SmarTS Lab
Smart Transmission Systems Laboratory

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From Vision to Implementation: The SmarTS Lab Concept

Dr. Luigi Vanfretti and Moustafa Chenine

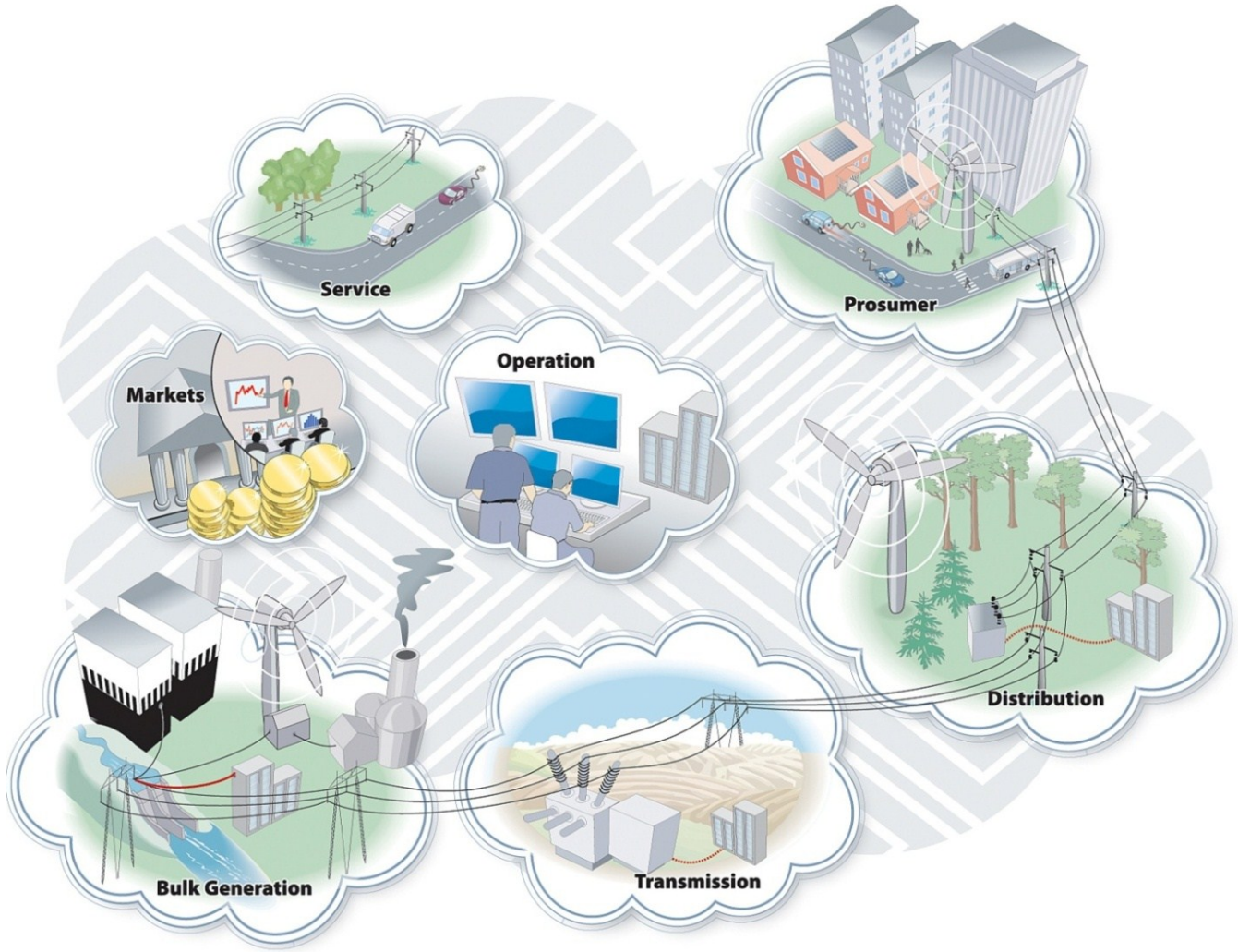
KTH Royal Institute of Technology, Sweden
E-mail: luigiv@kth.se, moustafa.chenine@ics.kth.se
Web: http://www.vanfretti.com

GRID PROTECTION ALLIANCE

Inaugural Grid Protection Alliance User's Forum

Atlanta, Georgia

September 6th, 2011



Elförsörjning – inget nytt under solen?

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Outline

- Lessons from history
- Smart Transmission Grids:
  - Why?
  - What?
  - How?
- From Vision to Implementation: The SmarTS Lab Concept
  - SmarTS Lab
  - openWAMS and KTH PowerIT
  - openPDC implementation
- Current and Future Projects
  - openPDC at SvK
  - Open and Soft PMU Projects
  - StrongGrid
  - iTesla
  - Real-Time State Estimation of Hybrid AC and DC Grids

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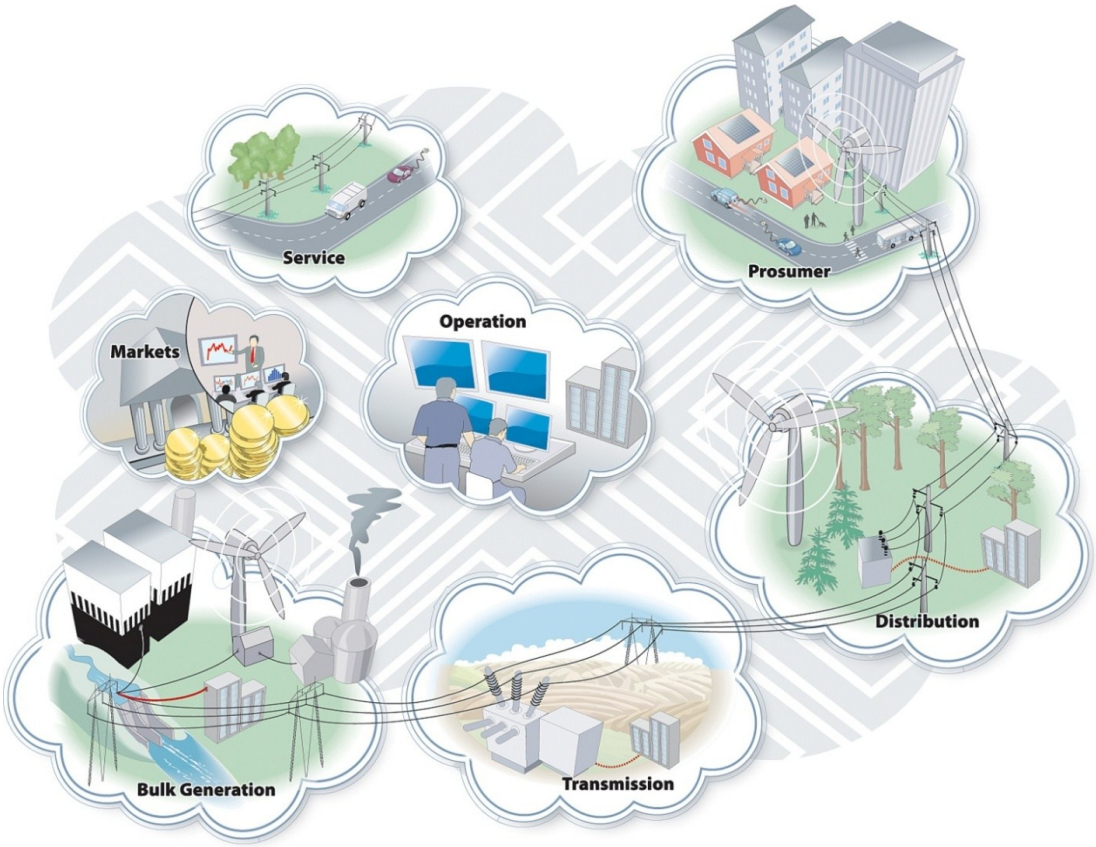
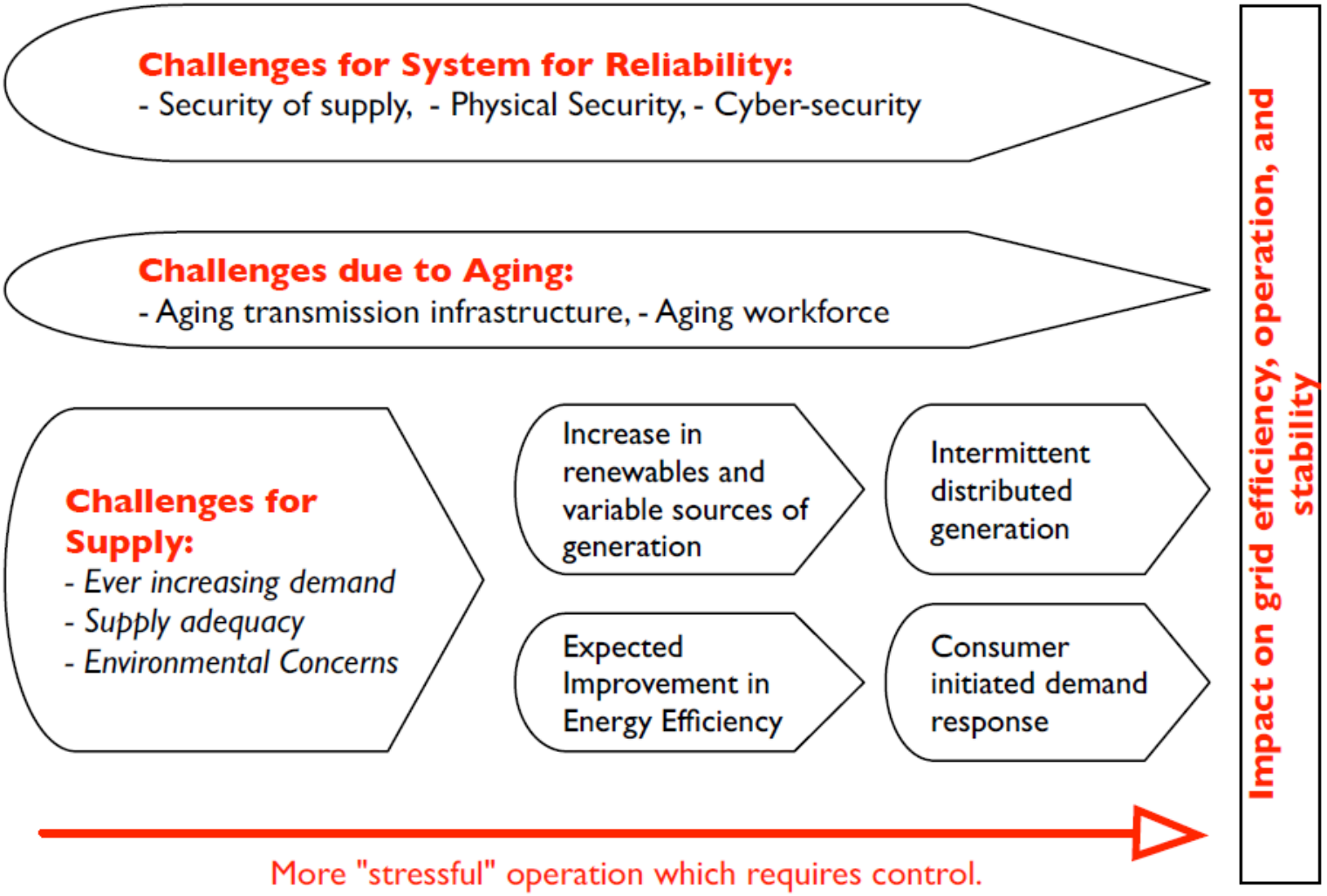


Smart Transmission Grids: Why?

Smart Transmission Grids – Why?



- All of these factors impact the grid's efficiency, operation, and stability
- More stressful operation requires control

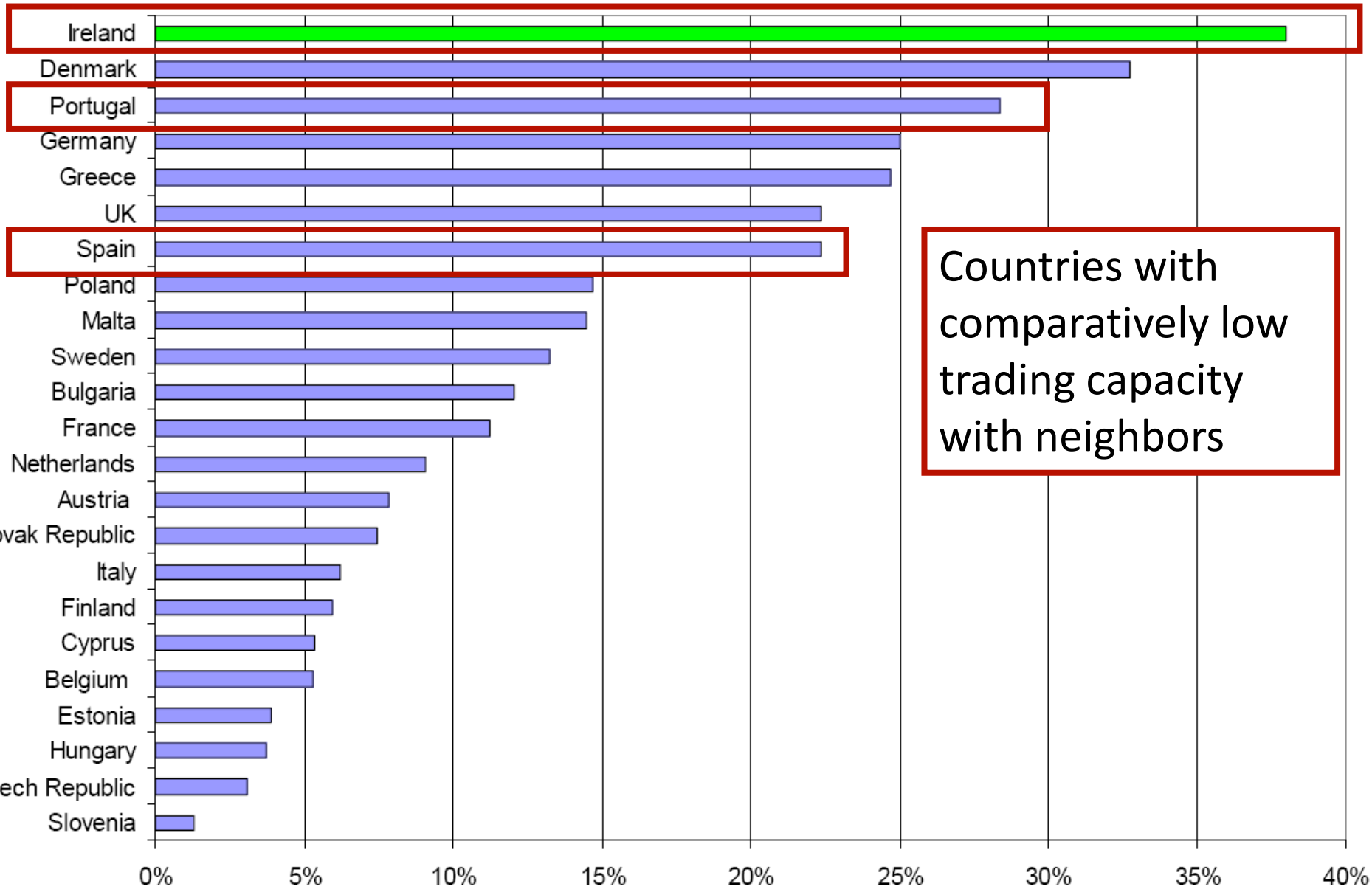
- Need to prevent the occurrence of high impact events.

The Challenges Today in Europe

- The broader perspective in Europe:
  - EU 2020 Targets.
- New types of generation – increased amount of uncertainties:
  - Large scale wind (already a reality in on-shore technology)
  - Large scale off-shore wind (North Sea)
  - Large scale PV (strong penetration in Germany, plans in Spain and North Africa)
- The progressive construction of a single European electricity market – increased amount of uncertainties:
  - Natural increase in power exchanges – increased interdependency
  - Much larger power transfers over long distances (off-shore wind)
  - Experience for 15 years of de-regulation: utilities are cost focused, projects driven by a business case, fewer engineers are managers
- The modernization of the transportation sector:
  - Large scale introduction of electric vehicles.
  - The market characteristic of this industry is forcing the conservative power industry to change.
- Increased Public awareness, and better connected consumers (for distribution)

The EU 2020 Challenge:

Wind as a Percentage of Total Electricity for Selected EU Countries



Meeting the Balancing Challenge: Wind Power and Transmission Capacities

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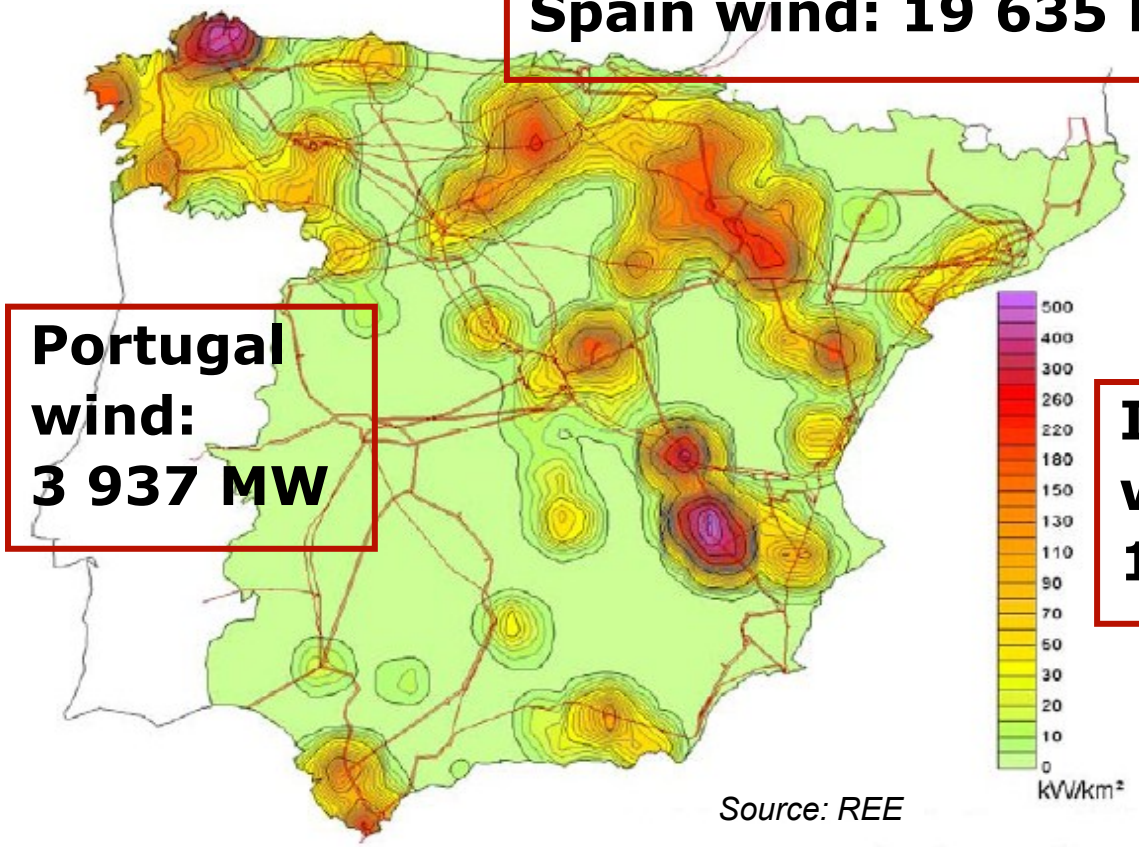
Spain wind: 19 635 MW

Portugal wind: 3 937 MW



Source: REE

Ireland wind: 1539 MW

	Wind Energy 2010
Sp	16 %
Po	17 %
Ir	13 %

	Wind max share
Sp	54 %
Po	81 %
Ir	52 %

Transmission Capacity:

- Portugal –Spain: 1200 MW
- Spain – France: 1200 MW
- Spain – Morocco: 650 MW

Transmission Capacity:

- Ireland - Scottland: 450 MW
- Planned: +850 MW

The challenges seen from the Electric Power Transmission Perspective

- On the market side - February 2011:
  - Central Western Europe market coupling process saw a drastic reduction of cross-border capacities
  - Red Flag had to be implemented to ensure security
  - Curtailment of allocated firm capacities
  - Clear sign of the effect of power system security on market efficiency.
- On the technical side – February 2011:
  - Poorly damped inter area oscillations between Italy and the rest of the European system. Oscillations resulted in power swigs of 25 MW in the North-South corridor lines through Switzerland with large frequency oscillations
  - Power system in central Europe is becoming stability-constraint: in the Nordel region this is already a reality.
  - Big challenge considering the desired expansion of the Pan European Power System.

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swissgrid

Current Date/Time **23.05.2011 14:44:43**
Sample Date/Time **23.05.2011 14:44:22**
This page is dynamically updated.

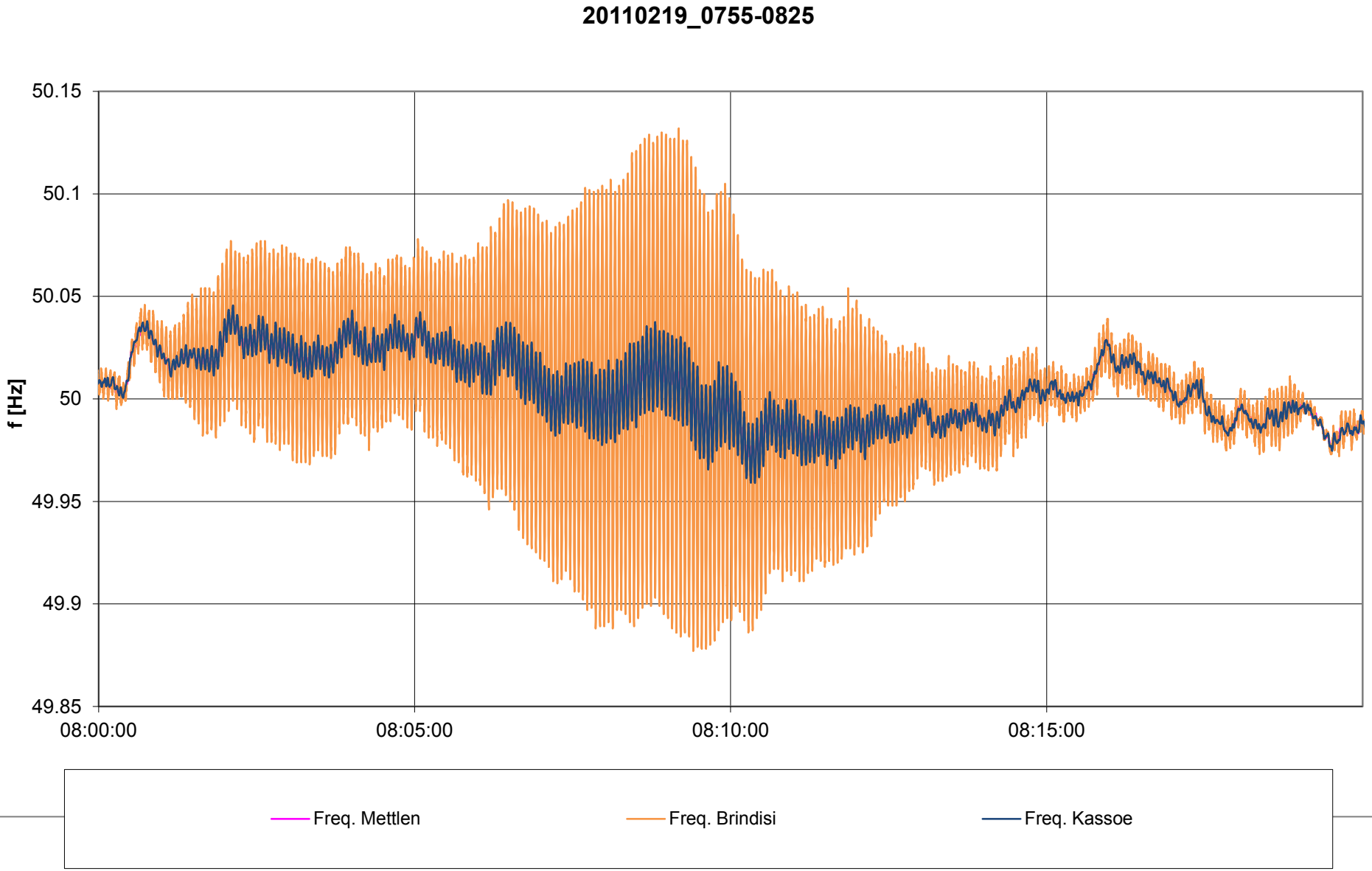
WAM Overview

The following picture gives an overview over the current situation of the UCTE network in respect to the frequency.

Frequency set point	49.990 [Hz]
Current Frequency	49.993 [Hz]
Current Frequency Deviation	0.003 [Hz]

Courtesy of Walter Sattinger

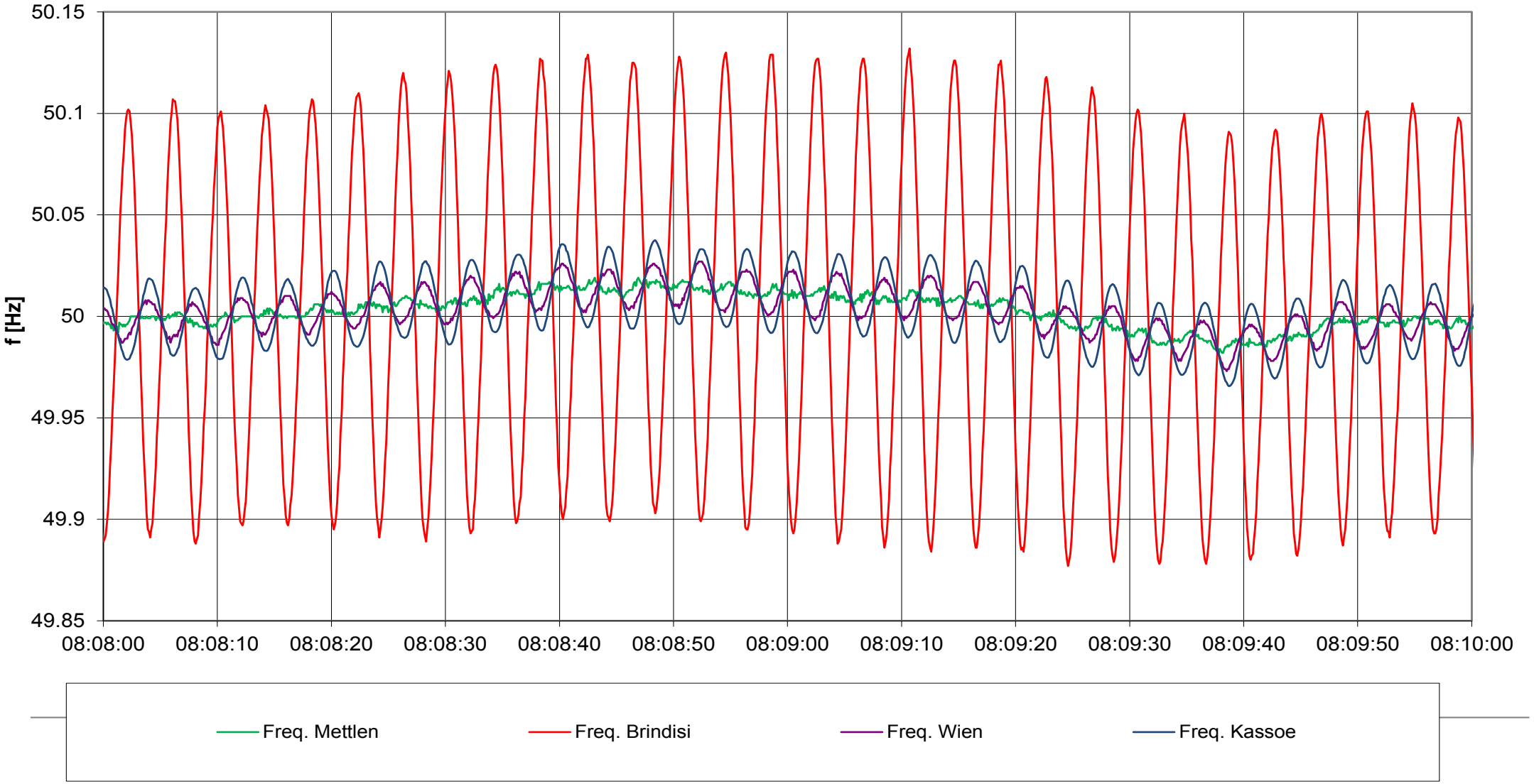
February 19th 2011 – North-South Inter-Area Oscillation



Courtesy of Walter Sattinger

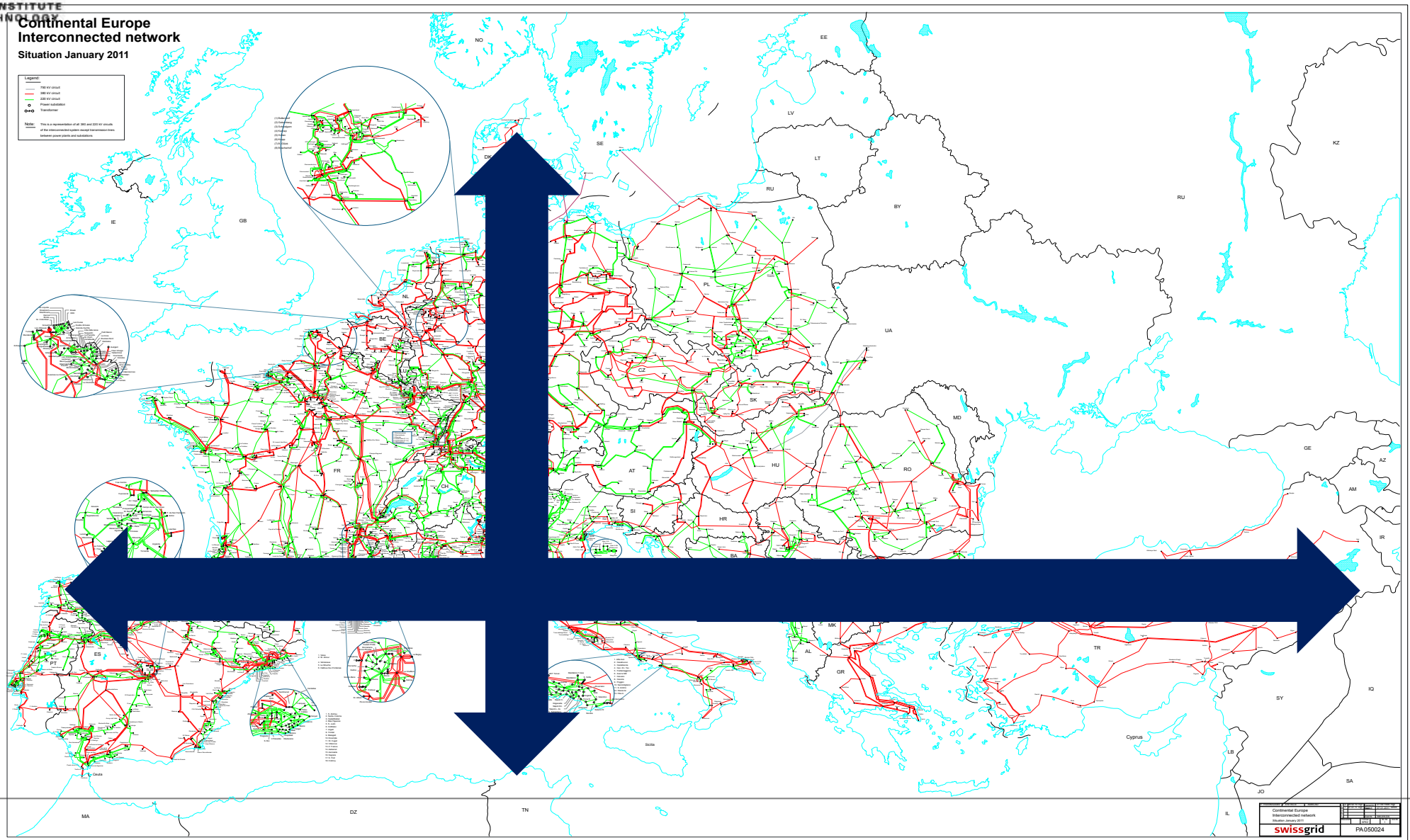
February 19th 2011, Frequencies

20110219_0755-0825 **Courtesy of Walter Sattinger**



Main Oscillation Axis

Courtesy of Walter Sattinger



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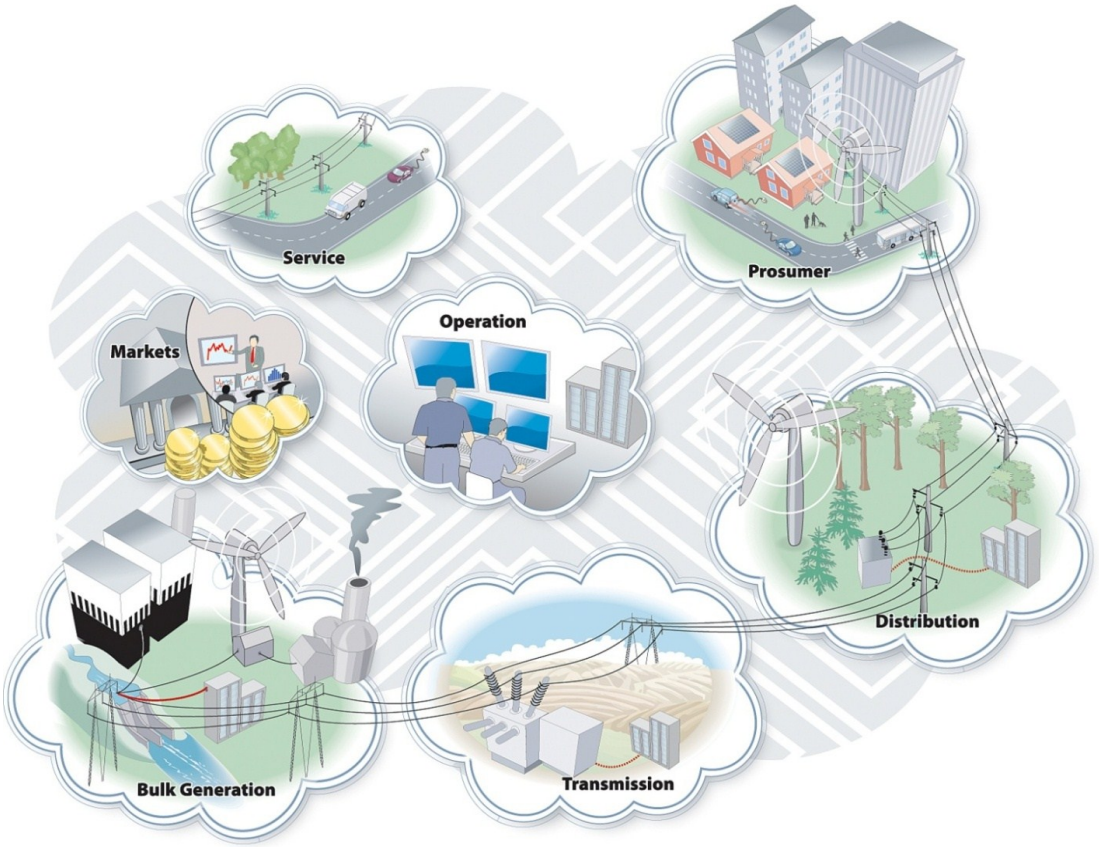


Smart Transmission Grids: What?

Smartgrids European Technology Platform

SMARTGRIDS

EUROPEAN TECHNOLOGY PLATFORM FOR THE ELECTRICITY NETWORKS OF THE FUTURE

- http://www.smartgrids.eu/
- Definition:
  - A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies
- Key Research Areas in its Strategic Agenda:
  - **New architectures and new tools for operation, planning and control of power systems**
  - Long distance energy supply
  - **European interoperability of smart grids**
  - **Information and communication**

Smart Grid Solutions
Functional level

Level 5: Smart Customers

Customers aware and actively participating

Level 4: Smart Energy Management

Management of end-use energy efficiency, aggregation, retail

Level 3: Smart Integration

Renewable energy, DG, electric vehicles, electricity storage and aggregation

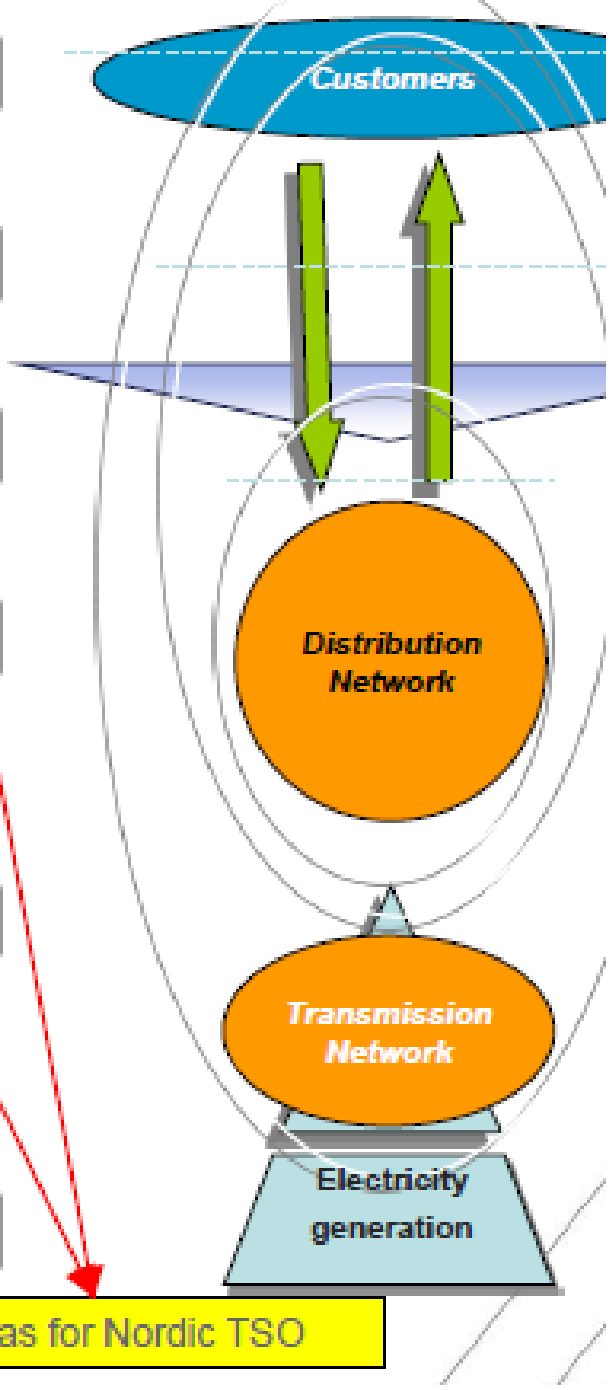
Level 2: Smart network and processes

More automated MV distribution networks with self healing capabilities.
Monitored and controlled LV networks
IT supported monitoring process

Level 1: Smart Transmission network

Innovative transmission grid architectures
State-of-the-art transmission/power technologies
Novel monitoring, control and storage methodologies
Shared electricity market simulators

Level 0: New generation technologies



European Electric Grids Initiative (EEGI)

Functional layers demand increased coordination between TSOs and DSOs

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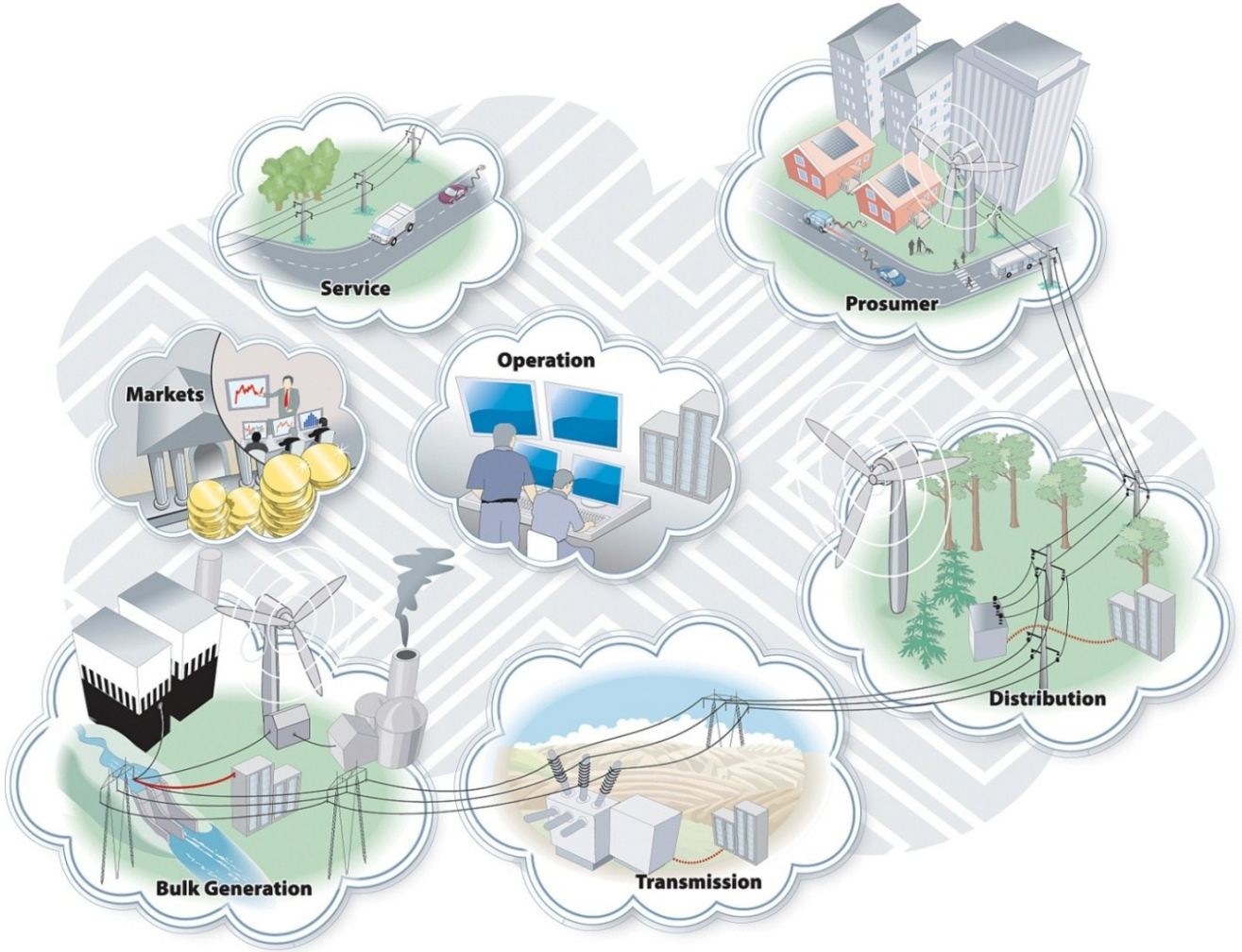
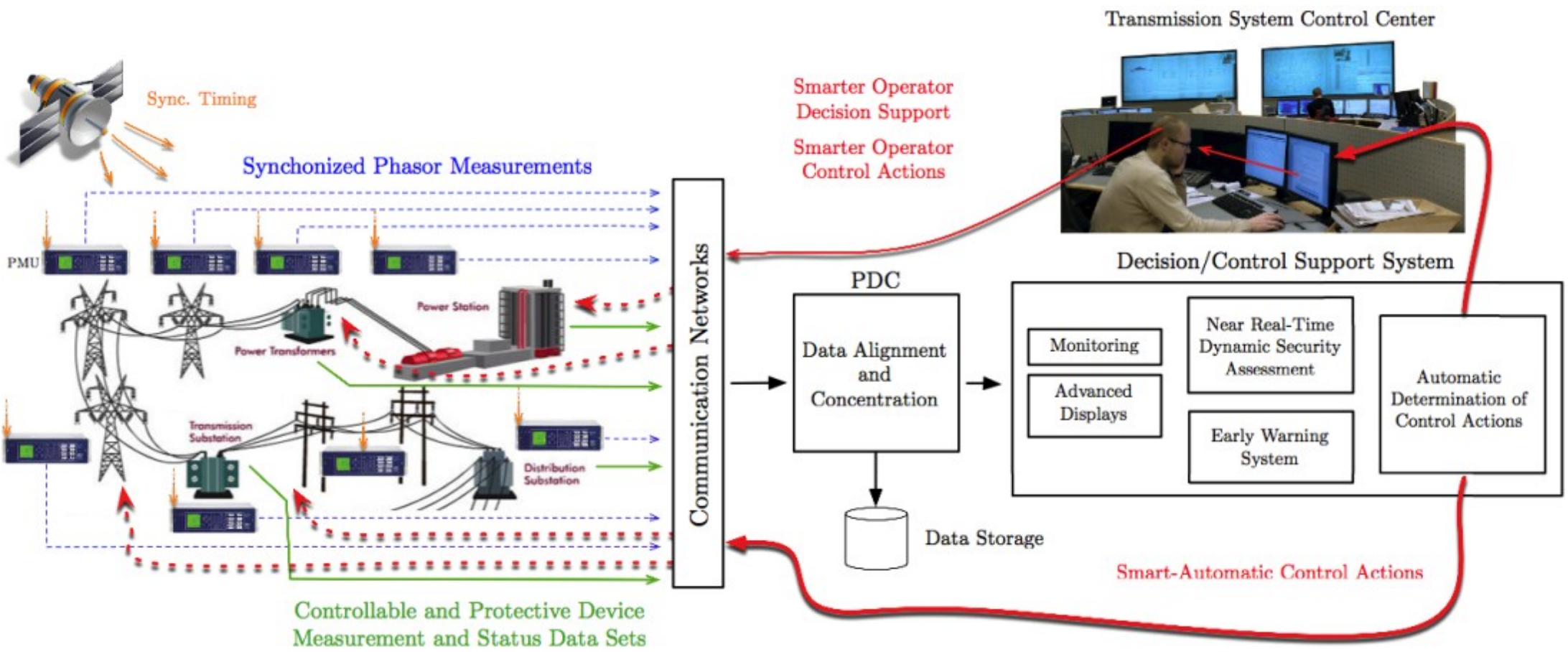


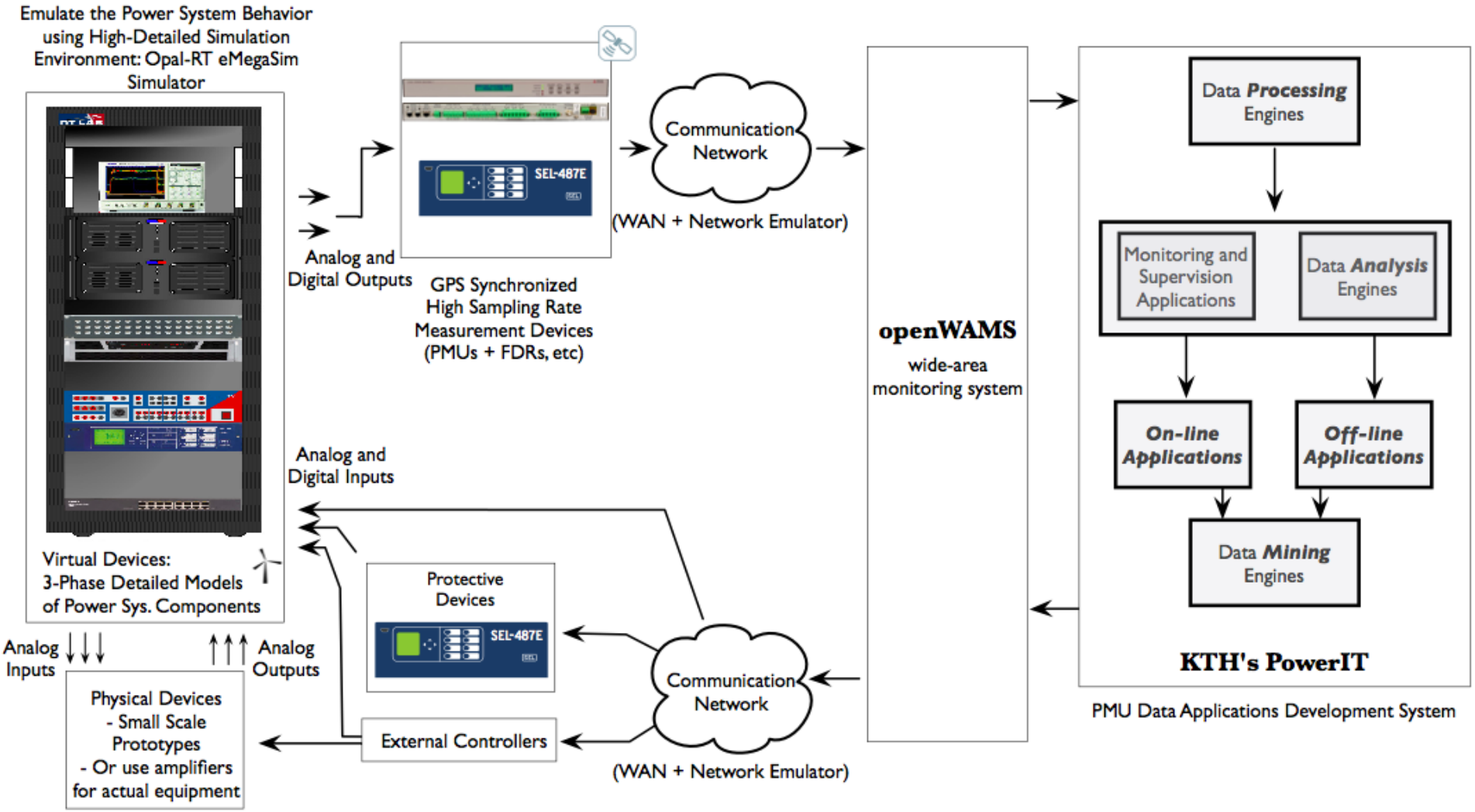
Smart Transmission Grids: How?



Smart Tramission Grids – How?

- Smart Grid require **Smart Operation and Control**: The ultimate goal should be to attain an automatic-feedback self-healing control system
- Measure – Communicate – Analyze (System Assessment and *real* limits) – Determine Preventive/Corrective Actions – Communicate – Control and protect
- **Build a controlled environment for development and testing of PMU applications considering all ICT and practical limitations.**

The SmarTS Lab Concept



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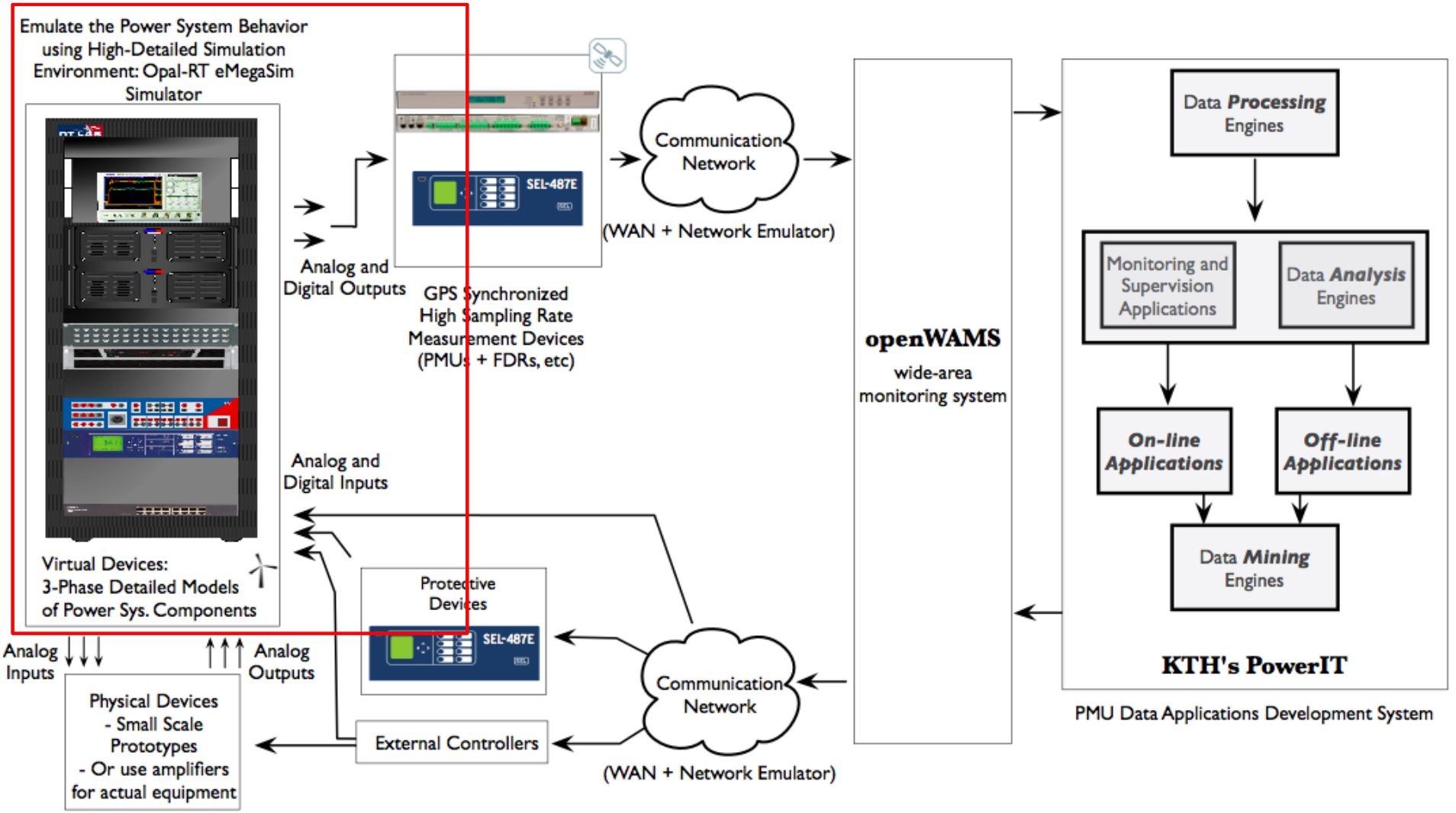
The SmarTS Lab Concept



An experimental research platform:

SmarTS Lab
Smart Transmission Systems Laboratory

SmarTS Lab RT Facility

Real-Time Simulator, Measurement/Protection Devices, ETC

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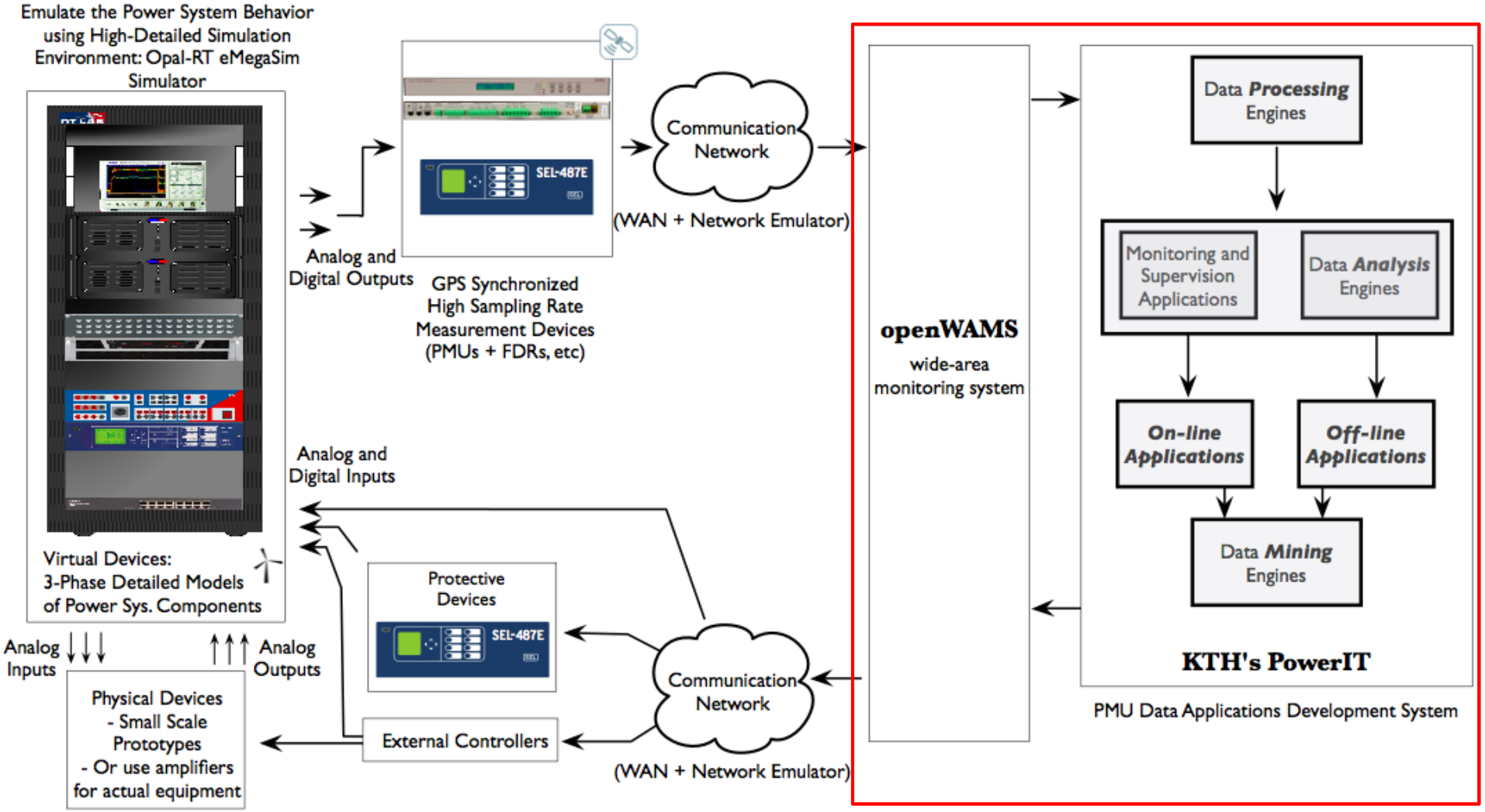
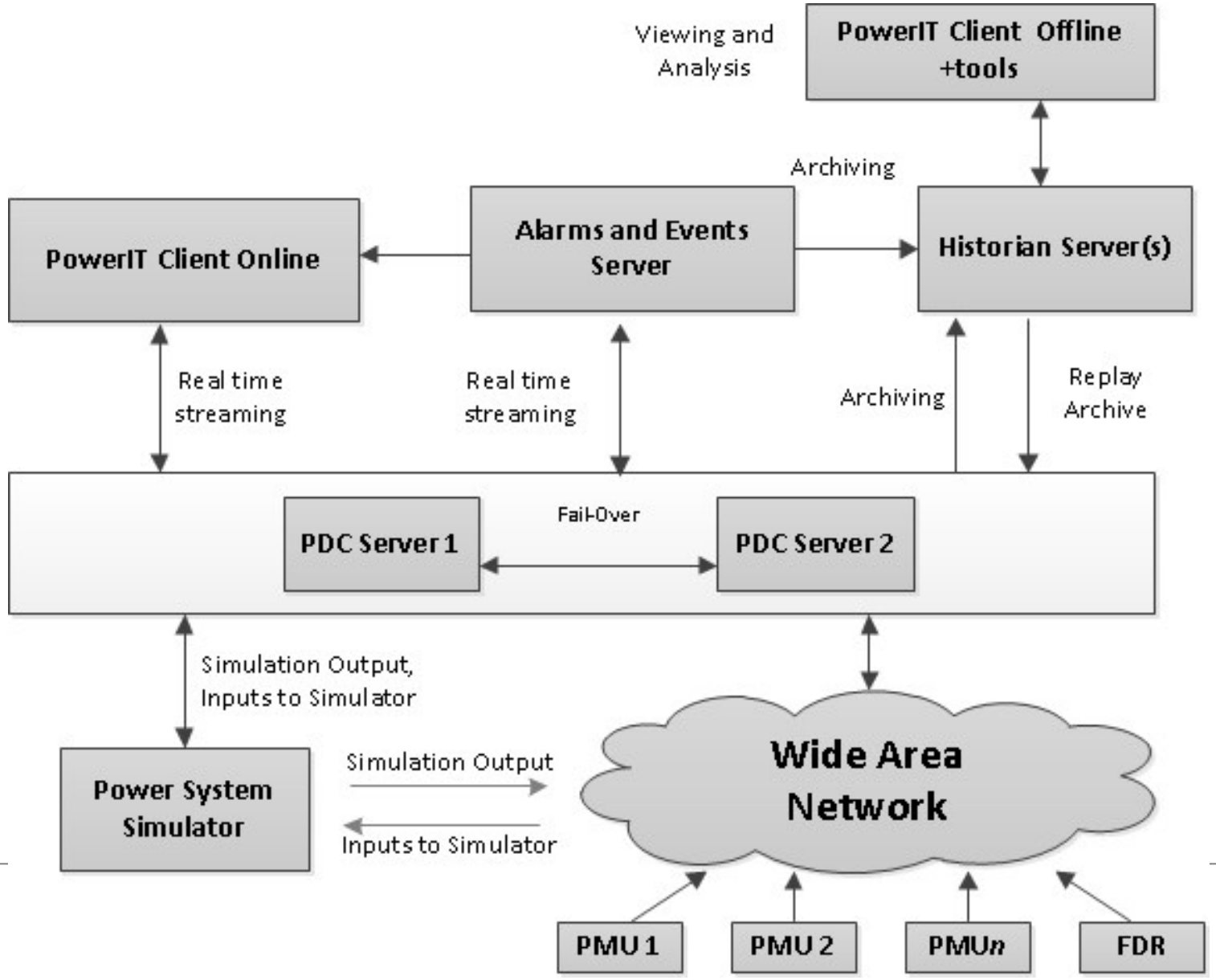
The SmarTS Lab Concept



openWAMS – A Wide-Area Systems Platform

- KTH's implementation of a WAMS/WACS Platform
- Integrating and utilizing several Open Source Software technologies, and developing others
- Vision: a fully fledged WAMS/WACS system (Including SCADA/EMS Integration)
- Component's of openWAMS:
  - Grid Protection Alliance's openPDC
  - Grid Protection Alliance's openHistorian
  - KTH's Power IT Platform

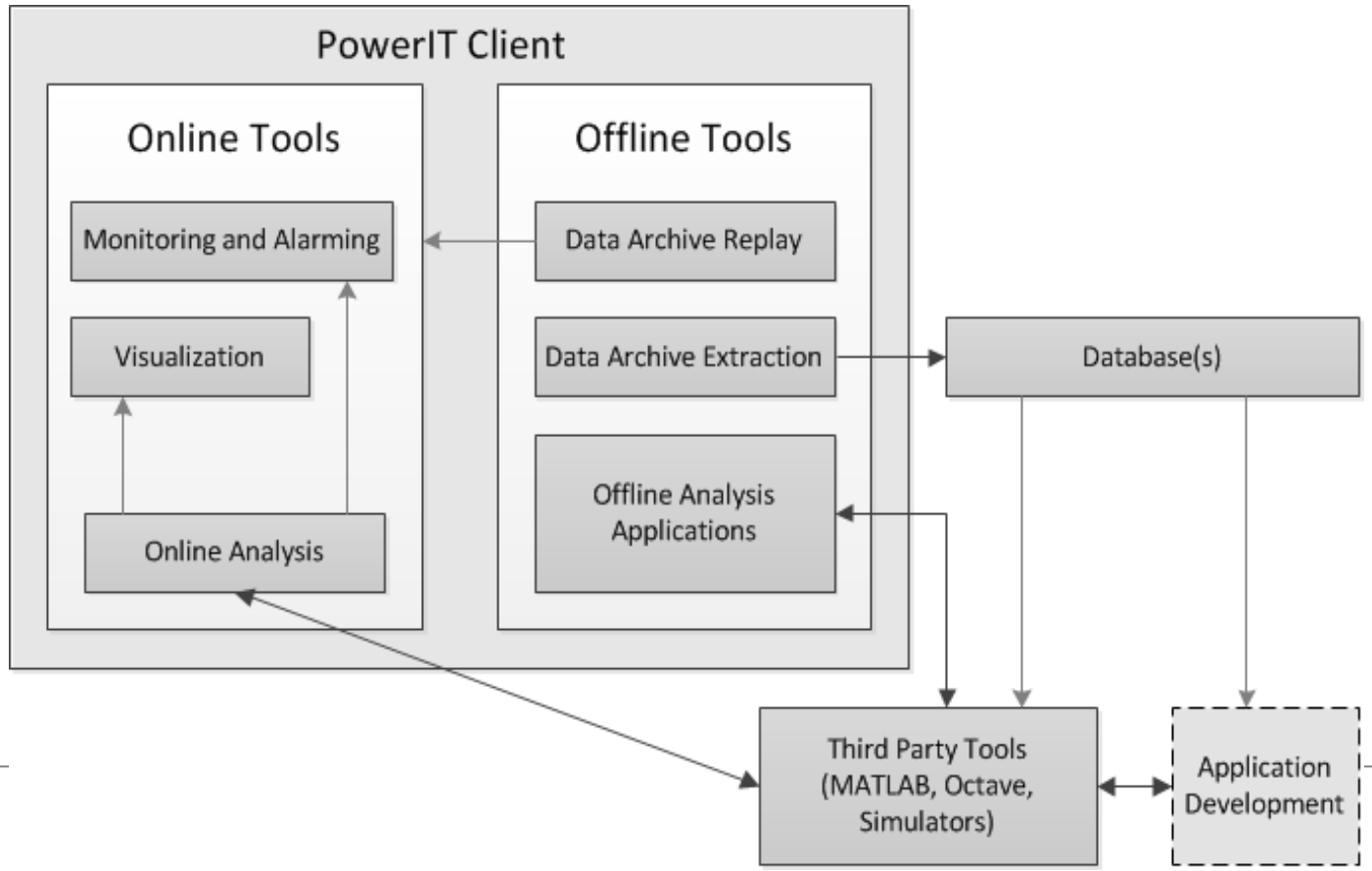
What is the KTH openWAMs Platform?



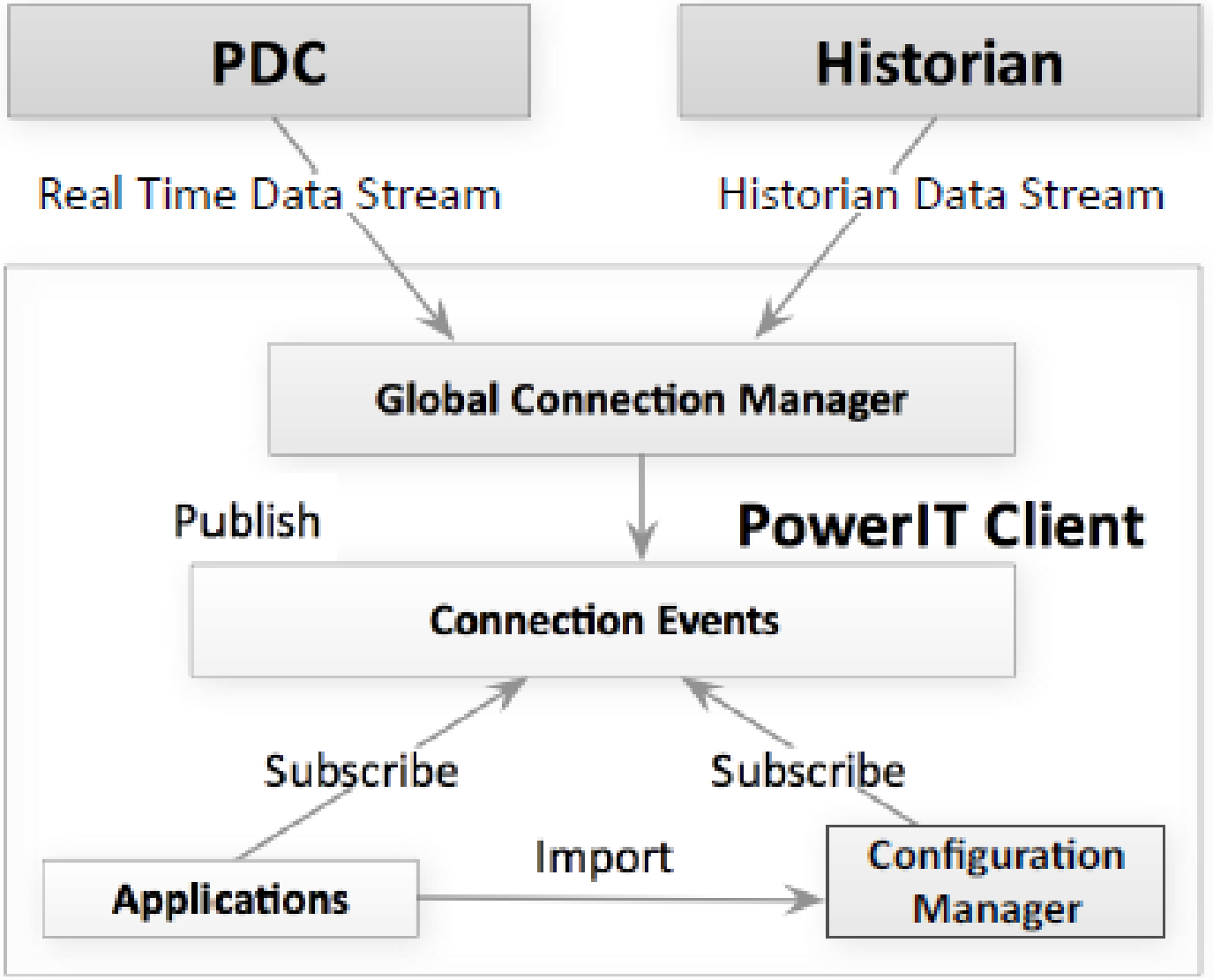
KTH PowerIT ©

Developed at KTH cooperation between ICS and EPS.

Objective is to eventually become a fully fledged WAMC/WACs HMI and Analysis platform



PowerIT Architecture Overview



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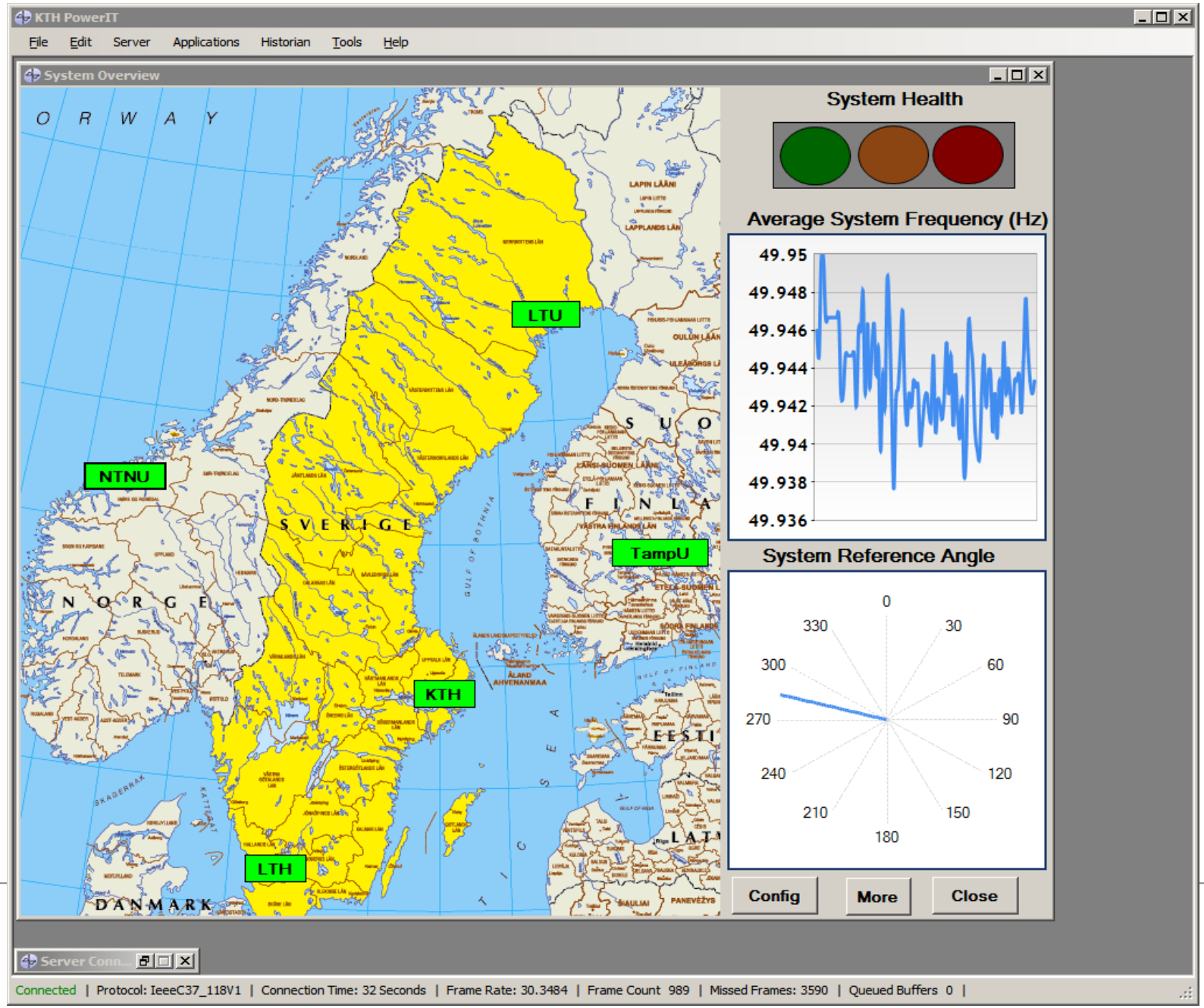
Online Applications

- System Overview
- On-Line Frequency Monitoring
- On-Line Mode Estimation

Power IT- System Overview Screen



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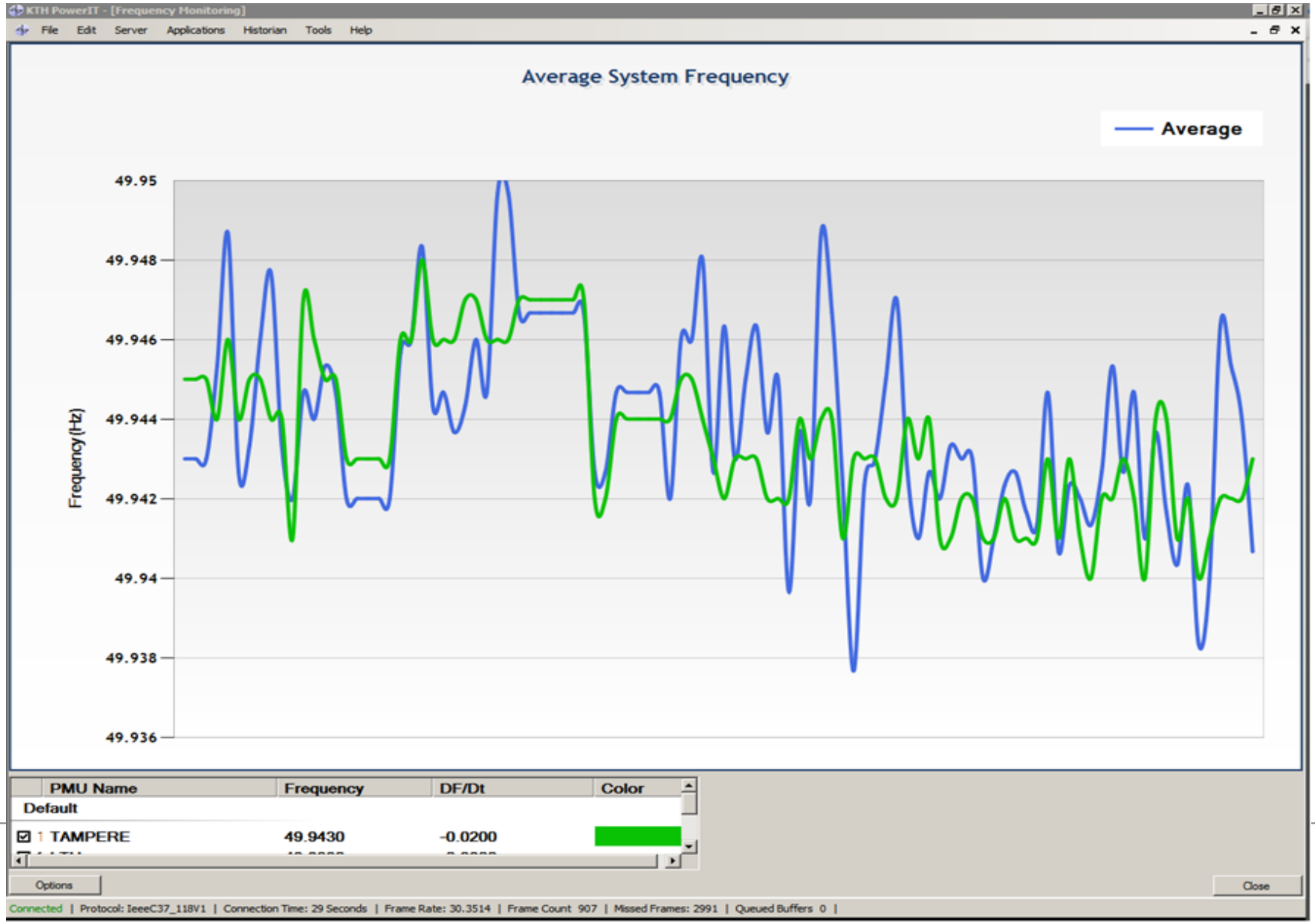
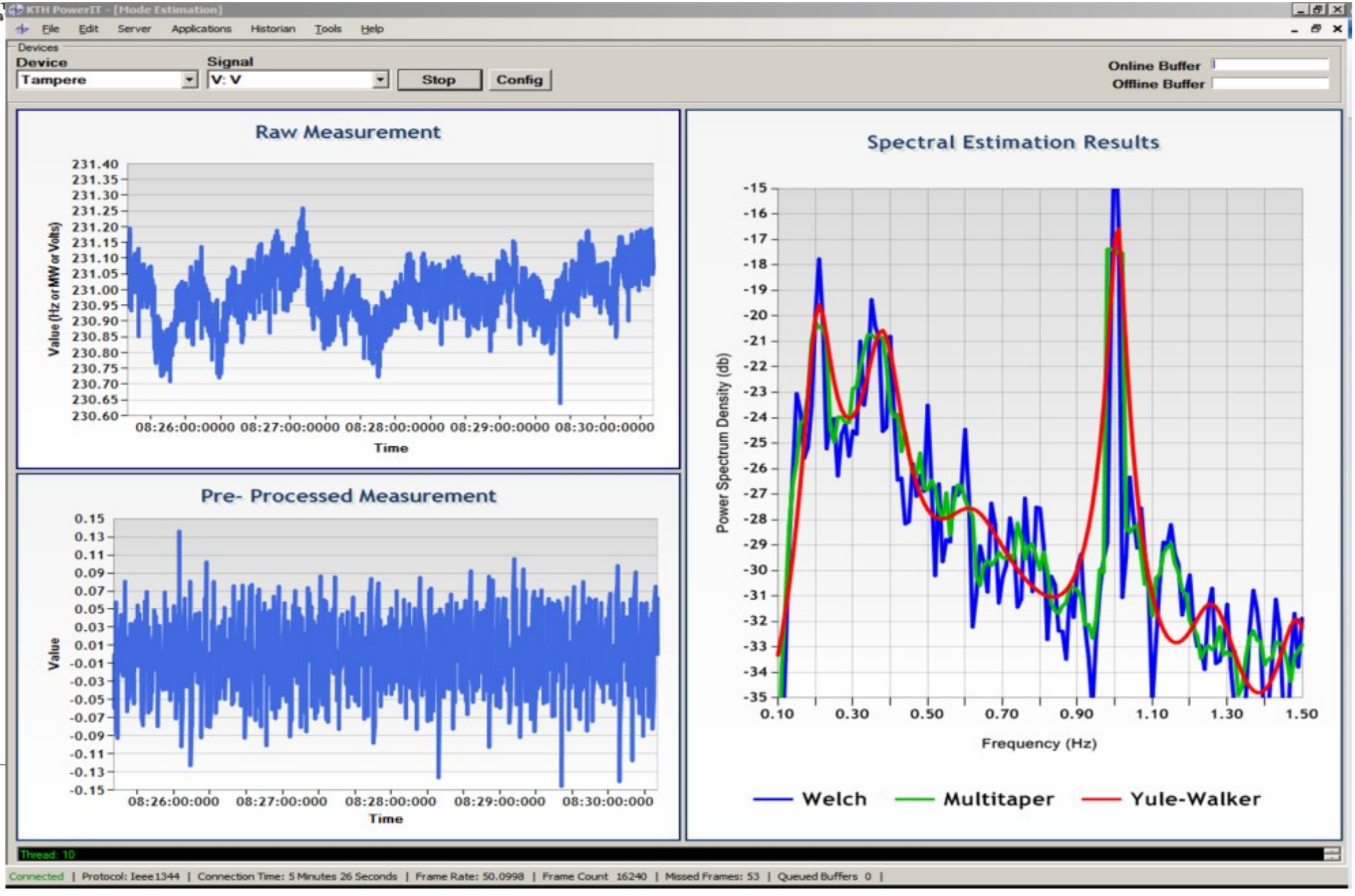
On-line Frequency Monitoring

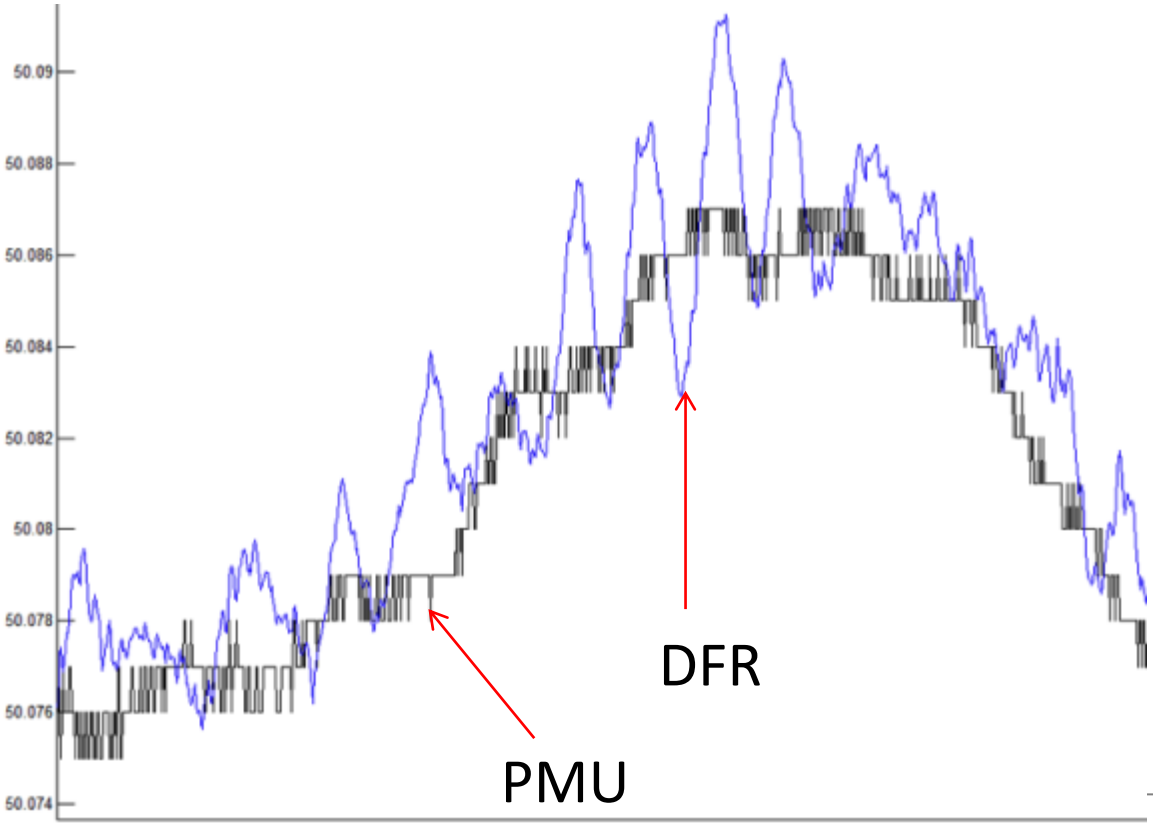


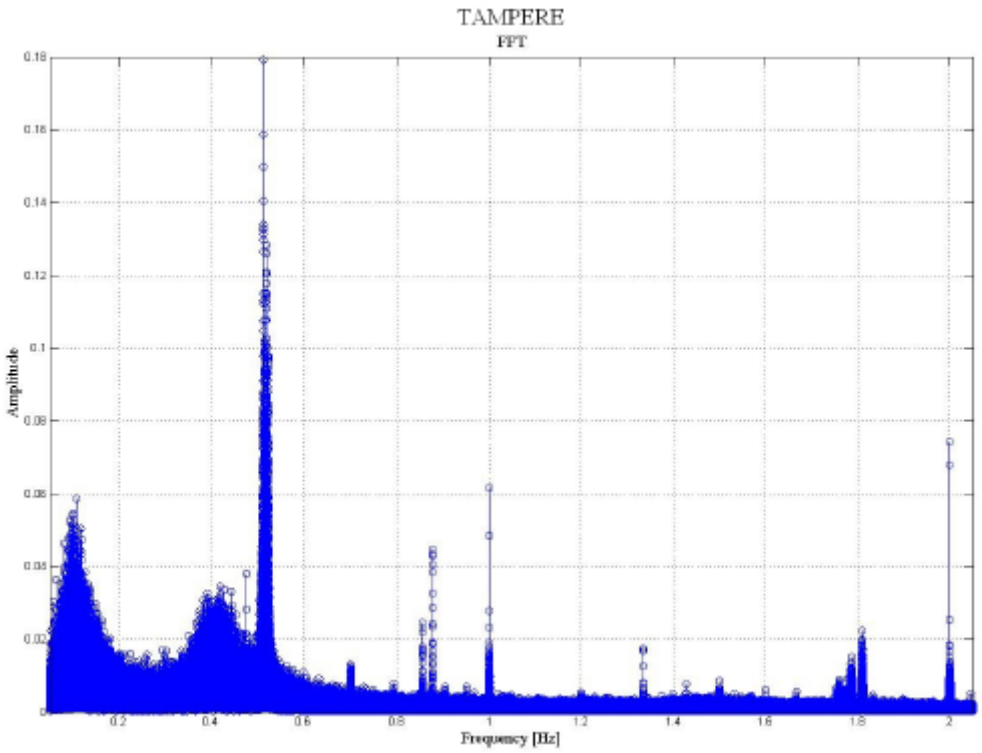
On-Line Mode Estimation



Challenges for On-line mode damping estimation in the Nordic Grid

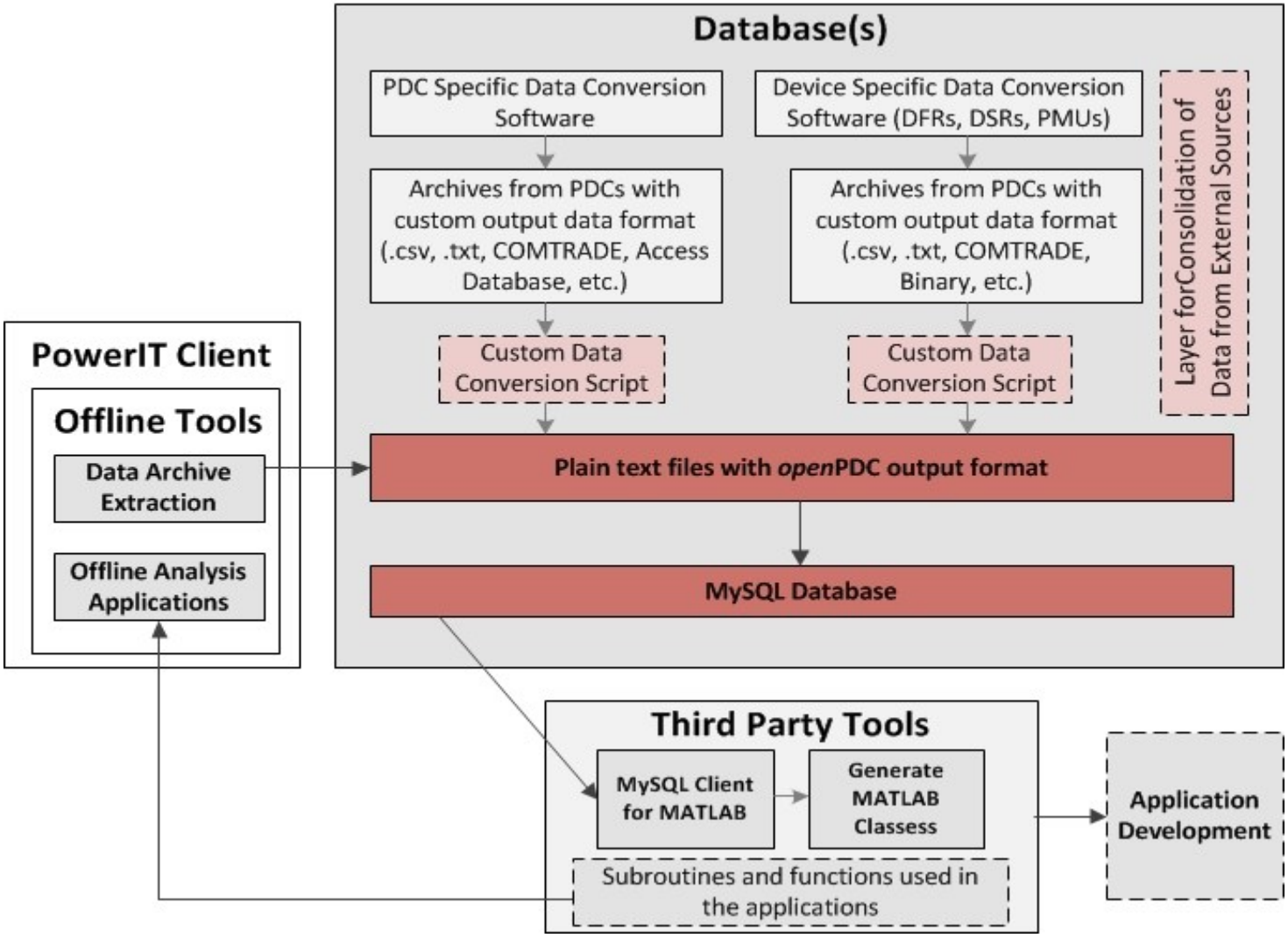
- Poor data quality from PMUs
- Unique features in the signals – forced oscillations, which affect damping estimates





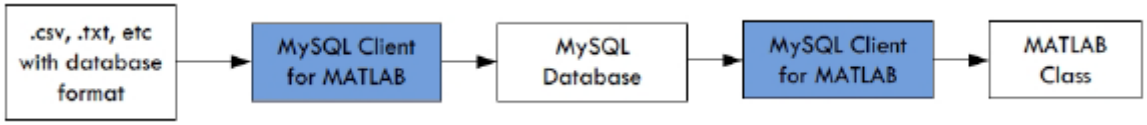
Off-line Applications Facilities

- Integrated apps added:
  - Historian Playback \ Extraction
  - Historian Viewer.



Off-line tool for data analysis

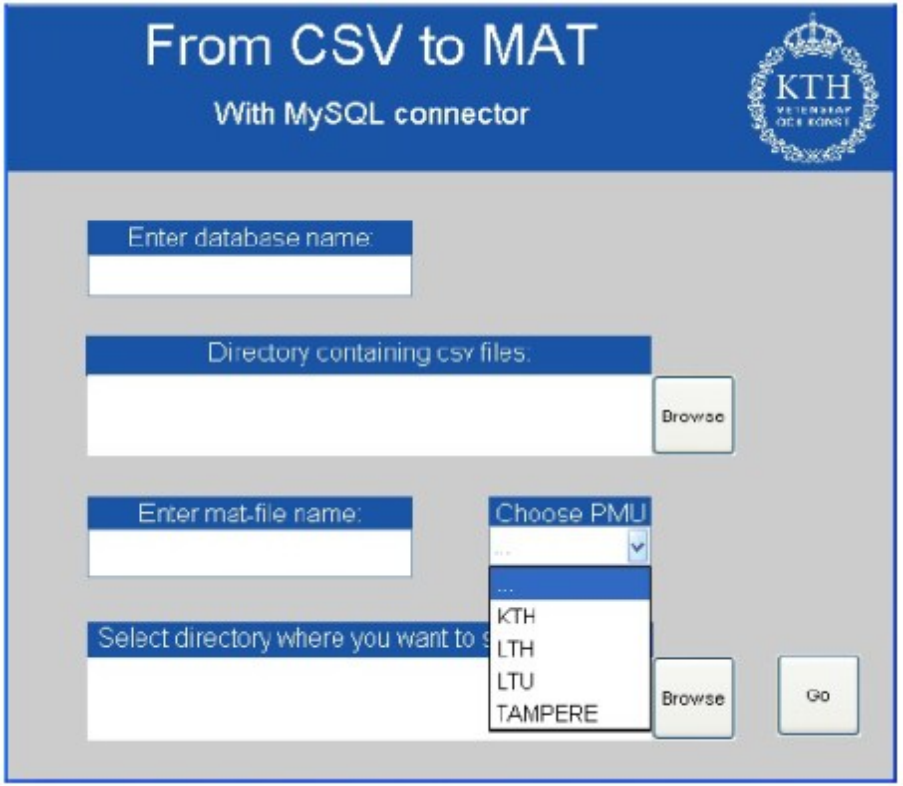
openPDC GRID PROTECTION ALLIANCE



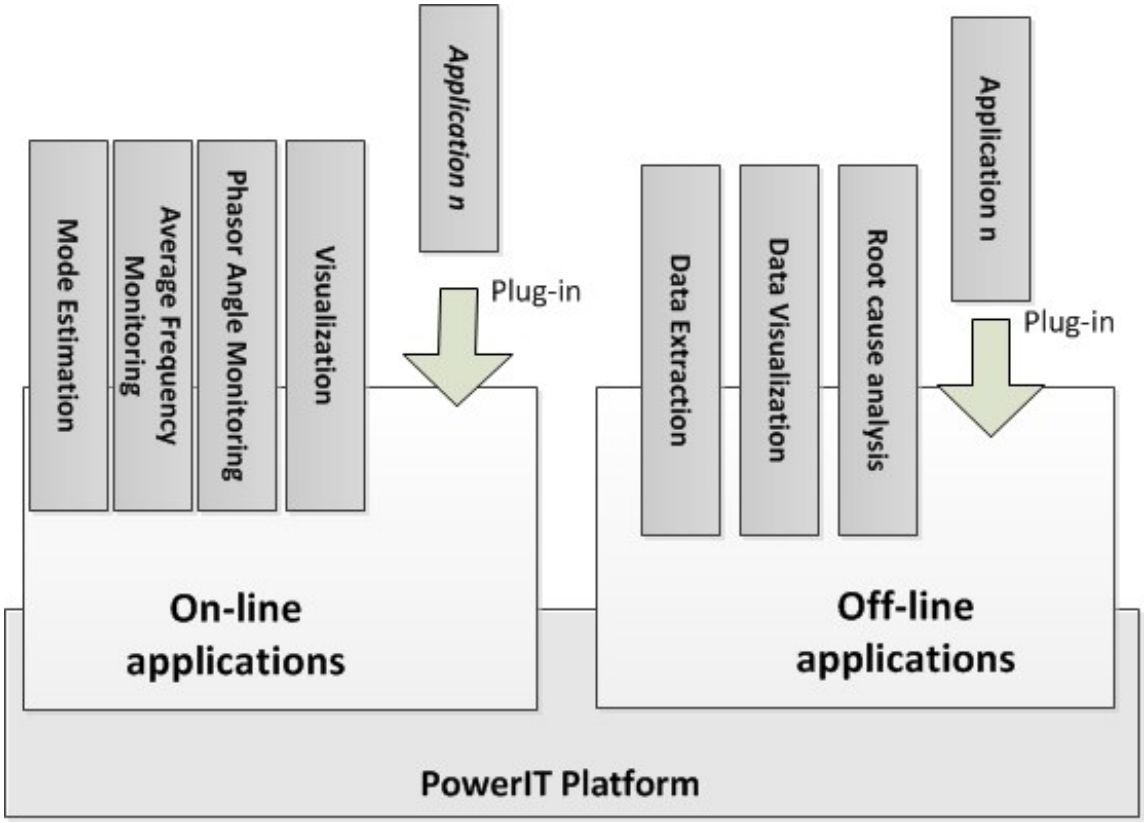
Historian
Playback Utility

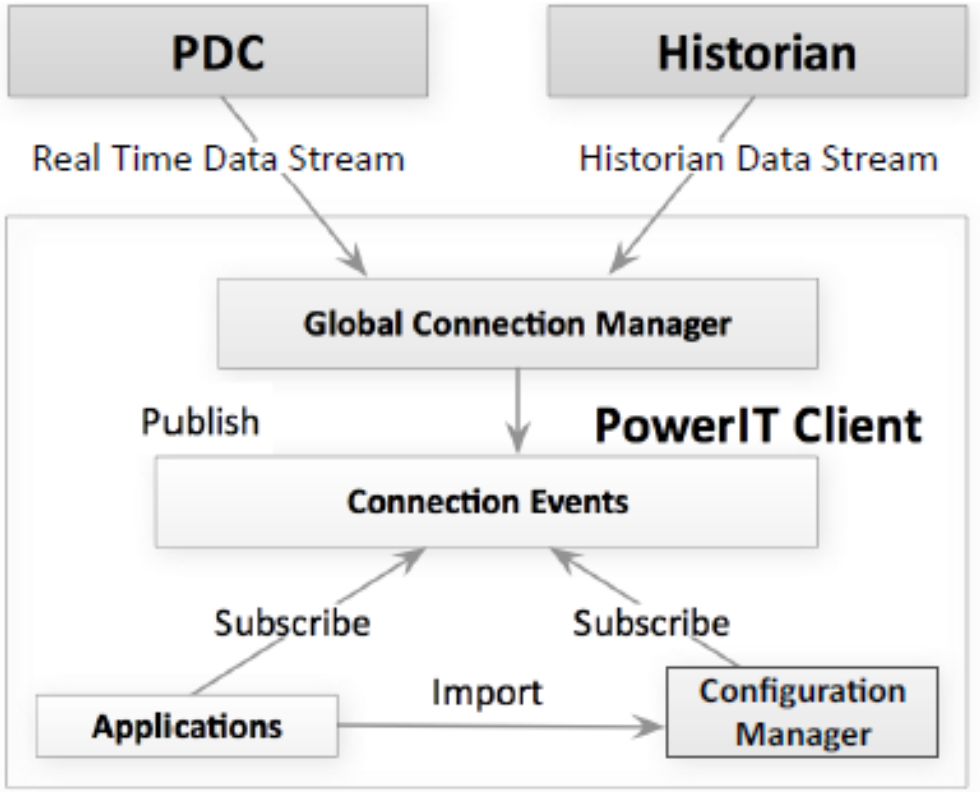
- Need to use data for mode estimation analysis
- Developed a process using MySQL, a MySQL client for MATLAB
- Process automated with a GUI

- Data has to be extracted using HPU and dumped into .csv files



PowerIT© Architectural Vision





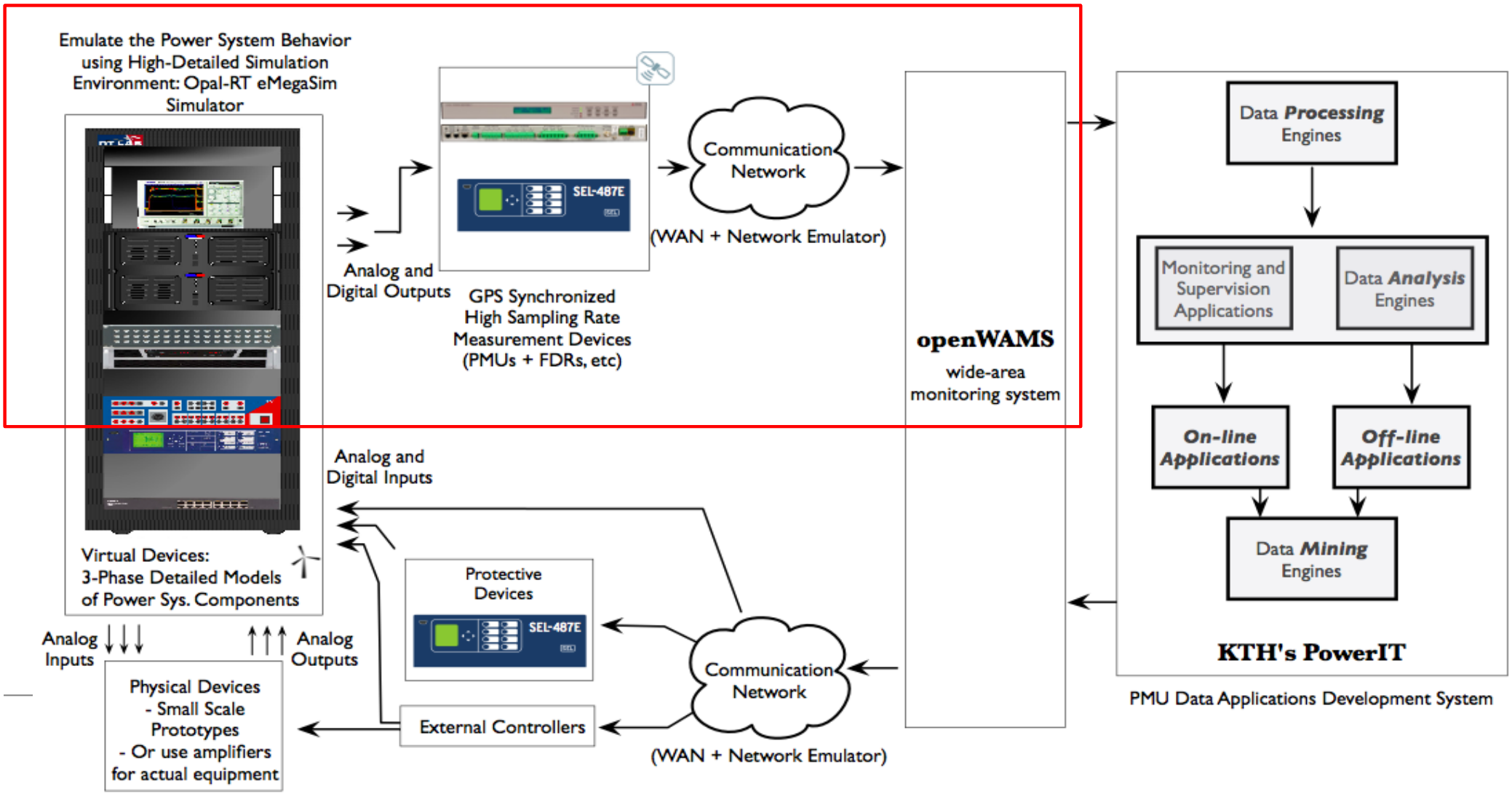
Department Industrial Information and Control Systems,
School of Electrical Engineering.
KTH, Royal Institute of Technology

Visions and goals of openWAMS and PowerIT- recap

- Provide a platform for:
  - Development of next generation monitoring, control and analysis tools and application/algorithims for power system management.
  - Testing of WAMC/WACs tools and applications
  - ICT nonfunctional quality analysis
    - Architecture contriants
      - Performance, Reliabilitiy, Cyber Security
    - Application requirements

Proof of Concept Experiment

Test the open-loop data measurement, transmission and collection stream



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Our Experiment

Real-Time Simulator

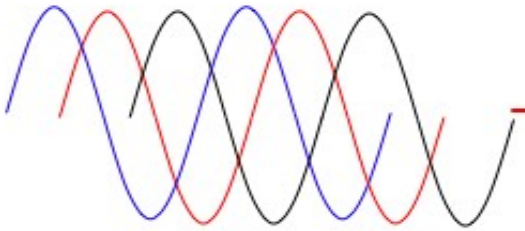
Generate 3-Phase Real-Time Signals
(Voltages and Currents)

Phasor Measurement Unit

Measure the Real-Time Signals,
Compute Phasors and
Time Stamp them with GPS Clock

Phasor Data Concentrator

Time-Align, Concentrate,
and Store Data

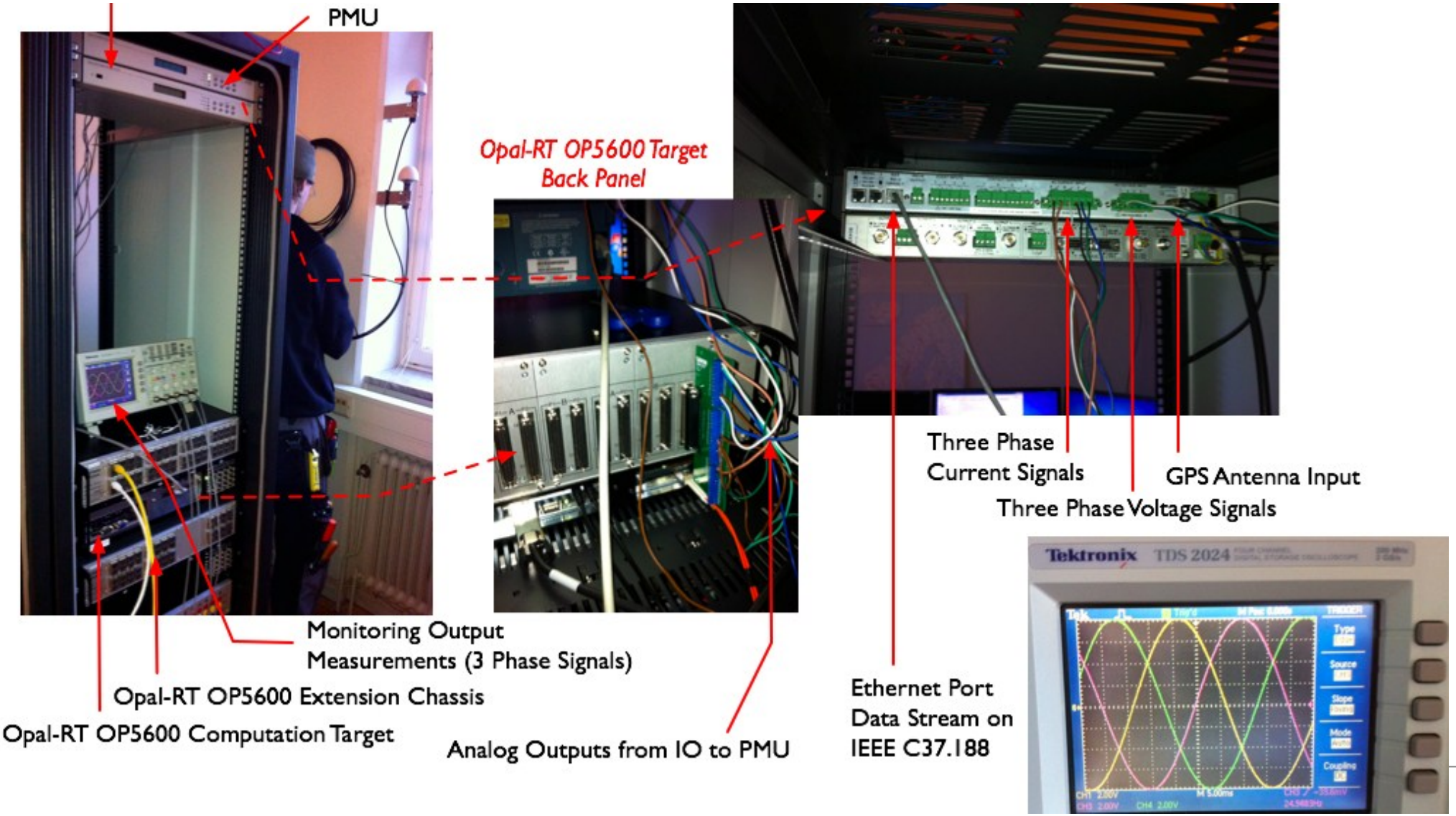


openPDC
GRID PROTECTION ALLIANCE

Simulator outputs signals into
+/- 16 V, and 0.2 A physical signals
Through Simulator's IOs

PMU Transmits Computed
Phasors (and for this unit)
3-Phase Measured Values
Through Ethernet using TCP/IP

Proof of Concept Experiment: Hardware Set Up



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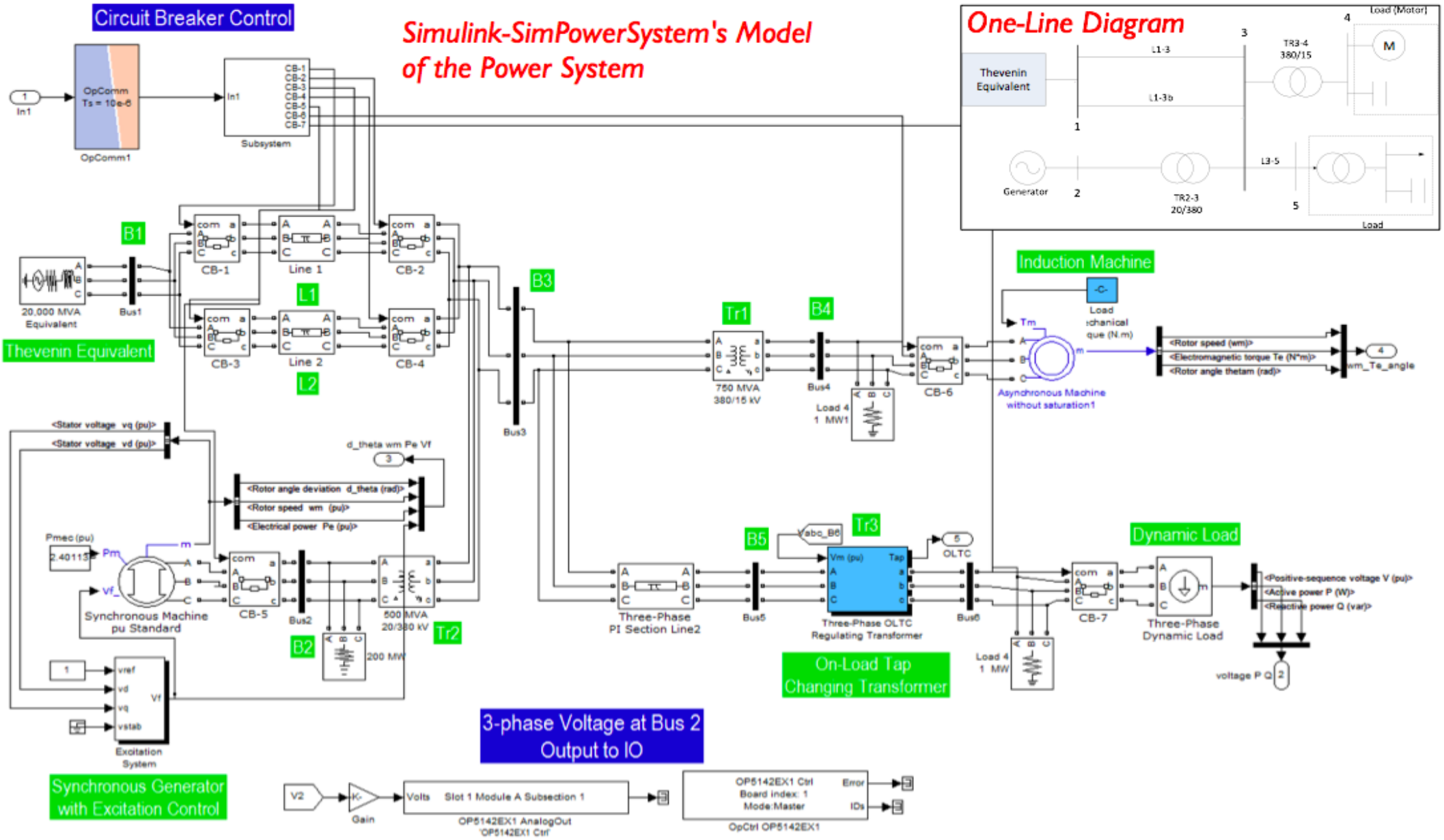
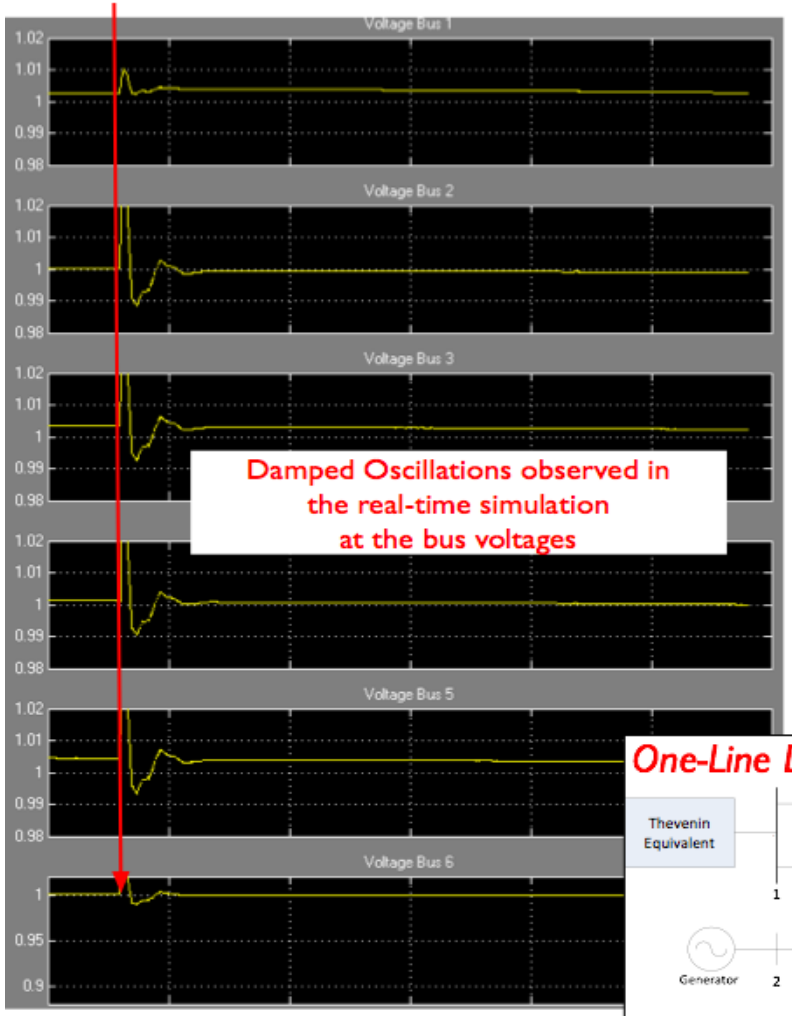
Proof of Concept Experiment: Real-Time Model of a Power System



Proof of Concept Experiment: The whole process, on real-time

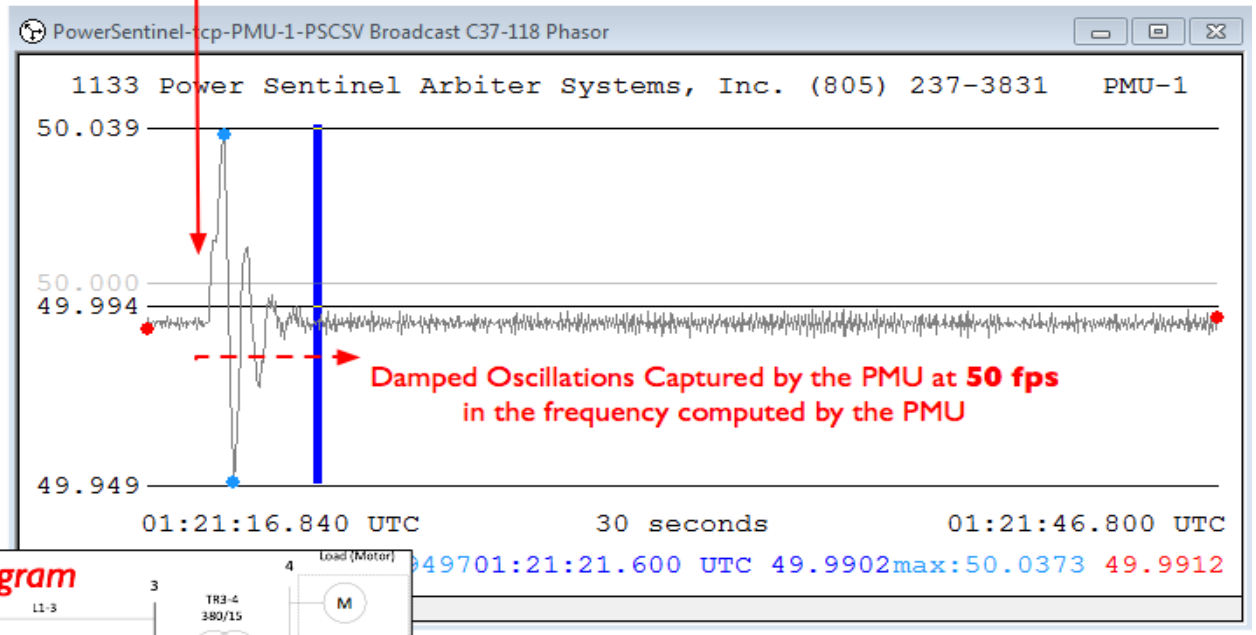
Real-Time Execution, 3-phase Analog Signal Output, and Data Transmission

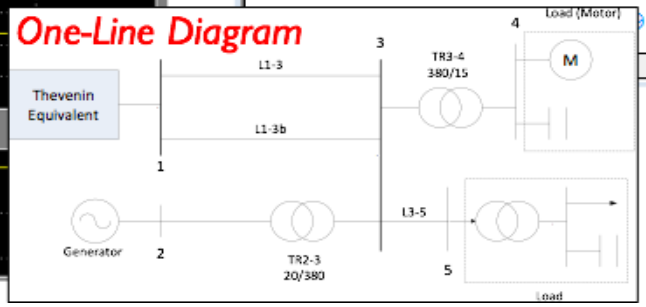
Generator Mechanical Power Perturbation



What is observed at the PMU at 50 fps reporting rate?

Generator Mechanical Power Perturbation





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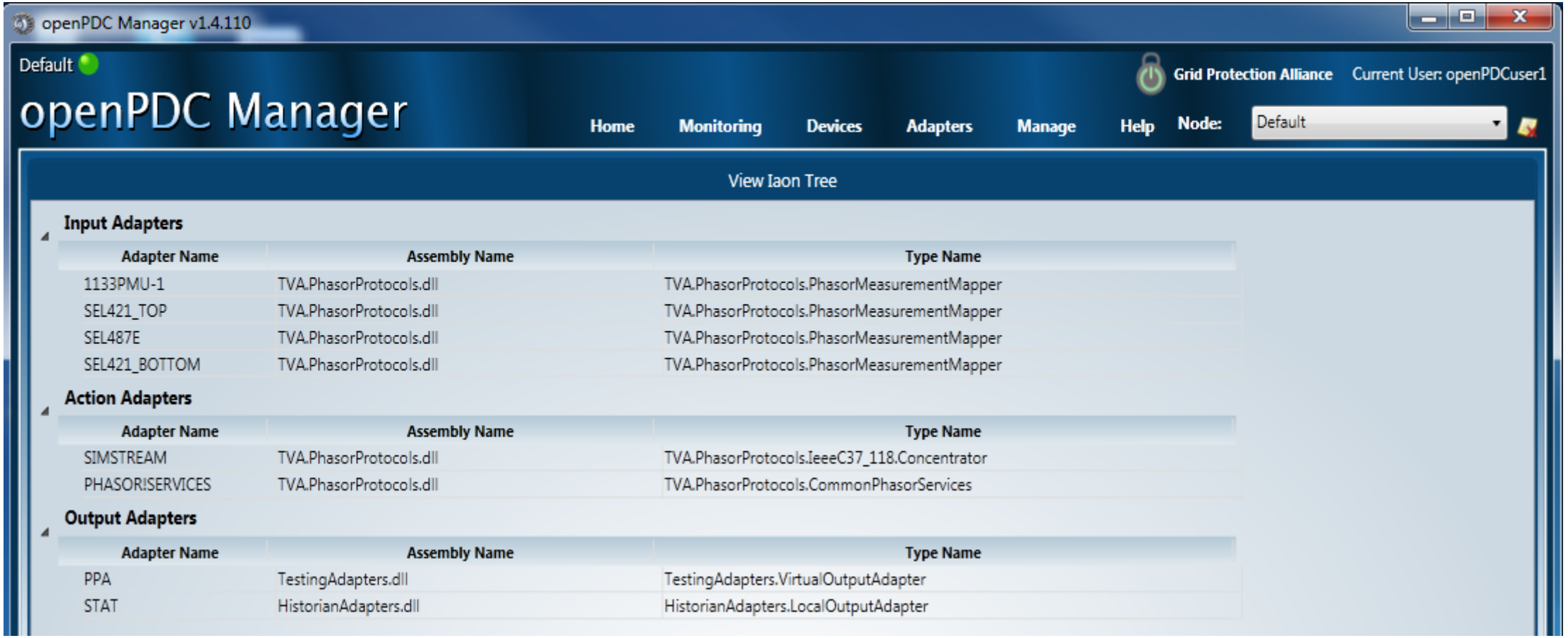
openPDC implementation in SmarTS Lab



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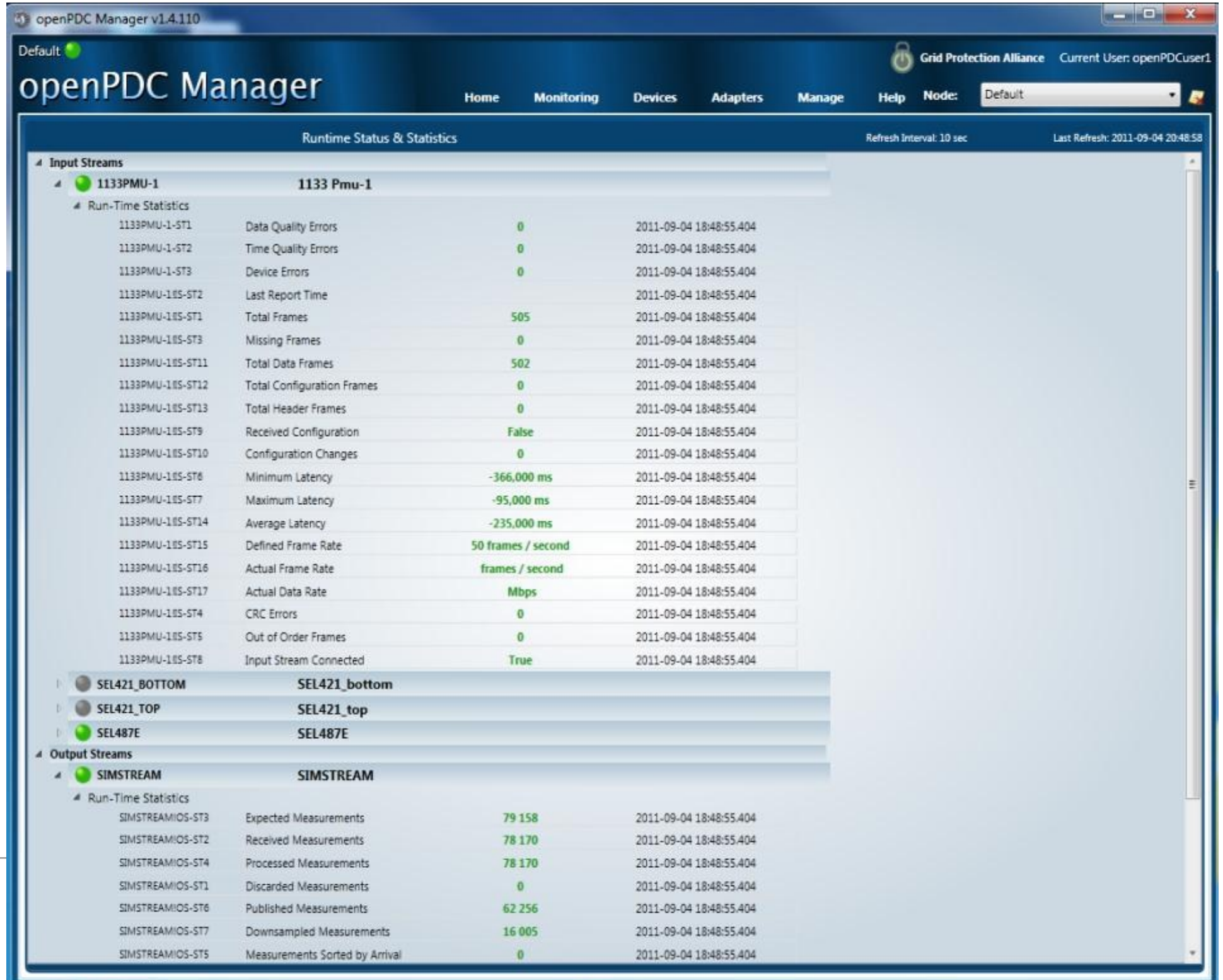


openPDC Manager v1.4.110

Default

openPDC Manager

Grid Protection Alliance Current User: openPDCuser1

Home | Monitoring | Devices | Adapters | Manage | Help | Node: Default

Input Status & Monitoring

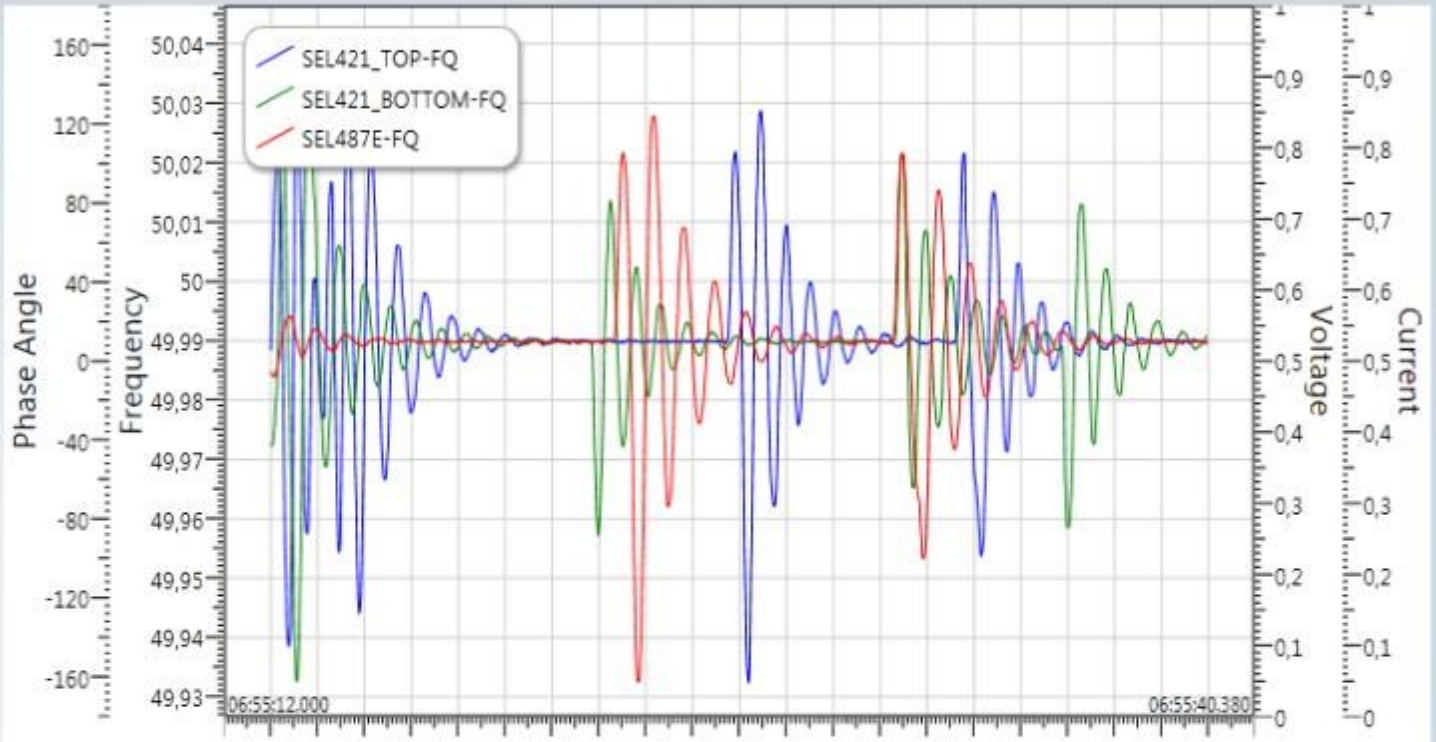
Refresh Interval: 5 sec Last Refresh: 2011-09-04 20:55:38.160

Save Display Settings | Load Display Settings

DIRECT CONNECTED — Devices Connected Directly

1133PMU-1 — 1133 Pmu-1 — Edit

1133PMU-1-AV1	2	
1133PMU-1-AV10	2	
1133PMU-1-AV11	2	
1133PMU-1-AV12	2	
1133PMU-1-AV13	24995	
1133PMU-1-AV14	25000	
1133PMU-1-AV15	24998	
1133PMU-1-AV16	24998	
1133PMU-1-AV17	1	
1133PMU-1-AV18	1	
1133PMU-1-AV19	1	
1133PMU-1-AV2	2	
1133PMU-1-AV20	1	
1133PMU-1-AV3	2	
1133PMU-1-AV4	2	
1133PMU-1-AV5	0	
1133PMU-1-AV6	0	
1133PMU-1-AV7	0	
1133PMU-1-AV8	0	
1133PMU-1-AV9	2	
1133PMU-1-DF	0	
1133PMU-1-DV1	0	
1133PMU-1-DV2	1	
1133PMU-1-DV3	2048	
1133PMU-1-FQ	49,986	Hz
1133PMU-1-PA1	-135,17	Degrees
1133PMU-1-PA10	-135	Degrees
1133PMU-1-PA11	0	Degrees
1133PMU-1-PA12	0	Degrees
1133PMU-1-PA2	-135	Degrees



254	SEL421_BOTTOM-FQ	2011-09-04 18:55:40.340	49,991	Hz	GOOD
142	SEL421_TOP-FQ	2011-09-04 18:55:40.380	49,99	Hz	GOOD
198	SEL487E-FQ	2011-09-04 18:55:40.380	49,99	Hz	GOOD

Acronym **Name**

Protocol **Vendor**

Frames/Sec **Measured Lines**

Run-Time Statistics

openPDC Manager v1.4.110

Default

openPDC Manager

Grid Protection Alliance Current User: openPDCuser1

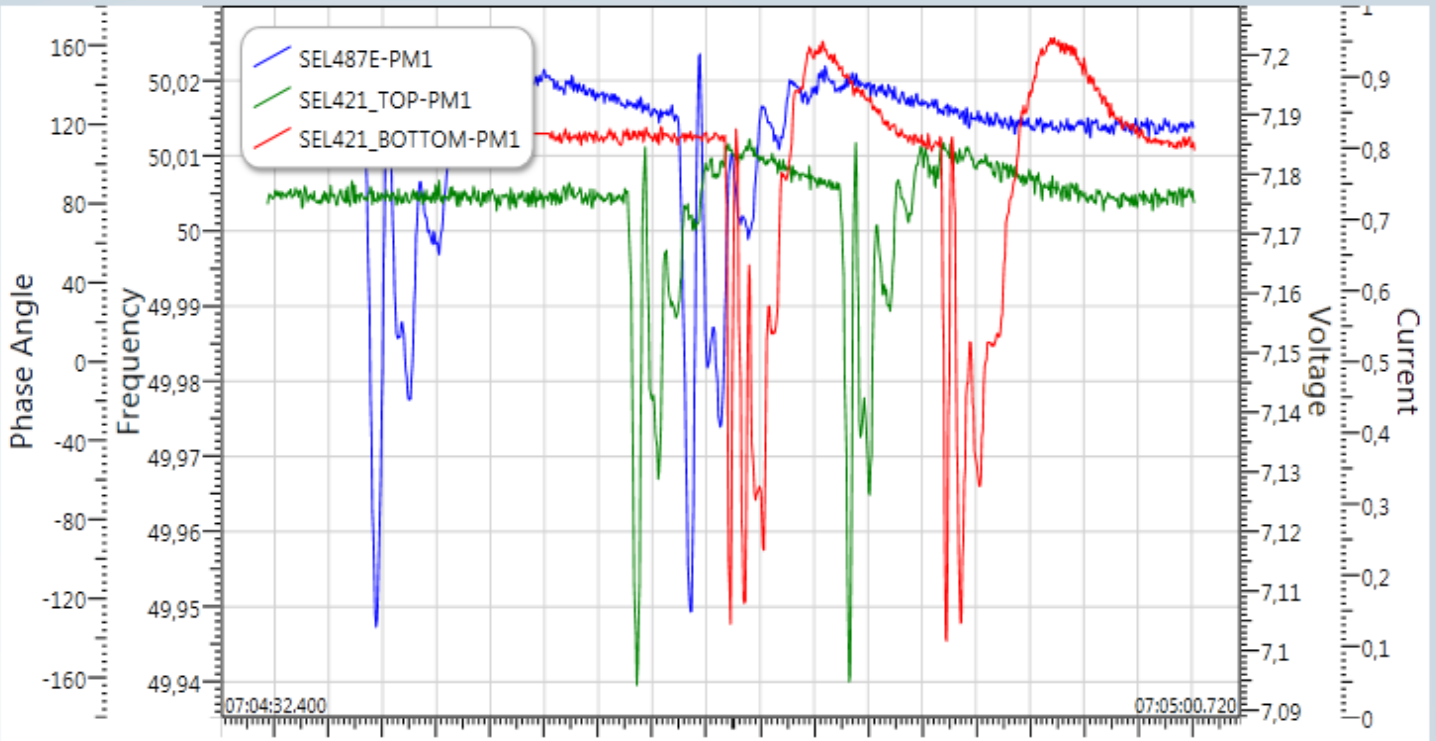
Home | Monitoring | Devices | Adapters | Manage | Help | Node: Default

Input Status & Monitoring

Refresh Interval: 5 sec Last Refresh: 2011-09-04 21:04:59.866

Save Display Settings | Load Display Settings

DIRECT CONNECTED	Devices Connected Directly	
1133PMU-1	1133 Pmu-1	Edit
SEL421_BOTTOM	SEL421_bottom	Edit
SEL421_TOP	SEL421_top	Edit
SEL487E	SEL487E	Edit



202	SEL487E-PM1	2011-09-04 19:05:00.720	7,188	Volts	GOOD
146	SEL421_TOP-PM1	2011-09-04 19:05:00.660	7,175	Volts	GOOD
258	SEL421_BOTTOM-PM1	2011-09-04 19:05:00.700	7,184	Volts	GOOD

Acronym **Name**

Protocol **Vendor**

Frames/Sec **Measured Lines**

Run-Time Statistics

openPDC Manager v1.4.110

Default

openPDC Manager

Grid Protection Alliance Current User: openPDCuser1

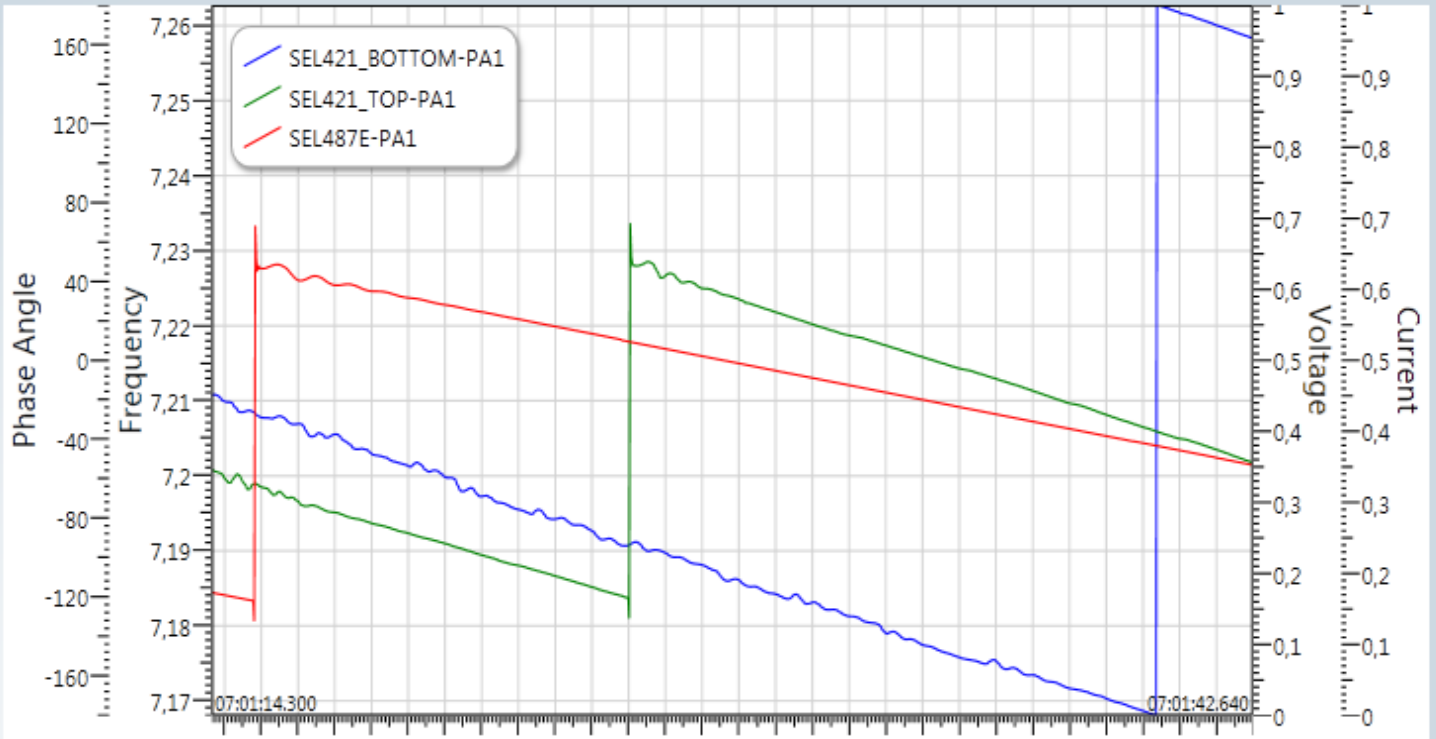
Home | Monitoring | Devices | Adapters | Manage | Help | Node: Default

Input Status & Monitoring

Refresh Interval: 5 sec Last Refresh: 2011-09-04 21:01:39.480

Save Display Settings | Load Display Settings

DIRECT CONNECTED	Devices Connected Directly	
1133PMU-1	1133 Pmu-1	Edit
SEL421 BOTTOM	SEL421_bottom	Edit
SEL421 TOP	SEL421_top	Edit
SEL487E	SEL487E	Edit



259	SEL421_BOTTOM-PA1	2011-09-04 19:01:42.600	163,453	Degrees	GOOD
147	SEL421_TOP-PA1	2011-09-04 19:01:42.600	-51,488	Degrees	GOOD
203	SEL487E-PA1	2011-09-04 19:01:42.640	-52,979	Degrees	GOOD

Acronym **Name**

Protocol **Vendor**

Frames/Sec **Measured Lines**

Run-Time Statistics

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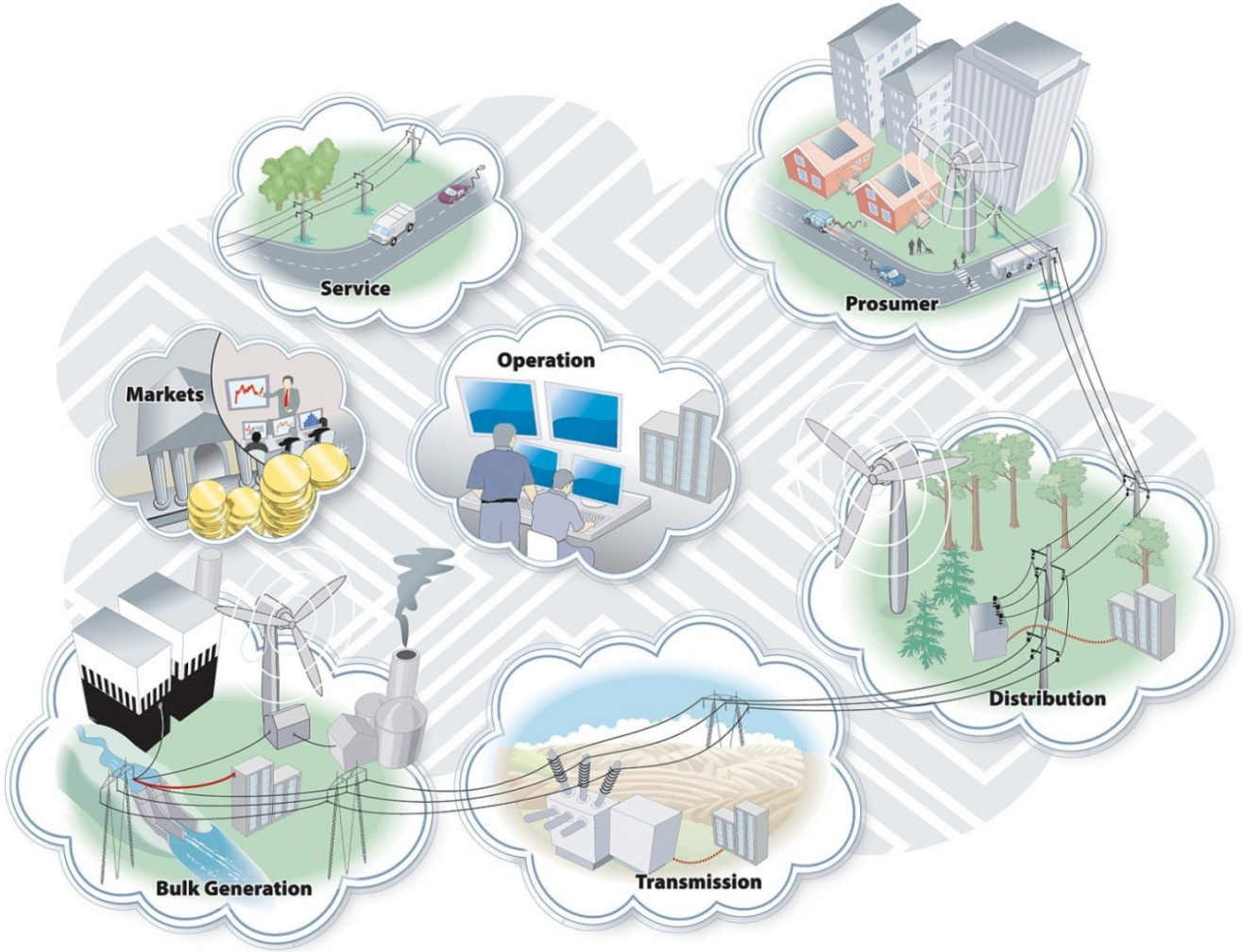


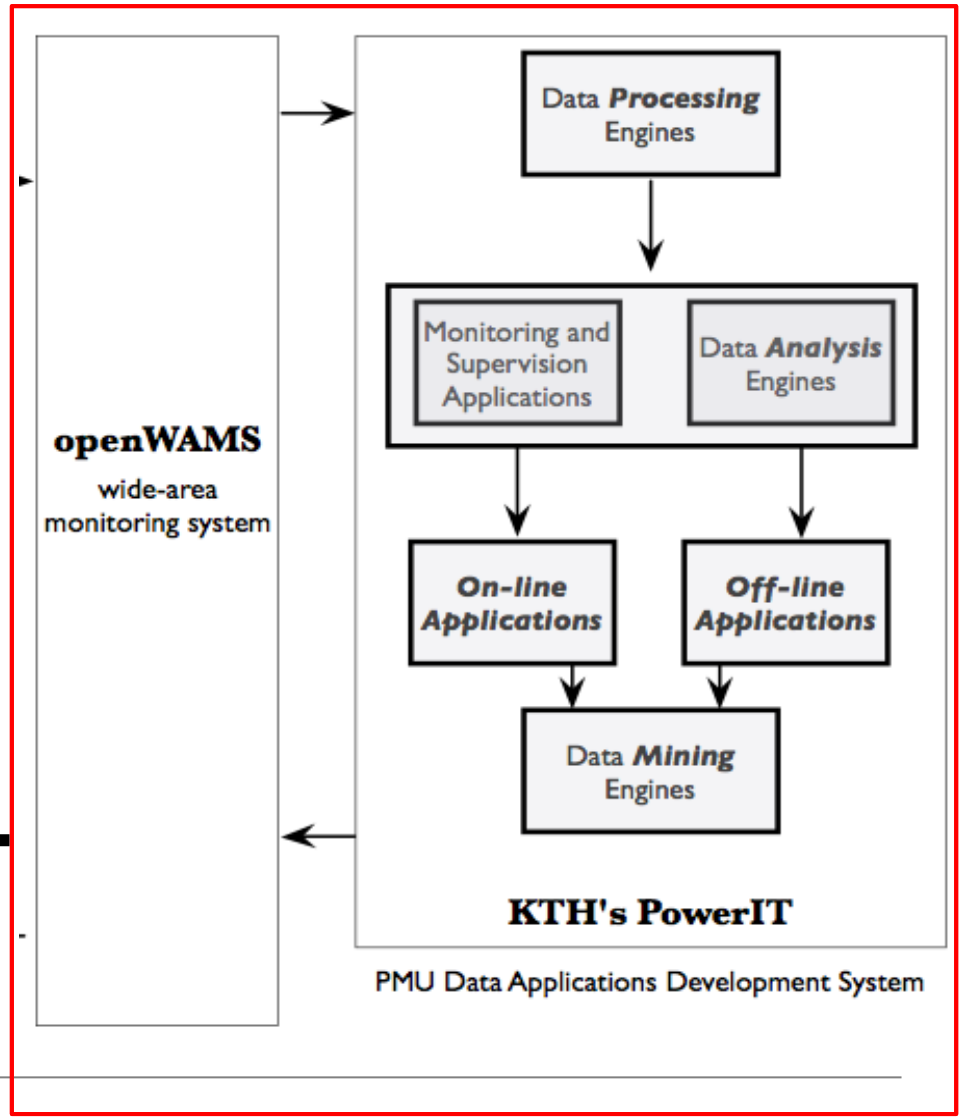
Current and Future Projects using the SmarTS Lab Platform

Going beyond the lab!

SVENSKA KRAFTNÄT

SmarTS Lab
Smart Transmission Systems Laboratory

The Nordic Synchrophasor Group



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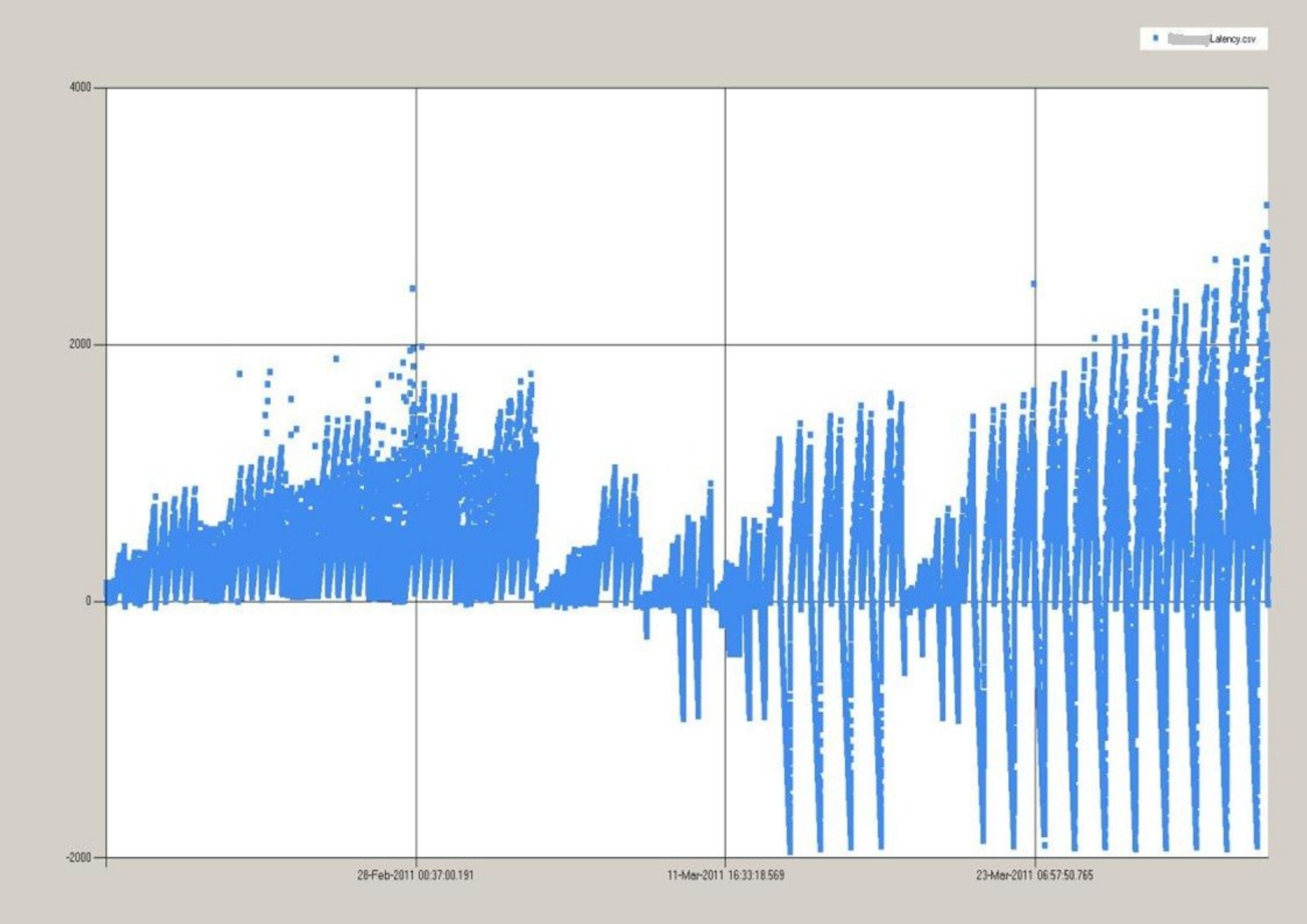
openPDC Deployment at the Swedish TSO (SvK)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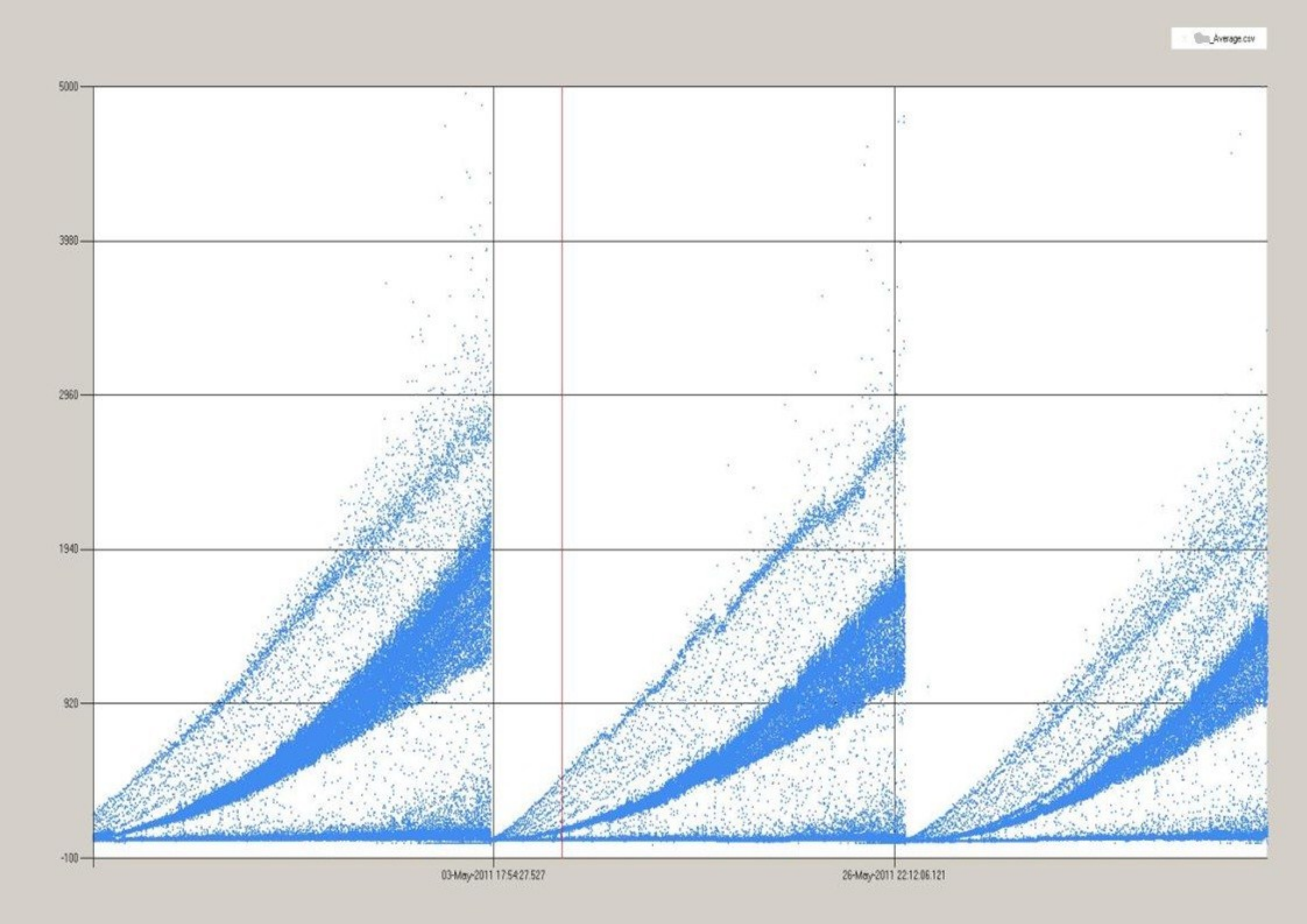
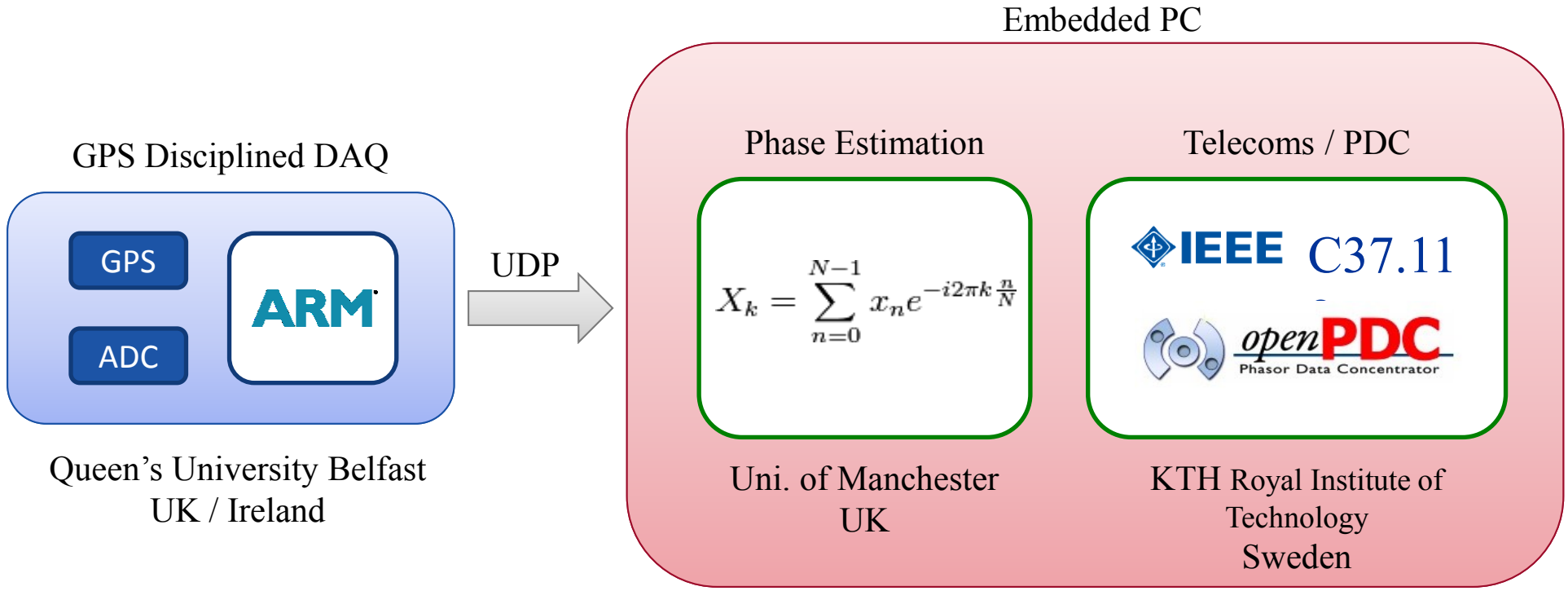
0
-2000
26-Feb-2011 00:37:00.191
11-Mar-2011 16:33:18.569
23-Mar-2011 06:57:50.765


_Average.csv
5000
3980
2960
1940
920
-100
03-May-2011 17:54:27.527
26-May-2011 22:12:06.121

openPMU and *soft*PMU projects



OpenPMU

Open Source Phasor Measurement Unit

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STRONgrid

Smart Transmission Grids Operation and Control

KTH - NTNU - AALTO - DTU - UI

Nordic Energy Research

Sustainable Energy Systems 2050

- Funded by Nordic Energy Research – Sustainable Energy Systems 2050 Call
- Co-funded by:

Statnett FINGRID SVENSKA KRAFTNÄT LANDSNET TROMS KRAFT

- Goal:
- Build an interdisciplinary experimental platform and formal methodologies that can support development of better tools for planning, operation and control of power grids interconnected across traditional national boundaries and at various voltage levels through the use of synchrophasor technology.
- *It is our vision that by advancing phasor measurement technology and applications in wide area monitoring and control many of these challenges can be met.*

Project organisation and main responsibilities

-Workshops and meeting place
- Dissemination and awareness

NTNU
Project coordinator:
Kjetil Uhlen

Steering Group
Fingrid, Statnett, Svenska Kraftnät, Troms Kraft Nett, Gothia Power

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GRID PROTECTION ALLIANCE

KTH
Lead WP1 :
(Luigi Vanfretti, Lars Nordström)
-WA development platform
-ICT architectures
- WAMS Applications and implementation

Aalto
Lead WP2:
(Liisa Harla)

- WA monitoring applications
- Wide area stabilising control

NTNU
Lead WP3:
(Kjetil Uhlen)

-PMU-applications in distribution
-Smartgrid control challenges
- Laboratory implementations

DTU
Lead WP4:
(Rodrigo Garcia-Valle)
-Education and dissemination
-Laboratory implementations
- WAMS applications

U-Iceland
(Magni Þ. Pálsson)

-Smart end-user metering as an aid in damping power oscillations
- Implement wide-area control algorithms.

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http://www.nordicenergy.net/section.cfm?id=3-0&path=220,240

10 top quality projects to be funded in Sustainable Energy Systems 2050 call

The board of Nordic Energy Research has selected 10 of the 90 applications for funding in the Nordic Energy Research Programme **Sustainable Energy Systems 2050**. The aim of the programme is to develop integrated solutions between renewables, low-carbon transport and grids & markets.

The ten projects cover solar energy, bioenergy, wind energy, smart grids, policy projects and projects in the field of transportation. A total of 100 MNOK is divided between 8 research projects and 2 industry projects. The project partners cover all the Nordic countries and come from universities, research institutions and industry.

norden
Nordic Energy Research

Sustainable Energy Systems 2050
NORDIC ENERGY RESEARCH PROGRAMME

10. **STRONgrid** (Smart Transmission Grid Operation and Control) project leader: NTNU

Building a Prototype Mirror System at KTH SmarTS Lab for R&D and Testing of Novel Applications

Nordic TSO(s)

Problems ???

Solutions!!!

KTH EPS and ICS

Phasor Measurements

Software Prototype

Control Data Stream

Phasor Measurements

Software Prototype

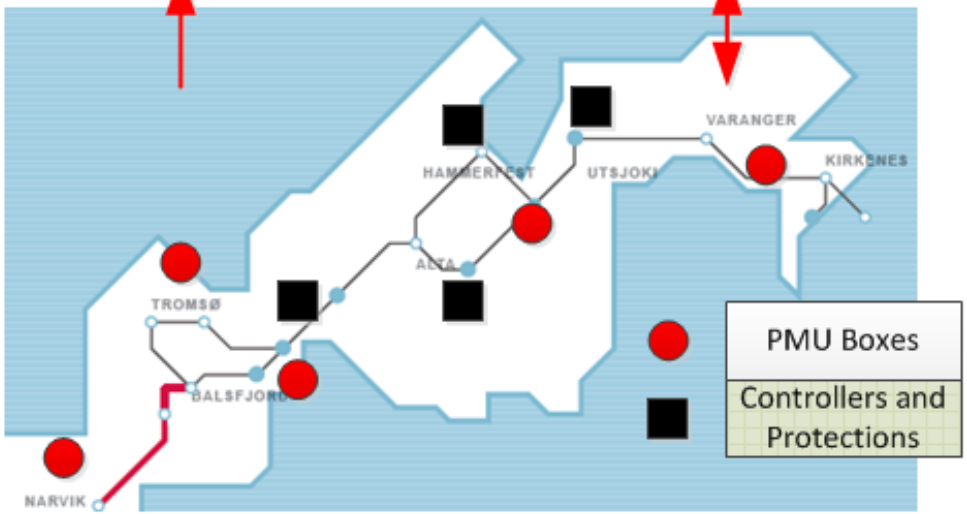
Control Data Stream

PDC

Communication

Control Data Stream

Controllers and Protections



PMU Boxes

Controllers and Protections

PDC

Communication

PMU Boxes

Simulated Controllers and Protections

Real Time Hardware In the Loop Simulator

Approximate model of the Nordic Power Network

Real-Time Estimation and Control of Hybrid AC and DC Networks

- Funded by:

Swedish Energy Agency

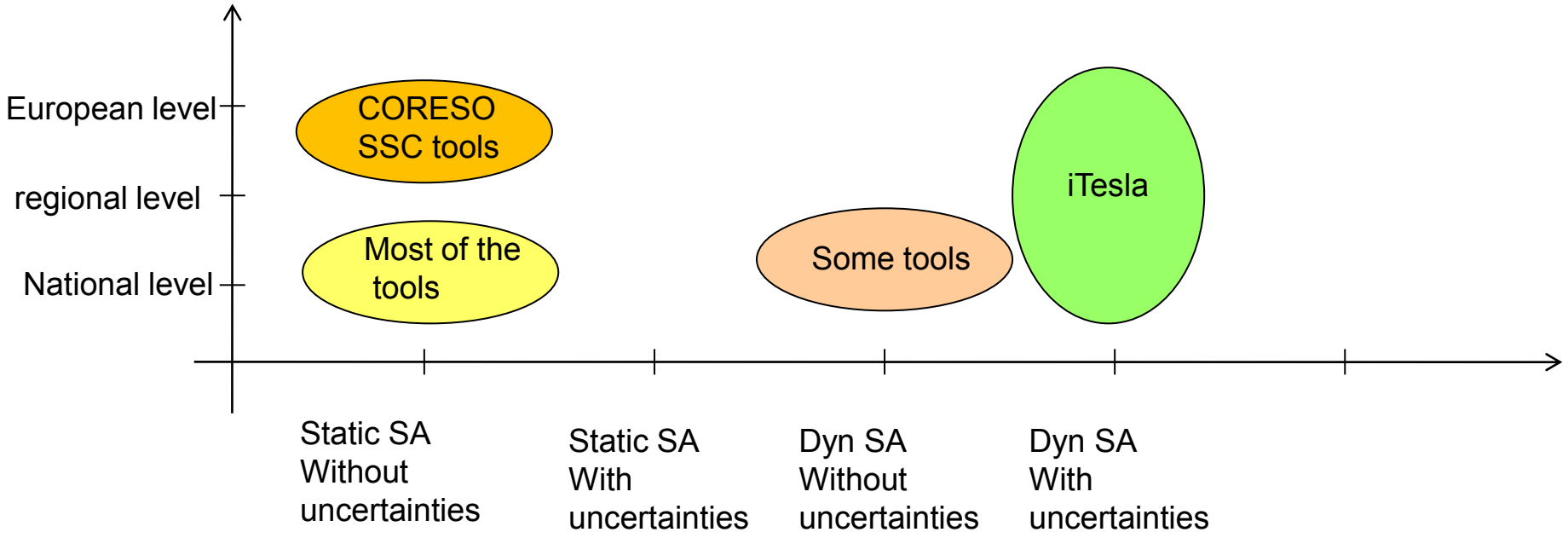
SVENSKA KRAFTNÄT

ABB

- Two parallel PhD projects at: KTH EPS and KTH ICS
- Project at KTH EPS:
  - Development of new paradigms for rapid state estimation of hybrid AC and DC networks, and algorithm implementation for real-time execution.
- Project at KTH ICS:
  - Development of robust and high-pressing SCADA/EMS systems architectures for real-time control of smart transmission grids.
- Applications for a New PhD student are being evaluated.

openPDC
GRID PROTECTION ALLIANCE

FP7 iTesla Project: Innovative Tools for Electrical System Security within Large Areas



- There is no agreed methodology to tackle pan-European security.
- Might be necessary to redefine *n-1 approach completely.*
- *Risk-based approach seems attractive: consider all time scales*
- *NO available tools can ACCURATELY model and perform computations on the entire system model – nor that AN ACCURATE model exists for dynamic performance.*
- **New tools must be developed: A huge challenge.**

FP7 iTesla Project: Innovative Tools for Electrical System Security within Large Areas

- 22 Partners involved, including: RTE (France), Statnett (Norway), National Grid (UK), Elia (Belgium) etc.
- KTH will be involved in 4 WPs:
  - WP2: Data management and mining
  - WP3: Off-line validation of dynamic models
    - Validate models of components (individual or aggregate) from measurement data (synthetic of field) - Use of PMU Data
    - Validate system-wide power system dynamic behavior – Use of PMU data
  - WP4: Off-line definition of Security Rules
  - WP5: Defense Plans and Restoration
    - Use of PMU data in defense plans

Who will be using these tools:

Coreso

(coordination initiative of Elia (Belgium), RTE (France), National Grid (UK), Terna (Italy) and 50 Hz (Germany))

SmarTS Lab

Smart Transmission Systems Laboratory

KTH VETENSKAP OCH KONST

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Thank you!

luigiv@kth.se, moustafa.chenine@ics.kth.se

http://www.vanfretti.com

Elförsörjning – inget nytt under solen?