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Study on Evolution of Communication Infrastructure for Smart Grid Operation and Management

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SUMMARY

With the connections of bulk renewable energy and distributed generation into power grid, the development of electric vehicles and the demand side actively participation in operation of power grid, the information for smart grid operation and management flow more frequently, and the dependence of grid operation and management on information and communication technologies have increased gradually. In the process of smart grid development, most of the power companies have deployed lots of automation and information systems. In order to control and operate the power grid, Some power companies have deployed intelligent energy dispatching system, wide area measurement system, grid condition monitoring system, electric vehicle charging monitoring network, distribution automation system, mobile operational applications for condition-based maintenance and advanced metering infrastructure, etc.. In the same time, some power companies also have deployed enterprise ERP system and centralized data centre in order to manage individual businesses effectively and efficiently.

In recent years, with the emergence of new information and communication technologies such as new generation network, cloud computing, big data analysis etc., new requirements are added to the original deployed communication network, but actually the current communication network affects the new smart grid application development and deployment because of its reliability and security constraints. On the other hand, many kinds of communication technologies are also in a rapid development state. For the power system backbone communication network, the transport network technology is transiting from SDH (Synchronous Digital Hierarchy) to OTN (Optical Transport Network), the convergence layer is transiting from MSTP (Multi-Service Transfer Platform) to PTN (Packet-based Transport Network),and the main network layer technology is transiting from IPv4 to IPv6 . These new communication technologies have played an important role to support new emerging smart grid applications and long distance power transmission network operation and management. For the power distribution communication system, many kinds of access network technologies such as xPON (Passive Optical Network) and industrial ethernet have been applied in the distribution network operation and management. For wireless communication application, 2G, 3G, 4G communication network and wireless sensor network have also been applied in power grid operation and management.

In the context of smart grid application rapid deployment, and communication technologies rapid development, first of all, this paper presents various actual use cases for the smart grid typical

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communication application. It analyzes the basic structure and basic component of smart grid communication system. The basic structure includes wide area communication network and field communication network etc., and the basic component includes communication system over all architecture, network management system, and clock synchronization system etc.. Secondly, this paper takes some typical use cases including a typical power system large-scale OTN network deployment case (more than 50 network nodes), a large capacity data communication network deployment case (more than 2.5G bps for main link), an IPv6 network technology application case , and a PTN deployment practice for example, after that , this paper summarizes the use cases above and refines the following approaches: 1),Analytic methods for business needs of smart grid communication system;2),Planning methods and steps for smart grid communication system;3), Operation and management framework for smart grid communication system; 4), Index system for smart grid application-oriented communication network ; 5),Monitoring and scheduling framework for smart grid integrated information and communication system. These refined methodologies and approaches can provide references for enhancing the reliability and flexibility of smart grid communication network, and for improving the communication network service level for power grid operation and utility enterprise management.

KEYWORDS

Smart grid, Communication infrastructure, Information and communication technology (ICT), ICT operation and management, Unified ICT monitoring system

1 INTRODUCTION

The first generation power grid was developed from around 1900 to 1950, featured by small generation unit, low voltage power transmission and small grid. The second generation power grid was developed from about 1960 to 2000, featured by lager generation unit, extra/ultra-high voltage power transmission, interconnected grids, and large-scale power production. The development of the third generation power grid was launched at the beginning of the 21st century, and expected to be completed over 2050, featured by intelligence and non-fossil fuel generation holding a significant share [1].

The third generation power grid is also known as smart grid. Communication technology is seen as an essential enabling component of future smart grids. Apart from power systems, networking technologies have gained tremendous development in the past decades as a separate industry sector. The creation of the Internet, mobile cellular networks, satellite networks, community networks, wired and wireless local area and personal networks, as well as the invention of diversified networking services has enormously enhanced our capability for information exchange. However, the modern networking technologies have not been leveraged sufficiently in power systems for optimized management. When we develop the smart grid, it is critical to take advantage of the advancements in networking technologies to enable the automated and intelligent system management [2]. From the year 2016 to 2020, the proportion of communication construction investment to power grid total investment is between 3%-7%. Communication network is one of the important pillars for the power system operation and management, and its main technology application development from the year 1950 to 2015 had experienced several stages include high voltage power line communication, private microwave communication and optical communication, et al [3].

In the smart grid, reliable and real-time information becomes the key factor for reliable delivery of power from the generating units to the end-users. To this end, the intelligent monitoring and control enabled by modern information and communication technologies have become essential to realize the envisioned smart grid. The operational and commercial demands of electric utilities require a high-performance data communication network that supports both existing functionalities and future operational requirements [4].

In this paper, a comprehensive but brief review on smart grid communications network evolution especially the newest practice is presented mainly from the view of smart grid construction practice in recent years. The paper is organized as follows. Section 2 presents smart grid typical backbone communication. Section 3 presents Smart grid typical feeder level communication Section 4 provides architecture and component of smart grid communication system Section 5 provides analytic methods for business needs of smart grid communication system. Section 6 discusses planning methods and steps for smart grid communication system. Section 7 presents operation and management framework for smart grid communication system. Section 8 discusses index system for smart grid application-oriented communication network Section 9 discusses monitoring and scheduling framework for smart grid integrated information and communication system. Sections 10 conclude the paper and discuss the further research issues.

2 SMART GRID TYPICAL BACKBONE COMMUNICATION

2.1 Transport layer of backbone communication

Synchronous Digital Hierarchy (SDH) and Optical Transport Network (OTN) are main backbone communication network for smart grid in China, in 2011, State Grid Corporation of China (SGCC) began to construct big capacity OTN, The range of the first stage OTN include corporate headquarters and corporate disaster recovery centre (data centre). OTN and SDH deployed can constitute double plane network so as to increase reliability and resilience.

SDH is standardized protocol that transfer multiple digital bit streams synchronously over optical fiber using lasers or highly coherent light from light-emitting diodes (LEDs). ITU-T defines an OTN as a set of Optical Network Elements (ONE) connected by optical fiber links, able to provide functionality of transport, multiplexing, switching, management, supervision and survivability of optical channels carrying client signals.

2.2 Network layer of backbone communication

In 2012, State Grid Corporation of China (SGCC) began to construct big capacity data communication network. The new system can be compatible with IPv6 network equipment .Data communication network transition from IPv4 to IPv6 had been deployed in SGCC smart grid communication network. IPv6 network application scenario includes grid condition monitoring, video monitoring, utility service portal and so on [5].

The range of this network include corporate headquarters , corporate disaster recovery centre (data centre), five headquarter sub-centre and 27 province sub-corporations.

This data communication backbone network has more than 8 Virtual Private Networks (VPN) and use Multi-Protocol Label Switching (MPLS) combined with DiffServ to provide different levels of quality of service (QoS) based on Precedence IP (IPP) and EXP MPLS tag.

3 SMART GRID TYPICAL FEEDER LEVEL COMMUNICATION

3.1 Optical communication

Optical communication has a significant advantage for reliability and bandwidth requirements, and these characteristics is very important for smart grid such as operation and control for distributed energy integration into grid, and could bring significant beneficial effects in future. In the smart grid communications, in 2009, EPON technology began to be applied in China, especially in the distribution automation projects it has priority to be applied. EPON network system consists of three parts, the OLT, ODN and ONU, due to the ODN does not need power supply, EPON has a large number of applications in public communication access network, its reliability, maintainability and cost performance will bring the stakeholder profits.

PON communication technology has been used for feeder level communication, and service for distribution automation and smart meter reading system. See Fig.1. Dual power source distribution network is mostly used for the urban power grid, in Dual power source distribution network, power from two 110/10 kV substation. At each substation can be deployed a OLT equipment, two sets of equipment and its uplink/downlink channel can be used alternately, so to improve the reliability of communication.

Each ONU can be connected to a variety of devices, including power distribution terminals, such as DTU, FTU, TTU, etc., also including smart meters, etc.. A variety of data can be isolated from each other in accordance with the security rules. If the distribution terminals are much more to 64 , OLT can be deployed in the 10kV/400V substation.

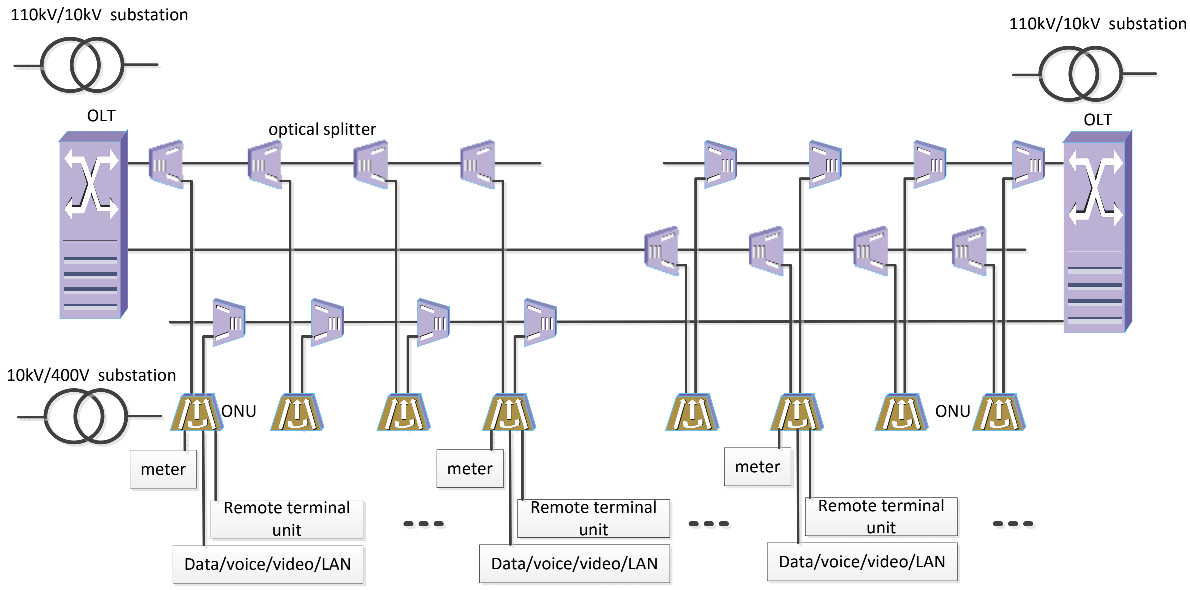

Fig.1 PON network for the feeder level communication

3.2 Wireless communication

With the development of smart grid, private wireless network get more and more attention as the smart grid business demand increases on the reliability and security. Smart grid is equipped with a lot of electric business terminals witch scatter over a broad area. Optical communication network although has advantage on business transmission capability, but the deployment is difficulty and needs high cost. Optical communication network is unable to meet the massive equipped electrical terminal communication requirements. With the rapid development of public broadband wireless communication technology, wireless communication application in smart grid area has been greatly improved. More and more utility consider using wireless communication. In China the radio frequency resources available in the smart grid are shown in the following Table1.

Table 1 Frequency band can be used for smart grid communication

Frequency band （MHz）	spectrum allocation	Application
223~235	Power system ,oil industry , gas industry	Application in load management, load control, etc.
1427~1525	Not allocation in country level	Microwave communication system for some power utility communication
1785~1805	Not allocation in country level, but can be allocated in province level	Application in smart grid feeder level communication

In the power system communication network, wireless communication is mainly used in the 230MHz frequency band, which is mainly used for load management and load control. In recent years, with the development of mobile communication Long Term Evolution (LTE) standard and technology applications, the power industry is also in the pilot application of LTE-230 and LTE-1.8G and other systems.

4 ARCHITECTURE AND COMPONENT OF SMART GRID COMMUNICATION SYSTEM

It is very important to construct the private communication network for the security of the power grid. The transport layer equipment of communication backbone network which service for large-scale power generation, transmission, substation is mainly made up of optical transmission equipment, microwave transmission equipment, carrier transmission equipment, and the network layer of communication backbone network including switches, routers, and so on. The transport layer equipment of communication backbone network which service for distribution and user communication includes passive optical network, industrial Ethernet, wireless communication, power line carrier, wireless sensor network, etc.. And its network layer is same as transmission communication.

Applications are divided into four security sections in master station in accordance with the rules of the China power grid security code. The data interaction between each region requires hardware security isolation device .For the first two security sections, data from filed need corresponding encryption and authentication to access master station. Architecture and component of smart grid communication system (private communication network) are presented in Fig.2.

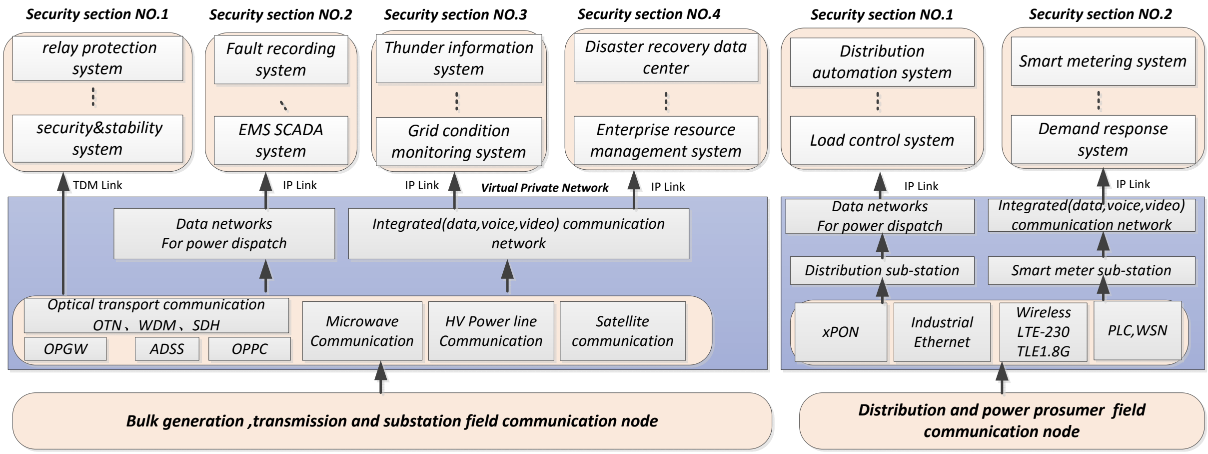

Fig.2 Architecture and component of smart grid communication system (private communication network)

5 ANALYTIC METHODS FOR BUSINESS NEEDS OF SMART GRID COMMUNICATION SYSTEM

Primary power system communication is mainly carried by the business for dispatching voice telephone, telemetry and remote signal. Communication mainly serves for the power system automation. The main business is dispatching automation and distribution automation. Traditional communication is mainly connected to the voltage level of the substation, power plant, control center. Smart grid needs to adapt to a variety of new energy access, including large-scale new energy base and distributed power supply, as well as electric vehicle charging infrastructure. New energy base due to the amount of information transmitted and a traditional power plant is different, the operation and management of communication networks need to consider additional and distributed power supply, electric cars, demand side management need to construct new operational monitoring network. Moreover, modern enterprise management needs information, including all kinds of office automation system, management information system, especially for large electric power enterprises and need to construct secure and efficient network communication and information systems to adapt to these requirements.

The object of network connection of communication network includes all kinds of enterprise management personnel, technical personnel, computer, intelligent electronic equipment, etc., in the smart grid to realize the connection between people and people, people and things, things and objects. Intelligent power grid communication systems need to send the information, including data, voice, video and images, etc.. The data includes all kinds of information collection, control signal transmission and so on. The voice includes dispatching telephone and administrative telephone, video conference system, image monitoring system and so on. Business requirements include high bandwidth, diversified business and flexible network organization.

At the same time, taking into account the important role of information communication in smart grid, the smart grid communication business is divided into the following aspects, see table 2.

Table 2 communication service classification

Communication service classification	**Communication service name**	**Communication and network used**
Production control area (high security, high reliability, low time-delay)	Dispatch voice	TDM (voice switcher)
	SCADA/EMS	IP network or fixed link
	Wide area monitoring system(PMU/WAMS)	IP network or fixed link
	Wide area protection and control system(WAPCS)	IP network or fixed link
	Generation plant SCADA	IP network or fixed link
	Protection system	TDM (SDH 2M interface)
	Security control system	TDM (SDH 2M interface)
	Substation Automation	IP network or fixed link
	Distribution Automation	IP network or fixed link
Production non-control area	Dispatcher training system(DTS)	Power dispatch data network(private)
	Protection and fault record information management system	Power dispatch data network(private)
	Metering system	Power dispatch data network(private)
	Market operation system	Power dispatch data network(private)
	Condition monitoring system	Power dispatch data network(private)
Production management area	Dispatch management information system(DMIS)	IP data communication network
	Dispatch record table	IP data communication network
	Thunder information	IP data communication network
	Weather information	IP data communication network
	Image /video monitroring	
Management information area	Management voice	TDM (voice switcher)
	Management information system(MIS)	IP network
	Office automation(OA)	IP network
	Customer management system (CMS)	IP network
	Enterprise resource plan ERP	IP network
	Video conference system	IP network

6 PLANNING METHODS AND STEPS FOR SMART GRID COMMUNICATION SYSTEM

Communication network planning is important for the network development. Since 2006 SGCC put the electric power communication network planning into normal work, after that the company published "Eleventh Five Year Plan 2006-2010", "Twelfth Five Year Plan 2011-2015 " and "Thirteenth Five Year Plan 2016-2020 " for power system communication development and deployment. Especially in 2006, SGCC began to develop the communications network planning as a special planning and determine the communication transmission network transition to SDH technology, data network transition to IP technology [6]. In 2009, in order to adapt to the development of smart grid and information technology development requirements, SGCC decided communication network planning as a sub item of the power grid planning. Bandwidth of data communication network for energy management system (EMS) and remote terminal unit (RTU) increased from 2Mbit/s to 2*155Mbit/s, Bandwidth of data communication network for utility management increased from n*155Mbit/s to m*1000Mbit/s, and achieve the goal that dispatching data communication network was dual plane, and the province level information network had double outlet [7].

The communication network planning index should be unaligned with the communication network planning objectives. Planning includes five years planning and rolling planning (planning for next year). Related key indicators are the metrics that are stable and unchanged for a long time. Communication system panning includes communication link planning, network topology or architecture planning, key communication node planning. Smart grid communication network planning process is summarized in Fig.3.

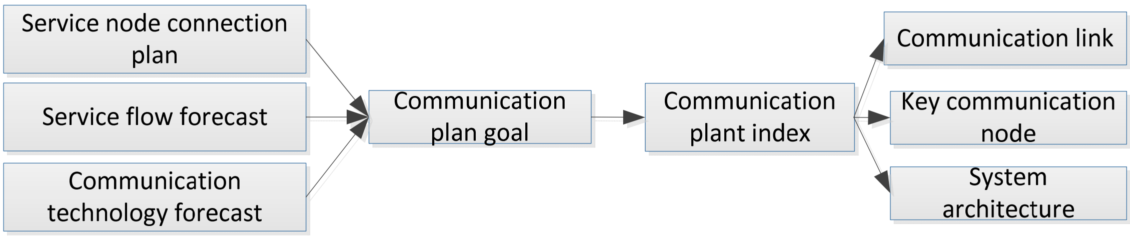

Fig.3 Smart grid communication network planning process

7 OPERATION AND MANAGEMENT FRAMEWORK FOR SMART GRID COMMUNICATION SYSTEM

Operation and management for smart grid communication system is a challenge. Statistical data for SGCC communication network until December 2013, the total number of optical transmission equipment is about 62560 and accounting for about 51% of the transmission network equipment; The total number of microwave transmission circuit equipment is about 1564 and accounting for about 1% of the transmission network equipment; The total number of carrier equipment is about 2572 and accounting for about 2% of the transmission network equipment; The total number of Pulse Code Modulation (PCM) equipment is about 56652 and accounted for about 46% of transmission network equipment. The optical transmission equipment constitutes the main equipment of the communication network and can be access to network management system (NMS).

Operation and management for smart grid communication system is an integrated platform which integrates database, data acquisition equipment, the data exchange system and four types of applications (communication real-time monitoring, communication resource management, communication operation management, and communication default process management).See Fig.4. System is deployed in the country, provincial and city three levels. Operation and management for smart grid communication system can comprehensively coverage all levels of power communication backbone network and communication access network through a hierarchical management and the distributed application.

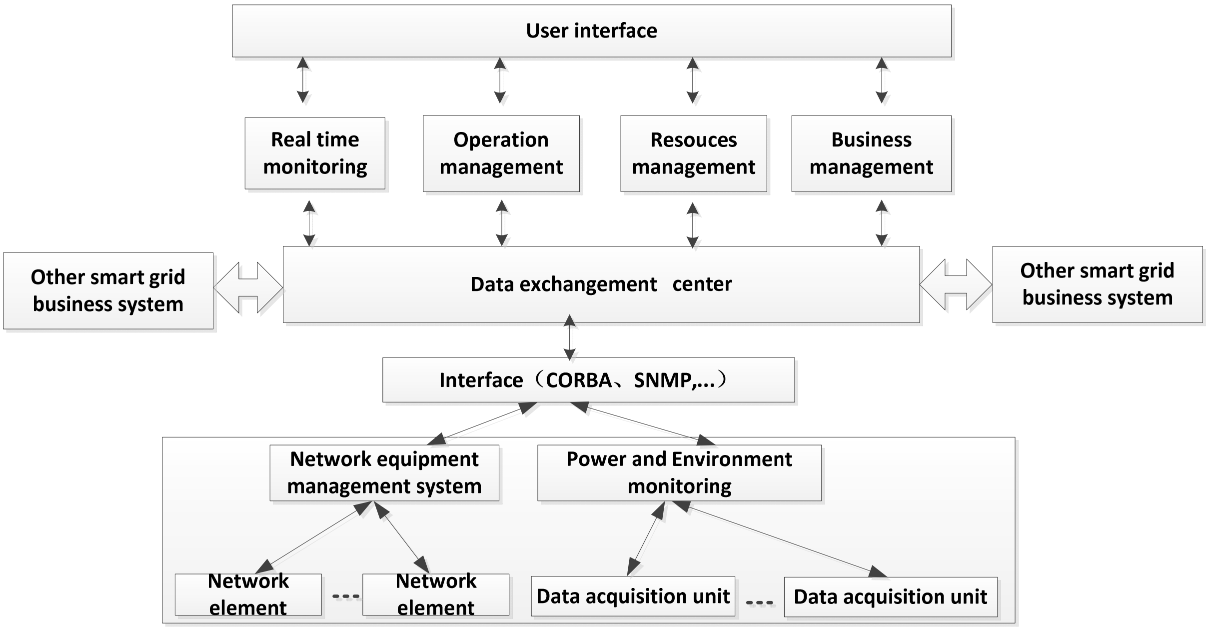

Fig.4 Operation and management framework for smart grid communication system

8 INDEX SYSTEM FOR SMART GRID APPLICATION-ORIENTED COMMUNICATION NETWORK

Smart grid development requires Qualitative ICT management change to quantitative ICT management, and building an index system for smart grid communication network and information system has a very important significance. Index system is the basis for the comprehensive evaluation of the operation situation and efficiency of smart grid ICT. ICT related index includes Key Performance Indicators (KPI), Key Quality Indicators (KQI), Quality of Service (QoS), and Quality of Experience (QoE). Design approach of smart grid communication system Index is presented in Fig.5

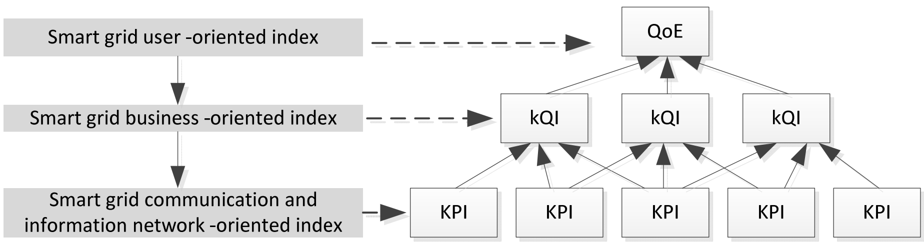

Fig.5 Design approach of smart grid communication system Index

The index system is not too complicated, and the index system can be simplified as much as possible to ensure the objectivity and comprehensiveness of the evaluation results, so that it can reduce or remove some indexes which have little effect on the evaluation results. Evaluation index related data is easy to gather for both the qualitative evaluation index and the quantitative evaluation index. The sources of information for index calculation must be reliable, and easy to obtain. Each evaluation index and calculation method should be standardized, and the accuracy and reliability of the data in the evaluation process should be controlled. Index system focuses on three aspects. First aspect is that index can be configured and can be dynamically adjusted. Second aspect is that index evaluation method can be configured and index score and weight can be dynamically adjusted. Third aspect is that user interface for index presentation can be configured and existing index system can be dynamically displayed. Index system for smart grid application-oriented communication network is presented in Fig.6.

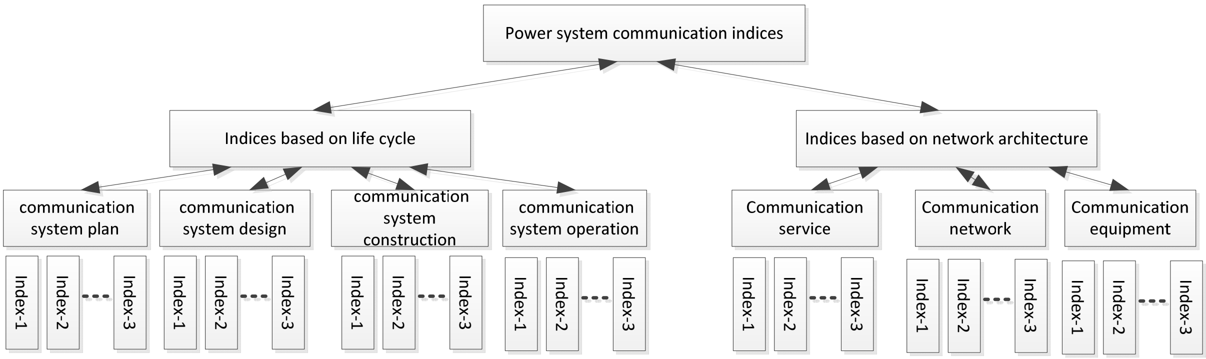

Fig.6 Index system for smart grid application-oriented communication network

9 MONITORING AND SCHEDULING FRAMEWORK FOR SMART GRID INTEGRATED INFORMATION AND COMMUNICATION SYSTEM

The monitoring system of communication network and information system is isolated in a considerable extent and failed to form a coordination ICT(information and communication technology) monitoring system .It is very difficult to conducted a comprehensive analysis and evaluation based on the monitoring data of information and communication network operation. For example, it is unable to accurately locate where the fault or alarm occurs in ICT system, and ICT system can not adapt to the future power grid operation and management needs.

2011, SGCC built unified ICT operation and monitoring centre and put it into operation. Unified ICT operation and monitoring centre enable the real-time monitoring of smart grid ICT, unified dispatch of ICT resources, and integrated security defence. The system ensure the company information and communication systems security operation.

ICT monitoring system realize ICT hardware and software unified monitoring include communication transmission network, data communication network, ICT power source, host computer, storage software, information security equipment , platform software, database software, operating system, middleware, et al. based on Service-Oriented Architecture (SOA) and Common Object Request Broker Architecture （CORBA） standards. Monitoring and scheduling framework for smart grid integrated information and communication system is presented in Fig.7.

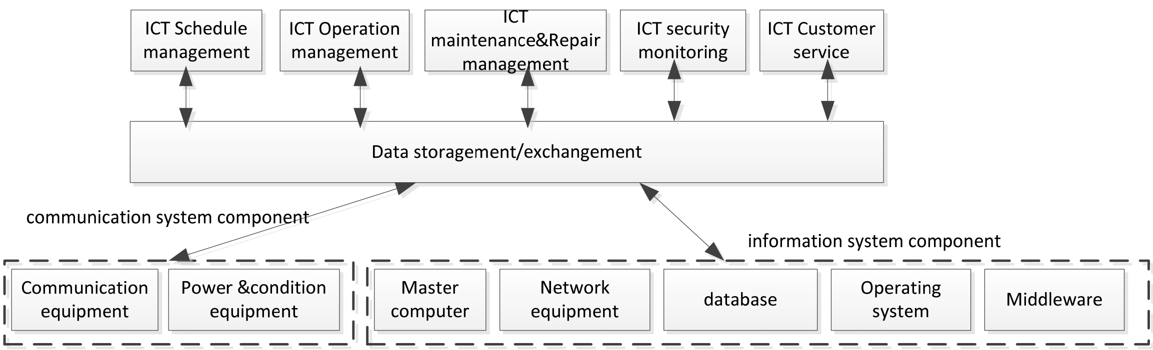

Fig.7 Monitoring and scheduling framework for smart grid integrated information and communication system

10 CONCLUSIONS

This paper summarizes the use cases especially from State Grid Corporation of China (SGCC) and refines the following approaches: 1),Analytic methods for business needs of smart grid communication system;2),Planning methods and steps for smart grid communication system;3), Operation and management framework for smart grid communication system; 4), Index system for smart grid application-oriented communication network ; 5),Monitoring and scheduling framework for smart grid integrated information and communication system.

These refined methodologies and approaches can provide references for enhancing the reliability, resilience, and flexibility of smart grid communication network, and for improving the communication network service level for power grid operation and utility enterprise management.

In recent years, with the emergence of new ICT and application such as next generation network, cloud computing, big data analysis etc., the convergence of communication and information technology will get more and more application scenarios, and the convergence of ICT and smart grid application will improve power system efficiency and effectiveness. Smart grid application-oriented, unified monitoring and scheduling for smart grid ICT and related research could be enable the next evolution event for smart grid communication network.

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