USING SYNCHROPHASORS IN DISTRIBUTION NETWORK FOR SYNCHRONIZED SWITCHING

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ABSTRACT

Sibelga is the Distribution System Operator for the Area of Brussels, the capital of Belgium. Because of the angle difference between the different primary substations at the medium voltage level, the increasing infeed directly into the Distribution network, caused by renewables and the poor data availability of measured data, it happened more and more that, during the reconfiguration of the medium voltage rings between different primary substations, unexpected problems occur. The idea is to monitor the voltage phase angles and amplitudes in the distribution system by Phasor Measurement Units (PMU) to have the necessary observability. These phasor data can be used for a manual check for synchronization or the calculation of the phase angle difference to simulate the exchange loads and to avoid difficulties in the reconfiguration process or during parallel couplings in the network.

INTRODUCTION

In a first pilot phase, 3 PMUs are installed in the SIBELGA network. These PMUs send the Voltage Phasors timestamped to a central Phasor Data Concentrator (PDC), located in the control center of Sibelga. The PDC processes the incoming data streams, sends them to an archive and makes it available to a User Interface. The User Interface can be set to online mode or offline mode. In online mode, the actual phasors are shown and the control center operator can react by giving the switch command in the control center in just the moment when the voltage phasors on the two sides of the switch to be closed are moving closely together.
The paper shortly explains the basic principles of Synchrophasor measurement. The pilot system setup is discussed. The results of the pilot phase are shown with a perspective for further use. Other useful applications in a wide area monitoring system are shown as an outlook for future applications.

BASIC PRINCIPLES OF SYNCHROPHASOR MEASUREMENT

Wide Area Monitoring systems with synchrophasors from PMUs can bring a very useful insight into dynamic phenomena in transmission and distribution networks [1]. The differences to the "conventional" SCADA measurements are the following:

- PMU-Measurements are transmitted in a continuous stream with configurable reporting rate (for example 10 frames per second) from the PMU to the Phasor Data Concentrator (PDC).
- Every measurement includes a timestamp which allows showing it together with measurements from other substations in a common view.
- Measurements of voltage and current include a phase angle (phasor instead of analogs are transmitted) so that additional conclusions about system state can be derived.

The availability of such measurements significantly improves the possibilities to analyze disturbances [2]. The full benefit of Synchrophasor measurements is realized if the PMUs are placed in the complete area of supply. The principle structure of a Wide Area Monitoring System (WAMS) is shown in Fig. 1.

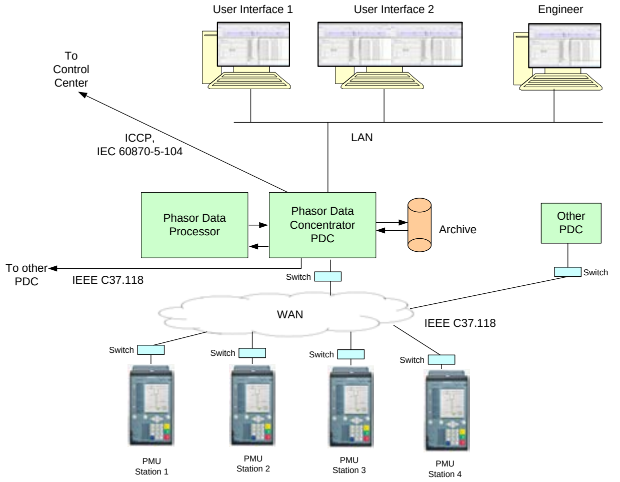

Figure 1: Structure of a Wide Area Monitoring System

An example for the application of synchrophasors is given in [2].
Main components of a WAMS are the following:

- Phasor Measurement Units as data source, spread across the electrical network (transmission or distribution, in several substations).
- Phasor data concentrator (PDC) for handling of the Synchrophasor data streams and the archive
- Phasor data processor which performs analytics

like Island State Detection, Power Swing Recognition and others
- User Interface for analysis of synchrophasors and application results
- Engineer for configuration

The main benefit from such a WAMS system is achieved by the real time observability of the voltage and current phasors, showing phase angle differences between the substations, and the frequency. Additionally, by switching to offline mode, the precise analysis of disturbances is possible. A WAMS does not require any topological model of the network; it just works with the measurement streams from the PMUs.
Fig. 2 shows an example for the phasor visualization at the user interface of a WAMS.

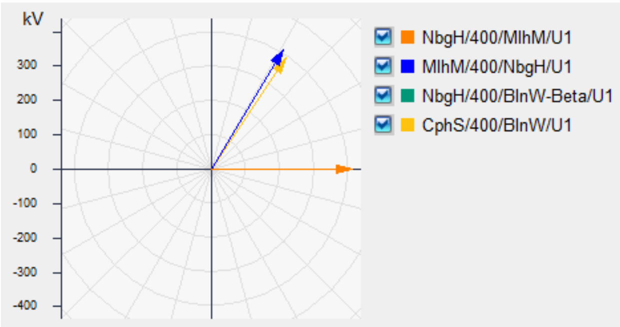

Figure2: Phasor visualization at WAMS user interface

PILOT SYSTEM SETUP

As Sibelga we opted to perform the installation of three PMUs in a setup which already has been subject of prior research and with known problems for parallel switching between the different 11KV grids.
The three substations are named Schaerbeek, Heliport and Marché (see Figure 4).
This setup allows the evaluation of the behaviour of the 11KV grid, referring to previously known problems of angle difference between the different sub grids. These problems occurred when switching the circuit breaker in the grid, due to unknown power flow during operation.
This part of our 11KV grid has been modelled completely in the Neplan calculation tool.
We have chosen to install the Siemens SIGUARD PDP software on a laptop, fulfilling the role of a standalone server.
The server is receiving the PMU Data via our corporate fibre Network at a rate of 10 frames per second and produces the necessary IEC60870-5-104 values which are also modelled in the SCADA application.
One of the three PMUs is set as the absolute reference and the calculations are based on this absolute reference.
The three PMUs are synchronized by GPS antennas, installed in each of the three primary substation.

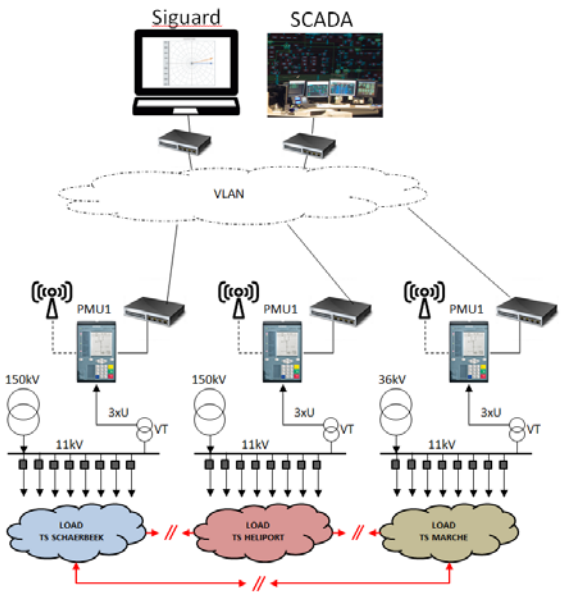

Figure 3: WAMS system scheme at SIBELGA

RESULTS OF PILOT PHASE

The pilot setup makes available the sampled values, Voltage Phasor Measurement, from the three sources to the stand-alone server.
There, the angle difference is calculated between two (or more) selected electrical sources.
Because of the constant data flow to the SCADA, the calculation can also be done in the SCADA application itself.

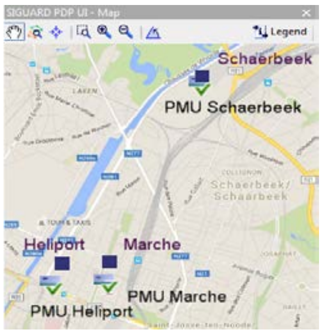

Figure 4: PMU locations in the city of Brussels

In this example we make a comparison between two sources: Schaerbeek and Heliport for parallel switching and we already know from prior analyses that the grid is relatively strong and that the parallel switching will result in an additional exchange current of approximately 140 Amps per degree above the normal charge. See Figure 5 for the scheme. The switching of the connecting circuit breaker between the two substations shall be allowed only if the phase angle difference, measured by PMU, is in the allowed range.
We can easily deduct the exchange current, just by monitoring the Synchrophasors.
This makes it possible to decide at all moment (online) whether the parallel switching is possible without causing

unexpected tripping of the protection relays. See Figures 6-8 for measured results.

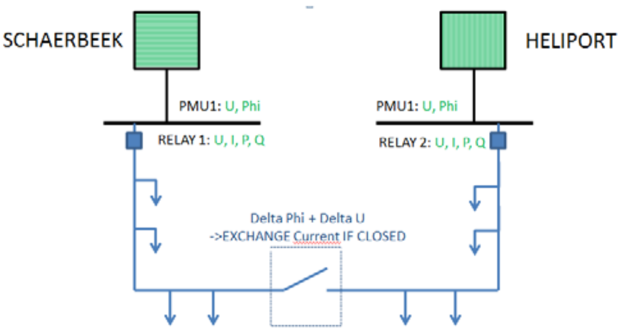

Figure 5: Scheme for supervision of phase angle

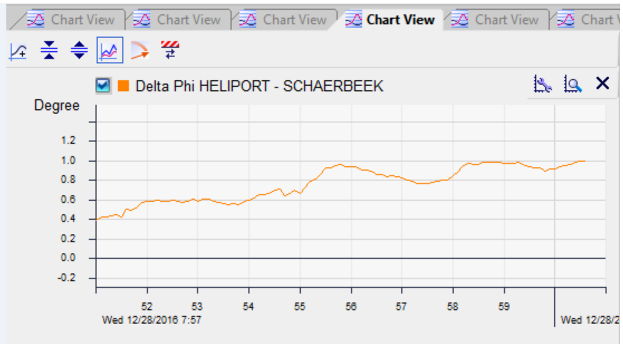

Figure 6: Example for measured phase angle difference

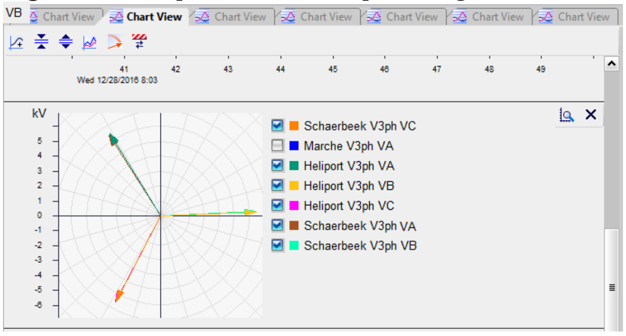

Figure 7: Example for phasor visualization in WAMS User Interface

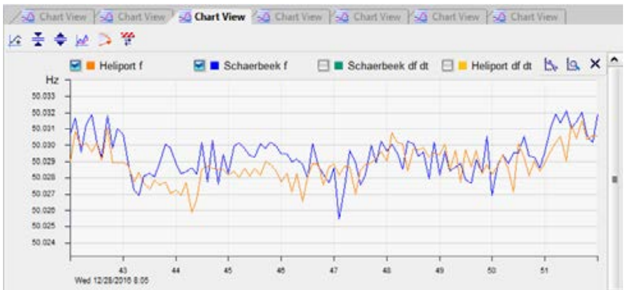

Figure 8: Example for frequency measurements from PMUs

In a second phase, we will also activate the Voltage monitoring relay function of the PMU Siprotec devices. The idea is to have an additional tool for analysing voltage disturbances, based on minimum and maximum voltage levels and phase-earth voltage settings, to compliment the protection function.

Supplementary voltage fault analyses are offered that way.

WIDE AREA MONITORING GENERAL FUNCTIONALITIES

This chapter describes other useful functionality of a WAMS which may be applicable in Transmission or Distribution Systems.

The currently available WAMS systems are able to supply the following functionalities:

- Online Monitoring: Frequency and measurement amplitudes in time charts, phasor views
- Offline Monitoring: Replay and analysis of events
- Power Swing Recognition: Automatic detection of critical power swings
- Island state detection by frequency analysis
- Alarms on limit violations (voltage, current, phase angle difference etc.)
- Detect short circuits (location, time)
- Detect loss of generation and loss of load
- Trigger “fault record” on predefined events

Fig. 9 shows two examples for visualization of a detected power swing: In a map (top) and in a mode view in the frequency-damping-chart (bottom).

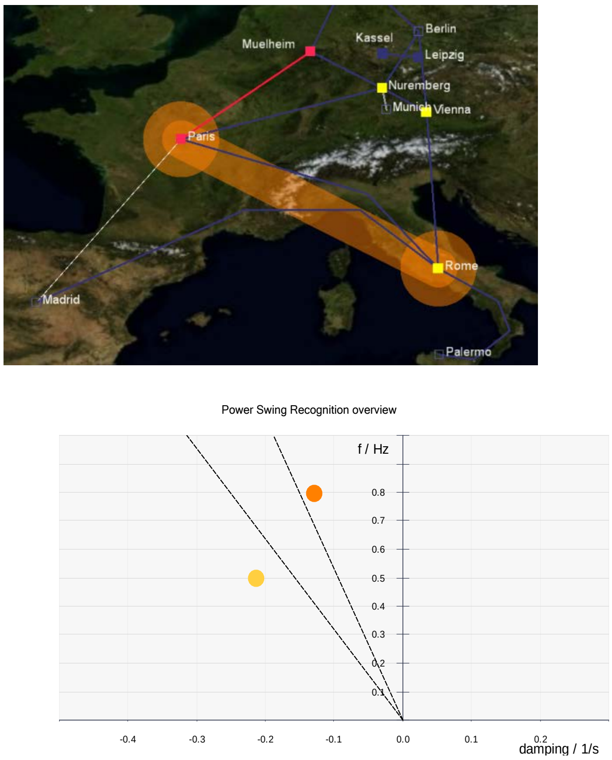

Figure 9: Visualization of Power Swing

The island state detection bases on the comparison of all measured frequencies and frequency changes (ROCOF, Rate of change of frequency). This function gives an alarm in case of frequency deviations and groups the PMUs into areas with the same frequencies which form the islands in the network (see Fig. 10: colored areas mark network parts with same frequency; data from PMU simulation).

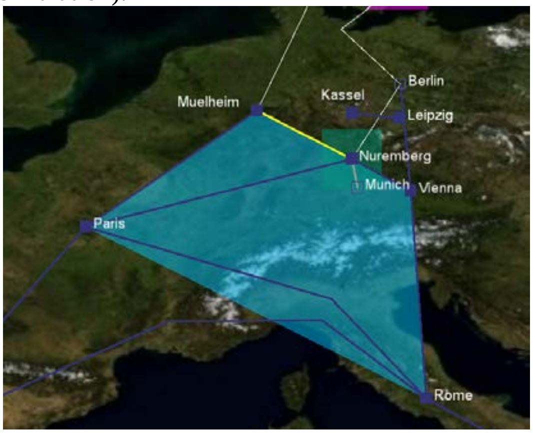

Figure 10: Visualization of detected islands in the WAMS User Interface

Another useful display shows the phase angle distribution with one reference substation in one graphic (Fig. 11) as proposed by the European TSO-Network. It gives an overview about the actual power flow situation.

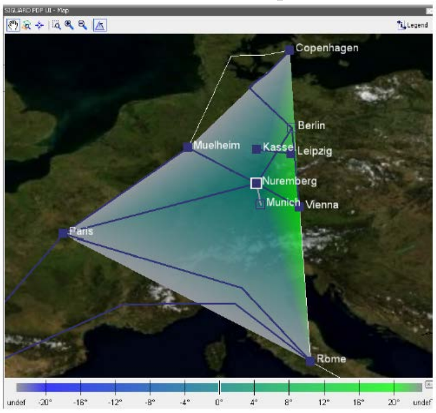

Figure 11: Phase Angle diagram (Example for a transmission system)

In such a diagram, the phase angle distribution and power flow in the whole transmission system can be analyzed at one single view.

SUMMARY

Up to now, Wide Area Monitoring systems with PMUs have been used mainly in Control Centers of Transmission System Operators (TSOs). Benefits are the clear view to all dynamic incidents, the simple structure and the possibilities for automatic recognition functions. Driver for introduction of WAMS are increasingly dynamic power flow due to renewable infeed, increasing load on the lines and higher requirements for reporting to authorities.

The use case described in this paper is from a Distribution System Operator (DSO). It shows that the benefits of WAMS can also be used in the distribution level. Even with a basic configuration and a low number of PMU devices, the simple information about actual phase angle difference brings the benefit of transparency about the current situation in the network which can be used for synchronized switching. Note that no topological information or configuration is needed for the WAMS, it simply works with the received synchrophasor streams.

REFERENCES

[1] “Application and Perspective of Wide Area Monitoring Solutions”, Author Dr. Markus Wache, Siemens AG, PACWorld Conference Budapest 2012, Paper OP019

[2] Report of the enquiry committee on grid disturbances in northern region [of India] on 30th July 2012 and in northern and north-eastern region [of India] on 31st July 2012, available at http://www.powermin.nic.in/pdf/GRID_ENQ_REP_16_8_12.pdf

[3] “Benefits of Phasor Measurement Units for Distribution Grid State Estimation: Practical Experience from an urban demonstrator”, Authors S. Uytterhoeven Laborelec Belgium, K. Hoornhaert Laborelec Belgium, D. Willems SIBELGA Belgium, 23th International CIRED Conference 2016 Lyon, Paper 0576