



PS5 – S2-05



Synchro-Phasor Measurement – German Experiences

Markus WACHE¹, Holger KUEHN², Chris O. HEYDE¹, Rainer KREBS¹
Siemens AG¹, Transpower²
Germany
chris.heyde@siemens.com

KEYWORDS

PMU, phasor, synchrophasor, wide area monitoring, phasor data concentrator, phasor data processor, overload, stability.

ABSTRACT

The stability of electrical transmission networks has been receiving more attention in recent years all over the world. Following several wide-area supply interruptions, so called blackouts, for example in Europe and North America, it is widely accepted that transmission networks have to be improved in terms of both capacity and stability.

The quick building of new lines is usually not an option, so measures to enhance the stability of existing networks are of great interest. One well accepted method, increasing the observability of the power system, is the use of phasor measurement data from widely spread positions in the power networks. With a suitable software solution, the information coming from the Phasor Measurement Units (PMUs) helps the control center engineers to gain an awareness of the stability situation throughout the whole network. This aids them in making the right decisions even in critical situations. The application of such a Phasor Data Processing System in a German Transmission System is presented and discussed.

1 INTRODUCTION

The use of synchrophasors for monitoring and improving the stability of power transmission networks is gaining in significance all over the world. The aim is to monitor the system state, to intensify an awareness for system stability and to make optimal use of existing lines. This way, system stability can be improved overall and even the transmission performance can be increased.

2 NETWORK STABILITY AND SYNCHROPHASOR MEASURED VALUES

2.1 Influences on Network Stability

Network stability can be affected by a number of occurrences (see Fig. 1). In the European coordinated grid (former UCTE network), particularly the growing proportion of wind energy infeed is playing a part. North-south transmission performance that fluctuates with the wind and load makes power system control a demanding job. Further causes of power swings can be:

- Line disconnection by protection following a fault
- Lack of reactive power
- Strong load fluctuations
- Weakly damped swings, particularly in wide areas

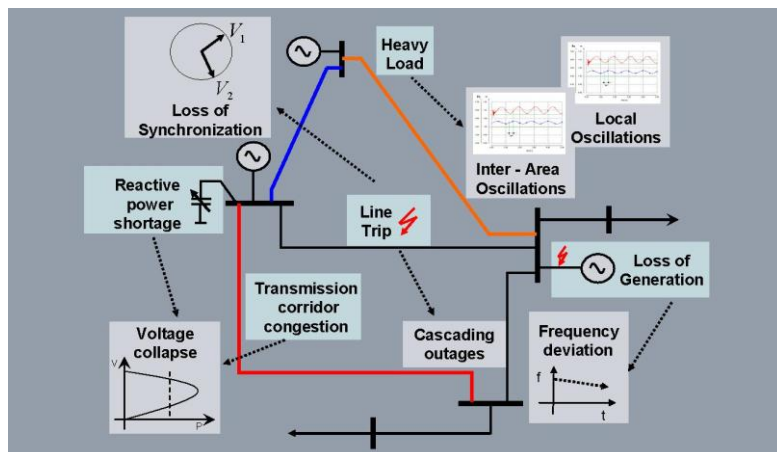


Fig. 1: Causes of instabilities in a power transmission network

In order to uphold network stability as effectively as possible, synchrophasors can be utilized. These fast realtime values allow a better assessment of the power system state, and the operators in the control center are aided in their decision whether to intervene.

2.2 Phasor Measurement Unit

The synchrophasors are recorded by the so called Phasor Measurement Units (PMUs). These are nowadays the state of the art. In transmission networks, specific PMUs are utilized; in distribution networks this function can be integrated in other devices, e.g. protective relays. Since a long time, the measurement and processing of phasors has been utilized in e.g. distance protection devices to determine pickup and trip decision. New is, that on one hand the phasors are time stamped using the Global Positioning System GPS, and on the other hand, that synchrophasors are gathered from a widely distributed transmission network at a central point, in order to suitably evaluate them there, as a monitoring instrument. The PMUs send the phasor measured values by means of the standardized protocol IEEE C37.118.

The use of synchrophasors has been discussed at numerous conferences; see [1] to [6]. Potential fields of application are:

- Verification of network models: Comparison of simulation data with measured values of the PMU [5].
- Identifying subsynchronous swings, with an analysis of the corresponding damping.
- Combination of slow RTU measured values with synchrophasor measured values in the network control center, to identify and analyze transient phenomena in the power system.
- Improving state estimation in the network control center.
- Utilizing the full transmission capacity of lines.
- Estimation of a voltage stability index.

Although the discussion leans in the direction of use in transmission networks, there is growing interest among distribution network specialists.

Fig. 2 shows the arrangement of the PMUs as measuring devices for fast realtime values with centralized evaluation for large network areas. In this consideration they are between the protective devices (fast measured values, but only possible local evaluation) and the network control centers (monitoring of large network areas, but with slow measured values).

So that the synchrophasors can actually be meaningfully compared with each other, the measurement must take place with a highly precise time stamp. Only this way can the central monitoring system, the Phasor Data Concentrator (PDC), display the correct phasor values together, thereby allowing an assessment of the dynamic state of the network. At a network frequency of 50 Hz an inaccuracy in the time stamp of 1 ms already represents a phase-angle error of 18 degrees. The accuracy of a PMU is expressed with the Total Vector Error (TVE), a combined deviation of the measuring accuracy of the PMU and the accuracy of its time synchronization. To comply with the standard IEEE C37.118, a PMU must demonstrate a TVE of 1% or better.

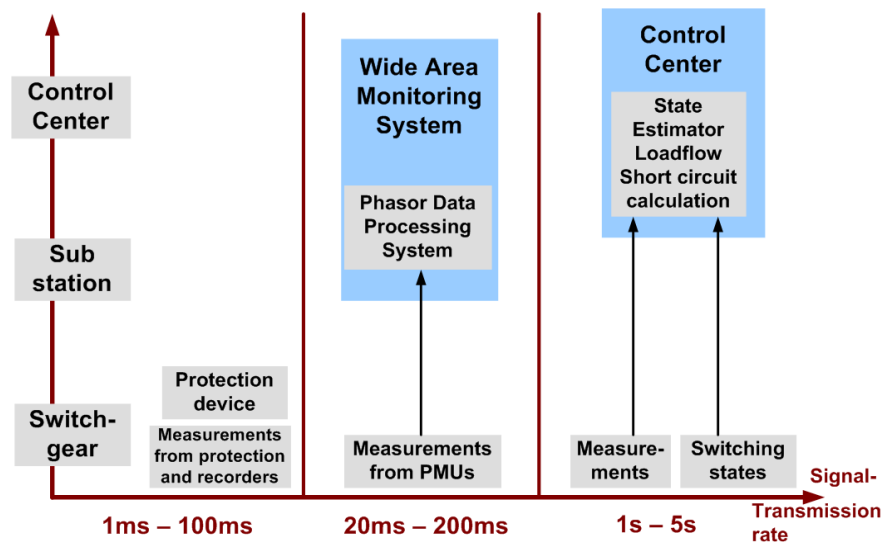


Fig. 2: Wide-area monitoring system in comparison to power system control and protection

The data transmission rate of the high-precision PMU- measured values is, in 50 Hz networks, usually 10 Hz or 50 Hz. Therefore not only slow, quasi-steady-state phenomena can be monitored, but also fast transient power swings. The monitored area can be a single transmission corridor with one or more lines, but also a wide-area transmission network like the UCTE system. In the transpower pilot project described here, the entire 400kV transpower transmission network is monitored. The region extends from the North Sea to the Alps, right across Germany.

2.3 Phasor Data Processing System

This article presents the Phasor Data Processing System SIGUARD[®]-PDP. This monitoring software helps the network operator in obtaining an overview of the state and stability of the power system. The SIGUARD[®]-PDP system shown in Fig. 3 is set up at a central point and is connected with the PMUs via a fast communication link (e.g. 2 MBit/s).

As central component of the system, the Phasor Data Concentrator receives via the communication channels the up-to-date measured values from the connected PMUs. These are current and voltage phasors, along with frequencies, frequency changes etc. These measured values are continuously written into the archive and passed to the graphical user interface (HMI). The monitoring for the communication links, the quality of the PMU data and the internal system functions are realized in the Phasor Data Processing System. At the HMI the user can select between direct observation of the online data and analysis of archive data in offline operation. It is possible to change between these two modes as desired, enabling a quick and uncomplicated 'look back into the past'.

In the following, the HMI of SIGUARD[®]-PDP is portrayed more closely and an application is described. The HMI must support the network operator in the identification and analysis of critical network states and provide help in the investigation of causes. The interface must be uncomplicated and must allow intuitive operation. The following requirements must be met:

- General display of the network state (OK/critical)
- Free configuration of the measured values to be observed during ongoing operation, with a choice between phasor or time diagram
- Setting of limit values to be monitored
- Ease of changing between online and offline operation, for quick analysis of critical occurrences
- Geographical representation of the power system with the PMU measuring points, for quick location of network regions with stability problems
- Data export for further analysis with independent tools and for reporting

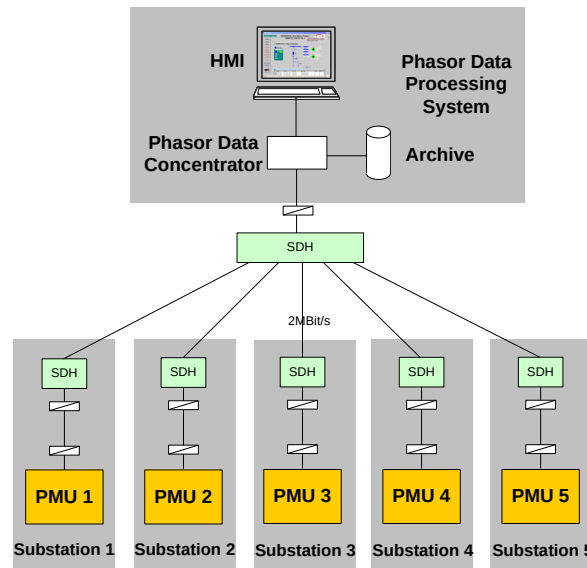


Fig. 3: Configuration of a Phasor Data Processing System with 5 connected PMUs

The following screenshots show the implementation of these requirements in the Phasor Data Processing System SIGUARD®-PDP. All screenshots are examples with simulated process data.

Fig. 4 shows the structure of the main monitor of SIGUARD in four parts:

- **Power System Status:** This diagram shows a cumulative index for the overall state of the monitored network. All those PMU measured values go into the calculation, which are subject to limit value monitoring. The nearer the curve comes to the dotted limit value, the more critical is the status of network. When at least one measured value violates a limit, the color of the Power System Status Curve changes from black to red, allowing quick and easy recognition.
- **Geographical view:** This window shows the geographical extent of the monitored transmission network, with lines and substations. Thanks to the coloring of the network elements, the operator can recognize immediately in which region there are problems e.g. with equipment overload if currents / powers are the basis for color coding. If voltage angles are the basis, steady-state stability can be monitored.
In the shown example, the color of the squares, representing the substations, indicates the voltage status (blue = OK, yellow = limit value 1 violated, red = limit value 2 violated). In the same way the color of the power lines indicates compliance with the limit values for current. If communication with the PMU is interrupted, the color of the network elements changes to gray, indicating invalid measured values.
- **Display area for measured values:** This central area shows the time characteristic of the selected phasors or other measured or calculated values. The selection can be made repeatedly in ongoing operation and adapted flexibly to the operating requirements. The selection is made from the list of all measured values in the configuration area.
- **Configuration area:** Here, all available measured values of the connected PMUs are listed. Various screening criteria (by name, type or unit) allow a quick overview. There are two types of measured values: Phasor (can also be displayed as time characteristics, e.g. current, voltage) and analog (can be displayed only as time characteristics, e.g. frequency, active power). If desired, a so-called 'PV-Curve' or 'nose curve' can be calculated and displayed.

The easy change between online and offline operation is made by means of the selector button (top right). The user can move easily back and forth between online monitoring and archive evaluation.

Figures 5 and 6 show various typical applications for the representations in the measured values area: Phasors in Fig. 5 and 'nose curve' in Fig. 6.

In the phasor diagram the phase angle and amplitude of the selected currents and voltages can be compared directly with one another. If phasors of PMUs, that are spatially widely distant located,

are combined in one view, an insight is provided into the load state of the network, the reactive power balance and the stability.

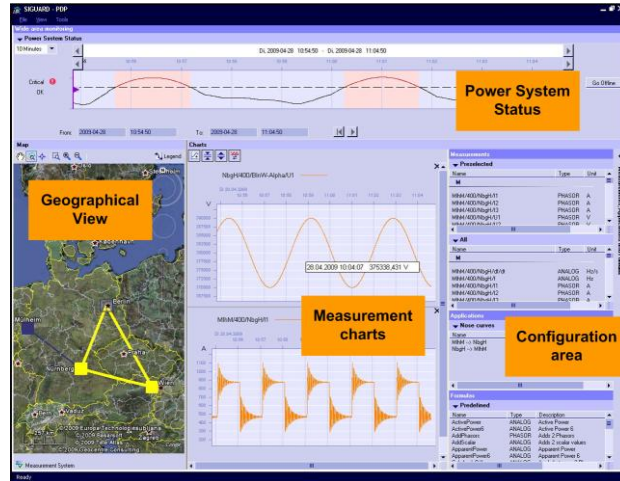


Fig. 4: Structure of the HMI of SIGUARD®-PSA

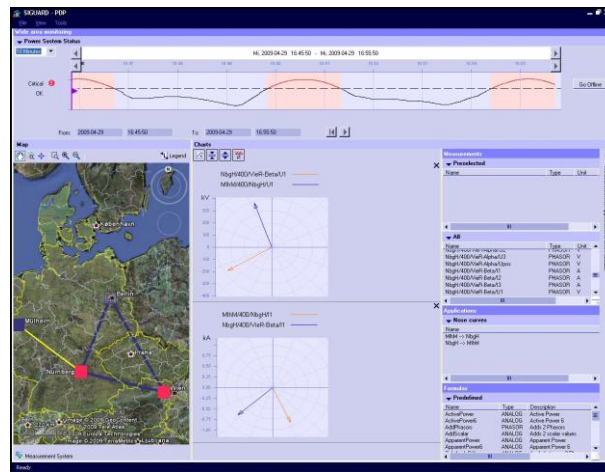


Fig. 5: Example of visualization in the measured values area

The ‘nose curve’ is the representation of the voltage over the active power for one transmission line. For the calculation and display, PMUs at both line ends are needed. By way of the measurement from both ends of the line, the nose curve can be dynamically updated, i.e. changes in the line parameters as a result of temperature or load fluctuations are automatically recognized. Comparing the actual point of operation (actual voltage versus actual real power) with the point of instability, it is thus possible to precisely gauge how much additional power the line can handle without losing steady state stability.

With the ‘Limit Value Editor’ up to six limit values can be defined for each measured value. The phasor data processor monitors all chosen measured values regarding off-limit conditions.

In offline operation, all archive data can be analyzed. The operator can select a range in the time axis of the Power System Status curve and then replay the events in this time range as often as desired, in order to analyze critical occurrences. The selection of measured values in the ‘measured value area’ can also be changed, in order to find the causes of network disturbances. During this ‘Replay’ mode, the colors of the system symbols in the geographical view are updated in line with the replayed measured value characteristics.

In offline operation, all recorded archive data of the selected time section can be exported as CSV file. This allows evaluation and documentation with other tools such as e.g. a tabular calculation, so as to produce reports both quickly and easily.

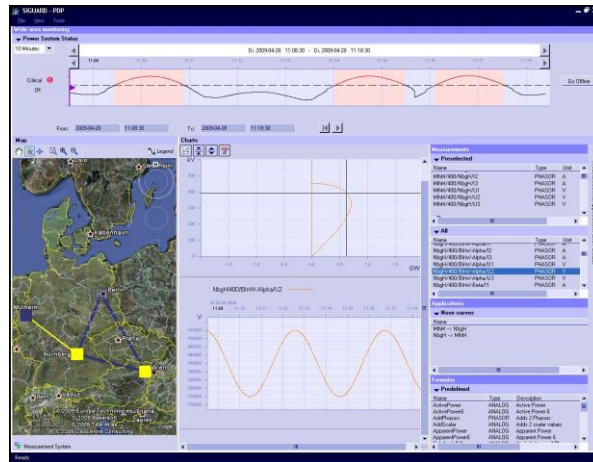


Fig. 6: Example for a nose curve

3 OPERATING EXPERIENCE

The Wide-Area Monitoring System SIGUARD®-PDP has been in use at transpower Stromübertragungs-GmbH (formerly E.ON Netz), one of the four German TSOs, for about half a year. In this time there have been no disturbances in the network, and the operating state has always been well clear of any critical situation. A small number of occurrences have had to be precisely analyzed, such as the shutdown of a nuclear power plant in Krümmel on July 4, 2009, whereby the phasor data delivered a extremely good data basis. The analyses were supported very well by the PMU data.

In the future, it is planned to extend the work with PMU data and their analysis and to use the wide area monitoring system SIGUARD®-PDP additionally for operator training on power system dynamics.

4 CONCLUSION

As a tool for centralized assessment of network dynamics and stability, synchrophasor monitoring systems are attracting interest worldwide. Tenders for such systems have been invited in numerous countries. Onward development is conceivable in terms of:

- Interfaces to control centers (common archive, measured value export, alarm list)
- Interface to other power system operators, for exchange of PMU measured values
- Incorporation of controllable network elements (phase angle regulation, Static VAR Compensator, HVDC transmission) as a preliminary stage of automated power system control

For interconnected grids like the European UCTE network, the transfer of synchrophasors between Transmission System Operators makes sense. Thanks to the knowledge of PMU measured values from crucial points in the overall network, which can be displayed by such monitoring solutions as SIGUARD®-PDP on a 'Europe monitor' for every TSO, the overview is even further improved. If such a system had been available on November 4, 2006, the large UCTE disturbance, the TSOs would have very quickly seen that the UCTE network had split up into various frequency zones.

The monitoring of transmission corridors between different TSOs becomes possible on the basis of PMUs.

The necessary communication channels for transfer of synchrophasors already exist widely as an 'electronic highway' between the control centers. With e.g. 50 Europe-wide distributed PMUs, an excellent overview of the state of the UCTE network would be possible. Making this a reality would be relatively uncomplicated, regardless of other control center interfaces.

Practical experience from pilot projects is helping manufacturers to proceed in the right direction in their product development work.

REFERENCES

- [1] P. Gomes, G. Krost and R. Pestana, 'System Operation and Control' CIGRE Session 2008, Special Report for Group C2.

- [2] T. Sezi, J. Warichet, B. Genet and J.-C. Maun, 'Bringing New Visualization Tools for the Detection and Mitigation of Dynamic Phenomena in the Transmission System' CIGRE Session 2008 Paper C2-112.
- [3] A. G. Phadke and J. S. Thorp, 'Synchronized Phasor Measurements and their Applications' Springer Verlag 2008.
- [4] C. Rehtanz, K. v. Sengbusch, T. Sezi and R. Simon, 'Schutz- und Überwachungskonzepte auf Basis zeitsynchroner Messungen' ETG/BDEW-Tutorial 'Schutz- und Leittechnik', Fulda, 11.-12. Nov. 2008.
- [5] B. Ayuev, P. Erokhine and Y. Kulikov, 'PMU Application for IPS/UPS Dynamic Performance Monitoring and Study' CIGRE Session 2008 Paper C2-101.
- [6] Z. Styczynski, Prof. Sauvain, B. Buchholz and M. Wache, 'PMU and Wide Area Measurements in Distribution Systems' CIRED 2009, 20th International Conference on Electricity Distribution Prague 8-11 June 2009, Round Table 3b.