APPLICATION OF PHASOR MEASUREMENT UNITS IN DISTRIBUTION NETWORKS

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ABSTRACT

This paper describes the principles and applications of Wide Area Monitoring with Synchrophasors from Phasor Measurement Units (PMU).
The first part explains the reasons for the use of Wide Area Monitoring and the principle. The second part deals with applications on the central level (PDC, Phasor Data Concentrator). The last part presents aspects of the market status from a vendor´s perspective and discusses some aspects of a R&D project in Germany.

INTRODUCTION

The principle of Wide Area Monitoring is the central monitoring of distributed fast time-stamped phasor measurements. These are acquired by Phasor Measurement Units (PMU). For reference, see [1] and [2]. There are some significant differences to measurements from Remote Terminal Units (RTU):

Measurements via RTU	**Synchrophasors from PMU**
Updated slowly typical every 5 s)	Fast update (measurement stream) with typical 10 values per second (= reporting rate)
No time correlation for measurements	Every measurement has a timestamp
RMS values without phase angles	Phasor values with amplitude and phase angle for voltage and current

Table 1: Significant differences between RTU and PMU

Resulting from the performance features of the Phasor Measurements, this method allows a dynamic real-time view on power swings and other transient phenomena in transmission and distribution networks. The principle is shown in Fig. 1.

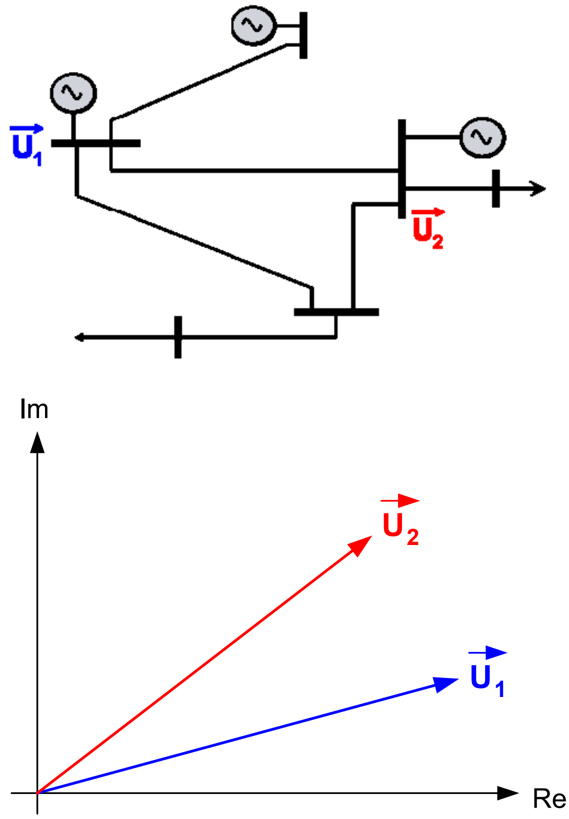

Fig. 1: Principle of PMU: Distributed measurement, central alignment of phasors

The improved visibility of dynamic phenomena is becoming more and more important because of increasing renewable power infeed and highly loaded networks. Loadflows are becoming more and more unpredictable and so the goal is to improve the observability. The technology has been developed for transmission systems, but can also be applied in distribution networks.

APPLICATIONS OF WIDE AREA MONITORING

On the level of the Phasor Data Concentrator, the synchrophasors are time aligned, archived and displayed on a screen (for example see Fig. 2).

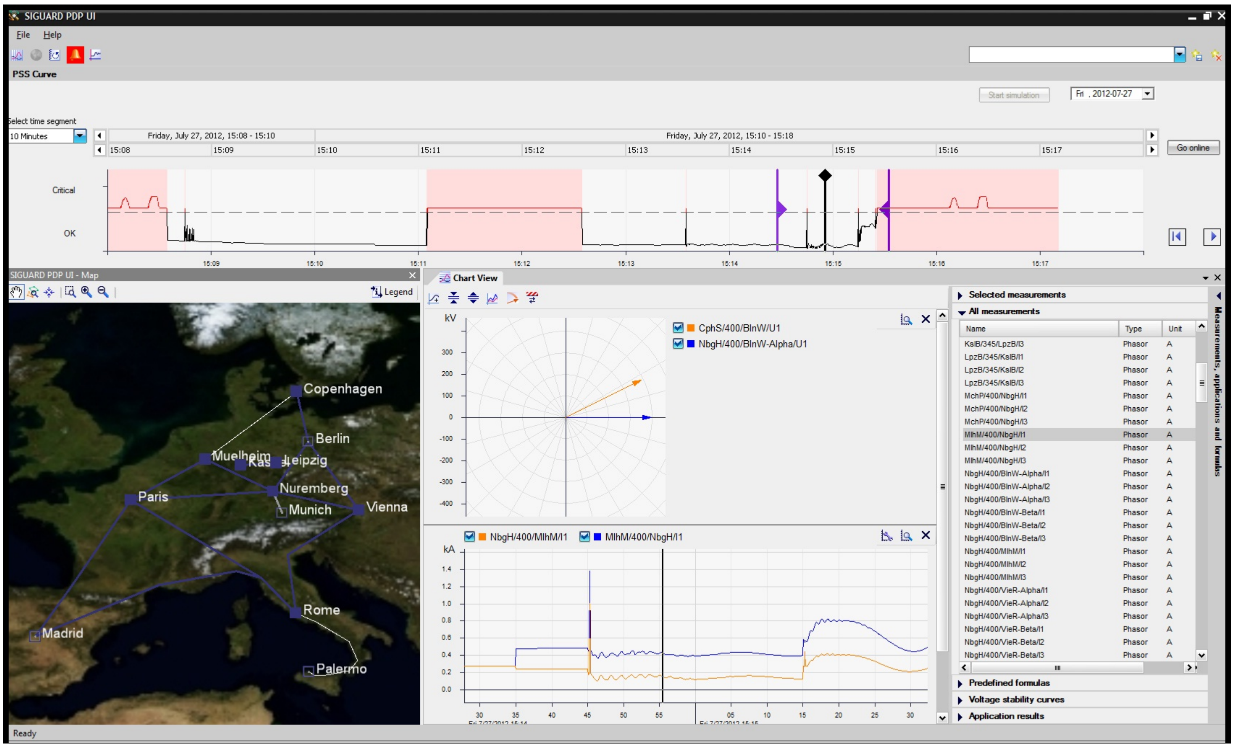

Fig. 2: Example for a User Interface of a Phasor Data Concentrator (PDC)

This direct monitoring of the phasors allows a real-time view on the network dynamic. Voltage and frequency curves inform about the reactive and active power status in the system. If the User Interface is able to show also archive values, the operator can analyze events and create detailed reports. This “historic view” can also help to verify the dynamic model of the network: The power swing modes (frequency of a power swing) can be calculated from an observed power swing and compared with the expected modes from simulation models.

Additional benefit of the synchrophasor measurements can be created with intelligent processing of the measurement streams. These processing functions are able to extract their recognitions fast and automatically from the measurements. Some ideas are presented in the following.

Island State Detection

The monitoring system has (among others) all frequency measurements from the network area available. So it is possible to compare all of them with each other. In case of frequency differences above a certain level, an alarm can be given because this indicates a network split. For example, in Fig. 3, both lines between the two regions have been interrupted. So the frequency measurements from PMU4 and PMU3 will be equal and the frequency measurements of PMU1, PMU2 and PMU5 as well. The difference in the frequency between the two PMU groups will significantly rise in the moment of tripping of both lines. So the User Interface of the PDC can indicate the Island State and announce the frequency difference. Such an event took place on Nov 4 2006 in the European transmission system; it was not clearly seen by all participants immediately.

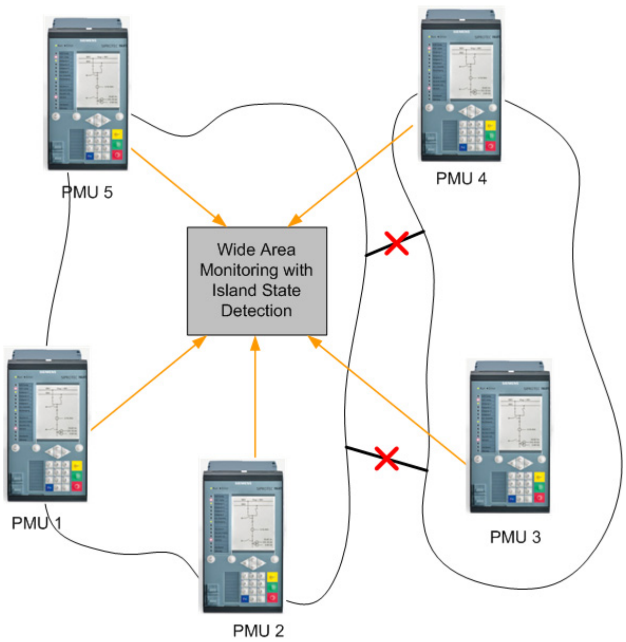

Fig. 3: Basic Principle of Island State Detection

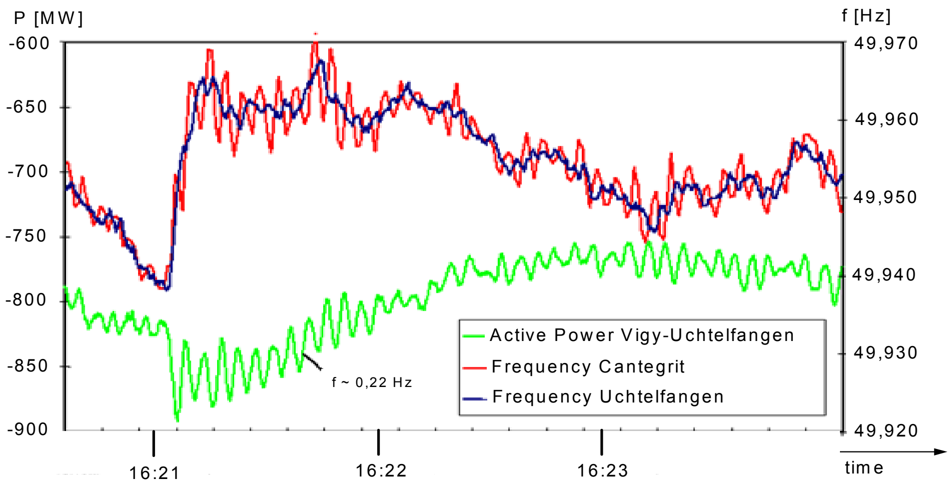

Fig. 4: Frequency and power measurements from a PMU, recorded during a system disturbance

Power Swing Recognition

Power Swings can be dangerous for the system stability if they are weakly damped or undamped. A Wide Area Monitoring system has the possibility to recognize and analyze power swings. As input data, active power measurements or phase angle differences are suitable.
Fig. 4 shows a system disturbance in Europe. It is nearly undamped during 2 minutes. In this case, an alarm would be given and the frequency of the power swing would be indicated (in this example 0,22 Hz).
The power signal can be taken from one single PMU. For the use of a phase angle difference, two PMUs are necessary.
Additional to alarms, the power swing recognition function can also visualize all detected modes in the frequency-damping-plane (Fig. 5). By this graphic, the operator immediately is aware of existing power swings in the system and their criticality. To calculate the criticality, both the damping and the amplitude of a power swing should be used. The result can be documented in a criticality index and the colour of the mode (like in Fig. 5, yellow = uncritical, orange = critical)

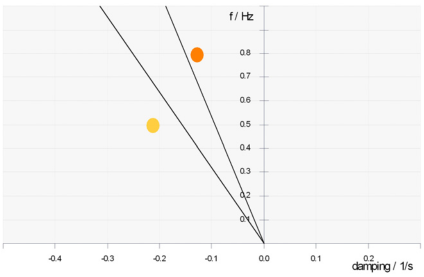

Fig. 5: Presentation of detected power swing modes in the frequency-damping-plane

The two diagonal lines in Fig 5 (left part) are indicating limits of 5% (left line) and 3% (right line). Left of the 5% line, the modes are uncritical. Modes that show up right from the 3% line are critical.
Such a Power Swing recognition Function can supervise all configured channels (not only for one pair of PMUs) fully automatic and is therefore a comfortable and secure help for the system operator.

Voltage Stability Monitoring

In many transmission systems there are transmission corridors between generation center and load center. These corridors must be prevented from being overloaded.
The characteristic of a transmission line is described in a P-V-Curve which shows the dependence of the voltage at the load end of the line from the active power flow across it (Fig. 6). If the power reaches the limit, the voltage collapses.
With PMUs on both ends of the corridor, it is possible to measure exactly the actual loading status of the corridor or transmission line. This can be displayed as operating point on the PV-curve (red marked cross in Fig. 6). So the operator is getting aware of the actual situation. All effects like voltage regulators are included in this result because it bases on fast real-time measurements.

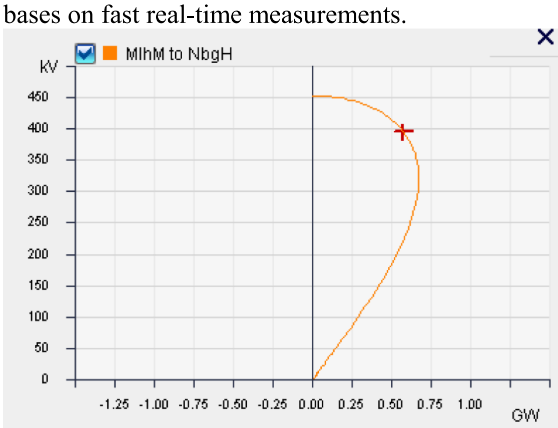

Fig. 6: Voltage-Stability-Curve (P-V-Curve)

With this information, the load flow can be kept on a secure level by control measures.

MARKET FOR WIDE AREA MONITORING

In the last years, many tenders for wide area monitoring systems have been released in Europe, South America, and Asia. All of them deal with transmission applications. The trend goes to an increasing number of PMUs. From India, the request for a system with more than 1700 PMUs has been published.

APPLICATION IN DISTRIBUTION

The application of Wide Area Monitoring systems started in Transmission Systems. Nevertheless, such systems can be beneficial also for distribution systems. One aspect is the observability. In networks where no or only few measurements are available, it can be interesting to introduce PMUs. With less PMU equipped measurement substations, a better picture may be created than with more RTU equipped substations.

But more benefits can be seen for distribution networks:

- Angle and frequency monitoring
- Post-Mortem-Analysis
- Voltage stability monitoring
- Improved State Estimation
- DG / IPP Applications
- Power System restoration

So this technology can also help in the distribution networks to increase observability and awareness for system stability. As an innovative example for application of PMUs in distribution network, the "RegModHarz"-project is discussed [3], [4]. The project "RegModHarz is applied to a region "Harz" in Germany. The goal is to group all local decentralized power generation into one virtual power plant and to control the loads where possible so that the region can operate without additional power flow from outside (see Fig. 7).

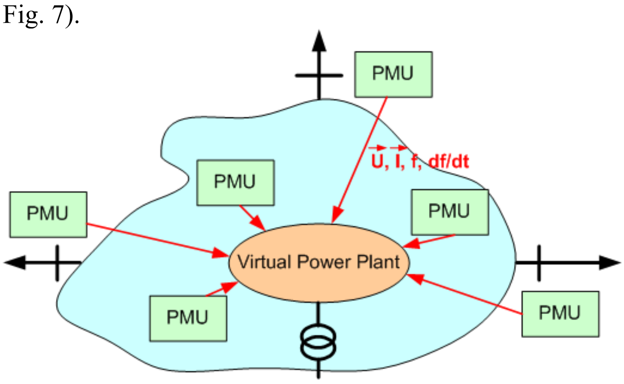

Fig. 7: System configuration in project "RegModHarz"

The PMUs are placed at the border connections of the regional grid with the surrounding electrical transmission network and at selected substations in the region. In total, 10 PMUs on 110kV voltage level are installed. They deliver their measurements to the central component "Virtual Power Plant" which coordinates the generation and the controllable loads. The achieved benefits include:

- Supervision of the virtual power plant
- High precision in energy accounting
- Coordination of generation and consumption
- Higher reliability for decision-making
- Delivering a data base for services like energy market

The region has available 250 MW wind power, 80 MW pump storage and 12 MW thermal/electric power station. Controllable load includes 10 MW in industry and 0,5 MW in households. The virtual power plant coordinates in the best possible way the power balance between these components. There are three different operating modes possible:

- Maximising renewable generation
- Cut-off load peaks
- Maximising network stability

This project delivers reports ([3]); it is still under progress.

CONCLUSION

Wide Area Monitoring with synchrophasors from PMUs is a proven technology for system monitoring. It has its benefits in providing a real-time view on dynamic events and in the ability to analyze events from the past. It can be a second-level tool in the control center to help in analysing critical issues.

The application in distribution networks is also useful. PMUs can enable the observability of such systems where no measurements are available up to now. In areas with fast changing power flow, caused for example from high amount of renewable infeed, synchrophasors can help documenting the system behaviour and recognize faster critical events.

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[4] M. Powalko, P. Komarnicki, K. Rudion, Z.A. Styczynski, 2010, "Enhancing Virtual Power Plant Observability with PMUs", Paper at CRIS Conference 2010 in Beijing, China