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Experiences with and Perspectives of the System for Wide Area Monitoring of Power Systems

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Abstract--**With the emphasis on higher utilization of power systems, monitoring of its dynamics is becoming increasingly important. This requires information with higher accuracy and update rates faster than those usually provided by traditional SCADA systems. In addition, it must be synchronized over a wider geographical area than that provided by traditional protection systems. The introduction of phasor measurement units as well as advances in communication and computational equipment have made it technically feasible to monitor the stability of the power system on-line, using a wide area perspective. This paper outlines the specialized applications to monitor and control voltage as well as frequency stability of power systems and describes their state-of-the-art platform, the wide-area measurement system, which is now commercially available.**

Index Terms **-- Power Transmission, Voltage Stability, Real-time, Frequency Stability, Voltage Stability, Wide Area Control, Wide Area Protection, Wide Area Monitoring, Asset Management**

I. Introduction

The major motivation for utilities to apply Wide Area Monitoring technology is to obtain these benefits:

- Transmission capacity enhancement achieved by on-line monitoring of the system safety or stability limits [security] and capabilities
- Power system reinforcement (investment planning) based on feed-back obtained during analysis of system dynamics
- Introduction of a coordinated approach for the execution of stabilizing actions in case of severe network disturbances
- Triggering of additional functions by wide area monitoring
- Better understanding of the dynamic behaviour of the system
- General installation of an early warning system

The paper describes one such commercially available Wide Area Monitoring System aiming to possess the above mentioned characteristics. The structure of the paper is as follows: First the possible uses and application cases are outlined. Then the system platform and the possible components (both hardware and software) are described. A short summary including the present and future work concludes the paper.

II. Goal and Application Cases of Wide Area Monitoring

Phasor measurement is more and more becoming the ultimate data acquisition technology, which will be used in wide area monitoring. Power utilities have already deployed PMUs in their grids, mainly for manual data acquisition and processing. Wide Area Monitoring Systems provide central data acquisition from already installed and planned PMUs enabling utilities to utilize phasor information wherever it is needed. Several customized forms of utilization of such data are possible.

A. Monitoring of the dynamic system behavior – stability assessment.

At present, power systems are usually operated based on static or quasi-dynamic information extracted from RMS measurements. Phasor measurements at nodes help system operators to gain a dynamic view of the power system and initiate the necessary measures in proper time. This can significantly be supported by the stability assessment algorithms, which are designed to take advantage of the phasor measurement information. This increases the efficiency of power system operation and maintains security at the desired level.

B. Monitoring of transmission corridors – congestion management.

The interconnections (transmission corridors) between the power systems are mostly used for energy trading activities and physical energy delivery, contributing a significant cost proportion to the energy prices in liberalized markets. The transmission capacity of such corridors is often constrained by the stability concerns having their origin in the uncertainty

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about the system state. The traditional way to reinforce the transmission paths is building of new lines. This solution offers very high availability, but, on the other hand, the associated cost is very high. The alternative solution can be significantly improved monitoring by using a Wide Area Monitoring approach resulting in the reduction of uncertainties and thus the operational risk. In contrast to the traditional investment into the assets (i.e. transmission lines), the transmission increase is significant only under certain conditions, not permanently. This can be e.g. an increase due to lower environmental temperatures. However, the solution can be far more cost-effective due to the much lower investment needed for acquisition of a WAM System. Therefore, the WAM system can be seen as a tool playing an important role in the congestion management.

C. Disturbance analysis and system extension planning

The continuous data storage functionality of the WAM system provides a very valuable source of information for the post-mortem analysis of incidents and disturbances in the power system. It improves the efficiency of power system analysis and helps to find real causes of the incident. This indication forms a very solid basis for system expansion planning and needed system reinforcements.

III. SYSTEM PLATFORM OVERVIEW

A. Phasor measurement as basic technology

Wide Area Monitoring Systems are essentially based on a new data acquisition technology. In contrast to conventional control systems, where e.g. RTUs are used for acquisition of RMS values of currents and voltages, a Wide Area Monitoring System acquires GPS-synchronized current, voltage and frequency phasor measurements, which are measured by Phasor Measurement Units (PMUs), from selected locations in the power system. The measured quantities include both magnitudes and phase angles, and are time-synchronized via Global Positioning System (GPS) receivers with an accuracy of one microsecond. Critical nodes in today's transmission grids are usually monitored using static or quasi-dynamic data based on RMS measurements. Phasors measured at the same time instantly allow snapshots of the status in the monitored nodes to be made. By comparing the snapshots with each other, not only the steady-state, but also the dynamic state of critical nodes in transmission and sub-transmission networks can be observed. Thereby, a dynamic monitoring of critical nodes in power systems is achieved.

B. System architecture of the Wide Area Monitoring platform

The wide area platform architecture for monitoring and protection comprises of the following hardware:

- Phasor Measurement Units (PMUs)
- Communication Links
- System Monitoring Center (SMC) containing phasor data and tailored applications

PMUs are placed in the substations to allow observation of the power system under any operational conditions (network islanding, outages of lines, generators, etc.), taking into account a certain degree of redundancy to provide secure information also in case of unavailability of some data (PMU outage, communication failure etc.). Measured data are sent via dedicated communication channels/links to a System Monitoring Center (SMC). The SMC is a central computational unit, where the collected measurements are synchronized and sorted (data preprocessing), yielding a snapshots of the power system state. This setup is shown in Figure 1.

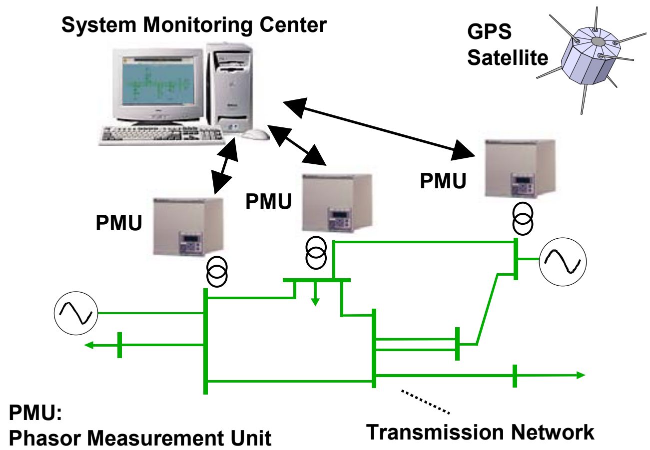

Figure 1: Setup of a Wide Area Mesurement System based on synchronized phasor measurements as input to the System Monitoring Center.

In case of meshed network topologies, the snapshot is then processed by the Basic Monitoring package (BM), which is part of the SMC. Basic Monitoring denotes the set of algorithms included in all installations of the wide area platform for different applications. They contain the following capabilities:

- ability to provide consistent input data for any application
- fast execution - leaving sufficient time to run additional applications within the sampling interval
- robustness - resistance of the system against poor quality of some of the input data (availability, range, synchronization)

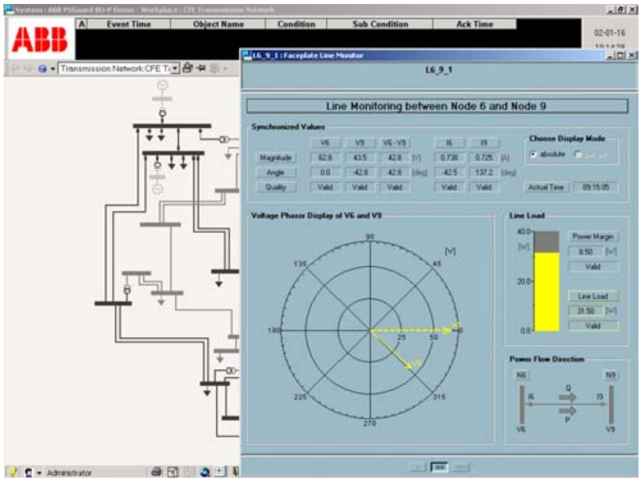

Figure 2: Graphical User Interface example of the Wide Area Monitoring System. On the right hand side the line monitoring faceplate showing the comparison of voltage phasors. The reference phasor can be chosen from other points of the grid.

Applications, which are linked to the output of BM, address various dynamic phenomena occurring in power systems. They predict the state of the power system and provide suggestions to the system operators for appropriate actions when rising instability is detected. An ergonomic Graphical User Interface (GUI) displays their outputs as well as the output of the BM to the power system operator. Access to historical data is provided for retrieval of phasor data during post-mortem analysis. A navigation facility is implemented for easy selection and display of required information.

IV. Activities & Advanced Software-Applications

To take full advantage of the Wide Area Monitoring System, the following step-wise procedure should be followed. First, the utility and the supplier of the WAM System perform an initial study aimed at identifying typical network problems and the most endangered area in which the WAM System should be deployed. The appropriate monitoring algorithms are chosen as well as the locations for the placement of PMUs. To assist quality during these various stages a number of algorithms has been researched and developed. These advanced applications are discussed in the following sections.

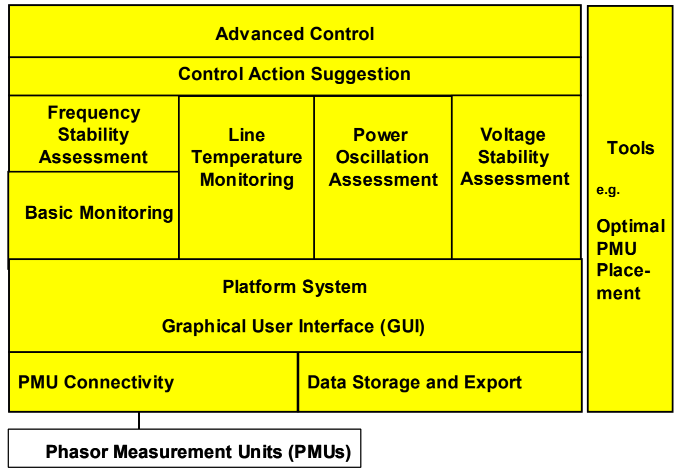

Figure 3: Platform System and Advanced Applications of a Wide Area Monitoring System

A. Platform structure

The fundamental software modules contain a GUI (single line diagram, popup windows, trend displays, easily scalable PMU connectivity package (2-40 or many more PMUs), data storage and export functions for further analysis.

B. Optimal PMU Placement

Placement of PMUs can be done according to various criteria. It is possible to place the PMUs in special locations such that they observe the topology as well. Thus the Wide Area Monitoring System can be run totally independent e.g. from a SCADA platform (or any other source of the actual topology information). The placement is influenced by the following criteria - minimal number of substations (when the engineering and commissioning cost are decisive as well as the use of communication channels), minimal number of PMU devices (considering PMU hardware and installation cost), observability of the topology based on the PMUs, consideration of the PMU type (i.e. number of analogue input channels of the PMU).

C. Basic Monitoring

Basic Monitoring provides accurate status information to the network operator. It might be called state calculation in contradiction of state estimation in conventional SCADA systems. Basic Monitoring processes the measured input data (voltage- and current phasors) and provides the full observables of the supervised area in terms of:

- all voltage- and current phasors
- topology (status of the branches - lines, transformers)
- islanding (e.g. if the power system has been subdivided, which buses form an island together).

Basic Monitoring provides the above information to the graphical user interface (GUI), but its main purpose is to serve as a prerequisite for the hierarchically higher algorithms (i.e. Voltage Stability Assessment and Frequency Stability Assessment of meshed networks), which receive the input data from Basic Monitoring. Though Basic Monitoring can be provided as a stand-alone algorithm, its enhanced value lies within in the connection with the advanced applications as described in the following.

D. Voltage Stability Assessment of the transmission corridors

The voltage stability assessment functionality provides a basis for monitoring of transmission corridors. Itself it depends on and extends the basic functionality of Wide Area Measurement Systems with functions related to the monitoring of voltage stability for a transmission line and/or corridor. It's main function is to provide the operator of the power system with sufficient information for the evaluation of the present power margin with respect to voltage stability. That is the amount of additional active power that can be transported on a transmission corridor without jeopardizing the voltage stability. Voltage in a power system may become instable because of shortage of reactive power. However this application provides monitoring functionality at present, and it's outputs are intended as the major decision support for operators. Actions that the operator may take to improve voltage stability may range from generation rescheduling or reactive load compensation, blocking of tap changers in the load area up to incremental or complete load shedding in extreme cases.

E. Line Temperature Monitoring

Loading of the lines is in many cases constrained more by thermal limits than by voltage instability concerns. The thermal limit of a line is usually set according to conservative and stable criteria, i.e. high ambient temperature and no wind. This results an assumption of very limited cooling possibilities and thus low loading. However, often the ambient conditions are much better in terms of possible cooling. That would allow higher loading of a line with a minimal risk. This is possible if an on-line working tool for line temperature assessment is available. One of the algorithms serves precisely this purpose.

F. Power Oscillation Assessment

Power Oscillation Assessment is the algorithm used for the detection of power swings in a power system. The algorithm is fed with the selected voltage and current phasors. The algorithm processes the input phasors and detects the various swing (power oscillation) modes. The algorithm quickly identifies the frequency and the damping of the least damped swing modes, that can e.g. lead to angular instability causing major power system disturbances (blackout) The algorithm employs adaptive Kalman filtering techniques.

G. Frequency Stability Assessment

Frequency Stability Assessment receives the data from Basic Monitoring. It early detects the disproportion between the consumed and generated power. The Frequency Stability Assessment algorithm estimates the impact of such a power unbalance on the frequency by modeling of the loads' responses and the generators' inertias. If the estimated frequency is not acceptable, the proposed actions to reach the desired frequency are computed and proposed.

V. Practical Experience with Wide Area Monitoring

Several systems with up to 16 PMUs have already been installed or engineered for practical application in several high voltage power grids.

A. Customer feed-back

Feedbacks based on prototype applications with customers sites are recorded with care. They confirmed system performance achieving customer benefits as

- Cost-effective grid operation through observation of critical network areas
- Detection and elimination of causes of Power Quality problems thanks to the high accuracy of the system
- Effective tool to investigate incidents properly providing additional strategic information for the utility's grid planning department

VI. Conclusions and Way Foreward

The commercial availability of a Wide Area Monitoring System is described in brief. Experience with existing prototypes show that a Wide Area Monitoring System can help to significantly improve grid utilization during phases of peak transmission demand while enabling the detection of critical factors influencing network stability. The described online monitoring applications will in the future help to significantly reduce investment cost for utilities while guaranteeing high levels of dynamic grid loading and availability. In this context, Wide Area Monitoring extends the capability of existing local monitoring and protection equipment to further levels of asset utilization.

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