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AN INTRODUCTION ON POWER SYSTEM MONITORING

The power system is a huge system as a result of interconnections between each service area to improve reliability and economic efficiency. The social system has been mainly developed based on electrical energy for a better life and economic growth. On the other hand, the power system is exposed to the natural environment at all times; thus, the system has some small or large disturbances, for example, by lightning, storm, and apparatus faults. Under these conditions, the system should maintain stable operation to avoid blackouts in the whole system using appropriate protection and control schemes. However, in a large-scale interconnected system, there are some difficulties in evaluating and maintaining the stability of the whole system.

Recently, a new issue in power systems has come out, which is the penetration of renewable energy sources, bringing more uncertainty that requires more severe operation. For energy security, the introduction of renewable energy sources is indispensable; therefore, to maintain system reliability and make efficient use of sustainable energy, power system monitoring should be a key technology to achieve flexible operation in the system.

On the other hand, in recent years, the development of information and communication technology (ICT) has enabled more flexibility in wide-area monitoring of power systems with fast and large data transmission. Especially, the wide-area measurement

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system (WAMS) with phasor measurement units (PMUs) is a promising technique as one of the smart grid technologies in the trunk power grid. In this chapter, basic concepts around power system monitoring are emphasized.

1.1 SYNCHRONIZED PHASOR MEASUREMENT

To monitor the power system, many measuring instruments and apparatuses are installed. Typically, the active power, reactive power, node voltage, and frequency must be monitored at all times. So far, the supervisory control and data acquisition (SCADA) system is a widely adopted monitoring system. On the other hand, the phase angle is also known as an important quantity that should be monitored for state estimation. If the phase angle can be measured, more flexible and precise monitoring could be expected.

The most important reason to measure the voltage phasor is to determine the phase reference of the measured sinusoidal voltage at all measuring points. This can be achieved by time synchronization. However, synchronized measurement is impossible by using the independent timers at the measurement points since at least 0.1 ms accuracy is required to measure the accurate phasor. On the other hand, since the global positioning system (GPS) has been opened for private use, it becomes easy to determine the precise time at a point on the globe; thus, the synchronized phasor measurement became a feasible technique.

The concept of synchronized phasor measurement was reported in the early 1980s [1]. In the literature, the method for time synchronization by GPS to calculate the phasor with high speed from the measured voltage has not been reported. In December 1993, the GPS system officially started its operation. The concept of synchronized phasor measurement using the GPS system was contributed to the *IEEE Computer Applications in Power* by Phadke [2]. Later, some advanced applications adopting phasor measurements, state estimation, instability monitoring, adaptive relay, controller tuning, and so on, were introduced. In 1998, the IEEE Standard for Synchrophasors for Power Systems was issued [3]. The synchronized phasor measurement system has been applied to the trunk power grid since the middle of the 1990s, especially in Europe and the United States. The synchronized phasor measurement can be considered as a powerful means for monitoring wide-area power systems. Some cases of worldwide blackouts have been fully monitored by the developed measurement systems [4–6].

1.2 POWER SYSTEM MONITORING AND CONTROL WITH WIDE-AREA MEASUREMENTS

Recently, some reports have been issued by the International Council on Large Electric Systems (CIGRE) on “power system security assessment” (CIGRE WG C4.601). A technical report dealing with power system monitoring on the “wide area monitoring and control for transmission capability enhancement” was also issued in 2007 [7].

In Switzerland, PMUs are installed at four substations to monitor the operating state since the system has a heavy load to the Italy system. System stability is monitored by using PMUs installed at other countries. On the other hand, in Italy, the PMUs are installed at 30 sites since the system experienced a large blackout in September 28, 2003.

There are some PMU projects at Hydro Kebec in Canada, Western Electricity Coordinating Council in the United States, and the eastern interconnected system. Virginia Tech has a project on synchronized frequency monitoring called the Frequency Monitoring Network with original measurement units.

In China, a project was started at the initiative of Tsinghua University in 1996. In the beginning, there were some issues on the communication speed and accuracy; however, the installation of PMUs has been supported since 2002. The PMUs were installed at about 88 sites by 10 new projects between 2002 and 2005. The system with functions of a graphical user interface, database, replay capability, and so on has been developed in order to monitor wide-area power system dynamics. The installation of several hundreds of PMUs has been reported at the IEEE General Meeting in 2007 [8]. The PMU is a prospective technology for the analysis of whole power system dynamics with huge networks.

In Sweden, wide-area stability is monitored by the PMUs installed at universities/institutes. Both 400 V and 400 kV nodes are measured to investigate the similarities. The monitoring network extends across three countries in Northern Europe. The interface for cooperative wide-area monitoring by sharing webpage-based online monitoring has been developed.

In Denmark, a large amount of wind generation has been accomplished, and almost all conventional generation is of the cogeneration type. The voltage and phasor of the eastern 400 and 132 kV systems are monitored to grasp the operation status for research purposes by the cooperative work of Elkraft Power Co. and the Centre for Electric Technology at Technical University of Denmark.

In Austria, the system is interconnected with many neighboring countries. The generated power at the northeast and south areas is transmitted via 200 kV lines. A number of PMUs are installed at Wien and Ternitz to monitor the power flow and temperature of transmission lines.

In Thailand, the Electricity Generating Authority of Thailand has a power system, which extends north and south, interconnected with Laos and Malaysia; therefore, the power flow is constrained by power oscillations with poor damping. The PMUs are installed at Surat Thani and Bang Saphan to monitor the state of tie-line between the central and south areas.

In Australia, the system consists of a 30 GW network of 110 and 500 kV with a distance of 5000 km. There is an issue of oscillation stability at the interarea network between the east coast and south area. The measurement network called Power Dynamic Management has been developed by the cooperation of the National Electricity Market Management Company as an independent system operator and PowerLink as the transmission company.

In Hungary, monitoring units are installed at six sites as part of the monitoring network of the Union for the Coordination of the Transmission of Electricity interconnected system called Power Log, which can measure three-phase voltage and current.

The result of monitoring interarea oscillations is used for tuning of the installed power system stabilizers.

1.3 ICT ARCHITECTURE USED IN WIDE-AREA POWER SYSTEM MONITORING AND CONTROL

It should be a very important aspect to collect the data measured by each PMU for system monitoring, state estimation, protection, and control. The measured data could be locally saved and then collected for postanalysis, or sent to a remote location in real time for system protection or real-time control. Therefore, it should be useful to know the ICT architecture. This section briefly introduces the ICT architecture used in phasor measurement systems.

Figure 1.1 shows a typical schema for a wide-area phasor measurement system including the communication and application levels. The measured data are collected by phasor data concentrators (PDCs) via a communication network. The concentrated data could be exchanged between utilities by using the standard data format including the time stamp of the synchronized GPS time. The important function of a PDC is to receive, parse, and sort incoming data frames from the multiple PMUs.

The basic requirements for a PDC are simple; however, usually the actual implementation requires a heavy computer processing task and a wideband communication. Therefore, the number of measurement units will be limited by the hardware of a PDC unit being used to handle the data concentration.

In addition, the data transmission type and communication protocols should be considered. The standards of the phasor data transmission protocol are established in IEEE C37.118. This protocol allows data-receiving devices to start and stop data flow as well as request configuration information about the sending data. Measurement systems can self-configure by requesting scaling and signal names from sending devices. This includes a notification bit to alert downstream devices for any changes in configuration.

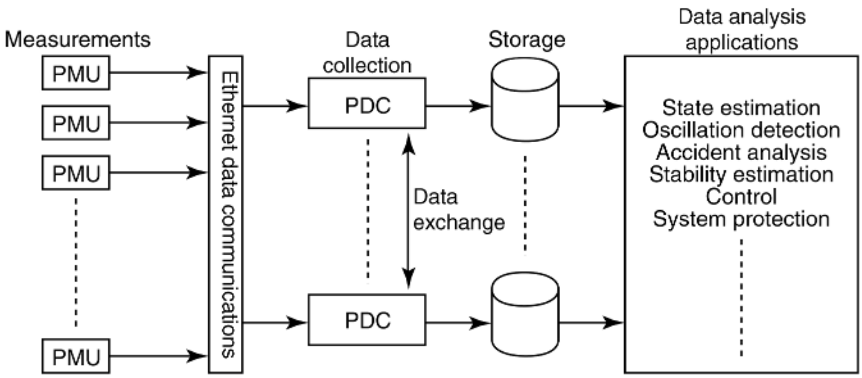

Figure 1.1. A schema of PMU/WAMS.

This protocol applies to sending data from the PMU as well as PDC devices, so it is scalable to the whole measurement system [9].

A wide variety of communication systems are used for the data collection. These include utility-owned communications, which can be a narrowband analog, digital, or wideband digital communication system. The public Internet with direct access or virtual private network technology, which is easy to implement, is now widely available. The most important aspects of choosing communications are availability, reliability, and bandwidth [9], especially for a real-time application, in which delay or interruption cannot be allowed. A narrowband communication channel could be enough to transfer data from a single measurement device. Data exchange between utilities requires a wideband communication channel since concentrated data by a PDC are accumulated data from many measurement devices.

Typical storage of data archiving for the phasor measurement system is in data files. The IEEE COMTRADE Standard (C37.110), which supports binary and floating point formats for time sequence phasor data, is widely used. The utilization of the standard file formats simplifies data exchange, analysis, and application development.

1.4 SUMMARY

This chapter introduces power system monitoring and control, especially with wide-area phasor measurement applying PMUs. Some global applications of WAMS and the ICT architecture used in the phasor measurement system have been outlined as an introduction.

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