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An Overview on the Architecture of Information System in Smart Power Grids

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Abstract

Smart power grids realize the further precise control of the energy and power by means of the advanced information technology based on the traditional power grid. Through the definition of smart power grids, the present situation of domestic and foreign development, and the main technical difficulties and challenges emphatically, this paper puts forward the suitable architecture of the information system for smart power grids from information technology perspective. The structure is divided into three levels: the first one is the infrastructure including the basic equipment of power system and the communication network, the second one is the supporting platform including the sensing measurement, data storage, analysis and decision-making, and the control and execution platform, the last one is the application system including the side of power supply , the grid and electricity . So it can really realize the interaction of physical, information and application system, meanwhile, it can also realize the high integration of information, energy and the business flow. This paper summarizes particularly the present situation of various aspects on the technology development the architecture involves, at the same time, it also points out the research direction that may bring the breakthrough in the future.

Keywords*: architecture, smart power grids, power system, communication*

1. Introduction

With the development of the modern communication, the computer, the network and control technology, we also continuously open up in the field of information technology. So the combination of information and energy technology has become an inevitable trend of the development, which also has given rise to a new concept: Smart Energy. It means that this energy can achieve the further precise control of the energy to enhance the level of energy management by the use of the advanced information technology.

Traditional power grid has some serious problems in the aspects of energy efficiency and environmental protection. The literature shows that the energy efficiency of power system in North America is about one-third in 2008, but the energy consumption of power generation, transmission and distribution accounts for two-thirds of the total. At the same time, more than 65% of the electricity comes from fossil fuels (coal, natural gas), which pollutes the environment seriously. In order to solve these problems, smart power grids in the future will improve the operation structure of the existing grid. Since a lot of distributed generation facilities that the new energy builds would be introduced in the system of power grid, power supply has been diversified; at the same time, the power model of electric power terminal will also become more elastic. Smart power grids in the future will show the similar features with many distributed computing systems, and its research will also be connected with the network system of computers more closely [1].

Smart power grids will mainly solve the following problems:

We guarantee the security, stability and reliability of the power grid while improving the equipment utilization. Since the grid system was highly coupled and the scheduling

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control was improper, a single failure can cause a chained failure, and it cause even the blackouts accidents and equipment damage, leading to the immeasurable direct and indirect losses [2]. So the grid system has the very strict requirement for the reliability. The intelligence scheduling of smart power grids means that it can solve the problems of the wide-area information collection, transmission, the analysis and disposal on the basis of the safety and reliability.

The interaction between power generation and electricity: The basic characteristic of the power grid is the balance between power generation and electricity. In the terminal user terms, the user can access the operation parameters of the power grid (such as the cost of electricity, the electricity consumption of different facilities) through the intelligent power terminal to adjust the usage of their electricity. For the grid system, it can build the accurate load model and improve the efficiency of power supply effectively by the information of electrical equipment. The construction of the traditional power grid is based on the one-way thinking of the generation, transmission, transformation, distribution and consumption, causing a large number of redundant wastes. Based on the high real-time communication system of the measurement, smart power grids can depend on the real-time control to achieve the balance of power load , which can reduce the hot standby and improve the stability of the system and the access of intermittent renew energy .

New energy contains primarily the wind power and photovoltaic power generation. The wind power resources in China are mainly concentrated in the northwest, which are also the areas with the abundant solar energy. And the areas that need the large electricity resources in China are concentrated in the Middle East, thus it causes that new energy power of our country must be transmitted in a long distance to get a load area inevitably. It requires that the grid should carry out optimization configuration for new energy power generation throughout the country. At the same time, it may affect the stability of the power grid system if the power grid is incorporated into it directly because the new energy power generation itself has the characteristics of randomness and intermittent. For instance, the wind power may cause a wide range of off-network because of the objective weather, causing the transient imbalance of power system, and then it will affect the whole stability.

Therefore, smart power grids needs to solve some problems of the traditional power grid information system in the information collection, transmission, processing, and the sharing, and the solution of these problems depends on the Internet of things technology that is gradually developing. The core technology of the Internet of things covers from the physical state of awareness, information representation, information transmission and information processing between the sensor network and the upper application system. Communications, the security, and the application of the upper in the information system of smart power grids will play an important role in it: sensor network technology can be used in the data acquisition and access to information of network communications terminal equipment such as smart meters. The real-time and safe communication technology can be used for the transmission of power grid operation parameters, realizing the real-time transmission of the operational data and the power load data. Data store and information technology can be used for the storage, management, query and organization of the huge grid data. Data distributed processing and task scheduling techniques can be used for the analysis on the security and stability of power system and a real-time deployment of the new energy flow after the new energy access it. The development of Internet technology makes the power system integrate into the computer digital environment from a relatively closed self control system, improving the stability of power grid and making new energy sources such as wind power and power easily integrate into the information system of smart power grids to make the unified plan and scheduling [3].

2. The Definition of Smart Power Grids

Smart power grids is usually the new grid system that the modern information system integrates into the traditional energy network so that the grid has the control and the objectivity better than before, solving some difficult issues such as the low energy efficiency of the traditional power system, interactivity, the analysis of security and stability. At the same time, based on the real-time control of the energy flow, new distributed energy power generation, the access and use of the distributed energy storage system become convenient.

The first significant characteristic of smart power grids is to have the strong objectivity, which is the real-time monitoring of the information of each node in the power system by information network technology. For instance, the definition of smart power grids in IBM has three levels, the first one is the real-time, comprehensive and detailed monitoring of the running status of the grid, the equipment status of assets and the power consumption information of the customers, eliminating the blind spot monitoring [4]. Tsinghua University put forward "CCCP"(the application of communications, computer and control technology in power system) in the 1980S, thinking that smart power grids is the integration and interaction of the traditional power system network and power information network.

Another feature of smart power grids is the dynamic interaction between power generation and the electricity. It can optimize the scheduling by the electricity grid information and user information that we gained. From the terminal user's perspective, the goal of the smart power grids needs to uniformly dispatch all of the power resources to provide more stable electric power for the terminal user in the cheaper way. For instance, Duke Energy put forward that the terminal users can monitor their electricity consumption and adjust their electricity usage for the reduction of the cost in the environment of smart power grids, and electric power company may allocate according to the needs of users guiding the user's needs by energy supply and the price means and reducing the total energy consumption. The strategy development planning of smart power grids in Europe refers that smart power grids should make all users connected to the electricity grid, generator and two-way equipment connection integrated together, strengthening the control of power generation side through intelligent monitoring, communication, and self-healing technologies and providing more schemes of power information and power optimization for users to reduce the influence of power system on the environment and improve the reliability and the safety of power supply.

The third characteristic of the smart power grids is the high reliability. It can restore automatically in the oscillation of the system, and it can also early warn and adjust the instability tendency of the system. For instance, the department of energy of the U.S defines that smart power grids should possess the recovery after the system shock, high robustness, security and stability etc. The third one of smart power grids in the IBM's definition is to have the advanced analysis on the basis of the information integration, improving the reliability, the profitability and efficiency goals and reducing costs.

Based on the above views, the definition of smart power grids we give is the following content: smart power grids is the composite system of comprehensive number with the integration of the sensing, communication, computing, decision and control on the basis of traditional grid, which can control and manage the electricity distribution by getting the resources and equipment running status of the grid nodes in each layer to realize the high integration of the energy flow, the information flow and the business flow [5].So it can improve the stability of power system and the maximize efficiency of the equipment, increasing the level of the safety and reliability and achieving energy conservation and emissions reduction, in the last, it can improve the quality of power supply for the user and the utilization efficiency of the renewable energy. The ultimate goal of smart power grids is that it can reduce the cost of the energy consumption and the electric power

operation, and improve the quality of residential electricity so as to promote the development of national economy.

3. The Present Situation and Challenge of Smart Power Grids

3.1 The Status of Smart Power Grids at Home and Abroad

The electric power research institute (EPRI) and the department of defense launched the CIN/SI project in 2001, putting forward to exploit a modeling, emulational, analyzable and synthesis tool in order to build the power system of network and infrastructure with the high robustness and high adaptability and the reconfigurable control.The Wired in June of 2001 introduced that it early mentioned the literature of airliner's vision in a smart energy network. After that, the electric power research institute had launched the IntelliGrid program and released the architecture of the IntelliGrid in 2004. GE, Cisco, lucent and other companies were involved in the research and development of the project [6]. The project contains the power system and control information system in the integrated energy system, giving the implementation steps and technical guidance of how to build smart power grids by the power information system and the service model. In 2003, the U.S. department of energy released the 2030 blueprint of the grid; meanwhile, it also founded the Grid Wise Alliance, which could build a new type of smart power grids to promote the combination of the traditional power system and information technology. Current members include 140 companies in the field of energy and information such as IBM, GE, Microsoft, Samsung, and Siemens in the world. Xcel Energy Company of the United States in March of 2008 announced that they would establish the pilot cities of smart power grids in Colorado (Boulder), which installed 23000 sets of intelligent monitoring equipment to provide more convenient and stable power supply for users and help users to save the electricity cost. In May of 2011, the United States in Maui of Hawaii established a new pilot of smart power grids. Overall, the technology of smart power grids in the US focused on the integration of the communication technology, control technology and the electric power system, at the same time; it also stressed the interaction of the end user and the grid system. Smart power grids report of the U.S. department of energy in 2009 pointed out that the construction of smart power grids system should develop in the six aspects of the transmission system, the distributed energy, the power distribution system, the information network, and the management and financial environment.

The construction plan of smart power grids in Europe originates from 2004. In the first international integrated conference of renewable and distributed energy resources, the stakeholders of the industry and research community put forward the idea of the electricity network technology platform of European in the future. Europe set up the European technology platform of smart power grids with the support of the European commission in 2005 to provide the plan for the development of electric power network in Europe in the future or in 2020. In 2006, the group released the design blueprint of European smart power grids, pointing out smart power grids that must include flexibility, the accessibility, reliability, and economy, and one part of accessibility particularly mentioned the access of renewable energy and low carbon efficient capacity . At the end of 2008, the group released the strategy development plan of smart power grids in Europe and the final version in April of 2010. The development of smart power grids in Europe is divided into six grades by priority, covering the grid optimization, distributed energy, information and communication technologies to the market operation, etc. All the targets will be completed around 2020. The target of the first stage(the optimization of power grid operation and use) was completed in 2008 ~ 2012, solving the operation and safety of power grid under distributed environment and the control problem of the market-oriented energy flow. Japan announced in April of 2009 the plan of development strategy and

economic growth, including the solar power grid, the empirical test of Japanese smart power grids in the future and the fast charging device of electric cars closely related to smart power grids. Federation of Electric Power Companies said that they will fully develop "the Japanese version of smart power grids" in July of 2009. South Korea issued a "green energy industry strategy “in 2008 and introduced the thinking of "Korean version Smart power grids”.

In our country, the state grid company in May of 2009 put forward the development plan of smart power grids of our country, dividing into three stages to promote the construction of smart power grids in China and intend to complete a unified smart power grids in 2020,we can give the characteristics of smart power grids in eight aspects of the power grid security and stability, energy scheduling, user interaction, the application of new power and so on. North China grid company announced in April of 2009 “the construction planning of smart power grids" of north China power grid. In September of 2010, new Mr. Golf garden district of Lang fang in Hubei built the first pilot area of smart power grids in China. Southern power grid company completed the wide-area damping control system in 2008, being one of the first project of wide-area closed-loop intelligent control system in the world. The system is based on wide-area measurement system (WAMS) including the synchronized pharos measurement unit (PMU), realizing the wide area control of adaptive closed-loop. Up to 2009 our country invested more than 1000 - PMU - 2 nodes in the northeast, north, east China, central China, Jiangsu, Henan, Yunnan, Guizhou, Guangdong and so on, setting up more than 10 WAMS centers and covering the 500 kv substations and main power plants more than the progress of the United States. Colleges also has many units that are carrying out the research of smart power grids, for instance, the team that Han Yingduo academician of Tsinghua university led has made certain achievements in the wide area power grid monitoring, solving the key technical problems of wide-area damping control project and proposing the construction scheme based on the security early warning of wide-area information in power system and the defense and control system by the cooperation with the quartet group. The team that Yu Yixin academician of Tianjin university led has made certain progress in the function of distributed generation system, putting forward the thought of technology train that the distributed generation functions such as solar energy, wind energy and small hydro system access to power grid in the form of micro network for improving the efficiency of energy transmission, the stability and reliability of power transmission and power quality to reduce costs.

Overall, the current research of smart power grids abroad puts particular emphasis on the access of distributed energy and the interaction of power consumption and power generation side. The research of smart power grids in China focuses on the access of information and the stability control of power grid system, it relates to the characteristics of strong coupling electric power network in China.

3.2 The Present Situation and Main Problem in Information System of Power Grid

The existing grid information system (power secondary system) refers to the automation network of electric power dispatching, the energy management system of EMS, the power distribution network management system of DMS and the wide-area monitoring system of WAMS. Energy management system mainly includes the data collection and monitoring system of SCADA, the automatic generation control system of AGC and power state estimation system, etc. The management system of distribution network mainly includes the distribution automation system of DAS, the geographic information system of GIS and the demand management system of DSM. The wide-area monitoring system contains the measurement unit with synchronous phase angle (PMU), realizing the real-time acquisition of the data in power grids. EMS and DMS system depend on the remote control unit RTU and the data acquisition monitoring system of SCADA, but the main problem is that the data acquisition time is too long and cannot

satisfy the real-time applications with the high demand such as power grid wide-area control and the scheduling of energy, etc. The response time of WAMS system is at the millisecond magnitude, but WAMS system relies on the building of private network, its cost is higher. PMU - 2 node deployments doesn't exist under 110kv voltage class at home. In addition, the existing grid information system has data acquisition and control just for power distribution terminal, high-power electric equipment. It is unable to get real-time information load and the energies' allocation is based on off-line prediction. Thus it has four major problems that the existing electric power network is facing:

(A) Important parameters of the power system are random, time-varying and not handsome, causing the forecasting and scheduling difficulties of power system.

(B) Real power transmission limit of the transmission line is unknown and it gains the reliability by the conservative degree, causing the low availability of line exploitation degree.

(C) We cannot grasp the information of the transmission fault with long-distance, such as the location and extent of the fault, just taking the testing method to deal with failure and then causing huge redundancy of equipment.

(D) Power system cannot store and keep the power dynamic balance, and its load cannot interact, creating the waste of the hot standby.

In order to solve the above problems, we need to add a large number of sensing devices, such as smart meters, PMU - 2 units, and the increase of sensing equipment means the increase of the amount of real-time data. Data real-time transmission and processing of electric power system under the large amount of data requires the advanced technology of the information, communication, network and computing, which is the problem that information system of smart power grids needs to solve [7].

4. The Infrastructure of Information System in Smart Power Grids

The infrastructure of information system in smart power grids is the hardware foundation of smart power grids, including the main parts of the power system, control, measurement equipment and communication network.

4.1 Power System Control and Measurement Equipment

Firstly it briefly introduces the composition of the power system; power system is mainly composed of power generation, transmission, substation, power distribution, and utilization and scheduling. The power generation mainly contains the traditional hydro-electric generation, thermal power, the new nuclear power, wind energy and solar power, in view of the power generation link control, we mainly focus on the generator frequency regulation, voltage amplitude adjustment, synchronous phase and active reactive power adjustment. The output of the generator voltage is generally in the range of 11 ~ 35kv. Transmission make the main generator and the load center of the grid system get together, constituting the backbone network of the grid system with the running of the highest voltage level (more than 220kv). The common transmission technology has a high voltage direct transmission and flexible ac transmission. Substation finished the secondary distribution process of electric power and connected the substation with distribution substation. Some big industrial load may be directly connected to the substation system. The voltage level of substation system is generally between 69 ~ 138kv. Through the substation transformer ratio and reactive power compensation equipment, power grid system can control the grid reactive power and voltage. Finally, distribution can complete the conversion between electricity and individual users. Distribution system is divided into primary distribution system and the secondary distribution system, primary

distribution system mainly supply the small industrial electricity in 4 ~ 34.5kv, secondary distribution system is used for residents and enterprises in 120 ~ 240v.

The measurement equipment of power system is the basis of the construction of smart power grids, smart power grids depends on the application and deployment of sensor; now the sensor of smart power grids include the maintenance and measurement system and the tested system of individual users. The maintenance and measurement system is mainly used for the collection of electric power system unit, such as power plants, distribution wire and electrical information of the motor side. The systems we commonly used are the remote terminal RTU of SCADA system and PMU of WAMS system. RTU unit has a variety of functions including measurement, communication and control, which is widely used in energy management system (EMS), but its main shortcoming, is that the frequency of data sampling is low and it cannot timely access to the dynamic information of power grid operation. The RTU unit has no synchronous clock and its data is not synchronized. For the unit RTU, PMU increased the measurement of phase angle. The measuring accuracy will become higher than before with GPS timing unit [8]. At the same time measurement frequency is also higher in tens of milliseconds. Individual user's measurement system is mainly used for measuring personal power usage, such as smart meters. The main function of the smart meter is to get the electricity data of the user in different electrical equipment and is to analyze it according to the operation of power grid, providing the power-saving energy-saving advice for the users in order to the two-way transmission of information. Smart meters should have the following functions: two-way communication, automatic data acquisition, power management, dynamic pricing management, demand response for load control.

At present, in the developed field of smart meter, there are two main ideas: the electric data acquisition by the multiple acquisition equipment. The collection of data is by a device and then the identification of the data by the classification algorithm. The drawback of the first idea is that each electrical equipment needs to install the sensor with the higher cost, and some electrical installations have difficulties and need the additional communication protocol. It also need the equipment to support data acquisition. In contrast, the cost of the second idea is lower, mainly having the electrical classification of the power characteristics based on pattern recognition algorithm so as to analysis different situations of electrical power. For the second method, the kind of data we gain by sensors becomes very important, because the selection of feature has the influence on the efficiency of pattern recognition algorithm .

4.2 Communication Network of Power System

Communication network is the important infrastructure of smart power grids. WAMS wide-area measurement system of smart power grids, wide area protection system WAPS and wide-area control system WACS depend on communication architecture. Because of the characteristic that the power grid system is diverse and decentralized, the grid system has no unified architecture. Based on the different underlying measurement of smart power grids, the communication networking of smart power grids can also be seen as two parts: the monitoring network of electric power condition including PMU and RTU measured by the state of grid. The features of network are that it has the less number of nodes within the scope of local area. Information network with the measurement units of the individual users who is characteristics is that the number of its network node is big and it has the high developing requirements [9].

4.3 The Main Indicator of Communication Network in Smart Power Grids

The construction of smart power grids communication network has the indicators including the stability and latency of the network. Different ways of network construction will lead to different network characteristics, how to select the construction scheme of

smart power grids communication network is a important research in the field of smart power grids.

There are two ideas that we explore latency and stability of smart power grids: From the perspective of network topology and the agreement itself, for instance, the literature studied the use of dedicated bandwidth and the sharing bandwidth of the network performance and its influencing factors in the separation of information network architecture mode. From the viewpoint of information theory, we studied transmission performance of smart power grids, for instance, smart power grids needed the wireless communication channel capacity to ensure the demand analysis of the safe communication. Based on the analysis of network performance, we consider the influence of the power system communication time-delay on control performance is the problem the networked control systems need to solve, but the current networked control system is usually carry on the analysis on a single network without the extension.

Now electric power information network sets up by the private network normally, but due to the dedicated bandwidth deployment cost restriction, the dedicated bandwidth cannot be very big, so in this case, the sharing bandwidth model can obtain the larger channel capacity, which stands for the better performance of transmission delay. But the problem is that the delay stability under sharing bandwidth model is greatly influenced by the network conditions. If the ratio of background noise is high, the network latency and packet loss are rising rapidly. Literature set smart power grids WAMS and WAMC model based on TCP/IP and analyzed the situation of the network latency and packet loss in the shared bandwidth mode with the background noise and QoS mechanism. We also compared the different conditions of the bandwidth sharing model. At present, smart power grid is the model of a private network, but due to cost constraints limited to the above of 220 kv voltage class, it is a difficult problem that how to guarantee the real-time and stability of the transmission in the conditions of the shared bandwidth network.

For the network measurement of individual users, its characteristic is the large number of network nodes, but the amount of a single node is limited. In addition, the network is built by the wireless network, how to collect the data and to ensure the real-time data is the problem that smart power grids needs to solve. Literature proposes the system model of a smart meter measurement for individual users system based on the compressed sensing technology, adopting the method of wireless access and discussing the time delay characteristics of the measurement system by the different signal-to-noise ratio and different sensors.

On the other hand, with the increasing of wide-area monitoring node, the existing power information network gradually cannot meet the demand of the system, at the same time; the pressure of large amount of data on the bandwidth is easy to cause the increase of time delay. If we can compress the raw data itself in power system, we can reduce the demand for bandwidth. Literature puts forward a model of measurement system based on matrix singular value decomposition for the measurement system of grid operation maintenance. Through the analysis of the coupling degree of grid connection, we can determine what data is needed to transmit between the areas, reducing the size of the data we need to transmit.

The main problem of traditional power grid in the communication control system such as SCADA system is that the delay is too large. How to keep the balance between cost and performance according to the physical limitations is the main difficulty of smart power grids research in the future. In addition, how to ensure the privacy and the security of smart power grids data channel is also a problem we will solve.

5. The Analysis of Construction Problems in Smart Power Grids

5.1 The Problems in the Power Generation, Transmission and Substation

The construction of smart power grids plays an important role in economic development of our country, having the great important significance to the development of power system. But due to a late start, so a lot of deficiencies still exist in the practical application. The power generation, the transmission and the substation are the operation links of the power grid. The shortage of smart power grids' construction shows in the following aspects: in terms of discharge, because the traditional grid generation is mainly done through the traversing of low voltage, and it is based on the use of natural energy to realize the power in the construction of smart power grids, but due to the shortage of the existing ability and the poor coordination, so power link is restricted certainly. In transmission, because the demand for electricity is not uniform and the distribution of the water power is more dispersed, so it shows the obvious shortage from power point to the transmission of the user and the capacity of electricity load and monitoring mechanism have some problems. Substation is an important part of the power supply. The strength of distribution network structure is not stable and the support of digital technology is not enough in its construction. The electrical terminals and network did not achieve a good docking, showing the shortage in the respects of compatibility and expansibility. These are the defects of smart power grids, restricting the further development of smart power grids [10].

5.2 Social Environment and Market Environment

With the rapid development of the economic construction, the demands of electricity gradually increased in the industrial production and people's daily life and in terms of standard. So the construction pressure of power grid increased in the standard of construction industry to guarantee the stability and reliability of power supply. A wide range of industries develop too fast, and the construction of smart power grids showed the obvious shortage in flexibility and extensibility, posing challenges to the efficient use of energy.

5.3 Internal Construction of the Power Grid

The electricity load of power grid gradually increased because of the increase of the electricity demand, many regions in our country appeared the short circuit in the large area, causing the great influence on the stability and security of smart power grids' operation. This kind of phenomenon need to have the comprehensive promotion and can't be done by the part adjustment.

5.4 The Stability of Power Grid after the Access of New Energy

New energy's access is a creative change for traditional power grid, but the operation of the new energy need the corresponding electrical equipment and technology, and the existing structure of power grid is unable to adapt to the demand of the new energy, so there is a big hidden trouble of the stability in the process of smart power grids operation.

6. Conclusion

From the perspective of information flow of smart power grids, this article analyzed and summed up the current research situation of smart power grids, prospecting the future research direction of smart power grids through the new computing technology and network technology. Based on the present study, smart power grids have higher requirements on network transmission performance, data storage and data analysis-

processing performance. Especially after the introduction of the distributed generation of new energy power and micro network system, the stable operation control of power grid will be more complicated.

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