Smart Transmission Grids Operation and Control

Kjetil Uhlen

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Outline

• Project objectives, drivers, ambitions and overview

• Nordic collaboration through common research platform

• Examples on application developments
A project funded by

– And co-funded by Nordic TSOs and DSOs

• **Objectives:**
  – Support the development of better *tools for operation and control* of power grids
  – Create innovative *applications* that will enable more reliable operation and control of the Nordic power grid and with better information about security margins.
  – Develop a *research platform* and software interfaces (software and hardware) for application prototyping and testing
  – Identify *technology gaps* and limitations that need to be addressed in the future *as an input to roadmaps* for smart grid and integration of renewable energies.
More extremes!

• Trends:
  - Faster and larger changes in operation
  - More variability and uncertainty
  - Less predictability → Less time to take decisions

• Operators need new tools!
  - More real-time information, higher resolution and synchronised measurements
  - Need for more automatic control

• New technology is available
  - New possibilities..
Project goals

• Create innovative *applications* that will enable operation and control of the Nordic power grid more reliably and with better information about security margins.
  
  ➢ Emphasis on PMU/WAMS as an enabler of Smart Grids

• Develop a *research platform* comprised by a power systems emulator (software and hardware labs), PMUs, PDCs and specialized software.
  
  – Create a “Nordic University Cluster”

• Develop a set of *software interfaces* allowing PMU-data application development, and implementation.
What is a phasor?

- The starting time defines the phase angle of the phasor.
- This is arbitrary.
- However, differences between phase angles are independent of starting time.

$$x(t) = \sqrt{2}A\cos(2\pi \cdot 50 \cdot t + \phi)$$

$$= \text{Re}\{\sqrt{2}Ae^{j\phi} e^{j\omega t}\}$$

$$\omega = 2\pi \cdot 50$$
Synchronized Phasor Measurements

By synchronizing the sampling processes for different signals – which may be hundred of miles apart, it is possible to put their phasors on the same phasor diagram.

Source: Phadke
Research Platform: Low voltage PMU Network

- PMUs are connected at the LV networks in our laboratories
Research platform: Distributed P2P Data Sharing for real-time PMU Data Exchange

- Each University (PMUs, PDC) exchanges an Output Stream” with each other university.
- PDCs installed locally allow data archiving and real-time access for all partners.
- Avoids SuperPDC, thus eliminates a single point of failure
Test-bench:
New WAMPAC software applications Development and Testing
**S³DK: Synchrophasor Software Dev Toolkit**

- **Real-Time Data Mediator:** Low level implementation of the IEEE C37.118.2 Standard
- **PMU Recorder Light:** Graphic interface to the mediator developed in LabView and a Toolbox with LabView Functions for App prototyping
Sample Application
WAMS Visualization Tool - Mobile

- Portable Monitoring Applications
Application developments

**STRONg^2rid «apps»**

- **Angle stability**
  - PMU-based Oscillation damping using reconfigurable controllers (Almas, Rebello, KTH)
  - Centralised LQR and MPC control for damping inter-area modes (Mäki, Aalto)

- **Voltage stability**
  - Real-time voltage stability monitoring using Lyapunov exponents (Lavenius, KTH)
  - Online voltage stability monitoring based on PMUs and system topology (Dinh Thuc Duong, NTNU)

- **State estimation**
  - Transmission line temperature and sag estimation by using PMU measurements (Putnins, IPE / Kaur, TUT)
  - Power oscillation damping using load control, (Gudrun, KTH / Landsnet)

- **Protection & Emergency control**
  - Identifying cascading outages (Petersen, DTU)

- **ICT**
  - ICT solutions for new generation WAMS and WACS, (Wu, KTH)
  - Damping estimation using LS (Tomi Kalmi, Aalto)

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**PMU Test and Applications for Small Signal Stability Assessments**, (Ghiga, DTU)
Collaboration

Collaboration with Partner Universities
A. 8 Educational Courses (2 on SmarTS-Lab, 2 on Labview Modules, 4 from International Faculty)
B. Several combined publications

SmarTS-Lab Training Program (Sept 23-October 04, 2013)

TuT-KTH collaboration (PMU compliance Testing)

Power System Dynamics and Control (Professor Taranto) 22-26 April 2013

3-day course on renewable energy integration, 2014
Concluding remarks

• A “Nordic University Cluster” has been established

• New competence have been gained at the Universities and at the TSOs through research, PhD education, courses and dissemination activities

• Increased awareness at the TSOs about the possibilities of utilizing PMU technology in operation and control.
  – TSOs are starting deployment and pilot installations

• STRONG motivation to continue the R&D collaboration at the Nordic/Baltic level
EXTRAS
Evolution of the Control Room

From analog to digital

Analog Tech.

From digital to digital

SCADA/Digital v.1.

SCADA/EMS/Digital v.2.

Appearance of EMS applications

SCADA/EMS+ PMU

starts being used in control rooms for monitoring displays & alarming (2002 – 2014)

Today: SCADA/EMS+ PMU + PMU Applications for Monitoring a few Specific Conditions → WAMS

The Future?

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Motivation: Increased Situational Awareness

- Utilization in the control room
Application developments

STRONG²rid «apps»

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PMU Test and Applications for Small Signal Stability Assessments, (Ghiga, DTU)

Damping estimation using LS (Tomi Kalmi, Aalto)
IPE research topics and results

- The objective of IPE task was PMU application for transmission line temperature, sag and clearance parameter estimation.

- Algorithm for sag and clearance in overhead power lines calculation was proposed and tested in real-time conditions with focus on thermodynamics and line mechanics behaviours.

- This research will contribute to real-time operation performance, then exact line sag and clearance calculation will increase potential maximal transmission power capability, namely total transfer capacity (TTC) corridor’s and cross-border trade.
In frame of the project in IPE was established PMU lab

For data visualization open platform [http://www.sqldashboards.com/sqlchart](http://www.sqldashboards.com/sqlchart) was used.

• journal publication, 2 conference publications

• Meeting & workshop in IPE, Riga
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**PMU Test and Applications for Small Signal Stability Assessments**, (Ghiga, DTU)
North Norway and North Finland transmission system
How to monitor frequency and damping of power oscillations based on PMU measurements?

- Ambient data / normal oscillations
Multivariate method (MAR)

- **Green**: SGN1, SGN2, parameters 1
- **Yellow**: SGN1, SGN2, parameters 3
- **Cyan**: SGN1, SGN2, parameters 2
- **Magenta**: SGN1, SGN2, parameters 4

Damping ratio

- 0.15
- 0.05

Time:

- 23:00
- 00:00
STRONG®rid «apps»

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Application developments

- Large number of PMU-assisted WAMPAC applications have been developed within the STRONg^2rid project.
- All these applications have been tested using Real-Time Hardware-in-the-loop (RT-HIL) facility at SmarTS-Lab.
Apps developed in collaboration with KTH

Monitoring & Visualization

Inter-Area Oscillation Assessment

Forced Oscillation Detection

Short-Term Voltage Stability Assessment

Mobile Apps

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VOLTAGE STABILITY MONITORING AT HASLE CORRIDOR

Information:
- Initializing
- Low power transfer
- System standby
- Recording data
- Expert
- Import

Instantaneous parameters:
- Power transfer: 226.2 MW
- Voltage: 412.67 kV
- Hasle - Borgvik: 18324.16 A
- Hasle - Halden: 1867.0 A

Open PRL
Save data

Setting:
- Impedance threshold
- Sensitivity threshold
- Zth/Load threshold
- Min power transfer (MW)

Indicator:
- 25 Ohm
- 40 Ohm
- 50 Ohm
- 60 Ohm

Graphs:
- PV curve
- Time
- Impedance (Ohm)
- Load and estimated max power

STOP
Major Challenges while developing WAMPAC applications

PMU-assisted WAMPAC applications are affected by:

- Communication latency
- Loss of data / bad data
- GPS vulnerability (Jamming/Spoofing Attack)
- Measurement noise due to hardware PMUs
- Signal scaling which affects overall SNR

Noise in the signal received from hardware WAPOD

Effect of Loss of GPS signal on Phase Angle computation by PMU
One of the major achievements within the project is development of a Smart Transmission System Laboratory which serves as a test-bench where new WAMPAC software applications are developed and tested. The laboratory is equipped with real-time simulators, PMUs and other equipment for performing Real-Time Hardware-in-the-Loop (RT-HIL) simulations.