European Network of
Transmission System Operators
for Electricity

Wide Area Monitoring – Current Continental Europe TSOs Applications Overview

Version 5

System Protection & Dynamics Working Group

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1. Content

2. Introduction

Power system operation has become more complex within the last years. Transmission system operators are faced with increasing challenges at the interface between power plant operators, industrial consumers, distribution system operators, balance responsible parties and regulatory authorities. Highly volatile power flow changes require enhanced tools for secure operation of the meshed transmission system. The importance of monitoring dynamic phenomena is also increasing due to the geographic expansion of the power system as well as the impact of the fast and dramatic changes of the power generation mix.

On the other side, **W**ide **A**rea **M**onitoring (WAM) has become a mature and reliable technology. Measurement of voltage and currents with **p**hasor **m**easurement **u**nits (PMUs) and treatment of special measured values as phasor values open new opportunities in data processing and increased system insight. Therefore, one of the key components is the exact time stamping of each measurand based on GPS time signals. Secondly data concentrators are able to acquire measurements from distant substations and overlap them precisely even in real time. By doing so enhanced information about the real state of the power system with respect to steady-state as well from dynamic point of view can be derived by using related application functions. Competition between important vendors has led to a significant high number of standard products available on the market for different either local or wide area applications.

Based on a questionnaire distributed within the Continental European transmission system operators, a short overview of the current WAM tools in use and approaches is given in this report. 15 TSOs have responded by completing the pre-prepared form and 8 have delivered additional information about their individual applications including man-machine interface or special data activation and data processing techniques.

3. Main Application Examples and Tool Usage

As the PMU devices themselves are derived either from protection relays or from RTUs coupled with transient recorders the measurements of voltage and current are gained either from the protection or the metering VT and CT cores correspondingly. As most of the current applications in use are related to the normal system operation conditions almost all TSOs acquire their WAM data via the metering CT and VT cores in order to maximise the measurement accuracy.

One key component for the application of WAM systems is a reliable and secure telecommunication network as in principle the measured data get lost if they are not immediately transmitted to the central **P**hasor **D**ata **C**oncentrator (PDC) due to the fact that for the usual sampling rate of 20 or 100 milliseconds between two subsequent measuring points related buffering capabilities are very relevant. TSOs use dedicated communication channels with related firewall protection for the data package transport (IEEE 1344 and IEEE C37.118 format) from the substation to the central located data concentrator.

However, the fact that PMU maintenance is performed by almost all TSOs currently only on ad hoc basis with low priority reflects the fact that we still deal with a new technology where not all processes are yet fully included in the state-of-the art TSOs applications.

The phasor technology is based on exact time synchronisation by the means of GPS receivers. Some PMUs get their time signal from own receivers, others are synchronised by central substation GPS clocks. Both approaches have their own advantages and disadvantages as we know from long experience over the last year’s applications in different power systems.

Depending on the application functions either all three individual single phase measurands or only the positive sequence values are processed. In principle measurements and calculated values are

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stored for a dedicated time before they are overwritten. Special automatically triggered or manual export functionalities create the basis for subsequent detailed analysis.

Within the last year special focus was also put on the creation of interfaces to the classical state-of-the-art SCADA systems in such a way that information extracted from high resolution measurements based on PMU technique is used as an additional input and decision support.

As WAM recordings deliver a perfect time synchronised picture of measurements from distant substations of geographical large interconnected systems in high resolution those recordings are ideal sources for dynamic model calibration.

Main CE TSOs WAM Application Tools

Transient Recorder Functionality

As the WAM technology offers the big advantage to have a dedicated time stamp for each individual measurement sample, the overlapping of geographically distant measurands opens new opportunities for detailed dynamic system analysis. Consequently this functionality is used in most of the CE WAM systems as priority one application either for post-mortem fault analysis or as input for several on-line awareness tools or as a basis for dynamic model calibration.

A set of pre-defined triggering conditions initiate automatic storage of measurements or the creation of alarms which partially are already transmitted to the TSOs main SCADA systems, e.g. inter-area oscillation detection.

Line thermal monitoring

Feeder related exact measurement of voltage and currents on both sides of a transmission line creates the possibility of accurate measurement of the active power losses along of a line. By the subsequent on-line calculation of the line resistance variation the average line temperature can be determined. However by using this method the hotspots will have to be identified with other methodologies but as the operator can control only one limit per line this method is quite useful and applicable wherever lines are equipped with PMUs on both ends. However, this might be used only as an additional tool for dynamic line rating applications.

In **Fig. 1** the line thermal monitoring interface from one WAM system as well as the related SCADA representation is shown.

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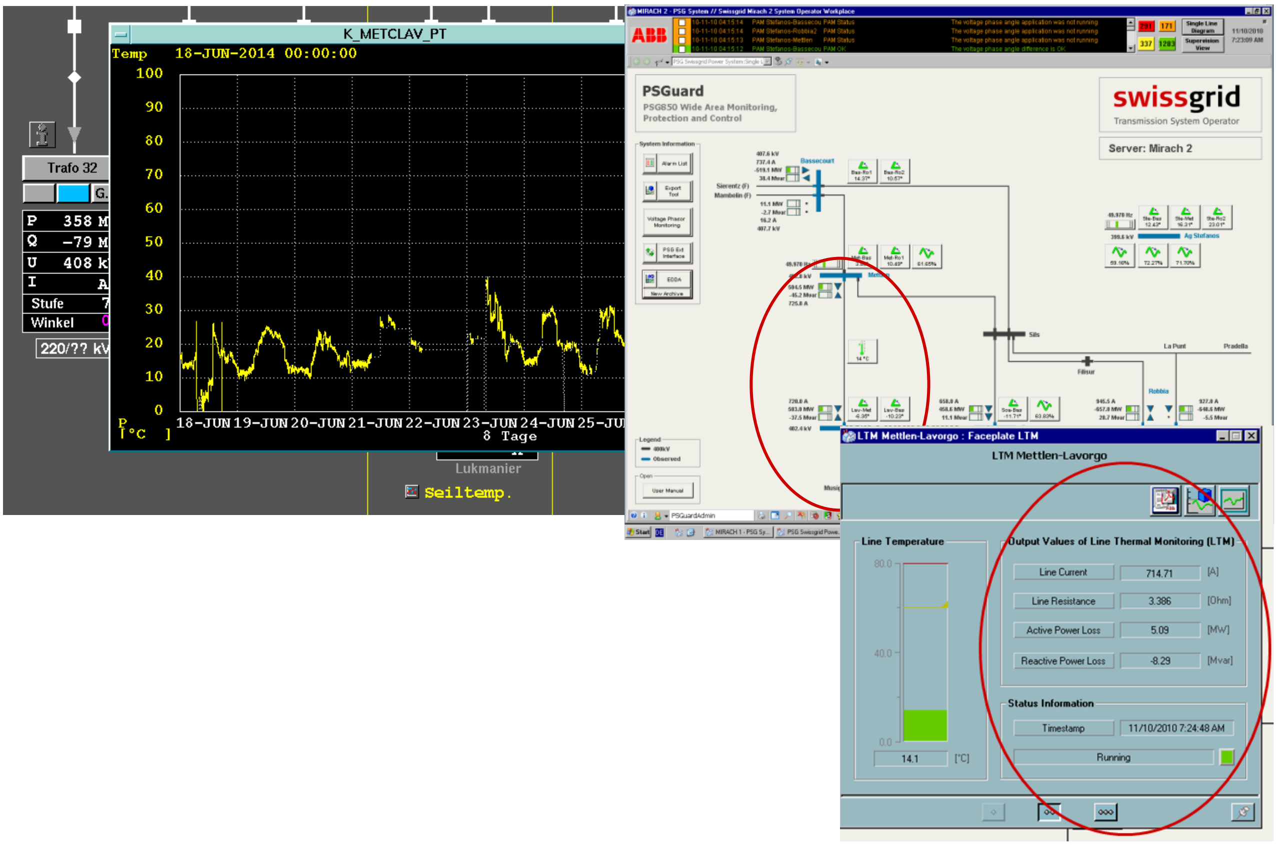


Fig.1: Line thermal monitoring interface, Source: Swissgrid

Voltage stability monitoring

By the evaluation of the voltage for critical substations the generation of the “nose curve” is possible which generally also includes the calculated limit or distance to voltage instability. One example of the corresponding Man-Machine-Interface is depicted in **Fig. 2**.

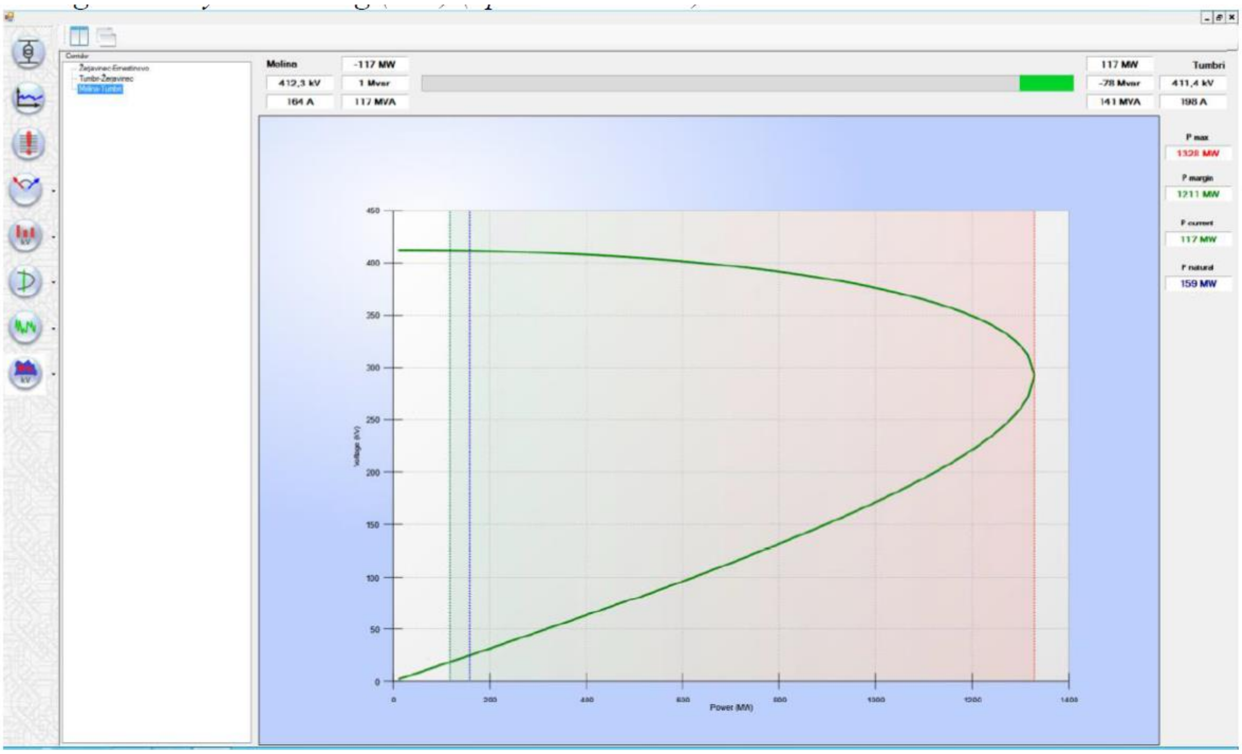


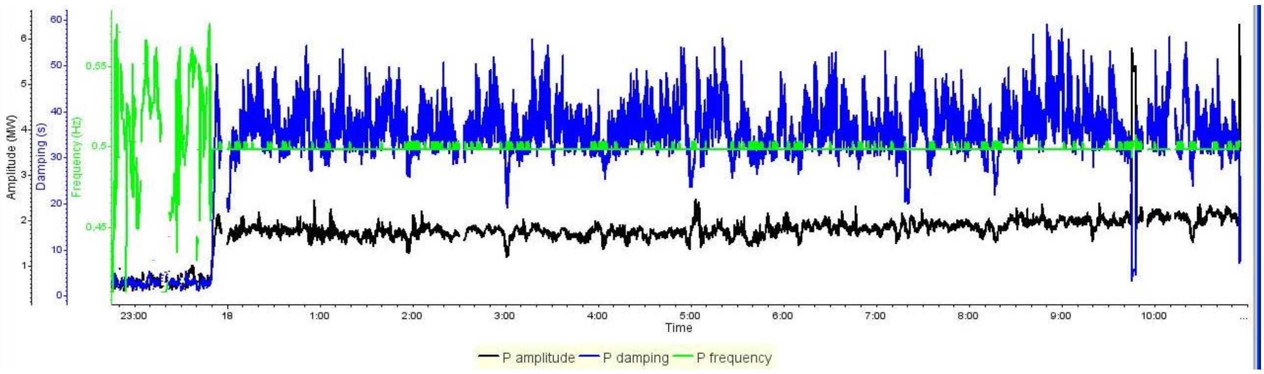
Fig.2: Voltage stability monitoring interface, Source: HOPS

Power oscillation monitoring

With respect to monitoring of system stability challenges due to inter-area oscillations WAM systems offer different approaches for detecting the most critical oscillation modes together with their main parameters as oscillation frequency or time period as well as damping factor and oscillation amplitude. By a clever combination of e.g. damping ratio and oscillation amplitude intelligent alarms are derived in such a way that only in the case of extreme oscillation activity detected operation staff receives corresponding alarms.

In **Fig. 3** the output of one on-line power oscillation tool can be seen, (damping blue; frequency green; oscillation amplitude black colour).

Fig. 3: Power Oscillation Monitoring output, Source: Energinet.dk



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Power system restoration tool

Taking advantage of the WAM high-resolution measurement principles with respect to accuracy as well as time resolution, this tools have demonstrated to be an useful tool for the power system restoration process as for system operation where monitoring of system dynamics is of crucial importance.

In **Fig. 4** measurements of a joint Italian-Swiss power system restoration test with voltage support from Switzerland are represented. All the related measurements were acquired with the help of WAM systems.

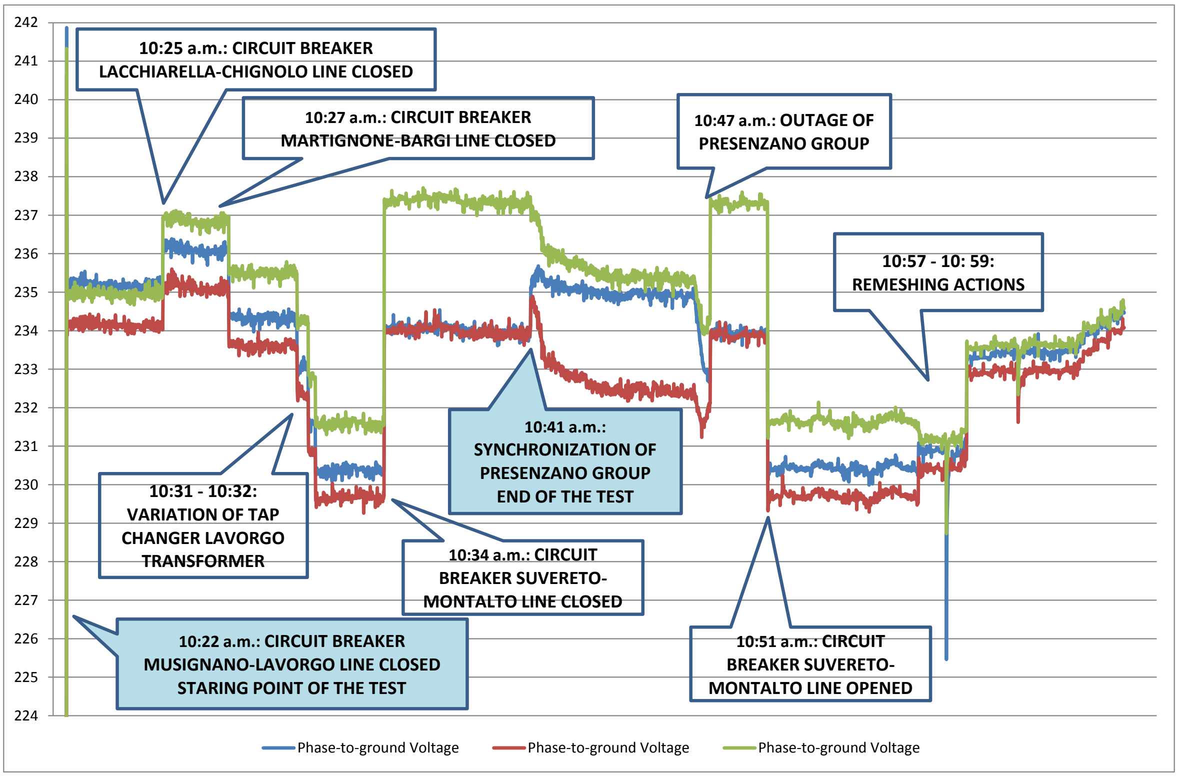

Fig. 4: Phase to ground voltages in Musignano substation during restoration test, Source: Terna

Monitoring tools, awareness tools

Of course, the man-machine interface for WAM systems offers a large variety of possibilities for power system state visualisation. Geographic system colouring base on voltage phase angle difference is used in order to show system corridor loading as the voltage phase angle difference is a good measure for enhanced representation of system loading.

Secondly, either direct time domain curves or information extracted from fast system changes creates a mirror of system state in steady-state as well as in the dynamic dimension. For oscillation patterns even common used polar representation visualises on-line the current system stage.

Single line graphics enriched with phasor information complete the picture and creates a first bridge between classical steady-state information and simplified dynamic information.

Two examples of alarming and awareness interfaces are shown in **Fig. 5,** coloured map with angle differences and **Fig. 6**, voltage and voltage phase angle.

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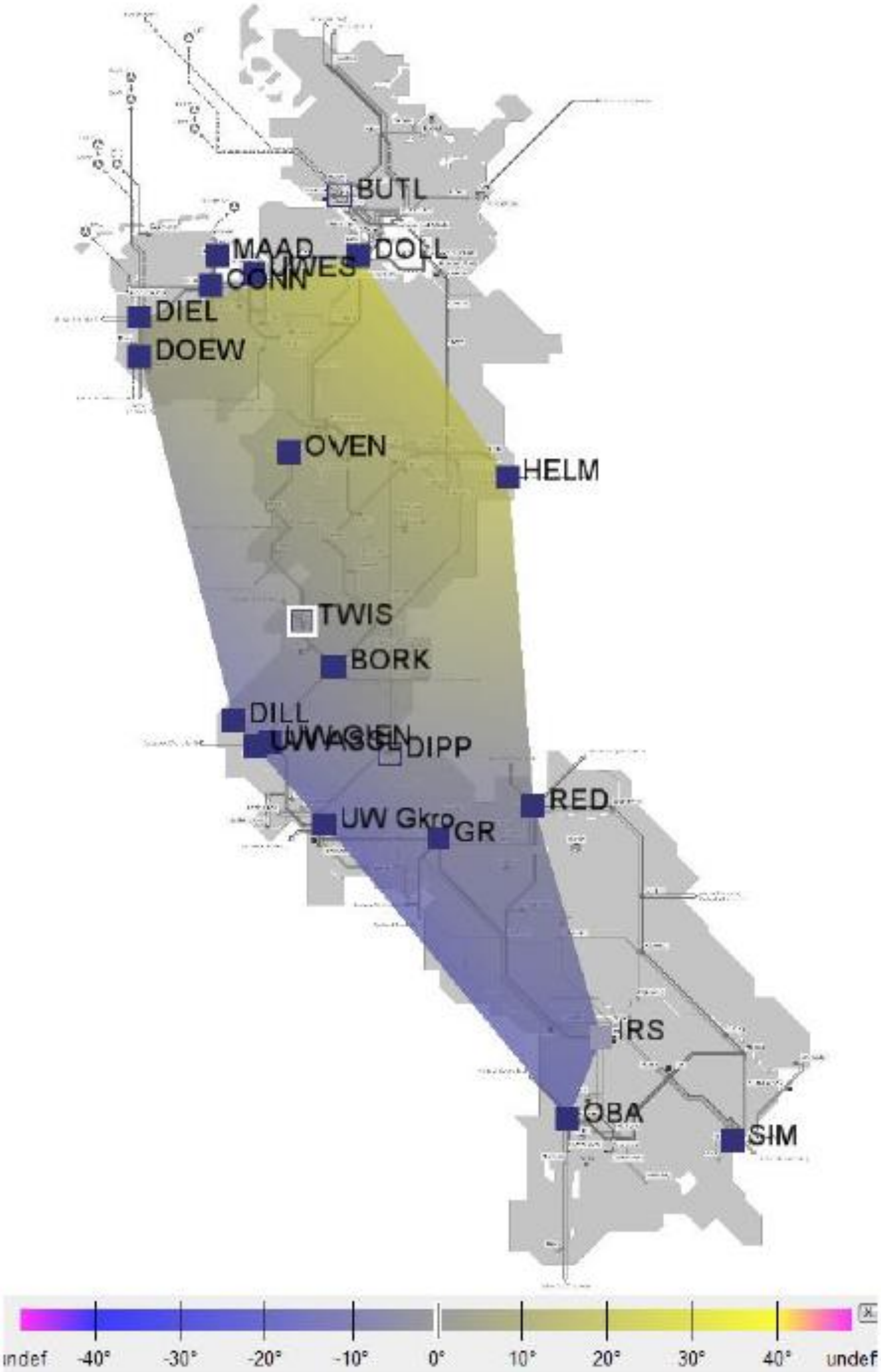

Fig. 5: Single Lin Graphic Online awareness Interface example, Source: TenneT DE

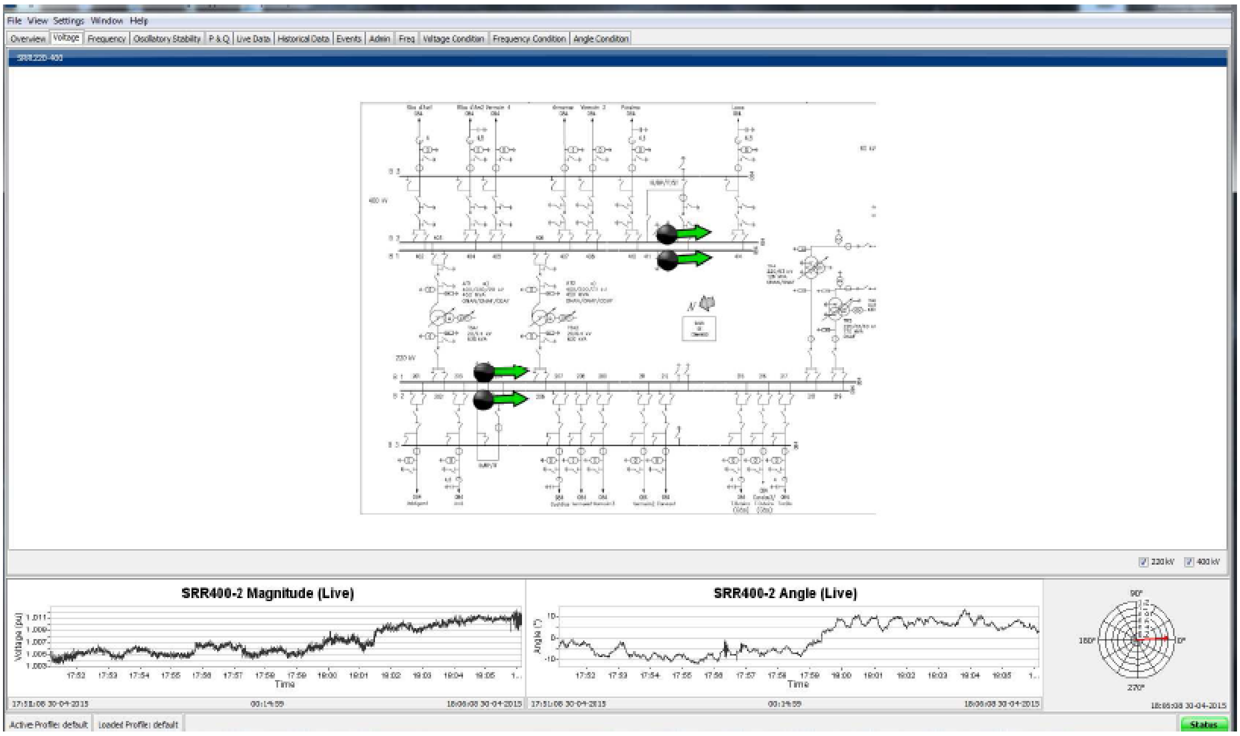

Fig. 6: Substation awareness, voltage magnitude and voltage phase angle, Source: REN

On-line short-circuit power calculation

By installing dedicated PMUs for monitoring eq. switchable shunt reactors, capacitors or filter batteries on the AC-side of HVDC interconnectors it is possible to on-line calculate the instantaneous available short-circuit power of that substation. This has proven especially useful for monitoring the available SC power at the LCC-type HVDC interconnectors in Denmark in operational situations with high wind power productions and thus few base-load power stations on-line. The challenge is to avoid commutation failures on the HVDC converters due to critical low SC power available while still running the system with a minimum number of base-load power stations in forced operation only to provide SC power.

Basically the method works on sets of PMU measurements of voltage and current phasors immediately before and after switching on or off of e.g. a shunt reactor. The most challenging part has been to identify the most optimal sets of voltage and current phasors.

At the corresponding PDC workbench the SC-calculation functionality has been automated in such a way that the SC-power is automatically calculated whenever a switching occurs on any of the monitored shunt devices. This gives the operator the possibility to perform a switching operation whenever he needs to check the (low) level of available SC-power in one of the monitored substations. The resulting SC-power is presented to the operator as depicted in Fig. 7.

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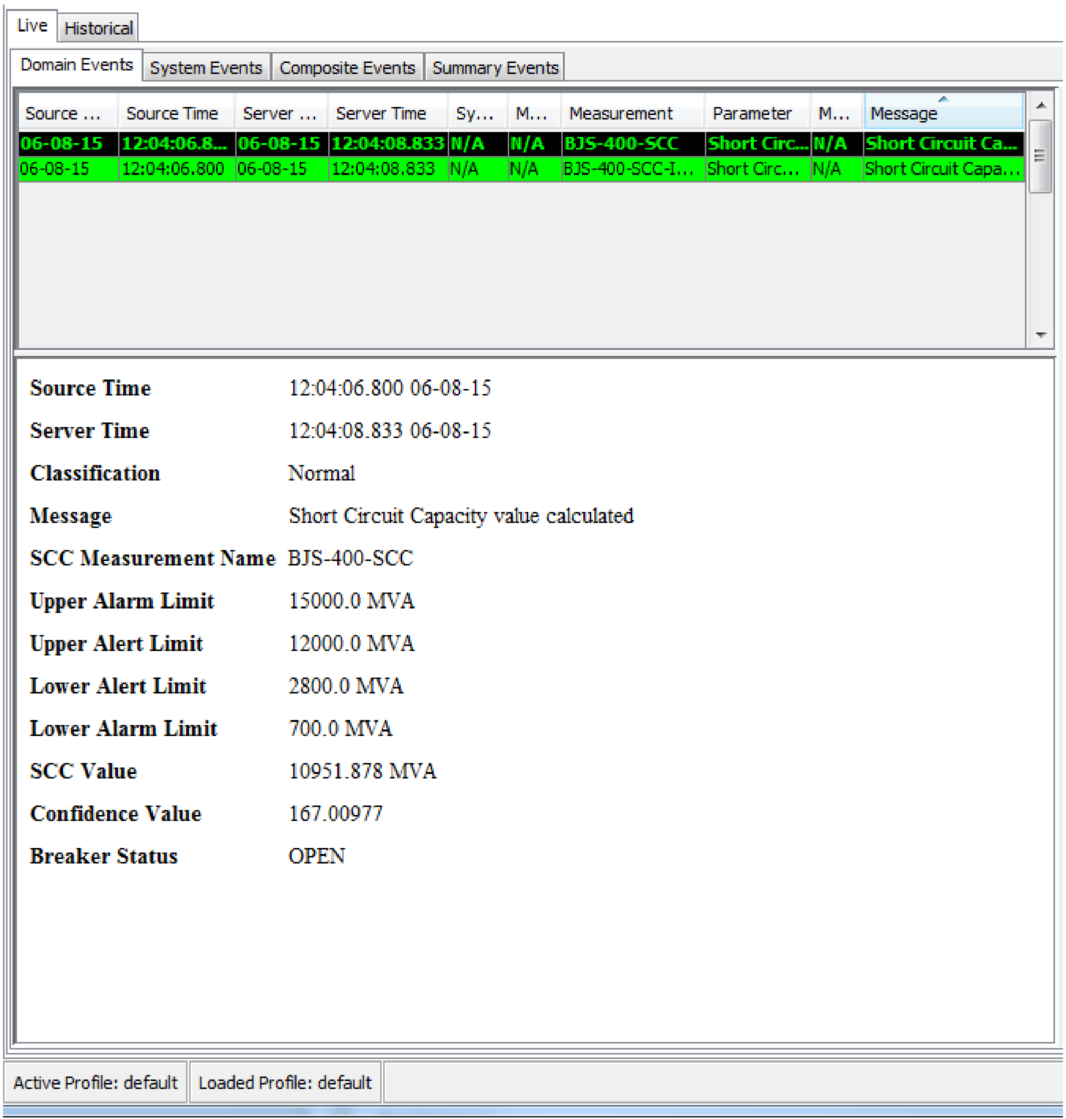

Fig. 7: Automatic calculation of SC power following switching incident in Energinet.dk 400 kV substation BJS, Source: Energinet.dk.

4. Conclusions and Outlook

Link to other systems, exchanges with other TSOs

As Wide Area Monitoring only becomes really effective by exchanging data between distant substations of a meshed interconnected system, the Continental European TSOs have started in an early stage to interconnect their WAM systems too by creating corresponding links between their data concentrators. However, in order to avoid an overload of the common dedicated telecommunication backbone only the information of a few strategic PMUs is currently exchanged. In principle the purpose of using WAM systems is for each TSO divided into two main categories:

a) Internal applications as e.g. corridor loading monitoring

b) External applications such as inter-area oscillation monitoring

This means that TSO-TSO WAM data exchange only requires exchange of a carefully selected subset of the TSOs measurands.

Open loop operation

As shown above several commercially available systems provide decision support by online visualisation and early warning signals. These applications are constantly improving and extended with new functionalities

Closed loop operation

Even if currently in the CE power system all WAM applications are still open-loop applications that mean only for monitoring, reporting or alarming in the future this might change and be extended in different directions:

1) Use WAM measurements or information as input for **s**pecial **p**rotection **s**chemes (SPS) for complex protection applications which include dynamic information for different interfaces, or
2) Wide Area Control by closing the loop by using power electronics as actuators (HVDC-control, STATCOM, SVCs, PSS etc.)
3) SCADA improvement, introducing “hybrid” state estimation application, more feasible and fast by combining current state of the art state estimation with WAM based state measurements
4) Use of WAM system enhanced awareness information for subsequent dispatcher decisions/actions as e.g. inter-area oscillation detection and LFC blocking

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