Wide-area Protection Research in the Smart Grid

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Abstract

The smart grid brings opportunities and challenges to the power system protection and control. Fast advancement in communication and measurement techniques accelerates the development of wide-area protection, based on the wide-area measurement system. In this paper, the background of smart grid is described. In the smart grid, advanced technologies such as the non-conventional instrument transformer, clock synchronization and data synchronization etc offer great opportunities for the development of wide-area protection. According to that, the concept as well as the content and development of wide-area protection is discussed. Some key technologies, like wide-area measurement system, and wide-area communication system are analyzed. Finally, the development trends of wide-area protection in smart grid are prospected.

Keywords: smart grid, wide-area protection, PMU, wide-area measurement system, IEC61850

1. Introduction

With the global resource and environmental pressures are increasing, the society demands for environmental protection, low-carbon economy and sustainable development are improving [1]. The process of electricity market is constantly deepening, and the power grid must be able to provide more secure, reliable, clean and high quality electricity supply. Distributed generation systems with diverse energy, which have the advantages of low pollution, high reliability, and flexible location, will be the strong supplies and effective supports to the big power grid in the future. Nowadays different countries and organizations, represented by the United States and the European Union, unanimously propose to build a flexible, clean, safe, economical, and friendly smart grid, and regard the smart grid as the future direction of the power grid [2-4].

As the largest user of primary energy, the power industry has responsibilities for reducing greenhouse gas emissions and climate impact in China. The State Grid Corporation of China proposed to build a leading and strong smart grid with Chinese characteristics [5-6]. One of the important characteristics of China’s smart grid is to strengthen the backbone of power grid construction. That is, establishing a smart
grid with a backbone grid of ultra high voltage (UHV) power grid, with high degree of coordination at all levels of power grid development.

The expansion of power grid scale and construction of UHV grid will lead to short current increasing. It will affect the operations of electrical equipment and the system reliability. Network reconfiguration, distributed power system, and development of micro-grid technology will cause problems such as coordinating of backup protections, the system impedance changes, multi-way power flows and so on. These will lead difficulties for conventional relay protection setting and operation.

At present, researches and applications on new technologies of Non Conventional Instrument Transformer, clock synchronization and data synchronization, computer information, fiber communications are deepening, which supply broader space for the protection and control development. Therefore, with the deepening studies of smart grid, the wide-area protection is catching more and more attention.

2. Wide-area protection and its development

Studies on WAPS are focused on two fields: one is security and stability control, and the other is relay protection. In the security and stability control field, Bertil Ingelsson proposed that WAPS is mainly used to prevent long-term voltage collapse. It is established on basis of the supervisory control and data acquisition (SCADA) system, with centralized decision-making structures, non-real-time data collection, and slow data refresh frequency. The communication system does not require fast, real-time data exchange. After that, WAPS is positioned as a system protection and control method between conventional protection and SCADA/EMS. The control measurements include automatic reactive power control, low frequency/ voltage load shedding, remote load shedding, generator shedding, system splitting, and flexible ac transmission (FACTS), etc. Compared to the traditional strategies of stability control, WAPS involves a wider geographical scope and requires more complex calculations in the processes of getting information, forming control strategies, and carrying out control measures.

In the relay protection field, reference [7-8] proposed to use globe positioning system (GPS) signals for precise time synchronization, and a dedicated fiber channel for multi-point current information transmission, based on that, a wide-area current differential backup protection is constituted. This method overcomes the problem that single-electrical-component-oriented current differential protections can not provide quick backup protection.

In regard to applications, the France electricity power company EDF has established a WAPS. The stability control system judges the system stability by phasor measurements of different areas. The goals of WAPS are splitting the grids and shedding loads when it detects loss of transient stability. Hydro-Quebec power company of Canada uses the phasor measurement data as the power system stabilizer (PSS) control input for generators, and it improves the system oscillation damping. The wide-area measurement system of WSCC includes 77 acquisition devices, 47 of which are dedicated phasor measurement devices, 20 are phasor measurement devices based on personal computers, and the rest are other measurement devices. The purpose of WAMS is the system disturbance monitoring, and the main functions are real-time continuous measurement and event logging. The WAMS has been carried out in East China Power Grid for many years. This system continuously monitors the performance of East China Power Grid, including the unusual frequency, low frequency oscillations, and the dynamic characteristics during and after various disturbances.

3. Key technologies of wide-area protection in the smart grid

3.1 Wide-area Measurement Technology
The current power systems have usually set up the SCADA systems for measuring and monitoring the system stability, and the fault recorder systems for measuring the fault transient process. However, it is still difficult to monitor and analyze the dynamic behaviors of the whole system because SCADA can only provide steady, low sampling density and asynchronous power network information at different moments.

The wide-area synchronized phasor measurement technology can describe the system dynamic behavior, which make it to have more extensive applications in the power system. Such as state estimation, adaptive protection, on-line instability prediction and fault recorder.

Phasor Measurement Unit (PMU) is the basic equipment of synchronized phasor measurement, and is installed in selected locations in the power system. It can measure the system real-time voltage, current, frequency, phase and amplitude information accurately, and send the information to a center for comparison, evaluation and other treatments. The typical structure of PMU is shown in Fig.1.

The PMU-based WAPS has an extensive application prospect. Some applications are as follows:

a) Real-time monitoring and fault recording. Recording the fault data can be used to replicate the fault process, and assess the performance of control and protection system to improve the system security.

b) State estimation. Traditional state estimation has disadvantages of poor real-time, long calculating time, non-synchronous remote sensing value, all of which cause state estimation deviations. After using phase measurement, the synchronized phase values from PMU will be combined in the dispatch centers, and the real-time accurate state values can be obtained. As a result, the state estimation accuracy can be greatly improved.

c) Self-adaptive protection. The self-adaptive protection can automatically adjust the settings and action equations to satisfy sensitivity and safety requirements of the new operating conditions, with changed information including current, voltage, phase, etc.

d) Stability prediction. The systems’ operating status can be assessed by using PMU measurement data. With this, protection and control system can improve the system transient stability.

3.2 Wide-area Communication System

Wide-area measurement technology is the basis of WAPS, thus it needs a secure and efficient communication system. In recent years, communication technologies develop rapidly. Ethernet is gradually replacing the industrial field bus. In many areas, synchronous digital hierarchy (SDH) optical fiber rings are laid between substations, or the substation local-area networks are connected into power
According to the status of the development of wide-area communications, choice of fiber as a medium, and the communication network in which the SDH carries ATM, can meet the communication requirements of WAPS. Currently, when most electric power companies construct or reconstruct the power private communication networks, the ATM modes are authorized. And the communication media is mainly optical fiber, which lays a material foundation for WAPS.

3.3 Wide-area Information Exchange

The communication system for data information exchange is the key technology for smart grid [9]. Wide-area measurement and data exchange is the critical basis for WAPS based on smart grid. Protection intelligent electronic device (IED) in WAPS must be able to efficiently and accurately exchange data. The simple diagram of wide-area data information exchange is shown in Fig.2.

Measurements send the acquired information to the substation process buses with IEC61850 protocol. Protections get digital information of measurement units from buses and determine if the fault is happened. If there is a fault, switchgears are ordered to trip. Wide-area information is introduced into protection systems, and local substation information is sent to control centers, which can realize protection and control with multiple components in this power grid.

4. Trends of wide-area protection in smart grid

4.1 Combined with Adaptive Protection

One characteristic of smart grid is self-healing and adaption, which brings up higher requirements for selectivity, reliability, speed and sensitivity of protections [10-11]. The development of wide-area
measurement and high-speed wide-area network technologies, makes the adaptive protection based on the whole network information possible. With high-speed wide-area networks, WAPS can not only accurately obtain current operating information in real time and analyze operation conditions, but also can change protection scheme to matches the grid operation modes, and which will greatly improve the protection performance.

4.2 Combined with Agent

Agent is a dynamic entity that can make inferences or decisions alone or under little guidance of human, and also a computer system under certain environment [12]. Multi-agent system (MAS) can coordinate intelligent behaviors among various agents. All the agents can feel environmental changes, and they are able to judge each others’ working states. Such as the circuit breaker position, the protection and operation information of the collaborators, and whether there is any fault in the line. Agents also have skills, such as communication, comprehensive judgments, and breaking switch. When MAS coordinate the intelligent behaviors, it also should obey some principles.

MAS mainly has two structures: hierarchical distribution and peer mode. The hierarchical distribution structure has good local autonomy with low real-time requirements. But when the system is large and there are lots of agents, the coordination models are complex. The MAS based on peer mode simplifies the complexity of communication and control, it can better achieve the goal of global optimization. WAPS has high requirements for real-time transferring of wide-area information, so the peer consultation mode is its good choice.

4.3 Wide-area System Communication Based on IEC61850

Because of the different functions of WAPS, requirements for their communication system function are different. With the object-oriented modeling technology and future-communication-oriented extensible architecture, the IEC61850 protocol standard can realize the “One World, One Technology, One standard” goal [13]. It has become the basis for realization of intelligent substations, and all the information modeling and exchange of different intelligent substation equipment will be under the framework of IEC61850. For WAPS, no matter manufacturers or device models are the same or not, information must be quickly and reliably exchanged.

5. Conclusions

This paper has discussed contents, development, and key technologies of wide-area protection. With the increased availability of data synchronization, phasor measurement, and communication technologies applied in the smart grid, they can provide high-precision synchronous data acquisition, meet the real-time and reliability of data transmission, and provide basic support for wide-area protection principles and applications. There seems to be a great potential for wide-area protection to combine with adaptive protection, multi-agent technology and IEC61850 protocol. Wide-area protection is currently a research hotspot in power system, and significant progress has already been achieved. With the in-deep studies on the smart grid, the wide-area protection technologies will be further developed.
References


