Synchronous measurement technology of source-grid-load in renewable energy power system

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Abstract: In this paper, the technology of synchronous phasor measurement and its application in power system transient stability prediction and control, state estimation and dynamic monitoring, fault location is introduced. The construction method of wide area measurement system based on synchronous phasor measurement technology is put forward. The important role of synchronous phasor measurement technology in these fields and its significance to power system security are analysed.

1. Introduction
Synchronous phasor measurement technology refers to the technology that integrates synchronous phasor measurement, transmission, analysis and application [1-3]. It mainly includes phasor data concentrator (PDC), phasor measurement unit (PMU), high-speed data communication network and analysis and Application Center (AAC) [4]. The core idea of synchronous phasor technology is to carry out one-to-one phasor for the real-time operation parameters of wide area power grid which are collected synchronously with high-precision (microsecond level) [5]. At the same time, the dispersed phasor data are collected by high-speed communication network, so as to obtain the dynamic information of the whole power grid in the space-time coordinates. It is a new idea and method to monitor, analyze and control power system [6-8].

2. Application and research of synchronous phasor measurement technology in power system

2.1. State estimation and dynamic monitoring of power system
At present, the application and research scope of synchronous phasor measurement technology in power system has been involved in state estimation and dynamic monitoring, transient stability prediction and control, fault location, construction of wide area measurement system and other fields [9,10].

In the modern power energy management system (EMS), state estimation is an important part of synchronous phasor measurement technology, and plays an important role in the power market environment. Other advanced EMS applications such as voltage stability analysis, transient qualitative analysis and security constrained scheduling are affected by the results of state estimation. However, the current state estimation software of power system takes a long time and is based on power flow and voltage phasor of the whole power grid. In the transmission process, the accuracy of the telemetry device may be affected by the error in the transmission process. The application of synchronous phasor measurement technology can directly measure the synchronous voltage phasor and current...
phasor in the system, improve the accuracy and speed of state estimation, and make it possible to estimate the dynamic state of the system.

2.2. Transient stability prediction and control
Voltage stability is an important issue in power system research. After more than 30 years of research, some achievements have been made. However, the previous methods for evaluating voltage stability, such as Jacobian matrix method and maximum power method, have the problem of too long calculation time, so they are not suitable for on-line real-time control. Some scholars put forward the application of synchronous phasor measurement technology in the evaluation and control of power grid stability, which has been widely concerned and recognized. After the disturbance occurs in the power system transient stability control, the synchronous phasor measurement unit (PMU) is used to measure some dynamic data, and then these data are used to predict the stability of the system, and corresponding measures are taken. This is much more accurate than the traditional prediction method.

The accurate location of transmission line fault plays an important role in accelerating fault elimination, which in turn promotes the spread of 3G network.

2.3. Construction of wide area measurement system based on synchronous phasor measurement technology
Based on synchronous phasor measurement technology, wide area measurement system (WAMS) is constructed to realize dynamic real-time monitoring of power grid, which is of great significance to the power system with increasing complexity due to the gradual increase of daily power consumption and production power consumption. The wide area phasor measurement system is mainly composed of the basic high-speed data communication network, the phasor measurement unit PMU located at the station end and the global satellite communication system (GPS) for positioning the operation status of power grid.

The structure tells us that the system protection center, which is used to coordinate and process the data of each protection center, is located at the top level; the middle layer is composed of various protection centers, and each protection center is directly connected with its own connected PMU; and the bottom layer is composed of PMU with additional protection function installed in different stations. The structure collects the measured phasor data through the high-speed communication network, thus creating conditions for the realization of global stability control system. Synchronous phasor measurement technology plays an important role in the relay protection of power system and the verification of power system model parameters, which is also of great significance to the power system. In the end, the theory and technical system of synchronous phasor measurement in intelligent distribution network are established. The overall research framework is shown in Figure 1.

![Figure 1 Research framework of D-PMU technology](image-url)
3. Phasor based system dynamic process monitoring

3.1. Marketing means
According to different customer groups and specific time to develop different characteristics of marketing programs, combined packaging of products, so as to achieve the rapid arrival of products to users, improve after-sales service, and improve marketing quality. Combined with the above different levels of division, for the subdivided customer groups, it integrates the upstream and downstream products of 3G value chain, provides basic services, value-added services and high additional application bundling integration application marketing strategy.

3.2. Phasor based system dynamic process monitoring
The current monitoring system can only monitor the system voltage, current and power, and the phase angle characteristic which is closely related to the system stability can only be calculated off-line. The power angle $\delta$ can directly reflect the power flow and stability of the system. When the system structure changes or accidents occur, the oscillation process is directly reflected in the power angle change (frequency change). The phasor information on each hub node of the power grid can directly monitor the stability and oscillation process of the system, and further can be used to guide the stability control measures and dispatching strategies of the system. The D-MPU frame structure is shown in Figure 2.

![Figure 2 Frame structure of D-MPU](image)

3.3. Power system active power monitoring
When the generator terminal potential and the receiving bus voltage remain constant, the active power transmitted by the line is a function of the phase angle difference at both ends, as shown in (1). The measured phasor value can be directly used to calculate the active power output. The relationship between the phase angle difference and the transmission power of different buses in each node of the power grid also accords with this relationship, so the power flow distribution can be calculated directly.

$$P_E = E_d U_s \sin \delta / X_d$$  \hspace{1cm} (1)

Among them, $P_E$ is the transmission power; $E_d$ is the generator end potential; $U_s$ is the receiving terminal voltage; $\delta$ is the angle between the potential $E_d$ and the voltage $U_s$, the transmission power is closely related to the phase angle, so it is called power angle. If the contact reactance $X_d$ between $E_d$ and $U_s$ and between them remains unchanged, changing the active output of the generator means changing the power angle $\delta$ of the generator.

3.4. Power system instability prediction
Synchronous measurement can monitor the transient process of the whole system in real time, which provides a new way for transient stability analysis. The state variables and derived values can be used not only for observation, but also for calculating the possibility of rocking in a certain period of time.
in the future by certain models, and corresponding protection and control measures can be taken to change the transient process.

4. State estimation and determination

4.1. Mathematical model calibration and parameter verification of system components
The traditional state estimation is based on the remote measurement (active power, reactive power, voltage, current) of each measurement point and the network topology, and uses the solution method of nonlinear equation to calculate the state variables. After the August 14 blackout in the United States, many countries attach great importance to the stability analysis of power grid, and PMU has been greatly developed. Because PMU provides phase angle measurement, the increase of PMU provides a new measurement equation for state estimation, so it provides more accurate state solution for state estimation. Synchronous phasor measurement has the following advantages:

(1) the voltage and current of each substation are measured at the same time, without estimating the state quantity, and an estimation result is obtained by multiplying the measurement result with a conventional matrix, which is a linear estimation;

(2) dynamic state estimation, that is, the dispatching center can receive a batch of phasor data from each measurement point every 2-5 cycles (40-100ms), which can reflect the dynamic process of the system in real time;

(3) By simulating various disturbance events, the validity of the power system model used for transient analysis can be evaluated and modified.

The design, monitoring, control, protection, operation and maintenance of power system need to be based on certain system model parameters. The correctness of the parameters of each component of the system can be verified and the mathematical model can be modified through the data recorded by phasor synchronous sampling.

4.2. System out of step protection and fault location
Current differential protection is a simple and fast protection method. In the past, due to the low accuracy of clock synchronization, it is very difficult to use current differential protection for long lines. Under GPS clock synchronization, if the sampling synchronization error is less than or equal to 1 μs, the current value is sent to the opposite end with time tag, which can simply complete the line differential protection. Similarly, the fault location based on the inrush current can also be solved. Based on the phase angle condition, it is easy to set parameters without considering the fault type. The application of phase angle will produce new protection ideas and devices.

4.3. Fault recording function
The fault recording function of recording all phasor parameters (including amplitude, phase angle, instantaneous frequency and positive sequence component) in the dynamic process of the system is the real fault recorder. The parameters obtained simultaneously provide a powerful means for fault recording and analysis.

5. Conclusion
Synchronous phasor measurement technology provides a new means in monitoring, analyzing and controlling power system, which makes it widely used in power system: building a comprehensive dynamic information platform for inter-regional power grid analysis, monitoring and real-time dynamic control; combining with PMU and conventional RTU, the existing SCADA / EMS system is reformed to make the stable EMS of dispatching center .The system functions should be changed to dynamic; static, dynamic and transient information should be integrated to realize unified time scale integrated management; online pre decision security and stability control strategy should be formed, but the dynamic stability of power system must be monitored and analyzed on the basis of dynamic
information platform; high-tech and high-level measurement and monitoring tools should be created to analyze dynamic security, stability and early warning of the whole system pre-decision.

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