Recent Trends in Power Grid Monitoring

April 12-13th 2010, at Imperial College London

REPORT OF EVENT

Introduction

An event called *Recent Trends in Power Grid Monitoring* was held at Imperial College in April 2010. New emerging measurement technologies using time-synchronised wide area measurements are essential to manage the operation of power transmission grids in a complex and rapidly changing environment. For instance, the UK grid must adapt by 2020 to bring power from many new wind generation sites to industry and population centres.

This industry-academia event on Wide Area Monitoring Systems (WAMS) for power transmission grids examined:

- The state of the art
- Future industry directions
- Recent research results

Speakers included industry experts, practicing engineers and university researchers.

Talks

National Grid Roadmap for PMU deployment: Alex Carter & William Hung, National Grid, UK:

Alex presented the talk in which he discussed the National Grid road map for deployment of Phasor Measurement Units (PMUs). He started by considering the impact on the transmission system of the 2020 and 2050 targets for increased renewable generation and reductions in carbon dioxide emissions. The portfolio of 2020 generation capacity (i.e. the amount of generation from nuclear, gas- or oil- or coal-fired plant, wind generation) is considerably different from the current portfolio. Alex gave insights about the challenges to National Grid in providing transmission capacity, for instance in response to forthcoming offshore wind farms.

In future, power flows around the network will change with the wind and will be hard to predict. He identified PMUs as essential for future the operation of the grid. For instance 20 PMUs would give improved state estimation and also enable the sources of power oscillations to be identified more easily, while 200 would provide full state estimation. He gave some details of the PMU specifications such as the sampling rate and the measurements that would be needed.

Alex ended his talk with the key message that National Grid is aiming to understand the current state of grid operation as a base case for the forthcoming changes.

Capturing long term trends using data-driven methods: Tuomas Rauhala, FINGRID, Finland

Tuomas works mainly on planning for HVDC projects and finds the ten PMUs in Fingrid very useful. Some applications include:

- Verification of performance of dynamic simulation, component models and real-time estimation. A validated model can be extrapolated to determine transfer limits.
- Gaining knowledge of the dynamic behaviour of the network and tracking trends and direction over long periods of time. Changes will come because of wind farms, microgeneration and new ways of operating loads as smart grid technologies become more widespread.

He identified decision support systems using filtering, visualization and intelligent methods as future technologies needed to make use of basic PMU measurements.

Tuomas also pointed out that R&D and planning on the one hand and operations on the other hand have conflicting requirements. The control centres tend to need single indicators of system stability such as a traffic light system based on data from ambient operation. However, the planning and R&D functions want to see the details in order to uncover unusual or rare events and features. This requires advanced monitoring and visualization tools.

Why PMU in a small country? Prof Srdjan Skok, Technical University Rijeka, Croatia.

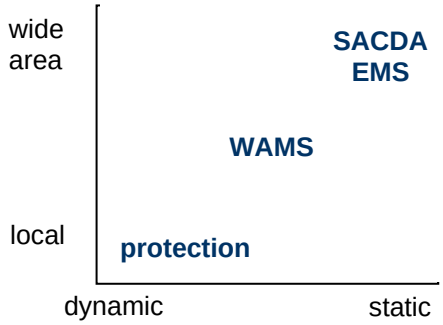
Croatia has the highest ratio of PMUs to feeders in Europe. Srdjan explained the reasons for a high density of PMUs include the shape of the country and the topology of the grid, the interconnections to neighbouring countries and the large energy transit through Croatia between the Balkans and other parts of the UCTE system. He also added that the PMU locations are optimized to be sensitive to dynamic disturbances and for the following purposes:

- Reduction of infrastructure investment by better control
- Managing increases in renewable and wind generation by 2020
- Dispatching of small power systems
- Preparing for the impact of Smartgrid.

The TSO uses a commercial phasor data concentrator, however there is work in parallel on other uses for PMU data in their own open-

architecture system. It includes hybrid analysis using data and models for activities such as hybrid state estimation. For instance, impedances of sections of the network can be estimated form data and compared to the impedance calculated from a first principles model determined from transmission line data. Voltage stability assessment, PV and QV monitoring is also included. The overall project is "Intelligent systems for power transmission.

PMU and WAMS Technology: Mats Larsson, ABB, Switzerland:
Mats briefly reviewed the ABB product portfolio. New PMU devices have high sampling rates and an open architecture allow linking to Matlab, Excel or data historians such as OSI PI. Mats placed the current state of the art in PMUs as suited to WAMS and protection functions in the figure below.



He described his research activities in power oscillation monitoring and control, damping estimation and closed loop oscillation control using PSS As in the previous talk, voltage stability, PV and QV assessments, power oscillation monitoring and wide-area control and protection are of interest. A recent development is the POM2 (Power oscillation monitoring) algorithm for (i) event detection, and (ii) detecting mode frequency and damping from ambient operation. Research involves visualizations to aid understanding such as phase angle displays. POM2 takes a multivariable sub-space approach using PMU measurements from different locations. A second project involves wide area control in collaboration with Statnett with state estimation, estimation of voltage nose curves and power flows.

Wide Area approach to system operation: Prof Liisa Haarla, School of Science and Technology, Aalto University, Helsinki, Finland
Liisa explored uses for WAMS in both operations and planning. For long lines, the limits for transmission capacity is constrained by stability and damping. Accurate estimates of P_{max} are of great importance. P_{max} is the maximum possible power flow for the *N*-1 contingency. If *P* (current power flow) exceeds P_{max} then a system breakdown is possible after an *N*-1 fault. On the other hand, if $P < P_{max}$ then some capacity is not being utilized. Liisa outlined the model-based approach for P_{max} calculations which require an accurate model. However, it is becoming increasingly hard to capture all the operating states and transmission patterns. WAMS can help to validate and tune the models. She identified research challenges in using damping estimates from PMU measurements of an intact grid to give information about the damping of different *N*-1 contingencies *before* they have occurred. The core idea is that when damping sets transmission limits, knowing the damping should help to define P_{max}.
Liisa's talk also discussed possible ways for determination of damping from PMU measurements during ambient operations, highlighting performance measures such as speed of response to changes and the standard deviation of the estimates.

Large-Scale WAMS. Bikash C. Pal, Imperial College London, UK; Kay Görner, Technische Universität Dortmund, Germany; Tadeja Babnik, ELPROS, Slovenia.
The speakers described the use of laboratory-based PMUs in Slovenia, Dortmund, Riga and the Netherlands. They can plug in to a single phase of the 220V level and detect events that are also visible at the 400kV level. The measurements from the four laboratory PMUs are coordinated via the Internet with a graphical user interface which has many different visualizations including oscillations in phase angles and frequency comparisons.
They showed comparisons of frequency in Germany and Slovenia and detection of an event recorded on all four laboratory PMUs. The conclusion is that it is possible to detect transmission system events by monitoring of the low voltage system using frequency and voltage angle. Comments from the audience suggested frequency may in general be the better signal because voltage can be influenced by local loads. Another comment was that 220V level may show some additional oscillations that are not present in the transmission system.

Poster forum

Vemund Aarstrand, Statnett: "Power oscillation monitoring and visualization."
Jukka Turunen, Aalto Univeristy: "Wavelet applications to analyse PMU signals."
Jerry Thambirajah, Imperial College London. "Detecting oscillation from ambient driven inputs".

Michael Weixelbraun, University of Technology, Graz, Austria: "Analyzing power oscillations in an 110kV network."
Linash PK, Pawel Regulski, Imperial College London & University of Manchester: "Connecting Manchester, Imperial and Strathclyde power system laboratories through PMUs."
PJ McNabb, Durham University, "Identifying Damping Problems using Wavelet Transforms",
The presenters in the poster forum each gave a short talk on their work and then talked to those who visited their poster.

Notes from discussions

The meeting ended with a discussion and wrap-up session.

Emerging themes: Some themes emerging from the event were:

- WAMS offers more than stop/go traffic light application in control centre of a transmission operating company. It is also useful:
  - for control and protection
  - for planning, model validation and P_{max} calculations which are needed as operations become more variable.
  - The information helps with maximising transmission capacity of exiting systems.
- WAMS is feeding into decision support e.g.
  - damping estimates
  - state estimation
  - estimation of the voltage nose curve
- WAMS information can be converted to a signature, e.g. the damping, which indicates changes in the system.

Decision support systems and visualization: There were many references during the event on visualization for decision support. It is clear from the talks that there are two distinct groups of users of WAMS data: (i) operators in the control room and (ii) system planners and designers. The displays depend on what people need to know for these two job functions.
The discussion considered how generic operator actions could be, or whether the required action would depend on the configuration and state of the network. It was felt that the operator actions are case-dependent because control measures depend on conditions. Standard counter-measures or maintenance decisions may not be valid if the conditions of the grid change.

Plug-in PMUs. The event had presentations on the use of PMUs at the 220V level for research purposes. The discussion considered what other uses there could be for PMUs at the 230V level. What might they be used for if everyone had one in their home? One response is that more PMUs make state estimation easier, and plug-in models may have a role. On the other hand, there are other technologies more suited to home applications coming with Smartgrid metering technology. It is not clear that PMUs would have any domestic applications.

Thank you: All those present thanked Bikash Pal for organizing the event and putting together a varied and interesting programme from a wide range of speakers. We also thanked all the speakers.

Organizers

The event was organized at Imperial College by Bikash C. Pal (E&E Engineering) with assistance from Martin Edwards (E&E Engineering), Nina Thornhill and Jerry Thambirajah (Centre for Process Systems Engineering).

Further information

Meeting presentations are available from the link below:
http://www.ee.ic.ac.uk/bikash.c.pal/WAMS-Workshp/WAMS-Workshp.zip

Further information on the WAMS project at Imperial College London is available at
http://www3.imperial.ac.uk/people/b.pal
and
http://www3.imperial.ac.uk/processautomation/research/wams

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Notes compiled by
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Photo Gallery