

Key Technologies of Smart Distribution Grid

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Abstract - In order to build a strong smart grid with Chinese characteristics, the smart distribution grid issue is studied. Some present questions hindering the futuristic development of electric power distribution are proposed. The definition of smart distribution grid is given. The detailed characteristics are analysed in the paper, several functional requirements are put forward, and the development in the corresponding field is reviewed. The key technologies deployed for the realization of the smart distribution grid are explored in depth, which would give advice for the further research and implementation of distribution network intellectualization in the future. By incorporating with new technologies like Big Data and Internet of Things, SDG is prone to obtain a new opportunity to develop.

Index Terms -Smart Grid, Smart Distribution Grid, Self-Healing Control, Micro Grid, AMI

I. INTRODUCTION

The distribution grid is always plays an important role between the power substations and consumers which accepts electric power from the former and distributes electricity to the latter at the voltage levels and with the degree of continuity. In recent years, in response to the challenges of the global environment, climate, energy issue and the technical progress, the United States and Europe firstly present the smart grid based on the communication integration, advanced components, advanced control method, key technology such as sensor and measurement, which could support interaction, optimization, compatibility, integration characteristics of the smart grid. More and more countries set out to construct a electric power network with higher standard, superior performance, to make our grid safer, more reliable, more economic, more efficient and higher quality. The United States and Europe have carried on the pioneering research to the smart grid investigate, and obtained some preliminary study results, such as Telegestore Project of Italy, Austin Project in United States, Ontario Project in Canada, etc. Through these projects, we accumulated some practical experiences preliminary.

Our country also put forward the concept of the strong smart grid, which is different from the United States and Europe, aiming to construct moderately prosperous society in an all-round way. Considering higher requirements for power supply and digital era, the smart grid combined the actual situation of China's power grid construction, primary energy and renewable energy together. We do some preliminary researches and plans, in order to solve the safety, stable operation, reliable power supply of the distribution network, the full use of renewable energy, the electric power enterprise assets, op-

erations management, the ability against the attack, and other problems.

Due to a variety of reasons of the electric power developments in our history, our country lags behind the development of power generation and transmission of power grid obviously. More than 95% current power outage is caused by the power distribution system, half of the grid loss is due to distribution network. Our country's distribution grid automation, intelligent, self-healing and the optimal operation ability is far behind the transmission grid [1]. The new problems of the power distribution grid urgently need to solve are as follows:

- 1) *Distribution grid optimal operation and self-healing control problem.*
- 2) *The influence of distributed generation on the distribution grid.*
- 3) *Renewable energy generation policy and market operation problem.*
- 4) *The influence of Plug-in Hybrid Electric Vehicle on distribution grid.*
- 5) *Distribution congestion problem.*
- 6) *User's participation and interaction in the power grid.*
- 7) *Load model transformation problem.*

II. SUMMARY OF THE SMART DISTRIBUTION GRID

A. Concept

Smart distribution grid is an important part of smart grid. In other countries most of the smart grid research and practice is concentrated in the distribution grid. Smart distribution grid is based on advanced automation technology technique. By making use of advanced measurement and sensor technology, control technology, computer and network technology, information and communication, intellectualized switch equipment, power distribution terminal equipment and visualization software support, renewable energy and distributed generation unit largely access the grid and also allow the micro grid operate in the grid. The smart distribution grid encourages all kinds of different power users to actively participate in interactive networks, in order to realize thorough monitoring, protection, optimization and self-healing control under abnormal operation state, in order to provide safe, reliable, high quality, economy and environmental protection power supply and other additional services for the electricity users.

Smart distribution grid is mainly composed of master station, station system, communication system, power distribution remote terminal. Through the distribution grid modules, the intelligent equipment, and geographic information system application, the smart distribution grid can coordinate and

optimize operation during normal operation. When any fault occurs, the smart distribution can rapidly position and isolate the fault, then it can recovery and load transfer to ensure the system runs steadily.

B. Characteristics

Compared with the traditional distribution grid, smart distribution grid has the following Characteristics:

1) *Higher Reliability*. Smart distribution grid can withstand natural disasters and Man-made destructions. It can process the fault intelligently in order to reduce the fault impact on users in the maximal degree. By using distributed generation and the micro grid constituted by renewable energy systems when the main grid was outage, smart distribution grid can ensure important user's power supply security and realize the real sense of self-healing.

2) *Better Power Quality*. By using advanced power electronic technology, power quality online monitoring and compensation technology, smart distribution grid can realize voltage, and reactive power optimization control, which ensures voltage eligibility. Smart distribution grid can also ensure some sensitive device continuous, high quality and continuity of power supply.

3) *Better Compatibility*. Supporting the access of the distributed generation unit, energy storage device, renewable energy, and distribution grid can realize the seamless connection. Method to realize the plug and play technique of the smart distribution grid. It also supports micro grid, effectively increase the flexibility of the distribution grid operation and the reliability of the electric for the load.

4) *Stronger Interaction Ability*. Through the intelligent meter and user response network, smart distribution grid supports customer's requirements. The distributed generation units supply power to the network during the peak hours to realize the user to grid mode. It makes service concept change from the center of the electricity power enterprises to the user-centered.

5) *Higher Utilization Rate of Power Grid Assets*. Real-time and on-line monitoring main equipment status, implement the state overhaul, can prolong the service life of equipment. It reduces investment, depreciation of the device, so that the users can get the cheaper electricity.

6) *Integrated Visualization Management Plat Form*. Real time distribution network and equipment operation data provide the operators advanced analysis and auxiliary decision-making graphical interface [2].

C. The Functional Requirements

To ensure the safe, reliable and economical electricity from the distribution grid to the user, it not only needs to have the grid and the communication network, but also need the software support which has integrated all kinds of advanced application functions.

1) *Grid Structure*: The smart distribution grid should have reliable and flexible layer, distribution of topology structure, in order to meet the requirements such as distribution

system operation control, fault handling, and system communication.

2) *Operational Control*: The smart distribution grid should have the ability of real-time monitor and forecast hidden trouble and intelligence adjustment, optimize operation ability, but also have the ability of self-healing during the abnormal operation system.

3) *Communication*: The smart distribution grid should be established in open communication architecture and unified technical standards based on high Speed, two-way, integrated communications network infrastructure, in order to unify the power flow, the information flow, and the business flow.

4) *Software Component*: The smart distribution grid should be based a complete system on UNIX and WINDOWS NT platform. Highly Integrated SCADA (Data Acquisition and Supervisory Control), PAS (Package of Advanced Software), DA (Distribution Automation), GIS (Geographic Information System), the DMS (Distribution Management System), the smart distribution grid can meet both the requirement of the safe operation as well as the need of the users [3].

III. RESEARCH AT HOME AND ABROAD

Different countries set different smart grid development goals according to current situation of the country's energy and power grid system. They focus on the distribution side. The United States focused on the backward grid infrastructure and updated them, in order to build a modern power system. The United States also pay attention to the demand side management and renewable energy applications. Europe focuses on distributed generation promotion. Their smart grid technology research mainly contains four aspects as the power grid Production, power grid operation and control, measurement, power generation and power demand side stored. Japan will build the smart grid, which mainly contains new energy resources. They combine renewable energy and the smart grid, in order to make it more reliable [4]. China wants to build the strong smart grid which is international leading, self-dependent innovation and has Chinese characteristics.

IV. KEY TECHNOLOGY

The intelligent power distribution grid is based on the advanced automation technology. Through the application of advanced power distribution grid automation technology, distribution grid management automation technology, user automation technology, distributed power grid connected control technology, these make the distribution grid supports a large number of distributed generation, renewable energy, energy storage device and micro grid. It enhances the two-way mutual between the electric power enterprises and users. Improve the comprehensive automation level, management level of distribution grid and electricity marketization level.

A. Self-Healing Control

Smart power distribution network and self-healing control use the application of advanced mathematics and the control theory. The self-healing control technology has improved the reliability and security of the smart distribution grid, which

can against a cascading failure and blackouts. It has a widely broad market prospects.

Smart distribution grid and self-healing control established the extraordinarily fragile area, maintenance area, and the normal operation area, by using the advanced mathematics and the control theory. Its real-time evaluation mode and hazard prediction mode make the grid safe, reliable, economic, efficient, environment protection, flexible interaction and open.

Smart distribution grid needs the following conditions in order to be self-healing and optimal controlled:

1) *With a variety of intelligent switch and intelligent equipments.*

Intelligent switch equipment has the characteristics of high performance, high reliability, maintenance-free, on-line monitoring, adaptation, and self diagnosis, etc, which also can provide network remote interface. The power distribution terminal equipment should have the function of fault automatic detection and recognition. The smart distribution grid also can provide UPS, which can meet outdoor working environment and electromagnetic compatibility requirements. Switch equipments and power distribution terminal equipments have the remote communication, remote sensing, remote control, and remote setting, etc.

2) *The distribution grid system has more power and flexible and reliable topological structure.*

The smart distribution grid must has distributed generation, renewable energy sources and energy storing device, which can schedule flexibly, in order to realize the "Hand in hand power supply". Space truss structure must be flexible, strong and reliable, which not only can realize topology optimization under normal operation, but also can rebuild the control topology rapidly.

3) *Reliable communication network*

The smart distribution grid operation optimization and self-healing control function come to realize through control or distribution center back online, real-time and continuous analysis and the remote control. The distribution grid must be reliable, considering the standby control spare communication network plan of the main communication network in the paralysis case, it also requires faster communication speed, stronger information processing ability [5].

Distribution grid self-healing and optimal control can be finally realized through embedded software module into the power distribution automation monitoring and control system. At that time, the smart distribution grid will improve the automation level of distribution network, optimization ability and the self-healing control ability, which can make contribution to the intelligent distribution network, and produce great economic and social values [6]. The smart distribution grid self-healing and optimized control system have the following advantages:

1) *Improve the level of distribution network automation significantly*

2) *Predict distribution network state continuous and real-time*

3) *The real-time distribution network state evaluation*

4) *The adaptive algorithm*

5) *The real time control of operation optimization and implementation of self-healing*

6) *Completely conform to the requirements of the smart grid*

7) *Integrity and unity of the system*

8) *Enormous economic and social benefits*

B. Distributed Generation and Intelligent Micro Grid Technology

Our country is short of oil and gas, and the proportion of coal in the energy structure is high. It is impossible to rely on fossil fuels, because is difficult to achieve economic, social and environmental coordinated development, and it is not in conformity with the strong smart grid development request. The demand for electrical energy is increasing with every passing day. The transmission and distribution network are already to load to their full capacity development of renewable energy has become a way to alleviate energy supply, reduced environmental pollution, and improve the global climate [7]. As the water energy, biomass energy, wind energy and solar energy resources are rich in our country, so that we can make full use of them in a large scale.

Micro grid is a new type which combines power electronic technology, distributed generation (DG), renewable energy to generate electricity technology and energy storage technology. It integrates multiple distributed generation units and the load as a separate system, in order to provide users with electricity and the heat [8]. From the macro watch, the micro grid also can be thought of as a "virtual" power supply or load in distribution grid.

In view that traditional resources will be exhausted in the near future, the large scale utilization of distributed generation system, namely its grid-connected operation, enjoys most attractive prospect, while the grid-connecting devices play a crucial role in the realization of the grid connection. The existing research and practice show that the distributed power supply accessd to the grid as the form of micro grid can make full use of the distributed generation.

Operation of micro grid system can not be separated from technologies that support from each part that make up the micro grid system, as the source of energy (distributed generation), energy storage, interconnect switches and micro grid control system. Technologies in energy sources distributed generation include the utilization of renewable energy sources such as photovoltaic, wind turbines, and fuel cells. Several power systems improve efficiency by implementing the use of flue gas using CHP technology (combined heat and power) as micro turbin [9]. Technologies in energy storage micro grid systems include battery, super capacitor and flywheels.

As a new paradigm of power systems, implementation of the micro grid still faces many obstacles. Less understanding about micro grid and unfavorable government policies become an obstacle in applying micro grid technology. In general, in addition can be applied as a solution to electricity in remote areas, micro grid technology can also be used as electrical

solutions such as urban residential complexes, offices, schools and others. In which implementation of micro grid technology will provide advantage compared if have to build a new transmission and distribution network.

In the future, it still has many problems about micro grid in China, such as policy, technology, industry, and many other issues. The small capacity amount of distributed generation connecting grid power is still a problem [10]. However, micro grid as a new technology, combined with DG and renewable energy, can have the effective way of dealing with the energy shortage, environment pollution and climate change in the future.

C. AMI Technology

AMI (advanced metering infrastructure) is a complex system which can meter, collect, save and analyze the information of the end consumers. It is usually consisted of the smart meters, metering data management system and communication system. Recently, the infrastructure has covered the network in the houses of the consumers. AMI is composed of four parts: smart meters, communication network, Meter data management system (MDMS) and Home area network (HAN). Besides, in order to make full use of the AMI data, many application interfaces for current application system need to be created. Smart meters serve as a gateway in some degree between electricity companies and users. The users can check its electricity consumption information and the current power price [11]. Smart meters can relay the load control command from the electricity board once the system is in emergency and the command is accepted by the users. However smart meters are more than a meter. It has some other typical functions:

- 1) *Provide two-way measurement for the users with smart distribution grid.*
- 2) *Remind the users the information about power outage alarm and power n restoration .*
- 3) *Supervise the power quality.*
- 4) *Set remote programming and update software.*
- 5) *Synchronize time.*
- 6) *limit loads in response to the situation of the demand side*

AMI is considered to be the first step of construction smart distribution grid. The power grid enterprises can collect much information of the users by using AMI. The user actively involved in the electricity market, to realize the positive interaction between the grid and the user [12]. Compared with the traditional form, AMI adds the user intelligence management center, which provides a support platform to interact between users and many devices.

From the late 1970s, China has begun to research and apply electric power load management technology. With the progress of science and technology and advancement of marketing information work for many years, load management system, concentrated meter reading system and power distribution transformer measurement and control system has played an active role in system marketing, safe production and management. The coverage rate of these systems is increased

and its application scope and effect has gradually expanded [13]. At the same time the China has established the according technical standard infrastructure about the above systems.

In May 2009, SGCC explicitly put forward to build smart grid based on strong grid that UHV (ultra-high voltage) power grid is the backbone and all levels of grid are coordinate developing. It is supported by information and communication platform, with information, automation and interaction characteristics, includes all aspects of power generation, transmission, substation, distribution, utilization and scheduling, covers all the levels of voltage and integrates power flow, information flow and business flow. Based on the research results of Europe and the United States, China launched a series of important research topics on smart grid, determined its development trends and announced the building program of planned pilot, comprehensive construction and leading promotion [14]. Now it's time for laying down the standard of advanced metering infrastructure. China Electric Power Research Institute, Tianjin University and other research institutions and universities have also set up smart grid research centers and begun to study and explore advanced metering standard infrastructure.

AMI is the basic information platform of the smart grid and a bridge to connect users with power system. It can rapidly measure, diagnose and adjust power quality, monitor and control distributed power generation and energy storage device, provide physical basis for the full bidirectional interaction. Advanced metering standard infrastructure for smart grid will unify the function, technology, type, service, management and application specification, security protection technology specification and communication protocol. It provide technical support for perceiving grid, intelligent control, flexible and interactive, friendly and open, economic and high efficiency application of advance metering system, which will have a very good development prospect in the future construction of smart grid.

V. CONCLUSIONS

This paper discusses the background and necessity to develop the smart distribution grid. Smart distribution grid plays an important part of strong smart grid with Chinese characteristics. It is a strategic weapon to response to China's future energy, the environment, the climate, economic and social challenges. It is also an effective means to solve the problems such as the weakness of the distribution grid architecture, the low level of automation, the negative impact of the distributed generation for the power grid, the interaction between user and the power grid and electricity network, and the low level of the operation control. The success of some regional demonstration projects will motivate more and more countries and companies to join the group developing SDG. Completing the construction of the SDG will require collaboration between policy makers and financial institutions. However, Developing SDG is convinced to be an overwhelming tendency despite of the difficulties. By conducting distribution grid self-healing control technology, distributed generation

and intelligent network technology Art, AMI technology, we can effectively promote the realization of the blueprint for the smart grid in China.

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