Experimental ICT Systems for Wide-Area Measurement and Control Systems

Lars Nordström
Assoc. Professor, Power System Management
Director of EKC^2
Dept of Industrial Information & Control Systems
larsn@ics.kth.se

Agenda

- Research Philosophy
  - Why do we do what we do
- Project Examples
  - What do we use the testbeds for?
- Experimental testbeds
  - What kind testbeds do we have and what can they do?

Industrial Information & Control Systems

Faculty: 5

- Cegrell, Johnson, Nordström, Ekstedt, Lilliesköld

Post-Doc: 4

- Saleem, Johansson, Sörkvist, Lagergren

Admin & Tech: 2

PhD Students 18 (10)

10 Master level courses

- Architecture analysis & design
- Computer Applications in Power Systems
- Requirements & Project management

Circa 30 Master level projects annual

Sponsors

- ABB, E.on, EU FP7, Vattenfall, Elforsk, Energy Agency, Vinnova

Parters

- INP Grenoble, TU Munchen, TU Berlin

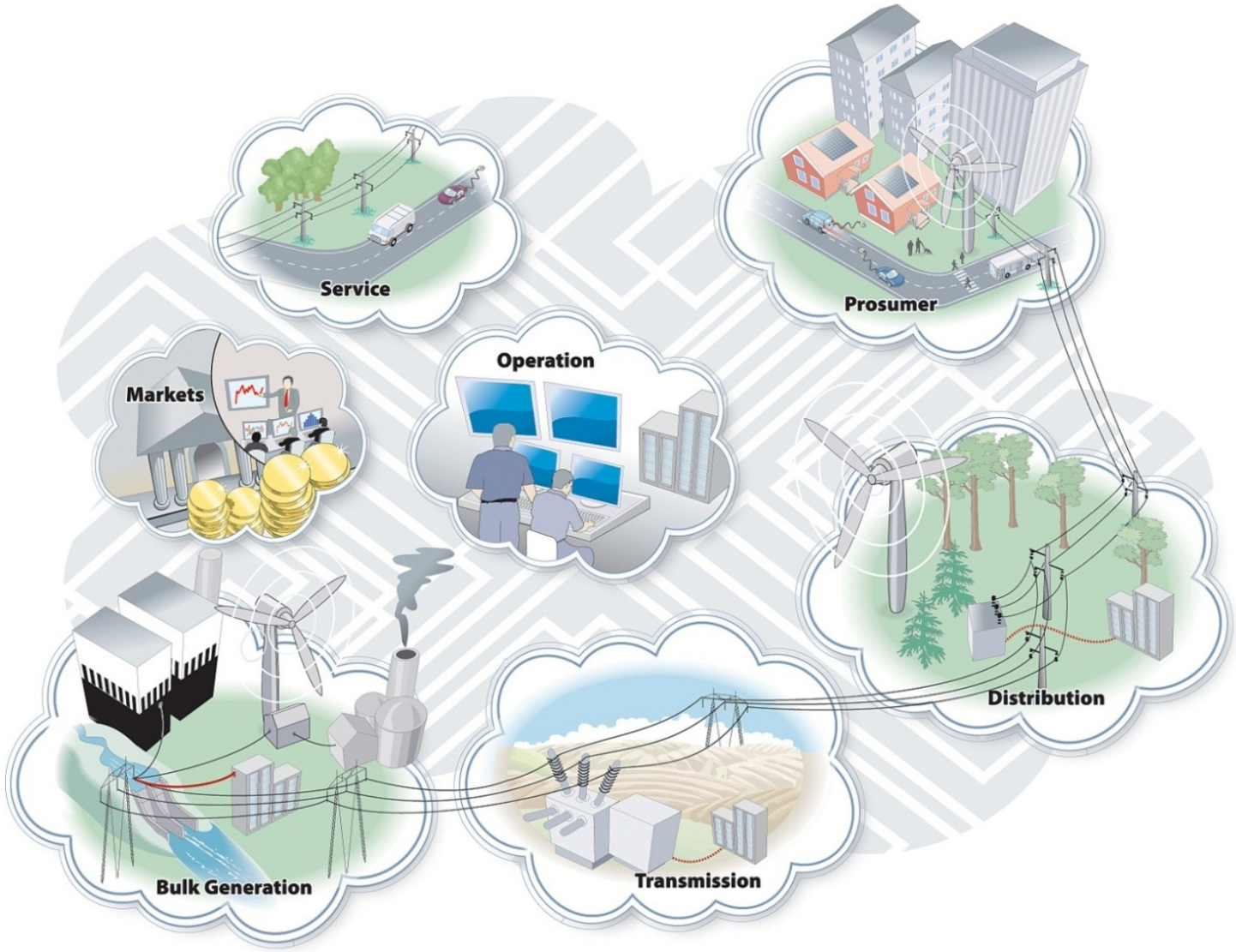
Budget

2,2 MEUR annual

Lars Nordström – in Brief

- Assoc Prof Power System Management
  - MscEE, PhD & Docent degrees from KTH, 50+ scientific publications
  - Director EKC^2 – Swedish Centre of Excellence in Power Engineering
- Scientific involvement
  - Member of IEEE, Cigre, CIRED
  - Program committes of ISGT-E, CRIS, CIRED, IEEE Smartgrid Forum
  - Local chair PSCC 2011, Editor Cigre scientific publ.
  - Editor for VR (Swedish Science Council) section on Power Engineering
- Society involvement
  - Swedish repr. in EU DG Energy Taskforce on Smart grids
  - Member of IEC Strategic group on Smart grids
  - Member of CENELEC/ETSI JWG on Smart grids
  - Swedish representative in IEA ISGAN
- Industry involvement
  - On board of Boo Energi – small Stockholm area utility
  - On the board of Powercircle, Sweden's Power Engineering cluster
  - Active in two ICT start-ups, led one to successful exit.

Smart grids= ICT + Power

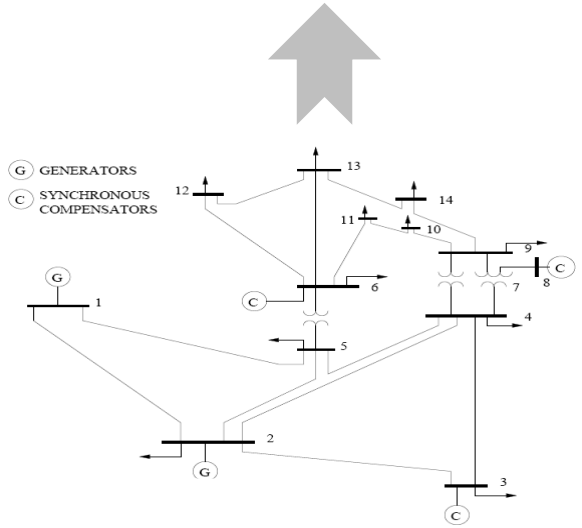


Power System Decisionmaking

- Power system analysis, control and operation is dependent on models
- Using the models, analytical and numerical analysis provides decision support for e.g.
  - Security
  - Stability
  - Optimal power flow
  - Contingency analysis
  - Expansion planning
  - Market clearing

$$0 = -P_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik})$$

$$0 = -Q_i + \sum_{k=1}^{N} |V_i||V_k|(G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik})$$

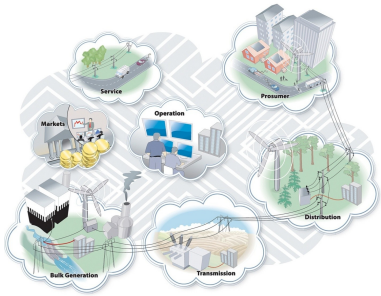


Smartgrids Decisionmaking

- Smart grids are power systems integrated with ICT systems
- Decisionmakers want to take informed decisions about:
  - Functionality
  - Security
  - Stability
  - Reliability
  - Performance
  - Interoperability
  - Usability

Analysis tools?

Models?



Our research goals

1. Modeling languages that capture power system as well as ICT system aspects
   - *Metamodels for specific modeling purposes based on UML*
2. Analysis tools that allow automated reasoning on the models.
   - *Object Constraint Language (OCL) and Probabilistic Relational Models are used to describe relations between classes and attributes in the UML models*
3. A means to validate the outcome of the analysis
   - *Co simulation*
   - *Experimental platforms*

Today's focus

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Projects w/ Experimental platforms

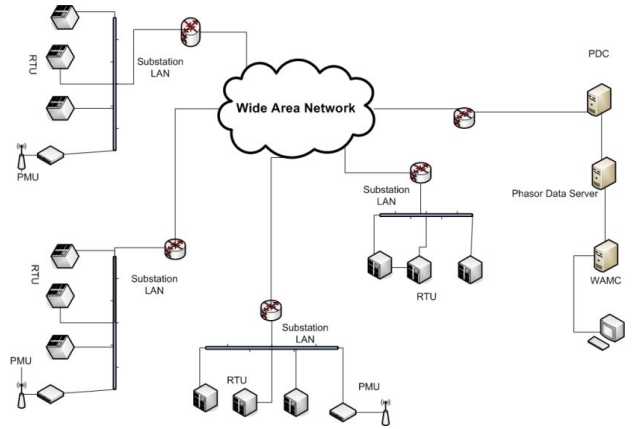
1. Real-time Performance in Wide Area Monitoring and Control Systems

2. Agent based distributed control of active distribution networks

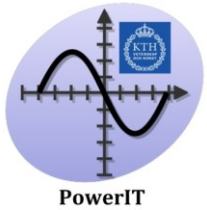
3. Probabilistic assessment of Cybersecurity protection

Real-time Performance in Wide Area Monitoring and Control Systems

- Traffic modeling for performance assessment including Interoperabilty and security implications on performance
- Traffic models built using OPNET simulator
- OCL - Object Constraint Language being used to developed System models
- Testbench implemented using TVA OpenPDC as base.



People, Partners, Products & Publications



- PowerIT toolbox of WAMS applications built on OpenPDC
- JUTS, Security and interoperability assessment framework for WAMC performance (EAAT tool)
- Helps industry to answer the question:
  - How safe is this control system?
  - What is the cost of a breach?

The Team:

Moustafa Chenine

Zhu Kun

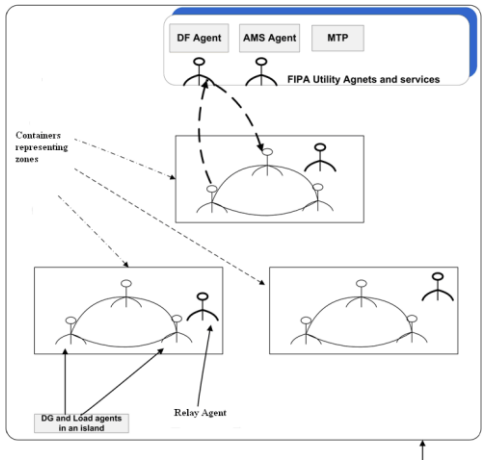
Lars Nordström

Luigi Vanfretti

- M. Chenine, L. Nordstrom *"Modeling and Simulation of Wide-Area Communication for Centralized PMU-Based Applications"* In **IEEE Transactions on Power Delivery**, 2011
- M. Chenine, L. Nordström et.al. ."*PMU traffic shaping in IP-based Wide Area communication*" In proceedings of 5th **Critical Infrastructure (CRIS), 2010 Conference**.
- M. Chenine, L. Nordström *"Investigation of communication delays and data incompleteness in multi-PMU Wide Area Monitoring and Control Systems"* Proceedings of **Electric Power and Energy Conversion Systems, 2009. EPECS '09.**
- K Zhu; M. Chenine, J König, J.; L. Nordström *"Analysis of data quality issues in Wide Area Monitoring and Control systems"* In Bulk Power System Dynamics and Control (iREP) - VIII (iREP), 2010 **iREP Symposium**

Agent based distributed control of active distribution networks

- Analysis and Design of distributed control architectures based on scenarios given regulatory constraints (market models) and ICT capability
- Optimisation of flexibility versus ICT capabilities (security, performance)



Partners, Products & Publications

- Topology inference method for distribution systems facilitating self healing
- Test-bed implemented in JACK & JADE platforms for Multi-agent control systems
- Control system for distributed resources
  - Smart Energy container
  - Wireless comms for Substation Automation

The Team:

Nicholas Honeth

Arshad Saleem

Rune Gustavsson

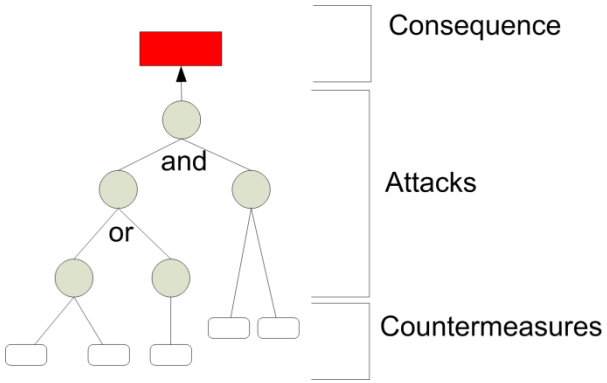
Wu Yiming

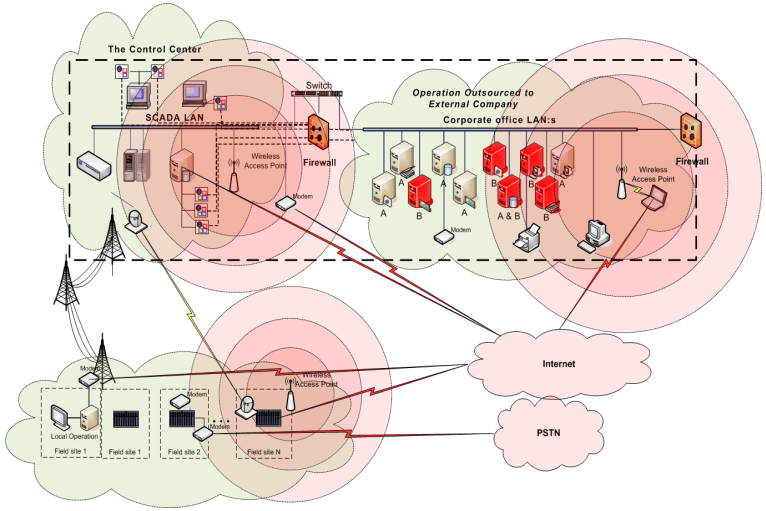
Lars Nordström

- N. Honeth, W. Yiming, N. Etherden, L. Nordström "Implementation of a control system for a Smart Energy container using the IEC 61850-7-420" In proceedings of **IEEE PowerTech 2011**.
- A. Saleem, N. Honeth, L. Nordström "*A case study of multi-agent interoperability in IEC 61850 environments*" In Proceedings of **IEEE ISGT Europe**, October 2010
- R. Gustavsson, B. Stahl, "*The empowered user - The critical interface to critical infrastructures*" In **5th Critical Infrastructure Conference (CRIS)**, 2010.
- A. Saleem, M. Lund, L. Nordström " *Knowledge based support for Multiagent Control and Automation*" submited to **ISAP Intelligent System Application on Power Systems,** 2011.

Probabilistic assessment of Cybersecurity protection

- Analysis of ”control-room system” vulnerabilities and protection based on attack-trees
- Probabilistic assessment of security levels using system architecture models





Partners, Products & Publications

- CyseMOF Cyber Security Modeling Framework, supported by EAAT
- ViSiCi – Cyber-breach cost assessment tool

- Helps industry to answer the question:
  - How safe is this control system?
  - What is the cost of a breach?

The Team:
Teodor Sommestad
Hannes Holm
Mathias Ekstedt

- T. Sommestad, M. Ekstedt, P. Johnson *"A Probabilistic Relational Model for Security Risk Analysis"* In **Computers & Security**, September 2010
- T. Sommestad, G. Ericsson, J. Nordlander, *"SCADA System Cyber Security - A Comparison of Standards"* In Proceedings of **IEEE PES General Meeting**, July 2010
- T. Sommestad, M. Ekstedt, L. Nordström *"Modeling security of power com-munication systems using defense graphs and influence diagram"* **in IEEE Transactions on Power Delivery**, October 2009
- M. Ekstedt, T. Sommestad "Enterprise Architecture Models for Cyber Security Analysis" In **IEEE PES Power Systems Conference & Exhibition (PSCE)**, March 2009
- L. Nordström *"Assessment of Information Security Levels in Power Communication Systems Using Evidential Reasoning"* In **IEEE Transactions on Power Delivery,** July 2008

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Flavours of the Experimental platforms

1. SmartTS Lab

   Fully fledged Transmission level real-time experimental platform allowing closed loop control with Hardware in the Loop

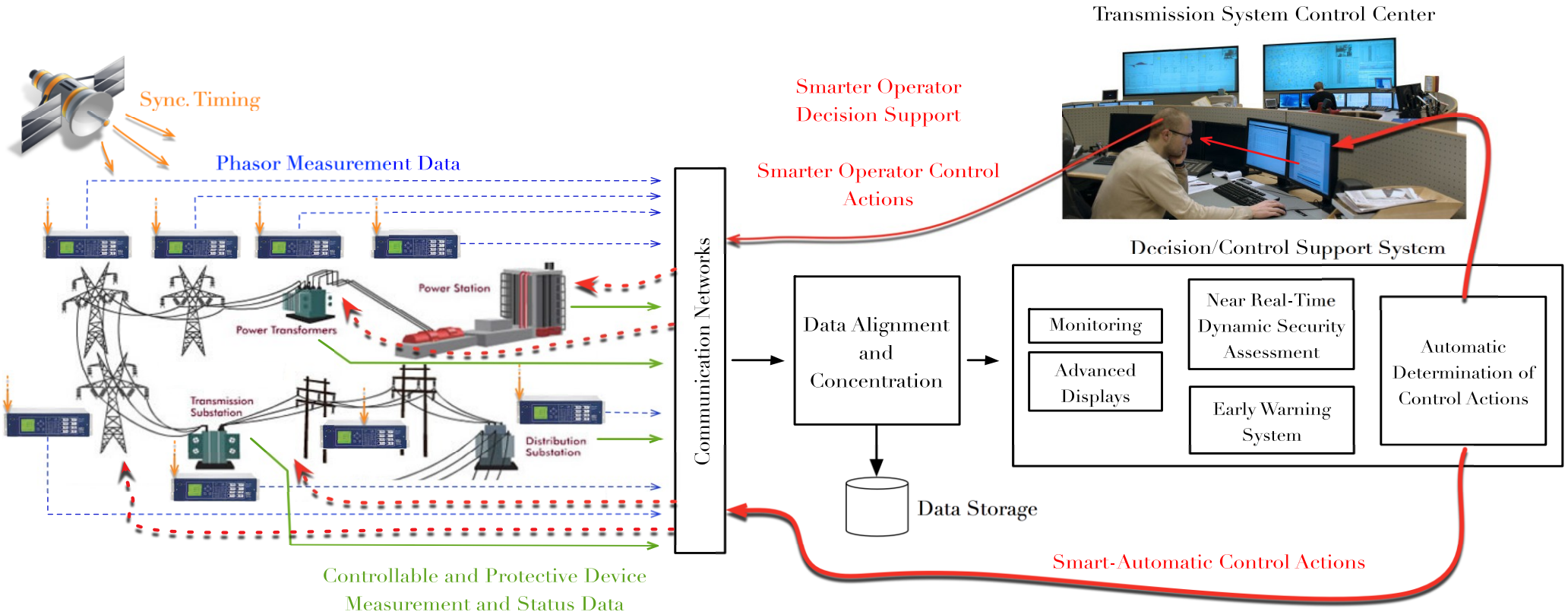
2. Multi-Agent System platform

   Use of the SmartTS as a SmartDS integrated with distributed control environment

3. Cybersecurity Testbed

   SCADA and WAN emulator with Hardware in the loop for cyberattack tests, including effects valuation.

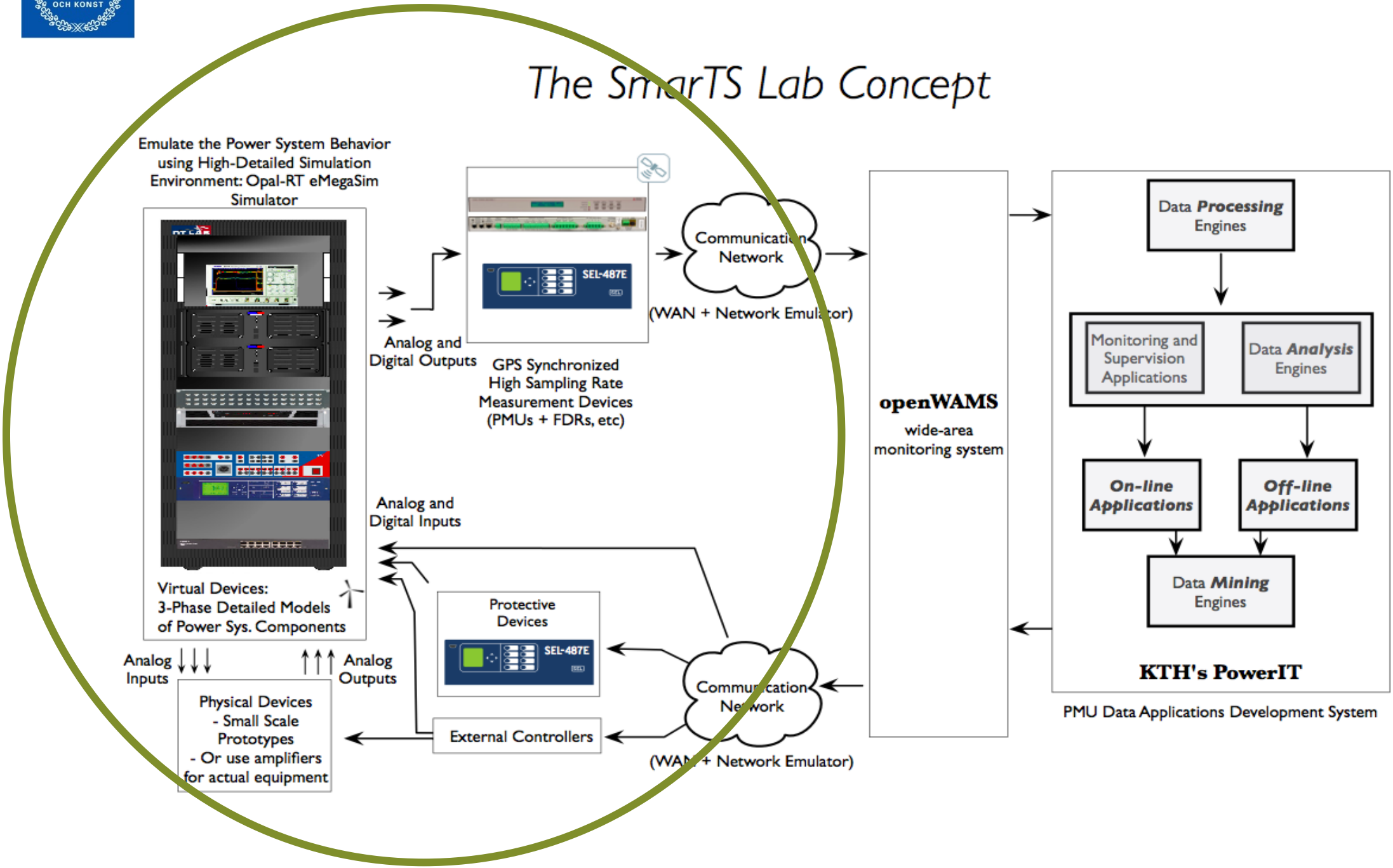
Experimental research platform for Wide Area Systems



SmarTS Lab:
Smart Transmission Systems Laboratory

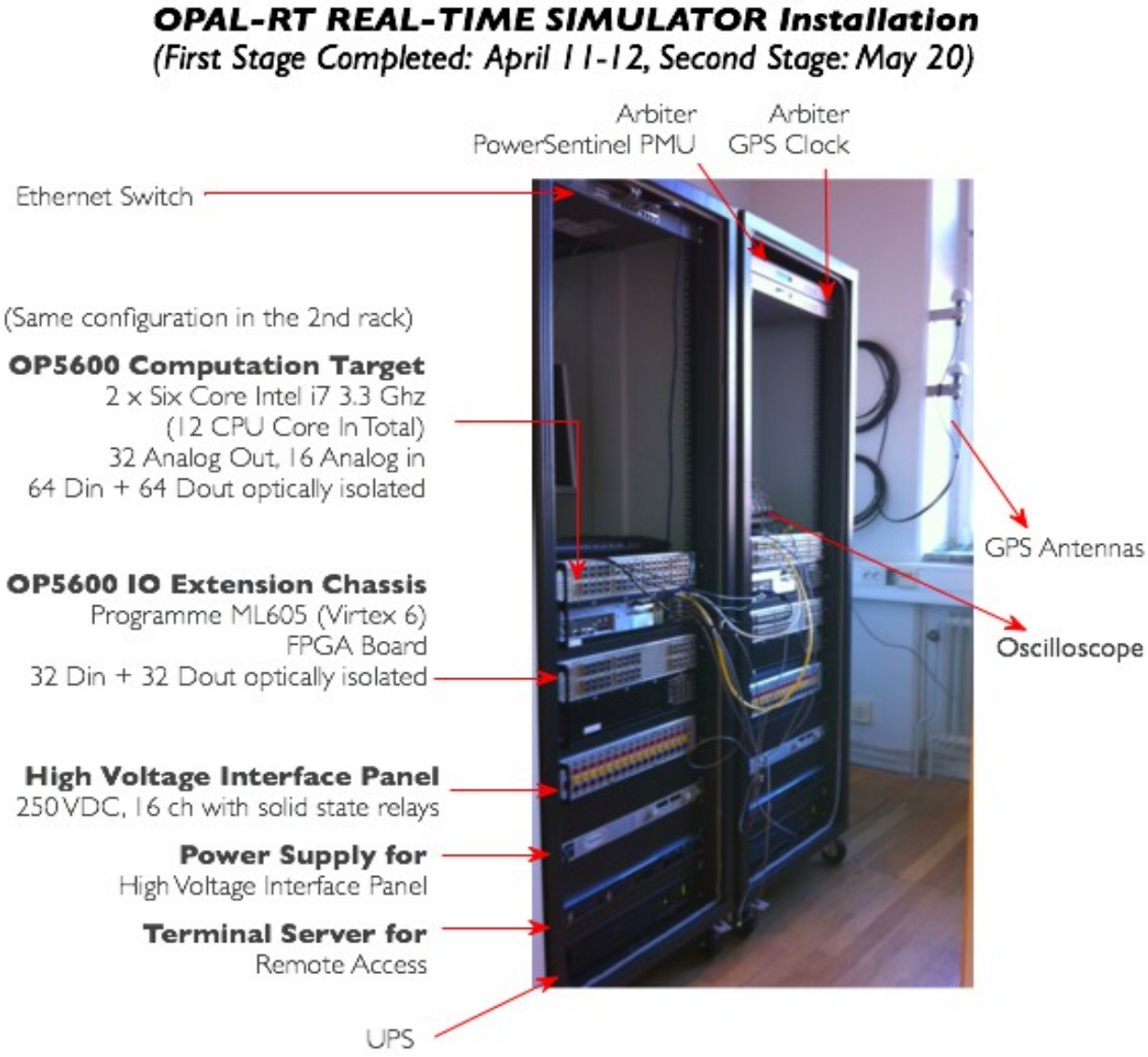
- Concept:
  - A hardware and software research platform bringing together Power Eng. and ICT expertise
  - Getting as close as possible to reality:
    - hardware in the loop, real-time emulation, comm. network, IT system, feedback control + protection
  - Also a collaboration platform:
    - EPS and ICS divisions interacting, building a strong collaboration for research and development of new technologies for Smart Grids
- Goals:
  - Conduct research in a controlled, accurate and reproducible environment, focusing on:
    - new power system operations methods; control methods, strategies, and algorithms;
    - communication network paradigms and computer system architecture paradigms;

The SmarTS Lab Concept

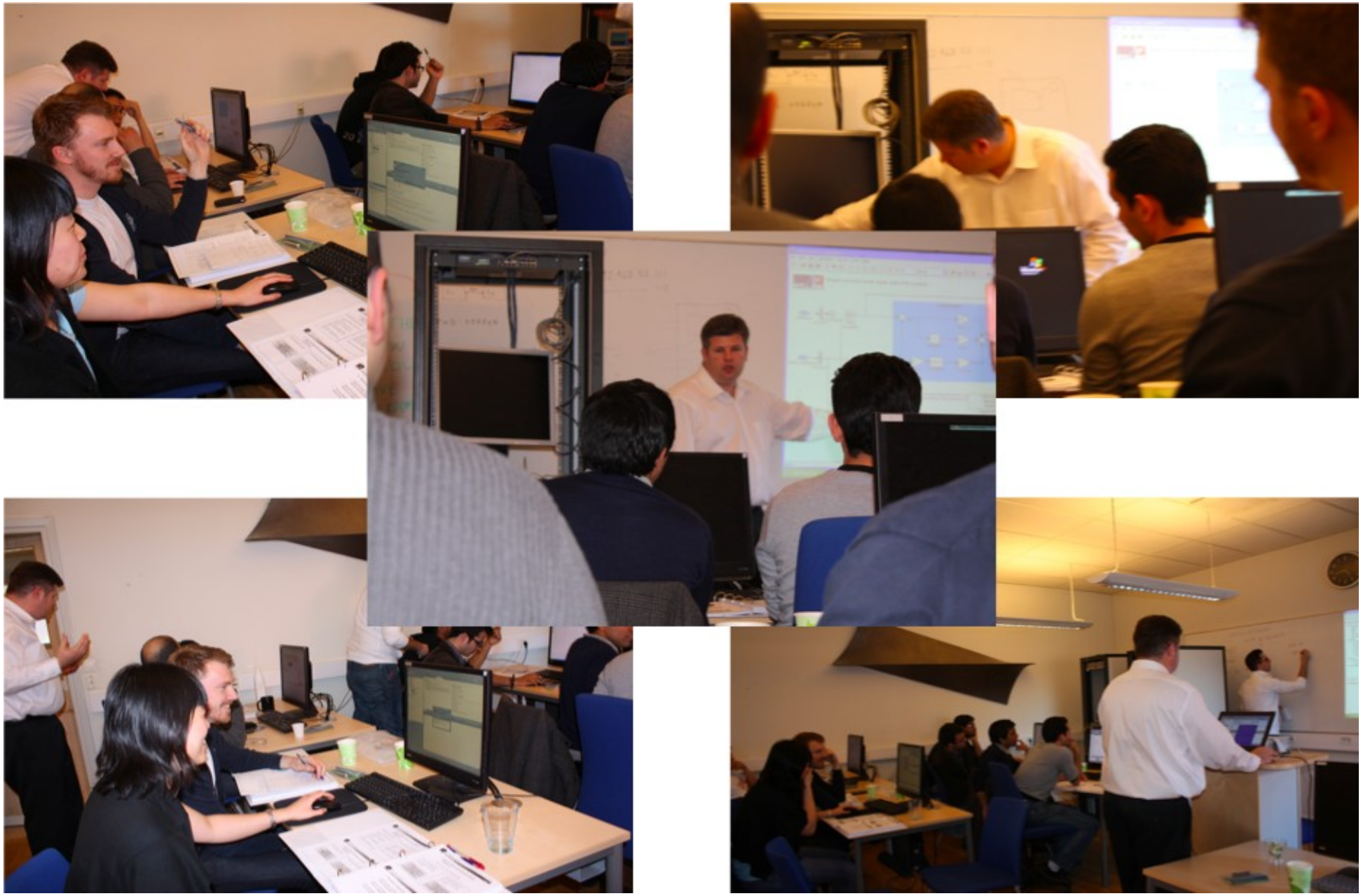


Real-Time Simulator Facility

- Opal-RT eMEGAsim simulator to installed April 11-12, 2011.
- A total of 24 CPU cores, integrated into 2 separate hardware-in-the-loop boxes.
- High-speed link to connect the two supercomputers into a single system.
- More than 350 fast IO channels
- IEC 61850 compliant communication with IEDs including GOOSE messaging and Sampled-Value messaging
- User-programmable FPGA co-processors for ultrafast simulation using Xilinx Virtex-6 FPGA
- PMU and GPS Clock on loan from



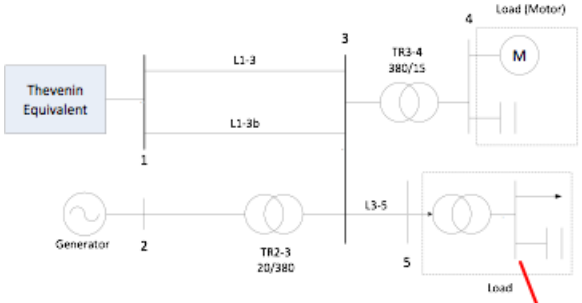
EPS+ICS Collaboration: Starts with our Students (Part 1 – April 13-15, Part II – May 17-19)



Proof of Concept Experiment 2

Real-Time Simulator

Generate 3-Phase Real-Time Signals
(Voltages and Currents)
From a Power System with Detailed Models
(see the impact from circuit breaker operations, and parameter changes reflected in real-time data)



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

Phasor Measurement Unit

Measure the Real-Time Signals **Generated from the Power System Simulation**
Compute Phasors and Time Stamp them with GPS Clock

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

Phasor Data Concentrator

Time-Align, Concentrate,
and Store Data
of the emulated power system

openPDC
GRID PROTECTION ALLIANCE

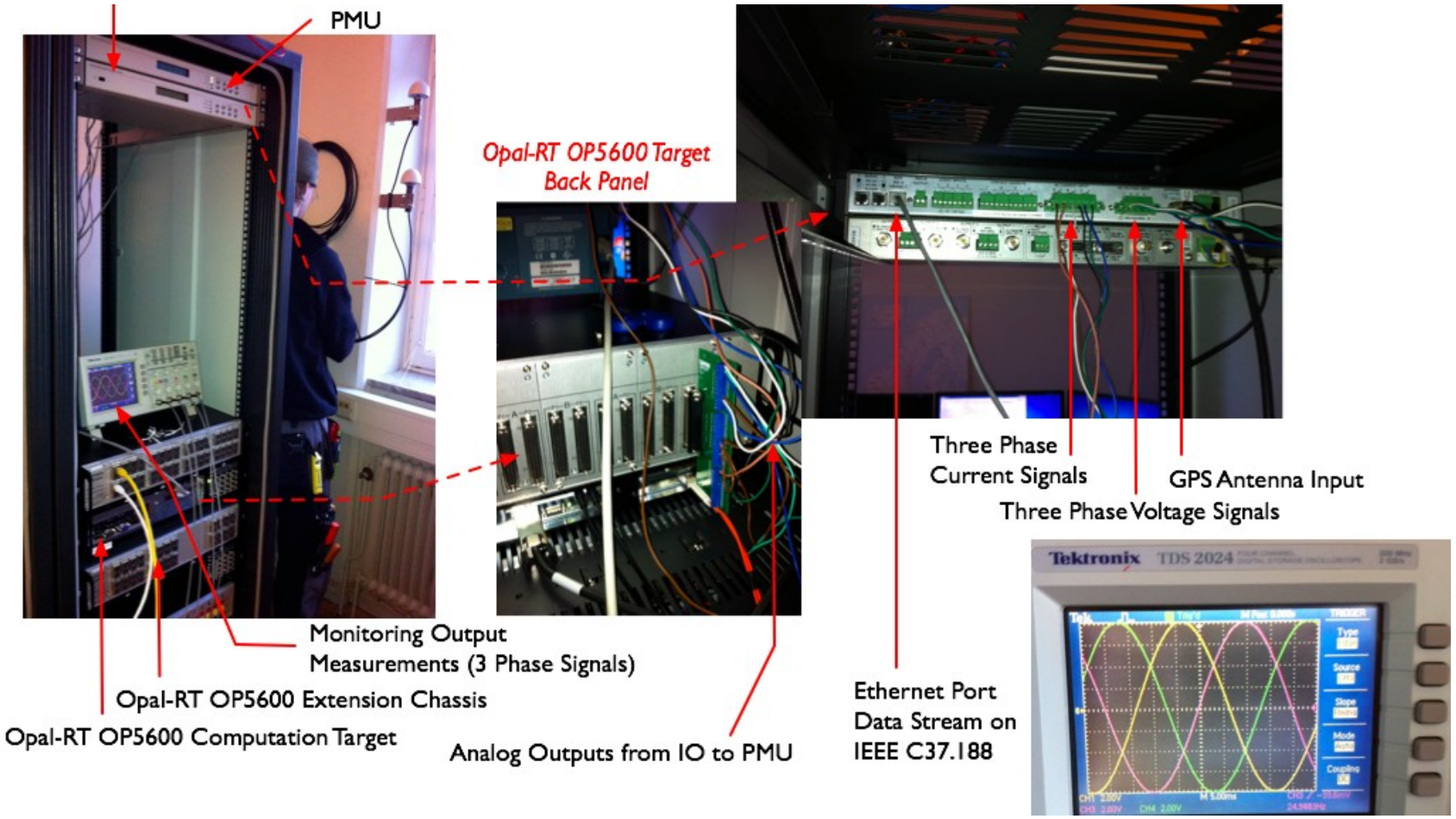
Who carried out the experiment?

Shoaib Almas
KTH EPS MSc Student

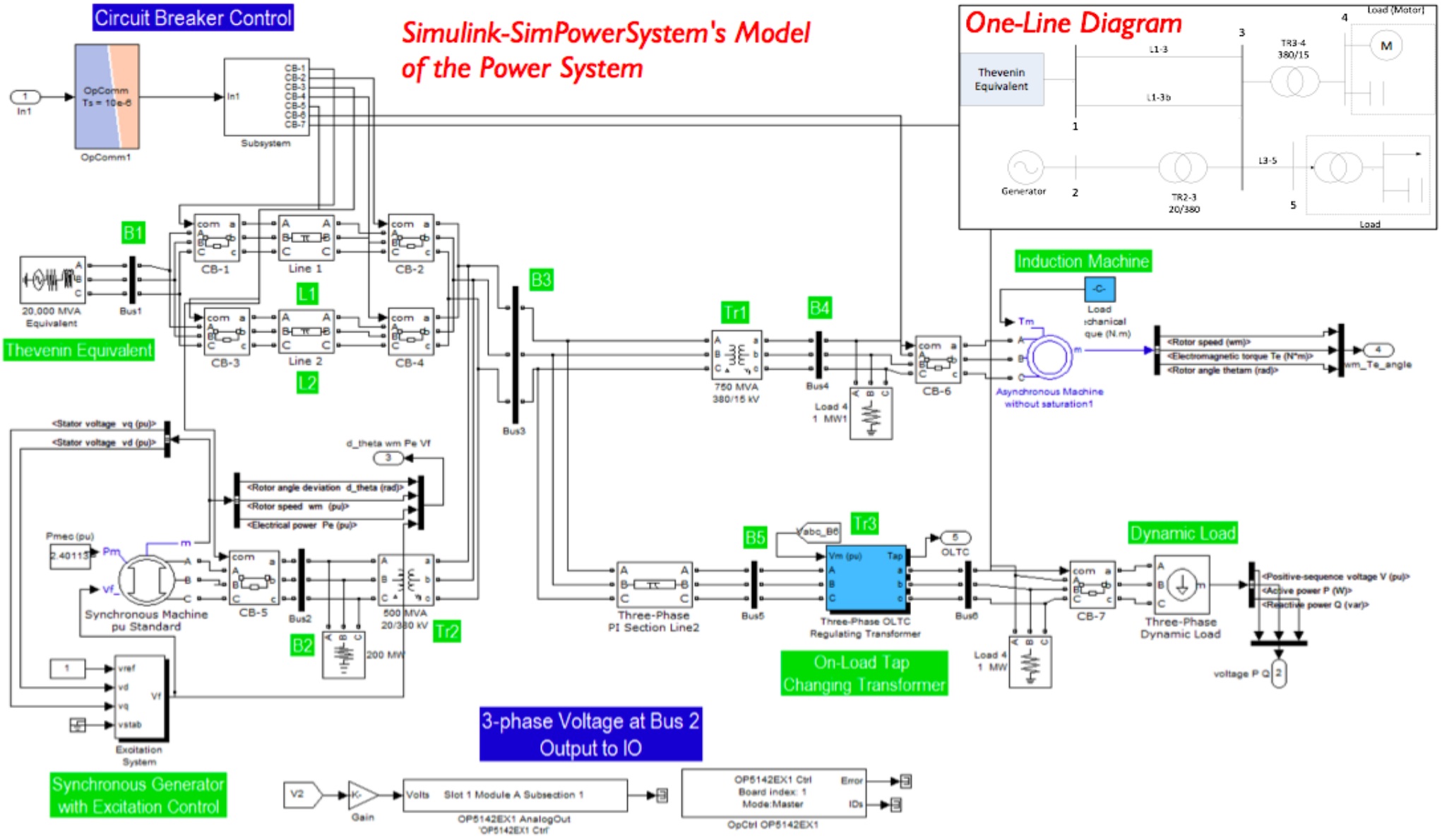
Moustafa Chenine
KTH ICS PhD Student

Luigi Vanfretti
KTH EPS, Assistant Prof.

Proof of Concept Experiment 2: Hardware Set Up



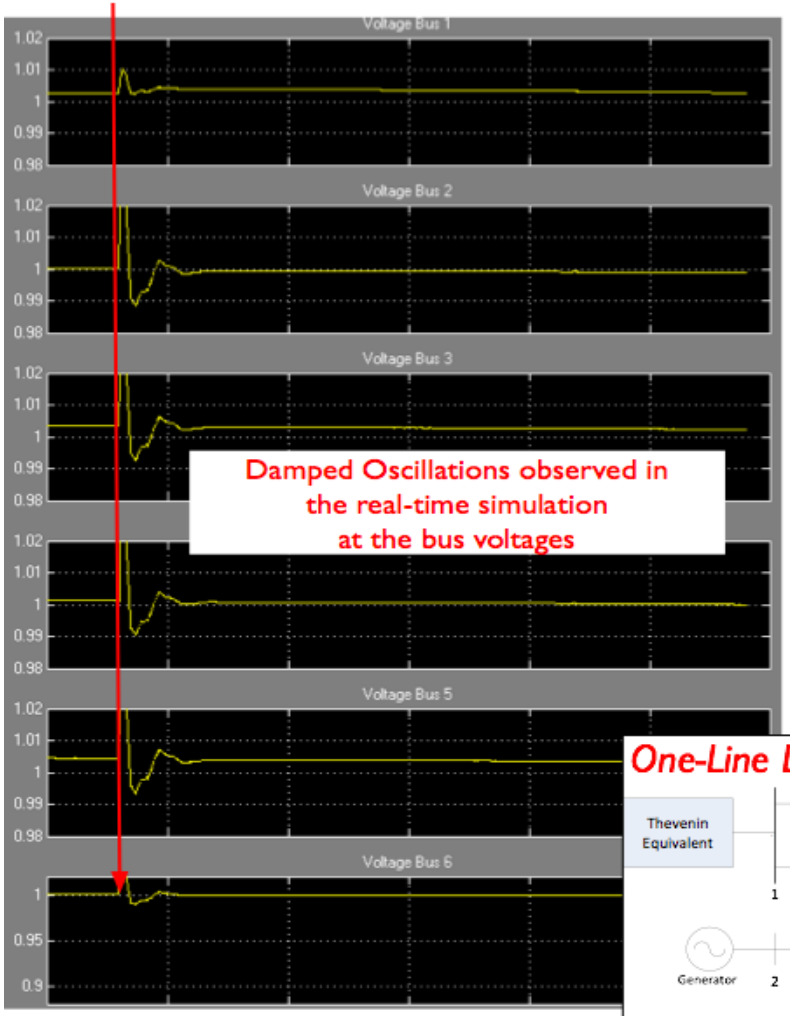
Proof of Concept Experiment 2: Real-Time Model of the Power System



Proof of Concept Experiment 2

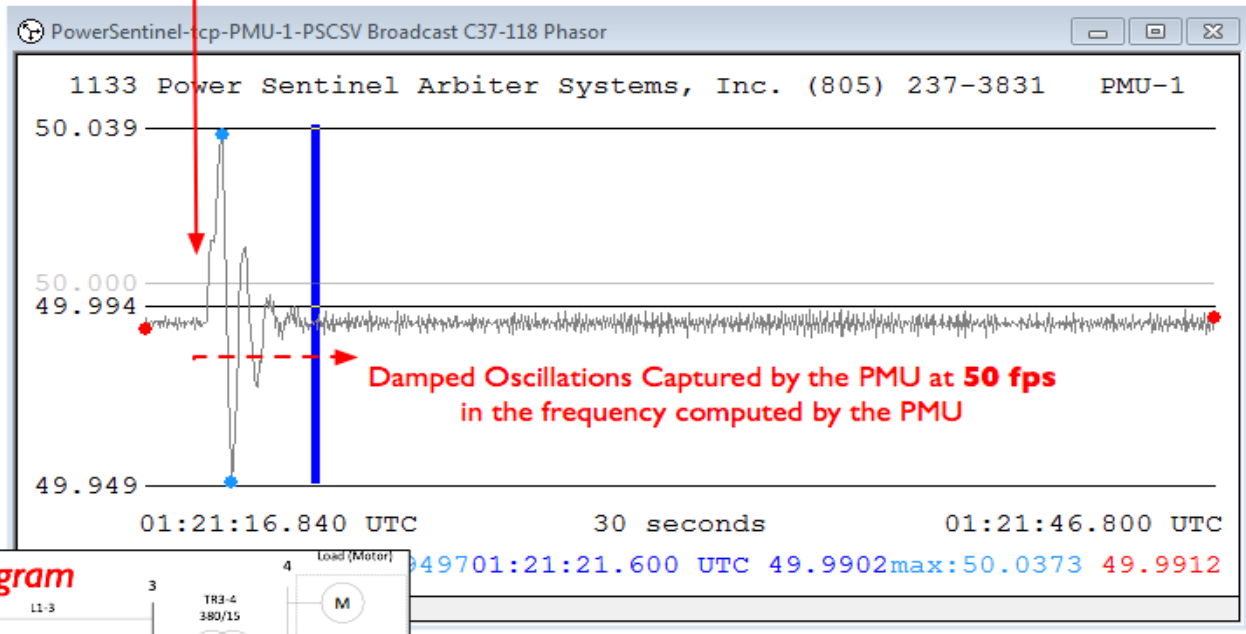
Real-Time Execution, 3-phase Analog Signal Output, and Data Transmission

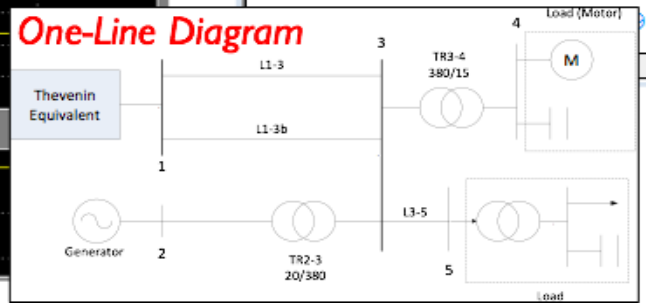
Generator Mechanical Power Perturbation



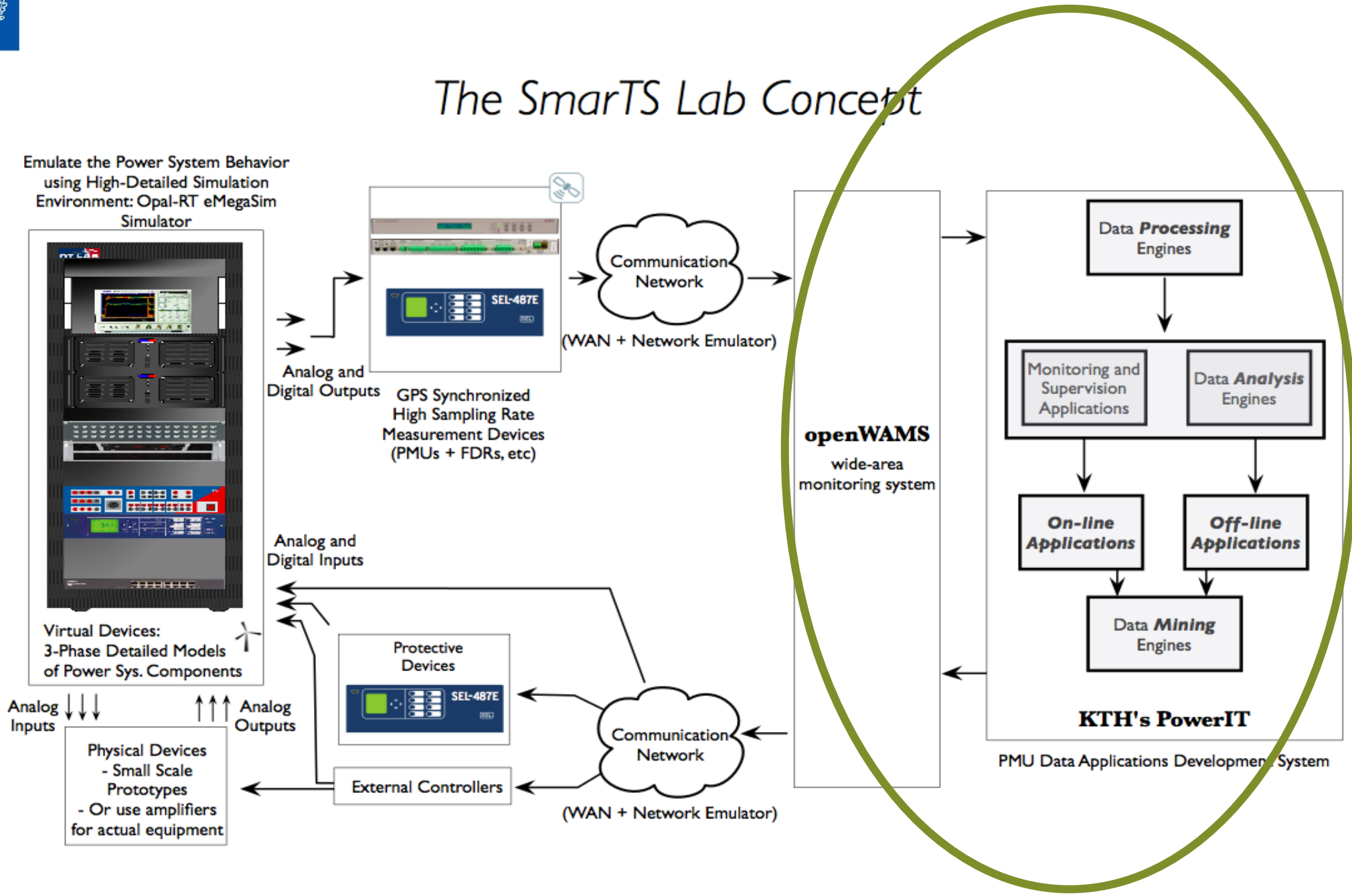
What is observed at the PMU at 50 fps reporting rate?

Generator Mechanical Power Perturbation

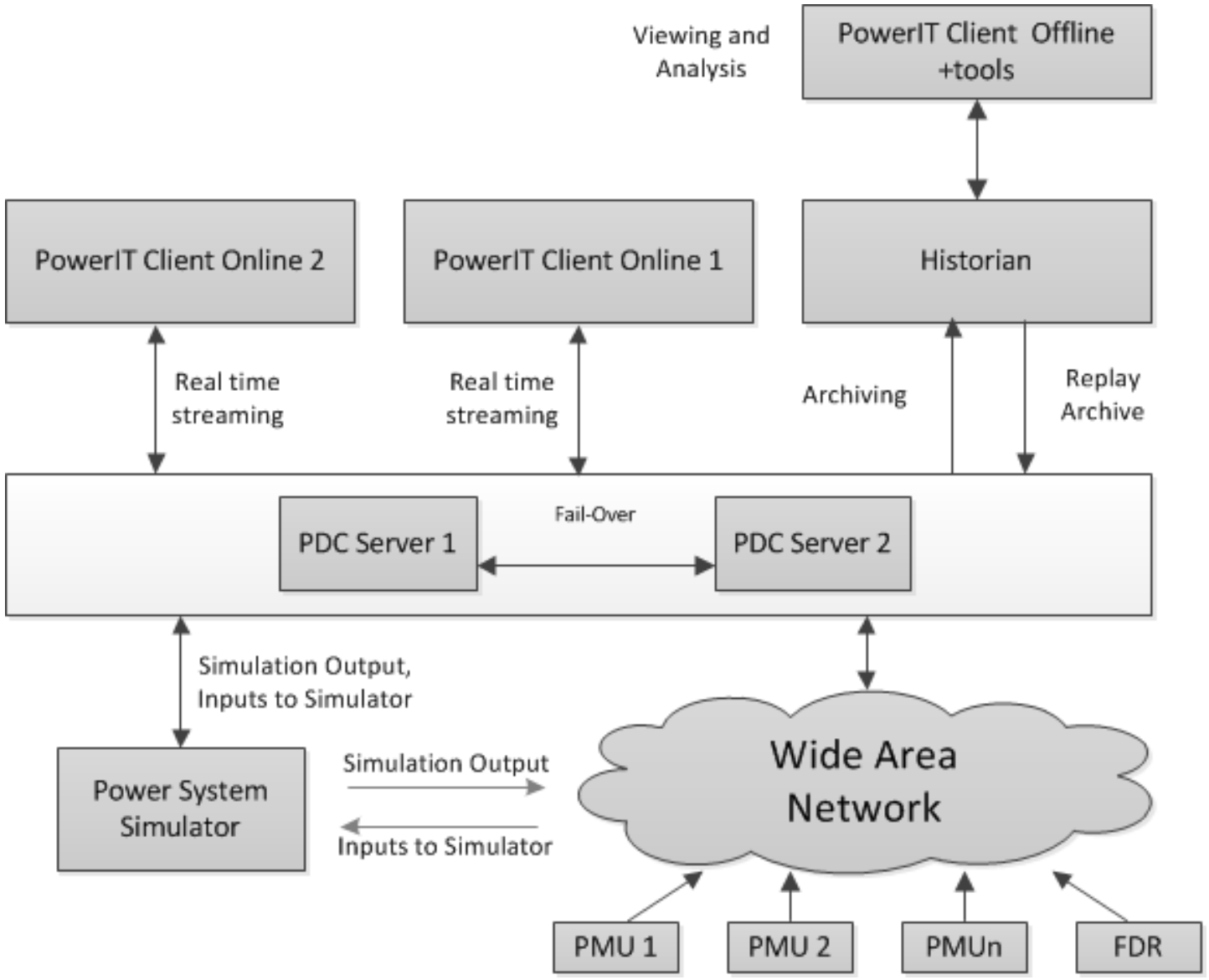




The SmarTS Lab Concept



What is the KTH openWAMs Platform?



What is openPDC /openHistorian

- Originaly Developed by the Tenessee Valley Authority, USA
- Now an open source project supported the Grid Protection Alliance, USA.
- openPDC is A Phasor Data Concentrator
- support many protocols : C37.188, IEEE 1344, FNET, BPA PDCStream.
  - openPDC is A Multi-Protocol Data Concentrator
- Data Concentration is Measurement-based.
  - Concentration is protocol independent
  - openPDC is a protocol independent Phasor Data Concentrator!!!
- The Phasor Data Concentrator is actually just one feature of openPDC.
  - openPDC is a time-series data management platfrom

Open Historian

The function of the Historian is to continously archive data for offline storage and analysis

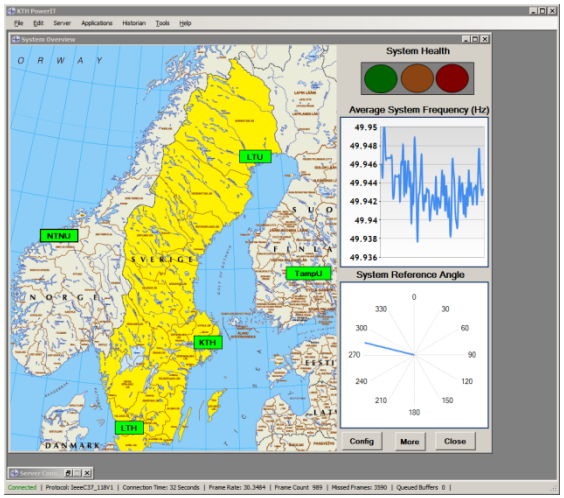
- openHistorian architecture is very similar to openPDC, very flexible and many options:
  - In process historian
  - Remote historian
  - Historian clusters.

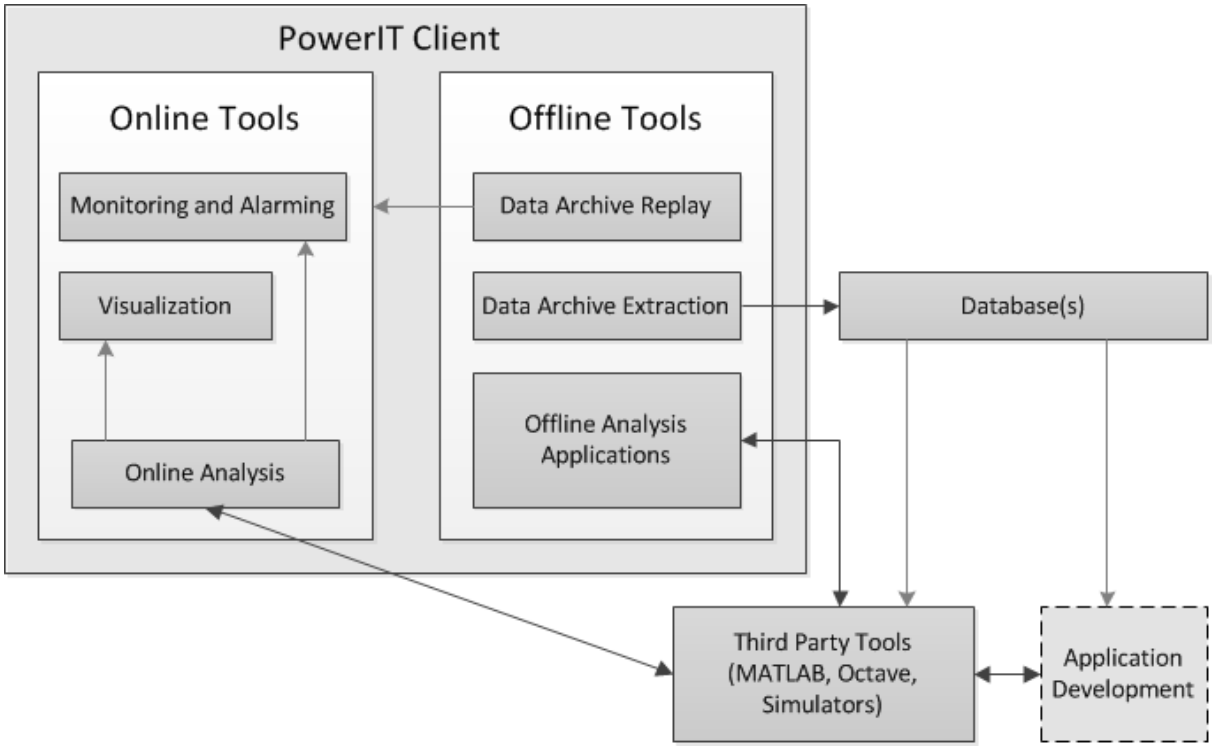
  - Default is ISAM based storage, for efficient storage and retrieval of humungous datasets. Relation Databases can also be used.
  - Supports distributed processing on standard off the shelf hardware.

KTH PowerIT

Developed at KTH cooperation between ICS and EPS.

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

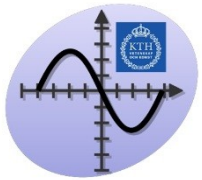


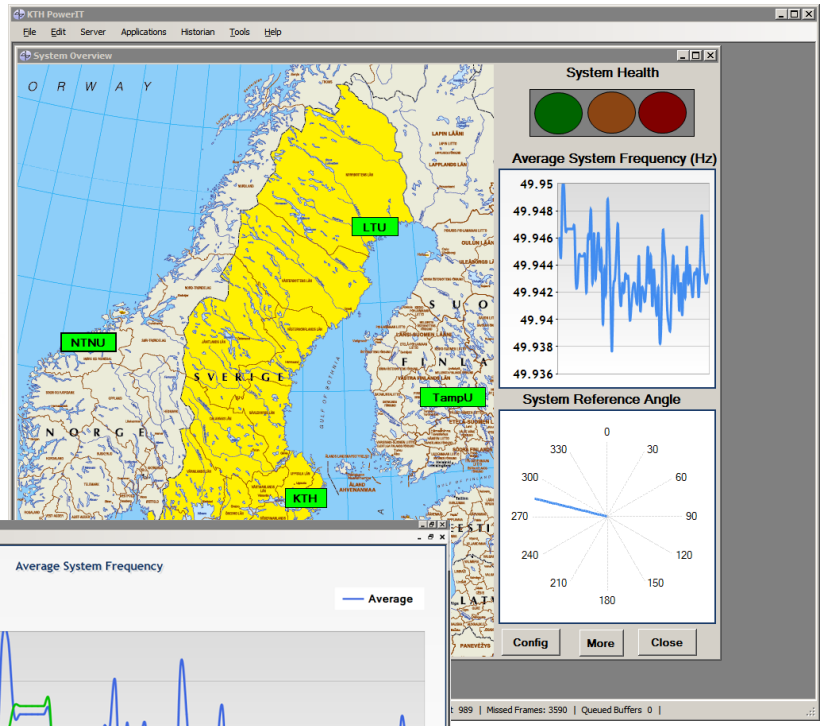


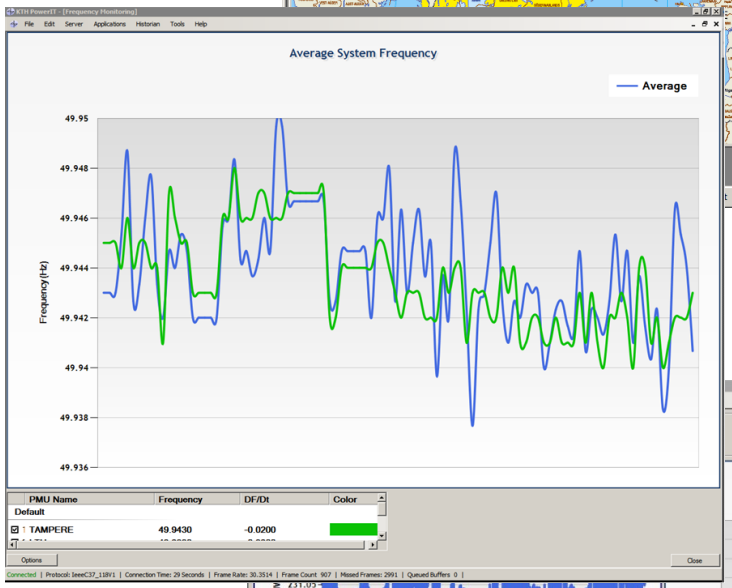
PowerIT Applications

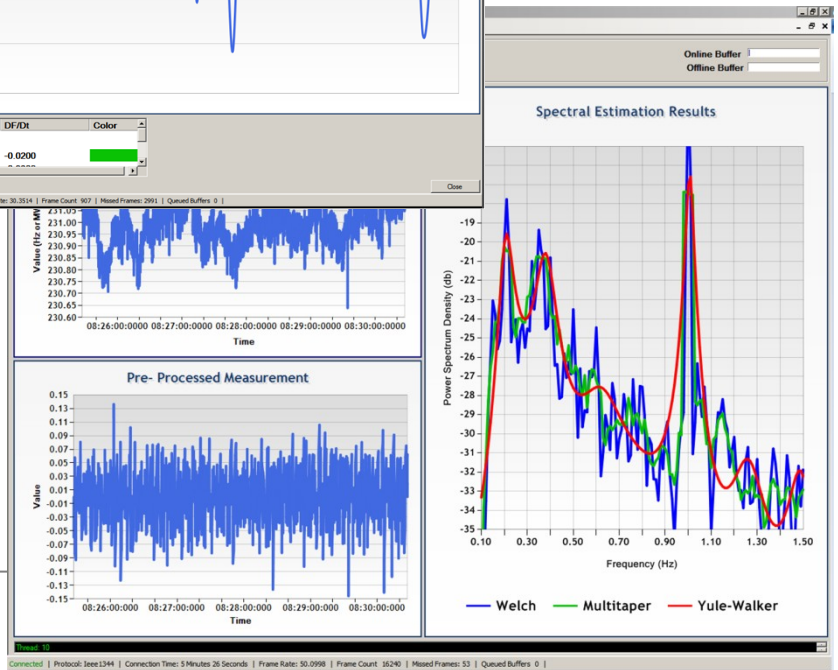
- Implemented a Preliminarly Mode Estimation System
- Implemented standard Frequency Monitoring
- System Overview Monitoring.

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

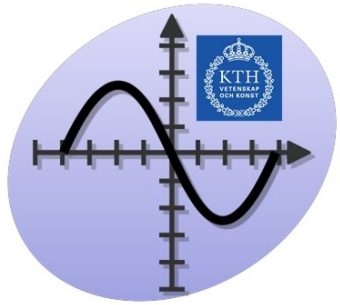


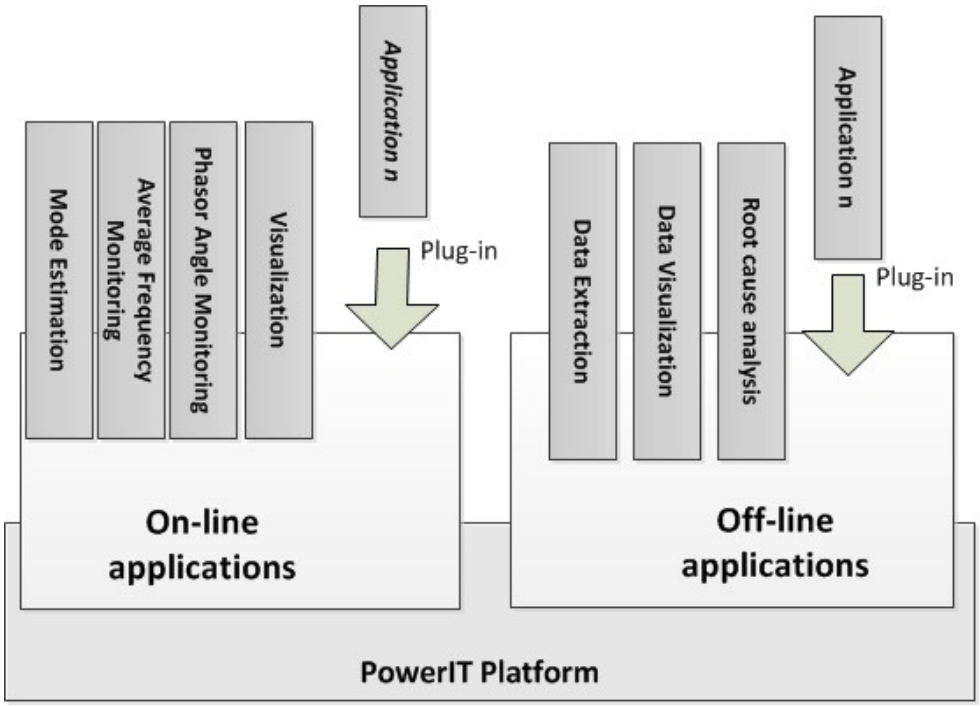


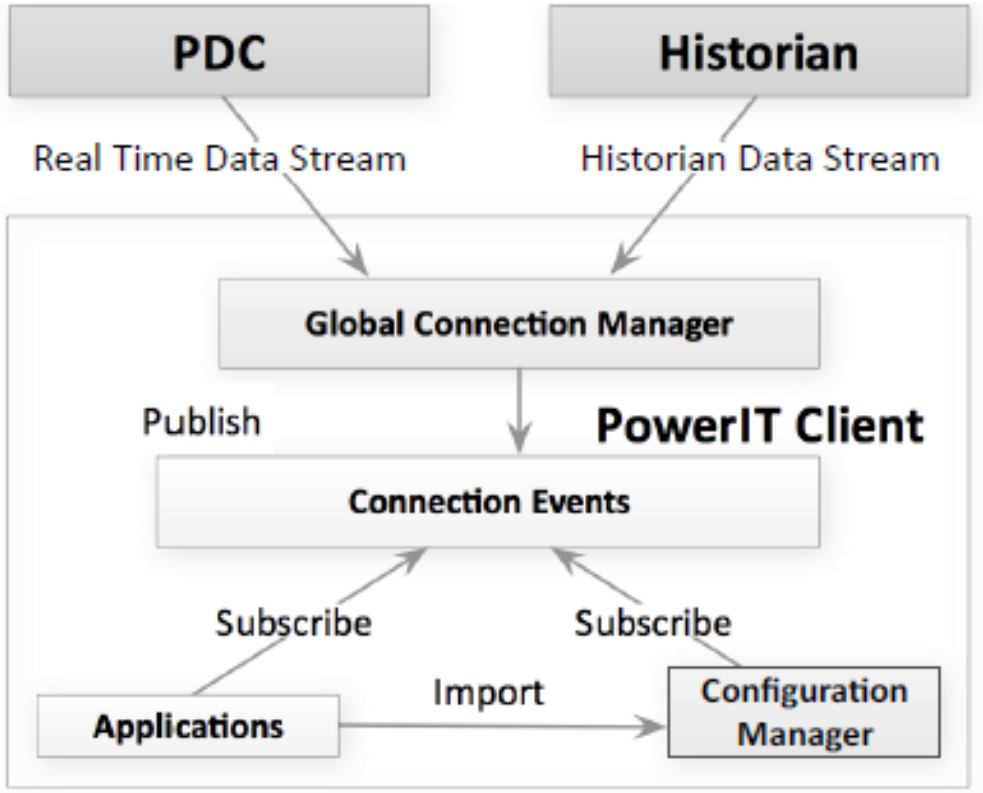




PowerIT Architectural Vision







Current Work in General

- In Terms of the openWAMs:
  - Deployment of openPDC at SvK for testing and collecting system performance.
  - Design of new online Applications : GIS -based monitoring.
  - Smarter Historian Tools design.
- In General:
  - Involved with SvK, specifically in the specification and deployment of the WAMs component of the new SCADA/EMS system

Flavours of the Experimental platforms

1. SmartTS Lab

   Fully fledged Transmission level real-time experimental platform allowing closed loop control with Hardware in the Loop

2. Multi-Agent System platform

   Use of the SmartTS as a SmartDS integrated with distributed control environment

3. Cybersecurity Testbed

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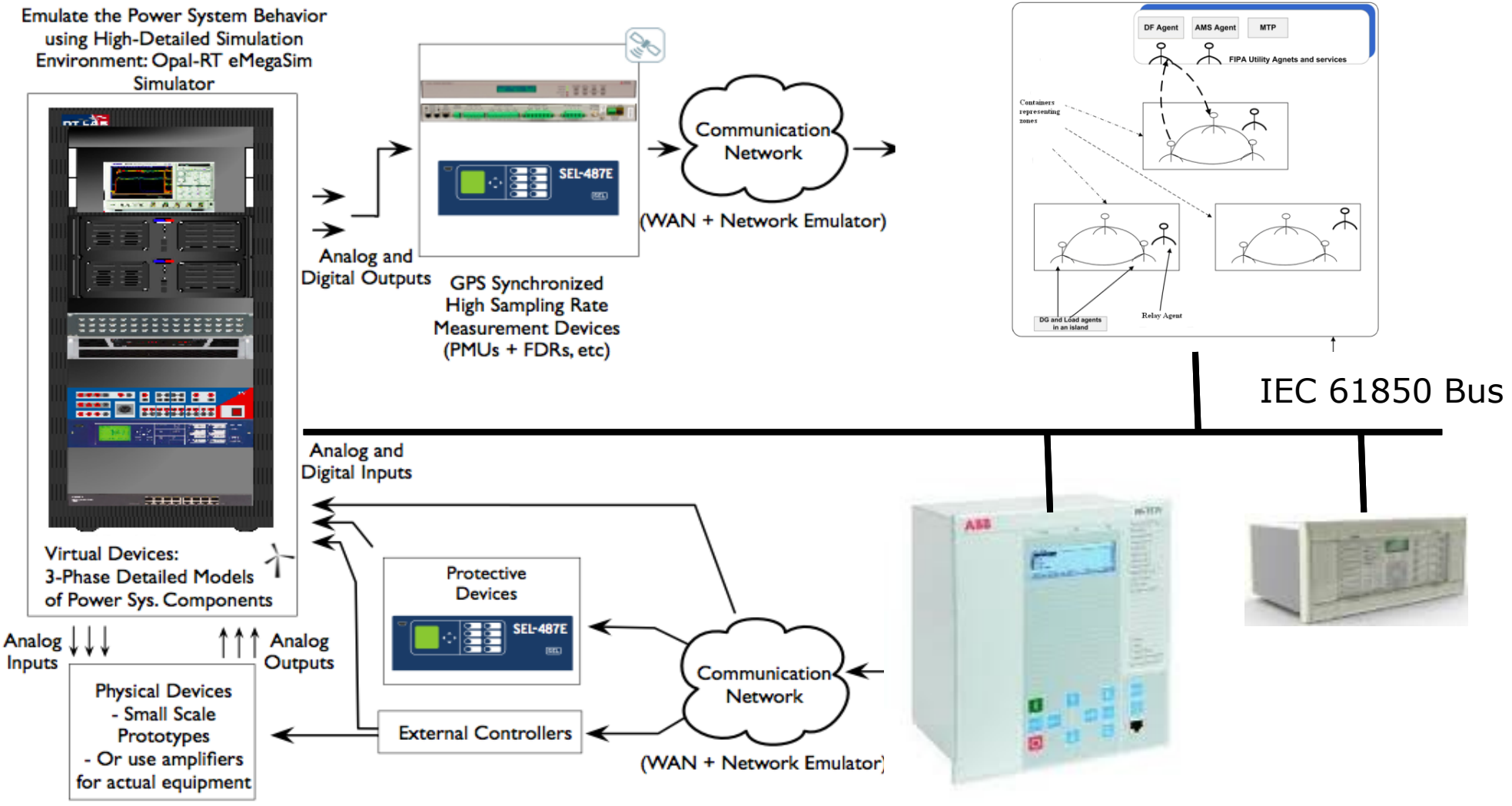
Multi-Agent System platform

The SmarTS Lab Concept



Cybersecurity testbed

IP WAN Emulator

SCADA & EMS

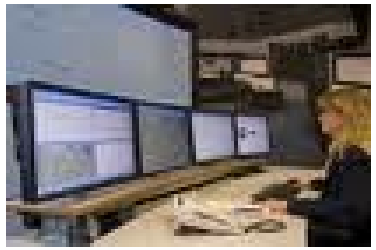
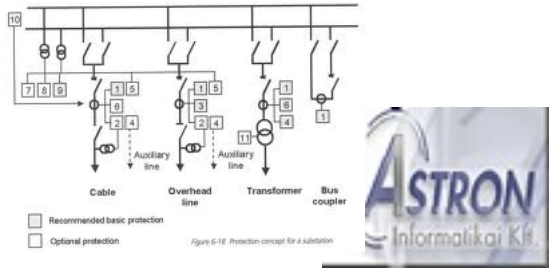


ABB Network Manager
Fully redundant
SCADA& EMS
State Estimator
DPF
OTS

Netcontrol RTUs
IEC 60870-5-101
IEC 60870-5-104



Astron Substation Emulator

Viking City Simulator

Thank You

Questions?

larsn@ics.kth.se