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Overview

1.1 Proposal of Smart Grid

Since the 1980s, great changes have taken place in computer, information, and communication technologies. With the continuous penetration of new technologies and materials, the electric power system – which is considered a traditional field of technology – is now facing great changes. The great change that is going to take place immediately is generated by the demand of users, national security, and environmental protection. On July 8 and 9, 2003, more than 200 experts from American Electric Power Industry Equipment manufacturing company, academia, industry organizations, national laboratories, federal and state government agencies met for the National Electric System Vision Meeting in Washington D.C.

The topics below were discussed in the meeting:

1) goals for the years 2010, 2020, and 2030 to achieve the vision;
2) challenges that may be faced in achieving the above goals and vision;
3) research, development, and demonstration needed for facing challenges;
4) time schedules for research, development, and demonstration.

At that time, the challenge for the American electric power supply was that the aged power grid and electrical facilities failed to meet the demand for economic development and held the economy back. Particular attention must be paid to this serious problem.

Power transmission and distribution play a significant role in electric power supply, and the market and America's economy (to a value of 10,400 trillion USD) are greatly dependent on a secure and reliable electric power supply. With the ever-increasing requirements of users for electric power supply, considering national security, environment protection, and energy policies, it is necessary to set out a strategy for power grid reformation: integrated approaches for market, policy, and technology; electric power system research, development, and demonstration; policy analysis and modeling; and coordination between federal, regional, and state departments. The aim is to form a competitive North American electricity market through plan "Grid 2030," providing sufficient, clean, efficient, reliable, and affordable electric power at any time and in any place, leading to the world's most secure electrical service.

Self-healing Control Technology for Distribution Networks, First Edition. Xinxin Gu and Ning Jiang.

All the above services are provided, based on:

1) Power backbone network – to achieve power exchange between the US East Coast and West Coast.
2) Regional Internet power grid – a strong supplementary to the power backbone network.
3) Regional power distribution network – to implement power distribution.
4) Final US power grid – including communication and control systems.

The conference proposed combining the technology of power grids with up-to-date communication, control, and electronic technologies in order to establish a more intelligent electric power system and thus achieve a real-time self-healing power grid by 2030 [1, 3].

1.2 Development Status of China's Power Distribution Network Automation

The pilot work of power distribution network automation that started during the upgrading of urban and rural power grids at the beginning of 2000 lasted for about 2 years. As power distribution network automation equipment and communication technologies are immature, most systems failed to achieve as expected, and the development of power distribution network automation was still not clear.

With the rapid development of China's economy, however, problems such as high load density of power supply, complex power supply modes, and increasing requirements for reliability of power supply occurred in major cities. Urban power distribution networks have the most concentrated loads, which is of concern for the security of state politics, the economy, and every household; therefore, reliable and safe power supplies are required, especially in major cities. Once an accidental power failure occurs in a major city, great losses will be felt.

In order to change the situation of power distribution networks lagging behind, the State Grid Corporation of China (SGCC) organized and launched 31 major power distribution network projects and an international consultation for Nanjing and Qingdao power distribution networks. These projects are intended to speed up the pace of power grid construction combined with urban development and optimize power grid structure, build a robotic power distribution network, and increase the capacity and reliability of power supply.

Since 2003, we have been studying the application of project "Grid 2030" and new technology in traditional power industries, and what we can learn from this to promote the development of China's electric power, especially Advanced Distribution Automation (ADA) as researched by the US Electric Power Research Institute (Epri) R&D team, led by Frank Goodman.

ADA is the future development goal of power distribution network automation. It mainly studies and aims to solve the following problems:

1) improving reliability and power quality;
2) reducing operating costs;
3) researching the integration of power distribution networks and distributed power supplies;

4) researching the coordination between power distribution systems and demand-side systems;
5) shortening the time of power outage and recovery;
6) providing more options for subscribers.

The fields of technology involved in the project include:

1) design of new intelligent electronic devices (IEDs);
2) research on low-cost and multi-functional static switchgears, sensors, monitoring systems, fault prediction, etc.

Figure 1.1 shows the future intelligent power distribution network described by ADA. The automation system is composed of a synchronous satellite, communication, sensors, intelligent electronic devices, a control substation (local agent), and a distribution control center. The power distribution system is composed of a distribution substation, FACTS, IUT, and DER. It is an ideal, controllable, and adjustable distribution network with a complete system that provides industrial, residential, and commercial consumers with secure, reliable, and high-quality power supply [2].

1.3 Development of Self-healing Control Theory

- Can the faults of an equipment system, if any, be controlled or eliminated by itself during operation?
- Are the faults able to self-heal like human or animal diseases?

Under the guidance of system science, the "self-recuperating" treatment principle of modern medicine, including immunization, defense, compensation, self-healing, and self-adaptation, can be used as a guideline for research on equipment self-healing and its application.

Following the self-healing control principle of an equipment system that aims at prevention and elimination of faults, the electric power system is constantly summarized, perfected, and improved in practice to create a self-healing control theory of electric power systems.

Modern equipment is becoming increasingly large, high-speed, automatic, and intelligent. In particular, high-speed turbo-machinery, industrial pumps, fans, compressors, centrifuges, and other major equipments that are widely used in the petrochemical industry, metallurgy industry, electric power industry, non-ferrous metallurgy industry, and other process industries are closely linked to the process of production, and thus form a great system. Should a failure occur in such a system, major accidents and great economic losses may be caused. Since the 1960s, the international engineering science and technology circle has developed equipment monitoring and diagnostic technology; predictive maintenance and intelligent maintenance are gradually being introduced to industrial enterprises and an emergency stop interlock system is widely used, which has played an important role in ensuring safety in production and achieving practical results.

The purpose of self-healing control research is to change the traditional methods that depend merely on emergency stop and manual maintenance and troubleshooting. Different from device diagnostic technology and predictive maintenance technology,

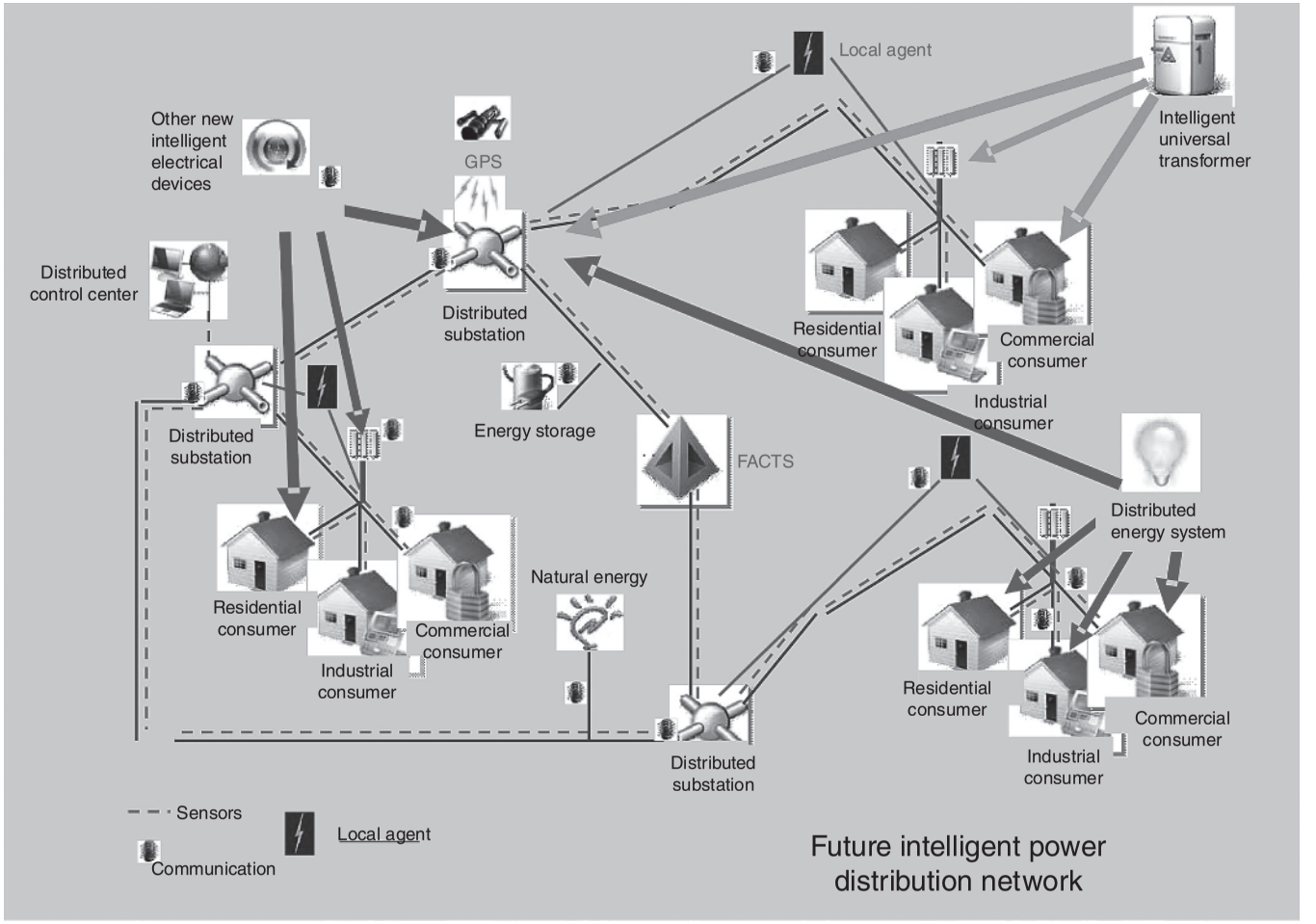

Figure 1.1 Future intelligent power distribution network as described by ADA.

this theory and method focuses mainly on how to provide the equipment system with a fault self-healing function and the ability to eliminate faults by itself during operation rather than employing manual troubleshooting with a mere emergency stop. Project practice has shown that the occurrence of most failures is a gradual progress, except for a few sudden failures. This means that equipment faults can be prevented by prompt and appropriate actions, once they are found at an early stage.

The occurrence of equipment failure is a gradual process. If the equipment is not designed with monitoring at important links, or it lacks intelligence, we may miss the opportunity to monitor and detect hidden dangers and these hidden troubles in the equipment will develop into failures.

Similar to an equipment system, an electric power system would first trip through the action of relay protection, followed by manual handling in the event of failure. An electric power system is a complex multi-device system and tripping can often cause multi-point disturbance; the possible consequences include large areas of disturbance or instability, such as splitting and generator tripping.

The concept of electric power system self-healing was first proposed in the Complex Interactive System Joint Research Project launched in 1999 by EPRI and the US Department of Energy. Later, the research projects Intelligrid of EPRI and Modern Grid Initiative of US Energy Laboratory both took self-healing as the main research objective, and deemed it the core technology for ensuring quality of power supply. The self-healing function has been a hot topic recently.

Self-healing refers to one function of a power grid that takes advantage of an advanced monitoring system to perform continuous on-line self-assessment of power grid operating conditions and takes preventative control measures so as to achieve timely detection, rapid diagnosis, rapid adjustment or isolation, with little or no human intervention. Remove the hidden danger and adjust the operating mode so that the failure can be isolated promptly upon occurrence, and the reconfiguration can be accomplished quickly and automatically; in this way the normal power supply would be unaffected, or affected as little as possible. Like the immune system in our human bodies, the self-healing function makes it possible for the power grid to protect against various internal and external damages (faults) to ensure secure and stable operation of the power grid and high-quality electric power.

The power transmission network is designed for a looped network and multiple feed structure, so that one or more components out of service won't affect the normal power supply of the system. Hence, the self-healing function on the one hand can achieve on-line monitoring of electronic equipment and find/remove potential faults by the removal of fault components in time through relay protection and on the other hand can perform on-line assessment of safety and warning/control so as to avoid widespread blackouts caused by power grid instability.

The power distribution network is user-oriented. Generally, power is supplied in a radiation mode. Any distribution network fault or power quality disturbance will have an effect on the quality of the power supply. Therefore, the self-healing function of a distribution network has some characteristics different from that of a transmission network. Self-healing functions of intelligent distribution networks include: firstly, reducing the duration and frequency of power failures, especially to avoid the problem of short-time unexpected power failures present in current power grids and increase the quality of power supply; secondly, optimizing the quality of power energy, especially

restraining sudden drops in voltage; finally, effectively improving the ability to prevent disaster and damage.

It is necessary to note that the self-healing function is not a totally new concept in terms of definition and technology; relay protection and automatic safety devices both belong to it. The self-healing function is developed on the basis of traditional relay protection and automatic safety devices, but is more advanced. Its ultimate goal is to provide an uninterruptable power supply without human intervention.

The research and development/application and dissemination of self-healing control technology play a significant role in the construction of a smart grid and the improvement of power supply quality.