station charging guidance is implemented inside the station to improve the local consumption rate of PV green electricity.

(3) Results

The PV power generation of the system is directly supplied to the power consumption end, and the surplus power can be stored in the energy storage modules and EVs and used directly during the power consumption peak. During the demonstration period, the total power generation of renewable energy was 92,517.14kWh, the number of charging times was 5,177, and the number of discharging times was 157. The total EV charging was 258,890.94kWh, and the total EV discharging was 4,711.36kWh.

Figure 2-15 Time-sharing charging & discharging diagram of the microgrid system



During the demonstration period, the proportion of peak electricity consumption in the park was significantly reduced from 47% to 24%. The proportion of electricity bills during peak hours has been reduced from 63% to 39%. The proportion of electricity consumption during valley hours increased from 24% to 42%. The percentage of electricity bills during valley hours has increased from 11% to 24%. From 2021 February to September, the cumulative cost savings was about CNY 87,000.

In terms of economic benefits, the total investment in the microgrid is CNY 11.75 million, of which the investment in equipment is CNY 4.75 million, which is about 20% lower than the investment in traditional microgrid equipment. Through PV self-generation, self-consumption and surplus-power-to-grid, energy storage power station and electric vehicle peak-shaving and valley-filling, EV charging service fee, etc., the annual revenue is about CNY 1.48 million, and the pay-back period is about 7.9 years.

(4) Lessons learned

The demonstration suggests that a renewable energy microgrid is able to optimize EV charging, distributed energy generation and storage, and therefore achieve sophisticated management of energy saving and consumption reduction. To further explore low-power DC charging equipment and combine applied technologies such as V1G, two-layer safety protection, and PV-ESS-EV charging integration and verify the universality and superiority of different scenarios such as industrial parks and residential neighborhoods, therefore accumulate experience and data for a large-scale promotion of low-power DC charging in the later stage.

Case 7: Integrated microgrid power by wind power and PV with ESS and EV charging in campus—— Shanghai University of Electric Power

Basic Information

Application Scenario: Campus

Applied technology: Integrated Wind microgrid powered by wind and PV with ESS and EV charging

Demonstration site: Shanghai University of Electric Power, Lingang Campus

Operator: State Grid Integrated Energy Service Group Co., Ltd.

Description: A integrated microgrid system has been built, with PV system at installed capacity of 2,061kW and wind turbine at installed capacity of 300kW. The system is equipped with a lithium iron phosphate battery with a capacity of 100kW*2h, a lead-carbon battery with a capacity of 150kW*2h, and a supercapacitor energy storage equipment with a capacity of 100kW*10s, to achieve a high proportion of renewable energy consumption by EVs.

Operation time: 2018 September to present

Total investment: CNY 35 million

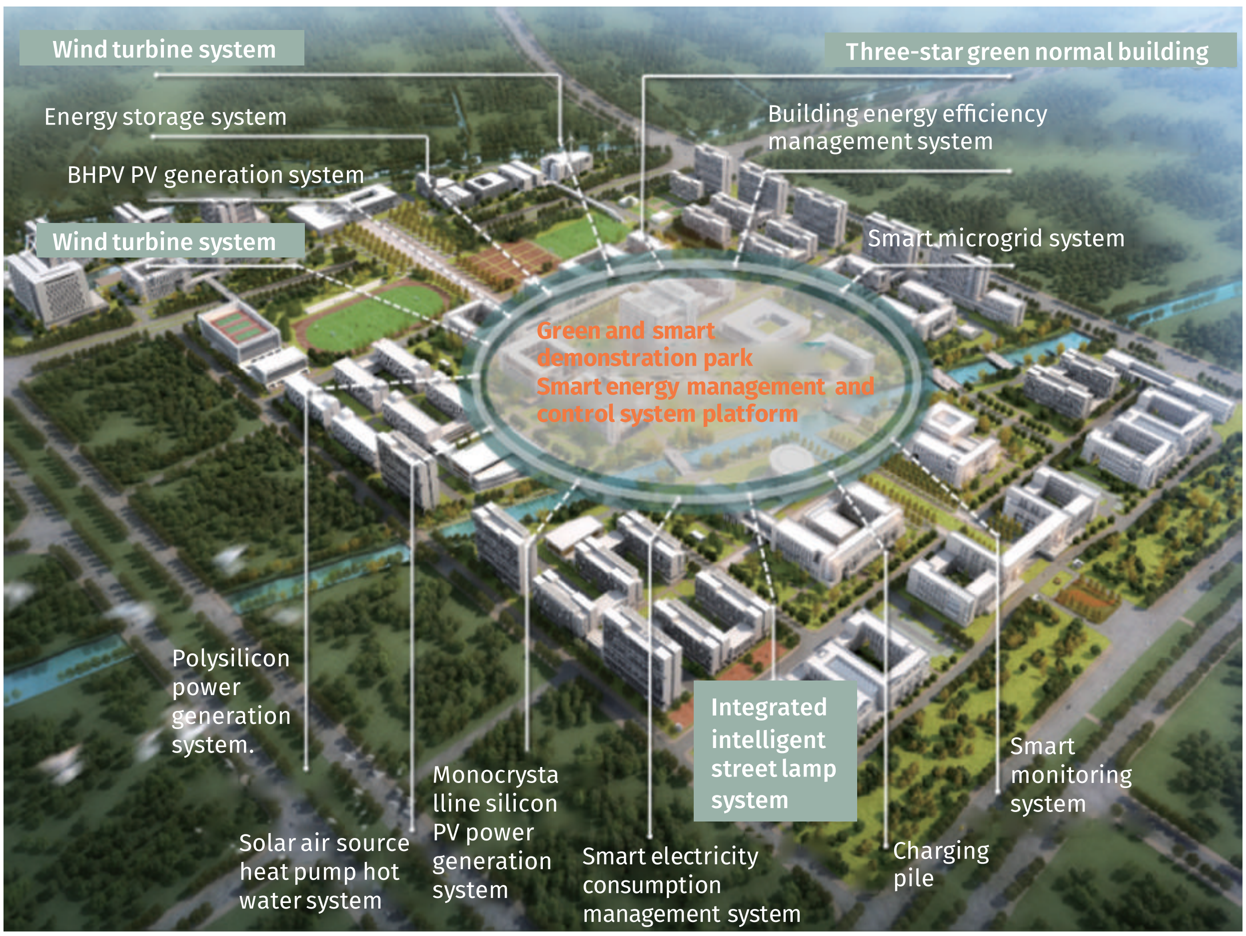
(1) Technology and equipment solutions

This project conducts a technical demonstration of a wind-PV-storage-charge microgrid at Shanghai University of Electric Power, Lingang Campus. The total installed capacity of PV is 2061kW, and the installed capacity of the wind turbine is 300kW. The smart microgrid system can realize on-grid switching and power generation schedule. It can be connected to the grid at ordinary times and can also operate off-grid. To ensure that in the event of a loss of power in the large grid, the microgrid can continue to maintain power supply for important loads in each building. The system is equipped with a lithium iron phosphate battery with a capacity of 100kW*2h, a lead carbon battery with a capacity of 150kW*2h, and a supercapacitor energy storage equipment with a capacity of 100kW*10s. In the off-grid operation mode, the ESS acts as the main power supply, providing the frequency and voltage to the island system to meet the needs of use. The microgrid system comprehensively regulates the

ESS according to PV and wind turbine output, and load conditions to achieve the real-time balance of power supply and load in the microgrid. In addition, there is a 180 EV fleet at Shanghai University of Electric Power, Lingang Campus, accounting for about 20% of the total EVs owned by faculty and staff. At the same time, 87 energy storage charging piles have been set up on the campus, which can meet the charging needs of EVs, promote the adoption of green electricity by EVs, and reduce CO_2 emissions.

As the center of the microgrid system, through 2017 monitoring points and more than 10,000 sensors, it dynamically monitors and manages comprehensive energy resources such as new energy power generation, campus electricity consumption, and park water supply in the entire campus. Statistics, analysis, comparison, and summarization of the utilization of various energy resources provide real-time energy statistical data for decision makers and form a comprehensive assessment of energy efficiency and energy saving. In addition, according to the needs of managers, comprehensive management and control of various energy-saving control systems can be realized to create an innovative comprehensive energy management model.

Figure 2-16 Microgrid system of Shanghai University of Electric Power Lingang Campus



(2) Business model

The model provides PV power generation and heating services for investors and operators and charges energy fees.

EV charging and discharging modes: when the charging demand is greater than the distribution capacity, both the grid and energy storage will supply power; when the charging demand is smaller than the grid capacity and the current period is the valley period, the grid shall supply power; when the charging demand is not greater than the mains capacity and the current period is not a valley period, the energy storage shall supply power; when there is no charging demand, the energy storage battery can be charged.

According to the specific situation of EV being charged on campus, the charging pile is mainly used from 9:00 am to 11:00 am, and the load is about 500kW. During this period, the energy storage and the grid work together to ensure the use of charging piles. When the external power grid fails, the energy storage is used as an emergency power supply to provide emergency power for the important loads in the school.

(3) Results

Since it was officially put into operation in September 2018, the renewable energy power generation for the smart microgrid system of Shanghai University of Electric Power had reached about 8,250MWh by October 15, 2021, accounting for about 10-15% of the total electricity consumption. The accumulated energy storage was 93.5MWh.

Through the project construction, Shanghai University of Electric Power Lingang New Campus has adopted the solution of collaborative operation and comprehensive management of source, grid, load and storage, which has reduced campus energy consumption by about 25%.

(4) Lessons learned

This project, taking the university campus as the application scenario, has realized a renewable energy self-generation and consumption loop by the means of an intelligent energy management and control platform. The project solves the problem of space-time dislocation of PV system power generation and charging piles. The daytime power generation in the teaching building area is transferred to the full day charging in the parking lot area, realizing a high proportion of renewable energy power generation for clean charging of electric vehicles. In addition, this project aims at the transportation issues of teachers and students in the Lingang area. By customizing travel routes, E-Bus Fleet adopts more green electricity, which further promotes the realization of green travel.

Case 8: Integrated microgrid powered by PV with ESS and EV charging in rural areas—Chongming District, Shanghai

Basic Information

Application Scenario: Rural areas

Applied technology: Integrated microgrid powered by PV with ESS and EV charging

Demonstration site: Yuhaitang Technology Park, Sanxing Town, Chongming District, Shanghai

Operator: Shanghai Yuhaitang Ecological Agriculture Technology Co., Ltd.

Description: An integrated microgrid has been built with a 1,000kWp distributed PV power generation system, a 100kW/359kWh centralized ESS and a 24kW/92kWh retired power battery ESS, a charging station with three 120kW DC charging piles, two 60kW DC charging piles, eight 7kW AC charging piles, and about 30 battery car/tourist car charging piles.

Operation time: 2019 January to present

Total investment: about CNY 8 million



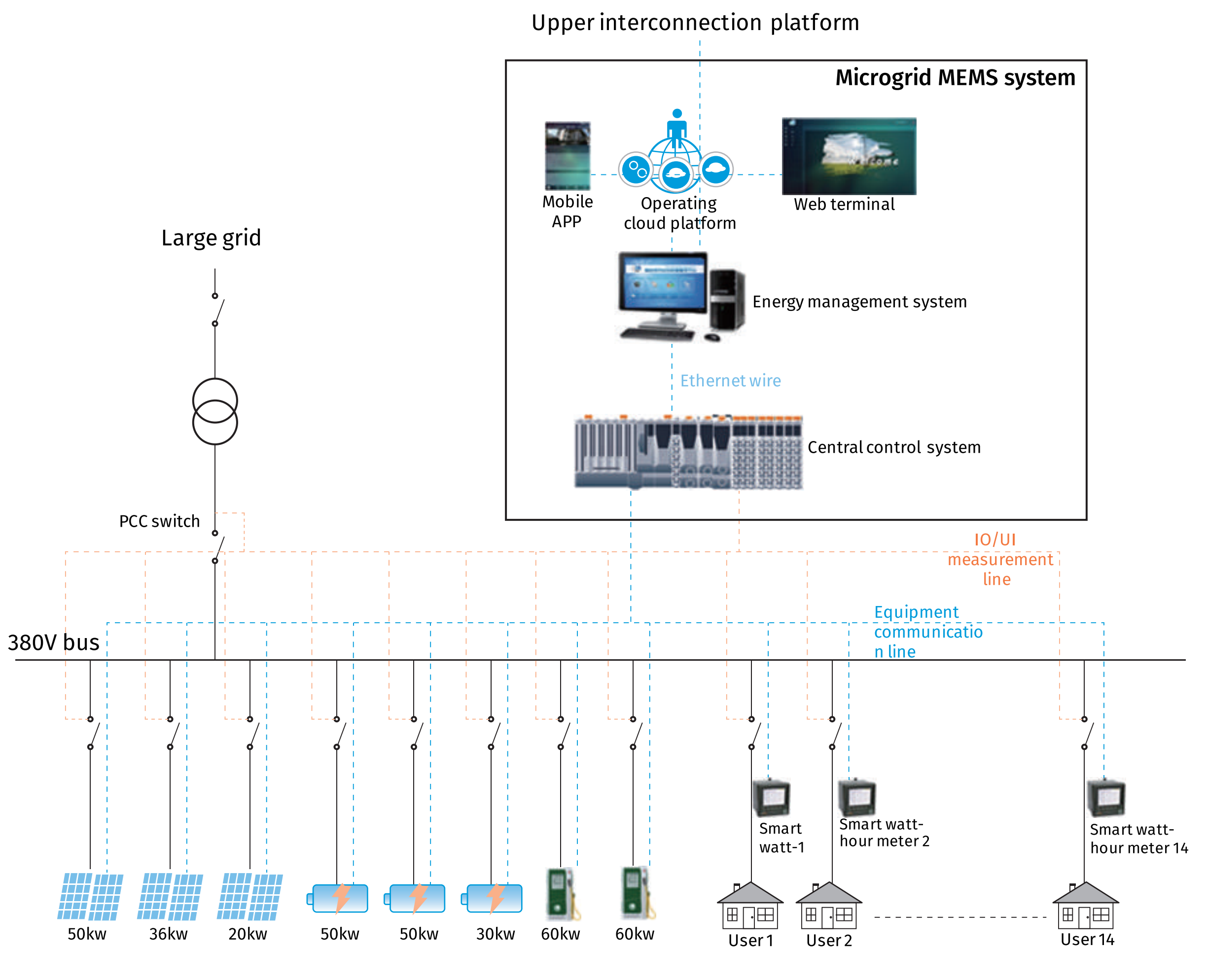
(1) Technology and equipment solutions

The construction of this project is divided into two phases: The first phase is an on-grid system with a pastoral complex as the center and an off-grid system with a straw-hat forum as the center. Among them, the on-grid system's access to the power distribution network realizes the self-generation and self-consumption of distributed energy and the surplus power is transmitted to the grid. This phase of the project makes full use of the village committee, residential buildings, straw hat forum buildings, and open space to install crystalline silicon PV modules, thin membrane PV modules, and 5kW small fans, to meet the production and household electricity consumption of village committees, pastoral complexes, and nearby residents. The second phase is the PV module system of the 24kW Han tile roof of the visitor center and the roof of the new energy parking lot, as well as the roof PV modules of the industrial park and the incubator, and is equipped with an ESS.

The ESS adopts a set of 100kW/359kWh centralized ESS and a set of 24kW/92kWh downcycled power battery ESS, which can effectively smooth the output power of renewable energy, reduce the impact on the power grid, and achieve stable Internet access. At the same time, the power quality at the end of the power grid can be optimized to meet the demand for a high-reliability power supply.

The project develops an energy management system that integrates control of all power generation and energy storage equipment in the on-grid/off-grid system to ensure its safe and stable operation. At the same time, the peak-valley electricity price difference and smart algorithms are applied to realize economic dispatch and reduce electricity costs. Through intelligent power consumption management, bidirectional interaction between power supply and users and optimal power consumption efficiency are realized.

Figure 2-17 Structure of the energy management system in the project



The information management system facilitates users to view the operation of the system and equipment in real-time through the web page or mobile APP, creating possibilities for flexible regional power transactions.

(2) Business model

This project aims to improve the utilization rate of regional renewable energy, provide sufficient green power for EVs, and at the same time build a zero-carbon village. The project solves the pain point of rural renewable energy development with smart microgrid technology and realizes multi-win for farmers, collectives, and power grids. It also promotes a new round of rural electrification development from both the consumption and supply ends, which is highly integrated with the construction of beautiful countryside.

Constructor cooperates with farmers to install crystalline silicon PV on the roof of farmers to provide them with household electricity and the surplus-power shall be transmitted to grid. They also cooperate with rural village committees, police stations, and other collectives to install PV systems on the roofs of the village committees' public buildings, so that the village committees can use electricity collectively, and the surplus-power shall be transmitted to grid. New energy parking lots integrating PV power generation, energy storage, and smart charging are also built. 100% of the electricity provided by the charging piles comes from the green electricity generated by PV power. The parking lot is equipped with charging piles for electric vehicles and electric bicycles and meets the objective condition that the number of electric bicycles in rural areas is far greater than that of electric vehicles.

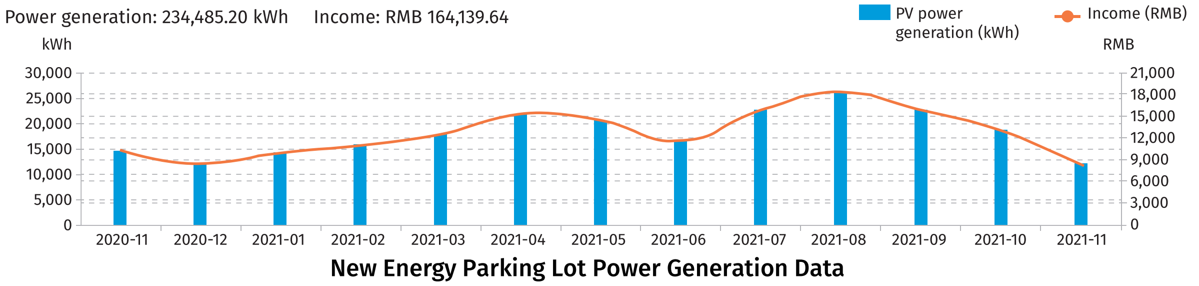
(3) Results

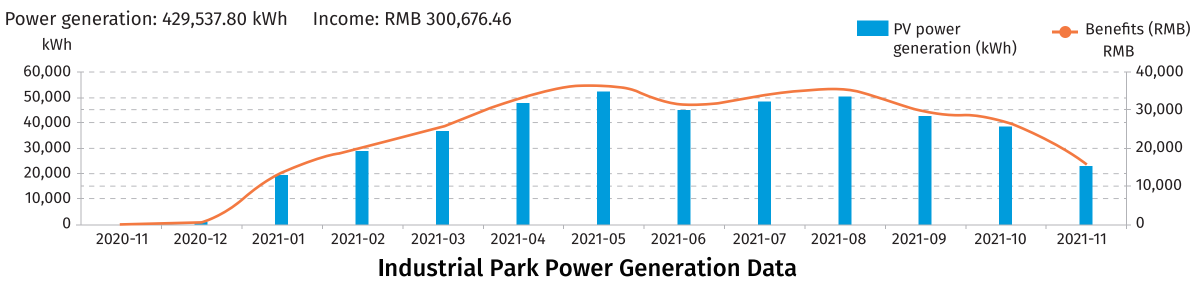
As of June 2021, PV power generation systems have been installed on the roofs of many factories, with power generation exceeding 1,000kWp. The constructor reached a cooperation intention with the owners of some public facilities in Chongming District (such as village committees, police stations, workshops, farms, public toilets, etc.) and planned to install PV modules for 21 village committees (with a total roof area of over 10,000 m2) in Sanxing Town in the second half of 2021, with a power generation of over 1,000kW. Statistics show that, from January 2019 to December 30, 2020, the PV system of the project generated a total of 620MWh electricity, and the overall operating efficiency of the system was 80%.

(4) Lessons learned

This project makes full use of the vast space in rural areas and low-rise buildings to install PV modules, and the construction costs are much lower than that of cities. Through cooperation with farmers and village collectives, a new cooperation model of digital rural cooperatives will be created. It can not only solve the problem of investment in rural construction, but also solve the problem of land occupation for PV module installation. The power is self-generated and self-consumed, and the surplus-power is transmitted to grid. So, it has achieved multi-win for farmers, collectives, and power grids. It has great demonstration significance for the development of the new energy industry in rural areas.

Figure 2-18 Power generation data of some scenarios in the park





It can be expected that there will be more and more new energy parking lots in rural areas in the future. On one hand, it solves the charging problem of electric bicycles and EVs. On the other hand, it will further promote the development of EVs in rural areas.

2.4 Cases of downcycling of retired power batteries

Power battery downcycling can extend the service life of batteries, which is of great significance in terms of resource security, energy saving and environmental protection, economic benefits, as well as extending the value chain. As large numbers of retired EV power batteries begin to enter the market, how to promote the efficient recycling of power batteries and create a circular economy system for power batteries has become a hot topic in the sector. Typical cases include demonstrations of retired EV batteries for energy storage in industrial parks and in communication base stations. There is also R&D on the mechanism of retired battery life attenuation, its technical solutions, and feasibility in energy storage and emergency power supply.

Case 9: Downcycling of retired power batteries for energy storage in industrial clusters —BAIC Group Blue Park Zhenjiang Base

Basic Information

Application scenario: Industrial clusters

Applied technology: Retired power battery downcycled for energy storage

Demonstration site: The Park of BAIC Group Blue Park Magna Automobile Co., Ltd., Dantu District, Zhenjiang City, Jiangsu Province (referred to as Zhenjiang Base)

Operator: Blue Park Smart Energy (Beijing) Technology Co., Ltd.

Description: There are three sets of 250kW/2MWh ESS consisting of retired power batteries connected to the transformers and public transformers in the painting workshop in the park, a total of 6MWh.

Operation time: 2021 April to present

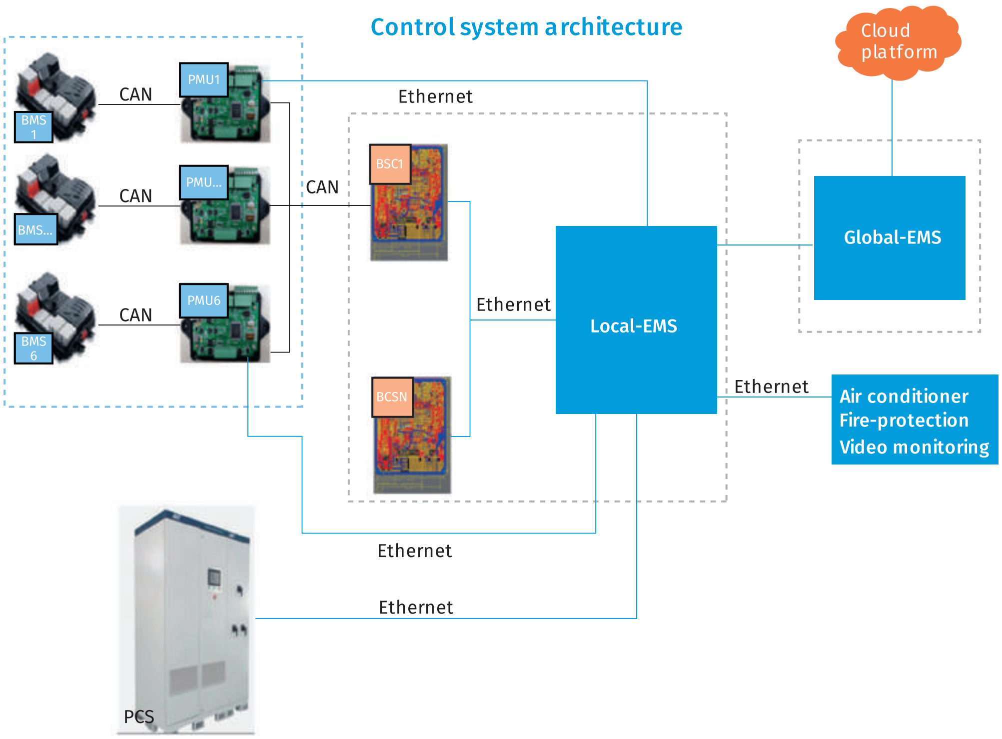
Total investment: CNY 3 million

(1) Technology and equipment solutions

In this project, the T2T3 transformer and the public T1T2 transformer in the painting workshop with high power consumption and stable load in the park respectively connect to 4 sets ESS composed of retired power batteries, and they are charged once a day and discharged twice a day.

The value of each battery can be maximized when retired EV battery packs are directly used in the ESS without any modification. However, the BMS communication protocol and control structure of different manufacturers and different vehicle models are different, resulting in the diversification of vehicle BMS control strategies and communication protocols, which brings great difficulty to the utilization of the whole package. In this case, Blue Park Energy uses the self-developed power management unit (PMU) to utilize the retired EV power battery pack as a whole package. PMU can identify different battery packs, and convert the communication protocol and control structure of different BMS into a unified standard so that a variety of vehicle battery packs can be mixed and matched for ESS without any changes.

Figure 2-19　Overall structure of the ESS



In this case, three sets of energy storage devices adopt a 36-bay system.

Table 2-8　Main equipment and technical parameters of the ESS

Category		36-bay	
		Specification	**Quantity**
System structure	Battery	Spare battery	36-bay
	PCS	Rated power 500kW	1 set
	Container components	13300*3000*3000mm	1 set
	Fire-protection system	70L (68KG dose)	1 set
	Air conditioner	Cooling capacity 4,000W	3 sets
	EMS	—	1 set
	PMU	—	44 sets
	Isolation transformer	630kVA	1 set

Each battery pack BMS is connected to a PMU, and the PMU supplies power to the corresponding BMS and cuts off or turns on the power supply as needed. For example, when there is a safety problem in the system, the PMU can immediately cut off the power supply of the BMS so that the batteries are disconnected from the electrical system to ensure the safety of the entire system.

(2) Business model

This project adopts a contract energy management model by signing service contracts, including project design, equipment procurement, engineering construction, equipment installation, commissioning, etc., directly with customers. The Zhenjiang Base is responsible for electricity consumption; Zhuhai Watt Electrical is responsible for investments in electrical equipment, construction, civil construction, grid connection, etc. Blue Park Energy is responsible for providing energy storage batteries and system integration. The revenue generated by the ESS's peak-shaving and valley-filling is divided between the two investors (Blue Park Energy and Zhuhai Watt Electrical) and the owner (Zhenjiang Base) according to the ratio of 9:1. According to the calculation of battery life, it is expected that all investments will be paid back within 5 years and will start to profit with a return on investment of 20%.

(3) Results

The ESS (minimum charge rate 0.125C/discharge rate 0.125C) is charged at the valley period and discharges at the peak period every day. It is charged once a day and discharged twice a day. Two peak-valleys can be utilized to support profit generation. At present, the first phase of the ESS is in normal operation, with a total energy storage capacity of 4.5MWh, a daily discharge of 4500kWh, and a peak-valley price difference of CNY 0.77/kWh. In addition to the peak-valley electricity fee revenue, the ESS can also obtain peak-shaving benefits by engaging in the demand response of State Grid Zhenjiang. Taking August 2021 as an example, the monthly peak-shaving response was 10 times, and the monthly valley-filling response was 10 times, with a total revenue of CNY 99,000. Combined with the arbitrage revenue of peak-valley prices, the total monthly revenue was about CNY 200,000.

(4) Lessons learned

This project fully utilizes retired power battery resources by mixing and matching a variety of EV battery packs without any modifications to the batteries. This results in a significant saving in investment in the ESS. The direct use of the whole battery pack makes it possible to easily read the historical data and identify the health status of the battery pack. By adjusting the peak-valley difference of the power grid, it engages with demand response and achieves good economic returns.

Case 10: Downcycling of retired power batteries for energy storage in communication base stations—Micro Communication Base Station of China Tower in Tianjin City

Basic Information

Application scenario: Public facilities—communication base station

Applied technology: Retired power battery downcycled for energy storage

Demonstration site: Haihe River Eastern Road, Hebei District, Tianjin

Operator: China Tower Co., Ltd. Tianjin Branch

Description: One set of communication micro base stations equipped with a retired power battery ESS, including one set of 51.2V 120Ah energy storage system, and one uninterruptible power supply (UPS).

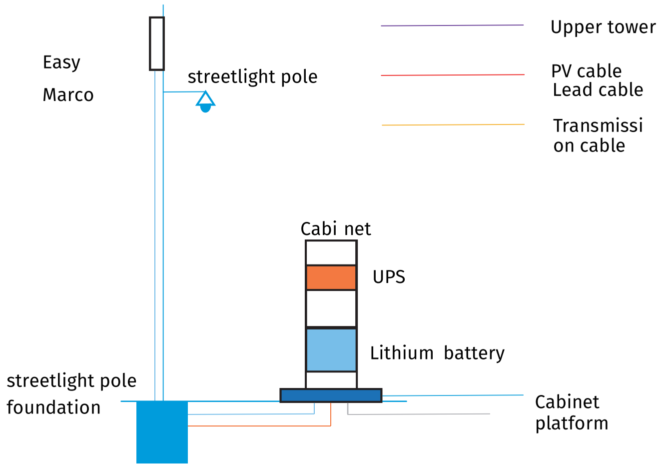
Operation time: January 2021 to present

Total investment: CNY 7,900

(1) Technology and equipment solutions

In this project, a group of retired EV power batteries is downcycled for energy storage and being installed under a streetlight pole to supply power to the communication micro base station.

Figure 2-20　Power supply solution of the streetlight's ESS



Structure diagram of energy storage system power supply scheme

Power supply system diagram

The ESS inverts the electric energy stored in the retired power batteries into AC power to supply the micro base station equipment through the uninterruptible power supply (UPS) inverter when the streetlights are not working (i.e., the streetlight power source does not provide supply). When the lights are lit (i.e., streetlight power is in supply), the UPS uses the streetlight power to charge the retired power battery through the rectifier, and the streetlight power supplies power to the micro base station equipment through the UPS rectifier and inverter. The ESS can be used for communication base station equipment with a power of not more than 300W and can use the daily intermittent power supply of streetlights (8-13 hours of the daily power supply) to achieve 24-hour uninterrupted operation of the communication micro base station.

Table 2-9 Retired battery parameters of the ESS

	Requirement
Batteries	3.2V single lithium iron phosphate battery
Battery pack specifications	51.2V/120Ah
Battery pack structure	16 strings of 3.2V single lithium iron phosphate battery
Battery pack operating temperature range	−15℃～ 55℃
Battery pack function	Standard heating components to ensure normal operation of lithium iron phosphate batteries below 0℃
Charging voltage	The float charging voltage of the single battery is 3.50V~3.70V, and the default value is 3.50V
Discharge termination voltage	Single battery discharge termination voltage range: 2.60V ~ 2.80V, the default value is 2.70V
Battery pack cycle life requirements	When the ambient temperature is 25℃ , the cycle life of the battery pack at 100% DOD 0.33C3 should not be less than 1,500 times

The power supply part of the ESS adopts a 1kVA UPS and customized 15A/30A charger solution, which can realize the simultaneous output of AC and DC and ensure that the battery is fully charged within 8 hours at night.

(2) Business model

The ESS of the communication micro base station is simple in structure and fast in construction. It only takes 3 hours to complete the installation of a micro base station equipped with a retired power battery ESS, which can meet the requirements of telecom operators for rapid delivery. With the rapid development of EVs, the replacement cost of retired power batteries will continue to decrease in the future, thereby further improving the economic returns of this solution. With good economic returns and practicability, it has good commercialization potential in specific scenarios.

(3) Results

On one hand, the ESS can help the peak-shaving and valley-filling of the power grid by charging at night and discharging during the day. On the other hand, compared with the traditional power supply solution of the micro base station, this solution has significant economic benefits. The traditional power supply construction solution is calculated according to the power supply distance of 100 meters. The cost of the pipe-drawing construction method is CNY 18,008, while the power supply solution cost of the ESS based on downcycling batteries in this solution is only 43.9% of the cost of the pipe-drawing power supply.

(4) Security guarantee

In terms of active safety measures, the operation data of UPS and the ESS are collected in real-time, and the safe operation of the ESS is realized through timely fault detection and process.

In terms of the on-site arrangement, the ESS are all located outdoor and maintains a certain safe distance from other facilities during the construction. Since the ESS itself does not have much power (5-6kWh), the damage is minimal and controllable even with fire.

(5) Lessons learned

The construction of communication base stations is gradually shifting from traditional macro base stations to micro base stations, which boasts the characteristics of small size, lightweight, low power consumption, small coverage, and low mounting height. These characteristics make them especially suitable for streetlight poles in densely populated areas and infrastructure construction sites. Through the combination of streetlight power supply and small ESS, as well as taking active early safety warning measures, the needs for rapid establishment of communication micro base stations can be met. As 5G networks further expand in China, it is expected that at least 500,000 micro base stations across the country are needed in the future. If each micro base station utilizes 8kWh of retired power batteries, a total of 4GWh of retired power batteries will be put into downcycling utilization, which is equivalent to approximately 80,000 EVs' retired batteries.

3 Technical Guidelines

3. Technical Guidelines

Built on China's relevant practice and research results in the field of EV-RE integration, this chapter introduces the trends and requirements for the integrated development of EV, grid and RE, proposes the application technical framework and standard framework for vehicle-grid integration, sorts out the relevant technical requirements in the key areas of EV charging and swapping infrastructure as well as grid-RE integration, and summarizes the reference requirements for typical application modes, technical solutions and basic configuration. It collects and provides the existing standards related to vehicle-grid integration, the draft standards in development without being officially published and the demands for some new standards, and briefly introduces the main standards. The content of this chapter mainly covers five technologies, including unidirectional smart charging (V1G), vehicle-to-grid bidirectional smart charging (V2G), integrated microgrid powered by PV with ESS and EV charging, energy storage and downcycling utilization of retired batteries, and vehicle-grid integration network information systems and communication security, especially V2X-PKI which is a public key infrastructure (PKI) security architecture for vehicle-to-everything (V2X) communications. Some contents are technologically forward-looking, which helps readers to gain a more comprehensive understanding of EV-RE vehicle-grid integration technologies and development trends. The relevant content can provide standard technical guidelines for the industry.

3.1 Application requirements and technical framework

Under the background of green development, the functions of traditional vehicles will be expanded, and the structure of traditional power grids will change. With digitization, intelligentization and sharing becoming the trends, it is of great significance to integrate the technologies in the fields of EV, power grids, RE and information communication, and establish a vehicle-to-grid integration service system and technology system that is in line with the development trends, which is quite necessary to promote the pace of technological innovation in transportation, energy, construction and communication, etc., and adapt to the upgrading and transformation of production and consumption modes.

3.1.1 Development trends and application requirements

In terms of the scale of EVs that by 2030, China will have 80 million to 100 million EVs, and the required annual power consumption will reach about 300 billion kWh. At that time, EVs will be connected to the grid on a large scale, generating a huge charging power load. The rational utilization of energy storage characteristics of EVs will create huge adjustable electricity resources for the energy grid. The construction of an electricity resource regulation network of vehicle-grid collaboration with efficient interaction can alleviate the security risk caused by large-scale disorderly charging of EVs to the power grid. Meanwhile, the complementary regulation of EVs and distributed RE generation can greatly improve the consumption capacity of RE, which is a valuable resource for realizing the green transformation of transportation energy.

On the vehicle side, by establishing interoperable interfaces among V1G, V2G, and charging and discharging facilities, the requirements for bidirectional interactive electricity control of EV-grid and online connection of terminals in long-link application scenarios will be met, and the improved requirements for safety protection performance of electrical components on high-voltage platforms will be adapted to. Meanwhile, the vehicle-pile slow-charging mode needs the establishment of a communication control link, with the communication connection capability of wireless coverage to realize the function of charging connection guidance, certification and cooperative control of piles. Therefore, it is necessary to carry out standard coordination in industries such as transportation and energy.

On the cloud side, a cloud platform service function can be established according to business needs, and the electricity resource regulation is implemented to meet the management requirements of vehicles, facilities, and battery electricity resources. Besides, the sharing of private piles and DC slow-charging and shared charging, as well as quick-swap battery rental and vehicle-battery separation and circulation have become the application trends. In order to adapt to the interactive management of electricity between different operating entities, it is necessary to identify not only the charging port identifier, but also the vehicle identity, battery identity and asset ownership for the subjects involved in charging and battery swapping services and participating in electricity trading. Universal coding rules, data encryption methods and multi-level mutual recognition mechanisms should be established to realize security certificate management, as that is the basis for realizing the digitalization of cloud architecture business that integrates traffic information and energy service information.

As for the digital operation of the network, the business service networks among vehicles and EV charging–ESS–discharging systems, user-side distributed microgrids, electricity aggregators and electric power dispatching systems should be established to connect vehicles and facilities to the cloud service platforms. Edge computing facilities provide distributed computing and data integration for edge connection, support the cloud to carry out electricity resource aggregation and transaction services, and ensure secure communication in terms of multi-subject contract-based business coordination, demand response, power dispatching, and energy spot trading.

On the ground facility side, a large amount of wind power and PV generation is disorderly connected to the power grid, which will have a superimposed impact on the power grid load and affect the stability of the power system. It is necessary to reasonably equip local energy storage devices on the microgrid system to improve the ability of the distributed energy storage system (ESS) to smooth and regulate the short-time, high-frequency and ultra-long scale load transitions, and form multiple protective measures conducive to improving the active consumption ability of RE access and realizing high safety operation. It is necessary to build a complementary ESS between the user side and the power grid side to adapt to the connection of multi-users in the local scope and the requirements of multi-scale operation regulation.

On the business model side, from the perspective of development trends, distributed charging and swapping infrastructure, wind power–PV–ESS microgrid facilities and the number of EV users keep expanding, the huge adjustable resources of electricity form a virtual power plant business through power aggregation, and electricity aggregators participate in electricity market transactions, which has shaped a new power service operation mode that is different from traditional power operation. At the same time, realizing cloud-network collaboration and data integration through multi-field business collaboration is the basic way to form multi-intelligence integrated business operation.

From the perspective EV-RE integration, the connection of large-scale RE and mobile energy storage entails the regional power balance adjustment, guidance on the connection points of EVs, as well as cloud-side-terminal collaborative computing concerning traffic conditions, microgrid's ESS load conditions and RE power generation forecasting, etc. Shared data push service among various operating platforms, data information integration simulation and decision control, as well as vehicle-grid integration will generate a large number of information interaction needs. Meanwhile, cross-platform business function collaboration will be formed at the business level. It is necessary to build a data exchange network and transaction payment platform for commercial operation services, and establish a software system functional architecture and a series of service interfaces based on the business service framework to meet the requirements of information exchange and interconnection among application service platforms.

In terms of application scenarios, in the future, the integration of intelligent charging and battery swapping technology and artificial intelligence technology will continue to penetrate the products and application systems with the increasing demands for intelligence and convenience, which will promote the broad application of automatic charging connection, instant charging automatic charging and battery swapping technology and non-inductive payment technology. In addition, products and systems need to realize the vehicle-pile-grid-cloud communication control capability with high availability, so as to meet the upgrading requirements of intelligent technology of autonomous driving and unmanned automatic charging and battery swapping systems. Besides, with the breakthrough of high-power and high-rate charging technology of power batteries, for high-power charging between vehicle piles and battery stability detection of ESS. It is necessary to conduct not only real-time diagnosis of the health status of power batteries with the help of big data services, but also the traceability analysis of battery characteristics, implementation of optimal matching of charging characteristics and service support of data security performance early warning.

Therefore, with the large-scale EVs, charging and battery swapping infrastructures and distributed RE facilities growing, it is necessary to integrate digital transportation system and digital energy system based on digital technology to form the vehicle-grid integration technical architecture of transportation and energy. Based on the digital integration of multiple information physical systems, the application service system is established to meet the collaborative requirements of business information and service functions such as vehicle-pile-cloud-grid-edge-terminal, thus realizing the interaction of traffic flow, energy flow, data flow and capital flow, and adapting to the requirements of intelligent and shared applications. Meanwhile, with the wide application of electricity interaction technology, it is also faced with the challenges of multiple information security vulnerabilities and data leakage risks. It is necessary to build up information security protection capabilities that adapt to large-scale transmission coverage with high-performance border security and depth security, implement the whole-process communication creditability authentication (PKI) mechanism from the vehicle to the charging system, as well as the microgrid and power dispatching, to ensure the high reliability and stable operation of the information system, which is also one of the key requirements for the construction of the EV-RE integration technology system. The cellular-vehicle-to-everything (C-V2X) is extended to the infrastructure and the energy dispatching, to realize the seamless energy exchange between the vehicle and the power system, and to meet the requirements of rapid response and interoperable control of the operating system. To achieve these, it is necessary to carry out cross-platform business information interaction, develop network information service systems and service function platforms that meet the requirements of large capacity and massive data bearing and stable operation, and realize the interconnection capability of integrated network information architecture and multi-industry basic business service functions. At the same time, in terms of standards, it is necessary to develop interface protocols, conformance tests and other evaluation standards as well as operation, management and service specifications that meet the information interaction between different systems for new business service functions.

3.1.2 Application technical framework

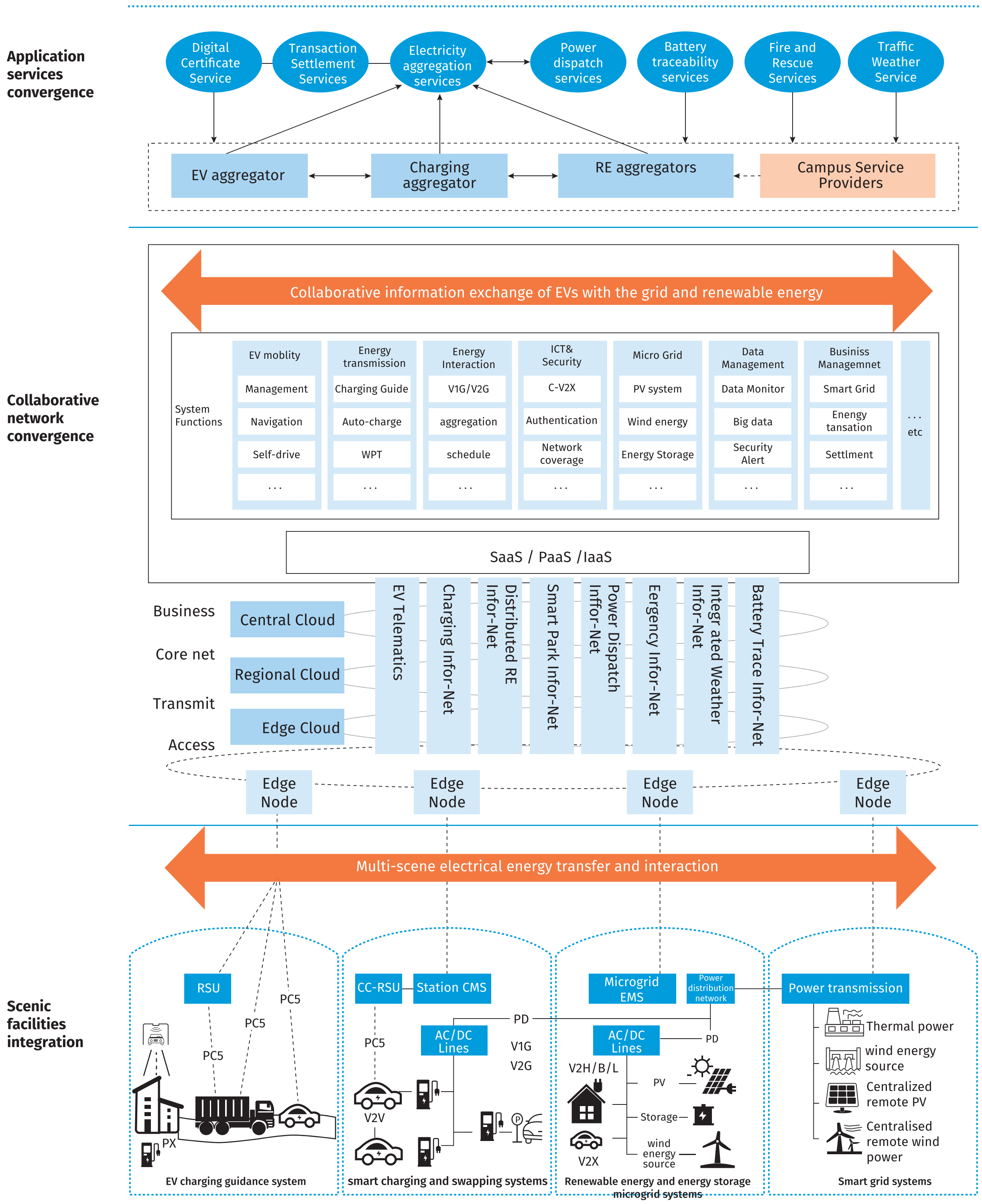
EV-RE integration means to connect EVs and coordinate the charging and discharging of the vehicle batteries to form a bidirectional energy interaction between the charging and battery swapping infrastructure and the grid, improve the consumption capacity of distributed RE power generation, stabilize the fluctuation of the power grid, and realize the efficient utilization and coordination and complementation of power resources. It is characterized by, through the integration of technology and system, forming a service form and a business operation mode with vehicle-grid integration and electricity interaction as application purposes, to meet the requirements of low-carbon development of transportation energy. Its integration will be conducive to promoting the wide range of applications of electricity interactive services and systems to accelerate the green development of transportation energy.

Based on the EV-RE integration application scenario, combined with the research on the Vehicle-to-Grid integration system, the EV-RE integration application technical architecture is proposed, as shown in Figure 3-1, which provides a basic framework for the standard system.

Application technical architecture designed a three-layer architecture for service integration:

(1) The scenario facility integration layer, i.e., the integration distribution or deployment layer of the vehicle and electricity interaction infrastructure, consisting of EVs, battery charging and battery swapping infrastructure, electricity load equipment, wind power–PV–ESS and other devices,

Figure 3-1 Technical architecture for the integration of EVs into the grid and RE applications



control equipment and auxiliary systems, as well as application devices and system fundamental functions to realize electricity interaction scenarios. The integration application functions include EV transportation and electricity supply connection guidance, smart battery charging and battery swapping system and operation functions, wind power–PV–ESS-charging-discharging and distributed energy microgrid system and operational functions, basic equipment, electrical systems, operation and maintenance stations and other facilities for electricity aggregation services and electricity interaction. It consists of four basic scenarios, as they are combined and superimposed to form a variety of vehicle-grid integration application scenarios. Among them, the electricity interaction function includes wind power–PV–ESS and vehicle-pile-gird and other sub-systems, with electricity bearing, electricity transmission and electricity resource regulation and control functions, and the optimal configuration and intensive deployment of the corresponding system. It is crucial to improve the system performance. Rational planning and optimized deployment can give full play to the role of EVs in RE consumption and the potential of the grid as a flexible resource of regulation can be released.

(2) The network collaboration integration layer is the information infrastructure based on the cloud-network integration architecture. It consists of systems including core business network operation systems, hierarchical connection systems, service platforms, and business collaboration information interaction networks. Through the composition of information technologies such as the business data integration realization, business-driven operating system development functions, and trusted communication interactions, it can provide local or wide-area communication interconnection and business interaction such as EVs' smart IOV, battery charging and battery swapping infrastructure network, distributed microgrid, electricity resource management, and power system dispatch. The information support for various types of operation control and management is also the information integration of smart EVs and intelligent infrastructure. In this way, the construction of network communication infrastructure for information interaction such as EV roaming battery charging and battery swapping, charging and discharging guidance, power resource coordination, power demand response, and cross-platform data service and information resource sharing can be realized. Among them, according to different vehicle-grid integration application systems, through the integration of data and information models, it is convenient to establish a development service architecture, which is conducive to multi-business collaboration and the sharing of basic services. At the same time, it supports real-time operation and control of the electricity interactive system through cloud-side-terminal collaboration, which is conducive to improving the multi-level operation and management capabilities inside the distributed system. The business support system based on the requirements of the information security protection level can provide information security for the reliable operation of the system and electricity transaction settlement etc. Therefore, combined with the multi-domain business collaborative application characteristics of the vehicle-grid integration information system, in terms of planning and system construction of network system, communication interface, service architecture, data resources, etc., we should fully consider the integration characteristics of the architecture, the compatibility of message interfaces and communication protocols, the interoperability of service functions, and the coordination of operational service management, to meet the support requirements of network information systems such as multi-business, high-throughput, big data, and high reliability.

(3) The application service integration layer consists of business service functions of different operation service platforms, operation monitoring, business dispatch management, and third-party collaborative service functions. Among them, the electricity aggregation platform is the most significant feature of the vehicle-grid integration business, including the aggregation services for power resources such as vehicle mobile energy storage, distribution of charging and battery swapping stations, wind power–PV–ESS microgrid, and green energy saving parks, as well as virtual power plant business and other operational services. The power dispatching platform is mainly responsible for coordinating distributed mobile energy storage and power balance adjustment between RE and large electric systems, and has a hierarchical dispatching management structure. The settlement trading platform is responsible for electricity payment transactions and settlements, and can also be different forms of third-party payment platforms. The digital certificate platform is essential for building a communication security guarantee system for an efficient and secure vehicle-grid integration business. It is responsible for establishing a trusted identity authentication mechanism for various operating entities engaged in electricity transactions, mainly used to provide digital communication authentication and identity authentication for vehicles, charging devices, etc. A secure authentication mechanism and a hierarchical management function are necessary for building a multi-level recognition key system. The battery traceability platform is used to provide the identity traceability for the power battery or energy storage battery system and realize the coordination of performance traceability and operation safety management. It is a third-party service platform for closed-loop management of battery life cycle resources. Fire-protection platform is a safety guarantee system for the EV-RE operating system to realize fire rescue cooperation. Traffic digital weather service provides regional weather forecast information service functions for travel, RE power generation, etc., facilitating users to improve the efficient utilization of RE and improve regional power resource dispatch and system control efficiency. In addition, third-party services also include collaborative applications of other information service systems, such as urban digital maps and traffic road conditions.

The above-mentioned technical architecture for integration applications, through people, vehicles, facilities, electricity, and multi-objective service connections, establishes the interrelationship between engaging in the EV-RE integration system and the main links of the service process. It reflects the basic requirements for the construction of a service system for the future-oriented connection to large-scale EVs and large-scale distributed energy, and adapting to the transformation of transportation energy to digital and intelligent operation. In terms of security and efficiency, the principle of composition starting from the high proportion of RE consumption and the realization of electricity interactive application scenario requirements are fully considered. From the service areas covered by the integration application technical architecture, it integrates applications such as smart IOV, battery charging and battery swapping facilities, and energy internet, and also reflects the basic requirements for cross-industry interconnection, security and reliability, and efficient operations.

The establishment of EV-RE application technical architecture can deepen the construction of the corresponding standard system and therefore help to promote the establishment of basic standards such as unified resource coding for equipment and entities participating in the electricity interaction of the vehicle-pile-grid. It can speed up the realization of highly automatic control and automatic settlement of electricity transactions based on automatic battery charging and battery swapping operation mode and automatic payment. Through the application technical architecture, we can drive the development of new products, and promote vehicle companies and battery charging and battery swapping infrastructure companies to make faster pace in V2G interface functions, promote technology development and product deployments such as electricity management and electricity aggregation service systems, and accelerate the construction and transformation of integration-type infrastructure, which is of great significance for accelerating the unleashing of the potential value of EV-RE.

3.2 Standard collaboration and system framework

3.2.1 Progress in standard collaboration

Collaborative establishment of the standard system promoted by industrial policies. The EV-grid-RE integration involves cross-industry, diversified and multi-level integration of industrial technologies, and requires cross-industry cooperation in establishing a coordinative framework for standardization. In terms of guidelines, the establishment of an integrated standard system should be promoted by the goals of peaking CO_2 emissions and achieving carbon neutrality, follow the principles of market orientation, coordinated promotion, following standards and innovative cooperation, focus on vehicle-grid integration and high-quality development of transportation and energy infrastructure, be led by green and low-carbon development, and improve the collaboration among EVs, grid and RE. In terms of promotion strategies, the “common language” attribute of standards and the technical connotation endowed by standards are used to improve the participation of the upstream and downstream of the industry chain in standard collaboration, promote the enterprise-dominated new technology development, application mode exploration and standard innovation activities in the industry, give play to the leading role of standards, and accelerate the development process of standards for vehicle-grid integration.

In recent years, standardization organizations in related fields have accelerated R&D of standards for EVs, charging and battery swapping infrastructure, energy storage facilities and Vehicle-to-Grid integration network, mainly R&D of the realization approaches to electricity exchange around EV-pile-microgrid-grid in terms of the upgrade of national standards and preparation of consortium standards, and established a sound standard system.

(1) Standards mainly involve two sectors: EVs and electric power facilities. The conduction charging connector between EVs, and the grid is the basic standard for EV-gird interaction. Standards mainly include *EV Conductive Charging System - Part 1: General Requirements (GB/T 18487.1-2015), Connection Set for Conductive Charging of EVs - Part 1: General Requirements (GB/T 20234.1-2015), Connection Set for Conductive Charging of EVs - Part 2: AC Charging Coupler (GB/T 20234.2-2015), Connection Set for Conductive Charging of EVs - Part 3: DC Charging Coupler (GB/T 20234.3-2015), Communication Protocol between Off-board Conducive Charger and Battery*

Management System (BMS) of EV (GB/T 27930-2015), EV Conductive Charging and Discharging System - Part 4: Discharging Requirements for EVs (to be published), Specifications of Charge-discharge Motor Controller for EVs (QC/T 1088-2017), etc.

(2) Relevant standardization organizations have accelerated the development of new standard requirements in terms of EVs, charging and battery swapping infrastructure, energy storage facilities and vehicle-grid integration communication network. For example, in the upgrade of the national standard of charge connector (2015 edition), a joint working group consisting of vehicle enterprises, parts enterprises, charging operation enterprises and electric power enterprises was formed under the joint promotion of the National Technical Committee of Auto Standardization and standardization organizations of the energy industry, and they carried out standard research and joint revision activities for several consecutive years. Meanwhile, several industrial academic organizations such as China Industry Technology Innovation Strategic Alliance for EV of China SAE and the Energy Storage Sub-society of China Electrotechnical Society have accelerated the work related to consortium standards for the EV-pile-storage-grid collaborative application, and played positive roles in promoting the establishment of the vehicle-grid integration standard system.

The contents to be revised in standards related to pile charge connectors include DC charge connector, charging control guidance circuit and DC charging communication protocol. The revisions are based on the principle of maintaining the DC charging system compatible with that in the 2015 edition, and the physical connectors are based on GB/T 20234.3-2015. By adopting the new control guidance circuit and communication protocol, the system solution can be optimized to achieve full compatibility with the standards for DC charging (2015 edition). The new system can realize many new functions such as high-power charging, scheduled charging, plug-and-charge, battery preheating, agility control, PE disconnection detection and vehicle discharge, and can improve the security of the charging system from many aspects. Revised standards can meet the development requirements for high-power charging of EVs and fully support the platform architecture of the new generation of smart EVs. New standards are expected to be published by the end of 2022 or early 2023.

(3) In terms of the collaboration between EVs and charging and battery swapping infrastructure, research on V1G and V2G technologies has been carried out. Based on the original standards, new standard requirements in the process of vehicle-to-grid integration have been fully considered. It mainly involves the mutual transmission, control, interoperation and safety requirements of AC electricity on the grid, DC electricity stored in EVs' power batteries and wind power–PV–ESS new distributed energy through energy conversion equipment. The grid and wind-PV-ESS charge EVs and support their mobility, and EVs feed electricity back to the grid and off-grid equipment. The wind power–PV–ESS electricity can be directly used for off-grid electrical equipment and on-grid electricity feedback. EVs serve as the charging and discharging connection guidance of the distributed ESS. Communication capability, integration data coding, interface or protocol of the grid, EVs and wind power–PV–ESS in the process of electricity conversion. Electricity dispatch, electricity consumption metering and electricity payment and settlement can be achieved.

(4) The standards for grid connection of distributed energy mainly stipulate the grid connection conditions, control, security protection and other requirements. The current standards include the *Code of Start-up Acceptance for Photovoltaic Power Station (GB/T 37658-2019), Technical Requirements for Photovoltaic Gird-connected Inverter (GB/T 37408-2019), Testing Specification for Photovoltaic Grid-connected Inverter (GB/T 37409-2019), Technical Specification for Grid Connection Protection of Distributed Resources (GB/T 33982-2017), Specification of Operation and Controlling for Distributed Resources Connected to Power Grid (GB/T 33592-2017), Technical Requirements for Grid Connection of Distributed Resources (GB/T 33593-2017), Specification of Operation and Control for Photovoltaic Power Station (GB/T 33599-2017), Security Specification and its Evaluation Generating Unit Interconnection (GB/T 28566-2012), Technical Requirements for Grid Connection of PV System (GB/T 19939-2005), Outdoor Empirical Test Requirements for Distributed Photovoltaic in Warm Damp Climate - Part 3: Grid-connection Photovoltaic System (GB/T 37663.3-2019), Technical Specification of Utility Interface of Residential Distributed Photovoltaic Power System (GB/T 33342-2016), Technical Requirements and Test Methods for Grid-connected PV Inverters (GB/T 30427-2013),* etc.

3.2.2 Standard system framework for EV-RE integration

According to the EV-RE application technical architecture and requirements, this section proposes the standard system framework for EV-RE integration, as shown in Figure 3-2. The system involves such technical fields as EVs, charging and battery swapping systems, microgrid systems, electricity interaction systems, EV-pile-cloud-grid collaborative secure communication system, energy storage and power battery recycling, and other relevant parts. In addition, standard requirements and layout are subdivided in each technology field, including basic general requirements or specific requirements, equipment and system functions and technical requirements, tests, appraisal methods, etc., aiming to clarify the synergistic relationship between technology and standards in all aspects of EV-RE integration.

The standard system framework can complement and integrate with existing standards in related fields, making it convenient for collating and proposing the development requirements of new standards from the technical composition of EV-RE application requirements. Since the systematic collation of the technical system of EV-RE standards is carried out for the first time in the section, this part is of great significance for promoting the establishment of the EV-RE standard system framework.

3.3 Technical guidelines

Based on the extensive demonstration and verification of the GEF funded project EV-RE Integration in China and the research results on related technical standards, this section has set out the technical guideline requirements for a total of five aspects of the integration applications of EVs and RE,

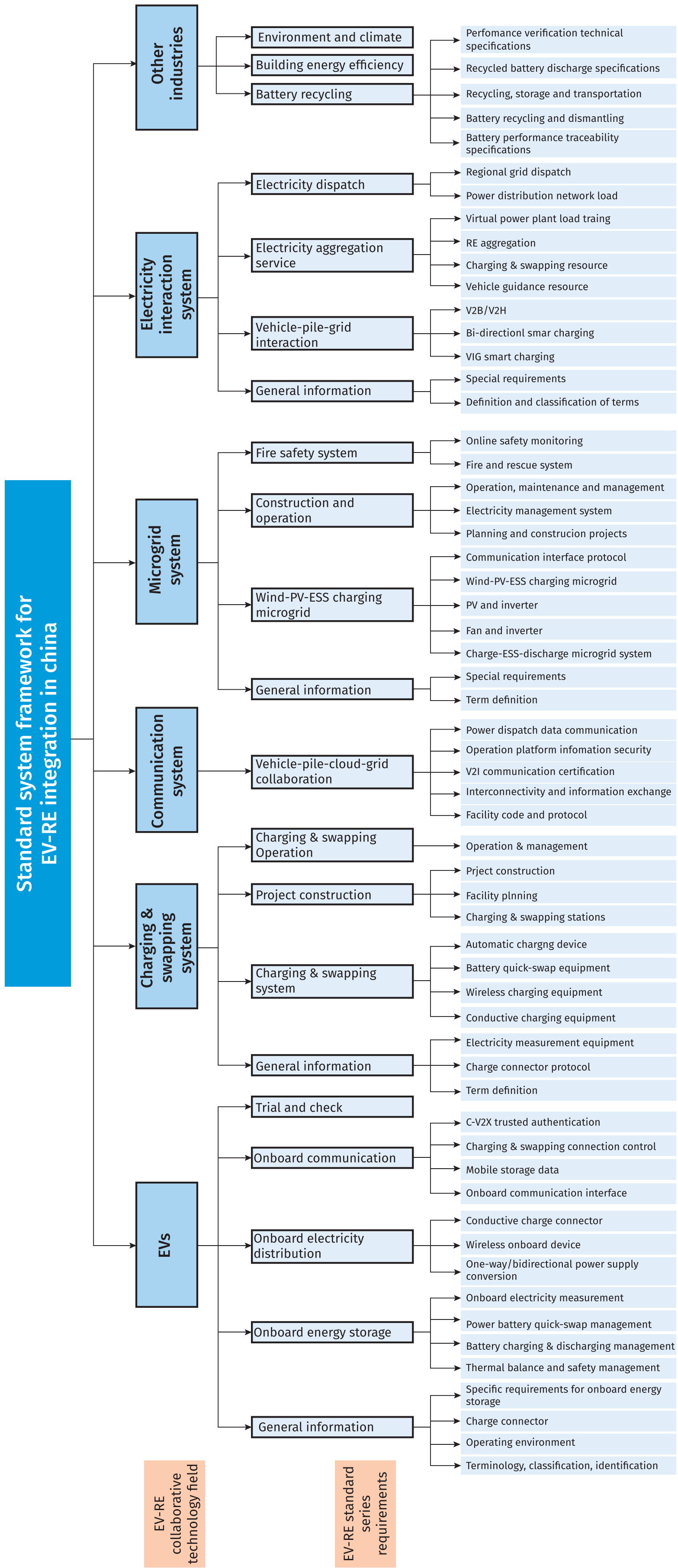


Figure 3-2 Standard system framework for EV-RE integration

including V1G, V2G, PV–ESS–EV charging microgrid, energy storage and the downcycling utilization of retired power batteries, network information system and the communication safety and reliability, and this section has presented China's main standards list and new standards development needs in each technical area, to enable practical application reference.

3.3.1 Unidirectional smart charging (V1G)

3.3.1.1 Overview

V1G is the current mode of peak-shifting charging control for EVs connected to the grid, and one of the grid demand response modes. It is characterized by unidirectional energy interaction from the grid to EVs, and bidirectional information interaction between EVs and the grid. V1G is the primary phase of the EV–grid interaction. V1G means optimizing and adjusting the EVs' charging time and power by economic measures of peak-valley electricity prices or intelligent control measures on the premise of satisfying EV charging demand. By changing the charging time and power, the power grid peak-shaving, frequency regulation, congestion elimination, renewable energy consumption and other demand responses can be realized to stabilize the load fluctuations. Research has shown that V1G can also fully and reasonably make use of electricity distribution facilities' capacity, to achieve the objectives of enhancing grid access to charging services, reducing investment in the distribution network, improving the charging economy, and boosting the clean energy consumption capacity.

V1G not only includes the effective management of the charging process by charging service providers and the grid, but also the active response of users to the electricity price mechanism such as peak-valley prices and the behavior of autonomous adjustment of the charging process. With the latter method, the charging quantity and charging period of EVs can be optimized and adjusted, so as to improve the capacity of renewable energy consumption, alleviate the power supply pressure of distributed energy resources, adjust the peak-valley load difference of the system, and obtain better social and economic benefits.

Based on relevant V1G research, standards and practical experience in China, this guideline summarizes and puts forward the requirements on V1G for references.

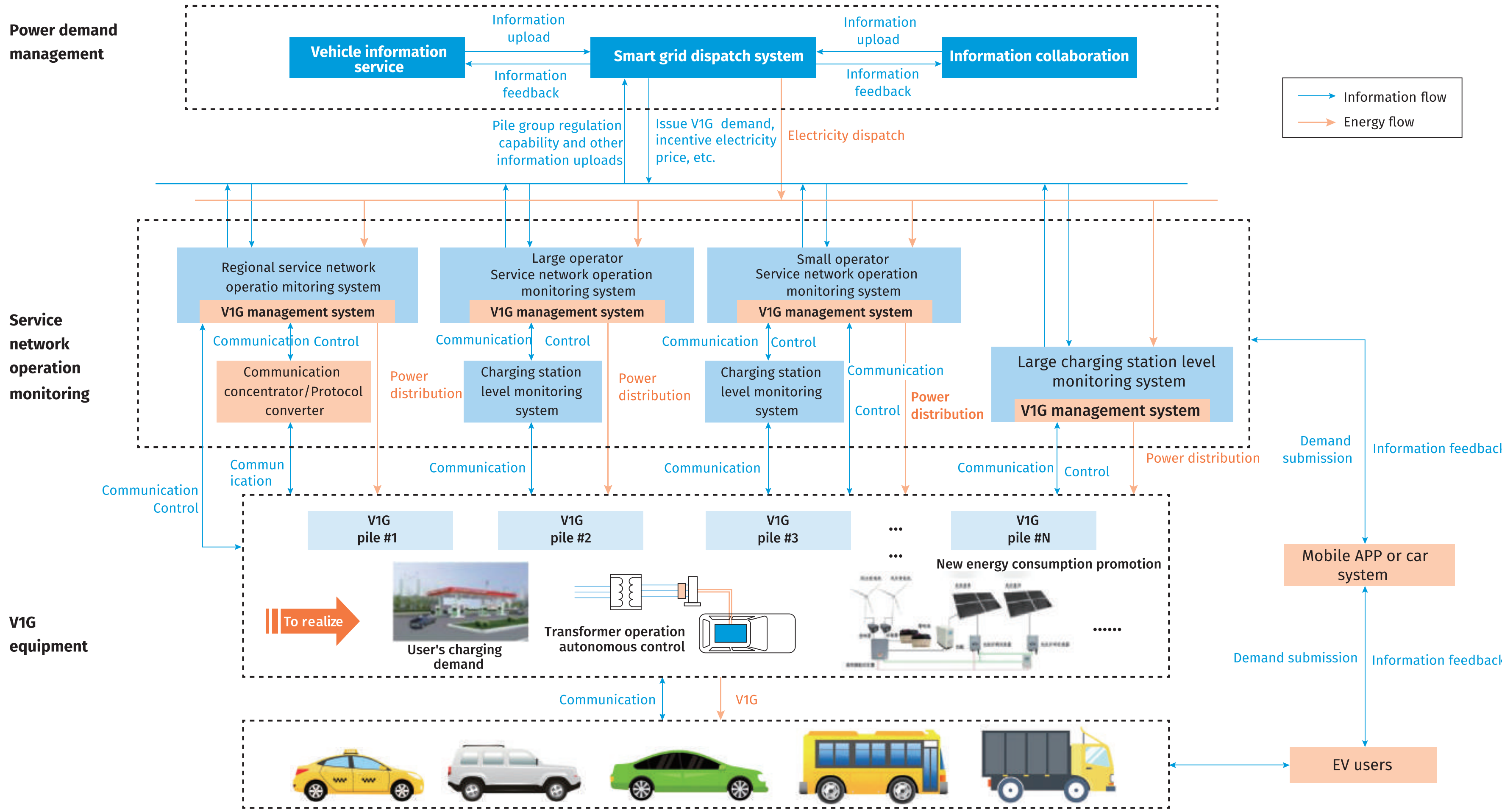
3.3.1.2 Technical requirements

3.3.1.2.1 Typical technical architecture

In the V1G phase, with the rapid increase of EVs, the weakness of power distribution networks in some areas where EVs are concentrated is gradually exposed. In order to meet the charging demands of large-scale EVs and slow down the scale of grid expansion and construction, V1G services are needed. V1G can be carried out at the regional or station level.

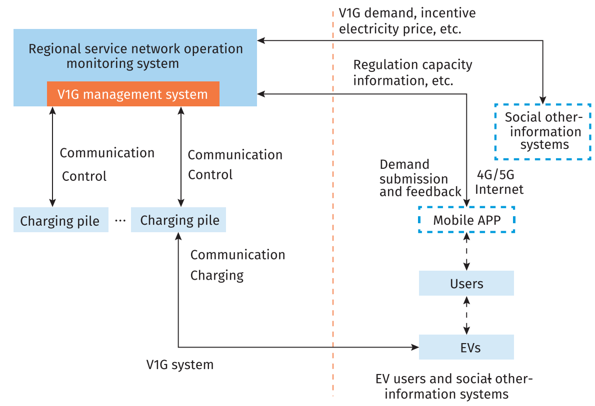
The typical V1G technical framework, as demonstrated in Figure 3-3, includes an V1G management system and V1G equipment. It can also include a transformer load information acquisition device, a communication concentrator of charging equipment and a dedicated V1G controller installed inside

Figure 3-3 Typical V1G technical architecture

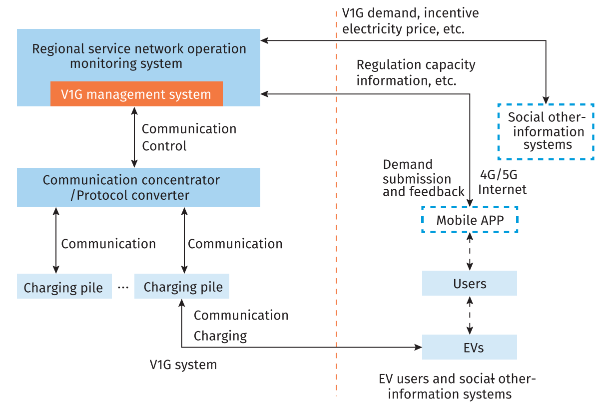


the charging equipment. Typical V1G connection modes are shown in Figure 3-4.

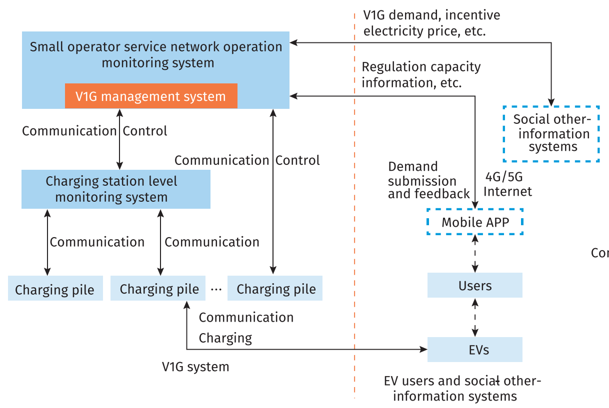
Figure 3-4 Typical V1G connection modes



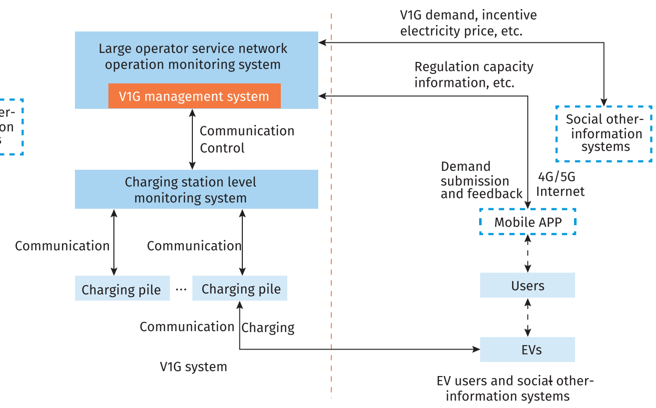
(a) The mode of a regional V1G management system directly connected to V1G piles



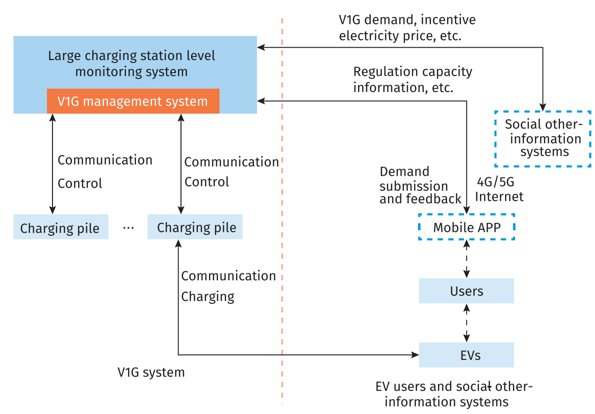
(b) The mode of a regional V1G management system connected to V1G piles through a concentrator or protocol converter



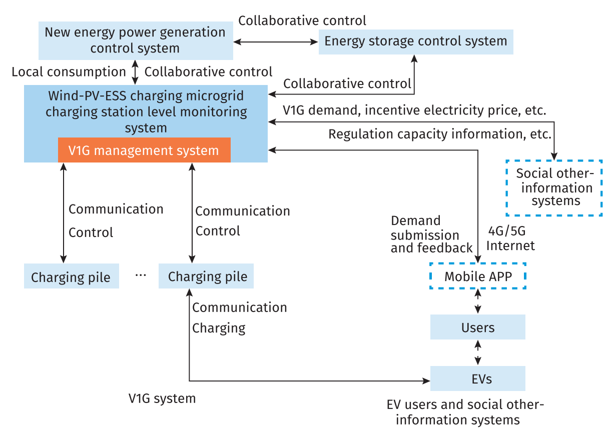
(c) The mode of a small operator's V1G management system directly connected to V1G piles



(d) The mode of a large operator's V1G management system connected to V1G piles through the charging station level monitoring system



(e) The mode of a large charging station's V1G management system connected to V1G piles through the charging station level monitoring system



(f) The mode of a windpower–PV–ESS–EV charging microgrid system connected to V1G piles for direct consumption of green electricity

The application conditions and characteristics of different connection modes are shown in Table 3-1.

Table 3-1 Application Conditions and Characteristics of Different Connection Modes

V1G application mode				
Mode	**Name**	**Connection mode**	**Application conditions**	**Mode characteristics**
Mode 1	The mode of a regional V1G management system directly connected to V1G piles	Figure 3-4 (a)	Scattered V1G piles	It is convenient for centralized management of scattered V1G piles
Mode 2	The mode of a regional V1G management system connected to V1G piles through a concentrator or protocol converter	Figure 3-4 (b)	Charging piles of different manufacturers and communication protocols	It can integrate and centrally manage V1G piles of different manufacturers and communication protocols
Mode 3	The mode of small operator's V1G management system directly connected to V1G piles	Figure 3-4 (c)	Small operators with the capability of V1G management	It can achieve V1Gg at the regional or wide-area level according to regulatory requirements or local load management objectives
Mode 4	The mode of a large operator's V1G management system connected to V1G piles through the charging station level monitoring system	Figure 3-4 (d)	Large operators that manage multiple charging stations in multiple areas	It can achieve V1G at the regional or wide-area level according to regulatory requirements or local load management objectives
Mode 5	The mode of a large charging station's V1G management system connected to V1G piles through the charging station level monitoring system	Figure 3-4 (e)	Large charging stations	It can achieve V1G according to regulation requirements or local load management objectives
Mode 6	The mode of a wind power–PV–ESS–EV charging microgrid system connected to V1G piles	Figure 3-4 (f)	Wind power–PV–ESS–EV charging microgrid	It can be combined with the microgrid control system to realize the local consumption of renewable energy

3.3.1.2.2 System functional requirements

(1) V1G management system

The V1G management system shall have the functions of V1G control and operation management, including but not limited to charging demand processing and charging guidance and execution response, V1G strategy generation and issuance, charging process monitoring, safety protection and inter-system information interaction.

The V1G management system generates V1G control strategies according to electricity price, transformer load, grid regulation, charging equipment operation and vehicle SOC, and controls the start and stop time of V1G equipment and the output power during charging process, and carries out V1G billing services. The V1G management system is suitable to be integrated as a sub-system of the operation management system or the station level monitoring system.

(2) V1G equipment

V1G equipment should have the communication function of information interaction with the V1G management system. The equipment types include but are not limited to AC V1G piles and DC V1G piles (off-board conductive chargers, including high-power and low-power DC V1G piles).

V1G equipment should have the functions of real-time adjustment of the available load current of the EV power supply equipment, display and manual input, making it convenient for users to submit charging demands.

(3) Human-computer interaction terminal

EV users can submit charging demands to the V1G management system through the human-computer interaction terminal (including but not limited to mobile APPs) and can obtain charging feedback.

In order to adapt to charging demands in different scenarios and guarantee users' charging convenience, Bluetooth communication can be used as an optional backup communication channel between V1G equipment and human-computer interaction terminals.

(4) EV

EV can have the function of uploading its information (battery capacity, charging power range, etc.), receiving and executing power adjustment commands, and supporting the functions of automatic power-off and recharging.

(5) Communication network

When the V1G management system is directly connected to V1G equipment, it can be connected through a mobile communication network or wired data communication LAN. When the V1G management system is connected to the V1G equipment through a communication concentrator or protocol converter, local data communication can be carried out between the V1G equipment and the communication concentrator or protocol converter through the narrowband carrier, broadband carrier, CAN2.0B, RS485, wired Ethernet, etc. The above communication modes can be realized by the built-in charging controller of the V1G equipment or the dedicated V1G controller installed separately.

The V1G management system is connected to human-computer interaction terminals (mobile APPs, In-Vehicle Infotainment system, etc.) through the mobile communication network, etc.

When the communication network cannot support the V1G operation mode, the charging facilities can adopt the ordinary charging method, and implement the mode featuring local billing and delayed settlement.

(6) Renewable energy power generation system

The wind power–PV–ESS–EV charging microgrid is generally composed of the central control layer, local control layer, renewable energy power generation control system, energy storage control system and V1G management system.

The central control layer of the wind power–PV–ESS–EV charging microgrid monitors the operating status of each system in the whole grid through high-speed data acquisition of the microgrid system, collects the output data of the renewable energy power generation control system, and calculates on this basis. In accordance with the control strategies, the central control layer distributes the power regulation plan for the V1G management system and energy storage management system, so as to realize the dynamic regulation and control of power supply, energy storage and EV loads and ensure the safe and stable operation of the wind power–PV–ESS–EV charging microgrid.

The local control layer of the wind power–PV–ESS–EV charging microgrid realizes local control and protection, and the integrated monitoring, protection and control of specific switches, distributed power supply, power conversion systems and loads.

3.3.1.2.3 Technical specifications

(1) System response time

For guaranteeing users' convenience, the response time of the V1G system should meet the requirements in Table 3-2.

(2) Technical specifications of V1G management system

The technical specifications of the V1G management system should meet the requirements in Table 3-3.

Table 3-2 V1G response time

No.	Function item	Response time
1	V1G response time for a charging request (V1G management system → pile → vehicle)	≤ 10s
2	Charging load data acquisition time (pile → V1G management system)	$<$ 15s
3	Planned dispatching cycle of V1G (V1G management system)	≤ 5min
4	V1G Real-time dispatching cycle (V1G management system)	≤ 1min

Table 3-3 Technical specifications of the V1G management system

No.	Parameter	Technical specifications
1	Annual system availability ratio	≥99.5%
2	Requirements for continuous system running	7×24h
3	System fault recovery time	≤2h
4	Success rate of equipment data receiving	≥99%

(3) Technical specifications of V1G equipment

The response time of V1G equipment shall be ≤ 1s.

The output power adjustment accuracy of V1G equipment shall be ≤± 1%.

The output power adjustment range of V1G equipment should be within 20% to 100% of the rated output power.

When an EV adopts the AC charging mode for V1G, the time for EVs to respond to the charging power regulation command shall be ≤ 5s.

3.3.1.2.4 V1G control strategy

(1) Configuration strategy of the V1G management system

Considering the space-time dynamic characteristics of EVs, grid and conventional loads, as well as the load characteristics of the power distribution network, under the premise of meeting the charging demand of EVs as much as possible, operators should formulate charging guidance and control strategies, take into account both the orderliness of charging at the regional level and users' charging convenience to ensure that the charging power does not exceed the surplus capacity of the transformer in the station area, and to improve the safety and service quality of charging.

1) System models

① EV model

Different EV models (identifications) are built according to existing EVs and battery types. And an expert base should be formed accordingly. Basic parameters include battery capacity, power range (minimum charging power, maximum charging power), and SOC, etc. Charging power characteristic curve is generally divided into three stages (trickle charging stage, constant current charging stage and constant voltage charging stage), different charging powers are allocated to different sections, and optimal energy allocation management is carried out on the system.

② Electricity price incentive model

Price curve: according to the regulations on electricity prices, a 24-hour electricity price curve is formed.

Incentive model: according to the formulated incentive measures of long cycle (such as day-ahead with one day in advance) and short cycle (such as real-time at hour level), an V1G incentive model is formed in the V1G management system, which has rolling correction function.

Demand response model: based on the formulated V1G incentive model, EV users are guided to participate in V1G application, so as to realize the transfer of charging loads in a certain period and respond to the regulation demands issued by the grid.

③ Power distribution network load model

Load model in the station area: the renewable energy output forecast curve, load optimization target curve and conventional load forecast curve (for loads other than EVs) are issued by the grid, including the day-ahead curve and real-time curve. The load demand planning curve is based on the EV charging plan uploaded by the operation monitoring system and the V1G management system and superimposed with the conventional load curve to form the load optimization planning curve which is sent to other public information systems.

(2) Implementation of V1G control strategies

1) Constraints

Electricity distribution transformer capacity should meet the transformer capacity constraints. The energy distribution strategy of EV should be optimized in space dimension to meet the operation requirements of transformer three-phase equilibrium.

2) Strategy calculation trigger method

In the following four situations, it is necessary to recalculate the charging strategy to ensure the real-time and rationality of the control strategy.

Order issuance: the controller automatically triggers the calculation of the control strategy when a new order or an original order is cancelled or adjusted.

Abnormal charging: the controller automatically triggers the calculation of the control strategy when the EV owner fails to park and insert the gun according to the originally planned time (which can be delayed by 10 minutes), or when the charging EVs do not complete the charging as planned (manually pulling the gun, vehicle failure, etc.).

Optimization adjustment: in order to optimize the control strategy, the controller automatically triggers the calculation of the control strategy when receiving the new load optimization target curve and the conventional load prediction curve.

Safe operation: when the transformer is overloaded and exceeded the limit (load prediction deviation), it needs to automatically trigger the calculation of the control strategy, and then it can be controlled.

3) Charging power adjustment solution

The wind power–PV–ESS–EV charging microgrid collaborative control system guides the microgrid to perform V1G according to the forecast information of renewable energy output, basic load information, and ESS configuration information to realize local consumption of renewable energy. Considering the uncertainty of renewable energy output, the affection of the renewable energy output prediction error on the actual system operation is reduced by adjusting the V1G power and the operation mode of the ESS. When the transformer load increases and approaches the upper limit of operation, it is necessary to coordinate and control the EV charging behavior in the transformer power supply area and formulate a power adjustment solution.

3.3.1.3 Standards and specifications

China has so far published many standards related to V1G, which mainly focus on the construction, design, operation management, testing, and safety of charging facilities and their systems. They can be used as a composition or supplement to this technical guideline. Table 3-4 provides a list of these standards and some under the preparation.

Table 3-4 Standards related to EVs, charging and battery swapping in China

Standard category	Application field	Standard	Standard number
National standard	General requirements	Terminology of EV charging and battery swapping infrastructure	GB/T 29317-2021
		Technical code for EV charging and battery swapping infrastructure interconnecting to distribution network	GB/T 36278-2018
		Power quality requirements for EV charging and battery swapping infrastructure	GB/T 29316-2012
		Graphical signs—EV charging and battery swapping infrastructure signs	GB/T 31525-2015
		Safety requirements for EV power batteries	GB 38031-2020
		Urban public facilities—Requirements for security and protection system of EV charging and battery swapping infrastructure	GB/T 37295-2019
		Urban public facilities—Specification for operation management and service of EV charging and battery swapping infrastructure	GB/T 37293-2019
	Conductive charging	General requirements for EV charging station	GB/T 29781-2013
		Code for design of EV charging station	GB 50966-2014
		Electric energy metering for EV AC charging pile	GB/T 28569-2012
		Electric energy metering for EV off-board charger	GB/T 29318-2012
		EV conductive on-board charger	GB/T 40432-2021
		EV conductive charging system—Part 1: General requirements	GB/T 18487.1-2015
		EV conductive charging system—Part 2: Electromagnetic compatibility (EMC) requirements for off-board EV supply equipment	GB/T 18487.2-2017
		EV conductive charging and discharging system — Part 4: Discharging requirements for EVs	GB/T 18487.4 (Draft for comments)
		Connection set of conductive charging for EVs—Part 1: General requirements	GB/T 20234.1-2015
		Connection set for conductive charging of EVs—Part 2: AC charging coupler	GB/T 20234.2-2015
		Connection set for conductive charging of EVs—Part 3: DC charging coupler	GB/T 20234.3-2015
		Communication protocols between off-board conductive charger and BMS of EV	GB/T 27930-2015
		Interoperability test specifications of EV conductive charging—Part 1: Supply equipment	GB/T 34657.1-2017
		Interoperability test specification of EV conductive charging Part — 2: Vehicles	GB/T 34657.2-2017
		Consistency test of communication protocol between off-board conductive charger and BMS of EV	GB/T 34658-2017
		Electromagnetic compatibility requirements and test methods for EV conductive charging	GB/T 40428-2021

(Continued)

Standard category	Application field	Standard	Standard number
Sectoral standards	Conductive charging	Specification for EV off-board conductive charger	NB/T 33001-2018
		Specification for EV AC charging pile	NB/T 33002-2018
		Communication protocols between off-board charger monitoring unit and BMS of EV	NB/T 33003-2010
		Code for construction and completion acceptance of EV charging and battery swapping station	NB/T 33004-2013
		Technical specification for monitoring system of EV charging stations and battery swapping station	NB/T 33005-2013
		Communication protocol between monitoring system in EV charging station and battery swapping station and charging and battery swapping equipment	NB/T 33007-2013
		Inspection and test specifications for EV charging equipment Part 1: off-board charger	NB/T 33008.1-2018
		Inspection and test specifications for EV charging equipment Part 2: AC charging pile	NB/T 33008.2-2018
		Technical guide for construction of EV charging and battery swapping infrastructure	NB/T 33009-2013
		Specification of operation and management for EV charging and battery swapping infrastructure	NB/T 33019-2015
		Off-board charger for EVs	JJG 1149-2018
		Specification for information exchange of power demand response	DL/T 1867-2018
		Specification of charge-discharge motor controller for EVs	QC/T 1088-2017
	Bidirectional interaction	Bidirectional interaction of EV charging and discharging Part 1: General Principle	To be approved
		Bidirectional interaction of EV charging and discharging Part 2: V1G	To be approved
Local standards	Smart charging	Technical requirements for intelligent charging piles and interactive response for EVs	DB31/T 1296-2021
Consortium standards	Conductive charging system and equipment	Technical specification for EV AC V1G piles	To be developed
		Communication protocol for EV AC V1G pile	To be developed
		Technical specification for EV AC V1G pile inspection	To be developed
	Bidirectional interaction	Electricity demand response information model Part 7: EVs	T/CEC 239.7-2019
		Specification for Interaction between Energy Internet and EV	To be reviewed

Among the above, *the Technical Guide for Construction of EV Charging and Battery Swapping Infrastructure* mainly stipulates the basic technical principles that should be followed in the construction of EV charging and swapping facilities. The construction of EV charging and swapping facilities should follow the principles of unified standards, unified specifications, unified identification, optimized distribution, safety and reliability, and moderate advancement. The design of EV charging and swapping facilities should be reasonably determined according to factors such as project characteristics, facility type, equipment capacity, site environment, energy saving, and environmental protection.

Bidirectional Interaction of EV Charging and Discharging Part 2: V1G mainly specifies the terms and definitions, technical framework, functional requirements, technical requirements, and information security protection requirements of the EV V1G system. It is suitable for the design, construction, operation, and maintenance of EVs' V1G system. The basic structure of V1G system includes an V1G management system and V1G equipment. It can also include a transformer load information acquisition device, a communication concentrator of charging equipment and a dedicated V1G controller installed inside the charging equipment. It has the functions of V1G, V1G equipment, user interaction and guarantee, and meets the requirements of system response time, system and equipment, and EVs' technical specifications. V1G equipment should have certain information security protection measures, including but not limited to access control, password certification, data encryption, etc.

The Technical Requirements for Intelligent Charging Piles and Interactive Response for EVs is based on optimizing the layout of EV charging facilities, standardizing the construction of smart charging facilities, ensuring the charging safety of EV owners, and reducing the adverse impact of large-scale charging on grid load. This specification specifies the applicable scenarios, general requirements, smart charging requirements, interactive response requirements, and platform interaction requirements of EVs' intelligent charging piles for intelligent charging and interactive response. It is suitable for intelligent charging piles that need to adjust the charging power of EV power supply equipment, including smart AC charging piles and smart off-board chargers.

The Technical Specifications for EV AC V1G Piles now is in development, and the basic composition, functional requirements, technical requirements, and requirements for marking, packaging, transportation, and storage of EV AC V1G piles need to be considered. Based on ensuring the safety and stability of the charging interaction process, it is necessary to solve the problem of information interaction with the upper-level system and EVs. Receive and quickly respond to the load regulation commands issued by the system, and adjust the charging sequence and output power flexibly. Improve the response speed of power adjustment, and standardize technical parameters such as charging and stopping switching time, frequency, ramp rate, etc., to realize the speed and accuracy of the execution of control instructions.

The Communication Protocol for EV AC V1G Piles is also in development and needs to be based on promoting bidirectional information interaction. The AC piles can not only download information such as charging power to EVs, but also collect and upload information such as EV charging requirements and adjustment capabilities in real-time, ensuring the completeness and accuracy of information interaction and providing support for the formulation of an V1G plan.

The Electricity Demand Response Information Model Part 7: EVs mainly specifies the modeling principles, general packages, and special packages of EVs' demand response information model in the demand response business. The establishment of EVs' demand response information model needs to follow the requirements of practicality, convenience, applicability, and scalability. The model general package includes equipment appearance information, user information to which the equipment belongs, equipment automation capability information, and user demand response contract information. Model-specific packages include charging mode classes, rated parameter classes, charging status classes, real-time parameter classes, and demand responsiveness classes.

3.3.2 Vehicle-to-grid bidirectional smart charging (V2G)

3.3.2.1 Overview

V2G is a mechanism that benefits multiple parties including EVs, charging operators, the grid, and more. On the premise of meeting the changing needs of EV users, EVs are regarded as distributed energy storage resources, and through demand response or active regulation technology, the following goals can be achieved: (1) to accept more EVs under the existing grid capacity and increase the penetration rate of EVs. (2) to provide auxiliary services such as peak-shaving, frequency regulation, backup, and block elimination for the power grid to achieve a win-win situation for EV users and the power grid. (3) to realize more consumption of renewable energy through integration technology. Taking engagement in the grid peak-shaving service as an example, based on relevant incentive policies, when the grid load or local load is too high, the charging power of EVs can be reduced or EVs can feed power to the grid or local load to achieve the purpose of peak-shaving. When the grid load or local load is in a valley, the grid or local load can be adjusted by means such as V1G to achieve the purpose of valley-filling. This technology typically needs bidirectional information exchange between EVs and the grid or local energy management system. Based on the given regulation target, the bidirectional flow of energy between EVs and the grid or local load is realized through analysis, decision-making, and control processes.

At present, V2G is still in the phase of technology exploration, demonstration, and promotion in the world, and there is no successful case of large-scale commercialization. The 2018 report *V2G Global Roadtrip*[14] listed the outcomes and development trends of 50 V2G projects around the world, of which 25 projects are in Europe, 18 projects in North America, and 7 projects in Asia. Most of the projects focus on the technical level (98%), and the experience of the past ten years has verified the technical feasibility of V2G, but social issues such as sustainable business models, technical standards, and incentive policies remain to be resolved. This guideline is mainly based on China's relevant research and practical experience in the V2G field, summarizes and puts forward the core technical requirements of V2G, and provides reference for the promotion and application of the technology.

14 V2G Global Roadtrip: Around the World in 50 Projects. UK Power Networks and Innovate UK. 2018

In the past decade or so, with the dedicated support of relevant state ministries and local governments, State Grid Corporation of China, China Southern Power Grid Corporation, scientific research institutions, automobile companies, and operators have carried out many beneficial attempts in the V2G field. The development of V2G in China will gradually move from the V1G stage characterized by unidirectional energy flow and bidirectional information flow to the V2G stage of the coexistence of unidirectional and bidirectional energy flow and bidirectional information flow.

With the development of V2G, and its standardization systems as well as incentive policies, distributed flexible resources of EVs further played their roles in grid balance regulation based on the consideration of maximizing the benefits of users, operators, the grid and other participants. As a result, users and operators can further reduce costs, and the power grid can obtain greater auxiliary service capabilities such as peak-shaving, frequency regulation, and backup while reducing operating costs and better realizing the integration of EV and renewable energy sources.

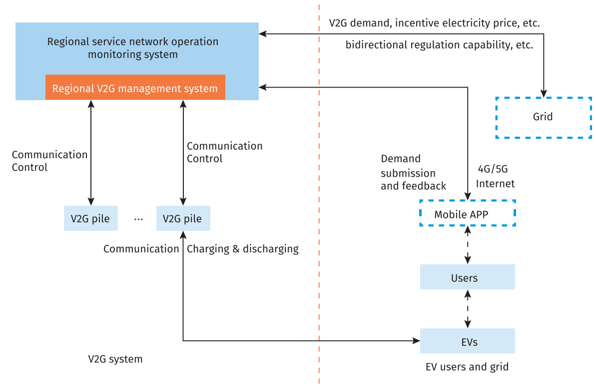
3.3.2.2 Technical requirements

3.3.2.2.1 Typical technical framework

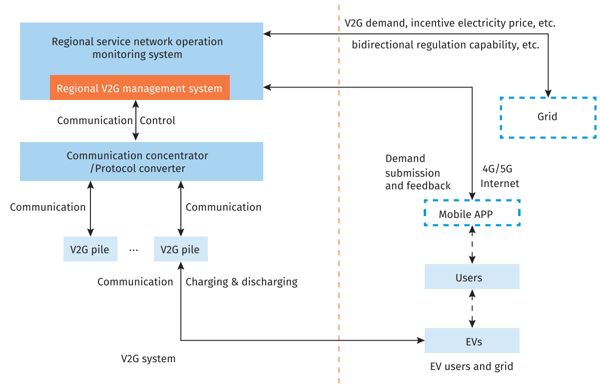
V2G technology is based on V1G. On the one hand, it is necessary to develop the bidirectional information system between EVs and operators and also between operators and grids that supports the bidirectional energy flow. On the other hand, it is necessary to develop EVs, V2G piles, energy management systems, and other equipment with the function of bidirectional energy flow, such as the V2G management system on the operator side, and the flexible load management sub-system of the grid dispatching system on the grid side.

The typical V2G connection mode is shown in Figure 3-5. The overall system connection mode is similar to the V1G system connection mode. The difference is that the energy flow between the EV and the grid can be unidirectional or bidirectional. The information exchange system, V2G management system, and related equipment need to support the bidirectional energy flow. Among them, the power grid accepts information such as the bidirectional regulation capability of the pile group uploaded by the monitoring system at the charging station level and calculates and distributes information such as V2G demand and bidirectional interactive incentive electricity price. The charging station-level monitoring system receives the demand information uploaded by the user, the status information uploaded by the V2G pile, and the adjustment capability information of the EVs. The V2G management system formulates the charging and discharging plan and sends it to the V2G pile for execution. The application conditions and characteristics of different connection modes are shown in Table 3-5.

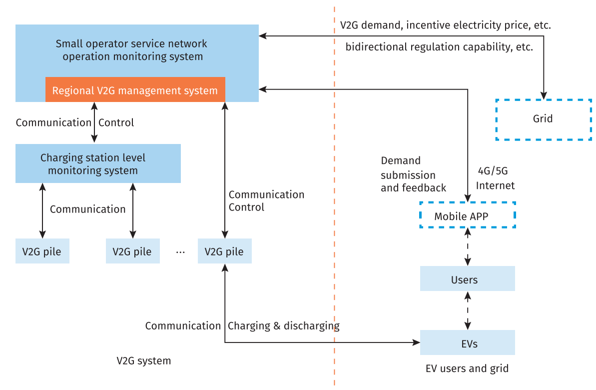
Figure 3-5　Typical V2G connection mode



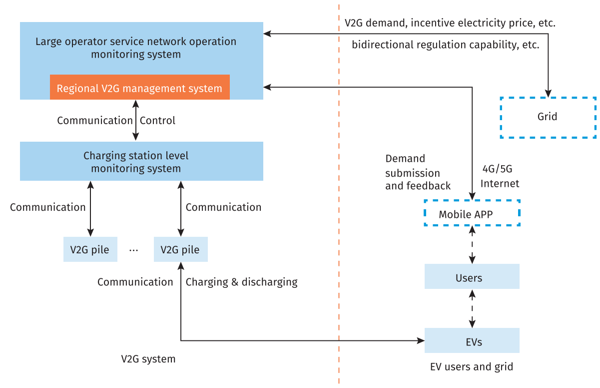
(a) The regional V2G management system directly connected to the V2G pile mode



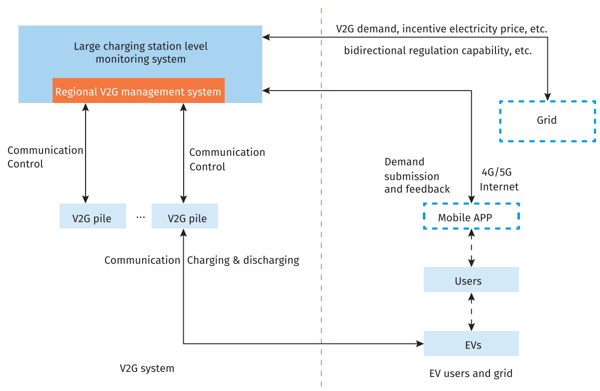
(b) The regional V2G management system is connected to the V2G pile mode through a concentrator or a protocol converter



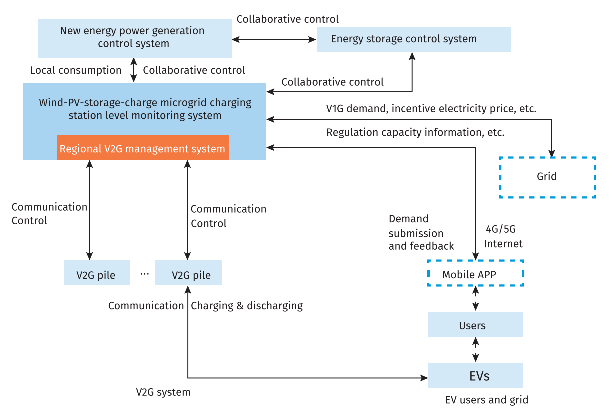
(c) Small operator V2G management system directly connected to V2G pile mode



(d) The V2G management system of large operators is connected to the V2G pile mode through the charging station-level monitoring system



(e) Large-scale charging station V2G management system is connected to V2G pile mode through charging station-level monitoring system



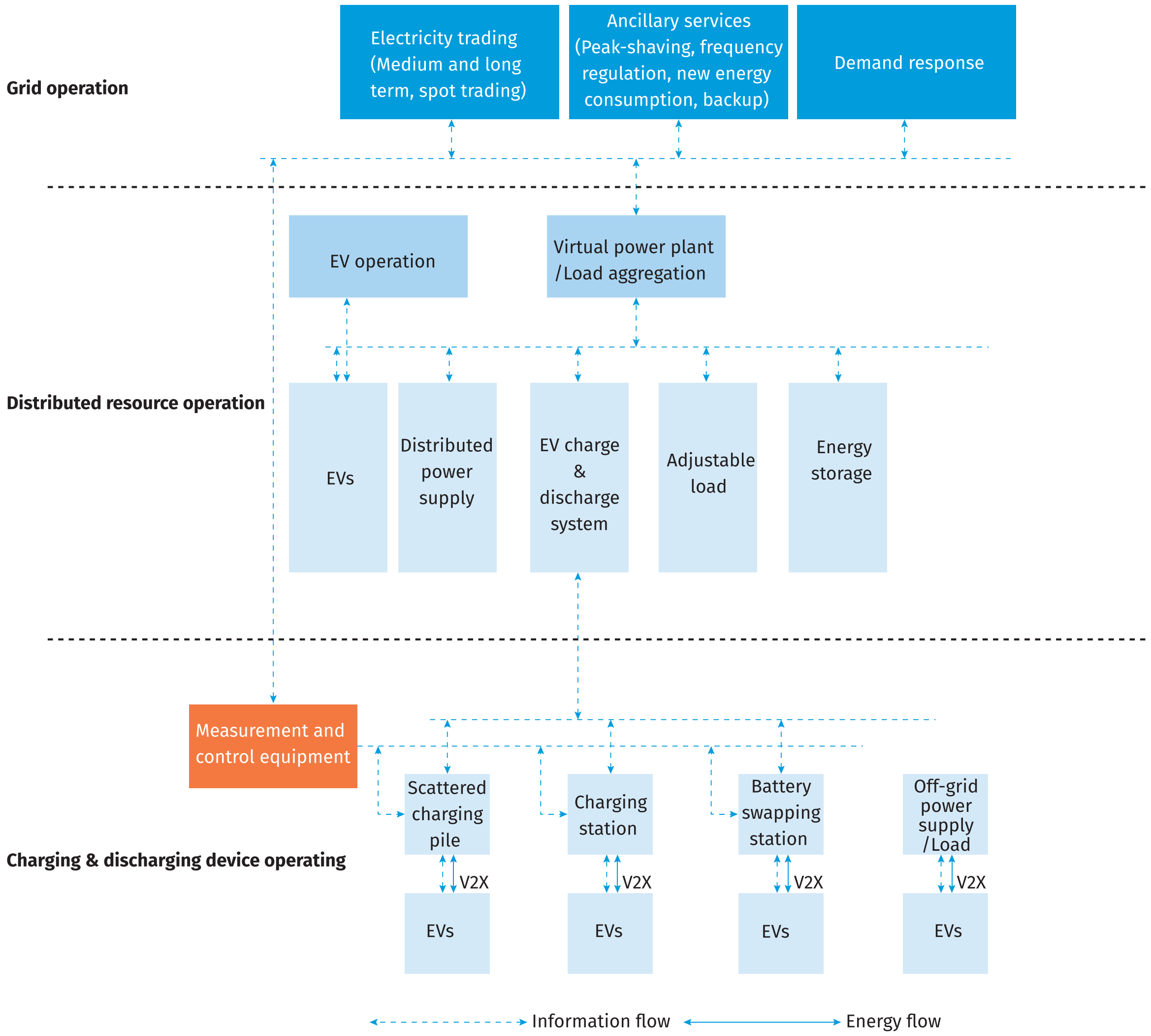
(f) Wind power–PV–ESS–EV charging microgrid system connected to V2G pile mode

Table 3-5 Application conditions and characteristics of different connection modes

Mode	Description	Connection mode	Application conditions	Mode characteristics
Mode 1	Regional V2G management system directly connected to V2G pile mode	Figure 3-5 (a)	Decentralized V2G piles	Centralized management of dispersed V2G piles.
Mode 2	The regional V2G management system is connected to the V2G pile mode through a concentrator or a protocol converter	Figure 3-5 (b)	V2G piles of different manufacturers and different communication protocols	Resource integration and centralized management of V2G piles of different manufacturers and different communication protocols.
Mode 3	Small operator V2G management system directly connected to V2G pile mode	Figure 3-5 (c)	Small operators with the capability of V1G management	The bidirectional interaction of charging and discharging at the regional or wide-area level can be realized according to the regulation requirements or local load management targets.
Mode 4	The V2G management system of large operators connected to the V2G pile mode through the charging station-level monitoring system	Figure 3-5 (d)	Large operators that manage multiple charging stations in multiple areas	The bidirectional interaction of charging and discharging at the regional or wide-area level can be realized according to the regulation requirements or local load management targets.
Mode 5	Large-scale charging station V2G management system connects the V2G pile mode through charging station-level monitoring system	Figure 3-5 (e)	Large charging stations	The bidirectional interaction of charging and discharging realized according to regulation requirements or local load management targets.
Mode 6	Wind power–PV–ESS–EV charging microgrid system connected to V2G pile mode	Figure 3-5 (f)	Wind power–PV–ESS–EV charging microgrid	It can be combined with the microgrid control system to realize the local consumption of renewable energy.

The overall V2G functional framework is shown in Figure 3-6. Based on the bidirectional interaction of information, the EV–grid bidirectional interaction can be realized, including three levels of power grid operation, distributed resource operation, and charging and discharging device operation.

Figure 3-6 V2G functional framework



The power grid operation layer is mainly responsible for carrying out businesses such as dispatching, auxiliary services, and demand response, engaging in power transactions, issuing on-grid commands, dispatching commands, and monitoring the operation status of the power grid. Grid-related business management should be performed on distributed resources such as EV charging and discharging facilities connected to the grid, and power and information support should be provided. The metering and billing data such as the electric power and quantity of electricity of the connection point of the charging and discharging facilities should be collected through the measurement and control equipment, and the load of the charging and discharging facilities at the connection point should be managed, and the emergency load shedding capability should be provided.

The distributed resource operation layer is mainly responsible for organizing the coordinated operation of power supply, energy storage, adjustable load, EVs, and other resources. Among them, EV charging and discharging operators are mainly responsible for managing their charging and discharging facilities and should monitor the operation status, billing settlement, and fault handling of charging and discharging facilities connected to their charging and discharging operation platform, to provide safe and efficient charging and discharging services for EV users. EV charging and discharging facilities can be connected to various distributed resource operator systems to engage in grid interaction. AC charging piles should have functions such as V1G and metering. The DC charger should have functions such as charging and discharging, bidirectional metering, and on-grid synchronization. During grid-connected operation, the charging and discharging service operator shall sign an on-grid dispatch agreement and/or a power generation and consumption contract with the power grid enterprise.

The charging and discharging device layer mainly includes the measurement and control equipment, charging and discharging devices, EVs, and the like. Among them, EV users can voluntarily engage in V2G collaboration according to their own needs. In the process of interacting with the power grid, EVs should be charged or discharged with a specified power in a specified time period according to the EV user's permission and the upper-level platform or related system information instructions to realize various EV charging and discharging interactive scenarios and interactive functions. EVs should have functions such as bidirectional charging and discharging, and on-grid and off-grid switching configurations. When the EVs are discharged on-grid, the EVs should be discharged externally through the charging and discharging device, and the EVs and their charging and discharging device should be connected to the power grid in the current source control mode. When EVs are discharged off-grid, EVs and their charging and discharging devices should not be connected to the grid for operation and should be operated in voltage source control mode.

3.3.2.2.2 System Functional Requirements

(1) Flexible load management sub-system of grid dispatching system

According to the basic load information, the charging demand of EVs and the bidirectional scheduling capacity uploaded by V2G management systems such as operators and combined with other flexible load resource information, the flexible load management sub-system of the grid dispatching system generates a flexible load control strategy based on the given regulation targets (including peak-shaving, frequency regulation, renewable energy consumption, backup, etc.), formulates flexible load scheduling plan, and distributes it to V2G management system and flexible load management system.

(2) V2G management system

V2G management system adds discharge management function based on the V1G management system, generates V1G and discharging control strategy according to grid regulation, electricity price, transformer load information, charging and discharging equipment operation and vehicle information. It can also optimize the start and stop time of V2G equipment and the output power of charging and discharging process.

(3) Bidirectional charging and discharging equipment (V2G pile)

The bidirectional charging and discharging equipment shall have the function of information interaction with EV and V2G management system, which can not only charge EV but also discharge the grid.

(4) EVs

EV should have the function of switching between charging and discharging, and also have the function of information interconnection with bidirectional charging and discharging equipment.

(5) Communication network

This part is similar to V1G management. Please refer to 3.3.1.2.2 (5).

(6) Human-computer interaction terminal

EV users can submit charging and discharging requirements to V2G management system through a human-computer interaction terminal (including but not limited to mobile APPs) to obtain charging and discharging feedback information.

3.3.2.2.3 Technical Specifications

(1) Response time of the flexible load management sub-system of power grid dispatching system

The response time of the flexible load management sub-system of the grid dispatching system shall meet the requirements in Table 3-6.

Table 3-6 Response time of the flexible load management sub-system

No.	Functional item	Response time
1	Data collection time	≤10s
2	Scheduling cycle of V1G and discharging plan	<5min
3	Real-time scheduling cycle of V1G and discharging plan	<1min
4	Regulation command issuance cycle	≤1min

(2) Response time of V2G management system

To guarantee users' convenience while ensuring the operation of V2G, the response time of the V2G management system should meet the requirements of Table 3-7.

Table 3-7 Response time of V2G management system

No.	Functional item	Response time
1	Response time of V1G and discharging request	≤ 10s
2	Load data collection time	<15s
3	Generation cycle of regulatory capacity data	<1min
4	Scheduling cycle of V1G and discharging plan	≤ 5min
5	Real-time scheduling cycle of V1G and discharging plan	≤ 1min

(3) Technical specifications of V2G management system

The technical specifications of the V2G management system should meet the requirements in Table 3-3.

(4) Technical specifications of V2G equipment

The response time of V2G equipment shall be ≤ 1s.

The output power adjustment accuracy of V2G equipment shall be ≤± 1%.

The output power adjustment range of V2G equipment should be within 20% to 100% of the rated output power.

The response time of EVs to the V2G regulation command shall be ≤ 5s.

3.3.2.2.4 V2G control strategy

(1) Configuration strategy of V2G management system

Feasible and effective control strategies take into consideration the time-space dynamic characteristics of EV, grid and conventional loads, as well as the time domain variation characteristics of charging loads of different models of EVs. Under the premise of meeting the charging demand of EVs as much as possible, constrained by the demand for safe charging and reliable operation, and to meet the regulation demand of the grid, they are formulated by the grid based on incentive information and power distribution network operation information. Thus, it is possible to achieve smart and efficient charging and discharging of EVs at the regional level or wide-area level.

1) System model

① EV model

Different EV models(identifications) are built according to existing EVs and battery types. And an expert base is formed accordingly. Different from V1G, this part also needs to consider whether the vehicle type supports a bidirectional electricity interaction function.

Basic parameters: battery capacity, whether the vehicle supports bidirectional energy interaction, charging and discharging power range (maximum charge power, maximum discharge power), SOC.

Charging and discharging power characteristic curve: according to different types of EVs and batteries, the charging and discharging power curve of EVs is formed.

Control parameters: whether the vehicle owner accepts bidirectional energy interaction; whether the EVs support the power control function, whether the EVs support the automatic power-off and recharging function.

Time domain model modification: with the increase in lifespan and charging and discharging times, the capacity parameters and power consumption characteristics of batteries will change. According to the acquired historical operation data, the controller adopts AI, big data analysis and other technical means to modify the model periodically (every six or three months) to improve the accuracy of the model and the control strategy calculation.

② Operator model

Parameters of charging stations: capacity parameters (rated capacity, capacity limit), the total number of charging piles, charging price information, discharging incentive information, and geographical location. State parameters: V2G pile state (number of fault states / number of normal state / maintenance state). Operating parameters: power (including energy flow direction), current (including energy flow direction), regulation ability.

Parameters of charging piles: capacity parameters (rated capacity, capacity limit), location, type of charging pile (traditional unidirectional disordered charging pile, V1G pile, V2G pile), access phase (phase A, phase B, phase C). Status parameters: fault state, normal state and maintenance state, of which the normal state is divided into charging state, discharging state, planned charging and discharging state and dormant state. Operating parameters: power, current, and regulation capability.

③ Electricity price incentive model

Price curve: according to the regulations on electricity prices, a 24-hour electricity price curve is formed.

Incentive model: according to the formulated incentive measures of the long cycle (such as day ahead, one day in advance) and short cycle (such as real-time, hour level), a charging and discharging incentive model is formed in V2G management system, which includes V1G price and discharging incentive, and has rolling correction function.

④ Grid model

The station areas of operators' points of interconnection are modeled. This part is similar to the grid model established in the V1G management system. Please refer to 3.3.1.2.3 (4).

2) Input and output of V2G management system

①Input parameter

Charging application information: receive vehicle charging application information (order information) from the user, including vehicle model (the system automatically matches the corresponding EV model, including capacity, charging power curve, control parameters and other information), SOC, charging mode (V1G, V1G and discharging, normal charging), and charging end time (end time / vehicle use time).

Load curve information: formulate the charging load optimization target curve at a fixed period (such as 30 minutes / 60 minutes, the period can be adjusted and set), or receive the charging load optimization target curve and other load prediction curves (including residential load, office load, etc.) issued by the superior platform, to provide basic data support for the formulation of charging and discharging strategies.

Incentive information: a bidirectional interactive incentive plan for a certain period of time is issued through fixed period, manual trigger or automatic trigger.

Station area status information: Operators acquire the operation information of the power distribution network periodically (every 30 seconds), and update the status information of the power distribution network model.

②Output strategy

Output to the operator service network operation monitoring system—vehicle charging and discharging plan: vehicle charging and discharging plan arrangement or adjustment information, including total charging, charging power, total discharging, total charging price estimation, discharge incentive income, etc. Charging exception information: if the vehicle fails to park and insert the gun at the planned starting time of charging, or the gun is pulled out during charging and discharging (not ending as planned), the corresponding exception information will be sent to V2G management system. Adjustment of vehicle charging and discharging plan: due to vehicle order adjustment, charging exception and other conditions, it is necessary to readjust some (or even all) vehicle charging and discharging plans (including charging and discharging time and power) to form an adjusted charging and discharging plan.

Output to the charging station monitoring system or bidirectional interaction pile—vehicle charging and discharging plan: vehicle charging and discharging plan arrangement or adjustment information, including total charging, charging power, total discharging, discharging power, charging price estimation, discharging incentive income, etc.

(2) Implementation of V2G control strategy

1) Optimization targets

Sorted by priorities, there are generally four goals: meet the charging demand, renewable energy consumption, electricity economy and general and local coordination.

2) Constraints

Electricity distribution transformer capacity: to meet the transformer capacity constraints.

Three-phase unbalance: to optimize the energy distribution strategy of EVs in the spatial dimension to meet the operation requirements of the three-phase equilibrium of transformer.

Charging and discharging power stability: to manage to reduce the number and frequency of power control of EVs being charged or discharged, and improve the charging service quality.

Battery life of EVs: in the whole charging and discharging cycle of EVs, the number of charging and discharging state switching should be reduced as much as possible to reduce the impact of bidirectional energy interaction on EV battery life.

3) Strategy calculation trigger method

In the case of four situations described in 3.3.1.2.4 (2), it is necessary to recalculate the charging and discharging strategy to ensure the real-time and rationality of the control strategy. This part is similar to the strategy calculation trigger method used in the V1G management system. Please refer to 3.3.1.2.4 (2).

4) Charging and discharging power adjustment solution

Taking stabilizing the fluctuation of the renewable energy output of the wind power–PV–ESS–EV charging microgrid as an example. The wind power–PV–ESS–EV charging microgrid collaborative control system guides the V2G in the microgrid according to the prediction information of the renewable energy output, the basic load information and the configuration information of ESS. On one hand, it realizes the local consumption of renewable energy, on the other hand, it considers the discharging demand of the grid. By adjusting the V2G power and the complementary operation mode of ESS, the response error of EVs to the discharging demand of the grid is reduced, and EVs play a role in flexible regulation of the gird.

3.3.2.2.5 Main application scenarios

(1) EVs engagement in grid operation interaction

1) Power trading

Distributed resource operators and charging and discharging service operators rely on the charging and discharging load resource capacity and demand of EVs. Grid operators jointly participate in cross-provincial and cross-regional medium and long-term power transactions and spot trading organized by power trading institutions at all levels according to the regional power and electricity quantity balance relationship and the consumption demand of renewable energy.

2) Ancillary services

According to their capabilities and needs, distributed resource operators and charging and discharging service operators work with grid operators to meet the regional grid stable operation needs and renewable energy consumption needs of grid operators, and to take charging and discharging load resources of EVs as grid frequency regulation, peak-shaving and backup resources. Thus, they engage in grid operation.

3) Demand response

Grid operators manage the transmission line load and transformer station area load according to the regional power balance relationship and the consumption demand of renewable energy, and guide the charging and discharging load resources of various EVs scattered in the grid to respond to the flexible regulation instructions of the grid through the demand response system at all levels.

(2) EVs engagement in distributed resource operation interaction

1) Virtual power plant

In the traditional physical structure of the grid, relying on the Internet and modern communication technology, EVs, distributed power sources, energy storage and other resources scattered in the grid are aggregated to realize coordinated and optimized operation. Through power trading institutions, power trading, ancillary services (peak-shaving, frequency modulation, backup, renewable energy consumption) and demand response are provided to realize multi-functional complementarity on the power side and flexible interaction on the load side.

2) Load aggregation

The charging and discharging loads of EVs with small monomer capacity and geographically dispersed ones are aggregated to form an EV group that can optimize collaborative control. It generates the interactive value potential of a large-scale vehicle-grid interaction, participates in power market transactions, provides auxiliary services and schedules resources for demand response.

(3) EVs engagement in microgrid and other interactions

1) Microgrid

The EVs, distributed power sources (wind power, PV) and energy storage form a microgrid. Through the interaction between charging and discharging of EVs and microgrids, the load is balanced locally, and renewable energy is consumed.

2) Wind power–PV–ESS–EV charging

The EVs, distributed power sources (wind power, PV) and energy storage form the wind power–PV–ESS–EV charging system. Through the interaction between charging and discharging of EVs and the power distribution network (or microgrid), the load is locally balanced and renewable energy is consumed.

3.3.2.3 Standards and specifications

The existing general requirements and standards on V1G facilities and systems in China are also applicable to V2G, such as the *Terminology of EV Charging and Battery Swapping Infrastructure, Power Quality Requirements for EV Charging and Battery Swapping infrastructure, Safety Requirements for EVs Power Battery, and Urban Public Facilities - Specification for Operation Management and Service for EV Charging and Battery swapping Infrastructure.*

Some existing relevant standards on conductive charging in China have not considered the bidirectional energy flow, such as *the Electric Energy Metering for EV AC Charging Pile", Electric Energy Metering for EV Off-board Charger, Communication Protocol between Off-board Conducive Charger and BMS of EV, Connection Set for EV Conductive Charging - Part 1: General Requirements, Connection Set for EV conductive Charging - Part 2: AC Charging Coupler, Connection Set for EV Conductive Charging - Part 3: DC Charging Coupler.* Relevant standards need to be modified to adapt to the V2G application.

Up to the date, there is one V2G related national standard in development, one sectoral standard in revision, and one sectoral standard in the approval stage in China.

Table 3-8 Standards related to V2G in China

Standard category	Application field	Standard	Standard number
National standards	Bidirectional interaction	Specifications for interaction between energy Internet and EV	To be developed
Sectoral standards	Conductive charging and discharging system and equipment	Specifications for EV off-board bidirectional charger	NB/T 33021 (in revision)
	Bidirectional interaction	EV charging and discharging bidirectional interaction Part 1: General Principle	To be approved

Among them, *the Specification for Interaction between Energy Internet and* EV is grounded in supporting the new power system based on renewable energy through EVs to achieve the maximum consumption of renewable energy. Through smart control, it achieves the balance of power and electricity in the grid, gives play to the supporting role of EVs on the energy Internet, and provides support for the efficient and local utilization of EV resources in the energy Internet and EV interactive system. The Specifications stipulates the relevant terms, basic provisions, overall framework, energy interaction, information interaction, business interaction and technical requirements of typical application scenarios of the interaction between energy Internet and EVs, which applies to the planning, design, construction and operation of the interaction system between energy Internet and EVs.

Based on improving the performance parameters such as charging and discharging efficiency and power factor, the revision of *the Specifications for EV Off-board Bidirectional Charger (NB/T 33021)* adds the charging and discharging conversion time, wind protection, anti-stealing protection, pre-charging, discharging response time and other clear definitions and specifications for the product requirements and inspection methods of off-board charging and discharging devices of EVs, so as to further strengthen the management of product standards, improve the level of product standards, and ensure product quality and safety. The specification stipulates the product requirements and inspection methods of charging and discharging devices of EVs, and it applies to charging and discharging devices of EVs that adopt conductive charging and discharging methods.

The draft of the EV Charging and Discharging Bidirectional Interaction Part 1: General Principle mainly stipulates the technical framework, main operation modes and relevant application scenarios of the EV charging and discharging bidirectional interaction system, which applies to the design, construction and operation of EVs charging and discharging bidirectional interaction system. The EVs carry out bidirectional interaction of charging and discharging with the grid or related loads, and bidirectional interaction of information with the superior platform or related systems, including three levels of grid operation, distributed resource operation, and charging and discharging device operation. Grid operators, power trading institutions, distributed resource operators, charging and discharging service operators, EV users, charging and discharging devices, EVs and other parties can respectively play their roles. The main operation modes can be divided into V2G, V2B, V2H, V2V and V2L, according to the differences in the bidirectional interaction range of charging and discharging of EVs and the on/off grid modes. The operation modes can be switched in accordance with the needs or application scenarios. Application scenarios include EV engaging in grid operation interaction, EV engaging in distributed resource operation interaction, and EV engaging in electricity distribution operation interaction.

Later on, it is also necessary to formulate standards for the operation management, testing, safety and other aspects of EV charging and discharging bidirectional interaction, and to standardize the technical parameters such as charging and discharging switching time, frequency, and climbing rate, etc.

3.3.3 PV–ESS–EV charging microgrid

3.3.3.1 Overview

With the rapid development of the EV industry, large-scale EV charging will threaten the safety of the grid, aggravate the peak-valley difference of the grid, and increase the marginal cost of power generation. If the electricity used by EVs comes from fossil energy, from the perspective of the whole lifecycle, EVs cannot give full play to their green and low-carbon characteristics. Therefore, while promoting the application of EVs on a large scale, it is necessary to build more flexible distributed power sources to power EVs.

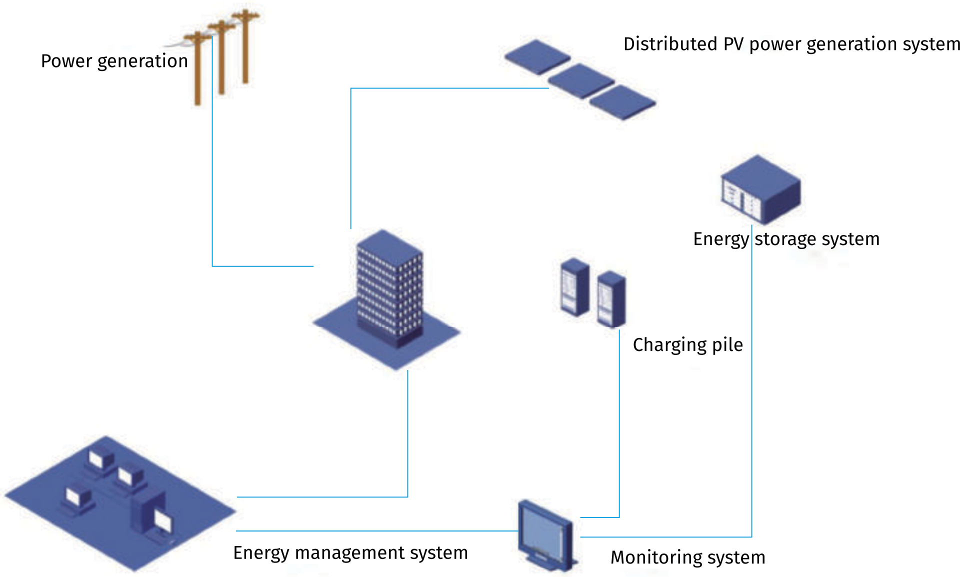
Distributed power generation based on RE can provide clean power according to local conditions, and at the same time, it can reduce electricity loss and delay the renewal of power grid lines. Thus, it has become an important part of the power supply system. The microgrid, as an effective and centralized management method of distributed power, is widely used. The PV–ESS–EV charging microgrid composed of solar distributed PV power generation, ESS and EV charging system can make full use of the solar energy as both RE and flexible load of EVs. On the one hand, it improves the utilization proportion of RE and ensures the greening and decarbonization of EVs throughout their lifecycle. On the other hand, it improves the power supply flexibility and stability of microgrid, and realizes ancillary service functions such as peak-shaving and valley-filling. The microgrid can manage various kinds of distributed power uniformly, which can not only be incorporated into the large electric system for ancillary operation but also be used as an independent system to supply power. Thus, it ensures the reliability of local load work and reduces the adverse impact on the large power grid. This section focuses on the technical requirements of the PV–ESS–EV charging microgrid system.

3.3.3.2 Technical Requirements

3.3.3.2.1 Technical framework

The PV–ESS–EV charging microgrid system is composed of a solar distributed PV power generation system, ESS and charging system, and it also includes other power load systems in general. It can be divided into on-grid microgrids and independent microgrids.

Figure 3-7 Technical framework of a PV-ESS-EV charging microgrid



(1) PV power generation system

The PV power generation system of the microgrid converts solar radiation energy into electricity through PV modules. It is mainly composed of solar PV panels, inverters and other equipment, which are generally installed in car sheds, roofs and other places. The array mode of PV module in the PV power generation system usually adopts the forms of a single axis, fixed, and double axis tracking. The installation angle of each array mode can be adjusted and determined according to different environmental conditions and system requirements. The inverter model in the system is mainly analyzed and confirmed from the aspects of performance, efficiency, data acquisition, protection function and so on. Common inverters include string inverters, distributed inverters and centralized inverters. The PV output gives priority to meeting the load in the microgrid, and the surplus output supplies power to ESS.

(2) ESS

ESS can effectively smooth the fluctuation of PV power generation, meet the demand of load capacity, and extend the battery life. ESS mainly includes the battery, battery management module, power conversion system (PCS) and other equipment. The types of energy storage batteries mainly include lead-acid batteries, lithium batteries, vanadium flow batteries, etc. Some microgrid demonstration projects recycle the retired EV power battery as an energy storage battery in downcycling. It can be combined with the flexible charging technology of downcycled battery to control the charging and discharging time of the downcycled battery at the optimal time control point. Thus, it improves the stability and charging and discharging efficiency of the retired battery. When the PV output of ESS is surplus, the residual output will be absorbed. When the PV output is insufficient to meet the load output, the discharge will make up the output. In addition to absorbing the surplus PV power, ESS also purchases electricity from the grid at night when the electricity price is low, and stores it. It then discharges it at the peak electricity price during the day to reduce the power cost of ESS.

(3) EV charging system

The EV charging system mainly includes DC/DC charging corresponding modules, power distribution controller, charging unit, charging energy controller and protective appliances. The charging system of EVs can adopt three modes: DC charging, AC charging and battery swapping.

1) DC charging uses the electricity of the DC bus as the power supply and charges through the charging connection device. It provides maximum power charging (120KW-240KW), with a fast-charging speed and shorter time requirements.

2) AC charging adopts a three-phase AC for charging. The general power ranges between 7-25KW. Generally, recharging from no power to full power takes 8-10h. AC charging has negligible impact on the service life of the power battery and the grid, but the charging time is long and therefore it needs to occupy a fixed parking space for a long time period.

3) In the battery swapping mode, the battery can be replaced through automatic or semi-automatic mechanical equipment, and the replacement time generally takes 2-10 minutes. At the same time, in the battery swapping mode, the battery pack can be used as a rechargeable energy storage battery to power the microgrid system.

(4) Energy management system

The energy management system is the core control unit of the PV–ESS–EV charging microgrid, which realizes the optimal operation mode through smart scheduling, including power monitoring, source network head back equipment, communication interface, calculation and control module and other equipment. The system is mainly responsible for data acquisition, display and storage of PV, energy storage, charging pile and incoming meter equipment. It coordinates and controls the energy according to the requirements of the PV–ESS–EV charging system to improve the reliability and economy of the system. Functions of the system mainly include generation prediction, distributed power management, load management, generation and consumption plan, voltage and reactive power management, statistical analysis and evaluation, and WEB functions.

(5) Microgrid operation mode

The energy management system implements corresponding strategies according to the operation state of the microgrid, on-grid or off-grid, to ensure the stable operation of the system in both states. At the same time, the energy management controller effectively coordinates and configures the point of interconnection of the microgrid to realize a smooth switching of on-grid/off-grid and off-grid/on-grid operation modes of the microgrid grid, which mainly includes four modes:

1) In case of sufficient sunlight, when there is excess electricity after the PV output fully meets the needs of the charging station if ESS is fully charged, it feed energy back to the grid; If ESS is not fully charged, it preferentially charges ESS through the bidirectional converter until it is fully charged, and then feeds the excess electricity to the grid.

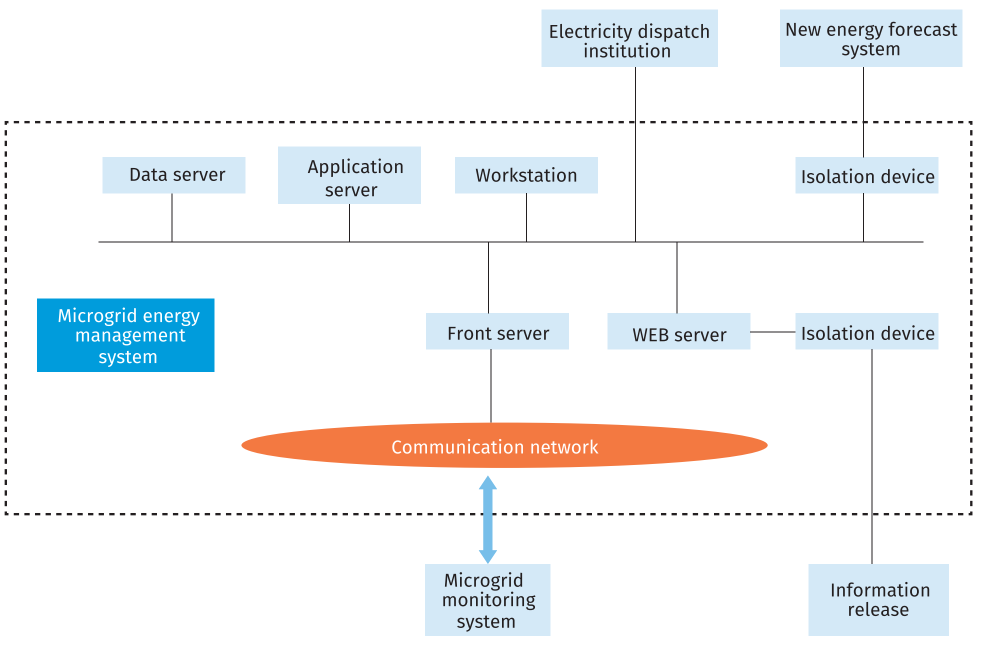
2) In case of insufficient sunlight, if the PV output cannot meet the demand of the charging station, the grid will supplement electricity to the charging station. If the ESS is not fully charged at that time, the grid can also supplement electricity to the ESS through the bidirectional converter until it is fully charged.

3) On rainy days or at night, the PV system cannot provide electricity. The grid provides electricity to the charging equipment and lighting loads. If the ESS is at a low level, the grid can charge the ESS until it is fully charged.

4) In case of power down or anomaly of the grid, it switches from on-grid to off-grid state. The electricity provided by the storage system through the bidirectional converter is used as the AC bus. The PV power generation gives priority to providing electricity to the charging station and excess electricity is fed to the storage system until it is full, and then it will be fed to the grid.

The PV–ESS–EV charging microgrid energy management system can also collect all kinds of user information and perform data information sharing, exchange, transmission and other functions based on Internet cloud storage, cloud computing and cloud service technologies as needed to meet the

Figure 3-8 Energy management system for microgrid



requirements of user center database. At the same time, the system can also work in cooperation with satellite weather stations and other equipment to monitor the sunlight intensity, wind speed, wind direction, temperature and other parameters in real-time and thus it optimizes the efficiency of the PV–ESS–EV charging microgrid system.

(6) Microgrid monitoring system

The microgrid monitoring system includes a series of automation equipment, such as a computer monitoring system, communication network, distributed power controller, load controller, microgrid central controller, interconnection interface device, and measurement and control protection device. The microgrid monitoring system shall be able to exchange data with the microgrid energy management system, upload the microgrid equipment operation data to the energy management system, and accept the control instructions issued by the energy management system. Functions of the system include data acquisition and processing, database management, man-machine interface, report processing, anti-malfunction locking system, clock timing, equipment disconnection control, authority management, microgrid operation mode control, sequence control, power control and communication, establishing a battery monitoring status analysis system, combining with the component battery health status analysis algorithm, implementing dynamic monitoring, analysis and management, and maintaining microgrid operation. Monitor the thermal runaway of the battery to strengthen the safety of energy storage.

3.3.3.2.2 Application Scenario

he main application scenarios of PV–ESS–EV charging microgrid include rural areas, clusters (mainly industrial parks, campuses, commercial parks) and public facilities.

(1) Rural areas

Due to their construction conditions, rural areas are rarely limited by space, therefore the utilization potential of RE resources such as PV is huge.

Scenarios:

Rural revitalization and rural urbanization provide opportunities for rural development of PV power generation systems, but at the same time, there are still geographical differences and economic imbalances in rural areas. Rural areas can be roughly divided into three categories: developed rural areas, rural areas with small and scattered villages, and underdeveloped areas lacking electricity or without electricity. In different types of rural areas, the construction of wind power–PV–ESS microgrids has different modes.

The typical characteristics of the daily driving of EVs in rural areas are that the driving range is relatively shorter than that of urban vehicles, and the daily power consumption is also lower than that of EVs running in urban areas or on the highway. The use of AC small power to supplement electricity at night can ensure daily use in most cases, and the AC charging facilities costs and construction costs are lower, which is more suitable for rural areas. In developed rural areas, the urbanization construction facilities are relatively sound with extensive human activities and businesses. The conditions for vehicles are almost equivalent to those in the suburbs of the city. It is recommended to refer to the distribution law of urban EVs in the suburbs and outer suburbs.

Construction mode:

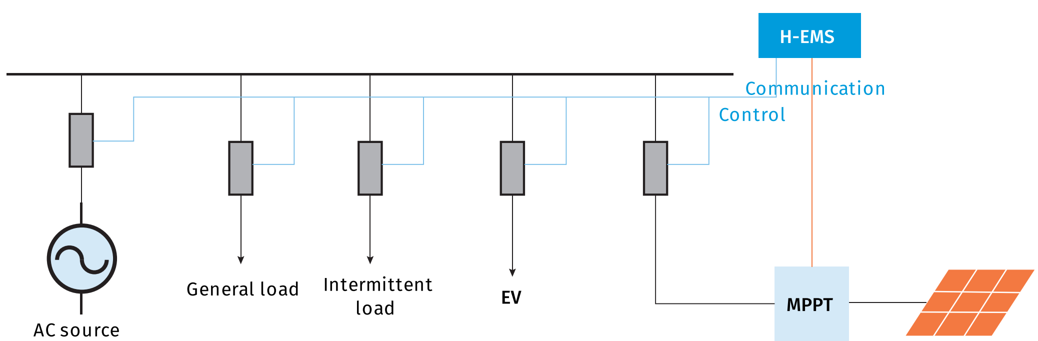
Developed rural areas have similar residential construction and living electrification level to that in cities, and similar industrial power consumption and domestic power consumption to that in cities, but with smaller scale, and it shows a strong need for distributed microgrid, as the intensity cannot reach city levels. The wind power–PV–ESS microgrid system can refer to the urban model and be built in conjunction with the industry, making full use of the roof of buildings or available land.

In rural areas with small and scattered villages, buildings are sparsely located. There is more land available, but the available consumption load is insufficient. Therefore, small-scale centralized PV and microgrid systems, household roof PV and microgrid systems, and multiple station areas interconnected microgrid systems can be built according to local conditions.

Small-scale centralized PV and microgrid systems are commonly used in combining PV and rural industries, such as PV greenhouses, PV fishponds and other modes. PV power generation is compatible with load power consumption, or a small amount of energy storage can be fitted to achieve self-generated and self-consumed, and complete consumption.

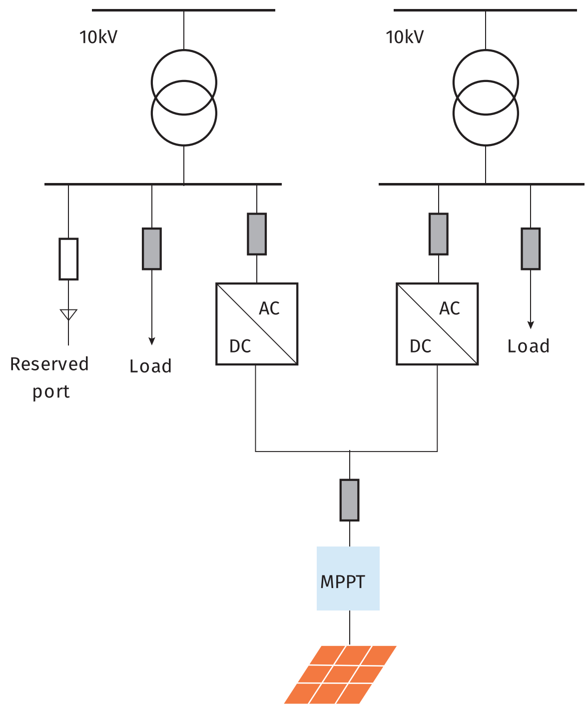
Household roof PV and microgrid systems are built on household roofs and use residential electricity as the basis to consume loads. With the gradual popularization of EVs in rural areas, EVs and two-wheeled EVs can work closely with PV power generation to form household PV–ESS–EV charging systems, Home-EMS regulated power generation, energy storage, charging and other available regulatory resources.

Figure 3-9 Interaction between household PV and EV



The interconnected multiple-station microgrid system forms an interconnected DC bus at the end of the scattered rural public transformer station area through the voltage-sourced converter based high voltage DC devices (VSC-HVDC). The DC bus side can be connected to the distributed PV power generation system and a small amount of battery energy storage and other microgrid components. This new construction method realizes the consumption of PV among loads of different stations, improves the consumption rate, and realizes the support of voltage drops that are common in rural areas, as well as improves the stability of terminal voltage, reduces line loss and improves electricity quality.

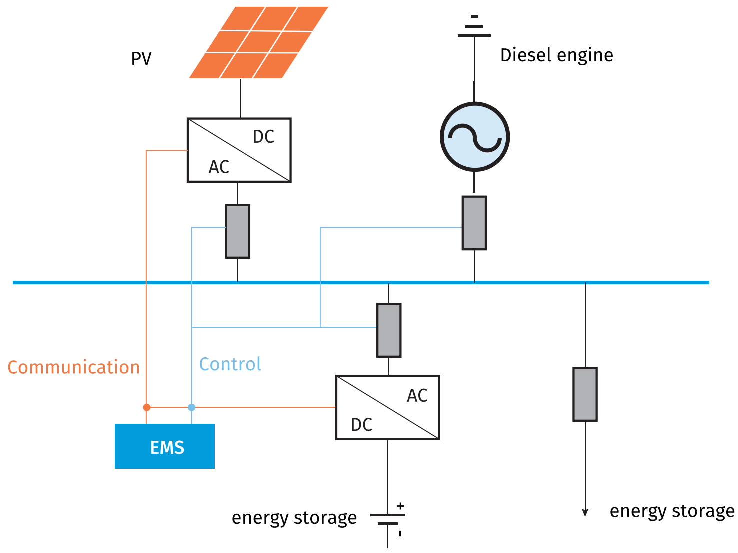
Figure 3-10 VSC-HVDC interconnected microgrid



In less developed rural areas with little or no electricity, or in remote and mountainous areas, or isolated islands, homes are more sparsely populated, and therefore the cost of power construction is high, with small electrical load and low power equipment utilization rate. The off-grid PV–wind power microgrid system can be used to supply power. When conditions permit, it can be combined with diesel standby generator sets to ensure an uninterrupted or emergency power supply. The combined system comprehensively controls the diesel generator and ESS through the microgrid control unit. While ensuring the power consumption, it makes the diesel engine work in the high-efficiency power range as much as possible, which can greatly reduce the consumption of diesel and improve the comprehensive efficiency of diesel power generation in the hybrid system.

Service object: it is mainly used to charge electric bicycles and EVs, and to supply electricity for farmers' daily life. It is built based on the conditions of farmers' self-own buildings and is used to meet their demands.

Figure 3-11 PV–ESS–diesel microgrid system



In term of infrastructure construction, as EV is entering the rural market, the charging mode should consider the power supply and power demand of different villages, and construct reasonable infrastructure in combination with the PV system, which shall not only be conducive to expanding the utilization of RE resources but also improving the power supply conditions in rural areas. In more developed rural areas, the application of PV–ESS–DC–flexibility technology and agriculture-PV complementation technology can be considered. In areas with poor power supply facilities, priority should be given to solving the problem of domestic electricity consumption. In rural areas where EVs are popular, the independent microgrid mode of EVs + PV can charge EVs during PV power generation, and the energy storage battery of EVs can be used as the domestic power supply for certain periods.

Table 3-9 Application mode

Application mode		Applicable scenario	Applicable conditions	Features and merits	Technical configuration and indicator
Mode 1	AC slow charging + PV	Household	Household PV + household charging	Using the roof area of the residence, vehicle-PV interaction consumption	10 ~ 20KW PV power generation system, 7KW AC charging pile
Mode 2	DC + AC slow charging + PV + energy storage	small PV-charging system	Small and centralized places	Make full use of spare areas	< 500kW PV power generation, equipped with a small number of DC charging piles and multiple AC charging piles, can be properly equipped with energy storage

(Continued)

Application mode		Applicable scenario	Applicable conditions	Features and merits	Technical configuration and indicator
Mode 4	DC + PV + energy storage + multi-station-area networking	Microgrid between decentralized station areas	Multiple decentralized stations deployment	PV multi-stations consumption, terminal voltage support and load balance between stations	< 1000kW PV power generation, equipped with VSC-HVDC devices with 30% capacity, and be equipped with energy storage

(2) Clusters

Construction scale: with a large-scale centralized PV power generation system and ESS, the charging demand in the clusters is relatively concentrated and the clusters are usually equipped with energy management systems to coordinate power with the large electric system inside.

Service object: it mainly provides charging for EVs and supplies power for office buildings in the cluster. It is usually built, operated and maintained by professional energy management companies. It mainly serves employees/students in the cluster.

Microgrid mode: employees' EVs are usually charged in the cluster during working hours, which coincides with the peak power consumption during the working hours in the cluster. When the charging demand of the cluster is concentrated or greater than the distribution capacity, the microgrid can work together with the mains electricity and it can store energy at night when the electricity price is low. Through the realization of peak-shaving and valley-filling of the power distribution network, saving the cost of electricity distribution capacity increase, increasing the consumption of renewable energy, and making up for the lack of continuity of solar power generation, a sustainable energy utilization mode is achieved.

The microgrid in the cluster can adopt a DC microgrid to enhance the regulation ability of renewable energy power generation, distributed energy, EVs and other energy utilization methods.

Combined with the construction conditions of the cluster, the PV–ESS–EV charging system can adopt a smart PV–ESS–DC–flexibility control system with high energy efficiency, and integrate the charging and discharging requirements of EVs to improve the comprehensive utilization rate of electricity of the PV system, which can further reduce the power consumption cost by using the peak-valley prices strategy of the grid.

(3) Public facilities

Construction scale: centralized public charging station and the scale of the PV-ESS system is determined according to the scale of the charging station.

Service object: private vehicles

Microgrid mode: It builds a public charging station according to the requirements of the integrated PV–ESS–EV charging power station, equipped with a small PV power generation and ESS to provide supplementary power for the charging station. At the same time, the station can also be equipped with battery inspection services and battery replacement services for EVs. According to the actual situation, the energy management system analyzes the PV power generation and the charging demand of EVs to alleviate the pressure on the power distribution network. When the load of the charging station peaks, it releases electricity to supply power to EVs and stores the PV output margin, so that the output grid power reaches the peak value, and the overall power supply performance improves. ESS improves the PV power generation characteristics, reduces the load fluctuation of the power distribution network during the EVs charging process, and achieves the effect of stabilizing voltage and improving phase angle and filtering. The charging system provides basic conditions for charging EVs. With the help of the charge connector, it provides charging services for EVs and realizes stable and fast charging. The integrated PV–ESS–EV charging station can also perform fast battery inspection while they are charged in the station, providing vehicle owners with inspection reports and risk warnings to ensure the safety and reliability of the battery and to extend its service life.

3.3.3.3 Standards and specifications

Up to the date, China has issued or is formulating a number of standards related to PV–ESS-EV charging microgrid, which can be used as a supplement to this technical guideline.

Table 3-10 Standards related to PV-ESS-EV charging microgrid

Standard category	Application field	Standard	Standard number
National standards	PV power generation	Technical requirements for grid connection of PV system	GB/T 19939-2005
		Security specifications and its evaluation for generating unit interconnection	GB/T 28566-2012
		Code for design of photovoltaic power station	GB 50797-2012
		Technical requirements and test methods for grid-connected PV inverters	GB/T 30427-2013
		Technical specifications for utility interface of residential distributed photovoltaic power system	GB/T 33342-2016
		Specifications for operation and control for photovoltaic power station	GB/T 33599-2017
		Technical requirements for photovoltaic gird-connected inverter	GB/T 37408-2019

(Continued)

Standard category	Application field	Standard	Standard number
National standards	PV power generation	Testing specifications for photovoltaic grid-connected inverter	GB/T 37409-2019
		Code of start-up acceptance for photovoltaic power station	GB/T 37658-2019
		Outdoor empirical test requirements for distributed PV in warm damp climate-Part 3: Grid-connection PV system	GB/T 37663.3-2019
		General technical requirements for electrochemical ESS in power system	GB/T 36558-2018
	Distributed resources connected to the grid	Specifications for operation and controlling for distributed resources connected to power grid	GB/T 33592-2017
		Technical requirements for grid connection of distributed resources	GB/T 33593-2017
		Technical specifications for grid connection protection of distributed resources	GB/T 33982-2017
	Microgrid	Technical specifications for monitoring and control system of microgrids	GB/T 36270-2018
		Technical specifications for energy management system of microgrids	GB/T 36274-2018
		Operation and control specification for microgrids connected to distribution network	GB/T 34930-2017
		Specification for test of microgrid connected to distribution network	GB/T 34129-2017
		Technical requirements for connecting microgrid to power system	GB/T 33589-2017
Sectoral standards	Power generation	Technical specifications for solar energy resources assessment of solar power projects	NB/T 10353-2019
	Vehicle-grid interaction	Technical guideline for synergistic dispatch of EVs charging with intermittent power integrated	NB/T 33029-2018
		General requirements for integrated charging station based on DC bus	To be developed
Consortium standards	Vehicle-grid interaction	Technical specifications for DC bus charging device of EV	To be developed

Among them, *the General Requirements for Integrated Charging Station Based on DC Bus is* based on promoting the economic construction and efficient operation of PV–ESS–EV charging system, which is convenient for adding DC photovoltaics, energy storage and other DC power supply grids (power supplies) to the DC bus to provide energy input. The specification stipulates the general requirements for the composition of the PV–ESS–EV charging integrated system based on DC bus, AC/DC rectification system, DC/DC charging system, DC/DC photovoltaic system, DC/DC ESS, monitoring and communication system. It applies to the design, manufacture and inspection of the PV–ESS–EV charging integrated system based on the DC bus.

Through connecting PV and energy storage via DC bus and reducing the loss of PV–ESS–EV charging system, *the Technical Specifications for DC Bus Charging Device of EV* aims at promoting the charging facilities to better coordinate with PV and energy storage, forming an efficient collaborative PV–ESS–EV charging integrated system, and helping to achieve the carbon peaking and carbon neutrality goals. The specification stipulates the technical requirements of DC bus charging devices for EVs, including the basic composition, classification, functional requirements, technical requirements, inspection rules, trial methods, marks, packaging, transportation, storage and transportation of DC bus charging devices. It applies to DC bus charging devices with a maximum rated voltage of AC 1,000V or DC 1,500V, a maximum rated output voltage of DC 1,500V and applying conductive charging mode.

3.3.4 ESS and downcycling utilization of retired power battery

3.3.4.1 ESS

3.3.4.1.1 Overview

All EVs, energy storage and RE can be used as schedulable resources to participate in the balance control of power supply and demand. On the one hand, various adjustable resources can participate in the consumption of RE and stabilize the fluctuation of RE. On the other hand, RE and energy storage can jointly supply power to EVs.

According to its function time, energy storage can be divided into below-minute level, minute-to-hour level and above-hour level. Electrochemical energy storage belongs to the minute-to-hour level, which has the characteristics of fast charging and discharging conversion frequency and considerable energy.

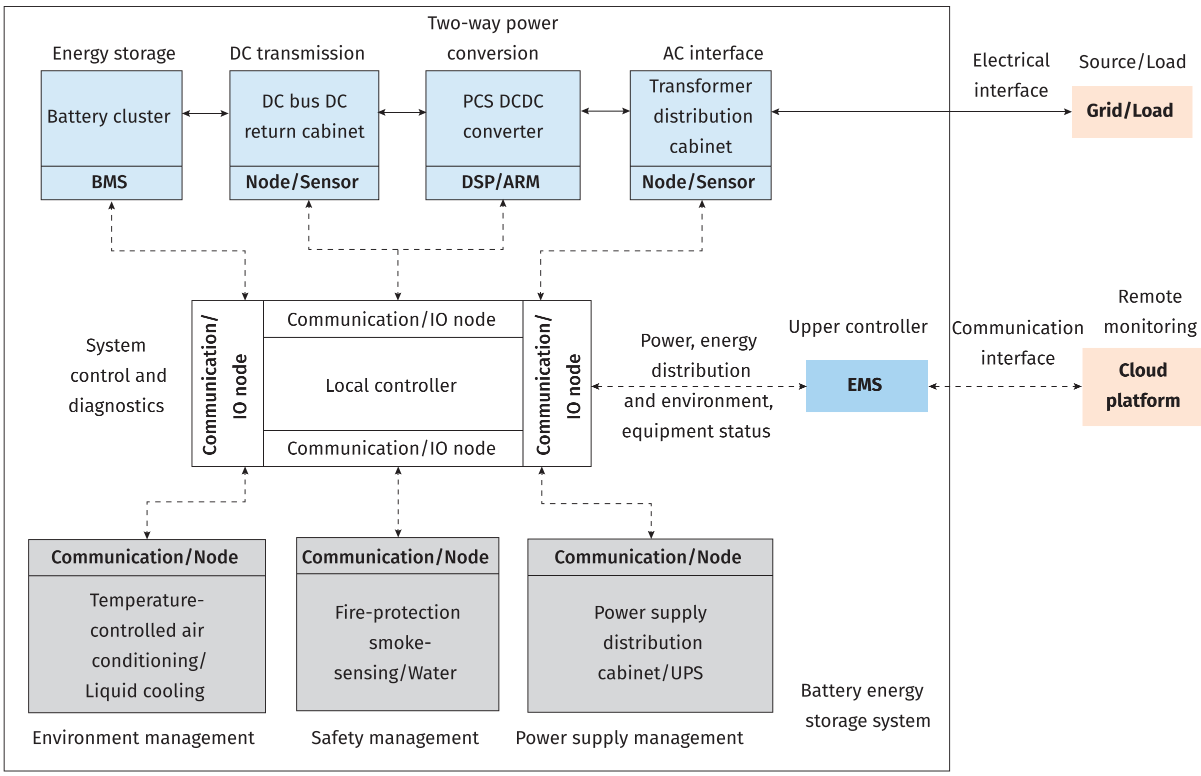
Electrochemical energy storage develops extremely fast in recent years. It is generally believed that the cost of investment in electrochemical energy storage is less than USD 250 /kWh, and yet it has an energy storage life of 15 years (more than 4,000 cycles) and an energy storage efficiency of more than 80%. Thus, it has a large-scale application prospect. Configuring energy storage in EV charging stations and PV–ESS–EV charging microgrids is an effective means to stabilize load fluctuations and alleviate the pressure on the grid. Generally, the configuration will be based on the following two ways: (1) according to the power of the charging station and the charging and discharging efficiency of ESS, and concerning empirical parameters, a certain margin will be fitted; (2) according to the peak-valley prices, the energy storage capacity is allocated with the economic operation of the charging station as the main goal.

The establishment of energy storage technology standard system is an important part of the energy storage sector. The formulation and revision of energy storage standards have received widespread attention at home and abroad. International Electrotechnical Commission (IEC) and other international standard setting organizations have been working on the preparation of energy storage standards since a long time ago. The National Institute of Standards and Technology (NIST) has listed electricity storage as one of the priority areas for the formulation of smart grid standards; The National Energy Administration of China issued *the Implementation Plan on Strengthening the Standardization of Energy Storage Technology,* stipulating that during the 13th five-year plan period (2016-2020), China would initially establish an energy storage technology standard system and form a number of key technical specifications and standards, and during the 14th five-year plan period (2021-2025), a more scientific and refined energy storage technology standard system should be formed.

3.3.4.1.2 Technical framework

ESS mainly includes batteries (energy storage), power conversion system (PCS or DC/DC and other power converters), local controllers, power distribution units, prefabricated cabins and other ancillary equipment such as temperature and fire protection. Under the unified management of local controllers, it remains independent or receives the instructions of the energy management system (EMS) to complete energy scheduling and power control. It connects with the cloud platform for remote monitoring, thus realizes a safe and efficient operation.

Figure 3-12 Technical framework of ESS



3.3.4.1.3 Capacity allocation calculation

To ensure the safe, stable and economic operation of the grid, various constraints, such as the limited capacity of the charging station, different user characteristics, and the energy storage battery of the charging station, should be fully considered in the allocation of energy storage capacity. For example, private vehicles usually stay parked for a longer time. If they are slowly charged in residential parking lots at night, the charging will add to the power load in the evening peak. If they are slowly charged in office building parking lots during the day, the charging will add to the load in the morning peak. Therefore, large capacity is needed in community charging stations. When the capacity of the grid is limited, the capacity of energy storage can be allocated according to the characteristics of users. To adjust the peak valley difference, stabilize the load fluctuation and reduce the impact on the grid, a few steps shall be taken, such as classifying different EV types, combining user demand and load prediction curve, and allocating power for charging before actual charging. When the grid is in normal operation, the energy storage capacity can be distributed according to the economic efficiency, aiming at reaching the lowest cost of charging and discharging for energy storage power stations.

When considering the power supply capacity of RE (taking wind power as an example), the constant power charging and discharging mode is generally adopted. The energy storage device needs to release the same inertia as the equivalent synchronous generator within the time of V_t:

$$E_B=E_{K\max}=P_B\times V_t=0.0392P_NT_J$$

Where P_B is the energy storage capacity, E_B is the equivalent kinetic energy stored by the energy storage device at rated power, and T_J is the time of inertia participating in the frequency modulation control.

Since the time for the power system to participate in frequency control by inertia is about 10s, here it is assumed that $V_t=T_j$, then:

$$P_B=0.0392P_N=0.0392(P_W+P_B)$$

$$P_B=0.0408P_W$$

Where P_W is the rated power of the wind farm.

The state of charge (SOC) of the energy storage battery has an important impact on user behavior decisions. A more accurate estimation of the state of charge will help to improve the operation performance of energy storage stations. Commonly used SOC estimation methods include ampere-hour integral method, data-driven method, neural network method and estimation method of fusion of various methods. Although the integral method is the most commonly used SOC estimation method, it can not estimate the initial SOC of the battery system. And the measurement of the available capacity change and coulomb efficiency of the energy storage battery system is not accurate enough. At the same time, there will be cumulative errors, so new SOC estimation methods are often used.

It stores energy through RE power generation such as wind and PV or stores energy and electricity off-peak at night. It releases electricity when the EV is charged. At the same time, according to the charging demand, two different operation modes, on-grid and off-grid can be realized, and the power supply reliability of the charging service center can be improved.

3.3.4.1.4 Application scenarios

(1) PV and wind power ESS in rural area

Due to the randomness and intermittency of the output of wind power and PV power generation, the power quality is worse than that of traditional energy. Due to the fluctuation of RE power generation (frequency fluctuation, output fluctuation, etc.) from seconds to hours, there are power-type applications and energy-type applications. Generally speaking, there are three types of applications: RE power time shift, RE power generation capacity solidification and RE output smoothing. The problem of curtailment in PV power generation requires the storage of the remaining electricity generated during the day for discharge at night, which belongs to the RE energy time shift. As for wind power, due to the unpredictability of wind power, the output of wind power fluctuates greatly, which needs to be smoothed. Therefore, it mainly uses power-type energy storage.

At present, local governments require that in principle, the energy storage capacity should not be less than 10% of the installed capacity of renewable energy projects, and the duration should last more than 2 hours.

(2) PV powered V2X systems (PV+V2X)

PV+V2X systems, such as PV–ESS–EV charging system, PV–ESS–EV charging and fast-charge system along the expressway, V2H and V2B PV systems of energy-saving park buildings, is a major application scenario. PV power generation systems providing electricity, ESS and EVs (both power users and distributed ESS) serve as energy storage media, and EVs, buildings and parks perform as terminals, thus forming a small microgrid. PV power generator generates electricity, which is stored in the ESS. When power is needed, the energy storage battery supplies electricity to the terminal.

According to demands, PV+V2X integrated microgrid is able to run on two different operation modes: on-grid and off-grid. Connecting PV+V2X integrated microgrid to the grid, in addition to receiving the energy from PV panels, the energy storage battery is also charged when the electricity price is low, and discharged to supply the terminal when the price is high. Thus, it reduces the cost of electricity while shaving the peak and filling the valley. It also makes up for the discontinuity of solar power generation. When the grid is powered off, the PV+V2X system goes to off-grid operation mode to provide emergency power to renewable energy vehicles and buildings.

3.3.4.1.5 User-side ESS

In order to save the cost of electricity, the energy storage power station can be charged during electricity consumption valley at night, and the electricity can be discharged during electricity consumption peak in the daytime. The National Development and Reform Commission (NDRC, China) issued the *Notice on Further Improving the Time-of-use Electricity Price Mechanism*, which requires that where the peak-valley difference ratio of the system exceeds 40%, the peak-valley prices difference shall not be less than 4:1 in principle, and not less than 3:1 in other places, and the price increase rate shall not be lower than 20% in principle on the basis of the peak electricity price. The widening of peak-valley price difference lays a foundation for the large-scale development of user-side energy storage. At present, when the general peak-valley electricity price difference reaches CNY 0.7, its investment value can be considered.

(1) Reduce the cost of electricity, and rely on energy management to accurately identify peak loads as well as send dispatch to the battery. ESS can release power to offset the impact of peak loads and reduce the cost of electricity through the peak-valley price difference.

(2) Dynamic capacity expansion is necessary for owners or construction companies on special occasions. For example, the transformer capacity can overload when the charging pile is renovated and runs at full capacity. An electrified kitchen runs at peak dining hours between 7:00 and 9:00 p.m. can also cause transformer capacity overload. In the face of overcapacity, the traditional approach is to apply for static capacity expansion to the power company. Static capacity expansion refers to applying to the power company for a larger transformer, but this method is quite expensive. For example, the expansion fee is CNY 5,000-10,000/kW, and the expansion of 100kW requires a cost of CNY 500,000. Another approach is dynamic capacity expansion, which can save higher costs by adding ESS to achieve capacity expansion.

(3) Demand-side response refers to the market participation behavior of guiding and encouraging power users to change their original power consumption patterns, through market price signals such as time-of-use electricity price or incentive mechanisms such as financial subsidies, to promote the balance of power supply and demand and to ensure the stable operation of the power grid. At present, Jiangsu, Shanghai, Henan, Shandong, Northern Hebei, and other places nationwide have launched the electricity demand response market. With the target of peaking carbon dioxide emissions, at the present phase, the subsidy is the product of the effective response quantity of electricity, the unit subsidy and the response coefficient.

With the rapid development of EV industry, the number of retired power storage batteries will continue to increase significantly. By the end of 2020, the cumulative installed capacity of energy storage projects put into operation in China was 35.6GW, accounting for 18.6% of the global energy storage market, with a year-on-year growth of 9.8%.

3.3.4.1.6 Standards and specifications

The existing standards related to ESS in China has been summarized in Table 3-11.

Table 3-11 Standards related to ESS in China

Standard category	Application field	Standard	Standard number
National standards	Design, construction and operation of ESS	Design code for electrochemical energy storage station	GB/T 51048-2014
		General technical requirements for electrochemical ESS in power system	GB/T 36558-2018
		Operation performance index and evaluation of electrochemical energy storage station	GB/T 36549-2018
	Energy storage batteries	Lithium-ion battery for electrical energy storage	GB/T 36276-2018
		Technical standard for BMS of electrochemical energy storage station	GB/T 34131-2017
		Safety of primary and secondary lithium cells and batteries during transport	GB 21966-2008
	Converter	Technical specification for power conversion system of electrochemical ESS	GB/T 34120-2017
	Grid connection	Technical rule for electrochemical ESS connected to power grid	GB/T 36547-2018
		Test specification for electrochemical ESS connected to power grid	GB/T 36548-2018
	Electromagnetic Compatibility	Electromagnetic compatibility (EMC)- Part 6-4: Generic standards - Emission standard for industrial environments	GB/T 17799.4-2012
		Electromagnetic compatibility—Testing and measurement techniques – Electrostatic discharge immunity test	GB/T 17626.2-2018
		Electromagnetic compatibility—Testing and measurement techniques—Radiated, radiofrequency, electromagnetic field immunity test,	GB/T 17626.3-2016
		Electromagnetic compatibility – Testing and measurement techniques – Electrical fast transient/burst immunity test,	GB/T 17626.4-2018
		Electromagnetic compatibility—Testing and measurement techniques – Surge immunity test	GB/T 17626.5-2019
		Electromagnetic compatibility—Testing and measurement techniques—Immunity to conducted disturbances, induced by radio-frequency fields	GB/T 17626.6-2017

(Continued)

Standard category	Application field	Standard	Standard number
National standards	Electromagnetic Compatibility	Electromagnetic compatibility - Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests	GB/T 17626.11-2008
Sectoral standards	Energy storage batteries	Technical specification for lithium-ion batteries of electrochemical energy storage station	NB/T 42091-2016
	Electromagnetic Compatibility	Technical Conditions for Inverter Power Supply of Static Relay Protection Devices	DL/ T 527-2002
Enterprise's standards	Energy storage batteries	Technical specification for energy storage battery pack and BMS	Q/GDW 1884-2013

The parameter requirements of some parts and components determined according to standards and market demand are for reference only.

Table 3-12 Required parameters for monomer battery

No.	Parameters	Requirement
1	Cycle time	Cycle times ≥ 5,000 0.5C rated multiplier /@25℃ 100%DOD EOL 80%
2	Energy efficiency	94.5%
3	Internal resistance (mΩ)	≤0.3 mΩ
4	Storage temperature range (℃)	-30℃ ~45℃
5	Operating temperature range (℃)	0℃ ~50℃
6	Humidity (%)	≤85%

Table 3-13 Required parameters for battery module (2P12S)

No.	Parameters	Requirement	Remarks
1	Insulation standard	Insulation resistance of single battery box≥1GΩ(1000VDC)	Refer to GB36276-2018
2	Voltage resistance standard	2830VDC, no breakdown phenomenon, leakage current <5mA	Refer to GB36276-2018
3	Overtemperature protection during charging	45℃	Battery temperature in the battery module
4	Overtemperature protection during discharging	50℃	Battery temperature in the battery module
5	Charging protection at low temperature	0℃	Battery temperature in the battery module
6	Discharging protection at low temperature	-20℃	Battery temperature in the battery module
7	Waterproof grade	IP21	
8	Storage temperature range (℃)	-30 ～ 50	
9	Storage environment humidity (RH)	5% ～ 95%	
10	Working environment humidity (RH)	≤85%	
11	Operation efficiency	≥94.5%	25℃ @0.5C (90%DOD)

Table 3-14 Required parameters for battery system

Parameter		Requirement	Remarks
Battery cluster rated energy efficiency		≥94.5%	CC-CV mode, 25℃ , DOD100%, At 0.5C/0.5C: Rated energy efficiency = (discharging Wh) / (charging Wh)
Overall efficiency		≥88%	Overall efficiency = ratio of on-grid electricity to off-grid electricity within evaluation period
System service life		≥5000 times	25℃ , DOD 100%, 0.5C/0.5C, EOL80% at standard conditions
Conformance requirements	Static voltage consistency	≤30mv	
	Initial capacity consistency	≤1%	Capacity of monomer battery: (Actual capacity-Nominal capacity)/Nominal capacity
	Self-discharging consistency	≤1%	Capacity maintenance after 28 days of full charge (Maximum - minimum)/Sampling average
	Discharging platform consistency	≤30mv	The amplitude of rated power charging and discharging curves in the platform area does not exceed 30mV

Table 3-15 Required parameters of BMS

No.	Parameter	Requirement
1	Monomer battery voltage detection range	0 ～ 5V
2	Monomer battery voltage detection resolution	1mV
3	Single battery voltage detection accuracy	≤±5mV

(Continued)

No.	Parameter	Requirement
4	Single battery voltage detection frequency	<500mS
5	Total voltage measurement range	0V ～ 1500V
6	Total voltage detection resolution	100mV
7	Total voltage detection accuracy	<0.5% FSR
8	Temperature measurement range	-40 ～ 125℃
9	Temperature detection resolution	1℃
10	Temperature detection accuracy	-40 ～ 75℃ ≤±1℃ 75 ～ 125℃ ≤±2℃
11	Total current detection range	-300A ～ 300A
12	Current detection accuracy	<0.2% FSR (FSR: full scale range)
13	Current detection cycle	100mS
14	Insulation monitoring	It falls into three levels 0: No fault (>500Ω/V), 1: General fault (250 to 500Ω/V), 2: Major fault (<100Ω/V)
15	Insulation detection accuracy	<10%
16	SOC estimation accuracy	SOC<8% (one charging/discharging calibration is required once a month)

BMS software protection function: it should have monomer battery overcharging/overdischarging alarm, high monomer battery voltage difference alarm, monomer battery charging and discharging high temperature/low temperature alarm, excessive temperature difference alarm, high/low total voltage alarm, high charging and discharging current alarm, low insulation alarm.

3.3.4.1.7 Construction principles and guidelines

(1) System planning

To plan the ESS under the application scenario of integration of EVs and RE, we should first stimulate the willingness of EV users to participate in, bring into play the load-side (EVs) adjustment and response capability, fully exploit and guide user enthusiasm by capturing sensitive price signals, and increase the flexibility of load-side adjustment. Secondly, on the power generation side (RE), it is necessary to increase the adjustment capacity of various power sources and fully release them to realize the sharing of adjustment resources in the power system. This requires increasing the proportion of renewable energy generation, promoting the nearby production and utilization of energy, and increasing the large-scale application of ESS.

ESS should be built according to the scale of 15-30% of renewable energy and the duration of charging should be no less than 2 hours. The ESS should meet the peak-shaving demand of the system, consume excess power, reduce wind power curtailment and photovoltaic power curtailment, and serve as a backup power source to improve the flexibility of power dispatch.

Electrochemical ESS power stations should not be located near or in places where inflammable, explosive and dangerous goods are produced, stored and operated, places with dust and corrosive gases, and protected areas of important power facilities. The circuit of the energy storage battery unit should be equipped with DC circuit breakers and other breaking devices, and the battery cluster should be equipped with cluster circuit breakers. The BMS should be characterized by power protection functions such as overvoltage, undervoltage, pressure differential, and overcurrent, as well as non-power protection functions such as overtemperature, temperature difference, and gas. It can send hierarchical alarm signals or tripping commands, therefore realizing fault isolation on the site. A combustible gas detection device should be installed in the energy storage battery equipment room. When the concentration of H_2 or CO surpasses 50×10^{-6} (volume ratio), the cabin-level and cluster-level circuit breakers should be disconnected, and the ventilation system and alarm device should be activated in linkage.

(2) Construction

The construction of ESS should be combined with the scale of power supply, characteristics of power output, the consumption capacity, load characteristics, to design and determine the scale and ratio of various power elements. Among them, the retired power battery from EVs can also be screened and reorganized into a downcycling power station, therefore can be put into practical applications.

In general, the planned scale of large-scale energy storage power stations is tens of MW/tens of MWh. In order to save land and investment costs, most of ESS are connected through the voltage level of 10 kV and below. If the surrounding location and interval of the 220kV substation site are limited, decentralized access to the 110 kV substation 10 kV of its power supply can also be considered.

(3) Operation

The interaction of EVs, RE and energy storage is an operation mode and technology that can maximize the utilization of energy resources. Through various interaction forms such as load-storage interaction, source-storage interaction and source-load interaction, the power dynamic balance ability of power system can realize a more economical, efficient and safe improvement, which is an important development path to build a new type of power system.

The general operation of ESS in the integrated application scenario of EVs and RE is as follows: from 00:00 to 8:00 every day, during the off-peak hours of load/grid power consumption, ESS uses the wind curtailment power to charge. From 9:00 to 12:00 at the electricity consumption peak, it can choose to discharge to load/grid to complete the cycle of charging once and discharging once; from 12:00 to 18:00 every day, the PV around the field area of ESS runs at full load, and ESS is charged by the power of photovoltaic curtailment. When the peak power consumption period from 18:00 to 23:00 comes, it can choose to discharge to the load/grid to complete the cycle of charging twice and discharging twice.

(4) Maintenance

It mainly follows the requirements of *Code for Operation and Maintenance of Energy Storage Station (GB/T 40090-2021)* to maintain ESS: ① Check the operation status of the power station through the EMS system of the energy storage power station, the equipment status is displayed normally, and the communication is normal, the data of the monitoring platform is consistent with the data of the on-site equipment, and real-time alarms and historical alarms can be viewed; ② Regularly check the battery appearance and structure, battery connection parts, etc.; ③ ESS operation and maintenance personnel must adopt the weekly, monthly, quarterly and annual inspections, repairs and maintenance of system facilities.

(5) Safety

The fire-protection safety design of ESS implements the policy of prevention first, the combination of prevention and elimination, based on self-prevention and self-rescue. Multiple fire protection measures are taken depending on different buildings (structures) and facilities. The process design, material selection, and floor plan are all carried out in accordance with the relevant fire protection regulations.

Install automatic fire detection and alarm equipment, access centralized alarm control panel, and interface with the computer monitoring system of the energy storage power station. The fire alarm system of the energy storage power station mainly comprises an automatic fire alarm controller and fire-protection linkage control device, point-type smoke sensing, temperature sensing fire alarm, sound and light alarm and linkage module, etc. A fixed automatic fire extinguishing system should be installed in the battery equipment room of the new (renovated and expanded) large-scale lithium-ion battery energy storage power station.

The cables shall be protected by taking firestop measures. All electrical equipment layout meets electrical and fire safety distance requirements. The fire-protection water system utilizes the existing fire-protection system of the industrial plant.

In the centralized control station, fire extinguishers are installed indoors according to *the Code for Design of Extinguisher Distribution in Building (GB 50140-2005).* Outdoor power distribution installations and utilities are equipped with portable ABC dry powder fire extinguishers according to specifications. Besides, the station should be equipped with a certain number of fire-protection equipment such as fire shovels, fire axes and fire-protection lead buckets.

3.3.4.2 Downcycling utilization of retired power batteries

The technical requirements in this part are mainly applicable to the downcycling utilization of single batteries, modules and battery pack systems of retired vehicle lithium-ion power batteries.

3.3.4.2.1 Overview

Retired batteries are applied to RE microgrid energy storage facilities, charging and storing energy when RE is sufficient, and discharging during power consumption peak, thereby increasing the utilization rate of RE. Therefore, green energy exchange can be achieved by integrating the deployment of large-scale distributed wind power–PV–ESS–EV charging microgrids, combining on-vehicle mobile energy storage and ground energy storage facilities, which can not only realize the power consumption of more RE resources, but also promote the contribution of the full lifecycle application of EV power battery to carbon emission reduction. It is also beneficial to realize the closed-loop management of the recycling of power battery materials, so as to avoid adverse impacts on the environment while improving the added value of battery products.

In terms of application, the large-scale use of retired batteries in energy storage facilities can not only prolong the service life of power batteries, and improve the residual value of retired power batteries, but also flexibly solve the problem of battery configuration or supply concerning electrochemical energy storage for wind-PV-ESS charging microgrid facilities and other energy storage application links, therefore saving a lot of energy consumption for the production and manufacture of new power batteries.

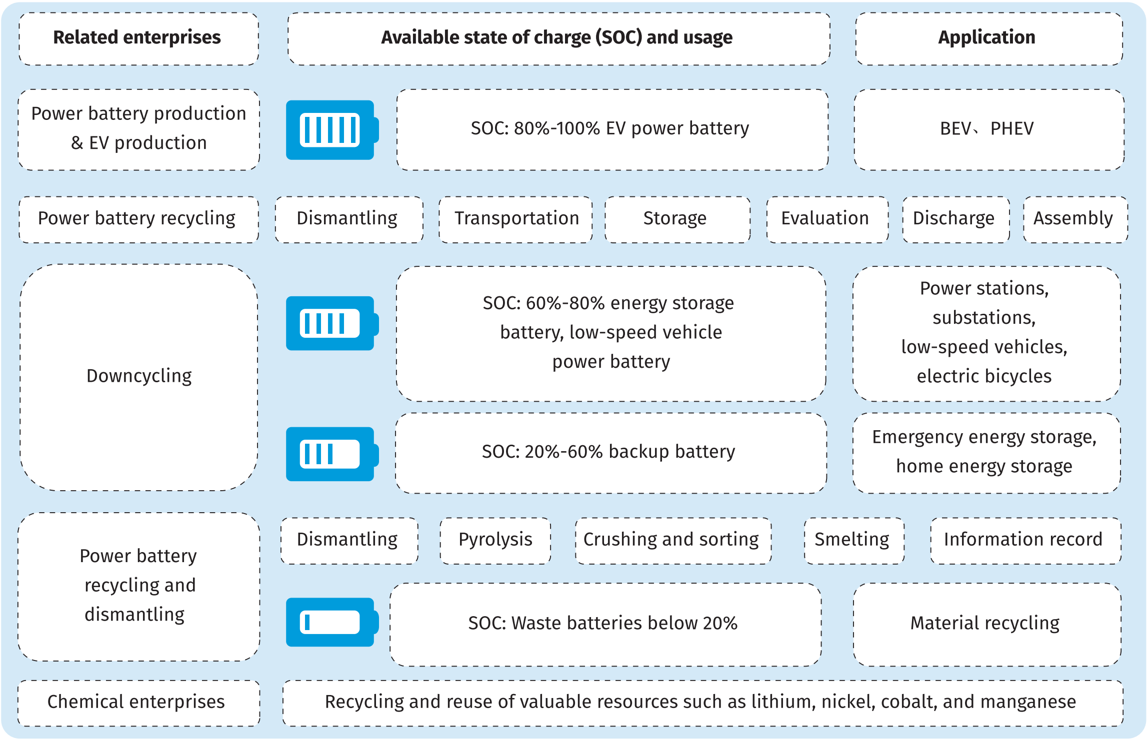
In general, when the remaining capacity of the power battery for EVs declines to less than 80%, it will no longer be suitable for the power demand of the vehicle. Therefore, on the premise of ensuring safety and controllability, the multi-level and multi-purpose rational utilization of retired power batteries according to the principle of downcycling first and then recycling can effectively improve the efficiency of resource utilization.

It should be fully considered that the electrical properties of power batteries, such as capacity, internal resistance, charge retention rate and consistency between battery cells, will change after the end of the service cycle of EVs. So, a performance evaluation of retired power batteries is needed before the downcycling, to determine the availability, duration and the application scenarios.

At present, relevant laws and regulations require EV manufacturers, power battery manufacturers, downcycling utilization battery enterprises, and end-of-life vehicle collection and dismantling enterprises to assume corresponding responsibilities in the process of power battery downcycling utilization.

In addition, for downcycling utilization of EV power batteries, real-time battery performance monitoring systems are required to implement early warning and protection of performance status. Moreover, passive safety protection devices with the fire suppression function are required to be equipped according to the working environment. The power battery that lacks the historical data record of the performance status and does not have the performance status verification and assessment of the downcycling utilization should not be used directly. In terms of battery material system, lithium iron phosphate material system is currently the main material system suitable for downcycling utilization. According to relevant regulations, retired power batteries with ternary material systems are not suitable for ESS of large and medium-sized capacity.

Figure 3-13 Downcycling utilization of retired EV power batteries



3.3.4.2.2 Technology requirements

In the short term, since downcycling utilization was not considered in the early power batteries regarding operating characteristics and cycle life, they are not suitable to be directly used in ESS. Recycled batteries should be disassembled in a closed environment to extract precious metals such as nickel, chromium and lithium from positive and negative electrode materials, so as to realize the recycling of battery materials and reduce the consumption of material resources.

With the widespread application of EVs, retired power batteries are expected to realize large-scale downcycling utilization via ground ESS on the premise that long life design is carried out to ensure the safety performance of battery products in the whole lifecycle.

Technical requirements

(1) The power battery is not only expected to meet the characteristics of the charging and discharging of EVs, but also to satisfy the requirements of the charging and discharging cycle of RE microgrid ESS after the battery gets retired. In short, the life cycle including downcycling utilization should be considered at the beginning of the design.

(2) The technical means of non-destructive testing for power batteries still need to be established. Without disassembling the power battery package, the downcycling working cycle can be calibrated and predicted to ensure product performance in different stages.

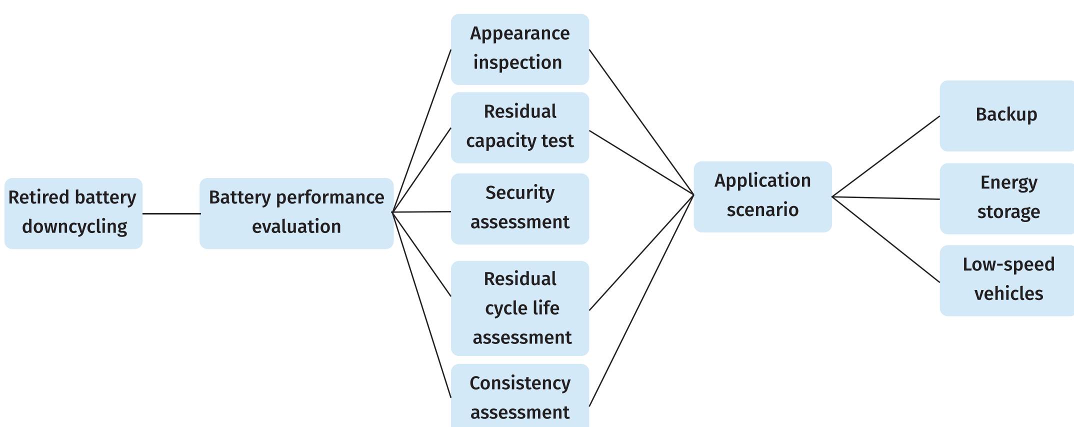
(3) A public service platform can be established for power battery performance traceability, and the real-time monitoring can be conducted throughout the application process, to give early warning to the battery health status during operation and to intervene in advance to prevent safety accidents.

(4) Based on the structure and maintenance scenarios of EVs and ESS, it is necessary to standardize product structure and interface, including the dimensions of battery modules, electrical interfaces and communication protocols.

3.3.4.2.3 Performance evaluation of retired batteries

The performance evaluation on retired power batteries to be downcycled should follow *the Recovery of EV Power Battery. Downcycling Utilization. Part 3: Downcycling Utilization Requirement (GB/T 34015.3-2021)* and *Recycling of EV Power Battery—Test of Residual Capacity (GB/T 34015-2017).* As shown in Figure 3-14, the detection before downcycling utilization mainly includes five steps, namely, appearance inspection, residual capacity test, residual cycle life evaluation, safety evaluation and consistency evaluation. Through detection and evaluation, the downcycling and application scenarios of retired batteries can be preliminarily determined.

Figure 3-14 Downcycling utilization steps of retired power batteries



(1) Appearance inspection

Under good light conditions, visually inspect the appearance of the power battery module and battery. Requirements are as follows:

The casting of retired power battery pack or module for vehicles should be in good condition, with no cracks, leaks or burn marks on the outside. The surface should be flat, dry, free from damage, artfully arranged, and properly connected.

The retired power battery monomers for vehicles should not have any leakage, damaged or fray. The surface should be smooth without damage or dirt, and the markings should be clear and correct.

If there is an active protection line, it should be removed before detection.

(2) Residual capacity test

The testing process should follow the relevant safety and environmental requirements, for example, professionals with battery inspection knowledge should be on duty to monitor the entire process, fire protection necessities must be equipped, and essential insulation measures should be taken.

The measuring instruments and dashboards in the testing process shall comply with the relevant accuracy requirements.

During the detection process, basic information such as nominal voltage, nominal capacity or nominal energy, and battery quality should also be collected. The voltage should be determined. The initial charging/discharging current and I_5 discharging capacity should be determined; and the battery material category should be determined.

All detecting steps should follow the relevant testing methods.

Under the condition of 25℃ ±2℃ , the battery residual capacity requirements for downcycling utilization in different application scenarios are as follows:

Downcycling products for vehicle battery application scenario:

Battery pack and battery module: I_3[15] (A) discharging capacity of the current value is not less than 60% of the factory nominal capacity.

Monomer battery: The discharging capacity of I_3 (A) current value is not less than 65% of the factory nominal capacity.

Downcycling products for energy storage batteries and other application scenarios:

15 I_3 is the 3h rate discharge current (A), and its value is equal to 1/3 of the rated capacity value.

Battery pack and battery module: The discharging capacity of I_5[16] (A) current value is not less than 50% of the factory nominal capacity.

Monomer battery: I_5 (A) Discharging capacity is not less than 55% of the factory nominal capacity.

Products not suitable for downcycling utilization: Discharging capacity of I_3 (A) current value reaches the end-of-life condition specified by the battery manufacturer or is less than 40% of the nominal capacity.

(3) Residual cycle life evaluation

The residual cycle life is mainly evaluated based on its basic data in the utilization process on the vehicle side. The main source of data is the vehicle data required by GB/T 32960 T*echnical Specifications of Remote Service and Management System for EVs* to be uploaded to the National Remote Monitoring Platform for NEVs (National Monitoring Platform for NEVs and Comprehensive Management Platform for Power Battery Recovery and Utilization Traceability) in real time. The data cover real-time temperature, SOC and charging current monitoring data during the charging.

(4) Safety evaluation

The safety evaluation of retired vehicle power batteries shall include but not be limited to battery temperature, voltage, appearance, high and low voltage connection, internal resistance, insulation performance, etc.

The safety of the battery for downcycling utilization should meet the relevant standard requirements of the industry, or the requirements determined by the supply and demand parties or refer to the standard GB 38031.

The power battery safety and reliability appraisal system can be constructed based on the power battery life cycle database to analyze the power battery fault alarm, the maintenance and replacement of power batteries in the national traceability management platform, mean time between failures (MTBF), failure rate and other parameters. The data cover real-time monitoring data of faults in the *Technical Specifications of Remote Service and Management System for EVs (GB/T 32960).*

(5) Consistency screening

The consistency evaluation of retired vehicle power batteries should include but not limited to temperature, voltage, internal resistance and capacity. The consistency of the voltage value of the monomer battery and the consistency of the temperature distribution inside the battery pack is selected as the indicators of the consistency evaluation system, and the distribution and expected value of its extreme values can be analyzed to evaluate the consistency of retired power batteries.

16 I_5 is the 5h rate discharge current (A), and its value is equal to 1/5 of the rated capacity value.

Meanwhile, a new commercial battery of the same type as the retired battery can be selected. The internal resistance of the battery under different open circuit voltages can be inspected and then drawn into R-OCV standard curve. In the environment of suitable temperature and humidity, the retired battery is charged with small and constant current, the SOH of the battery is calculated and divided into intervals, and the retired battery is filled into the corresponding interval according to different SOH values. Then, the batteries are further divided by the internal resistance difference to screen out the retired batteries with similar consistency.

3.3.4.2.4 Standards and specifications

Up to the date, China has published or is developing a number of standards related to the downcycling utilization of retired EV power batteries, mainly focusing on downcycling, recycling, fire-protection safety and other aspects, which can serve as a supplement to the technical guidelines, shown in Table 3-16.

Table 3-16 Standards related to downcycling utilization of retired EV power batteries

Standard category	Application field	Standard	Standard number
National standards	General requirements	Recycling of EV power battery—General requirements—Part 1: Terms and definitions	In draft
		Recycling of EV power battery—General requirements—Part 2: Specification for compilation of battery disassembling instruction manual	To be developed
		Recycling of EV power battery—General requirements—Part 3: Technical conditions for retired batteries	In draft
		Recycling of EV power battery—General requirements—Part 4: Specification for classification technique	In draft
		Recycling of EV power battery—General requirements—Part 5: Enterprise safe production general requirements	GB 38031-2020
		Recycling of EV power battery—General requirements—Part 6: Green factory evaluation specifications	GB/T 37295-2019
	Downcycling utilization	Recycling of EV power battery—Downcycling Utilization—Part 1: Test of residual capacity	GB/T 34015-2017
		Recycling of EV power battery—Downcycling Utilization—Part2 : Removing requirements	GB/T 34015.2-2020
		Recovery of EV power battery—Downcycling Utilization—Part 3 : Downcycling Utilization requirement	GB/T 34015.3-2021
		Recovery of EV power battery—Downcycling Utilization—Part 4: Labels for Downcycling Utilized battery products	GB/T 34015.4-2021

(Continued)

Standard category	Application field	Standard	Standard number
National standards	Downcycling utilization	Recovery of EV power battery—Downcycling Utilization—Part 5: Design guide for downcycling	In draft
		Recovery of EV power battery—Downcycling Utilization—Part 6: Specification for remaining life evaluation	In draft
	Recycling	Recycling of EV power battery—Recycling—Part 1: Dismantling specification	GB/T 33598-2017
		Recycling of EV power battery—Recycling—Part 2：Materials recycling requirements	GB/T 33598.2-2020
		Recycling of EV power battery—Recycling—Part 3: Specification for discharging technology	In draft
		Recycling of EV power battery—Recycling—Part 4: Specification for compilation of recycling and disposal report	In draft
	Management specification	Recycling of EV power battery—Management specification—Part 1：Packing and transporting	GB/T 38698.1-2020
		Recycling of EV power battery—Management specification—Part 2: Specification for the construction of recycling service outlets	To be developed
		Recycling of EV power battery—Management specification—Part 3: Specification for loading and unloading and moving	In draft
		Recycling of EV power battery—Management specification—Part 4: Specification for storage	In draft
	Hazardous waste management	Packing symbol of dangerous goods	GB 190-2009
		Safety code for inspection of large packagings for dangerous goods	GB 19432-2009
		General specifications for transport package of dangerous goods	GB 12453
	Energy storage power station	Design code for electrochemical energy storage station	GB 51048-2014
		General technical requirements for electrochemical ESS in power system	GB/T 36558-2018
		Code for fire protection design of building	GB 50016

(Continued)

Standard category	Application field	Standard	Standard number
National standards	Other	Dimension of EV power battery	GB/T 34013-2017
		Terminology of EVs	GB/T 19596-2017
		Electrical performance requirements and test methods for EV power batters	GB/T 31486-2015
		Technical specifications of remote service and management system for EVs	GB/T 32960.1-2016
		Automobile recovery - Terminology	GB/T 26989-2011
Sectoral standards	Fire safety	Testing code for fire protection systems	XF 503-2004
		Regulations concerning road transportation of dangerous goods	JT/T 617-2018
Consortium standards	Fire safety	Fire safety technical requirements for small electrochemical energy storage power stations	T/CSAE 88-2018
		Technical specification for fire protection of lithium iron phosphate battery energy storage power station based on prefabricated cabin	TCEC373-2020
		Risk assessment guide of fire safety in energy storage power stations for downcycling utilization of power batteries	To be approved
		Performance requirements and test methods for fire prevention and control devices in power lithium-ion battery downcycled ESS	To be approved
		Fire safety design requirements in power lithium-ion battery downcycled ESS	To be approved
		Guide for fire emergency plan compilation of power battery downcycled energy storage power stations	To be approved
	Energy storage technology	Guide for compressed air energy storage power station identification system	T/CES 061-2021
		Technical guide for the energy management system of port shore electric ESS	T/CES 062-2021
		Technical specification of retired power battery for screening detection	T/CES 063-2021
		Specification of applied technology for directed cascaded electric storage energy system based on medium voltage	T/CES 076-2021

(Continued)

Standard category	Application field	Standard	Standard number
Consortium standards	Energy storage technology	Technical requirements for safety data acquisition and application of remote monitoring of mobile energy storage	T/CES 077-2021
		Technical requirements for compressed air energy storage power station connected to grid	T/CES 078-2021
		Framework design specification for big data platform of electrochemistry ESS	T/CES 079-2021
		Technical specifications for the fire-fighting centralized monitoring system of prefabricated cabin energy storage power station	T/CES 080-2021
		Guidance for field test of black start of auxiliary gas turbine unit of ESS	T/CES 095-2022
		Test specifications for connecting the flywheel ESS to the power grid	T/CES 096-2022
		General information data standard for electrochemical ESS power stations	T/CES 097-2022
		Technical specifications for design of prefabricated cabin electrochemical energy storage emergency power supply system	T/CES 115-2022
		Technical specifications for reorganization, evaluation and grading of retired power batteries	T/CES 117-2022
		Technical specifications for power distribution network electrochemical ESS configuration	To be approved
		Technical specifications for smart operation and maintenance of lithium-ion battery energy storage power stations	To be approved
		Technical specifications for retired power battery management system of energy storage stations	To be approved
		Test specifications for lithium-ion battery clusters of electric energy storage	To be approved
		Mobile lithium-ion batteries for electrochemical ESS	To be approved
		Technical specifications for ESS test platform	T/CES 116-2022
		Methods for performance appraisal of fire foams for power stations	In draft

(Continued)

Standard category	Application field	Standard	Standard number
Consortium standards	Energy storage technology	Technical specifications for coordinated operation of household PV-ESS thermal storage system	T/CES 118-2022
		Technical specifications for energy management system of electrochemical ESS power stations	In draft
		Technical rules for electrochemical mobile emergency energy storage power system	In draft
		Technical guidelines for remote fire monitoring and early warning for electrochemical ESS power stations	In draft
		Technical specifications for local wireless networking of integrated energy system	T/CES 094-2022
		Technical specifications for connecting distributed ESS to the power distribution station area	In draft
		Guidelines for energy efficiency appraisal of electrochemical ESS power stations	In draft
		Procedures for safe operation of the system of hydrogen production from water electrolysis	In draft
		Technical requirements for dispatching control system of electrochemical ESS power stations	In draft
		Regulations on technical supervision of energy storage equipment in electrochemical ESS power stations	In draft
		Technical requirements for actual measurement of parameters of the control model of electrochemical ESS power stations	In draft
		Technical specifications for commissioning of electrochemical ESS power stations	In draft
		Technical specifications for tests of automatic generation control and automatic voltage control system in electrochemical ESS power stations	In draft
		Specifications for on-site handover test of energy storage equipment in electricity distribution station areas	In draft

3.3.5 Vehicle-grid integration network information systems and communication security technologies

3.3.5.1 Overview

In order to build an application system for the integration of EVs with the grid and RE, it is necessary to establish an interactive information support network for electric energy that is applicable to the collaborative application of vehicle-charger-storage-cloud-grid based on application service scenarios and operation management requirements, to realize the integration of information services based on vehicle-grid information, to adapt to the network of transportation vehicles, the network of charging and swapping facilities and the energy internet to form a highly coordinated vehicle-grid integration information support system. The network will meet the needs of business activities and operation management and adapt to the future application development trend of intelligent energy services. Various communication networking technologies and software service functions are used to establish a service system for electrical energy exchange and trading, to realize secure communication connections between information platforms and electrical energy bearing equipment, and business information collaboration between operation service platforms, and to ensure information security and communication safety and trustworthiness are the basic objectives of building a vehicle-grid integration network.

Due to renewable energy's volatility and intermittency, the reliability of the grid load regulation capacity, communication links and other information security assurance is an important prerequisite for the stable operation of the grid system. Among them, the latest development of communication security authentication technology, through digital encryption, digital certificate, identity authentication, control confirmation and other trusted authentication and multi-level key mutual recognition security mechanism, can effectively guarantee the security of the communication link data information of the operation system.

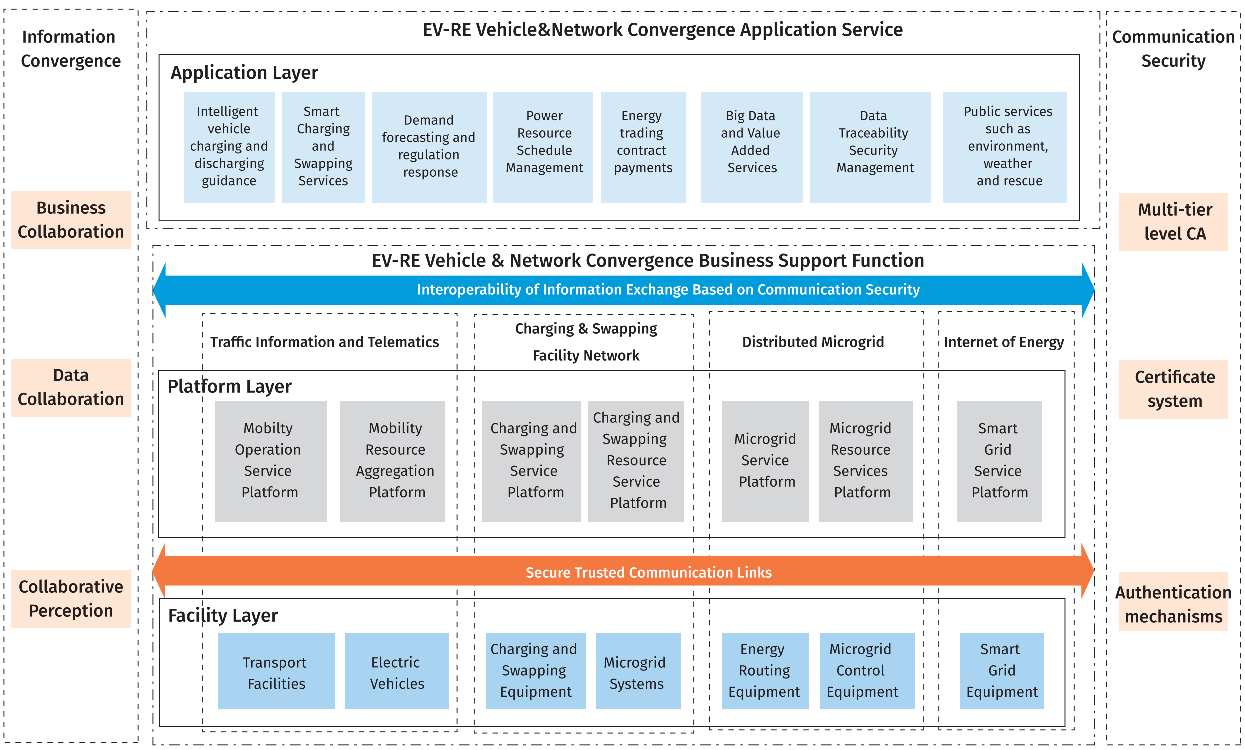
Based on the EV-RE vehicle-grid integration application, this section proposes a vehicle-grid integration information system infrastructure and information security technology guidelines for EV mobile energy storage to access the grid to consume distributed PV and wind power generation as well as participate in electrical energy interaction. At the same time, based on the rapid development of China's C-V2X technology in the vehicle-networking field and the demand for extension to the infrastructure end, this chapter proposes a reliable communication security solution for vehicle-to-infrastructure/other equipment, which has a positive guiding role in accelerating the establishment of a fully compatible vehicle-grid integration communication security authentication mechanism and promoting the development of data interface standards. The multi-level mutual certificate-based authentication system and data link encryption method reflects the inheritance and extension of the technical route of the vehicle-to-infrastructure convergence system standard. At the same time, it provides an overview of the current information security standards and the requirements for the development of new standards, and provides a solution for the planning, construction and technical development of vehicle-grid integration information systems.

3.3.5.2 Technical solution

3.3.5.2.1 Vehicle-grid integration information architecture

Vehicle-grid integration system is a joint system for the purpose of electrical energy interaction to coordinate the business of vehicle-side battery participation in charging and discharging, microgrid energy storage, distributed PV/wind power generation, grid power supply and the coordination and complementarity of power resources. The vehicle-grid integration information system architecture, as shown in Figure 3-15, is a three-layer information system service support system with relative unity and information convergence with the characteristics of security and reliability, which is based on the basic requirements of multi-domain business collaboration and multi-network information convergence. The architecture of the vehicle-grid integration information system reflects the principle of service demand orientation. In various aspects such as business functions, data interconnection, resource collaboration, operation management and information security, etc., the system should follow the idea of deep integration from the industrial Internet. In terms of the application mode and service ecology, the system should establish a comprehensive connection to users, vehicles, facilities, electrical energy and multiple systems to realize the entire process interaction from vehicles to the power resource. Taking the network as its foundation, the platform as its core, the data as its key element and security as its guarantee, the system can establish a comprehensive information service support platform for cross-industry application and can adapt to the need of industrial chain upgrade and extension. From the current information architecture covering the field, it integrates the application areas of vehicle-networking, EV charging and battery swapping facilities and energy Internet, reflecting cross-industry interconnection, security, reliability and efficiency. When facing the development of transport

Figure 3-15 Vehicle-grid integration information system infrastructure architecture



and energy in innovative technologies and application modes, the system can. adapt to the overall development requirements of low carbon, digitalization, networking and intelligence, as well as the need for the construction of future intelligent energy service ecology.

(1) Layered functions of vehicle-grid integration information service architecture

The vehicle-grid integration information system architecture consists of the facility layer, the platform layer and the application layer. The facility layer and platform layer are the support systems for business convergence. The platform layer relies on network security and communication trustworthiness to form business service support capabilities through business collaboration, information modelling and data convergence. Platform layer software architecture services support electric energy interactive business collaboration and information interaction through open architecture. The application layer coalesces to provide application services in different fields for EVs, EV charging and battery swapping infrastructure, wind power–PV–ESS distributed energy microgrid systems, power resource aggregation and regional power balancing and dispatching, including payment and settlement of electric energy transactions and other operation guarantee services. The facility layer consists of various entities and objects involved in electric energy interaction, including EV, battery systems, roadside measurement and control equipment, EV charging and battery swapping power station systems, wind power–PV–ESS–EV charging–battery swapping multifunctional microgrid systems and other electromechanical equipment and facilities. It is also the basic object for carrying out various business services such as aggregation of electrical energy resources, dispatching, electrical energy trading, energy efficiency analysis and data statistics.

(2) Business support functions for vehicle-grid integration information systems

It mainly includes EV power battery charging and discharging control, energy balance adjustment of wind power–PV–ESS–EV charging–battery swapping system, relevant scheduling and operation management, etc. The corresponding service process includes the entire process from coordinating vehicle-side mobile energy storage access to the production, transmission, distribution, storage, conversion, consumption and trading of various energy modes such as ground-based wind power–PV–ESS system. In terms of business types, it mainly involves:

1) Intelligent service guidance for vehicle-side mobile energy storage and EV charging/battery swapping station and electrical energy access ports.

2) Realization of smart power transmission and demand response control between the EV charging/battery swapping stations and the distribution system or the user-side system.

3) Electrical energy regulation and control of EV charging/battery swapping systems or wind power–PV–ESS systems participating in grid connection.

4) Power resource aggregation management and development of virtual power plant services, large-scale vehicle and storage power demand forecasting, regional power balance collaborative calculation

and dispatching interacting with grid dispatching system.

5) Distributed energy generation forecasting and regulation strategy development integrating with environment and weather.

6) Planning and regulation of vehicle priority consumption of renewable energy operation and efficient strategy.

7) Monitoring and verification of safety warning of power batteries and energy storage stations, identification tracing of battery performance diagnosis, and traceability of compliance downcycling utilization of batteries.

8) User and operation process data resource management, etc.

3.3.5.2.2 Communication Security

To realize the core service capability of the vehicle-grid integration system, communication security capability is the foundation, and information exchange established on a trusted communication link is the key support to realize the convergence application. The vehicle-grid integration communication security architecture is shown in Figure 3-16. The communication security architecture consists of the application service system, the electric energy interaction facility and the communication security infrastructure, where the communication security architecture contains the vehicle-grid integration application security subsystem and the security management system, and each functional entity is described as follows:

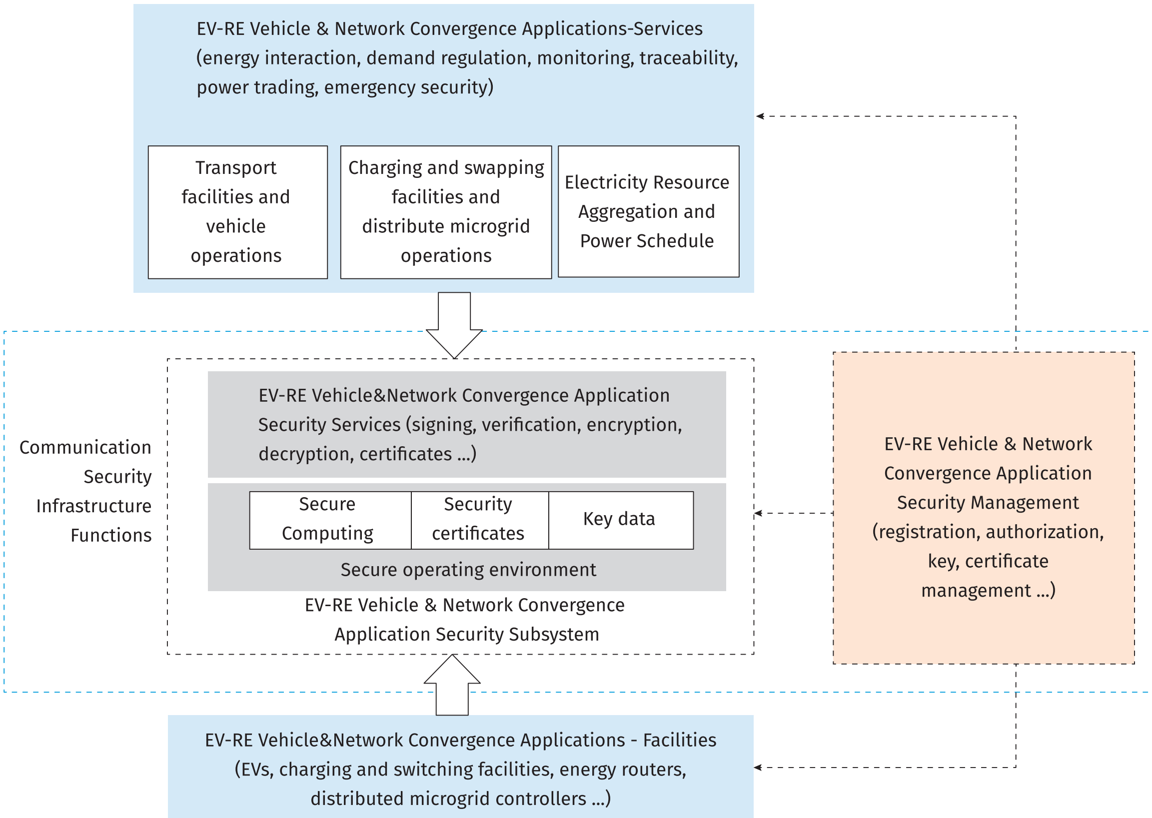
(1) Security subsystem: a system or module located in EVs, EV charging/battery swapping facilities, energy routers, distributed microgrid controllers and service provider operation service platforms that provides communication security control functions.

(2) Security management: the management entity responsible for the security configuration and provisioning of security data for each security subsystem or security function module, such as registration, authorization, key supply and certificate issuance.

(3) Application of security service: located in the vehicle-grid integration application security subsystem, it completes key application, certificate application writing and other operational functions by completing message signing, verification, encryption and decryption operations.

(4) Security environment: important security data will be stored, such as CA certificates issued by certificate authority (CA), public and private keys and encryption/decryption keys. It also provides important security calculations for security services, such as digital signatures, data encryption and decryption, etc.

Figure 3-16 EV-RE vehicle-grid integration application communication security architecture



3.3.5.2.3 Dependable authentication

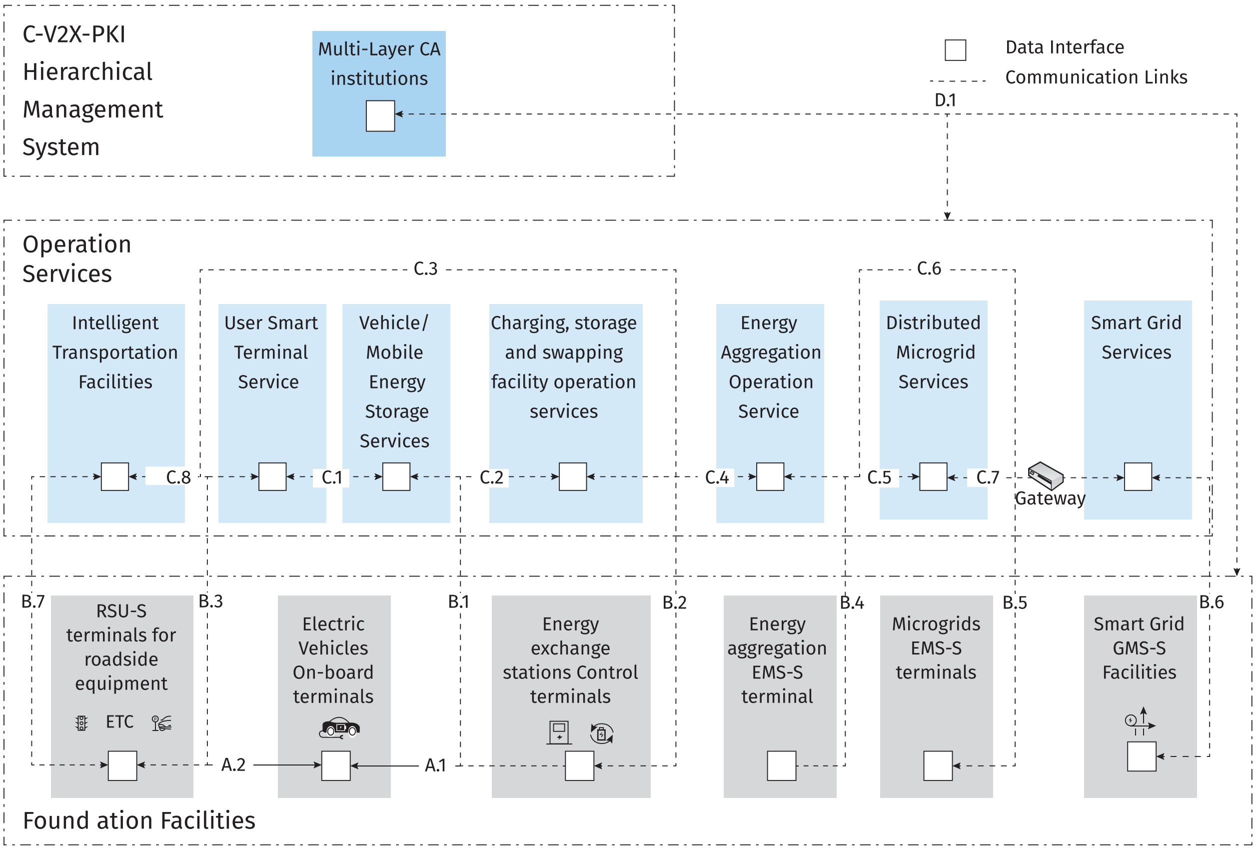
The communication security architecture under EV-RE vehicle-grid integration application scenario is based on C-V2X-PKI technology, and sets up multi-level CA bodies as the vehicle-grid integration application security management entities to realize communication dependable authentication applications.

The C-V2X-PKI-based communication dependable authentication mechanism establishes a secure communication connection between each interactive entity, and the main secure communication links are shown in Figure 3-17.

(1) Infrastructure. It refers to the control unit used by EV charging/battery swapping equipment, roadside equipment, and microgrid and other equipment and facilities to achieve PKI secure communication, with the ability to communicate with other equipment or platforms, and with the functions of completing certificate application, loading and verification.

(2) Business function service platform. It mainly comprises various operator service platforms that provide vehicle-grid interaction services, such as operation management platforms involving EV services, EV charging/battery swapping facilities services, user microgrids or wind power-PV-ESS, as

Figure 3-17　EV-RE Communication dependable authentication architecture



well as service platforms that support vehicle scheduling, coordinated EV charging/battery swapping, and micro-grid energy aggregation. It covers the system that carries out contract service and power market transaction service with power resource dispatching, and can also extend to other platforms such as battery resource recovery management platform. Besides, it includes public service platforms that provide unified interfaces based on Saas, Paas and Iaas. Account or identity verification is performed between service platforms through certification, and business data can be transmitted on the Internet after the communication link is encrypted.

(3) Communication security authentication mechanism. Based on C-V2X-PKI vehicle-grid communication authentication, it realizes certificate management and identity traceability including inter-platform and inter-device communication, including hierarchical mutual recognition key issuance, transmission link encryption of each communication segment, digital certificate generation and authentication, business function confirmation and other security and trustworthiness mechanisms.

(4) Communication connection function as shown in Table 3-17.

Table 3-17 Communication interfaces and menus

Type	Interface	Function definition	Main communication methods and protocols	
Information exchange between devices	A.1 Iac-V2C	Information exchange between EVs and EV charging/battery swapping equipment Functions: V1G and discharging, automatic charging and discharging and access guidance	Mode	Wired: usually using the CAN bus. Wireless: usually C-V2X, Bluetooth, WIFI, RFID, etc.
			Agreement	Wired: GB/T 27930 Wireless: relevant specifications under study Charging voucher: T/CEC 102.5
	A.2 Iac-V2R	Information exchange between roadside equipment and EVs Functions: ETC payment, control and automatic lever lift	Mode	Wireless: C-V2X, Bluetooth, WIFI, RFID, etc.
			Agreement	Relevant norms under study
Equipment and platform information exchange	B.1 Idev-V2VP	Information exchange on EVs and vehicle management service platforms Functions: interaction of vehicle identity information, operational status and authentication control, etc.	Mode	Usually using C-V2X, 4G/5G, etc.
			Agreement	Relevant norms under study
	B.2 Idev-C2CP	Information interaction between EV charging–ESS–battery swapping and their platforms Functions: Interactive control signals for device status, power flow and charging and discharging	Mode	Usually using 4G/5G, NB_IOT, etc.
			Agreement	T/CEC 102.6
	B.3 Idev-V2UP	Information interaction between EVs and user service platforms Functions: interactive user information, vehicle information, data notifications, etc.	Mode	Usually using C-V2X etc.
			Agreement	Relevant norms under study
	B.4 Idev-A2AP	Information interaction between the power aggregation terminal and its service platform Functions: interactive control messages, etc.	Mode	Usually using 4G/5G, NB-IOT, RS485, power line carrier, LoRa, etc.

(Continued)

Type	Interface	Function definition	Main communication methods and protocols	
Equipment and platform information exchange	B.5 Idev-M2MP	Information interaction between microgrid facilities and their service platforms Functions: Interactive electrical energy flow and control signals, etc.	Agreement	Electricity demand response: GB/T 32672-2016, DL/T 1867-2018 EV-RE business specific specifications under study
	B.6 Idev-G2GP	Information interaction between power dispatch platforms and distribution terminals Functions: interactive electrical energy flow and control signals, etc.		
	B.7 Idev-R2SP	Information interaction between roadside devices and smart city information service platforms Functions: equipment data state acquisition, signal control of signal lights, ETC, etc.	Mode	Usually using 4G/5G, NB-IOT, etc.
			Agreement	Related specifications in development
Information exchange between platforms	C.1 Isev-UP2VP	Information interaction between user platforms and vehicle management platforms Functions: interactive charging guidance, automatic parking and other business information, etc.	Mode	Internet Web Services
			Agreement	Related specifications in development
	C.2 Isev-VP2CP	Information interaction between vehicle management platform and EV charging–ESS–battery swapping operation platform Functions: interactive device status, business information, etc.	Mode	Internet Web Services
			Agreement	T/CEC 102.7
	C.3 Isev-UP2CP	Information interaction between the user platform and the EV charging–ESS–battery swapping operation platform Functions: interaction of business information, control information, accounting information, etc.	Mode	Internet Web Services
			Agreement	t/cec 102.2, t/cec 102.3
	C.4 Isev-CP2AP	Information interaction between the EV charging–ESS–battery swapping operation platform and the power aggregation platform Functions: Interactive business information, accounts information, etc.	Mode	Internet Web Services

(Continued)

Type	Interface	Function definition	Main communication methods and protocols	
Information exchange between platforms	C.5 Isev-AP2MP	Information interaction between energy aggregation platforms and microgrid service platforms Functions: Interactive business information, accounts information, etc.	Agreement	Electricity demand response: GB/T 32672-2016, DL/T 1867-2018 EV-RE business: specific specifications under study
	C.6 Isev-AP2GP	Information interaction between the power aggregation platform and the grid dispatching platform Functions: Interactive business information, accounts information, etc.		
	C.7 Isev-MP2GP	Information interaction between microgrid service platform and grid dispatching platform Functions: Interactive business information, accounts information, etc.		
	C.8 Isev-UP2SP	Information interaction between user terminals and smart city information service platforms Functions: Interactive traffic and weather information, as well as operational information such as charging and parking guidance and control signals	Mode	Internet Web Services
			Agreement	Relevant norms under study
Safety certification	D.1 Iauth-CAP2X	CA bodies interact with various types of information on the security authentication interface of the participating interactive platforms Functions: Interactive certificate content, certificate application, revocation, etc.	Mode	Internet Web Services
			Agreement	Communication security: YD/T 3594-2019, YD/T 3957 Transport Digital certificate format: T_ITS 0127-2020 CA service-related interface specification under study

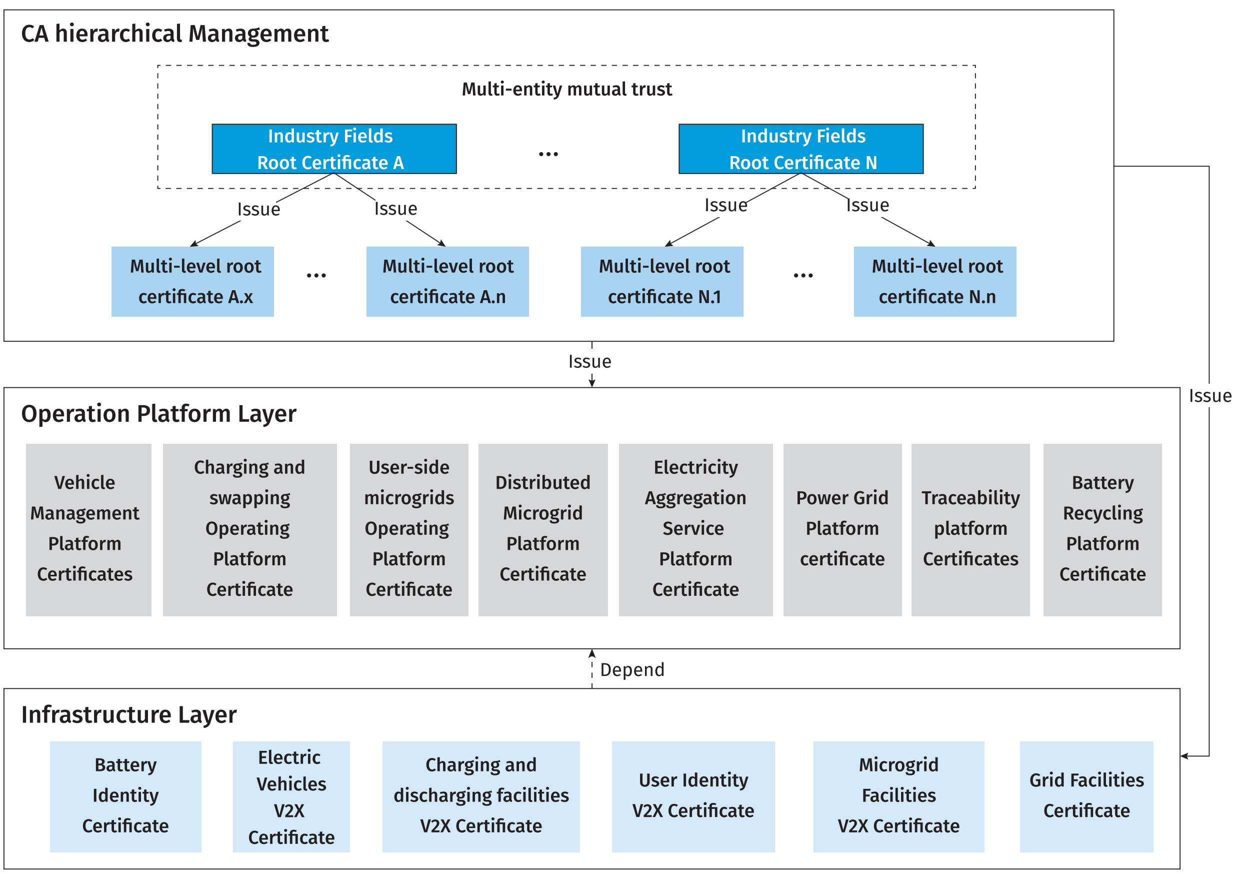
Table 3-18 Description of interface type identifier numbers

Interface type identification	Description of interface types
Iac	Communication interfaces between the various device terminals
Idev	Communication interface between the device and the service platform
Isev	Communication interfaces between platforms
Iauth	Open service authentication interface provided by CA platform

3.3.5.2.4 Certification system

The certification system for EV-RE scenario is shown in Figure 3-18, with package contents: certificate management structure, certificate loading authentication mechanism.

Figure 3-18 Multi-layer certification structure



(1) Multi-layer certificate management structure

According to *ISO/IEC 9594-8 Information Technology—Open Systems Interconnection—The Directory—Part 8: Public-key and Attribute Certificate Frameworks*, the C-V2X-PKI technology system is established in accordance with the principles of China's vehicle-grid integration application. The system is divided into three layers, which are CA hierarchical management layer, operation platform layer and infrastructure layer.

CA hierarchical management: corresponding to the root certificate, the operating entity at this layer is the CA. The root certificate issues identity or application certificates for platforms and facilities in the lower tier and has management functions. At the same time, the root certificate can issue secondary root certificates to authorized sub-CA authorities to realize the capability of multi-level CA authorities. As EV-RE involves cross-industry and cross-sector work, it allows the establishment of multiple root certificates and realize s cross-industry and cross-sector authentication of ID certificates and application certificates through an effective multi-root mutual trust mechanism.

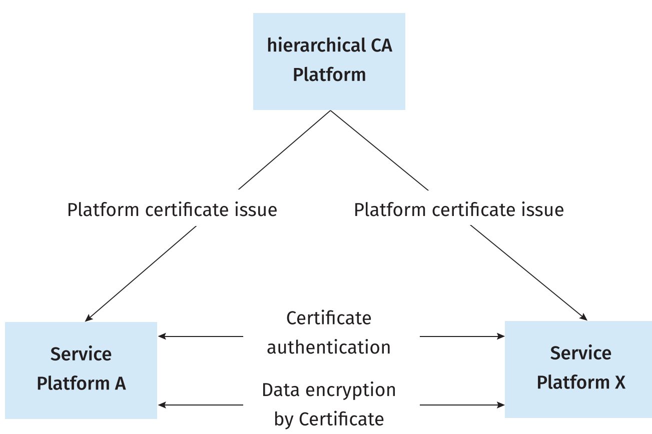
Operation platform layer: corresponding to the platform ID certificate, the operating entity of this layer is each service provider. The platform ID certificate is loaded in the service platform system and is used to achieve trusted identity authentication and data encryption from device to platform, and between platforms.

Infrastructure layer: corresponds to the device application certificate or certificate of identity, and the entities in this layer are the respective devices and facilities. The device certificate is subordinate to the platform certificate to which it belongs at the business level, which is used for identity authentication and data encryption between devices.

(2) Hierarchical certificate loading authentication mechanism

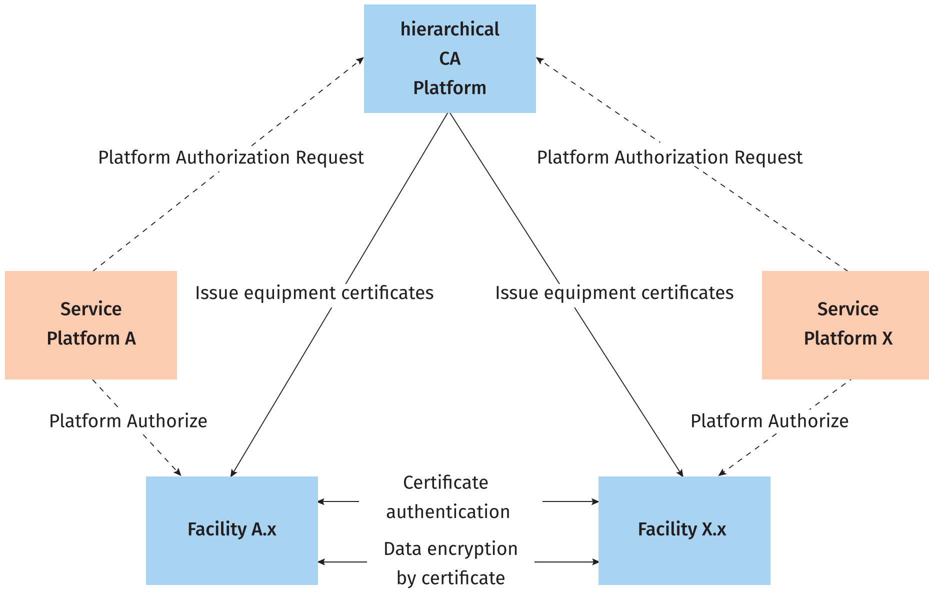
The application of the platform certificate needs to be submitted by the platform to the CA, which will then be examined by the CA in conjunction with the industry requirements and security requirements. The certificate will be approved after the examination. After the platform obtains the certificate, it is loaded into the platform system and subsequently used for identity certification when interacting with external platforms or devices. It also uses the certificate as the key and adopts asymmetric encryption to realize the encrypted transmission of business data.

Figure 3-19　Platform certificate loading and authentication process based on PKI system



The application for a device certificate requires the platform to obtain authorization from the CA first, and then the device applies for a device certificate from the CA. After obtaining the certificate, the device is loaded in the device control system and subsequently used for identity authentication when interacting with external devices or platforms. The certificate is used as the key and asymmetric encryption is adopted to achieve encrypted transmission of business data.

Figure 3-20 Device certificate loading and authentication process based on PKI system



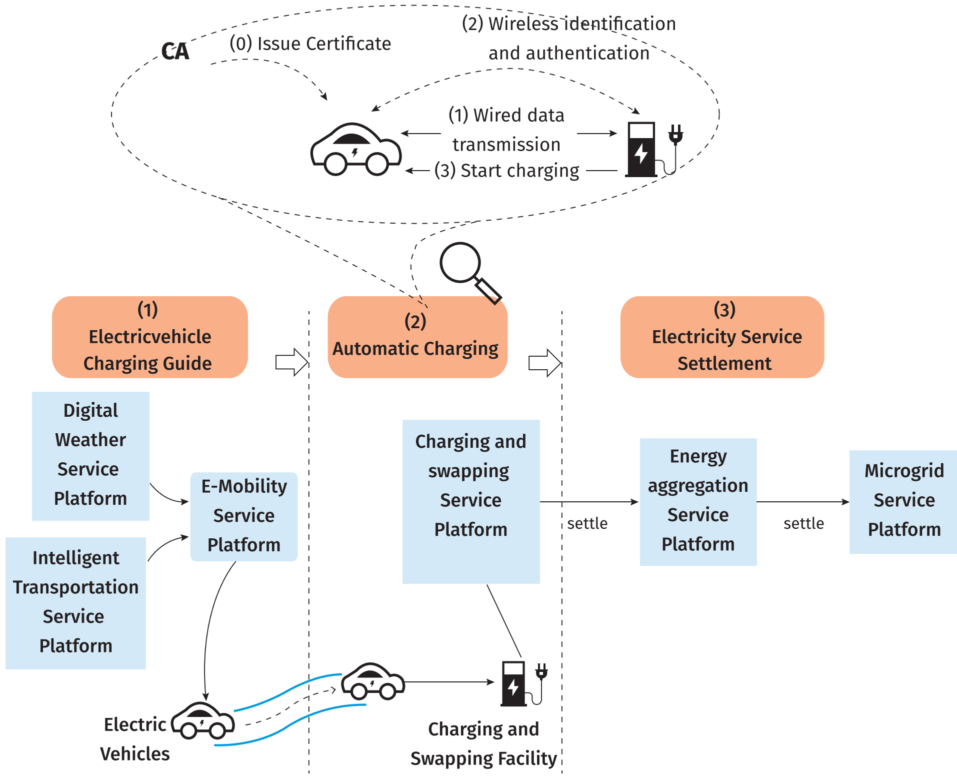
3.3.5.2.5 Example of automatic charging

Relying on the EV-RE vehicle-grid integration security technology, it can support the implementation of the entire process scenario of automatic charging of EVs. There are various combinations of scenarios for the specific implementation process of automatic charging based on EV-RE vehicle-grid integration scenarios, and in this section the process of automatic charging with plug-and-charge communication certification example is selected for description.

The example process of automatic charging is shown in the figure below, describing the three main stages of automatic charging: (1) EV charging guidance: The vehicle platform can guide the EV to the destination charging site based on data from the digital weather service and the intelligent transport service platform. (2) Automatic charging: EVs and charging facilities are activated for automatic charging through certificate authentication communication. (3) Electric energy settlement: The charging facility platform, the electric energy aggregation service platform and the micro-grid service platform use the trusted identity as the transaction credentials to complete the settlement.

For the automatic charging phase, a plug-and-charge solution based on a certificate mechanism is divided into 4 steps: (0) Certificate issuance, a pre-step, where the EV needs to apply for a charging credential certificate from CA and load it validly before charging. (1) Wired data transmission, where

Figure 3-21 Example of automatic charging



the EV and the charging pile interact with each other through CAN lines for simple data interaction and exchange of identity verification code. (2) Wireless identification and authentication, the EV and the charging pile exchange digital certificates and authentication codes via C-V2X communication for bidirectional identification and authentication. (3) Start charging, after data verification is completed, the charging pile starts charging to the EV.

3.3.5.3 Development strategy

Combined with the current state of industry development, the vehicle-grid integration information security technology should be implemented in phases.

Initial stage: telematics, energy internet, charging facility operation network and smart city network are in the early stage of new ecological construction, which should focus on forward planning of information security technology, technology testing and standard system construction. the level protection requirements are needed mainly for information system interconnection, network communication, interaction interface, data storage, boundary access and other key parts so as to form industry specification rules.

Development phase: business systems and convergence service network are gradually improved. Validation of business interaction and data interoperability projects, pilot promotion and application of results are carried out. For network construction and maintenance, establish data security specifications and measurement solutions, and improve the identity authentication industry management system and business mechanism.

Mature stage: each industry basically completes the construction of business systems and data integration mechanisms and form the mature application of vehicle-grid integration network, a better cross-industry collaborative ecological operation, service industry resource sharing mechanisms. The information exchange and security communication norms are extended to intelligent energy collaboration to form identity authentication mutual trust mechanisms in multiple fields.

3.3.5.4 Standards and specifications

Table 3-19 summarizes the standards related to secure communication in China.

Table 3-19 Standards related to secure communication

Standard category	Application areas	Standard	Standard number
National Standards	General Information Security Requirements	Information technology—Open Systems Interconnection—The Dictionary—Part 8: Public key and attribute certificate frameworks	GB/T 16264.8-2005
		Information security techniques — Public key infrastructure — Bridge Certification Authority leveled certificate specification	GB/T 29767-2013
		Information security technology — Common security techniques requirement for information system	GB/T 20271-2006
		Classified criteria for security protection of computer information system	GB/T 17859-1999
		Information security technology—Implementation guide for classified protection of cybersecurity	GB/T 25058-2020
		Information security technology—Classification guide for classified protection of cybersecurity	GB/T 22240-2020
		Information security technology— Baseline for classified protection of cybersecurity	GB/T 22239-2019
		Information security technology— Technical requirements of security design for classified protection of cybersecurity	GB/T 25070-2019

(Continued)

Standard category	Application areas	Standard	Standard number
National Standards	General Information Security Requirements	Information security technology — Testing and evaluation requirement for classified protection of information system	GB/T 28448-2019
		Information security technology-Testing and evaluation process guide for classified protection of cybersecurity	GB/T 28449-2018
	Operation service platform	Information technology—Software life cycle processes	GB/T8566-2007
	Cross-platform information interconnection	Specifications of systems and software engineering—Interface and data exchange	GB/T 38557.1-2020
	System quality and safety	Software engineering—product quality	GB/T 16260-2006
	Transportation	Transportation—Digital certificate format	GB/T 37376-2019
Sectoral standards	Communication	LTE-based vehicle networking communication security technical requirements	YD/T 3594-2019
	Communication	LTE-based vehicle networking wireless communication technology security certificate management system technical requirements	YD/T 3957-2021
	Transportation	Technical specification of communication certificate management for vehicle infrastructure cooperative system	T/ITS 0127-2020
consortium standards	Energy	Charging and battery swap service information exchange for EVs	T/CEC 102-2016

The Information Technology—Open Systems Interconnection—The Dictionary—Part 8: Public Key and Attribute Certificate Frameworks (GB/T 16264.8), which corresponds to the international standard ISO/IEC 9594-8:2001, IDT, is based on the specification of an identity system for the development of information systems data interconnection, defines a set of frameworks as the basis for all security services and specifies the security requirements in terms of authentication and other services It defines a framework for public key certificates, attribute certificates and authentication services.

The Information Security Techniques - Public Key Infrastructure - Bridge Certification Authority Leveled

Certificate Specification (GB/T 29767-2013) is based on the current situation of China's PKI system construction, based on the X.509 certification system bridging different structures of the PKI system, to achieve the mutual trust function of certificates under different PKI systems. This document specifies the certificate security registration division of the bridge CA system, which is applicable to the design and implementation of certificate policy of the bridge CA system.

The Information Security Technology Common Security Techniques Requirement for Information System (GB/T 20271-2006) based on the standardization of information security construction of information systems, from the security technology point of view of the physical security of information systems, network security, system security, application system security and management measures of the five levels of security functions to describe, each security technology requirements have universal applicability. This standard specifies the requirements of each security level of security technology required for the security of information systems, and is applicable to the design and implementation of secure information systems according to the requirements of hierarchy, and can be used with reference to the testing and management of information systems security according to the requirements of equal plans.

The Classified Criteria for Security Protection of Computer Information System (GB/T 17859-1999), Information Security Technology-Implementation Guide for Classified Protection of Cybersecurity (GB/T 25058-2020), Information Security Technology—Classification Guide for Classified Protection of Cybersecurity (GB/T 22240-2020), Information Security Technology-Baseline for Classified Protection of Cybersecurity (GB/T 22239-2019), Information Security Technology-Technical Requirements of Security Design for Classified Protection of Cybersecurity (GB/T 25070-2019), Information Security Technology - Testing and Evaluation Requirement for Classified Protection of Information System (GB/T 28448-2019) and the Information Security Technology-Testing and Evaluation Process Guide for Classified Protection of Cybersecurity (GB/T 28449-2018) are China's series standards for the network security grade protection system. It is based on regulating the network security technical requirements of various types of information through a hierarchical approach. The series of standards stipulate the information security grade classification, grading, implementation, basic requirements, design technical requirements, grade protection assessment and other requirements, specifying the security requirements for information systems, cloud computing, mobile internet, internet of things and industrial control systems. It is applicable to the security construction and supervision of non-confidential information systems.

The Technical Requirements for LTE-based Vehicle Networking Communication Security (YD/T 3594-2019) is based on the construction of a secure communication specification under LTE-based communication architecture, which regulates the communication security architecture, secure communication requirements, security processes and data structures based on PC5 and LTE-Uu. This document specifies the general technical requirements, interface security requirements and security processes for LTE-based vehicle networking communication security. It applies to LTE-based vehicle networking communication systems.

The Technical requirements for LTE-based Vehicle Networking Wireless Communication Technology

Security Certificate Management System (YD/T 3957), based on the specification of the technology for realizing V2X secure communication through certificates in vehicle networking application scenarios and the mutual trust function of multi-PKI system for dV2X certificates, focuses on the classification, management, content and process of V2X digital certificates and the technical requirements for PKI mutual trust. This document specifies the technical requirements for LTE-based vehicle networking security certificate management system, which mainly includes the security certification management system architecture and the related explicit certificate format and interaction process. It applies to LTE-V2X devices and security certificate management systems.

The Technical Specification for Communication Certificate Management for Vehicle Infrastructure Cooperative System (T/ITS 0127-2020) is based on the application scenario of vehicle infrastructure cooperation and realizes the functions of V2X secure communication and PKI mutual trust based on certificates between vehicle-mounted device (on-board unit, OBU) and road-side device (road-side unit, RSU), focusing on the technical specification of V2X certificate management applicable to Vehicle-Road Co-operation. This document specifies the interface specification for OBU/RSU to apply for communication certificate, including the interface specification for applying for ID certificate and application certificate. It is applicable to OBU/RSU applying for ID certificate/application certificate.

The Transportation—Digital Certificate Format (GB/T 37376) is established in the transport industry. It is based on the national classification of digital certificates, combined with various application scenarios of transport information systems, which focuses on the requirements of various data security services on digital certificate length, computing efficiency and other aspects in the application of intelligent transport systems. It defines the format of ITS device certificates in a standardized manner. This document stipulates the classification of digital certificates and digital certificate formats in transport information systems. It is applicable to the software and hardware system involved, research and development and testing related to digital certificate application in transportation information system.

The EV Charging and Battery Swapping Service Information Exchange (T/CEC 102) is based on the EV charging/battery swapping service scenario and aims to achieve interconnection and interoperability between EV charging/battery swapping facility operation platforms, user platforms, data platforms and EV charging/battery swapping facilities. It specifies the general requirements for the exchange of information on EV charging/battery swapping services, including the structure of the EV charging/battery swapping service information exchange system, information exchange service process, information exchange functions, security mechanisms and performance index requirements. It applies to the exchange of information on EV charging/battery swapping services between EV charging/battery swapping operation service platforms belonging to different operators, and between EV charging/battery swapping operation service platforms and third-party service and management platforms.

3.3.5.5 Demand for new standards

Table 3-20 shows the demand for the new standards for information communication security in EV-RE integration scenarios.

Table 3-20 Demand for new standards for EV-RE secure communications

No.	Standard	Description	Standard categories (national, sectoral, consortium)	Time period
1	Resource coding specification for EV-RE services	Formulate resource definitions, coding rules and application requirements for equipment/facilities, and platforms of EV-RE services	Consortium standard	2 years
2	Unified data model for EV-RE services	Formulate data specification requirements for equipment/facilities, and platforms of EV-RE services	Consortium standard	2 years
3	Information exchange specifications for EV-RE services	Formulate a series of standards for the specification of data exchange between equipment/facilities and platforms of EV-RE services	Consortium standard	2 years
4	Technical requirements for secure authentication of vehicle-pile-network cooperative communication based on digital certificates	Formulate term definitions, application scenario descriptions, digital certificate management system, certificate classification, structure and content, functional structure of CA platform services, as well as testing and judging requirements	Consortium standard	2 years
5	Automatic charging guidance data exchange specification	Set the term definitions automatic charging guidance, processes of data exchange and control, and error handling.	Consortium standard	2 years
6	Energy aggregation data exchange specification	Set the term definitions for energy aggregation platforms and the process for exchanging data between operation platforms.	Consortium standard	2 years

4 Conclusions

4. Conclusions

This Guidelines provides a detailed account of existing technical standards and future development requirements related to five technologies in China: V1G, V2G, integrated microgrid powered by RE with ESS and EV charging, downcycling utilization of retired EV power batteries, and network information system and communication security. The Guidelines also examines how these technologies are applied in various scenarios through ten case studies. While each case study reflects significant economic and climate benefits of the five technologies, perhaps the most striking feature is the approach taken by these ten operators - adapting to local context.

This should caution against drawing conclusions too broadly. In other words, these ten cases cannot be used to draw sweeping conclusions about EV-RE integration technologies in China. Nor can we conveniently draw lessons that will apply to other countries considering China's unique conditions. However, the Guideline suggests some important building blocks for deployment and diffusion of EV-RE integration technologies that are fundamental and universal. These building blocks are summarized in the following findings:

4.1 Findings

(1) Role of domestic policy: incentive policy and deliberate plan are the keys to the EV-RE integration.

The industry development plan clarifies the overall direction and specific policy support for EV-RE integration, which can provide action guidance on EV-grid/RE integration. Various policy guidance and incentive measures can strengthen the confidence of automobile, power and related industries in the R&D and application of vehicle-grid interaction technology, and have a critical impact on fostering emerging industries and multi-industry collaboration. Therefore, grasping key points and taking comprehensive measures will effectively promote the synergy and development process between the automobile industry and RE.

(2) Technical pathways: there are four pathways to the EV-RE integration from the technical perspective.

Pathway 1: The local PV power generation from RE can supply power to EVs via electrical devices of the local power distribution network station level system, and EVs consume photovoltaic electricity directly. This pathway is suitable for the current priority construction scenario of distributed EV charging and battery swapping facilities and PV integrated stations. The construction mode and promotion of new EV charging and battery swapping facilities will be the main bodies to realize the integrated application.

Pathway 2: Through local aggregators and their grid dispatching systems, the electricity generated by the distributed microgrid from RE can be regulated on-grid. With the integrated microgrid facilities such as building energy efficiency designs and EVs in the industry park, the interactive consumption of RE in local areas can be carried out. By aggregating EVs, RE power generation and energy storage resources in the region, on-grid regulation of comprehensive electricity resources and the power balance regulation featuring peak-shaving and valley-filling can be achieved. It is necessary to promote vehicle-pile cloud network technology and application integration so as to accelerate the application of V2X and smart power distribution network technology, to speed up the process of standardization and improvement, and to encourage the virtual power plant business to participate in electricity market transactions, which will be the key to realize the vehicle-grid integration.

Pathway 3: The remote large-scale centralized RE power generation can be accelerated by utilizing regions rich in PV and wind power resources. The comprehensive regulation capability of the grid can be improved through the remote transmission of the smart grid based on the large-scale green electricity consumption by EVs. This pathway is suitable for large-scale development and utilization of green energy and acceleration of the upgrade of V2G technology for EVs, and large-scale on-grid construction of remote centralized wind power generation and PV power generation. It can be an accelerated scenario to peak carbon dioxide emissions with green energy as an alternative.

Pathway 4: The remote centralized RE power generation can be combined with the regionally distributed energy power generation, which will achieve in-depth integration of digital transportation and digital energy system through the intelligent energy regulation system. The development and application of RE can also be both centralized and distributed, and the energy structure layout can gradually evolve and be adjusted. The large-scale connection of EV regulation resources will provide a high proportion of green electricity and a guarantee for continuous and uninterrupted electricity interaction regulation capability for the energy network, presenting characteristics of future intelligent energy scenarios.

(3) An operation platform: a three-layer operation platform forms the base for the EV-RE integration.

The EV-RE integration needs to be based on a three-layer technology platform, namely the vehicle-infrastructure integrated application layer (scenario-facility integration), the information infrastructure layer based on a cloud framework network (network collaborative integration), and the application service layer (application-service integration). Through the interactions with humans, vehicles, facilities, electricity and multiple objectives, the service collaboration of all main links in the entire process of the EV-RE integration system is established, which reflects the basic requirements for adaptation to the large-scale connection of EVs and distributed energy, and the transformation of transportation energy to the digital and intelligent operation mode. In terms of security and efficiency, a high proportion of RE consumption and the composition principle of demand-driven electricity interaction application scenarios should be fully considered.

(4) Inter-sectoral standards: designing national-level and inter-sectoral standards is the key to further development.

The EV-RE integration is a complex inter-sectoral and cross-field system engineering, which needs both energy interaction and information interaction, involves multiple industries, and covers a wide range of fields. In terms of industries, in addition to automobiles and power sectors, it also involves infrastructure construction, information technology application, and new business model innovation. In terms of value chain, downstream industries include EVs, EV charging and battery swapping, communication, microgrid, energy storage and power battery recycling, building energy efficiency, smart control technology, etc. Upstream industries involve raw materials, key component technology, and inter-sectoral, diversified and multi-level industrial technology integration. Inter-sectoral standardization collaboration should be encouraged to form reasonable and efficient technical solutions, to promote the R&D and construction of innovative technology in the industry.

(5) New market and promising business opportunities: lucrative business opportunities are to be materialized as key V2X technologies are being rapidly commercialized, and a suite of sharing-economy business models is being explored.

For the V1G technology

The technology is suitable for large-scale promotion and application as it can relieve the pressure of grid capacity expansion and transformation, and grid companies have the willingness to promote them. Further, the technology itself is mature and has been the main slow charging approach to grid's on-demand response. Moving forward, business opportunities will arise from the optimization of the power distribution network and the main network, as well as the participation of third-party operators in different electricity markets, so as to increase the sharing of market dividends in the development of EVs.

For the V2G technology

Technically it is suitable to commercialize the DC slow-charging and slow-discharging mode, as well as the interactive framework for realizing direct and flexible control of user-end microgrid. Business opportunities will arise from the standardization process of charging and discharging interfaces, the collaboration between energy service/charging & discharging service providers and automobile manufacturers in standard formulation, and pre-installment of V2G interfaces by automobile manufacturers to prevent EV users from accessing power distribution networks for bidirectional interaction in the future. From the business model perspective, governments at various level need to design and enforce more holistic incentive policy. In this spirit, power companies should accelerate the friendly transformation process of the grid structure, and widen the peak-valley price difference to form an all-win situation. These actions by power companies are indispensable for promoting the large-scale application of V2G and looping in EVs into RE consumption.

For the PV-ESS-EV charging V2X microgrid technology

The technology's application and commercialization depend on a breakthrough in V2X system-level technical connectivity and coordinated electricity management technology. Therefore, business models that explore and accelerate the application of the technology should be encouraged. In the near term, the focus is to transform power distribution equipment, prioritize the consumption of local PV electricity, and increase the share of green electricity in local grid. Further into the future, the priority is to create regional coordinated V2X integrated electricity management and dispatching system. Currently, there is no overall solution for layered management platform and implementable open interconnection yet. The solution has to come from inter-sectoral collaboration, establishment of integrated and applicable standards, acceleration of pilot demonstration and verification, and expansion of green energy participated by EVs.

For the energy storage and downcycling utilization of retired EV power batteries

ESS is an important link to RE's capacity and will play a more significant role as share of RE in electricity generation and consumption further increases. The Guidelines provides calculation methods for storage and distribution as well as guidance and requirements for construction. In terms of downcycling, the Guidelines proposes some technical specifications and their application scenarios. Large-scale downcycling, in the long run, is an essential way to realize the efficient utilization of battery resources. This, of course, should be promoted and implemented under the premise of technology reliability and whole life-cycle safety.

For the network information system and communication security

The establishment of a vehicle-grid integrated and cloud-based network as well as information security technology is the foundation of an EV-driven low-carbon, smart and shared economy. Business opportunities will arise from the connectivity between cloud network and vehicle-grid integration network, changes in current data utilization silo, and advancement in multi-field cross-platform information interconnectivity. In longer term, the goals are cross-industry business collaboration, and establishment of a service-based cloud-edge computing collaboration infrastructure to support information platform, and to meet the future intelligent application scenarios of cloud-intelligence integration. In the use of modern technologies such as cloud framework, big data and artificial intelligence services, attention should be paid to information security and communication security guarantee. The Guidelines puts forward a reference solution based on the construction of the vehicle-grid integration network infrastructure platform with whole-process and whole-network information services and communication security technology, which meets the development trend and requirements of the future network support system for achieving efficient service, convenient application, and security and reliability.

4.2 Recommendations

For the automobile manufacturers

Tremendous opportunities exist in large-scale production and diffusion of vehicle models with the functions of V1G and V2G. On the vehicle side, by establishing interoperable interfaces among V1G, V2G and charging facilities, the requirements for bidirectional interactive electricity control of V2G and online connection of terminals in long-link application scenarios will be met, and the improved requirements for safety protection performance of electrical components on HV platforms will be adapted to. The vehicle-pile slow-charging mode needs the communication control link, with the communication connection capability of wireless coverage to realize the function of charging guidance and vehicle-pile cooperative control.

For the charging infrastructure service providers

Construction of new charging facilities with bidirectional charging functions is where new revenue streams flow. Therefore, developing effective business models to materialize the revenue streams is critical. The basic vehicle-pile-microgrid application systems dominated by V1G, V2G and V2H should be established, and EVs, EV charging/battery swapping infrastructure, power systems and building energy efficiency and other industries should be integrated, so as to implement integrated industrial development, to promote industrial technological changes, and to build new transportation and energy infrastructure service systems. Public charging piles shall be transformed and constructed into V1G piles in a centralized and smart way, and the one-to-many advantage between public piles and public parking spaces should be utilized to improve the utilization rate of charging piles. The sharing of private piles and DC slow-charging should be actively developed, battery fast-swapping and vehicle separation and circulation and other services should be promoted, and business operation modes should be innovated to achieve a win-win result for both users and the grid.

For the information service providers

Market penetration comes from an acceleration of data interconnection, cross-platform data sharing, accelerated application of internet of things, and expansion of C-V2X integrated application and extended development with smart infrastructure. The cross-platform information integration and interconnection across industries and fields such as automobile, energy and infrastructure, and secure and reliable communication should be achieved, so as to improve the compatibility of the integration communication network, the safety of interoperation control, and the intelligence of the application system. On the cloud end, according to the management requirements for the electricity operation service business, the service function should be established, and electricity resources should be regulated so that they can adapt themselves to electricity resource management of vehicles and facilities, and realize the identification of charging ports, vehicles and batteries. On the grid side, the business service networks among vehicles and charge-storage-discharge systems, user-side distributed microgrids, electricity aggregators and electric power dispatch systems should be established to connect vehicles and facilities to the cloud service platforms. Edge computing facilities provide distributed computing, support the cloud to carry out power resource aggregation, transactions and services, and implement multi-subject agreement coordination, demand response and power dispatching.

For the power sector

New opportunities lie in coordinated development of smart EVs and smart grid, improvement of a pricing system for EVs charging, and creation of a transaction mechanism for load aggregators to participate in spot market transactions. Power resource aggregation and multi-level power coordination services should be provided to achieve a high proportion of utilization of massive storage resources (mobile energy storage and microgrid energy storage). Vehicles, EV charging /battery swapping facilities and centralized and distributed ESS should be gradually adapted to the technical platform with distributed energy interconnection and operational requirements, so as to achieve electricity production and consumption mode of source-grid-load-ESS, and source-load interaction. The innovation in technologies and modes will be promoted, and the development of vehicles, energy and power infrastructure will be effectively promoted in an efficient, low-carbon and win-win manner, so as to enable the upstream and downstream industries of the value chain to promote and support each other and pursue coordinated development. According to the characteristics of target groups in different interaction scenarios, a collaborative and interactive intelligent energy system should be established at the main grid and distribution network level through smart electricity consumption and regional dispatch, so as to motivate EV users to actively participate in demand response by market means. On the one hand, the charging cost of users will be reduced, and the utilization rate of charging facilities will be improved. On the other hand, the capabilities of new energy consumption and demand response will be effectively improved to form a virtuous cycle of source-load development. A complete electricity spot market and auxiliary service market should be established. The types of market participation and methods for revenue calculation should be clarified. The mechanisms for market access, settlement, assessment and participation in the market competition should be defined. And the third-party entities such as EVs and energy storage should be encouraged to participate in the operation of the auxiliary service market.

For the regional planners

Construction of PV-ESS-EV charging microgrid systems is especially suitable for rural areas and regions with a high EV penetration rate. The PV-ESS-EV systems can not only accelerate the application of EVs in rural areas, but also enhance the local consumption of RE. In industrial parks, campuses, business parks and other cluster scenarios, large-scale centralized PV power generation systems and energy storage systems can be built. Energy management systems can be fitted in such scenarios to coordinate power management together with the large electric systems in the cluster, for charging of employees' EVs and electricity consumption of office buildings. In rural areas, small and distributed PV power generation systems and energy storage systems can be built for residential electric two-wheelers, EV charging and household electricity consumption of villagers. For public facilities such as EV charging/battery swapping stations, public charging stations can be built according to the requirements of the integrated PV-ESS-EV charging power station, equipped with a small PV power generation and ESS to provide supplementary power for the charging station. At the same time, the stations can also offer battery inspection services and battery swapping services for EVs. According to the actual situation, the energy management system will analyze the PV power generation and the charging demand of EVs to alleviate the pressure on the power distribution network.

For the EV battery producers

The breakthrough for EV battery producers comes from the safety protection and control technology of power batteries' life cycle application. The development of new battery systems should be accelerated to tackle difficulties in safety performance. The socially shared application of battery consistency management and tracing systems should be developed to support the deployment of safe and efficient RE storage systems and guarantee the life-cycle safety of battery systems. In addition, the prediction and planning of intelligent energy technology and the research and construction of technical systems should be accelerated.

In an integration scenario, surplus electricity required by EVs can participate in the electricity market transactions through the shared service platform. **For EV users,** incentives should be given to guide valley-period charging and off-peak charging to effectively reduce the electricity consumption cost of charging facilities, obtain revenues from auxiliary services, and improve users' willingness to purchase vehicles and the satisfaction. **For grid operators,** focuses should be dedicated to providing sufficient and balanced service resources, effectively improving the instantaneous balance capability of the grid while improving the fast-charging capability, mitigating cost for grid's capacity expansion and transformation, and improving the operation efficiency of the grid assets to overally enhance grid resource allocation capability. **For the market,** the key is to develop new operation mechanisms for electricity aggregation services. Innovative business models shall be accordingly created. **For energy modes,** the priority is to encourage green charging, fundamentally increase RE consumption, so as to realize the original intention of deploying and diffusing EVs - to promote sustainable energy development.

In summary, China has accelerated its deployment of RE-EV integration in recent years, indicating its commitment to becoming a global player in the low-carbon economy, and contributing to the goal of global carbon neutrality by 2050. While reflecting on China's success and lessons-learnt, it is important not to lose sight of China's unique advantages – the sheer size of the Chinese market and governments' policy design and enforcement capacity. Nevertheless, the decisive role of the government in providing clear and lasting signals for all low-carbon technologies and the central role that government-funded pilots and demonstrations can play give some clear instances of success from which other countries can benefit. Such lessons are critically important to global efforts to scaling up low-carbon technology deployment to tackle climate change.

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