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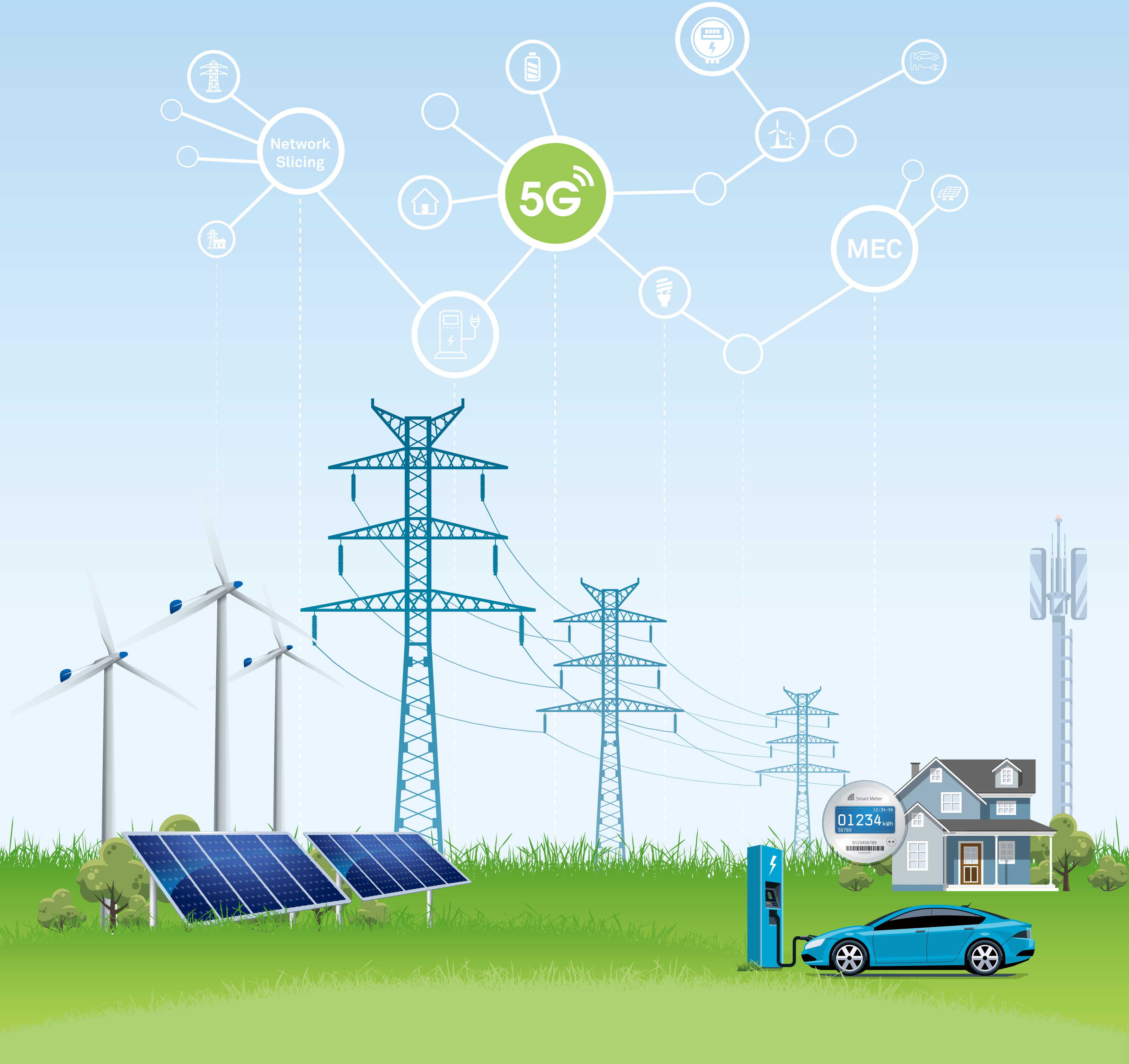
5G Network Slicing Enabling the Smart Grid



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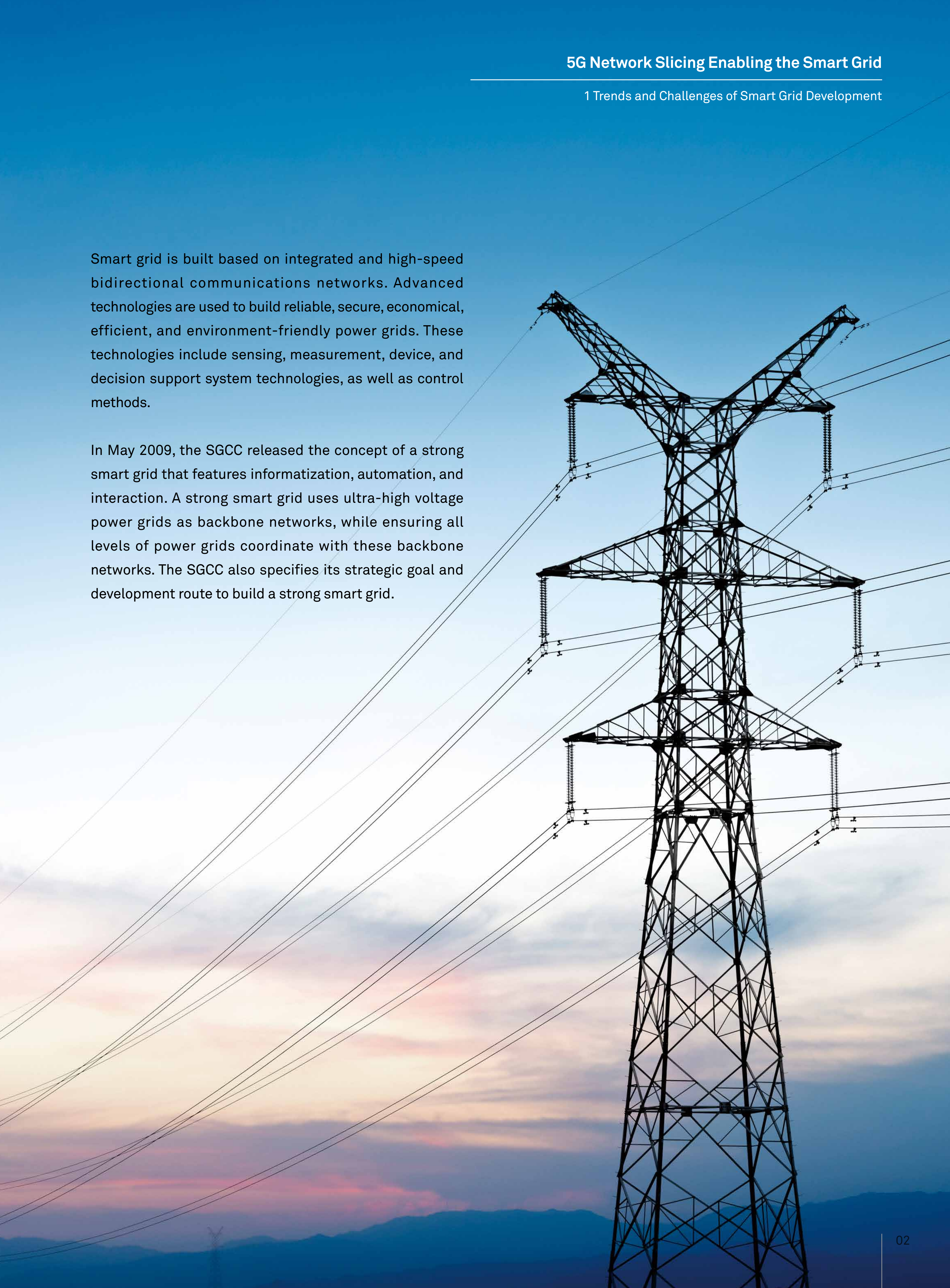
Introduction

In recent years, the State Grid Corporation of China (SGCC) has been building a strong smart grid to improve the security level of the power grid. By implementing the Internet+ strategy, the SGCC comprehensively improves the informatization and intelligence of the power grid and fully utilizes modern information communication technologies and control technologies. This achieves effective security, clean energy, close coordination, and intelligent development of the power grid and provides reliable power for economic and social development. With the rapid development of power consumption information collection, distribution automation, distributed energy access, electric vehicle services, and bidirectional user interaction, the communication requirements of various power grid devices, power terminals, and customers are rapidly increasing. New real-time, stable, reliable, and efficient communication technologies and systems, suitable for the electric power industry, are urgently needed for monitoring the status of and collecting information about intelligent devices and triggering new working modes and power service modes.

4G changes lives, but 5G changes societies. Vertical industries represented by power grid will complete digital transformation in the 5G era. "Industry 4.0" of Germany and "Made in China 2025" both require fast network connections. 5G networks will bring better bandwidth experience and enable vertical industries. In the 5G era, diversified vertical industry applications will bring more extensive requirements for mobile networks. Ultra-high bandwidth, ultra-low latency, and an ultra large number of connections will change the operating and working modes of core services in vertical industries, improving the operational efficiency and decision-making intelligence of traditional vertical industries. Network slicing emerges from this background. It provides agile and customizable capabilities that allow the construction of dedicated networks for different applications.

Intelligence technologies represented by artificial intelligence (AI) are driving the fourth industrial revolution. Electricity is the blood of industrialization, and network connections are the nerves. The combination of power grids and 5G networks will provide a solid foundation for the intelligent industrial revolution and help "Made in China 2025" to achieve its target.

Smart grid is the basis of smart energy and is important for promoting economic and social coordination and sustainable development. It provides strong support for a better life, cleaner environment, and more harmonious society. This helps refine energy management and enables transformation to clean energy and electrical energy.



Smart grid is built based on integrated and high-speed bidirectional communications networks. Advanced technologies are used to build reliable, secure, economical, efficient, and environment-friendly power grids. These technologies include sensing, measurement, device, and decision support system technologies, as well as control methods.

In May 2009, the SGCC released the concept of a strong smart grid that features informatization, automation, and interaction. A strong smart grid uses ultra-high voltage power grids as backbone networks, while ensuring all levels of power grids coordinate with these backbone networks. The SGCC also specifies its strategic goal and development route to build a strong smart grid.

1

Trends and Challenges of Smart Grid Development

Smart grids are facing new challenges and opportunities during development and construction.

- New energy: Renewable energy is vital for electricity generation to cope with global warming and achieve sustainable development. The large-scale deployment of renewable energy brings new challenges to the operation and management of power grids. The intermittent and random power generation of renewable energy brings difficulties to power balancing and operation control. On the other hand, the deep penetration of distributed energy resources (DER) transforms distribution networks from passive networks with one-way flows to active networks with bidirectional power flows.
- New users: The rapid development of electric vehicles increases requirements for available charging capacity. For better demand-side management (DSM) (such as peak load shaving), new methods can be used to manage electrical power. For example, an electric vehicle can charge when necessary rather than upon connection.
- New requirements: New devices and new scenarios require higher quality of consumption. For example, some high-tech digital devices require zero interruption of power supplies. In addition, requirements for asset utilization efficiency are gradually increasing from the perspective of power grid operation. Such requirements include improving device utilization efficiency, reducing the capacity/load ratio, and reducing line loss. In this case, the load and power supply of power grids must be adjusted with more accuracy.

2

Typical Service Scenarios of a 5G Network Slicing Enabled Smart Grid

From the current perspective, a power grid consists of five phases: power generation, transmission, transformation, distribution, and consumption. Requirements of electric power industry partners are fully surveyed, discussed, and analyzed. There will be four typical smart grid application scenarios that may require wireless communications and are likely to be enabled by 5G network slicing in the future. These scenarios include intelligent distributed feeder automation, millisecond-level precise load control, information acquirement of low voltage distribution systems, and distributed power supplies.

Typical Service Scenarios of Smart Grids

Intelligent distributed feeder automation

Millisecond-level precise load control

Information acquirement of low voltage distribution systems

Distributed power supplies

Figure 2-1 Typical service scenarios of smart grids

2.1 Scenario 1: Intelligent Distributed Feeder Automation

2.1.1 Service Scenario

Distribution Automation is an integrated information management system that uses computer technology, data transmission, control technology, modern equipment, and management. It is used to improve the reliability of power supplies and the quality of consumption, provide high-quality services to users, reduce operational costs, and reduce labor intensity. The development of the Distribution Automation system can be divided into three stages:

- In the first stage, automatic switching devices, which are mainly reclosers and sectionalizers, work together, and communications networks and computer systems are not required. If a fault occurs, the automatic switching devices isolate the area in which the fault occurred and continue supplying power to other areas. During this stage, automatic reclosers and standby reserved auto-switch-on devices are used, and manual operations are still required. These systems are still widely used.

- In the second stage, communications networks, feeder terminal units, and backstage computer networks are used. When the power distribution network is running properly, the Distribution Automation system monitors the operating status of the power distribution network and changes the operating mode remotely, allowing prompt fault detection. In addition, a dispatcher can isolate the fault area remotely and restore the power supply in other areas.
- As computer technology develops, the Distribution Automation system moves to the third stage. In this stage, automatic control functions are added. These functions enable an integrated automation system that uses the supervisory control and data acquisition (SCADA) system, power distribution geographic information system, DSM, dispatcher scheduling simulation, fault call service system, and work management. In addition, a distribution management system (DMS) is provided. This system has more than 140 functions including substation automation, feeder section switch control, capacitor bank regulation control, user load control, and remote meter reading. Currently, the Distribution Automation system is developed based on these functions.

2.1.2 Development Trends and Characteristics

Centralized distribution automation is now the mainstream solution. This solution's communication system mainly transmits data service traffic including telemetry and teleindication information that is uploaded from terminals to primary sites (uplink direction) and routine instructions and remote control commands for line fault isolation and restoration in line or segment locating that are delivered from primary sites to terminals (downlink direction). There is more uplink traffic than downlink traffic, and primary sites are deployed in prefectural-level cities.

High-reliability power supply areas are required for providing a continuous power supply and ensuring the accident isolation time does not exceed milliseconds. This brings more severe challenges to the centralized processing capabilities and latency of primary sites in centralized distribution automation. Therefore, intelligent distributed feeder automation becomes one of the trends of power distribution network automation. In intelligent distributed feeder automation, the processing logic of primary sites goes to smart power distribution terminals. By means of peer-to-peer communications between terminals, intelligent judgment, analysis, fault location, fault isolation, and power supply recovery in non-fault areas can be implemented. This makes the troubleshooting process fully automated, minimizing the duration and scope of power failures and shortening the troubleshooting time from minutes to milliseconds.

Development Phases of Distribution Automation

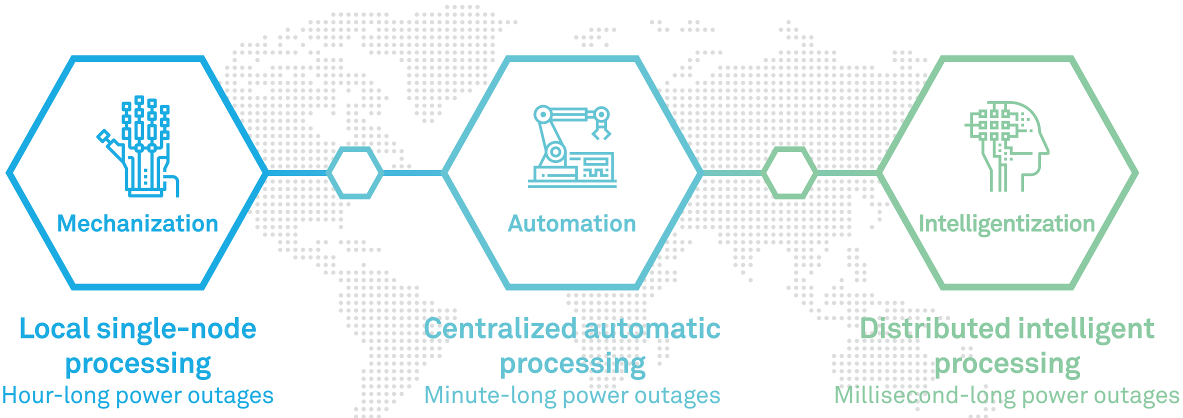


Figure 2-2 Development trends of distribution automation

2.1.3 Key Requirements for Communications Networks

The key requirements of intelligent distributed feeder automation for communications networks are as follows:

- Ultra-low latency: milliseconds
- High isolation: Distribution automation is a service in the I/II production area of the power grid. It must be completely isolated from services in III/IV management areas.
- High reliability: 99.999%

Network Requirements of Intelligent Distributed Feeder Automation

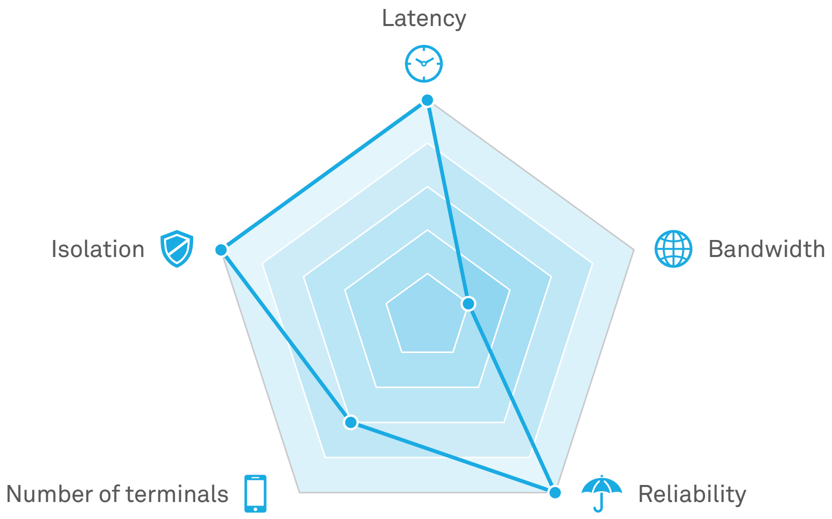


Figure 2-3 Key performance indicator (KPI) requirements of intelligent distributed feeder automation for communications networks

2.2 Scenario 2: Millisecond-Level Precise Load Control

2.2.1 Service Scenario

Power grid load control mainly includes two control modes: scheduled batch load control and marketing load control. When the power grid fails, the stability control system urgently removes the load to prevent the power grid from being damaged. The low frequency and low voltage load reducing device can be further used to avoid the breakdown of the power grid. Load removal using the stability control system will have a great impact on society, and the use of the load reducing device means a larger scale of power loss. During the transition to ultra-high voltage (UHV) AC/DC power grids, a secure and stable control system is an important means to ensure power grid security in emergencies. If a feed-in UHVDC system encounters bipolar blocking and the power loss of the receiving-end power grid exceeds a certain limit, the power grid frequency will drop seriously, or the system frequency may even break down. To ensure the stable and secure operation of a power grid after DC faults occur, the power of the power grid is balanced by means of multi-DC improvement and pump switching at pumped storage power stations. However, if these measures cannot make up the frequency drop caused by severe DC faults, urgent load removal is still necessary. If severe faults, such as DC bipolar blocking, occurs and the traditional method of centralized load removal on 110 KV lines is used, power accidents will be triggered, which will cause a great social impact. If the precise load control system based on the stability control technology is used, interruptible load within enterprises is controlled, which meets the emergency handling requirements and involves only enterprises. In this case, only interruptible load is removed, thereby minimizing the economic loss and social impact. This is a technical innovation in the current load control system.

2.2.2 Development Trends and Characteristics

Traditional power distribution networks are not deployed with sufficient communications networks and do not support precise load removal. Generally, only an entire power distribution line can be removed. To reduce impacts on services and user experience, precise control is required to first remove interruptible less-important load, such as electric vehicle charging piles and non-continuous production power supplies in factories.

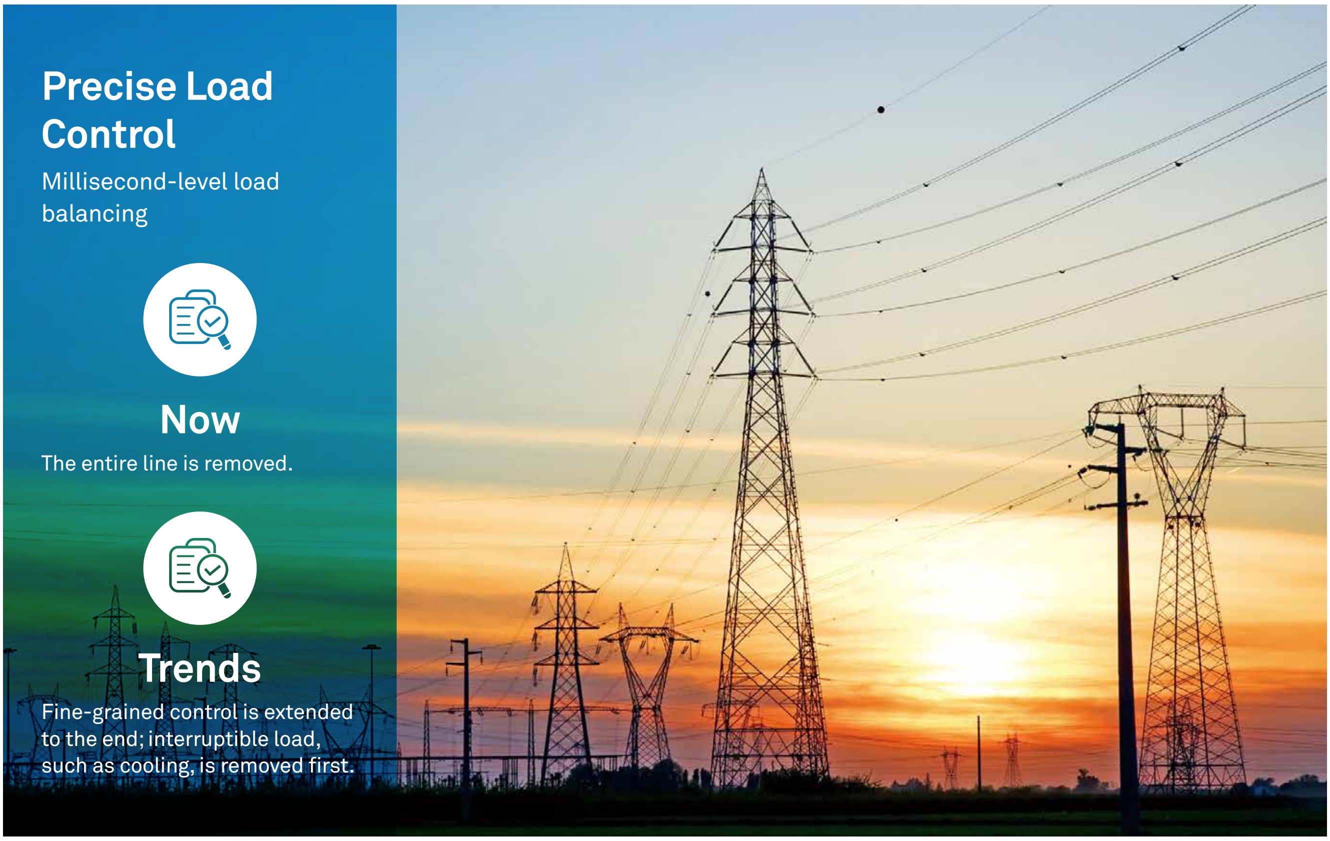


Figure 2-4 Development trends of precise load control

2.2.3 Key Requirements for Communications Networks

The key requirements of millisecond-level load control for communications networks are as follows:

- Ultra-low latency: milliseconds
- High isolation: Precise load control is a service in the I/II production area of the power grid. It must be completely isolated from services in III/IV management areas.
- High reliability: 99.999%

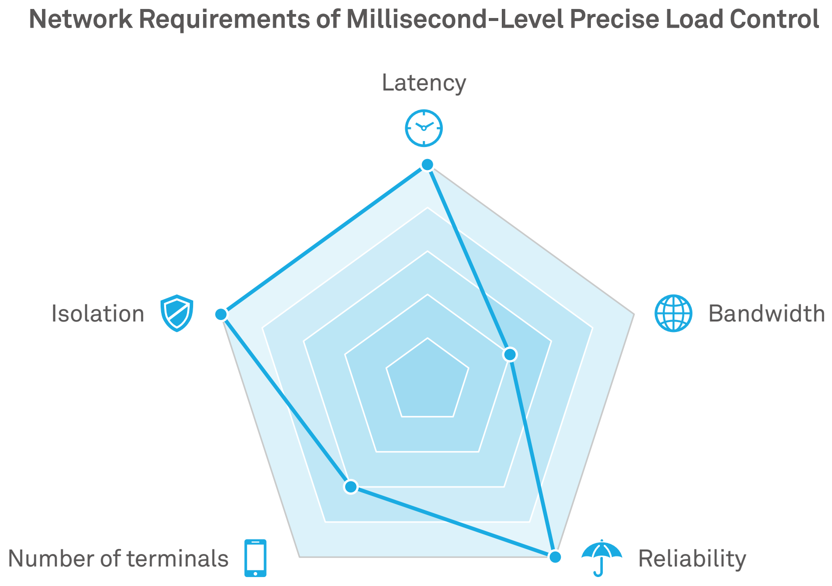


Figure 2-5 KPI requirements of millisecond-level load control for communications networks

2.3 Scenario 3: Information Acquirement of Low Voltage Distribution Systems

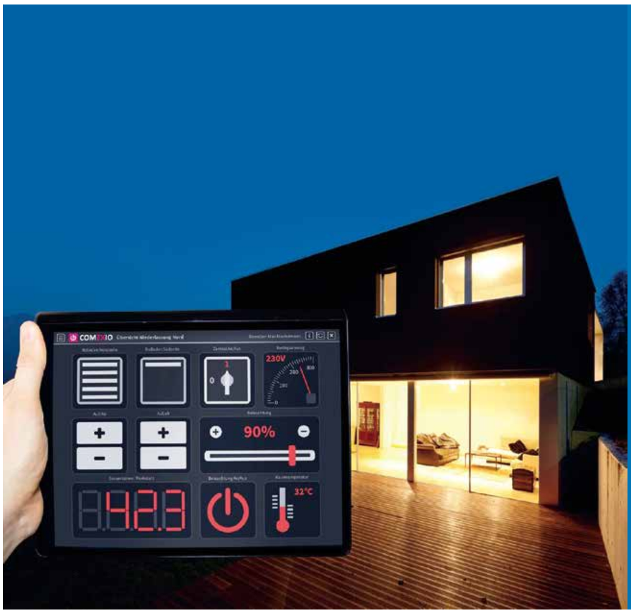
2.3.1 Service Scenario

Power consumption information of electric power users is collected, processed, and monitored in real time. This enables various functions including automatic power consumption information collection, monitoring of abnormal measurements and the quality of consumption, power consumption analysis and management, related information release, distributed energy monitoring, and information exchange of smart electric devices.

2.3.2 Development Trends and Characteristics

The power user electric energy data acquire system is mainly used for metering and primarily transmits data service traffic. The traffic includes state parameters uploaded from terminals to primary sites (uplink direction) and routine instructions and commands delivered from primary sites to terminals (downlink direction). There is more uplink traffic than downlink traffic. Existing communication modes include 230 MHz dedicated networks, wireless public networks, and optical fiber transmission. All types of terminals adopt concentrator mode. Currently, primary sites are deployed in centralized mode in provincial companies. There were 24 measurement points every day. Currently, information is collected at a 5- or 15-minute interval as well as at 00:00 every day.

New services will bring requirements for real-time and quasi-real-time reporting of power consumption data. In addition, the number of terminals will be further increased. In the future, the collection of power consumption information will be further extended to families to obtain the load information of all electric terminals. This will ensure a more refined balance between supply and demand and guide reasonable off-peak power consumption. For example, the multistep electricity price policy has been implemented in certain countries. In this case, the electricity price needs to be publicized in real time so that users can purchase electricity as required.



Information Acquirement of Low Voltage Distribution Systems

Extended to families to guide reasonable off-peak power consumption for a balance between supply and demand

Now

Small-scale, low-frequency, used for metering

Trends

Massive, quasi-real-time, used to promote off-peak power consumption

Figure 2-6 Development trends of information acquirement of low voltage distribution systems

2.3.3 Key Requirements for Communications Networks

The key requirements of information acquirement of low voltage distribution systems for communications networks are as follows:

- Massive access: tens of millions of terminals
- High frequency and high concurrency: second-level to quasi-real-time data reporting in the future

Network Requirements of Information Acquirement of Low Voltage Distribution Systems

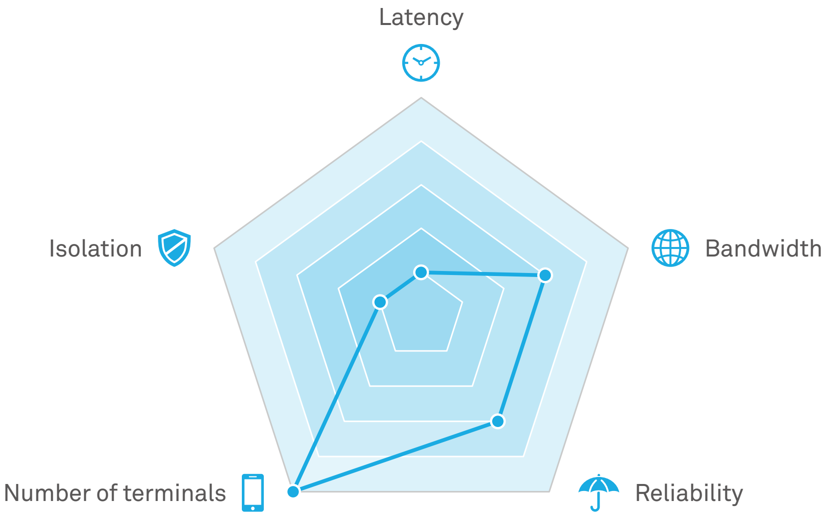


Figure 2-7 KPI requirements of information acquirement of low voltage distribution systems for communications networks

2.4 Scenario 4: Distributed Power Supplies

2.4.1 Service Scenario

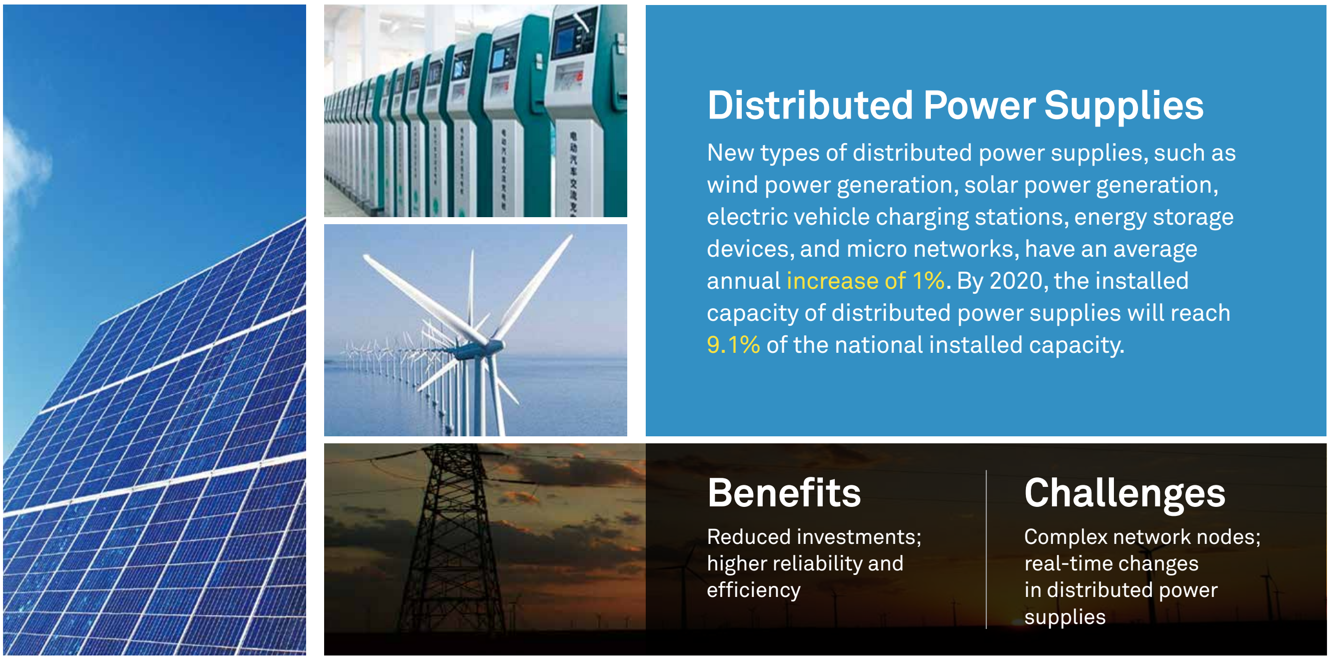
New types of distributed power supplies, such as wind power generation, solar power generation, electric vehicle charging stations, energy storage devices, and micro networks, are energy supply modes built at the user end. Such power supplies can run independently or be deployed on power grids. As energy transformation develops, the fast integration and accommodation of clean energy have become pressing issues for power grid enterprises.

In China, distributed power supplies are developing rapidly. The proportion of these power supplies increases year by year, with an average annual increase of nearly 1%. By 2020, the installed capacity of distributed power supplies is predicted to reach 187 million kilowatts, accounting for 9.1% of the national installed capacity at that time. Integrating distributed power supplies into power grids is an indispensable link in the development of strong smart grids and will bring great benefits. This saves investments on power transmission networks, improves the reliability and efficiency of the entire system by providing emergency power and peak load power grid support. In addition, the system will be more flexible. For example, if a power grid is damaged by the weather, distributed power supplies can form isolated islands or micro networks. These can provide emergency power supplies to important areas, such as hospitals, traffic hubs, and broadcast and TV stations.

2.4.2 Development Trends and Characteristics

Connecting distributed power supplies to power distribution networks also brings new technical problems and challenges to the secure and stable operation of the power distribution networks. This is because distributed power supplies were not considered in the design of traditional power distribution networks. After distributed power supplies are integrated, a radial network with a single power supply becomes a network with two or more power supplies. The power flow mode on the power distribution network is more complex. Users are both users and generators of electricity, and current flows are bidirectional and change dynamically in real time.

Therefore, new technologies and tools are required to increase the reliability, flexibility, and efficiency of power



Distributed Power Supplies

New types of distributed power supplies, such as wind power generation, solar power generation, electric vehicle charging stations, energy storage devices, and micro networks, have an average annual increase of 1%. By 2020, the installed capacity of distributed power supplies will reach 9.1% of the national installed capacity.

Benefits

Reduced investments; higher reliability and efficiency

Challenges

Complex network nodes; real-time changes in distributed power supplies

Figure 2-8 Development trends of distributed power supplies distribution networks. A distributed power monitoring system can be used to automatically monitor and control the operation of distributed power supplies. This system has many functions including data collection and processing, active power adjustment, voltage/reactive power control, grid islanding detection, scheduling and coordination control, and interconnection with related service systems. The distributed power monitoring system consists of the distributed power monitoring master station, distributed power monitoring sub-stations, distributed power monitoring terminals, and communication system.

2.4.3 Key Requirements for Communications Networks

The key requirements of distributed power supplies for communications networks are as follows:

- Massive access: millions of to tens of millions of terminals
- Low latency: Distributed power supply management includes uplink data collection and downlink control. Downlink control flows require second-level latency.
- High reliability: 99.999%

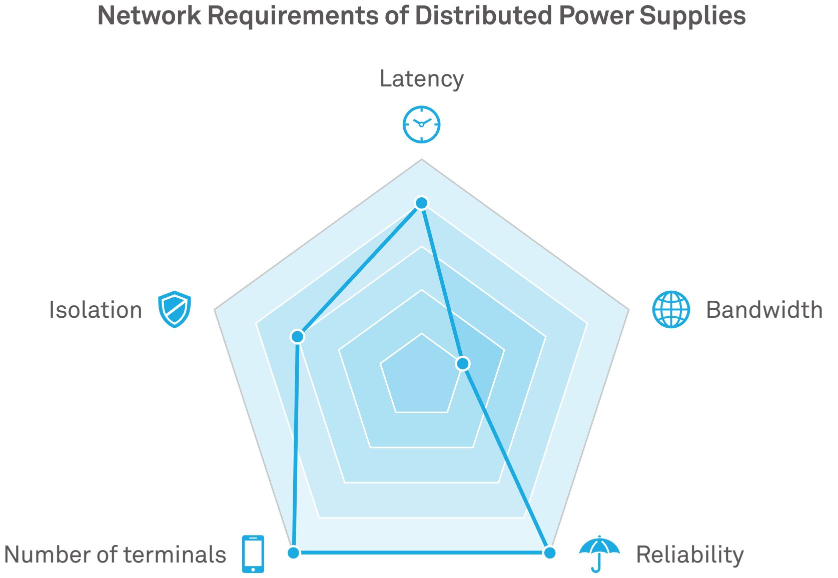


Figure 2-9 KPI requirements of distributed power supplies for communications networks

5G network slicing is designed to handle specific service requirements, meets differentiated service level agreements (SLAs), and automatically builds isolated network instances on demand. 5G network slicing provides end-to-end (E2E) network assurance for SLAs, service isolation, customizable on-demand network function, and automation. It enables communication service operators to dynamically allocate network resources and provide network as a service (NaaS). It also provides more agile services, stronger security isolation, and more flexible business models for industry customers.

3

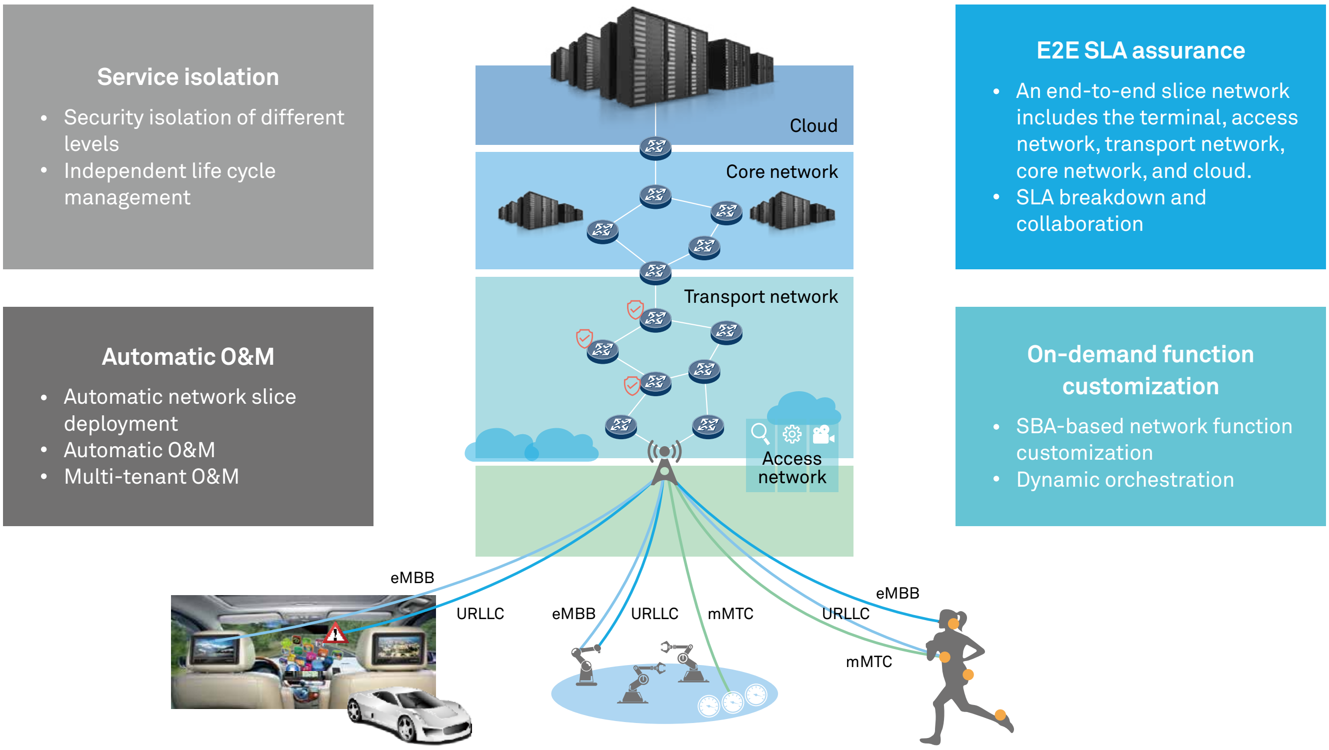
5G Network Slicing

3.1 Concepts and Features of 5G Network Slicing

5G network slicing has rich features. Generally, a network slice is a tenant-oriented virtual network, meets differentiated SLA requirements, and can be managed independently in terms of the life cycle. 5G network slicing is designed to handle specific service requirements, meets differentiated SLA requirements, and automatically builds isolated network instances on demand.

5G network slicing provides E2E network assurance for SLAs, service isolation, on-demand network function customization, and automation.

- **E2E SLA assurance:** A 5G network slice consists of multiple sub-domains, such as the core network, wireless network, and transport network. The SLA of the network slice is ensured by the E2E network consisting of multiple sub-domains. The network slice implements collaboration among multiple sub-domains, including network requirement breakdown, SLA breakdown, and deployment and networking collaboration.
- **Service isolation:** Network slices are used to construct different network entities for various applications. Logically isolated dedicated networks ensure that services of different slices do not affect one another.
- **On-demand function customization and dynamic orchestration:** Service-based architecture (SBA) and service-based restructuring of the software architecture enable network orchestration capabilities on 5G networks. To meet diversified network requirements of different industries, on-demand orchestration capabilities on 5G networks provide different network capabilities specific to each application. Additionally, 5G networks allow services to be deployed in different locations to meet different latency requirements.
- **Automatic O&M and multi-tenant O&M:** Automation is the goal of network development. A traditional large network meets all requirements. 5G uses slicing to split one network into multiple networks. Theoretically, 5G proliferation will increase O&M difficulty. Therefore, automation is an inevitable requirement for 5G networks.
  It is very difficult to implement full automation at once. Operations of each phase in the life cycle of a network slice can be performed manually, semi-automatically, and then automatically, step by step. Full automation is achieved gradually along with the development of network planning capabilities and the flattening and simplification of networks.
  Network slicing allows specific tenants, such as industry users, to use customized network services. Each tenant has their own capacity for operating and maintaining their networks, but the level of expertise of tenant O&M personnel is different from those of traditional operator O&M personnel. Therefore, O&M GUIs that are easy to observe, operate, and manage are generally required for tenants to self-manage their networks.



Service isolation

- Security isolation of different levels
- Independent life cycle management

Automatic O&M

- Automatic network slice deployment
- Automatic O&M
- Multi-tenant O&M

E2E SLA assurance

- An end-to-end slice network includes the terminal, access network, transport network, core network, and cloud.
- SLA breakdown and collaboration

On-demand function customization

- SBA-based network function customization
- Dynamic orchestration

3.2 E2E Architecture of 5G Network Slicing

A network slice consists of multiple sub-domains and involves the management plane, control plane, and user plane. The following figure shows the E2E architecture of 5G network slicing.

The E2E slice life cycle management architecture consists of the following key components:

- Communication Service Management Function (CSMF)

  The CSMF is the first step to slice design. It fulfills service system requirements, converts the requirements into E2E network slicing requirements, and transfers the converted requirements to the Network Slice Management Function (NSMF) for network design.
- NSMF

  The NSMF is responsible for E2E slice management and design. After obtaining E2E network slicing requirements, the NSMF generates a slice instance, combines and divides the requirements based on sub-domain/subnet capabilities, and then transfers the deployment requirements for sub-domains/subnets to the Network Slice Subnet Management Function (NSSMF). Additionally, the NSMF collaborates with multiple sub-domains/subnets of the core network, transport network, and wireless network during the life cycle of a network slice.

- NSSMF

  The NSSMF manages and designs slices of sub-domains/subnets. The core network, transport network, and wireless network have their own NSSMFs.
- The NSSMF reports sub-domain/subnet capabilities to the NSMF and obtains deployment requirements specific to the sub-domain/subnet from the NSMF. Then the NSSMF implements autonomous deployment and enabling in the sub-domain/subnet and manages and monitors the slice network of the sub-domain/subnet during operation.

  The CSMF, NSMF, and NSSMF collaborate to complete E2E slice network design, instantiation, and deployment.

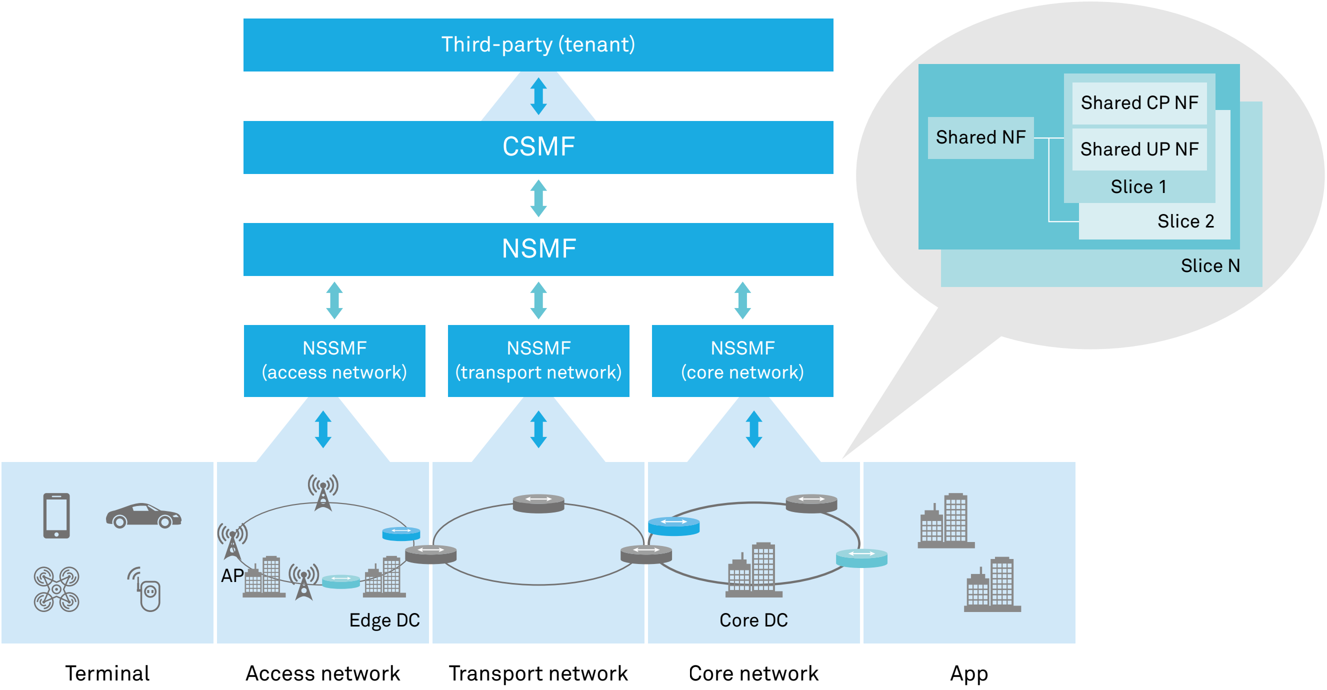
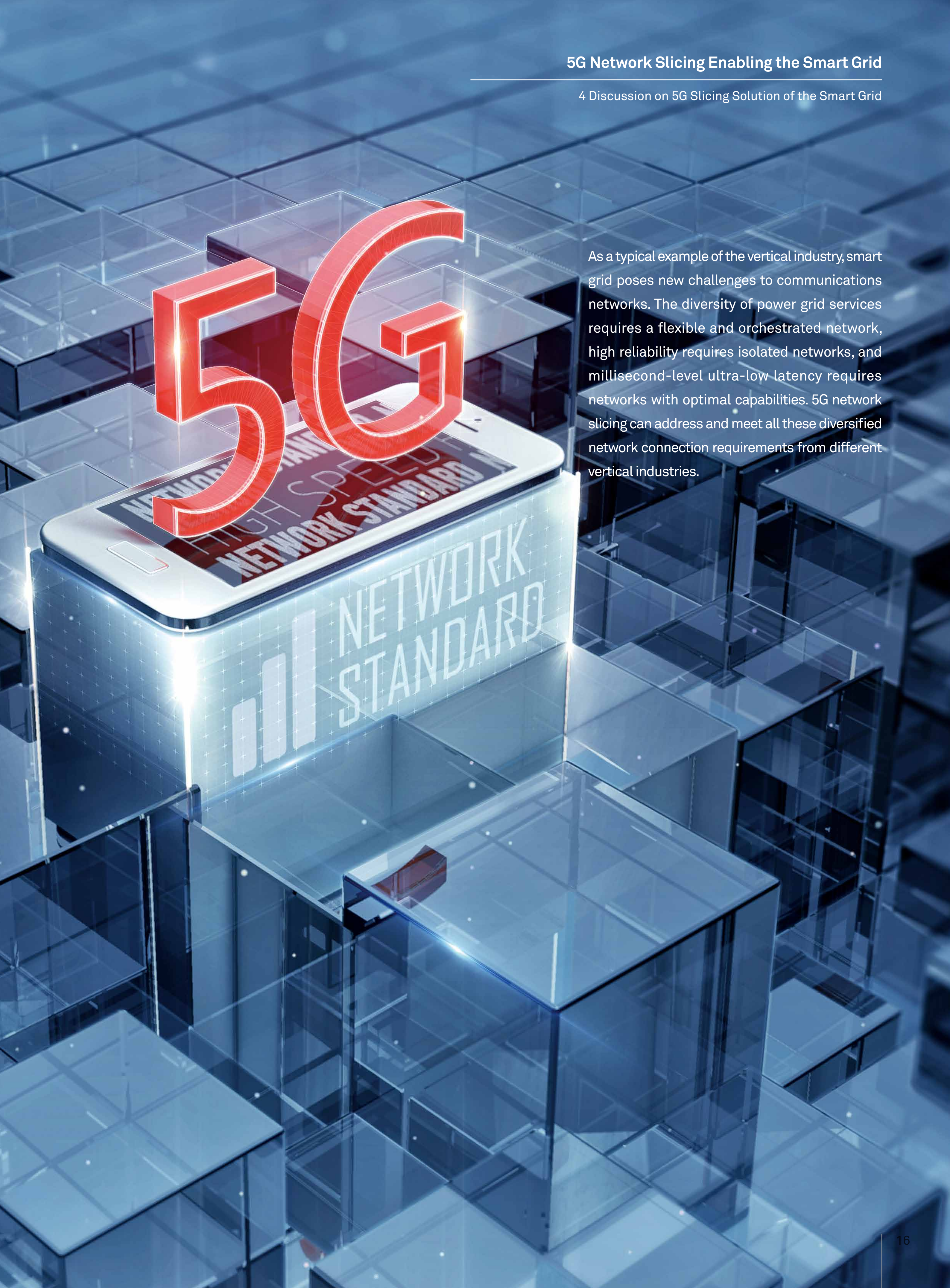


Figure 3-1 E2E architecture of 5G network slicing

3.3 Benefits of 5G Network Slicing

5G slicing can bring the following benefits to end users, tenants, and operators:

- End users can enjoy the best service experience through guaranteed SLAs provided by device-pipe-cloud collaboration on E2E slice networks.
- **Tenants have the following benefits:** (1) Resource sharing reduces network costs. (2) Isolation and on-demand deployment ensure E2E network SLA achievement. (3) On-demand function customization can quickly meet service deployment, upgrade, and evolution requirements. (4) Capability exposure of slice networks enables simple O&M and network capability availability.
- **Operators have the following benefits:** (1) Maximized use of network infrastructures helps operators develop a large number of vertical industry user groups. (2) Resource sharing and dynamic deployment enable efficient and fast network construction. (3) Fast service rollout and innovation promote a new industry ecosystem.



As a typical example of the vertical industry, smart grid poses new challenges to communications networks. The diversity of power grid services requires a flexible and orchestrated network, high reliability requires isolated networks, and millisecond-level ultra-low latency requires networks with optimal capabilities. 5G network slicing can address and meet all these diversified network connection requirements from different vertical industries.

4

Discussion on 5G Slicing Solution of the Smart Grid

4.1 Smart Grid Enabled by 5G Network Slicing

As a typical example of the vertical industry, smart grid poses new challenges to communications networks. The diversity of power grid services requires a flexible and orchestrated network, high reliability requires isolated networks, and millisecond-level ultra-low latency requires networks with optimal capabilities. Even when a 4G network is lightly loaded, its ideal latency can only be about 40 ms, which does not meet the millisecond-level latency requirements of power grid control services. Besides, all services on the 4G network are running on the same network, and services may directly affect one another, which does not meet the service isolation requirements of the power grid. In addition, the 4G network provides the same network functions for all services, which does not meet diversified service requirements of the power grid. 5G network slicing addresses these problems and can meet the diversified network connection requirements of vertical industries.

5G network slicing enabling the smart grid

Diversification of services
New energy, new users, and new requirements bring new challenges of load balancing for the power grid.

Security isolation
Communication isolation and independence are required for key services.

High performance requirements
Remote control of the power grid services requires millisecond-level latency for communication with each single terminal.

High costs of dedicated networks
Ten millions of power distribution terminals do not have network access means.

On-demand deployment
Network functions are customized according to service requirements.

E2E SLA assurance
5G network slicing provides E2E millisecond-level low-latency guarantee.

Network slicing

Isolation
Logically isolated dedicated networks are constructed on the shared telecom infrastructures.

Automation
Shared infrastructures, automatic deployment, and automatic O&M reduce costs.

Distribution automation	Power consumption data collection	New energy vehicle	Distributed power supply	Precise load control

Figure 4-1 Smart grid enabled by 5G network slicing

4.1.1 Technical Perspective

From the technical perspective, 5G network slicing can meet connection requirements of core industrial control services of power grids.

- 5G is a new-generation wireless communications technology. Its design considers the scenarios of not only the human-human communication but also the thing-thing and human-thing communication. The ultra-low latency (1 ms) and massive access (10 million connections/square kilometer) network capabilities can well meet the connection requirements of core industrial control services on the power grid.
- The network slicing technology, which is first introduced by 5G networks, can achieve security and isolation at the same level as dedicated networks with greatly decreased construction costs compared with dedicated fiber networks built by enterprises.
- The 5G edge computing technology enables distributed gateway deployment to implement local traffic processing and logical computing, which saves bandwidths and reduces latency. This further meets the ultra-low latency requirements of industrial control services on the power grid.

4.1.2 Service Perspective

From the perspective of service characteristics, typical smart grid service scenarios discussed in this document are classified into two types:

- Industrial control services: Typical examples are intelligent distributed feeder automation and millisecond-level precise load control. Ultra-reliable and low-latency communication (URLLC) is a typical slice designed for this type of services.
- Information collection services: Typical examples are information acquirement of low voltage distribution systems and distributed power supplies. Massive machine type communication (mMTC) is a typical slice designed for this type of services.

In addition to the two typical slice types, the power grid industry may also require eMBB (typical service scenario: remote inspection using drones) and voice slicing (typical service scenario: manual maintenance and inspection).

4.1.3 Deployment Perspective

From the perspective of service deployment, 5G not only enables new power grid industrial control services but also inherits the information collection services supported by the current 2G/3G/4G public networks. In this way, multiple slices of the power grid can be deployed, managed, and maintained in a unified manner, which helps customers of the power grid industry reduce costs effectively.

Service Scenario	Communication Latency Requirement	Reliability Requirement	Bandwidth Requirement	Terminal Quantity Requirement	Service Isolation Requirement	Service Priority	Slice Type
Intelligent distributed feeder automation	High	High	Low	Medium	High	High	URLLC
Millisecond-level precise load control	High	High	Medium/low	Medium	High	Medium/ high	URLLC
Information acquirement of low voltage distribution systems	Low	Medium	Medium	High	Low	Medium	mMTC
Distributed power supplies	Medium/high	High	Low	High	Medium	Medium/ low	mMTC (uplink) + URLLC (downlink)

Table 4-1 5G network slices meeting various requirements of different Smart Grid scenarios

4.2 Smart Grid's Multi-Slice Architecture

Based on the application scenarios of smart grids and the architecture of 5G network slicing, the overall architecture of 5G smart grid design and management is as follows.

The slices of information acquirement of low voltage distribution systems, intelligent distributed feeder automation, millisecond-level precise load control are used to meet the technical specification requirements of different service scenarios. Domain-specific slice management and integrated E2E slice management are used to meet service requirements in these scenarios.

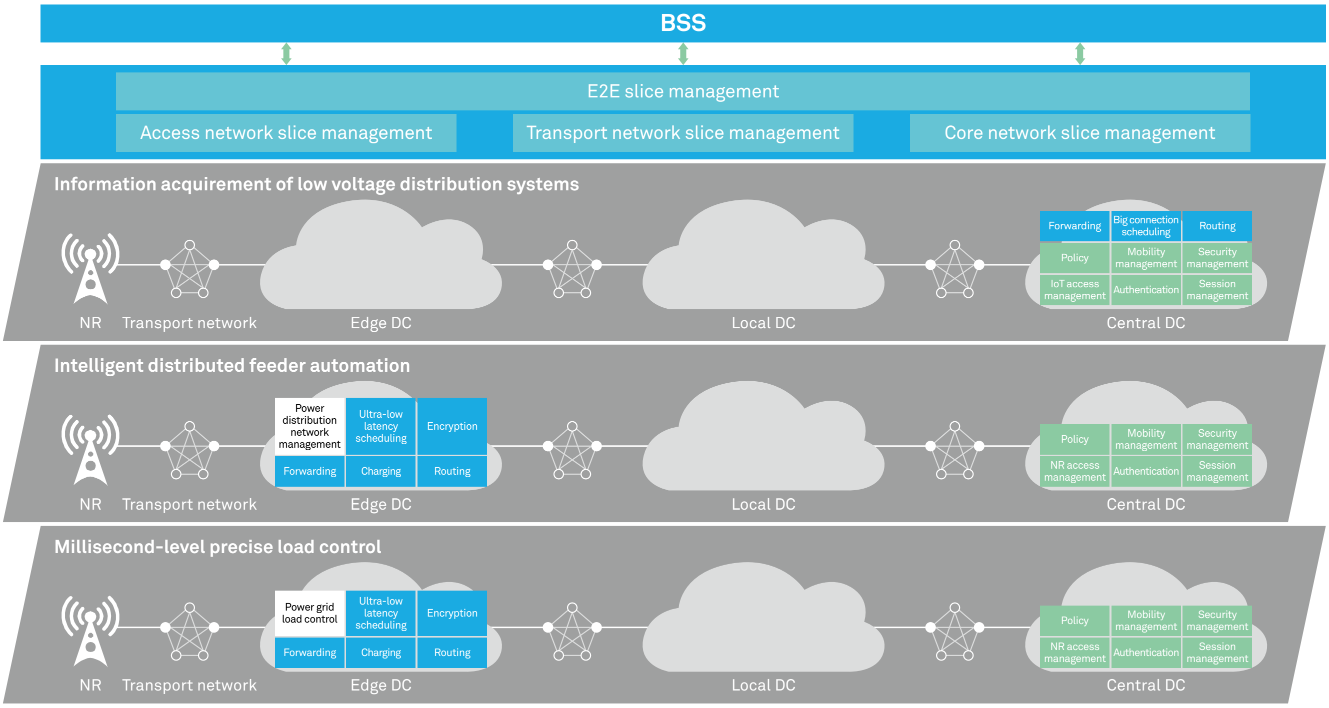


Figure 4-2 5G Network slicing architecture of smart grids

4.3 Life Cycle Management of the Smart Grid

Life cycle management of 5G network slices includes slice design, deployment and enabling, slice operation, closed-loop optimization, O&M, and capability exposure.

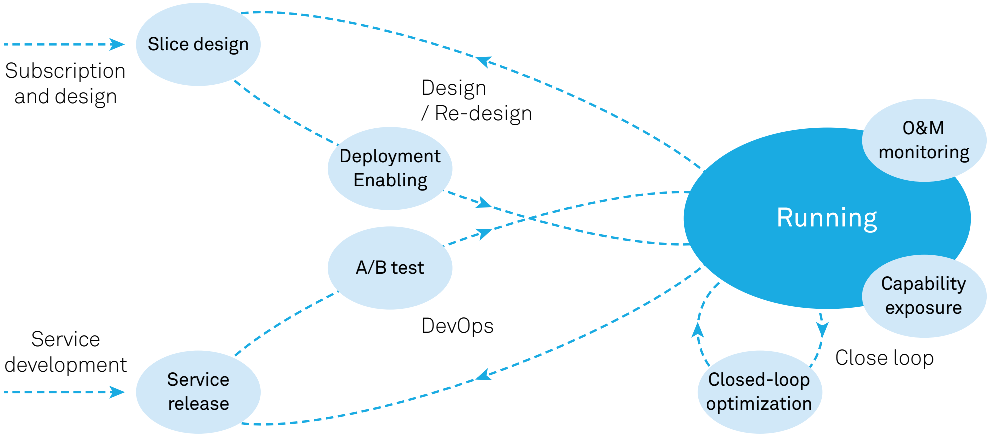


Figure 4-3 Life cycle management of 5G network slices

4.3.1 Slice Design on the Smart Grid

Slices can be customized to ensure agility and service uniqueness. Slice design includes template design and instantiation design. In the template design phase, the CSMF, NSMF, and NSSMF collaborate in capability notification, breakdown, and matching, assemble an E2E slice template, and verify the template on the test bed to ensure that the template can provide the expected network capabilities. The slice instantiation design phase is triggered by specific order requirements. When a tenant needs to use a network slice, a preset slice template or a customized template can be used by the CSMF, NSMF, and NSSMF to confirm deployment information layer by layer, and instantiation deployment is performed to generate an available slice network.

4.3.2 Slice Deployment and Enabling on the Smart Grid

Smart grid slice deployment means deploying slicing network function (NF) instances on resources of the virtualized infrastructure layer. In the network functions virtualization (NFV) scenario, the MANO is used to apply for virtual resources. Network slices may be deployed in distributed mode. Therefore, network slices need to interact with the MANOs of multiple DCs.

Enabling means that basic configurations can be performed after a slice is deployed to enable it to provide network services. Typical configurations include basic networking configuration, global parameters, and preset environment variables.

The key objective of slicing deployment and enabling is automation, which reduces the capital expenditure (CAPEX), increases the speed of network opening, and enables tenants' self-services and automatic network deployment.

4.3.3 Operation of Smart Grid Slices

The wireless side of the smart grid needs to select an appropriate access and mobility management function (AMF) based on user attributes. The AMF needs to select a proper session management function (SMF) and user plane function (UPF) according to user service attributes. These selection procedures are required regardless of whether an exclusive NF or a shared NF is used.

The entire SBA is considered in slice selection. During the NF registration phase, slice information is imported to the network repository function (NRF), and policies are added to instruct the network slice selection function (NSSF) to select a slice.

4.3.4 Slice O&M Monitoring on the Smart Grid

Both operators and power companies are involved in O&M of smart grid slices. Two types of O&M need to be designed because industry users have different levels of expertise and O&M processes and maintenance requirements from operators.

The differences are as follows.

Item	For Operators	For Power Companies
GUI	Same habits based on the traditional EMS	Easy to use
Purpose	Comprehensive network perception	SLA confirmation
Presented data	Comprehensive status and statistics, fixed	Customized key information, variable
Control scope	Comprehensive service and resource configurations	Restricted service configurations
Slice range	Cross slices	Inside a slice

Table 4-2 Two types of O&M modes for 5G network slices on the smart grid

For operators, the fault, configuration, accounting, performance, security (FCAPS) capabilities are required so that operators' O&M personnel can improve both overall service capability and network efficiency. For tenants, a simple and easy-to-use O&M GUI is required to help tenants achieve the fastest speed, the most natural experience, and value through both networks and applications.

4.3.5 Closed-Loop Optimization of Smart Grid Slices

To achieve optimal user experience and maximum network resource efficiency in a complex network environment, closed-loop optimization of slices must be implemented.

Closed-loop management means monitoring the network and service status. When a target deviation occurs, the network and services are adjusted to ensure the expected performance levels.

Closed-loop optimization of network slices is classified into two types.

Item	Local Closed-Loop	Remote Closed-Loop
Trigger source	SLA awareness	Network efficiency and SLA awareness
Purpose	Rapid SLA improvement	Network-wide optimal efficiency and best SLA
Input	Partial information	Global information
Real-time requirements	Real-time/Quasi-real-time	Non-real-time, slow
Running mode	Best effort under certain rules	Optimal solution based on data analysis

Table 4-3 Two closed-loop optimization modes of 5G network slices on the smart grid

Local closed-loop and remote closed-loop are combined to ensure real-time service assurance and overall network efficiency improvement.

Local closed-loop is implemented by presetting policies and adjusting logic on the control plane and user plane. When the service capability reaches the threshold and will be or has been damaged, the network deployment and network parameters can be quickly adjusted to improve user experience of current and subsequent services. For example, for a smart grid slice, when a new power device is deployed in a region or a new distributed power supply is connected to the network, the network can automatically scale in or out the function nodes in the edge area and deploy the power grid load adjustment function locally to improve the SLA assurance capability of the region.

In remote closed-loop, the system collects and analyzes long-term network operator data, searches for regularities, obtains optimization directions, and automatically adjusts networks periodically or triggers network redesign to improve network service capabilities.

4.3.6 Slice Capability Exposure on the Smart Grid

Slice capability exposure is a key means to achieve the combination of applications and networks to enable network capabilities to be easily applied to the electric power industry. The detailed requirements are as follows:

- Network capability orchestration: Based on the service-oriented concept, network capabilities are atomized. Each atomic capability can become a part of the industry service process and can be flexibly assembled according to different user requirements.
- Flexible network capability exposure: The network exposure function (NEF) provides secure and manageable open capabilities, including services and data, for the electric power industry. The power industry can invoke the RESTful interface to obtain certain types of user parameters and service parameters as required.
- Application integration: In addition to network capability exposure to the electric power industry, certain applications can be integrated to the networks based on the requirements of the electric power industry. The electric power industry provides a certain type of atomic network service capability (such as security) to become a part of end user service processes.

Network slicing is not only a technology but also a new business model. In addition to the smart grid industry, network slicing is also available in automatic driving, industrial control, and smart city, which help form a win-win relationship between operators and vertical industries and create a smart digital society.

5 Conclusion and Outlook

5G network slicing fully integrates the software-defined networking (SDN)/NFV technology to flexibly match service requirements with network resources, meeting the specific function requirements of different vertical industries in the 5G era. For operators, 5G network slices will help build agile and flexible networks and extend services to vertical markets. Operators' infrastructures are shared, which greatly improves the network resource utilization. In addition, operators provide different slicing capabilities to meet the technical requirements of differentiated services in vertical industries. The flexible and open network architecture can provide independent operation capabilities for vertical industries to ensure flexible and personalized service provisioning. For vertical industry users, 5G network slices will help operators gain on-demand service assurance without constructing mobile private networks. In this way, vertical industry users can improve their capabilities of quickly developing personalized services and expand service markets as soon as possible.

The application scenario analysis of the smart grid shows that the service requirements based on technical specifications vary greatly according to scenarios. Operation enterprises and network equipment vendors should further quantify network technical specifications and architecture design based on the technical specification requirements of these industries, including:

- Further quantifying slice security requirements, service isolation requirements, and E2E service latency requirements
- Negotiating network capability exposure requirements and network management GUIs
- Discussing business collaboration modes and future ecological environment
- Providing a complete solution that meets differentiated requirements of multiple scenarios in the electric power industry
- Performing technical verification and demonstration of the solution

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