SmarTS Lab

A real-time hardware-in-the-loop laboratory for developing WAMPAC applications

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Smart Transmission Systems Laboratory

NASPI Meeting - Denver

Denver, Colorado – June 5, 2012

Outline

- whoami
- Smart Transmission Systems Research Group
- SmarTS Lab
  - Overall architecture and hardware implementation
  - Comm. and Synchronization Architecture and Implementation
  - Software implementation
  - Model-to-Data Workflow for Hardware-in-Open-Loop and Hardware-in-the-Loop
- SEL Products for Smart Transmission: How we use SEL products
  - How we use SEL products
  - Configuration of relays for Synchrophasors and IEC 61850
  - PDC Configuration
  - Visualization and Historian Configuration
- Research Project Example
- Lessons Learned and Future Research Activities

Smart Transmission Systems Lab. and *Research Group @ Electric Power Systems Department*

- ***Research Group Leader: Dr. Luigi Vanfretti, PhD***
- PhD Students
  - Rujiroj Leelaruji, Methodical command of protection and controllable devices through synchronized measurement technology. Funded by EKC2.
  - Yuwa Chompoobutrgool, Wide-Area Damping through Generator Control. Funded by ELFORSK.
  - Vedran Peric, Estimation of Electromechanical Mode Properties. Funded by Erasmus Mundus SETS PhD Program.
  - Tang Doan Tu, PMU-Assisted Voltage Instability Detection and Control. Funded by Erasmus Mundus SETS PhD Program.
  - Wei Li, Real-Time State Estimation of AC/DC Grids. Funded by the Swedish Energy Agency, SvK and ABB.
  - Muhammad Shoaib Almas, Real-Time Wide-Area Control of FACTS and VSC-HVDC in Hybrid AC and DC Grids . Funded by NER through the STRONGrid project
  - Tatiana Bogodorova, Synchrophasor-based Dynamic Model Validation.Funded by the EC through the iTesla FP7 project.
- MSc Student: Maxime Baudette. Real-Time Monitoring of Intra-Wind Farm Interactions. Start May 2012.

Dr. Luigi Vanfretti

Rujiroj Leelaruji

Yuwa Chompoobutrgool

Vedran Peric

Tang Duan Tu

Wei Li

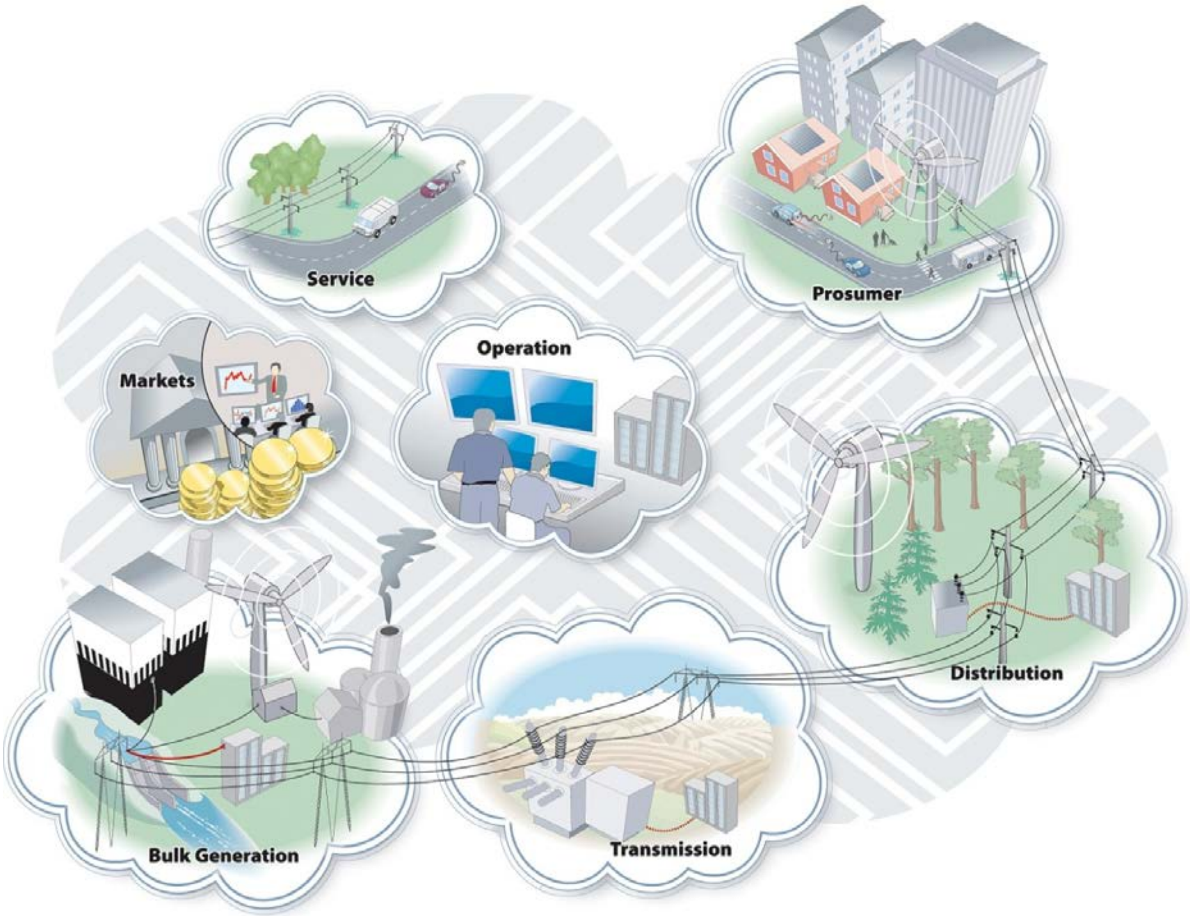
Shoaib Almas

Tetiana Bogodorova

Maxime Baudette

PhD Students

MSc. Students



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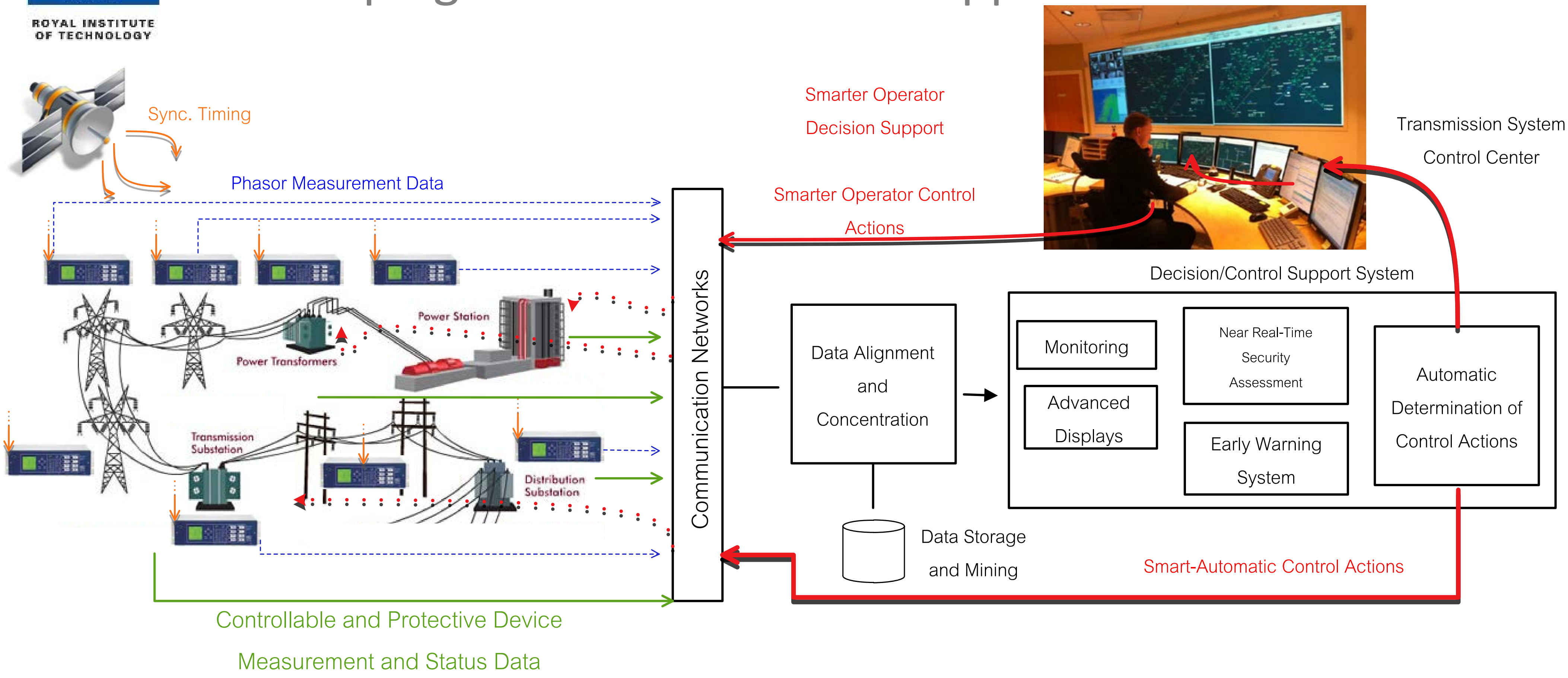
The Smart Transmission Systems Lab.

How to develop a controlled environment for developing Smart Transmission Apps?



- Smart Grid require **Smart Operation, Smart Control and Smart Protection**:
  - 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
- ***To achieve this vision, new applications need to be developed in a controlled environment, allowing testing and considering the ICT chain***

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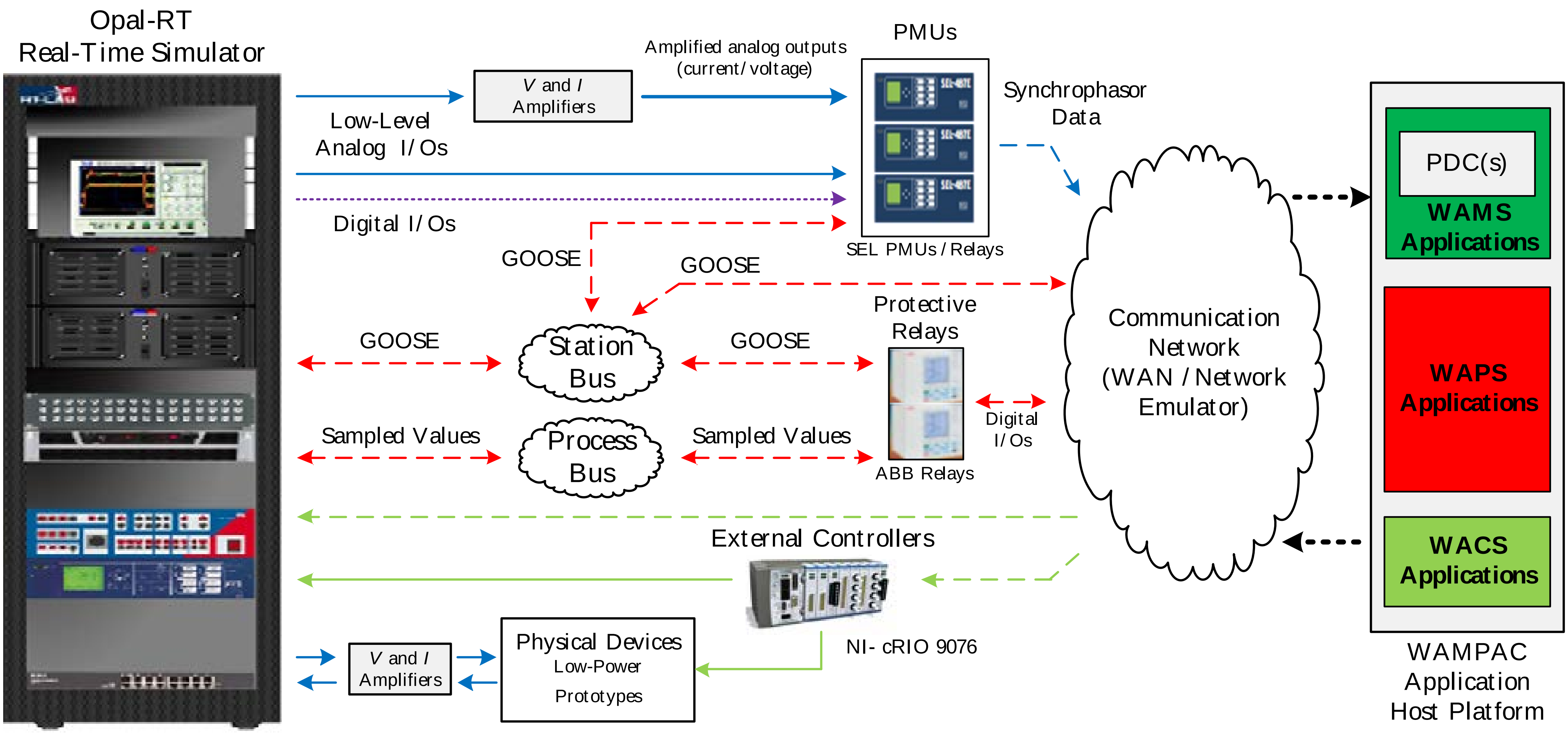
SmarTS Lab
Smart Transmission Systems Laboratory

The SmarTS Lab Architecture



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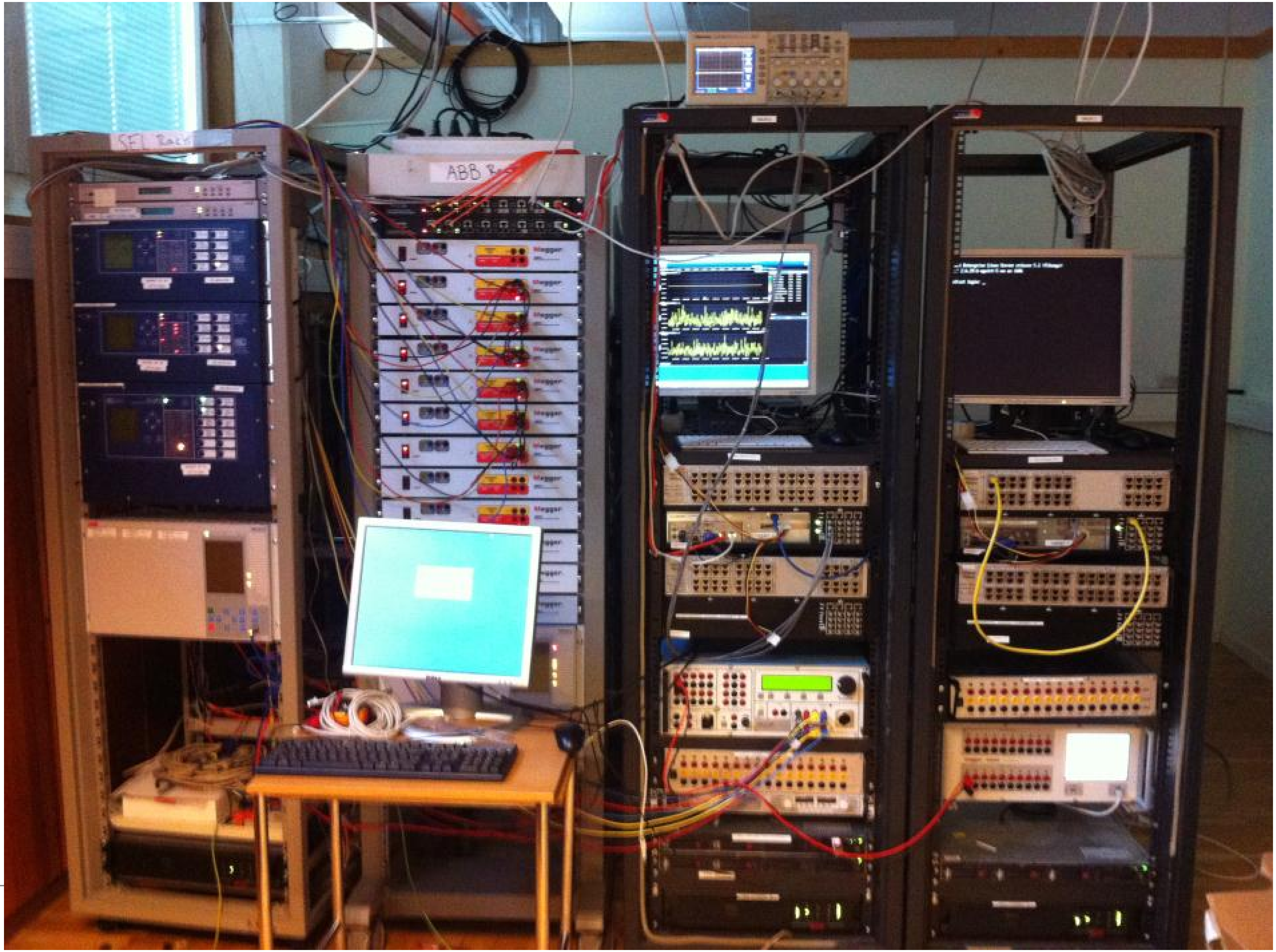
Hardware Implementation



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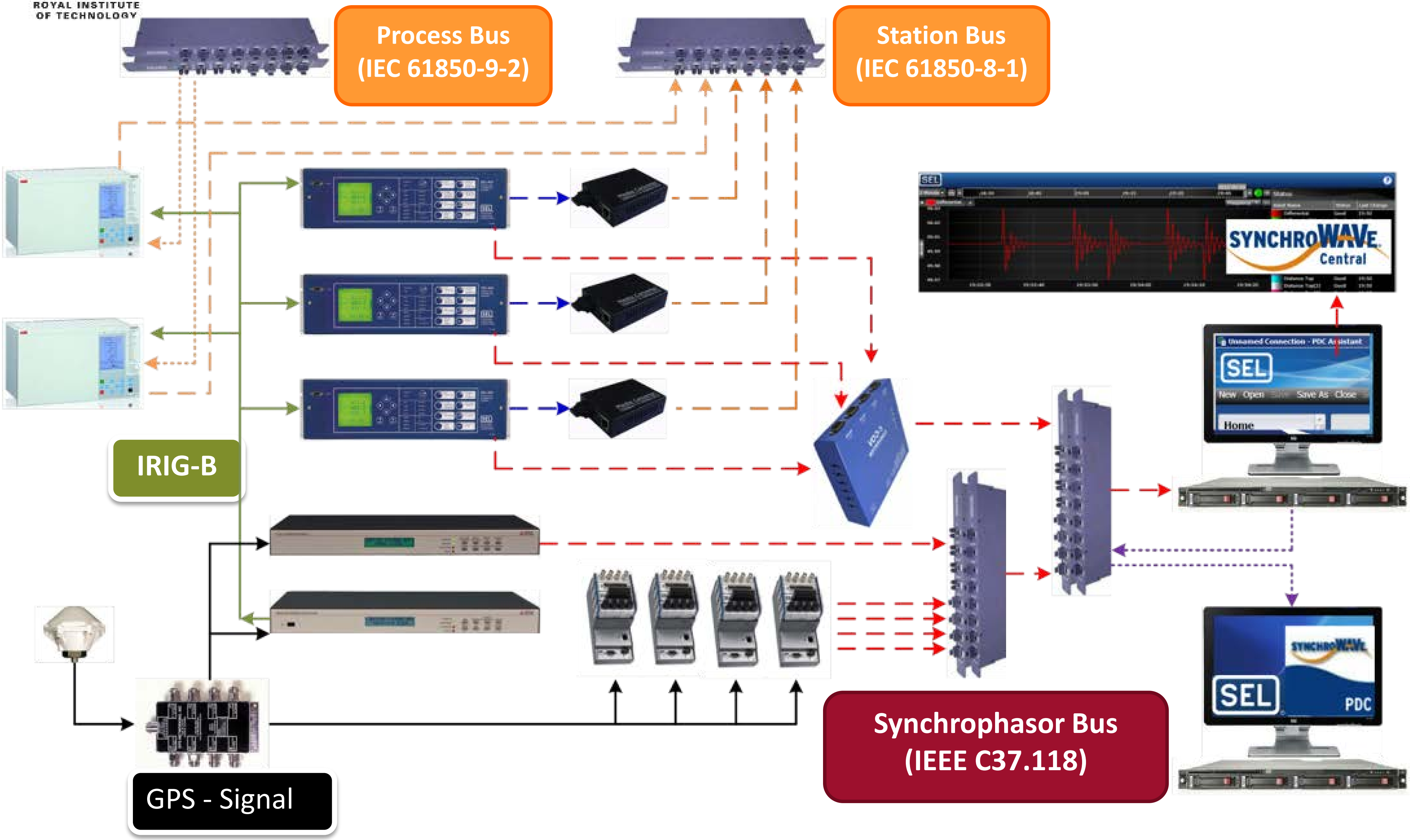
Comm. and Synchronization Architecture and Implementation



Synchrowave Phasor Data Concentrator – Gathering PMU Measurements, Time Alignment and Archival

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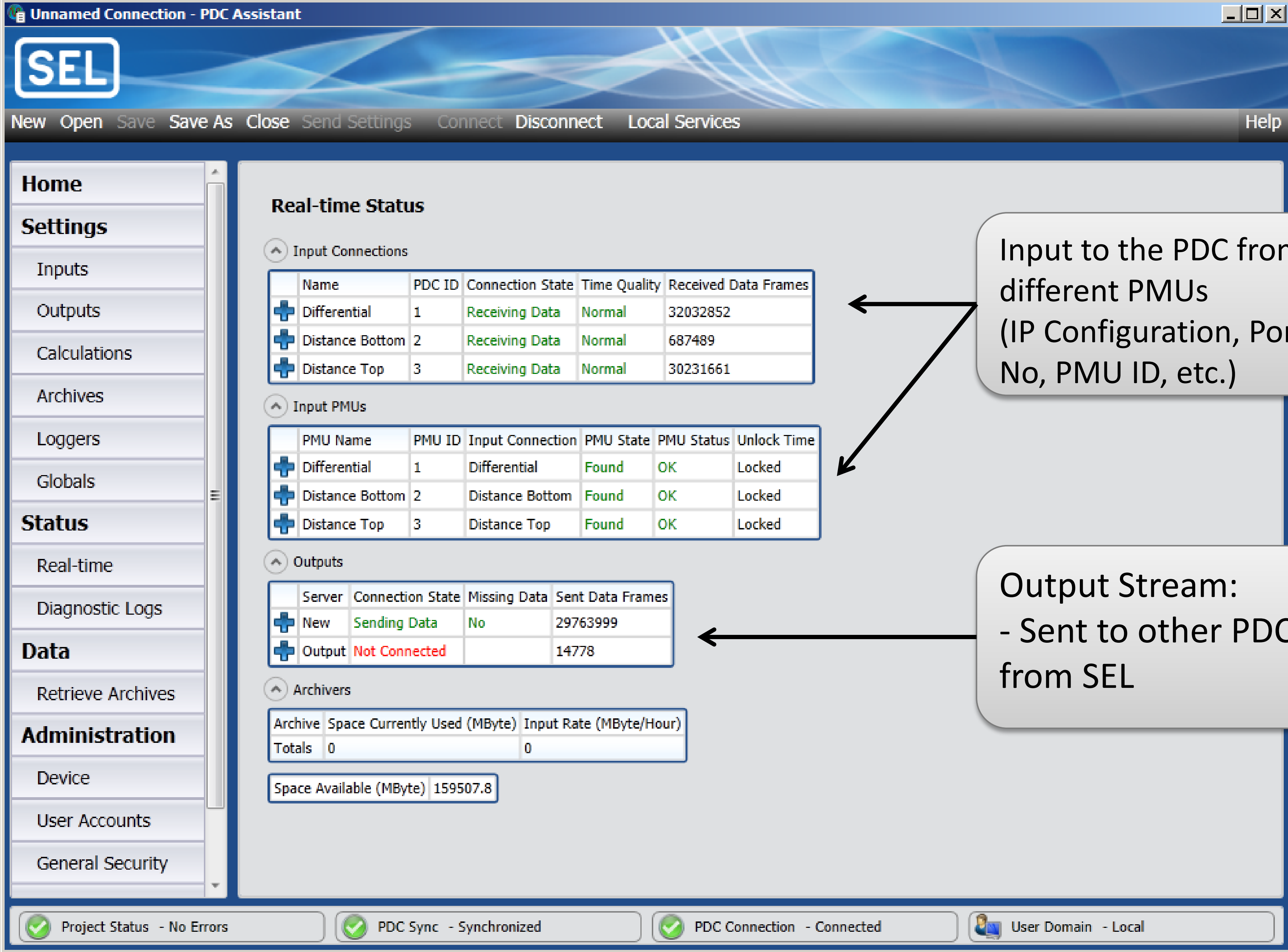
Software Implementation



Input to the PDC from 3 different PMUs (IP Configuration, Port No, PMU ID, etc.)

Output Stream:
- Sent to other PDC from SEL

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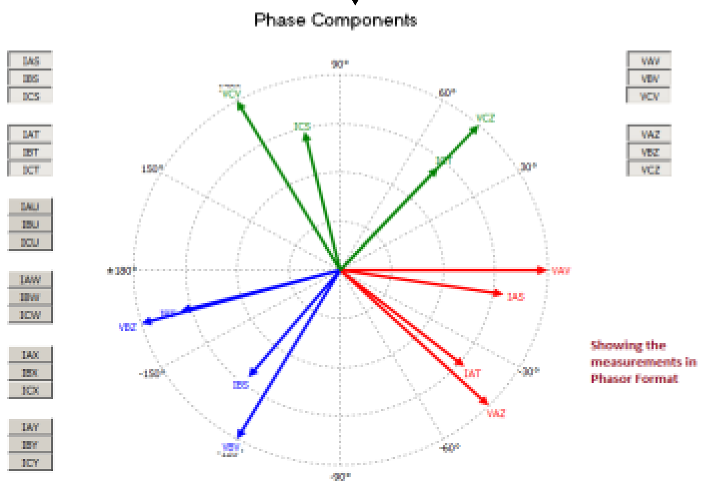
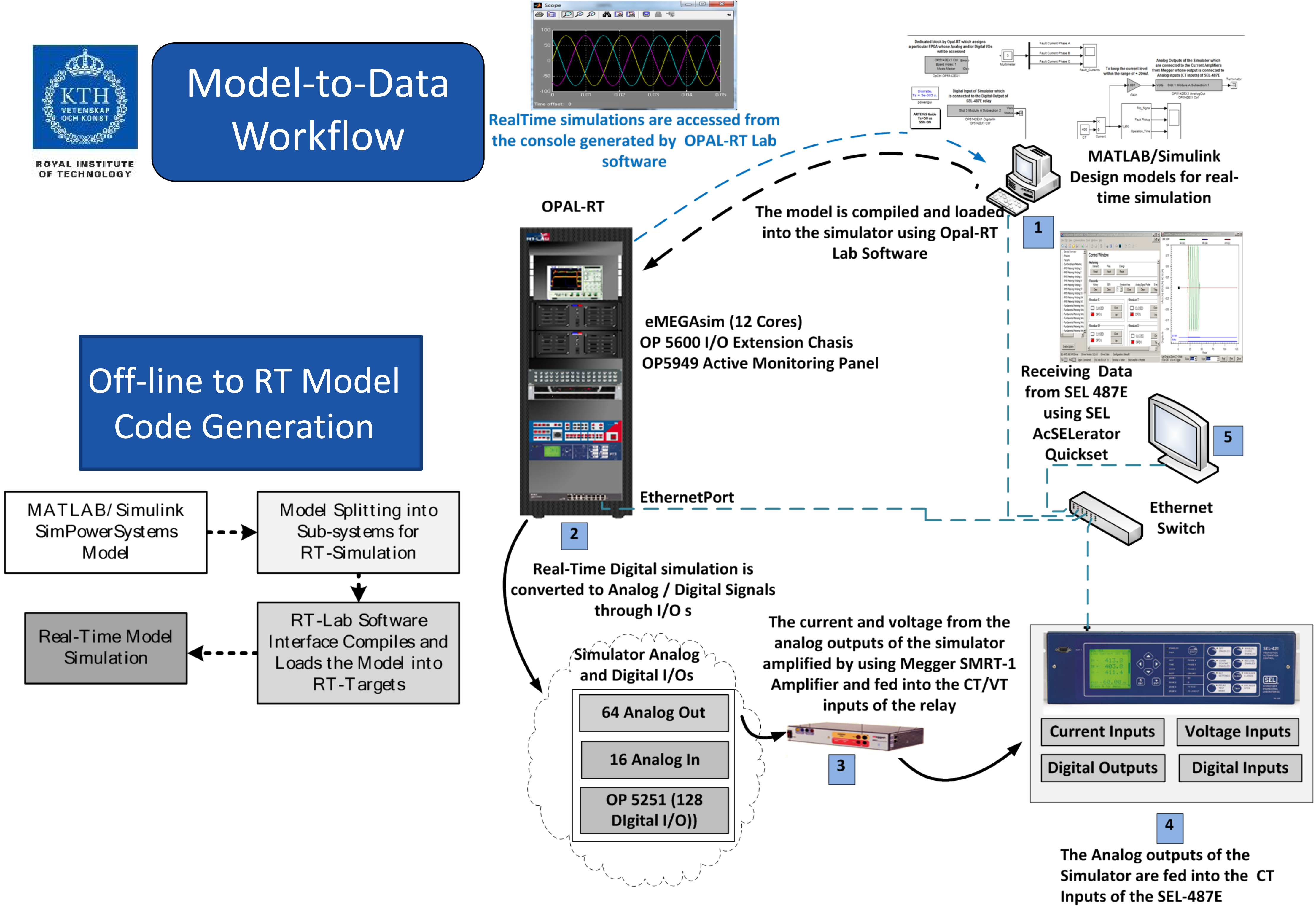
SmarTS Lab
Software Implementation

Synchrowave Central (Visualization of PMU Data)
SEL AcSELerator Quickset (Relay Settings and HMI)

Display of real-time PMU data streams from SEL PDC

SEL AcSELerator Display for Voltage and Current Phasors

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Model-to-Data Workflow
Off-line to RT Model Code Generation
MATLAB/ Simulink SimPowerSystems Model
Model Splitting into Sub-systems for RT-Simulation
RT-Lab Software Interface Compiles and Loads the Model into RT-Targets
Real-Time Model Simulation
RealTime simulations are accessed from the console generated by OPAL-RT Lab software
MATLAB/Simulink Design models for real-time simulation
The model is compiled and loaded into the simulator using Opal-RT Lab Software
1
OPAL-RT
eMEGAsim (12 Cores)
OP 5600 I/O Extension Chasis
OP5949 Active Monitoring Panel
EthernetPort
2
Receiving Data from SEL 487E using SEL AcSELerator Quickset
5
Ethernet Switch
Real-Time Digital simulation is converted to Analog / Digital Signals through I/O s
Simulator Analog and Digital I/Os
64 Analog Out
16 Analog In
OP 5251 (128 DIgital I/O))
The current and voltage from the analog outputs of the simulator amplified by using Megger SMRT-1 Amplifier and fed into the CT/VT inputs of the relay
3
Current Inputs
Voltage Inputs
Digital Outputs
Digital Inputs
4
The Analog outputs of the Simulator are fed into the CT Inputs of the SEL-487E

Model-to-Data Proof of Concept Experiment (Hardware-in-Open-Loop)

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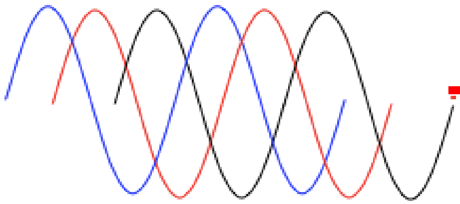
Real-Time Simulator



Generate 3-Phase RT Signals (Voltages and Currents)

Output signals, low level through simulator I/Os (+/- 16 V., +/- 20 mA)

Amplifier

Amplifying from low-level to standard rating (1-60 Amp, 60-300 V)

PMU/Relay

PMU Transmits Computed Phasors through Serial Port

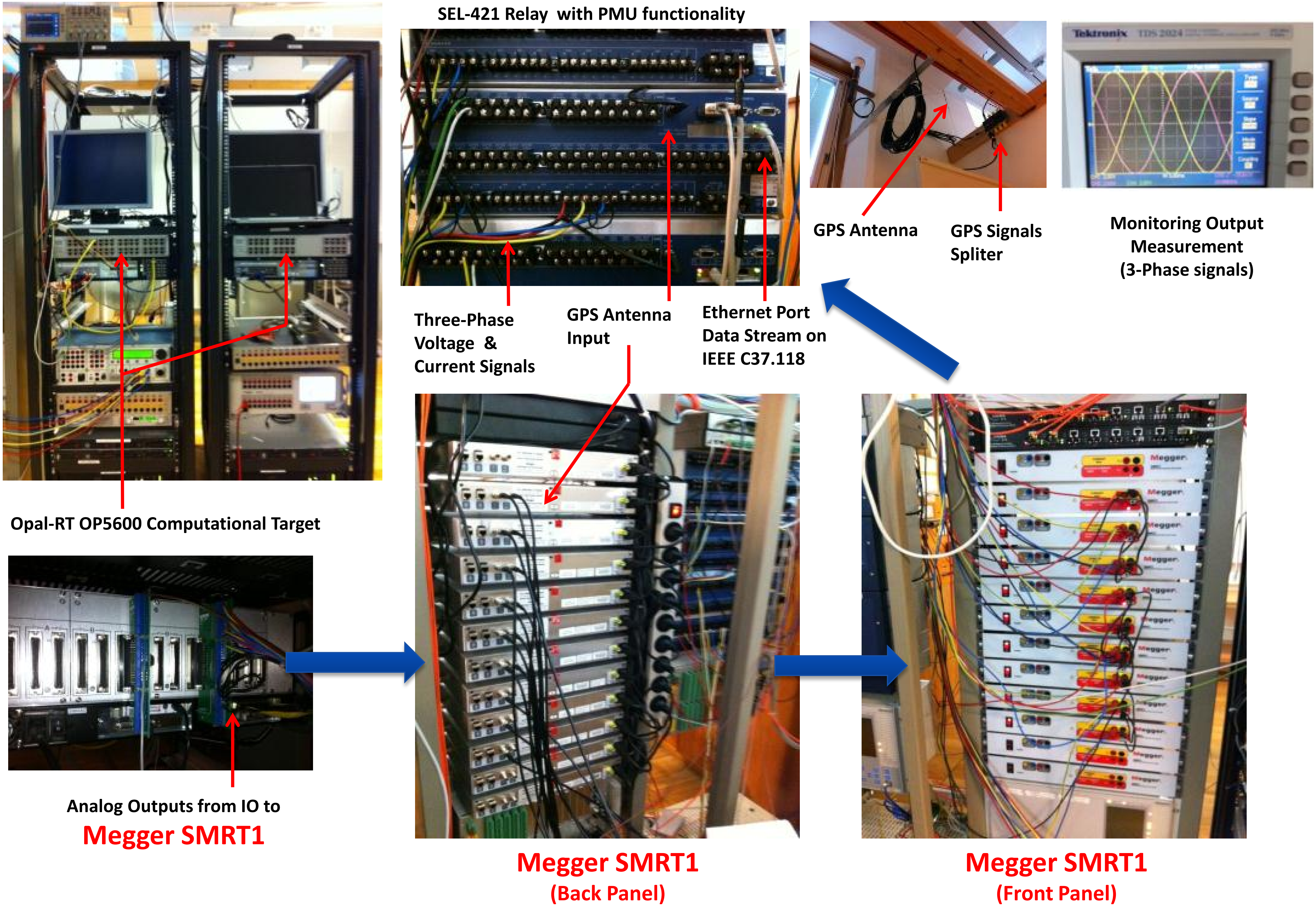
Media Converter

RS232 to TCP/IP over Ethernet

SEL Synchrowave PDC

Hardwired

Ethernet


SEL-421 Relay with PMU functionality
GPS Antenna
GPS Signals Spliter
Monitoring Output Measurement (3-Phase signals)
Three-Phase Voltage & Current Signals
GPS Antenna Input
Ethernet Port Data Stream on IEEE C37.118
Opal-RT OP5600 Computational Target
Analog Outputs from IO to
Megger SMRT1
Megger SMRT1
(Back Panel)
Megger SMRT1
(Front Panel)
Tektronix TDS 2024
Megger

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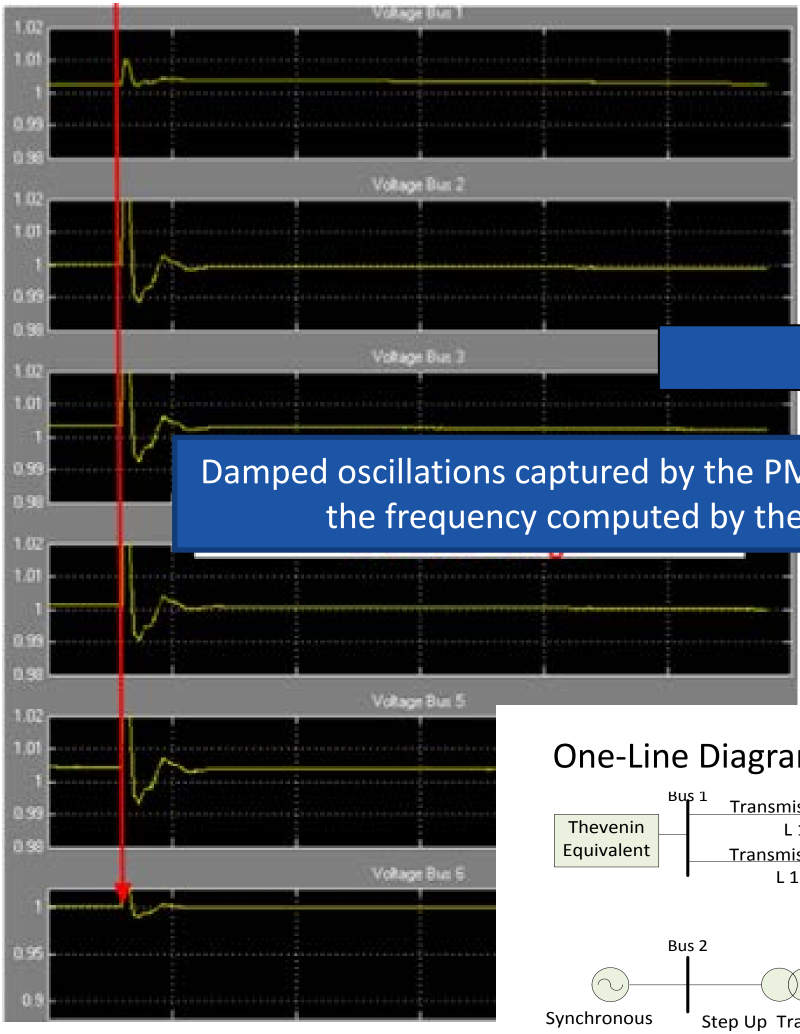
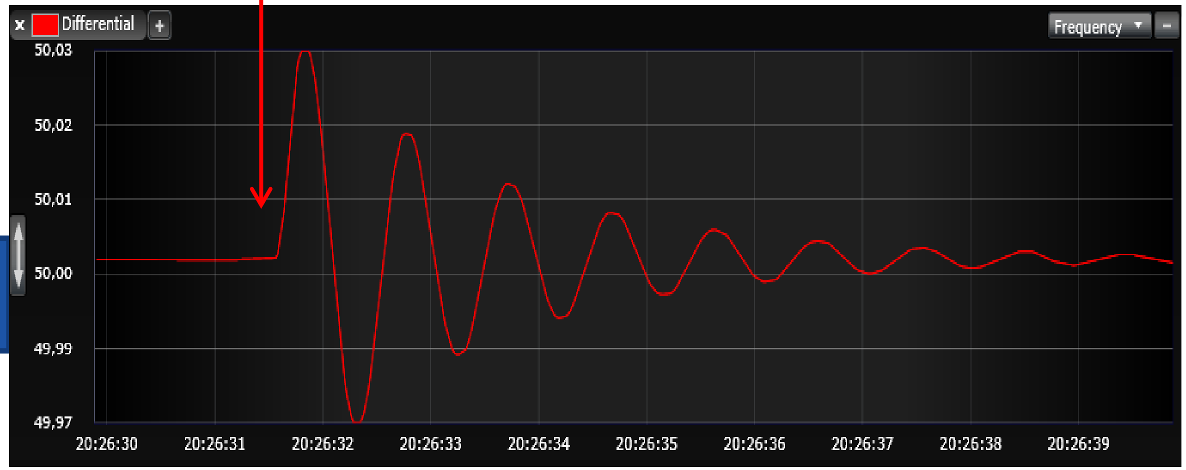
The whole process in real-time:
Interaction with the model in real-time (Hardware-in-open-loop)

Generator mechanical power perturbation

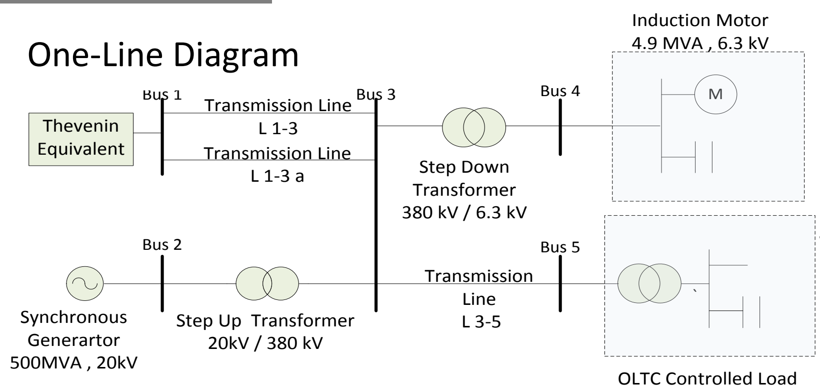


What is observed at the PMU at 50 fps reporting rate?

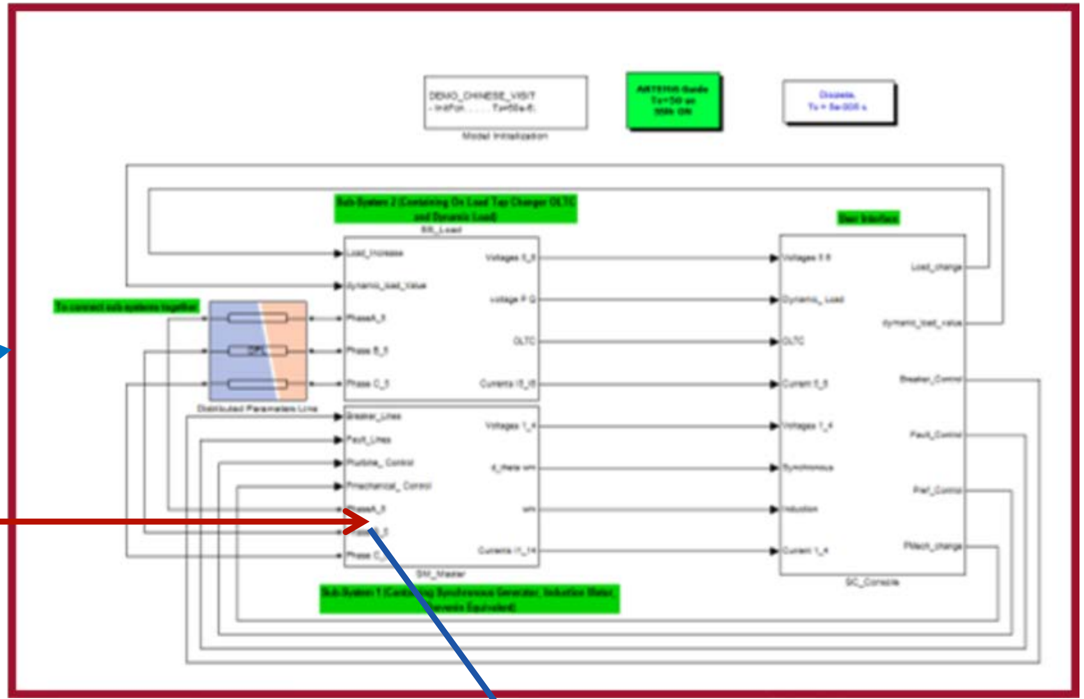
Generator mechanical power perturbation

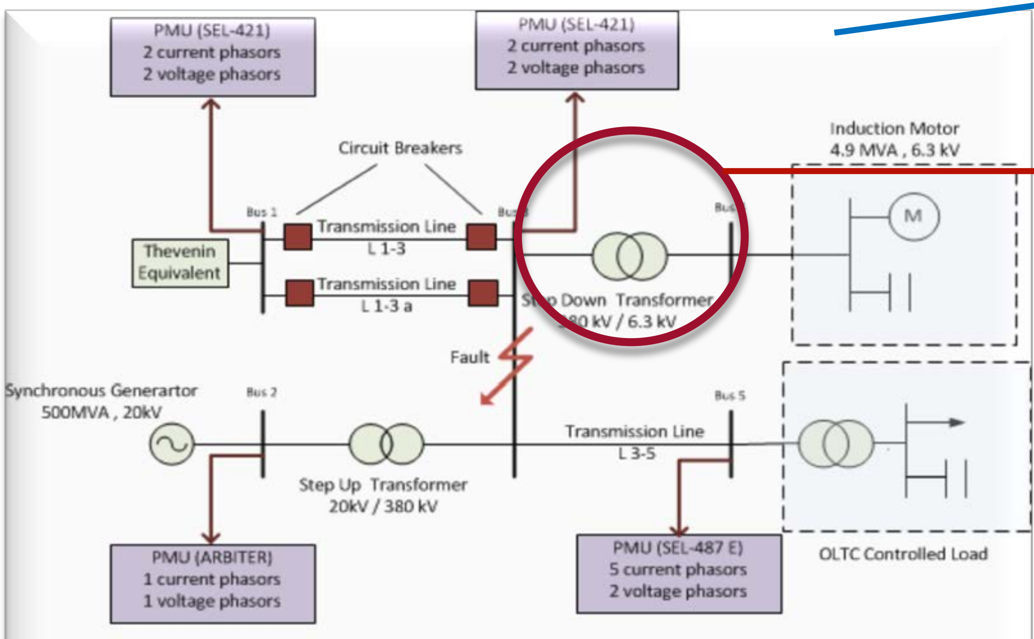


Damped oscillations captured by the PMU at 50 fps in the frequency computed by the PMU

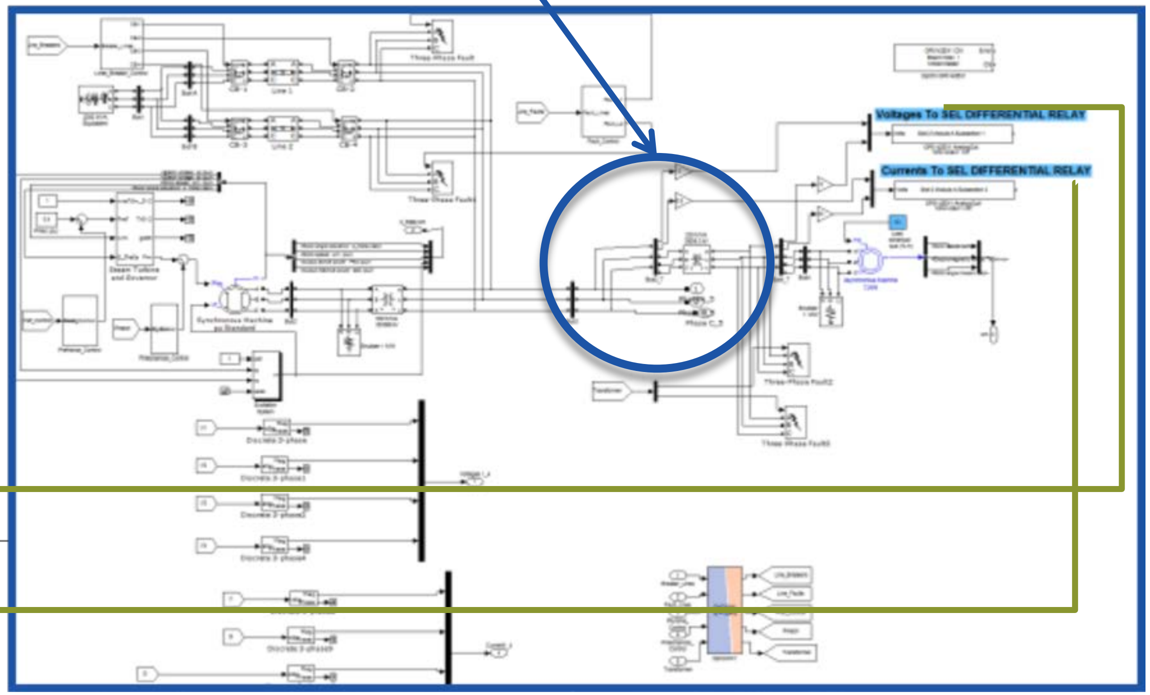


Modeling for Real-Time Hardware-in-the-Loop Simulation

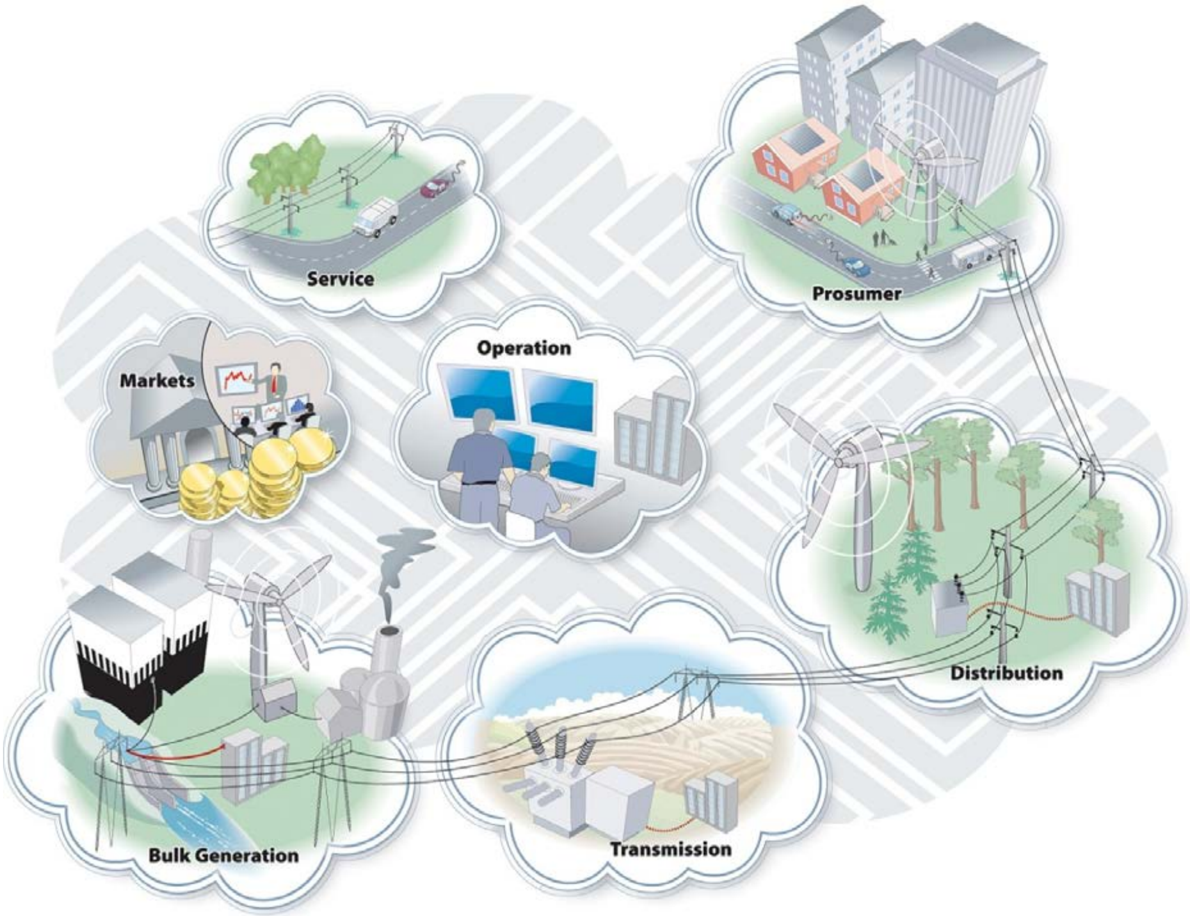




Analysing the dynamics of the Power System By Disconnecting Lines, Inserting Faults, Shedding Loads, etc.



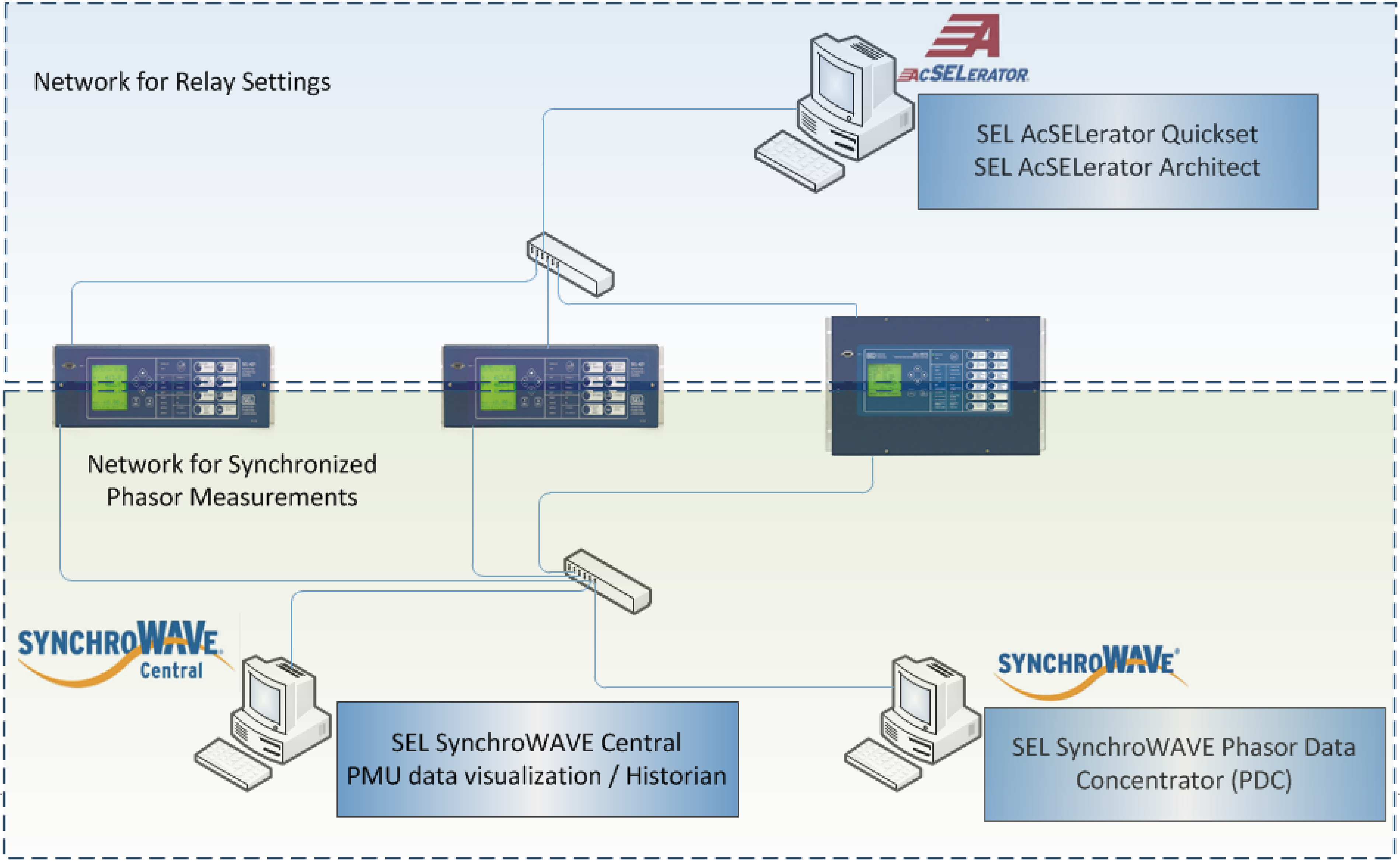
Video!



SEL Products for Smart Transmission

How we use SEL Products in our Lab.

How we use SEL products in SmarTS Lab?



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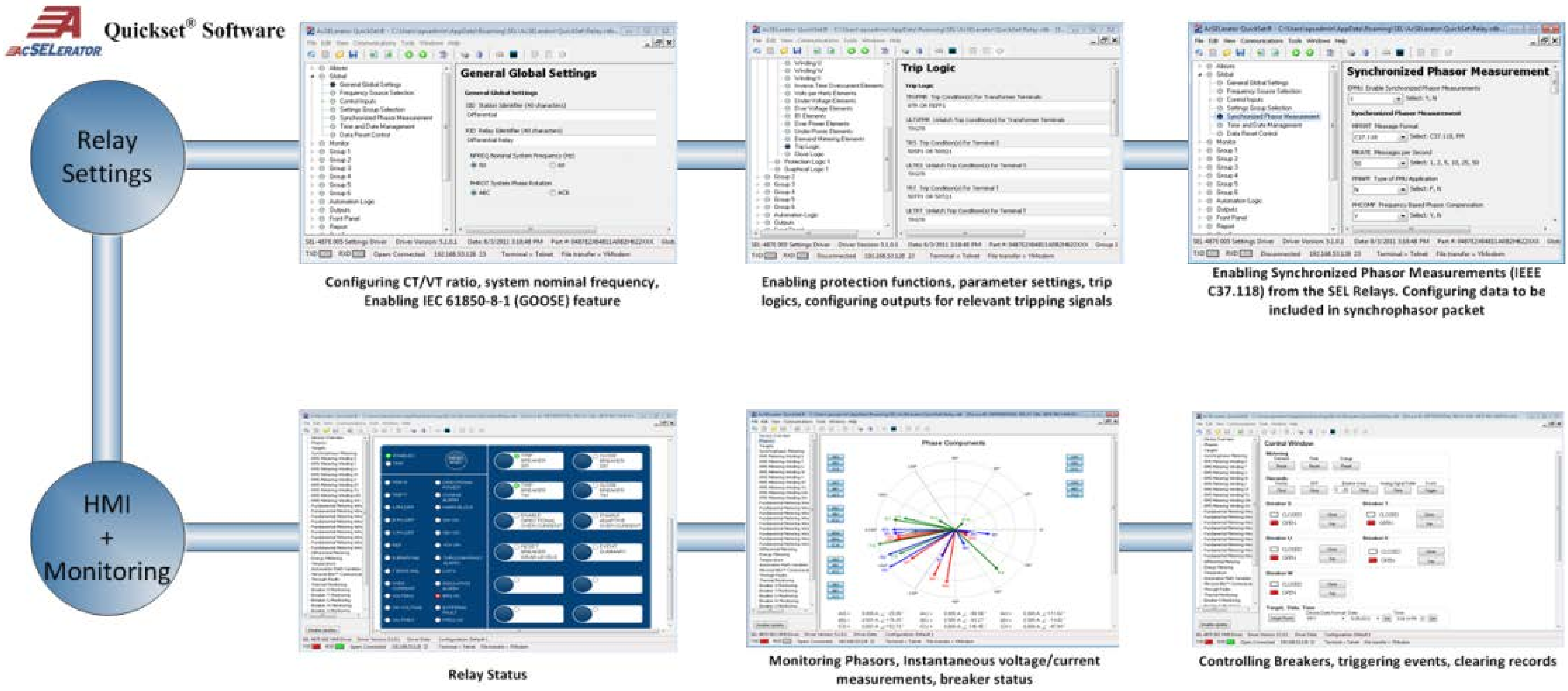
Configuring Relay and PMU Features



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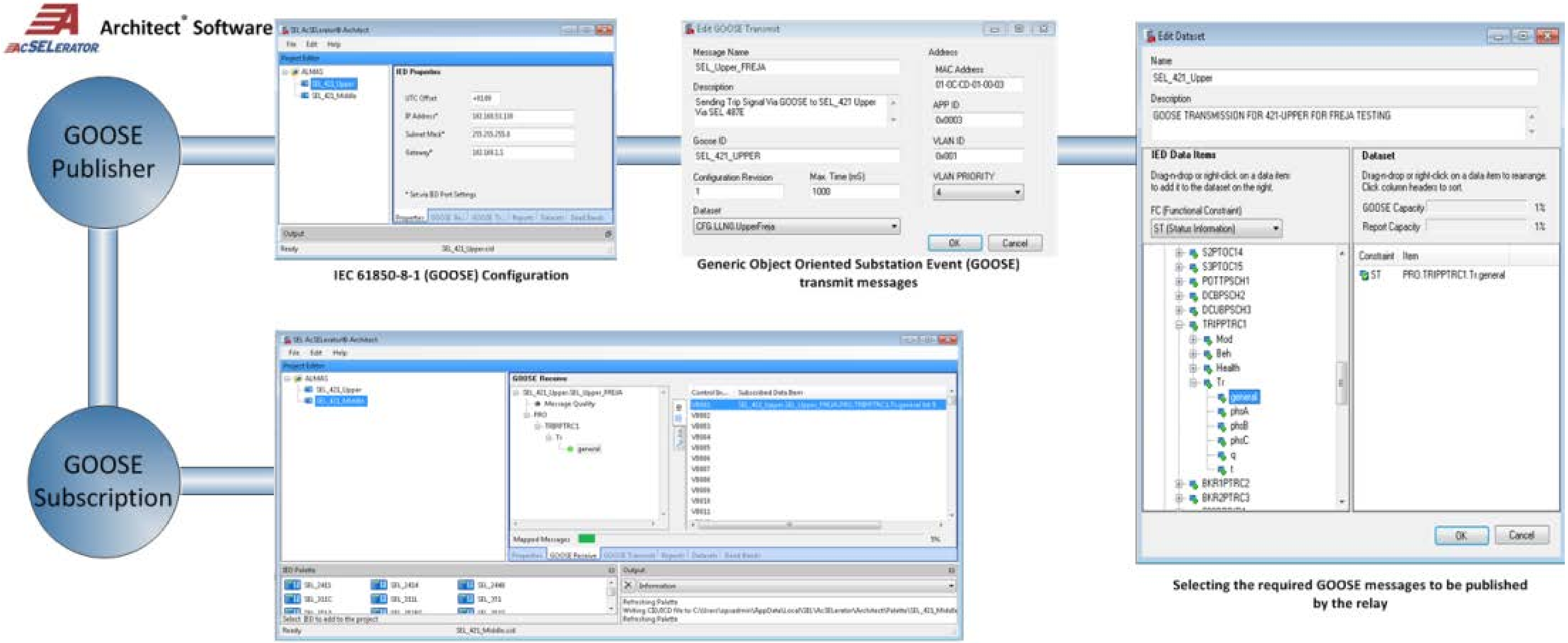
Configuring IEC 61850-8-1 (GOOSE) Features



IEC 61850-8-1 (GOOSE) Configuration

Generic Object Oriented Substation Event (GOOSE) transmit messages

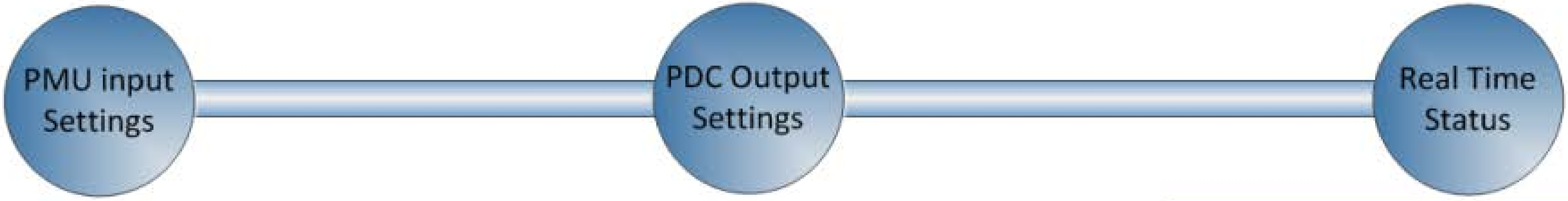
Selecting the required GOOSE messages to be published by the relay

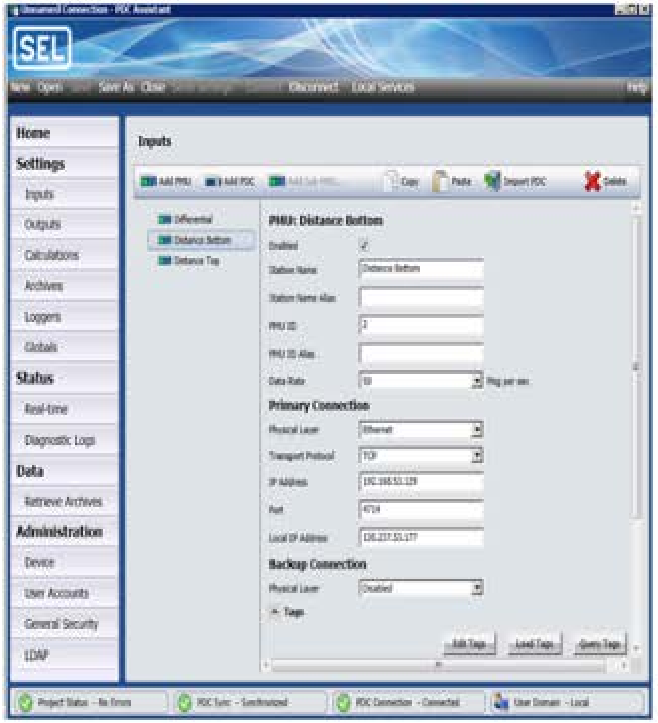
Map GOOSE receive messages to IED's input bits from SEL and non-SEL relays

Configuring Synchrophasor Data Concentrator

SYNCHROWAVE

Phasor Data Concentrator





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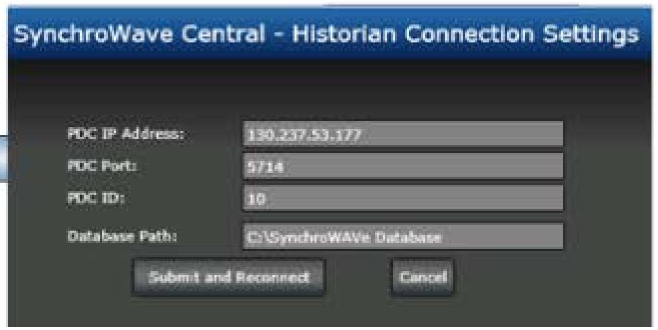
Visualization and Historian Configuration

Real-time or Historian Display

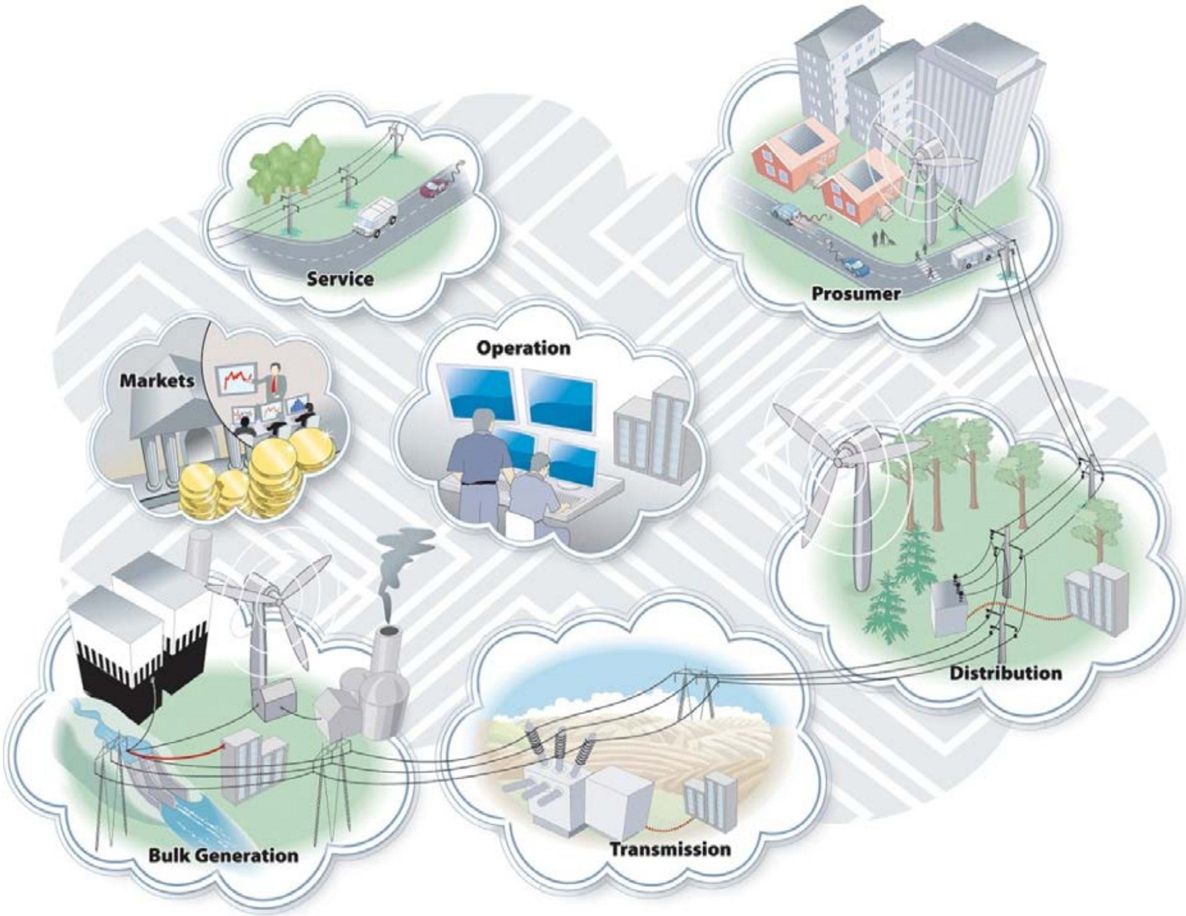
SYNCHROWAVE Central **PMU data Visualization Software**

PMU data Visualization

Historian Setting



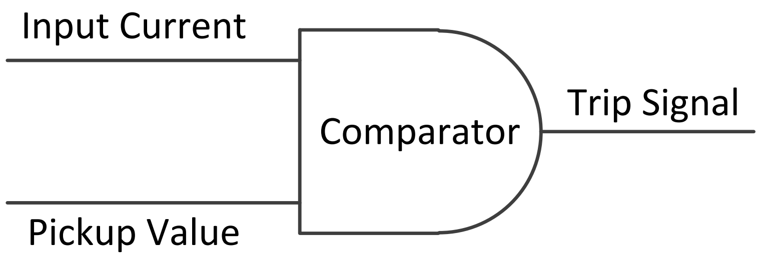
PDC IP Address, PDC Port number and PDC ID should be the same as set in the outputs of PDC SEL-5073 software



Research Project Example

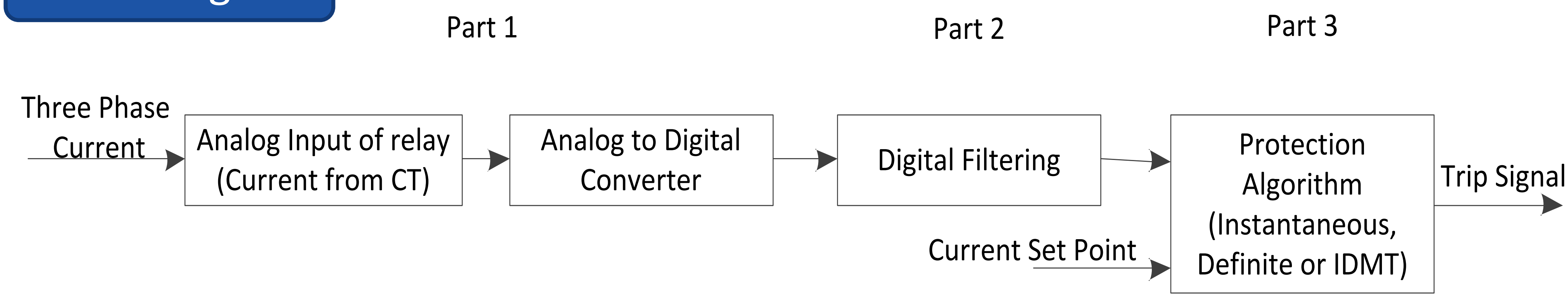
Overcurrent Relay Modeling and Validation for PMU-Assisted Protection

Model Validation of an Over-Current Relay

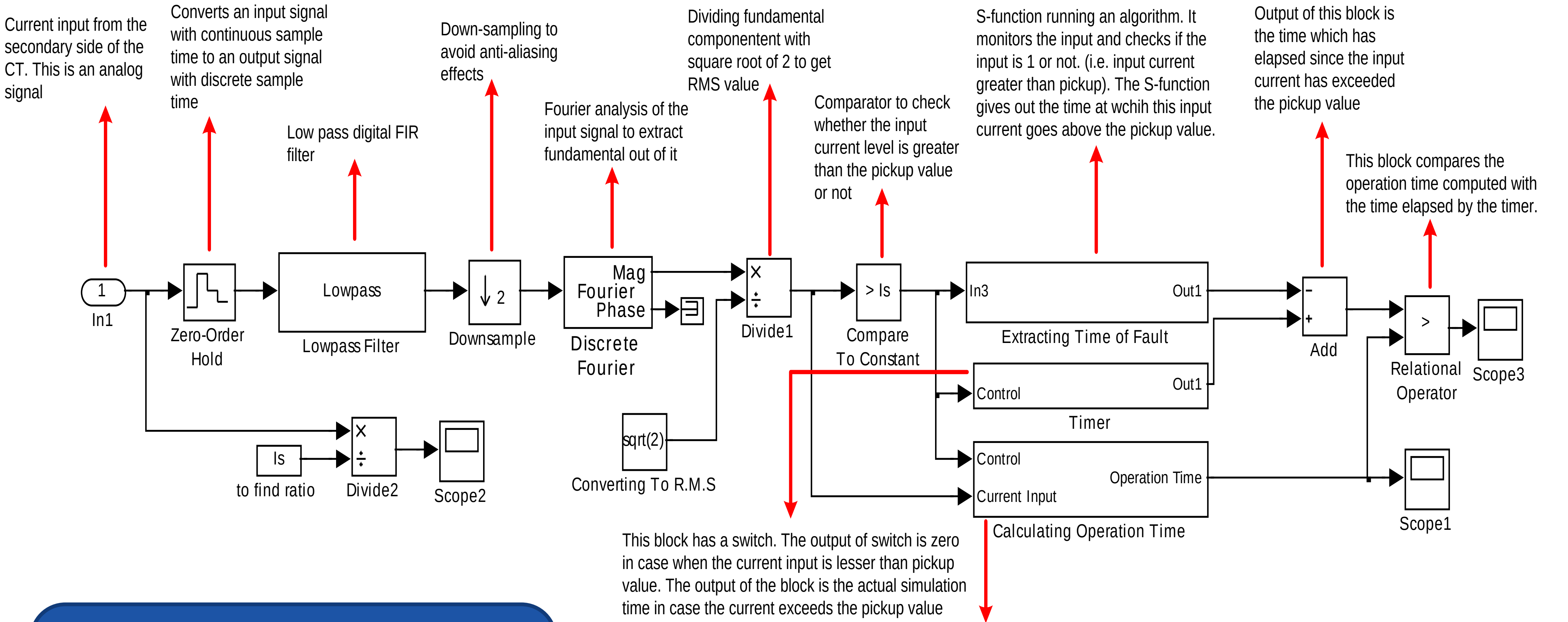


Principle

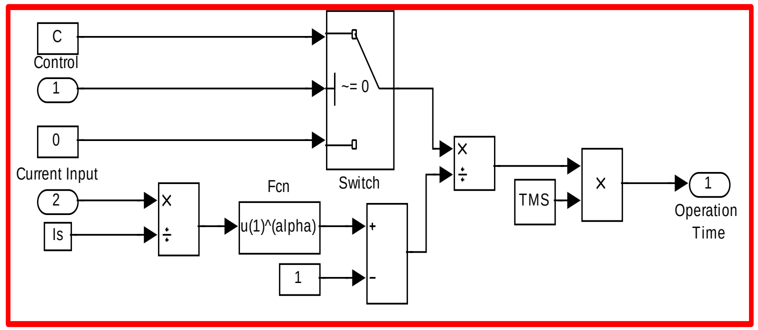
Block Diagram



Modeling and Implementation for RT Simulation



Implementation in SimPowerSystems (MATLAB/Simulink)



This block implements the mathematical equation $T = \frac{C}{\left(\frac{I}{I_s}\right)^{\alpha} - 1} \times TMS$ to compute the operation time corresponding to the type of characteristic curve chosen by the user

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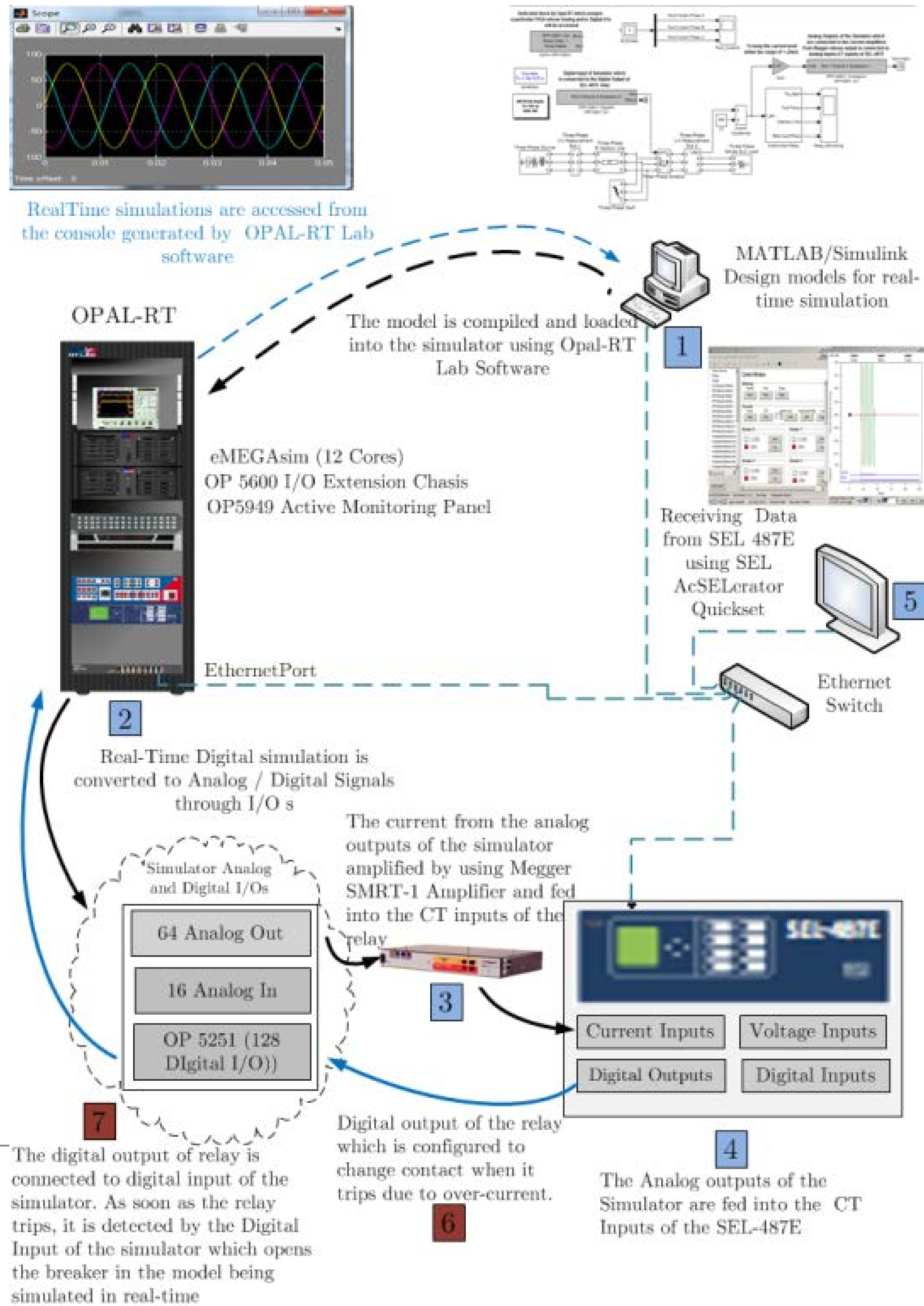
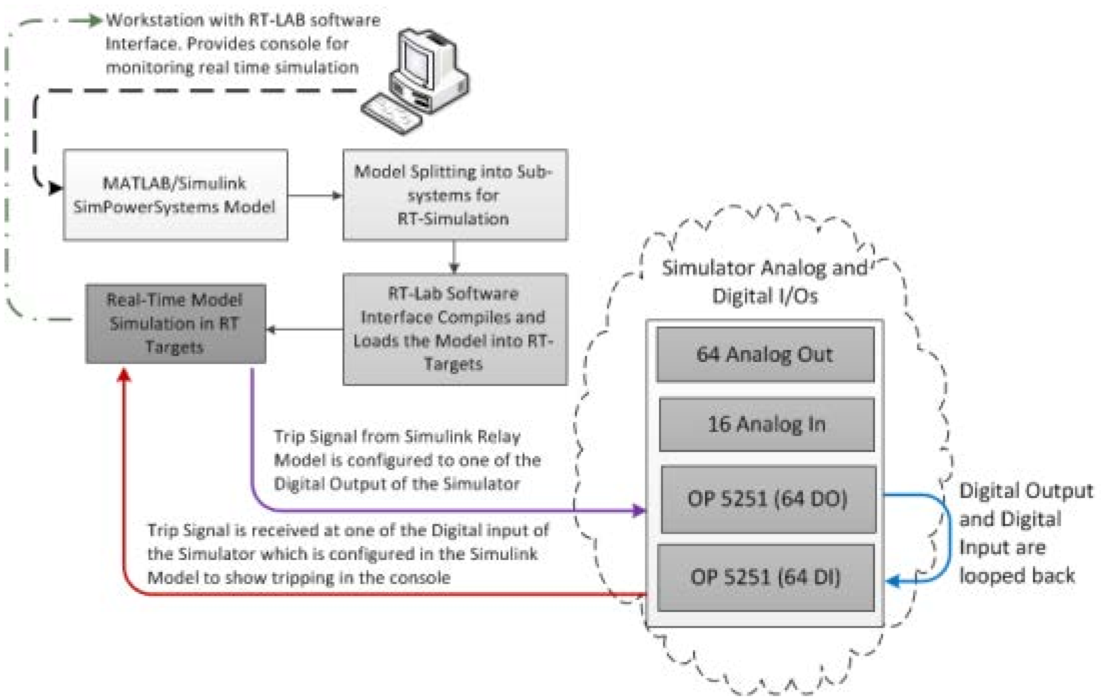
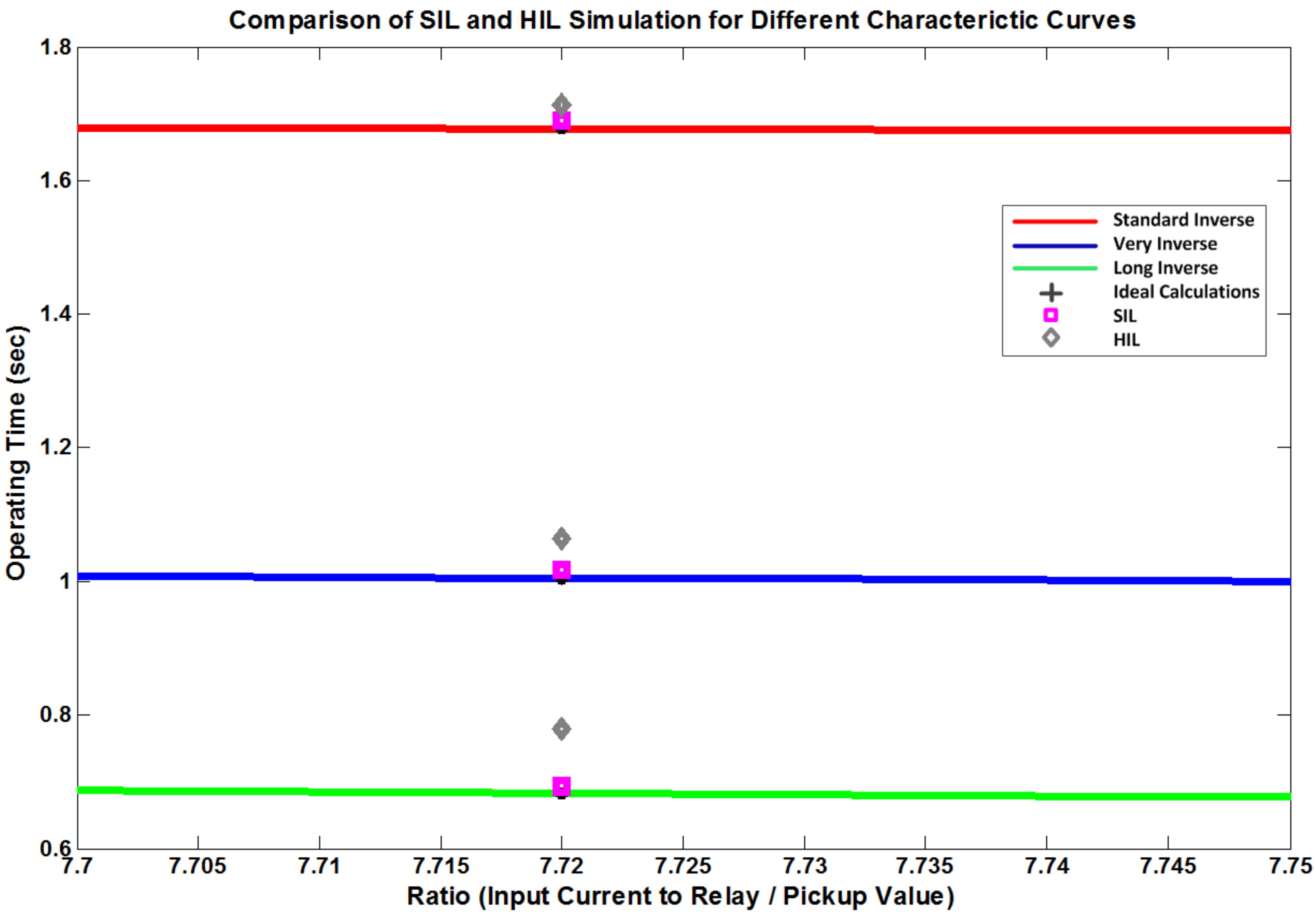
Hardware-in-the-Loop Validation



Software-in-the-Loop Validation



Validation Results



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Lessons Learned
A fun experience!

- When building such laboratory, many details need to be considered: Cost and Procurement.
  - Choice of real-time simulator - It should fit your needs - Research needs ≠ industry needs.
- When operating such lab., a broad range of expertise is needed:
  - Clear knowledge on Real-Time modeling and simulation, with associated modeling phylosophy
  - From configuration of relays/PMU to PDC, and beyond (media converters, comm. network…)
- Having devices that are flexible in their configuration is very helpful:
  - SEL products have make it possible to configure different experiments without complications.
  - The generosity of SEL made it possible to have the **justification** to make additional expenses.
- Big lessons:
  - Separate your communication networks depending on the data type they will carry.
    - In our experiments having large amounts of PMU data had large impacts in the performance of IEC-61850-8-1 and -9-2 (relay trip time was longer than using hardwires)
    - Performance can be enhanced by separating IEC-61850-8-1, -9-2, and PMU data - having IEC-61850-8-1 operate **even faster** that hardwired tests.
    - Question: how can this be dealt with when all of the data will be under IEC 61850 with PMU under -9-5?
  - When using amplifiers, synchronization between each amplification source can be source of error for protection applications.

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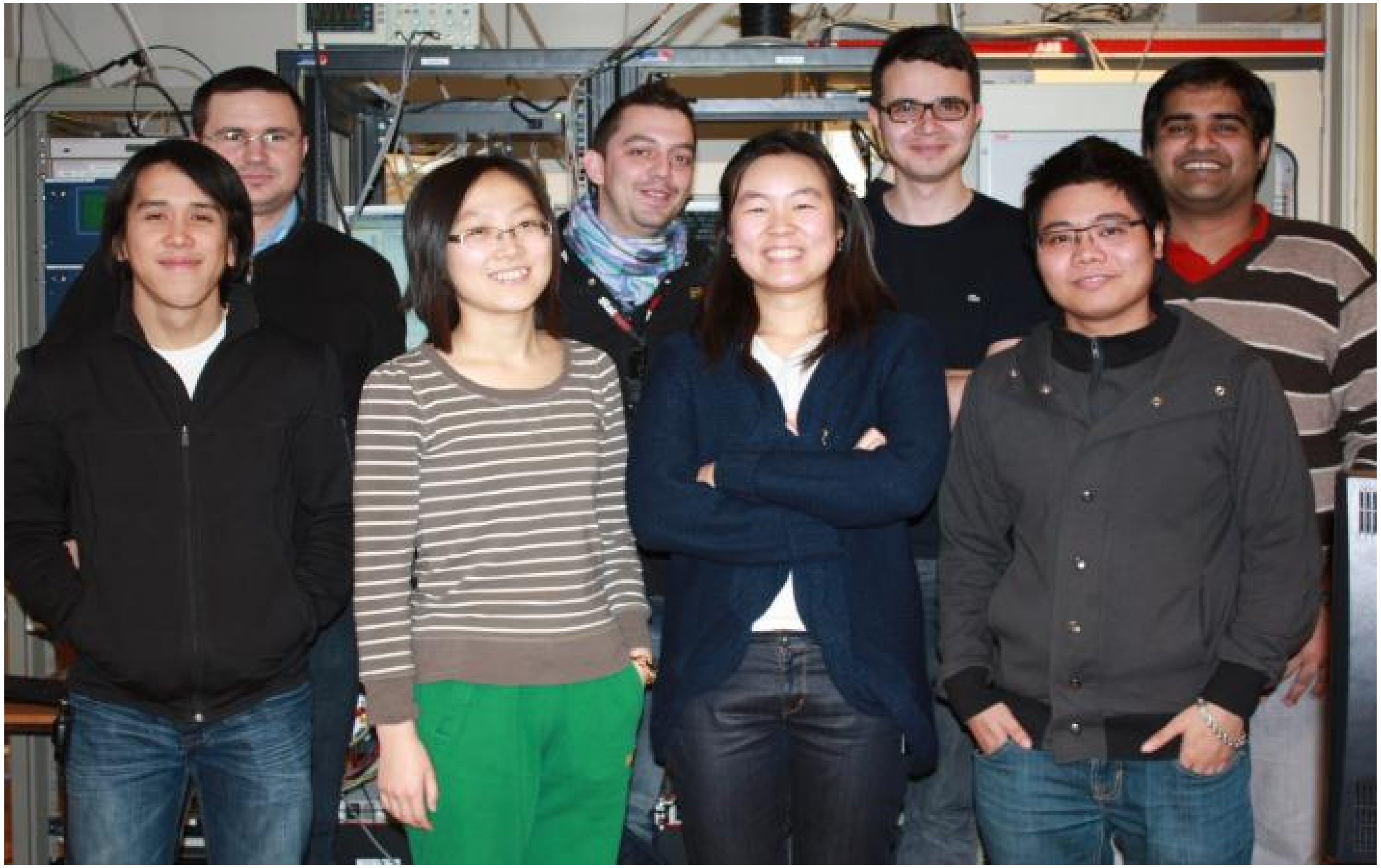

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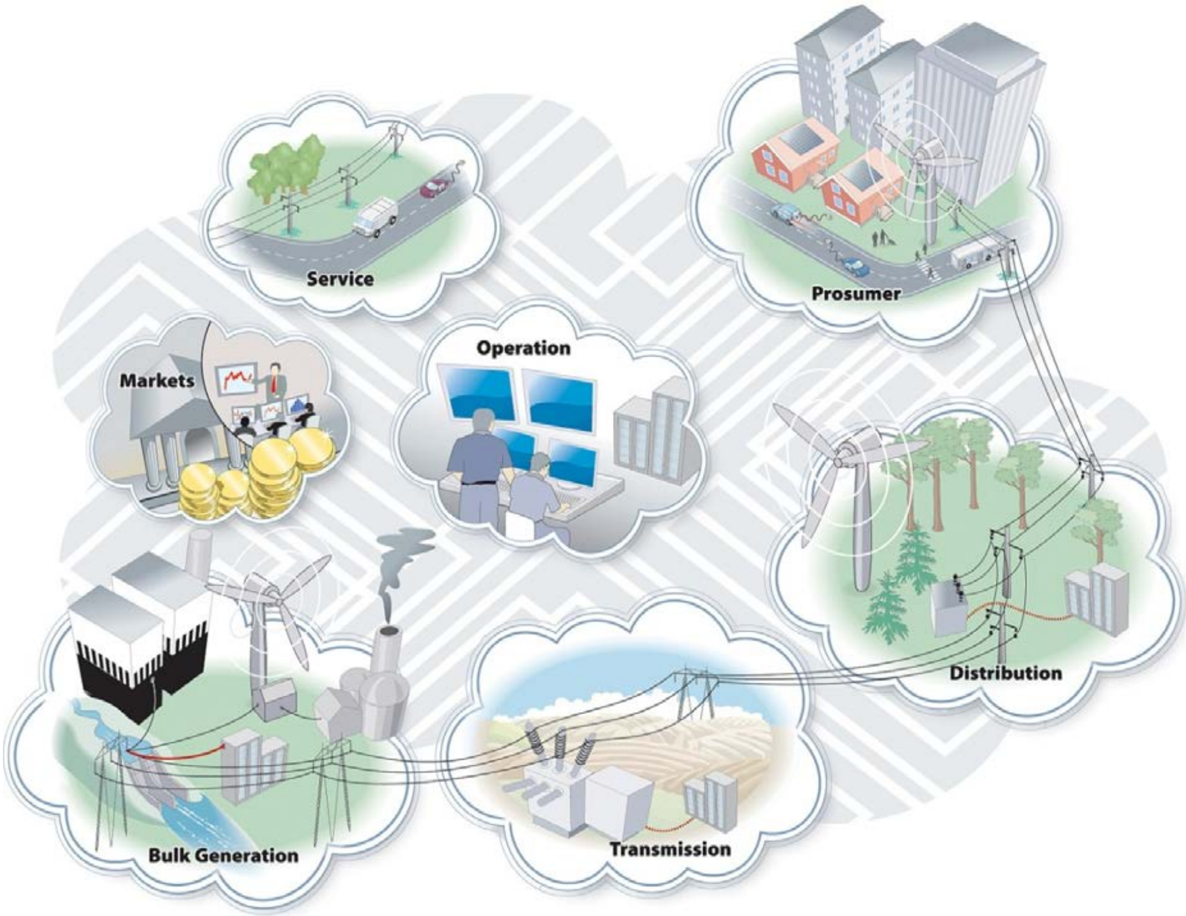
Thank you!



Back up slides:

Real-Time Simulation:

Fundamentals and Applications

What is a real-time simulation?

- The term “real-time” is used by several industries to describe ***time-critical technology.***
  - *Ambiguity:*
    - For some sectors of the power industry real-time can range from seconds to 5-10 minutes, while for others is in the range of milliseconds and lower.
    - This is connected to the “physical process” which is being dealt with, e.g. real-time markets (~10 min), real-time balancing (~5 min.), real-time control (5-20 ms), and protection (~10-50 micro sec.).
- The most proper usage of “real-time”, <u>*and the one we will use*</u>, is in the reference of **embedded systems**.
- **Embedded systems** are (intelligent) electronic devices which interface with the real world to provide control, interaction and convenience.
  - Controllers, protective relays, etc.
- So, when talking about “real-time” we will be talking of process taking place in fractions of a second (10-50 micro sec.)

Real-Time System Configurations and Applications

Rapid control/protection prototyping

controller

I/O

Plant

Hardware-in-the-loop

controller

I/O

Plant

Pure Simulation

controller

I/O

Plant

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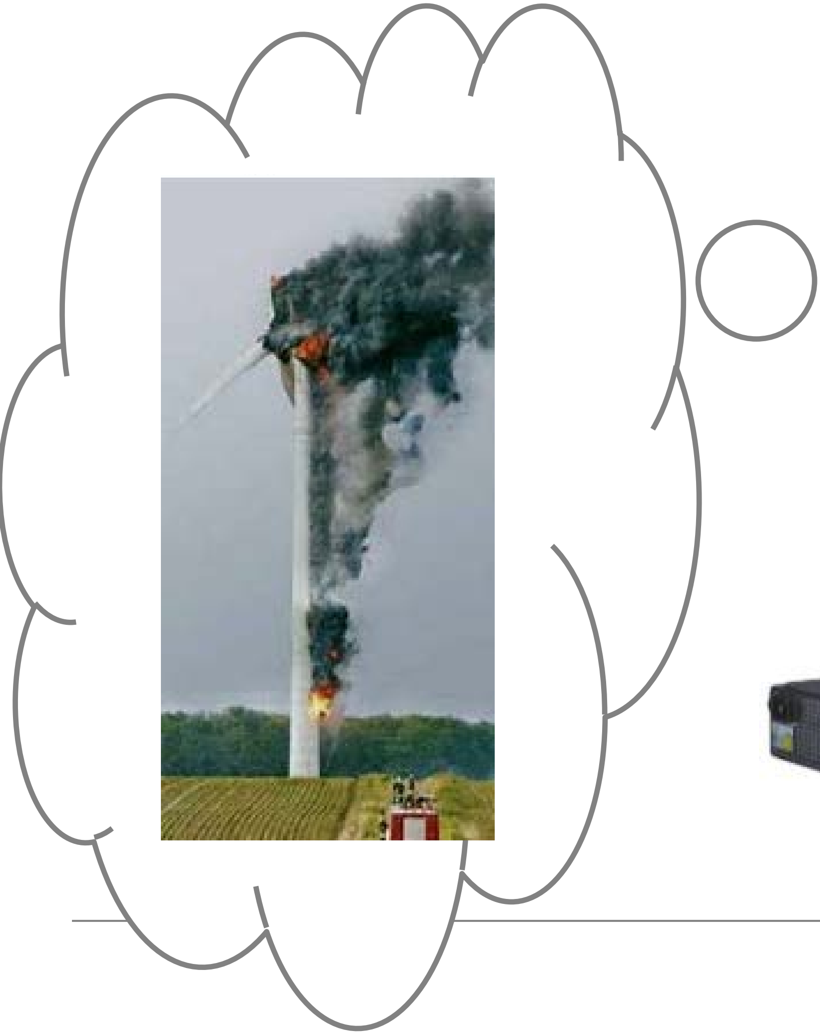
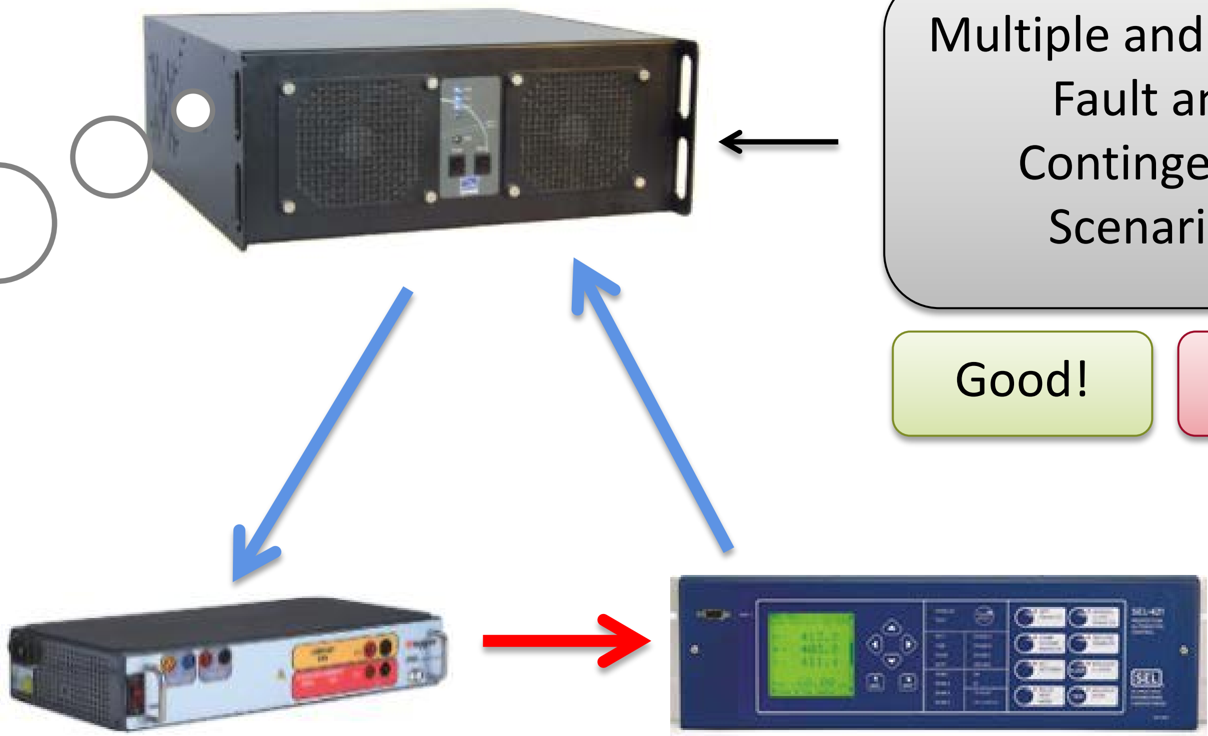
Why use Real-Time Simulation?

Typical Application
Hardware-in-the-loop control and protection testing





Testing and Validation

Multiple and Diverse Fault and Contingency Scenarios

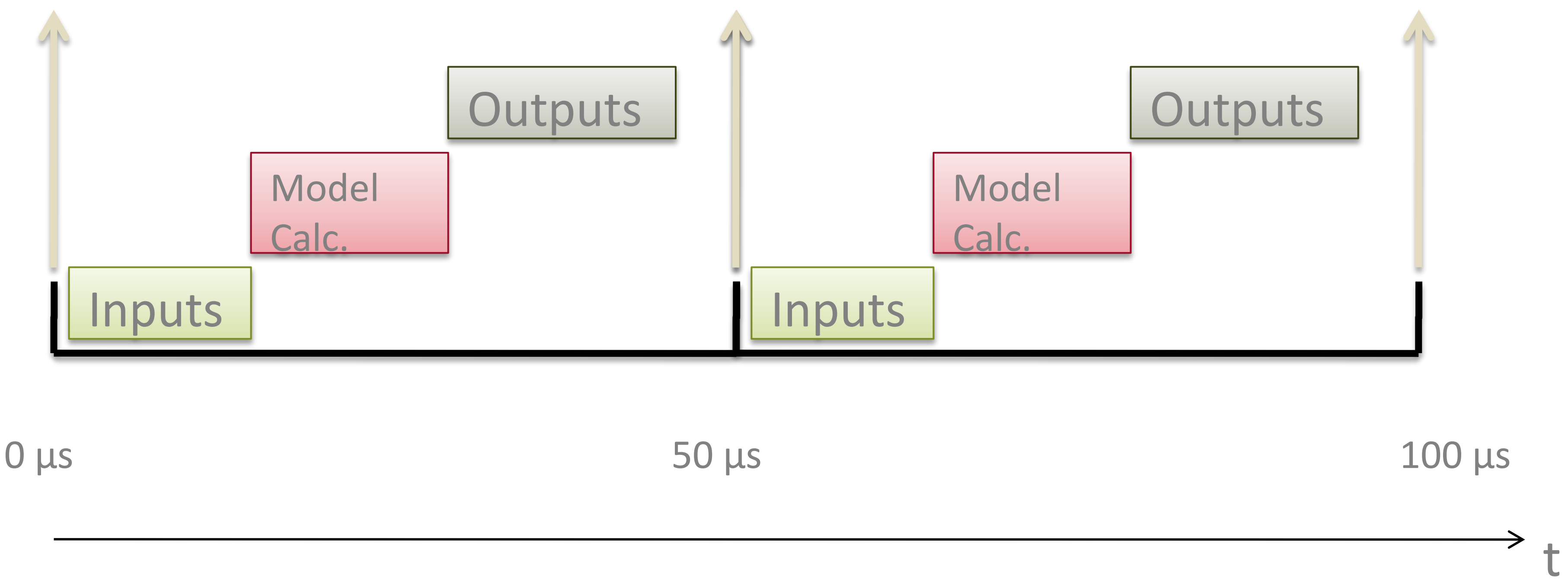
Good!

Bad!

What is a real-time simulation ?

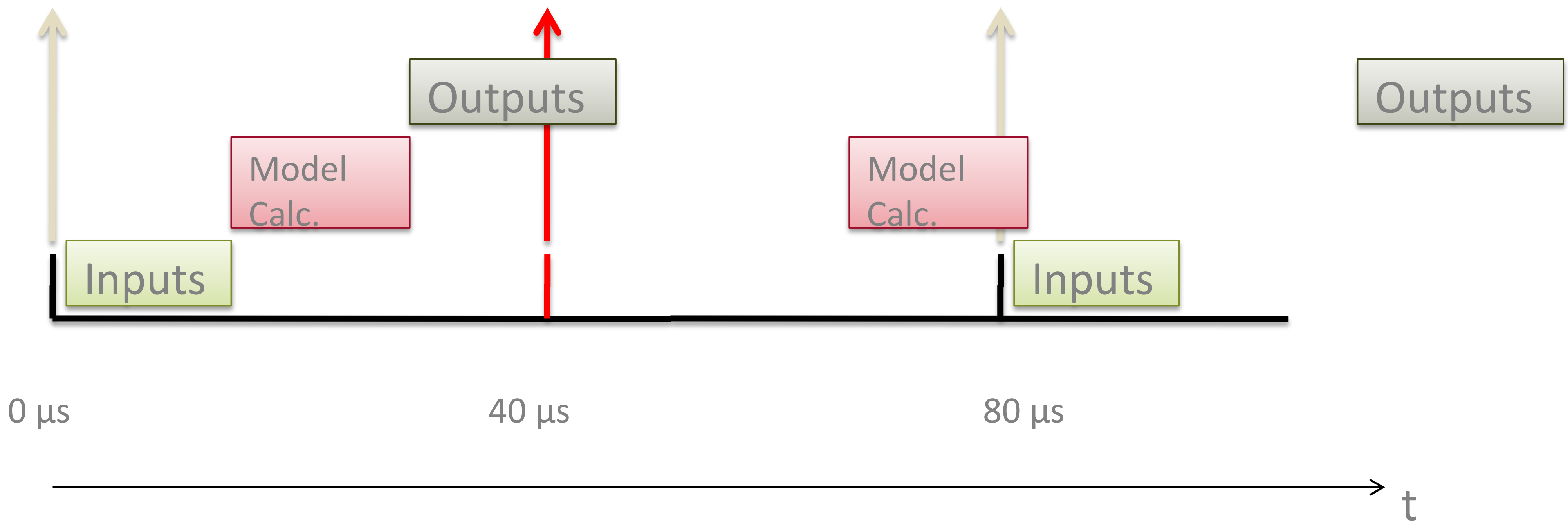
Definition : In a real-time system, we define the Time Step as a predetermined amount of time (ex: Ts = 10 µs, 1 ms, or 5 ms).

Inside this amount of time, the processor has to read input signals, such as sensors, to perform all necessary calculations, such as control algorithms, and to write all outputs, such as control signals (through analog, digital, or comm.ports).



What is a real-time simulation ?

Overruns : In a real-time system, when a predetermined time step is too short and could not have enough time to perform inputs, model calculation and outputs, there is an overrun.



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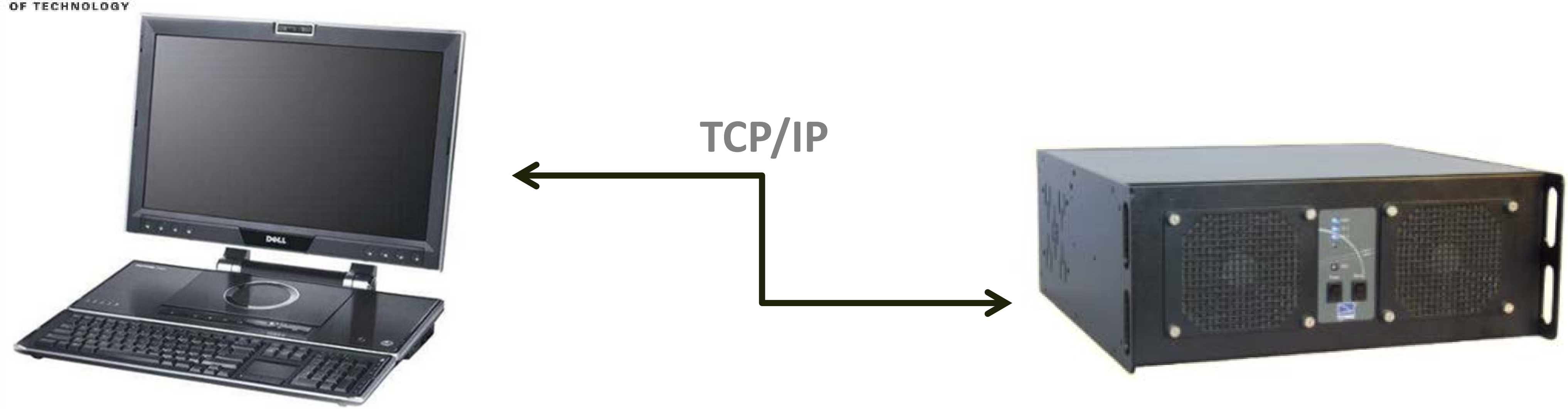
What is a real-time simulation ?

Fixed-step solvers solve the model at regular time intervals from the beginning to the end of the simulation.

The size of the interval is known as the step size: ***Ts***.

Generally, decreasing ***Ts*** increases the accuracy of the results while increasing the time required to simulate the system.

Opal-RT and RT-LAB system architecture



Host Computer-Windows

Target Computer

- Edition of Simulink model
- Model compilation with RT-LAB
- User interface

- I/O and real-time model execution
- QNX or Linux OS
- FTP and Telnet communication Possible with the Host