Sustainable Energy Systems 2050
NORDIC ENERGY RESEARCH PROGRAMME

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Nordic Energy Research

Smart Transmission Grids Operation and Control

Kjetil Uhlen

October 22, 2015

STRON2grid
Smart Transmission Grids Operation and Control
KTH - NTNU - AALTO - DTU - UI - TUT - FEI

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NTNU – Trondheim
Norwegian University of Science and Technology

Project partners

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Academia

NTNU

KTH VETENSKAP OCH KONST

LUND UNIVERSITY

Aalto University School of Science and Technology

DTU

UNIVERSITY OF ICELAND

Institute of Physical Energetics

TTÜ 1918

Industry

Statnett

SVENSKA KRAFTNÄT

TROMS KRAFT

gothia power

FINGRID

LANDSNET

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Outline

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- Project objectives, drivers, ambitions and overview
- Nordic collaboration through common research platform
- Examples on application developments

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Smart Transmission Grids Operation and Control

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A project funded by

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– *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!

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- 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..

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Project goals

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- 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.

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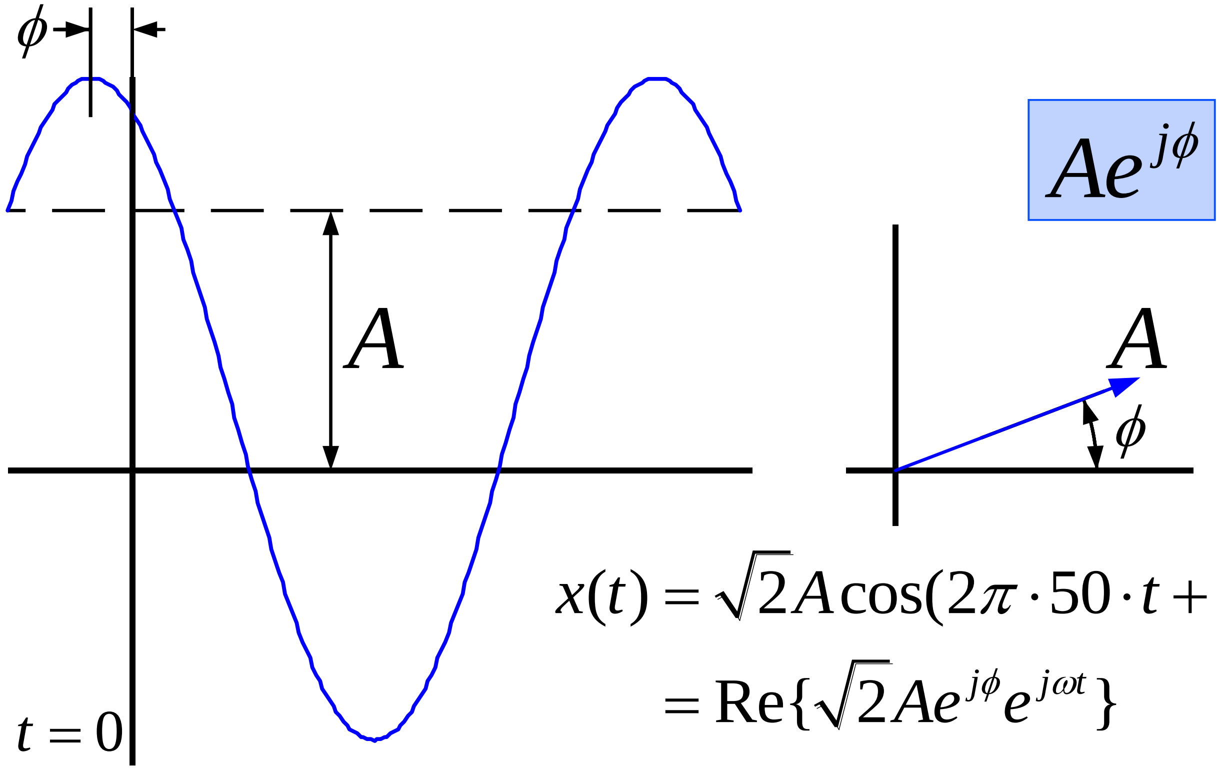
What is a phasor ?



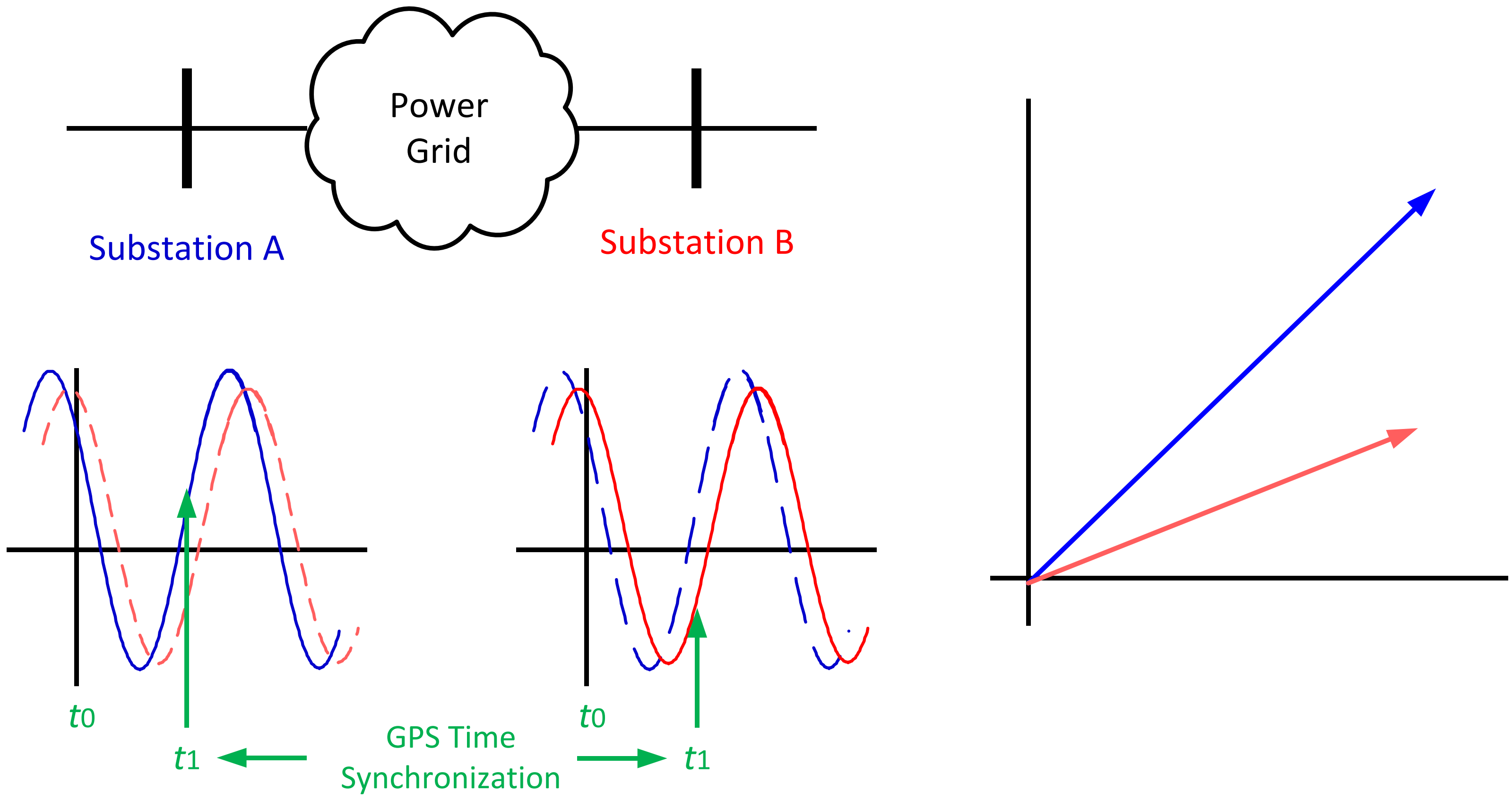
$$x(t) = \sqrt{2}A\cos(2\pi \cdot 50 \cdot t + \phi)$$

$$= \mathrm{Re}\{\sqrt{2}Ae^{j\phi}e^{j\omega t}\} \qquad \omega = 2\pi \cdot 50$$

Phasor representation of a sinusoidal wave form

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

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

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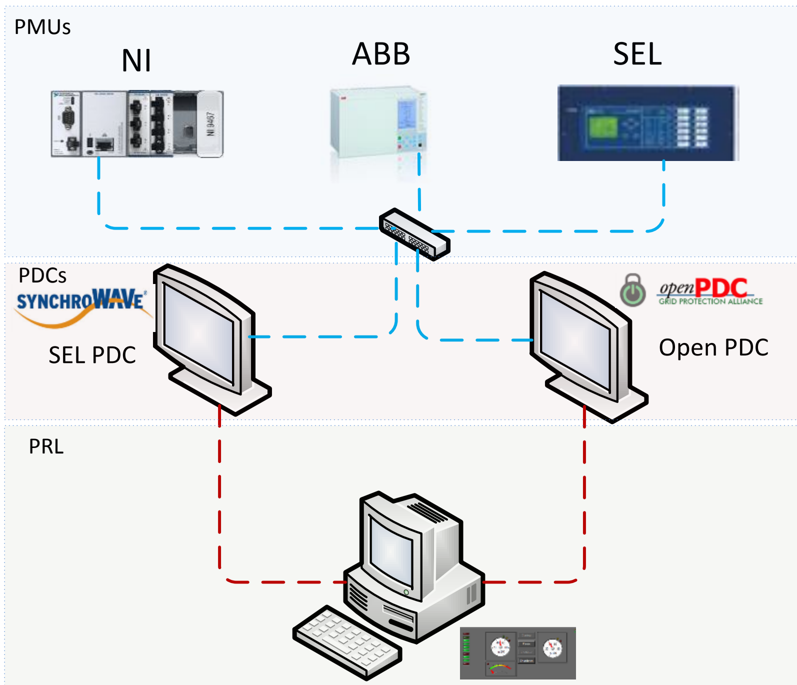
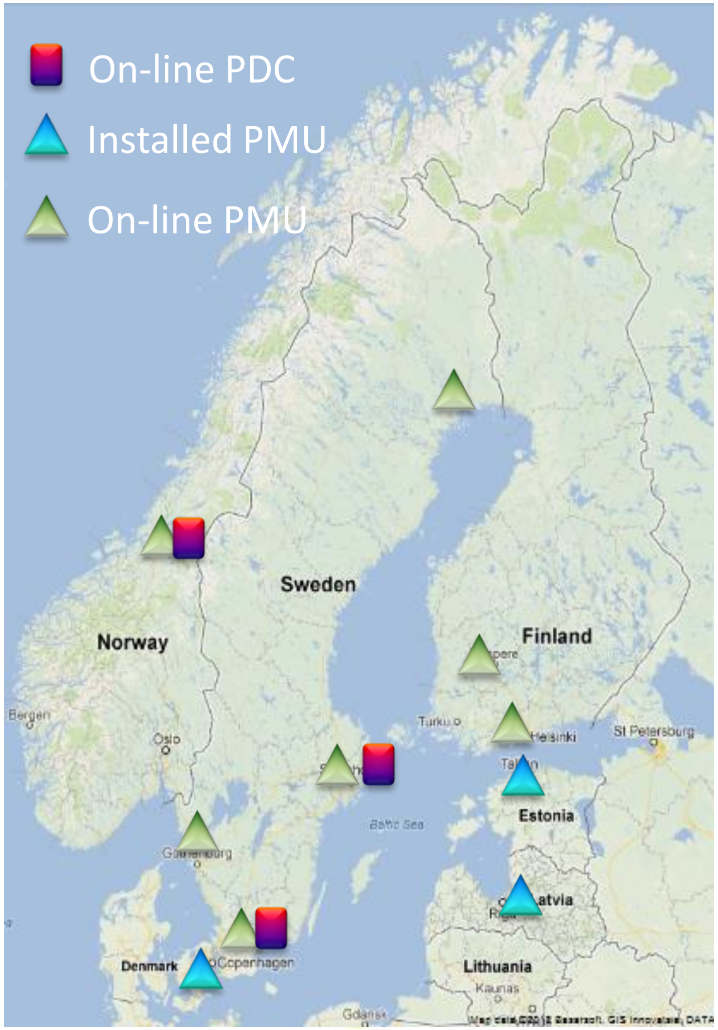
- PMUs are connected at the LV networks in our laboratories





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Research platform:

Distributed P2P Data Sharing for real-time PMU Data Exchange

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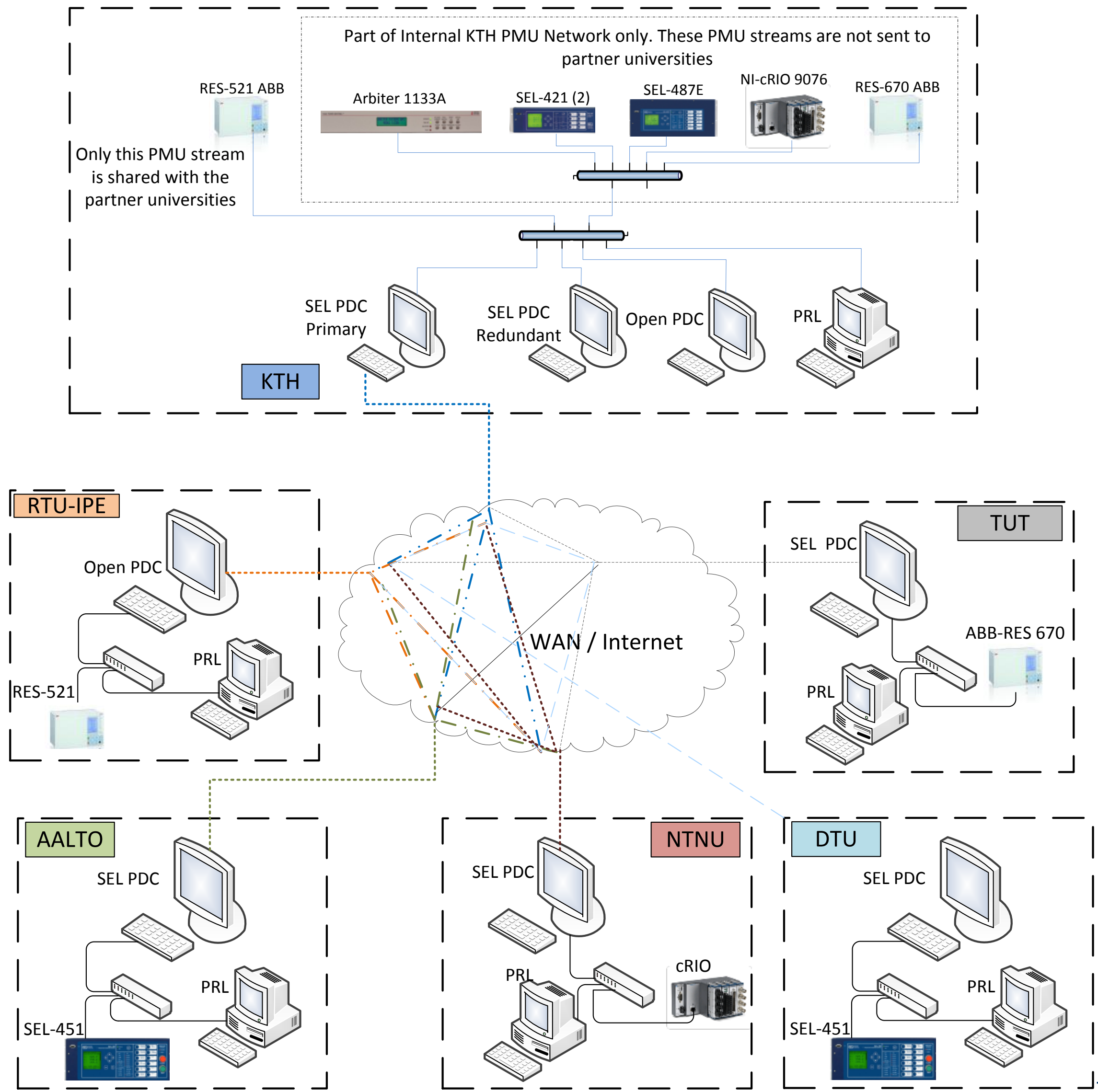
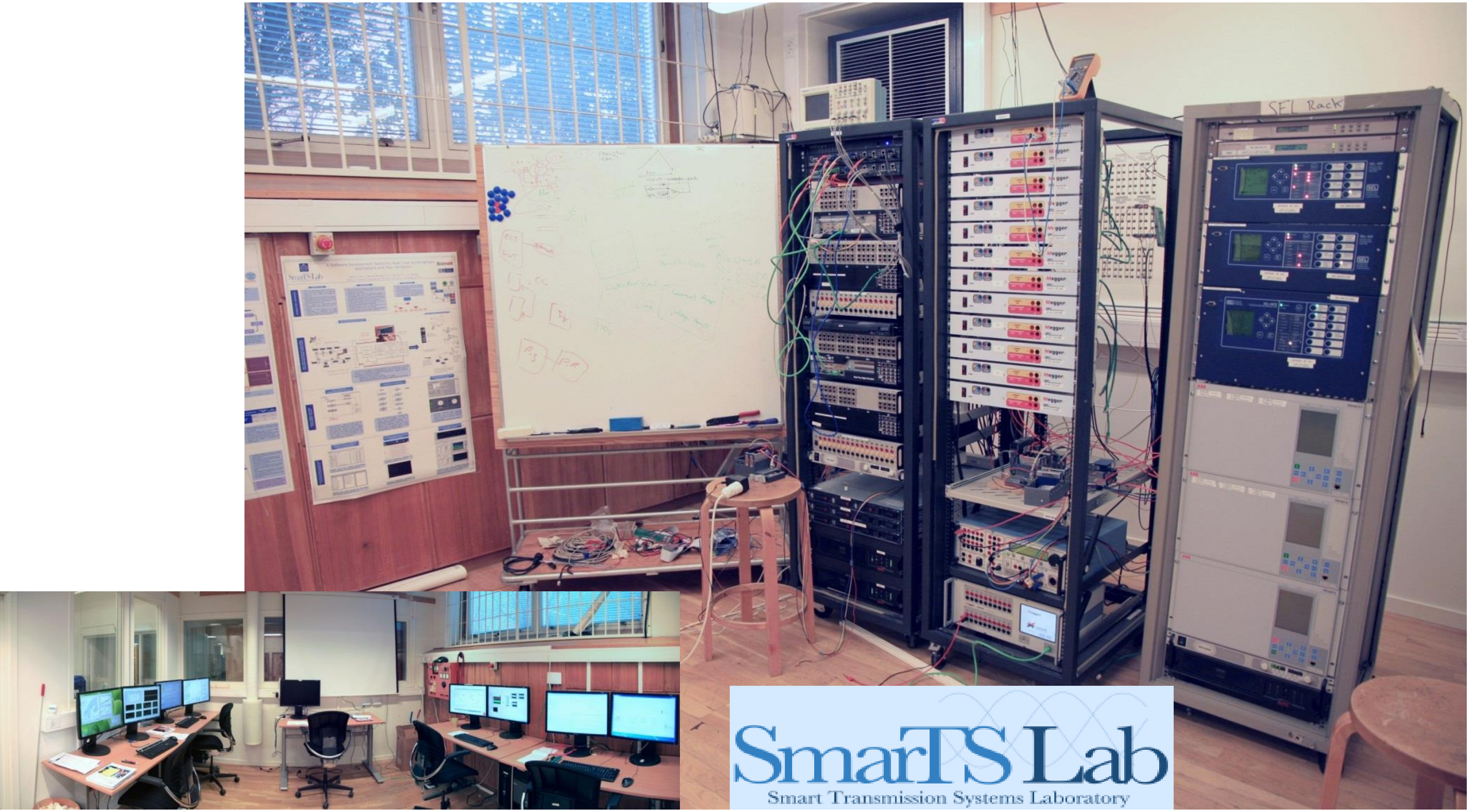
- Each University (PMUs, PDC) exchanges an Output Stream" with each other university.
- PDCs installed locally allow data archiving and real-time access for all partners.
- Avoids SuperPDC, thus eliminates a single point of failure



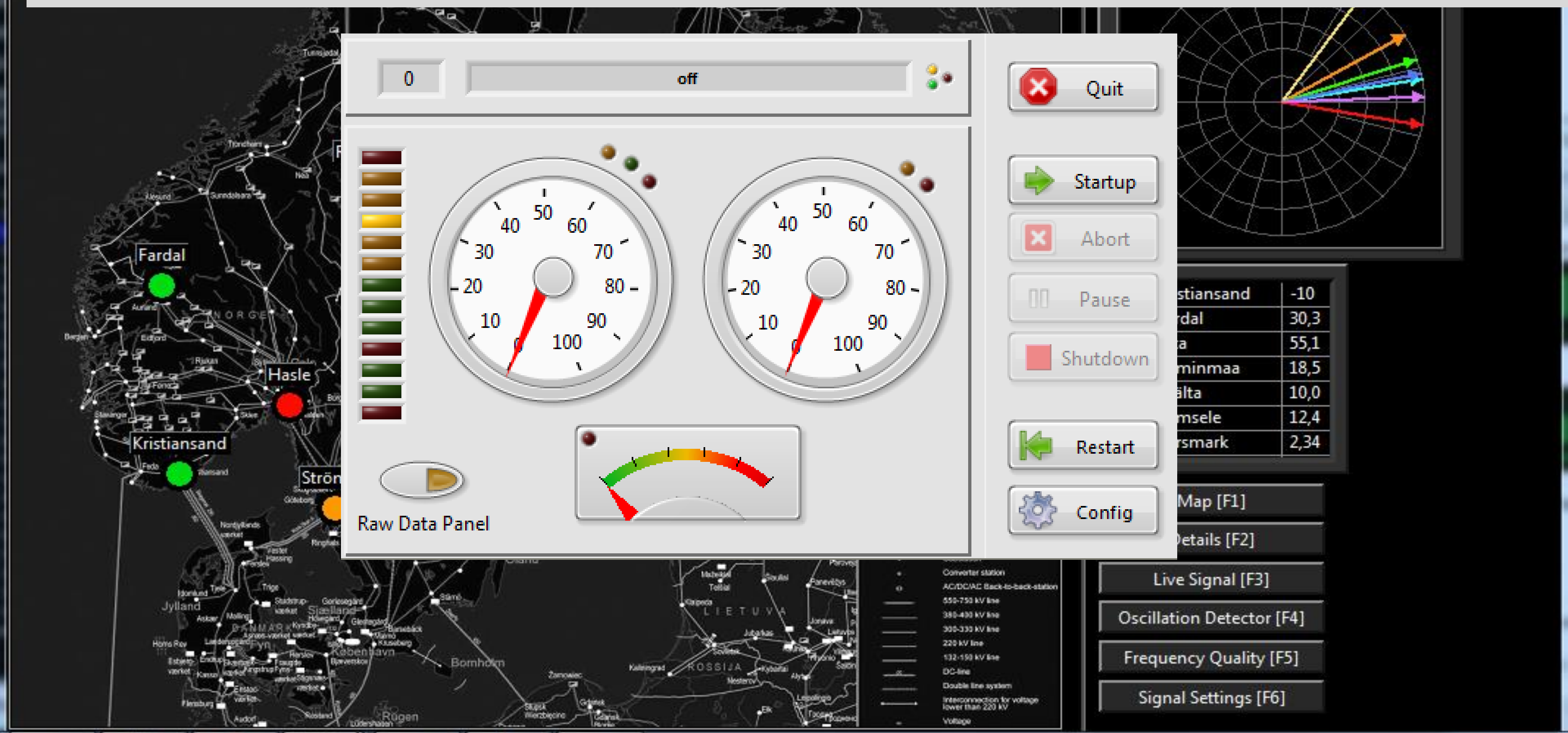
Test-bench:

New WAMPAC software applications Development and Testing



S^3DK: 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

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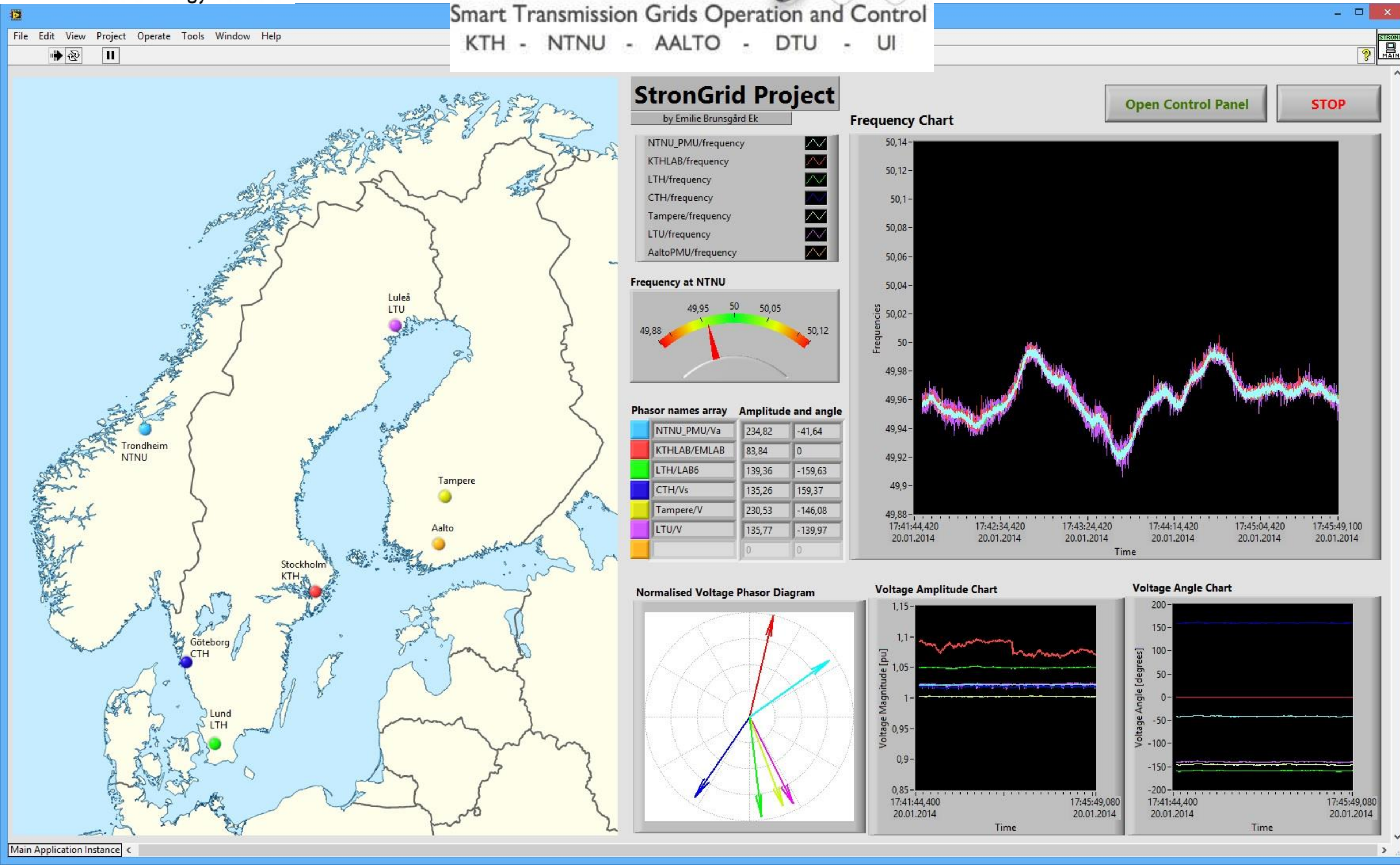

Application developments

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- **Angle stability**
  - PMU-based Oscillation damping using reconfigurable controllers (Almas, Rebello, KTH)
    - Centralised LQR and MPC control for damping inter-area modes (Mäki, Aalto)
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- **Protection & Emergency cntrl**
  - Identifying cascading outages (Petersen, DTU)
- **ICT**
  - ICT solutions for new generation WAMS and WACS, (Wu, KTH)

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Collaboration

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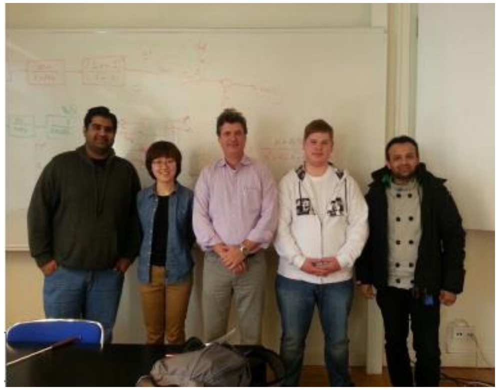
Collaboration with Partner Universities

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)



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

TuT-KTH collaboration
(PMU compliance Testing)

3-day course on renewable energy integration, 2014

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Concluding remarks

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- 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

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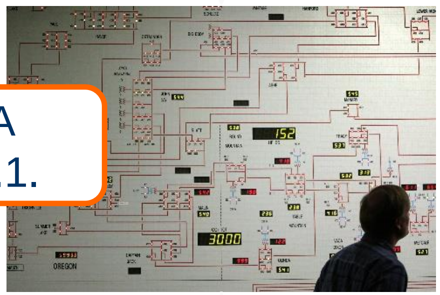
EXTRAS

Evolution of the Control Room

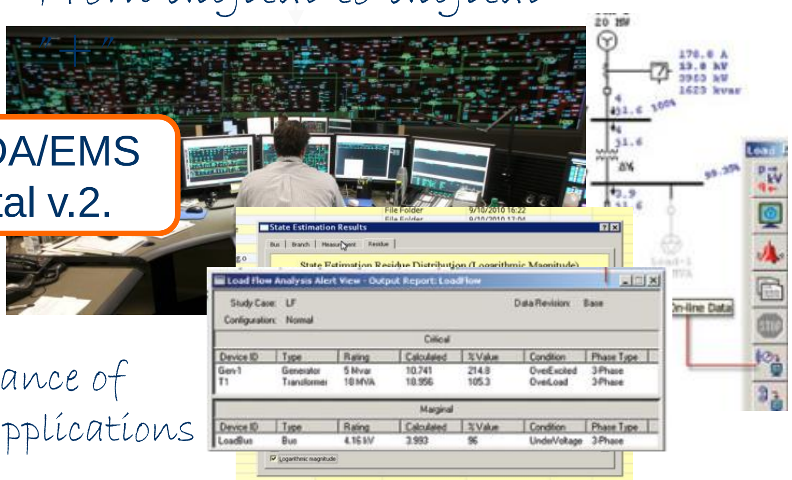
Analog Tech.

From analog to digital



SCADA Digital v.1.

From digital to digital



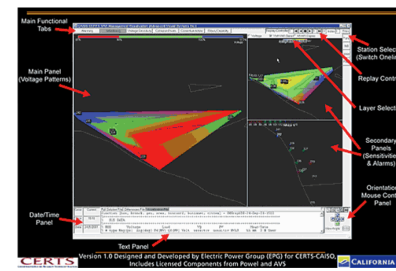
SCADA/EMS Digital v.2.

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?

Motivation:
Increased Situational Awareness

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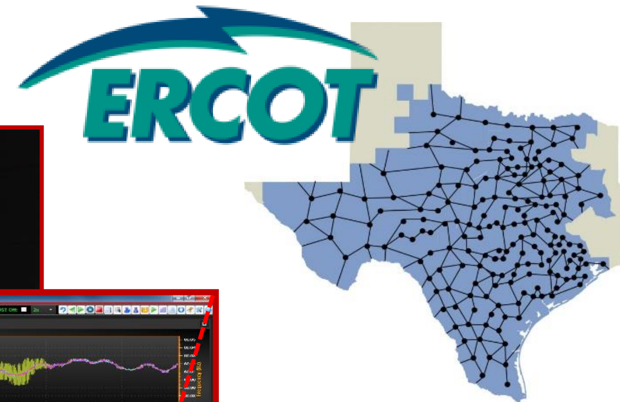
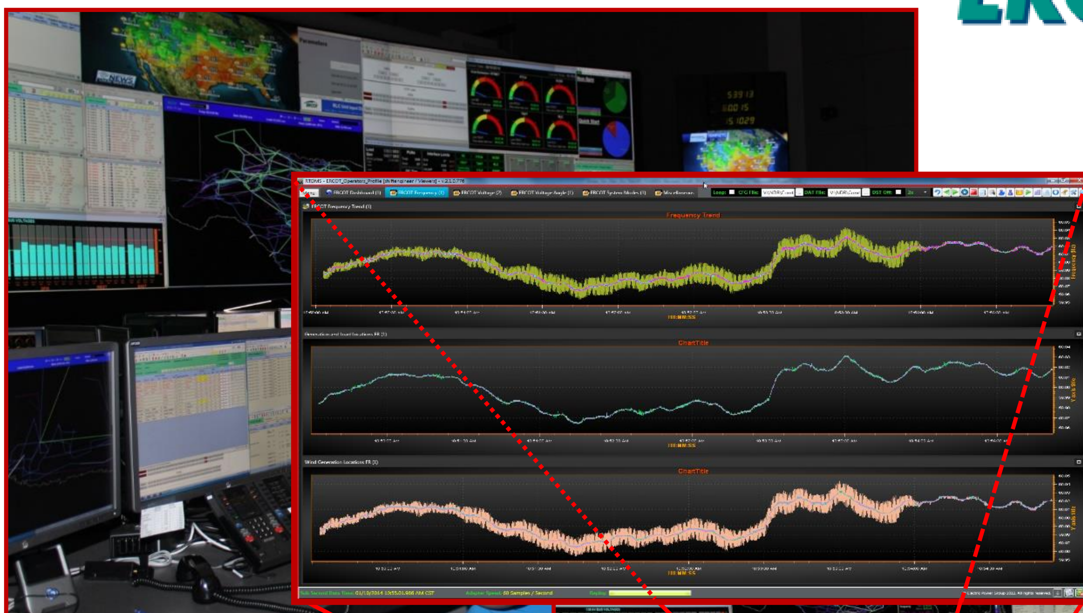
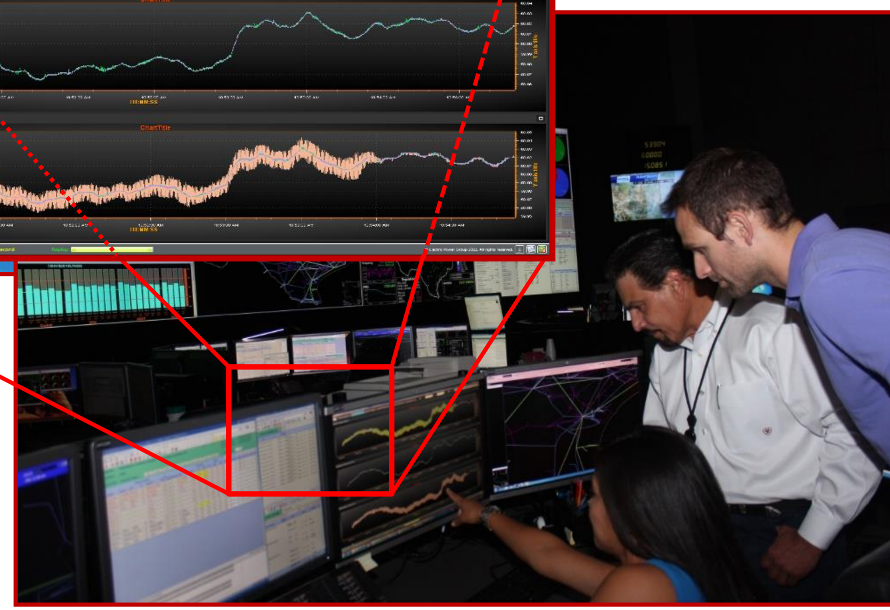
- Utilization in the control room







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Application developments

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STRONg²rid «apps»

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IPE research topics and results

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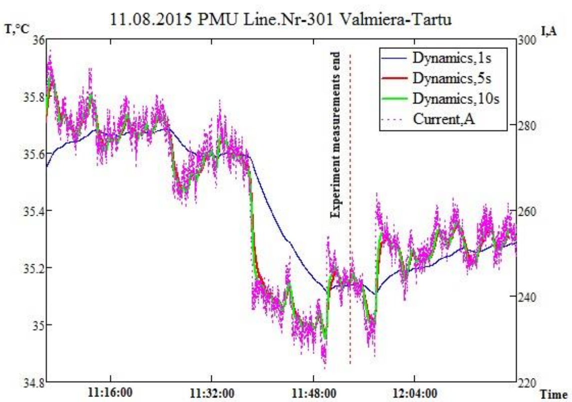
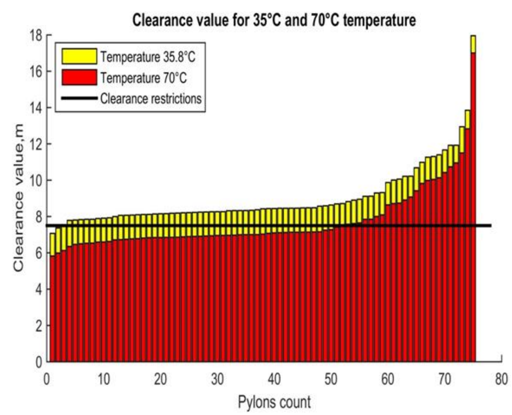
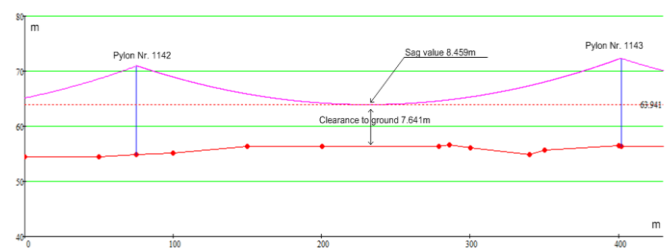
- The objective of IPE task was PMU application for transmission line temperature, sag and clearance parameter estimation.
- Algorithm for sag and clearance in overhead power lines calculation was proposed and tested in real-time conditions with focus on thermodynamics and line mechanics behaviours.
- 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.







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IPE research topics and results

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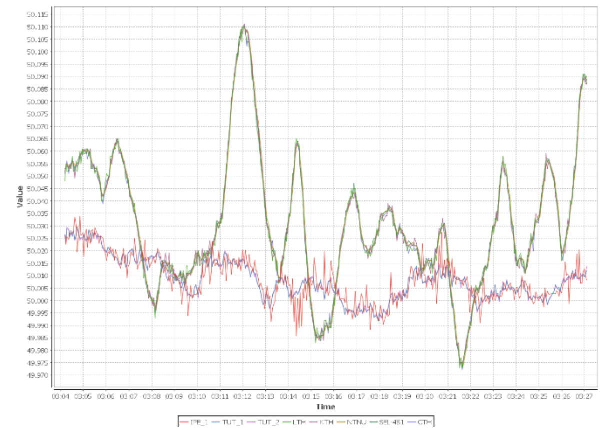
- In frame of the project in IPE was established PMU lab



For data visualization open platform http://www.sqldashboards.com/sqlchart was used.

- journal publication, 2 conference publications

- Meeting & workshop in IPE, Riga

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North Norway and North Finland transmission system

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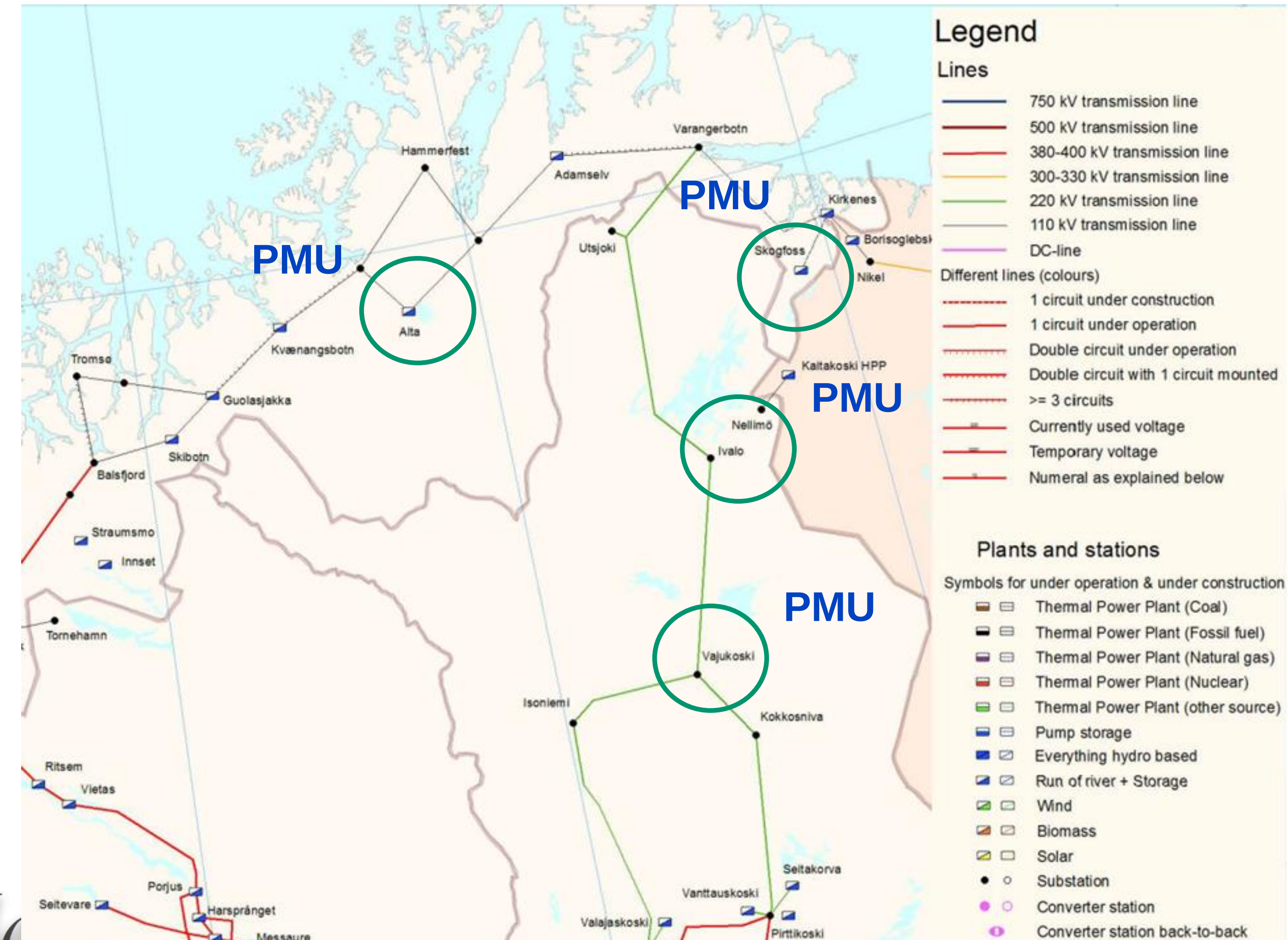

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How to monitor frequency and damping of power oscillations based on PMU measurements?

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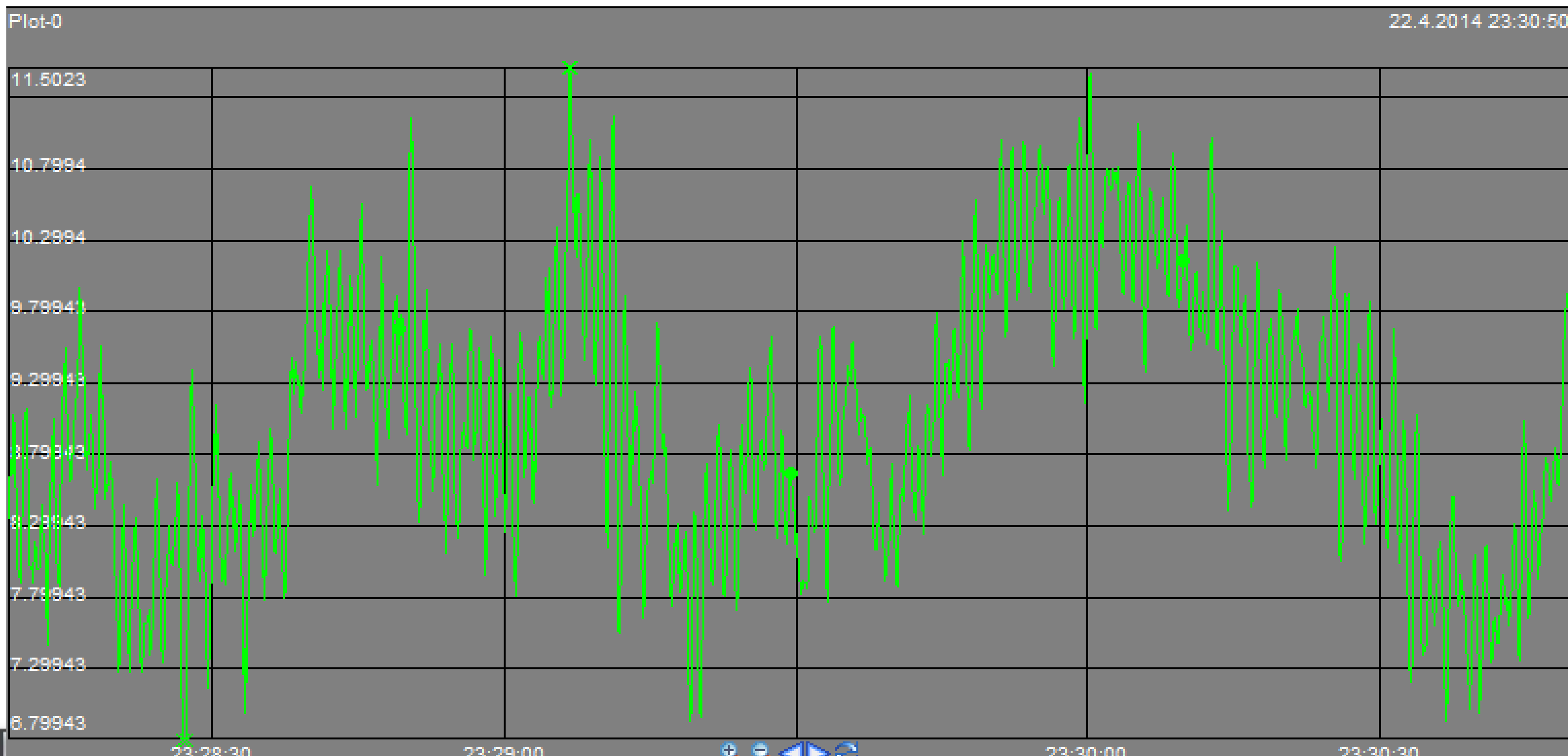
- Ambient data / normal oscillations

MW



Multivariate method (MAR)

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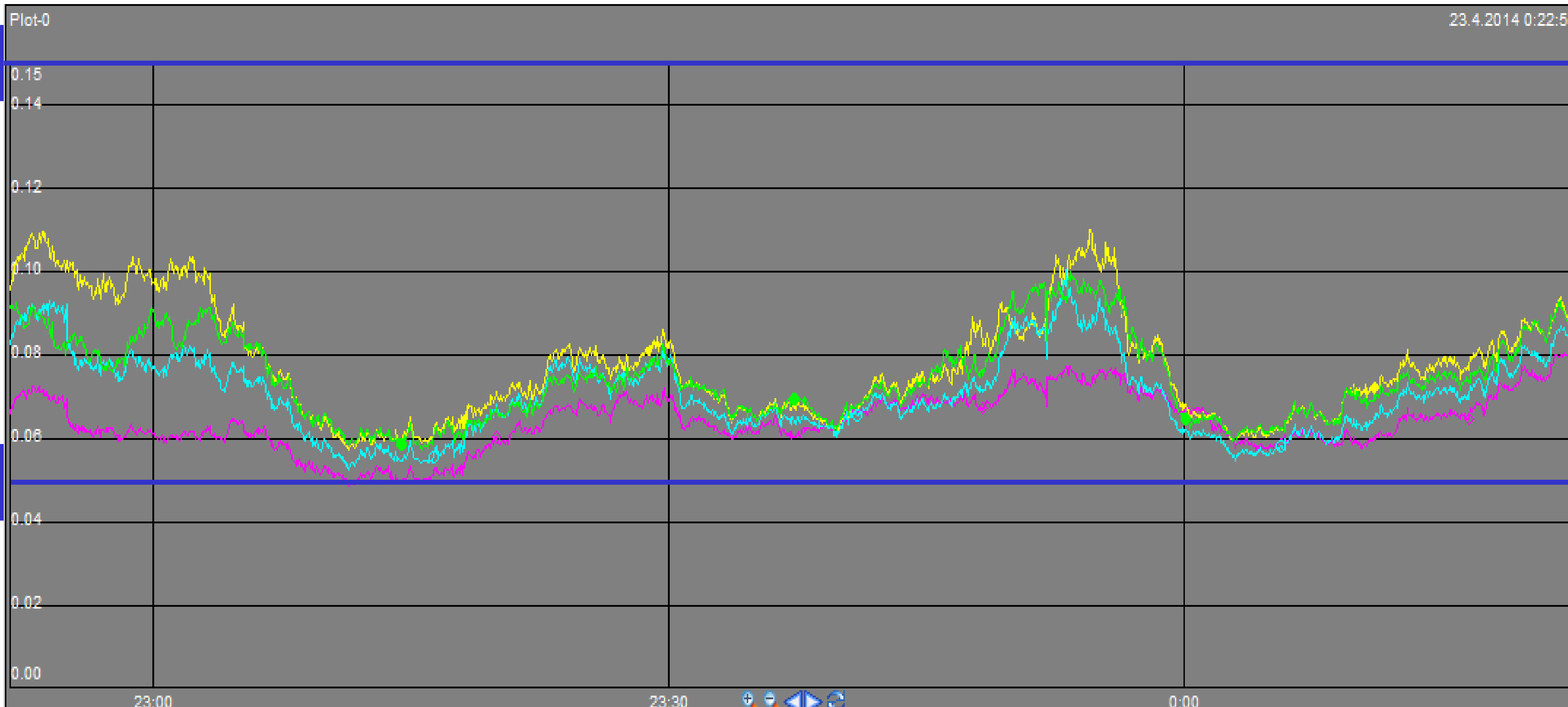
damping ratio



23:00 time 00:00

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

Application developments

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Application developments

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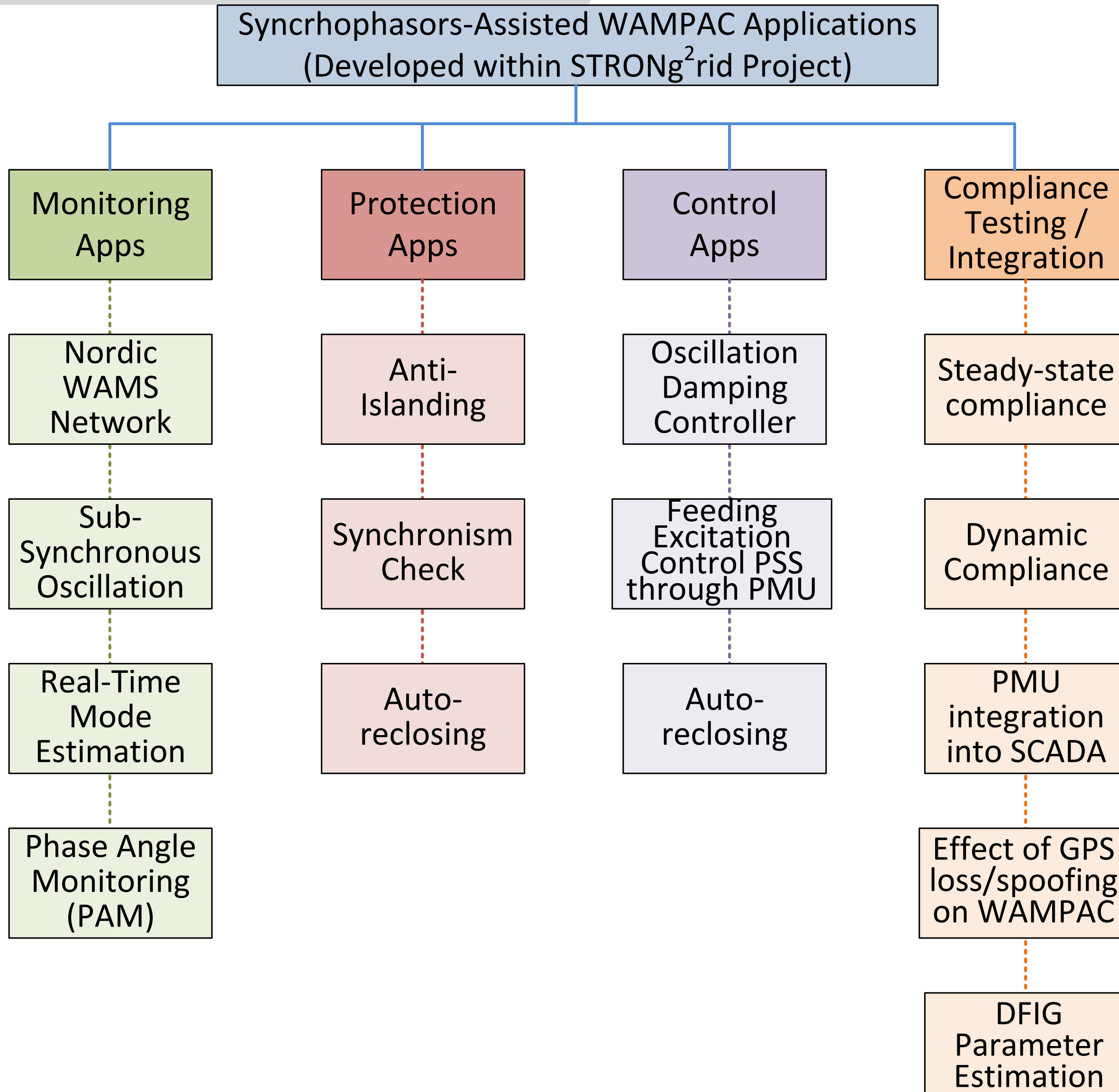
- Large number of PMU-assisted WAMPAC applications have been developed within the STRONg²rid project.
- All these applications have been tested using Real-Time Hardware-in-the-loop (RT-HIL) facility at SmarTS-Lab



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Apps developed in collaboration with KTH

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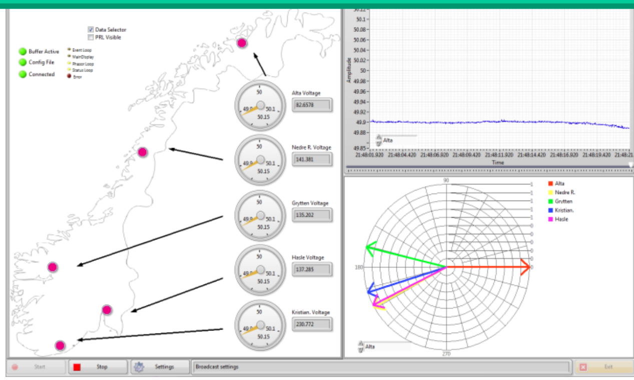
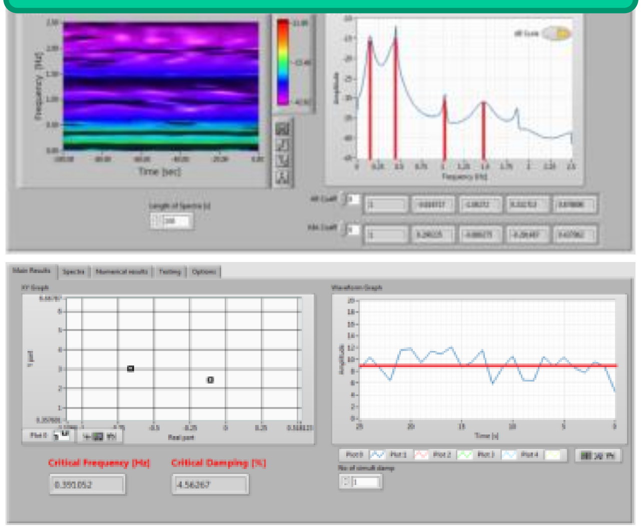
Monitoring & Visualization

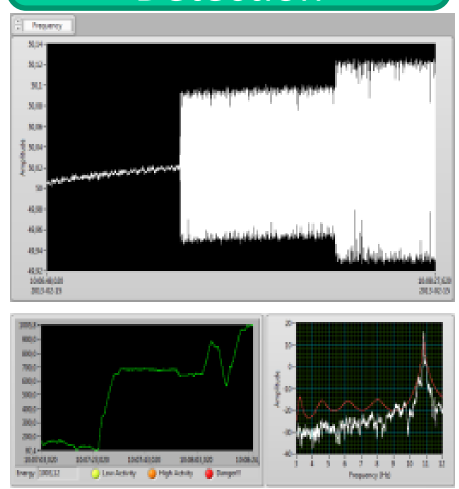


Mobile Apps

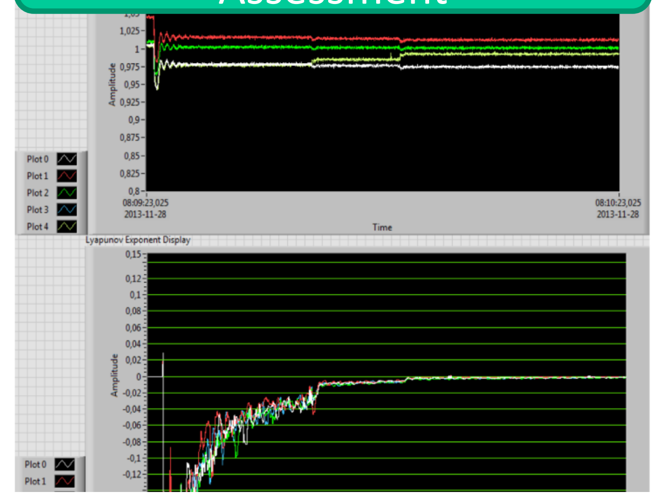
Inter-Area Oscillation Assessment



Forced Oscillation Detection



Short-Term Voltage Stability Assessment



Application developments

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STRONG^{2}rid «apps»

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Apps developed in collaboration with NTNU

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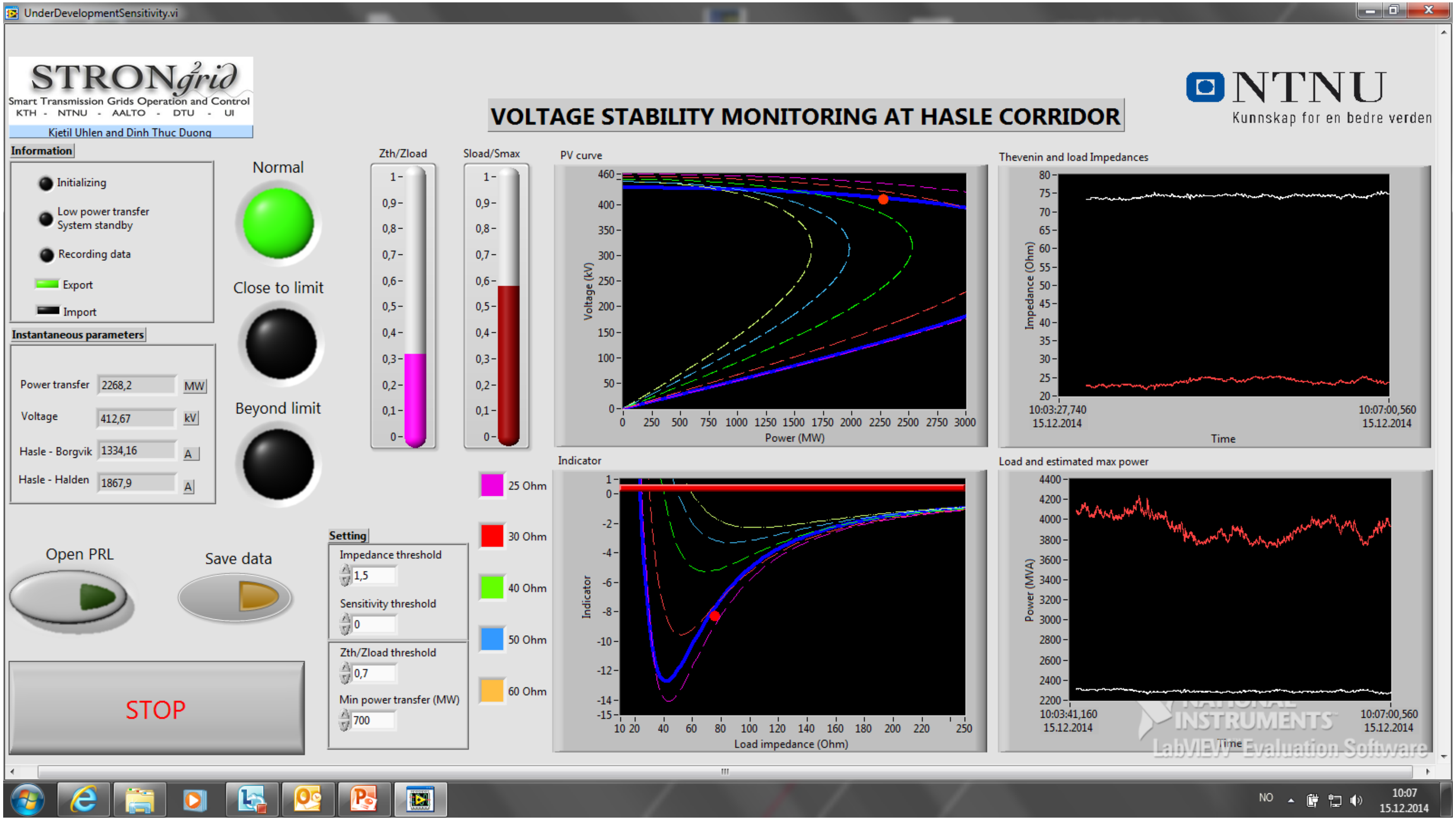

Major Challenges while developing WAMPAC applications

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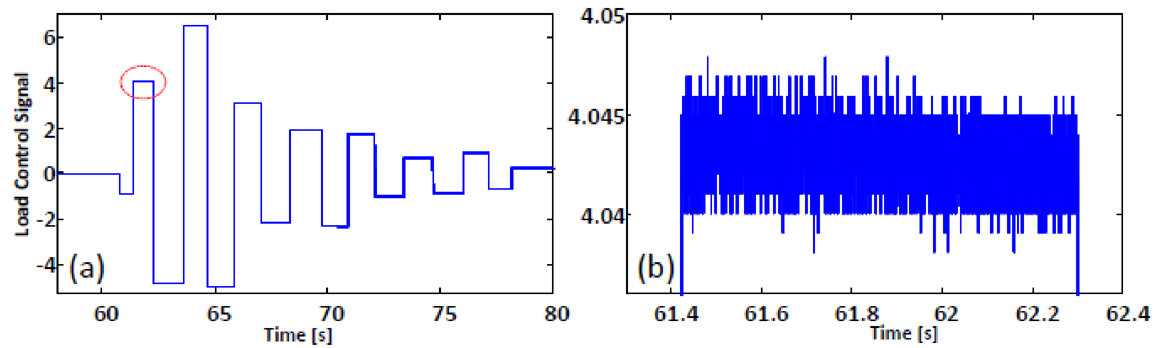
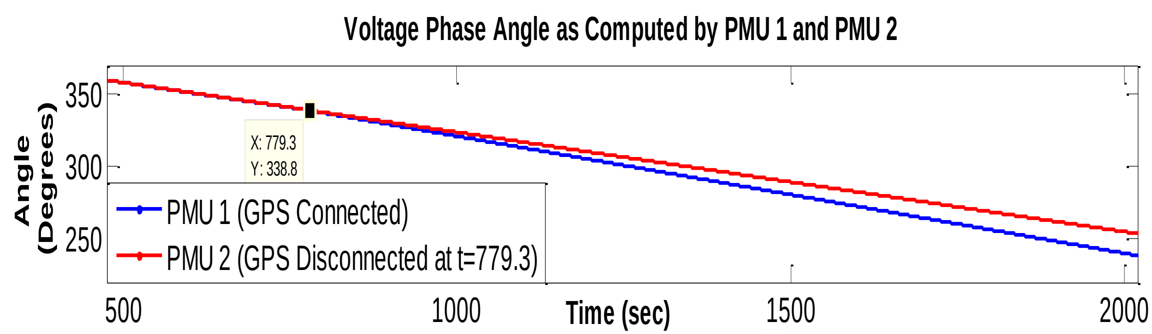
PMU-assisted WAMPAC applications are affected by:

- 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

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Test-bench:

New WAMPAC software applications Development and Testing

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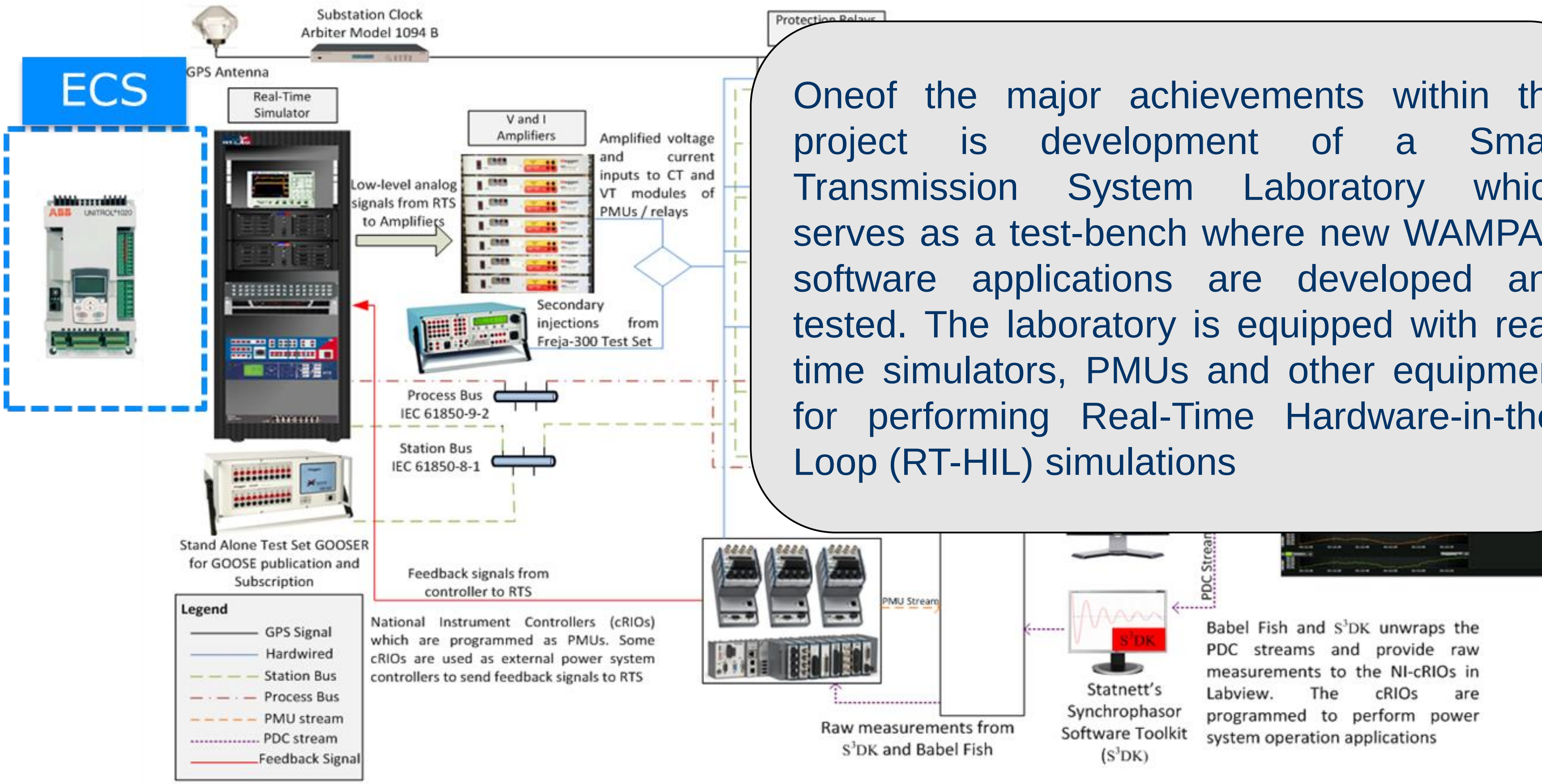
SmarTS Lab
Smart Transmission Systems Laboratory



Oneof 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

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