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Real-Time Hardware-in-the-Loop Validation for WAMPAC: Power System Protection and Communication

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SmarTS Lab
Smart Transmission Systems Laboratory

3rd IEEE PES Innovative Smart Grid Technologies (ISGT)
Real-Time Simulation of Smart Grids
Panel Session
Berlin, Germany– October 14-17, 2012

Outline

•Motivation for RT-HIL Approach
•SmarTS Lab: An RT-HIL Lab for WAMPAC Apps Dev.
•Model-To-Data Workflow for SIL and RT-HIL Validation

•Recent Projects at SmarTS LAB for Power System Protection and Communication
- •Power System Modeling of Protective Relays
- •Power System Communication (GOOSE and Sampled Values) Validation using RT-HIL
  - •Interfacing RTS for Station Bus and Process Bus Implementation
  - •Comparison of Conventional and RT-HIL approaches for Power Protection Relay Testing

• A software development toolkit for developing and testing PMU based applications for Wide Area Monitoring, Protection and Control

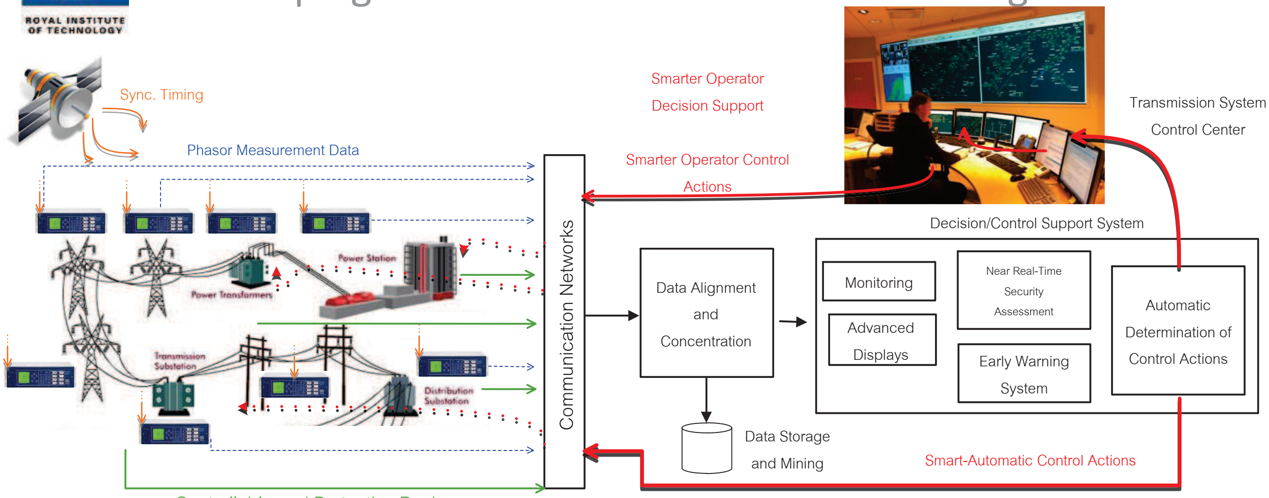
Timeline for M. Shoaib Almas

- Almas joined KTH, The Royal Institute of Technology, in 2009 to pursue his Masters in Electric Power Engineering majoring in Power Systems. Previously he has obtained a Bachelors in Electrical Engineering from National University of Sciences and Technology (NUST), Pakistan.
- He has two years of experience working as a Design Engineer for designing protection schemes for substations (132kV, 220 kV and 500kV) through microprocessor-based relays.
- His professional experience includes substation automation and coordination of protective relays to minimize the effect of faults in power transmission networks.
- He performed his master thesis "*PMU-Assisted Local Optimization of the Coordination between Protective Systems and VSC-HVDCs*" at the Electric Power System (EPS) division of KTH.
- Currently PhD. Candidate, Project Title "*Real-Time Wide-Area Control of Hybrid AC and DC Grids*"

Motivation

- Each substation has in average 50 IEDs performing protection (differential, bus-bar, overcurrent, over/under voltage, over/under frequency etc.) and communicating with various protocols/standards (C37.118, GOOSE, SV, MODBUS, DNP 3.0)
- In order to accurately model a power system, these IEDs along with their respective communication techniques need to be modeled precisely with the same settings as the real hardware relay → ***Power System Modeling***
- With substations adopting IEC-61850 standards, RT HIL approach proves beneficial to exploit interoperability, the use of Station/Process Bus effectiveness, etc. → ***Power System Communication***
- Digital Real-Time Simulators are compatible with long-established modeling software like MATLAB/SIMULINK (Opal-RT) and are IEC 61850 compliant (GOOSE & Sampled Values)
- RT-HIL approach provides freedom to carry on research related with Smart Transmission Grids:
  - Wide Area Monitoring Protection and Control (WAMPAC)

How to develop a controlled environment for developing Smart Transmission Grid Technologies?

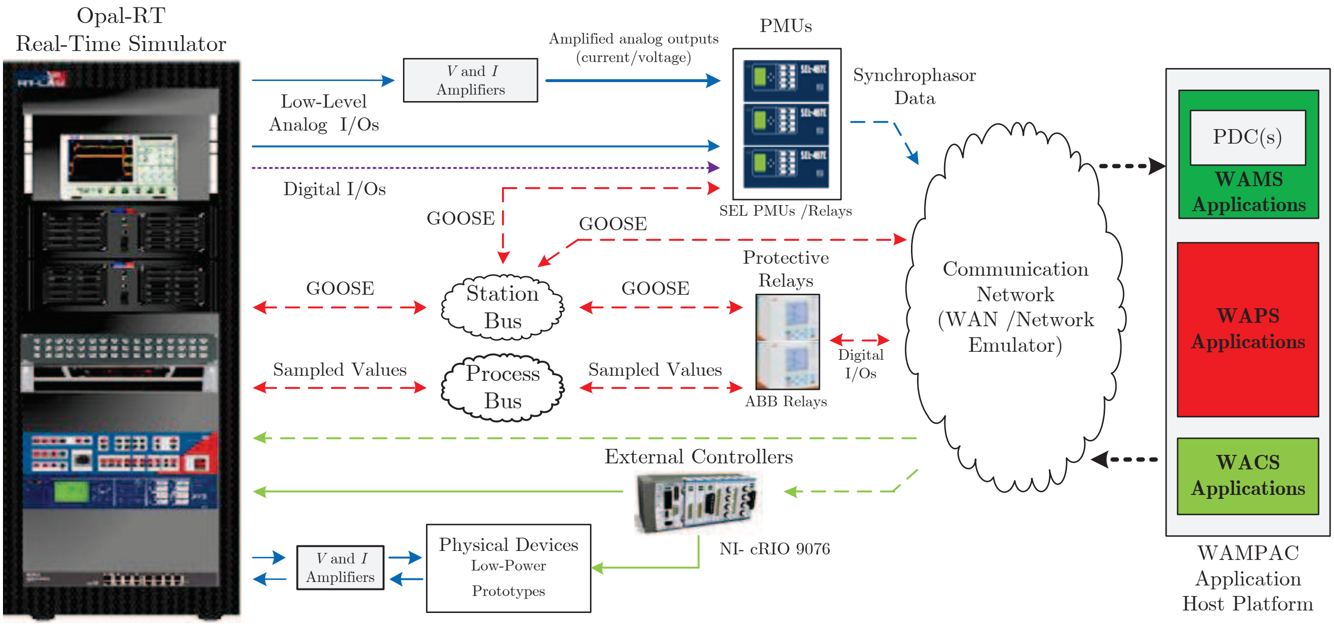


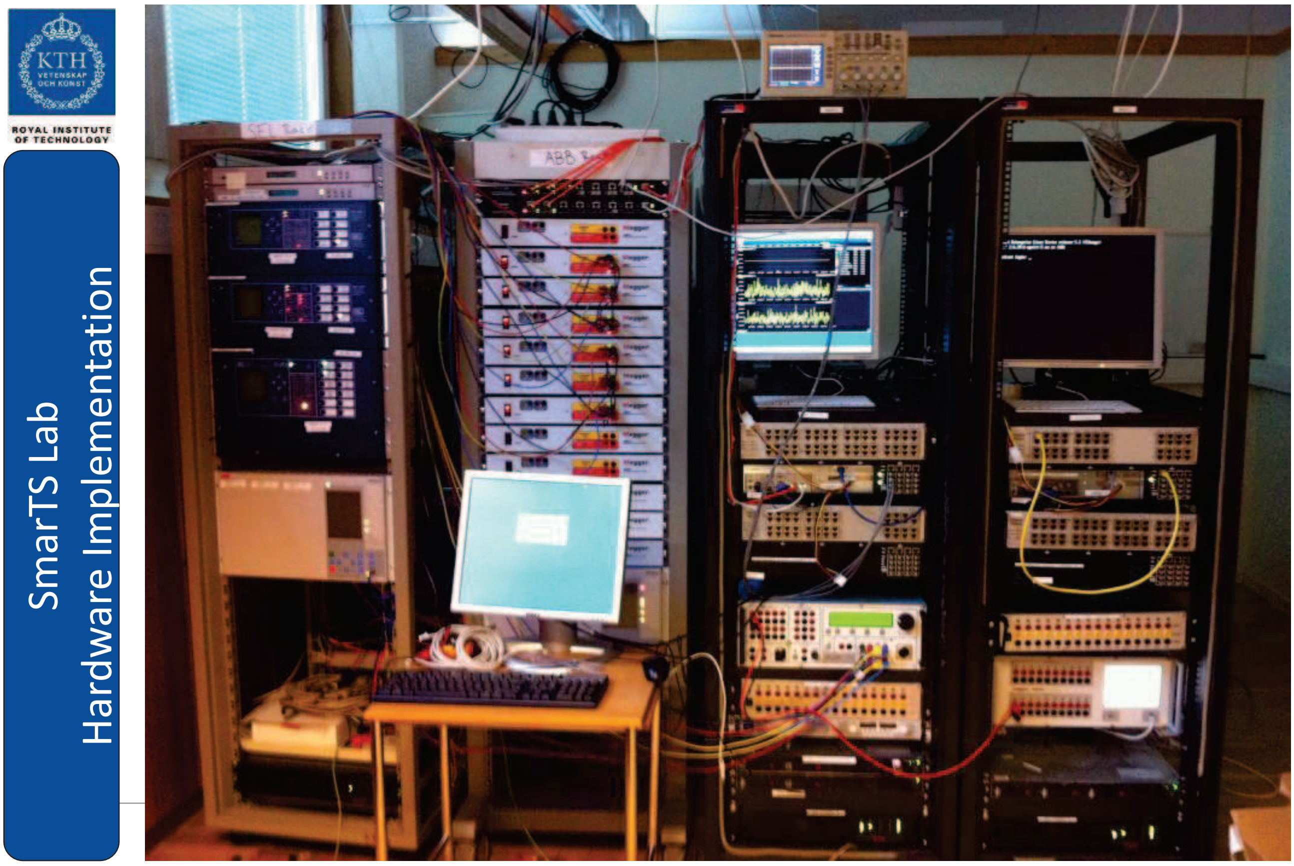
- Smart Grid require **Smart Operation, Smart Control and Smart Protection**:
  - The ultimate goal should be to attain an automatic-feedback self-healing control system
- Measure – Communicate – Analyze (System Assessment and *real* limits) – Determine Preventive/Corrective Actions – Communicate – Control and protect
- ***To achieve this vision, new applications need to be developed in a controlled environment, allowing testing and considering the ICT chain***

SmarTS Lab

Smart Transmission Systems Laboratory

The SmarTS Lab Architecture

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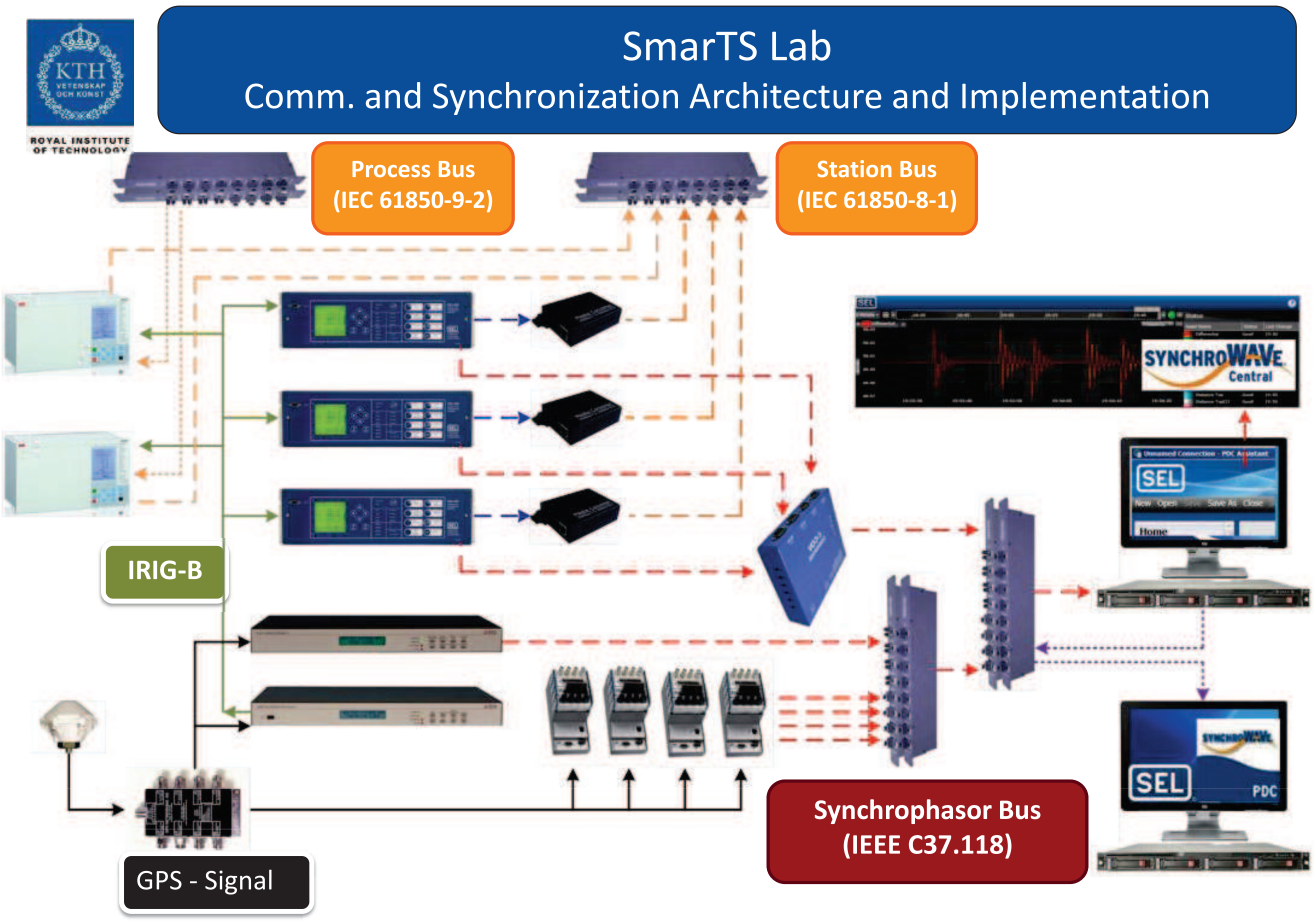
Hardware Implementation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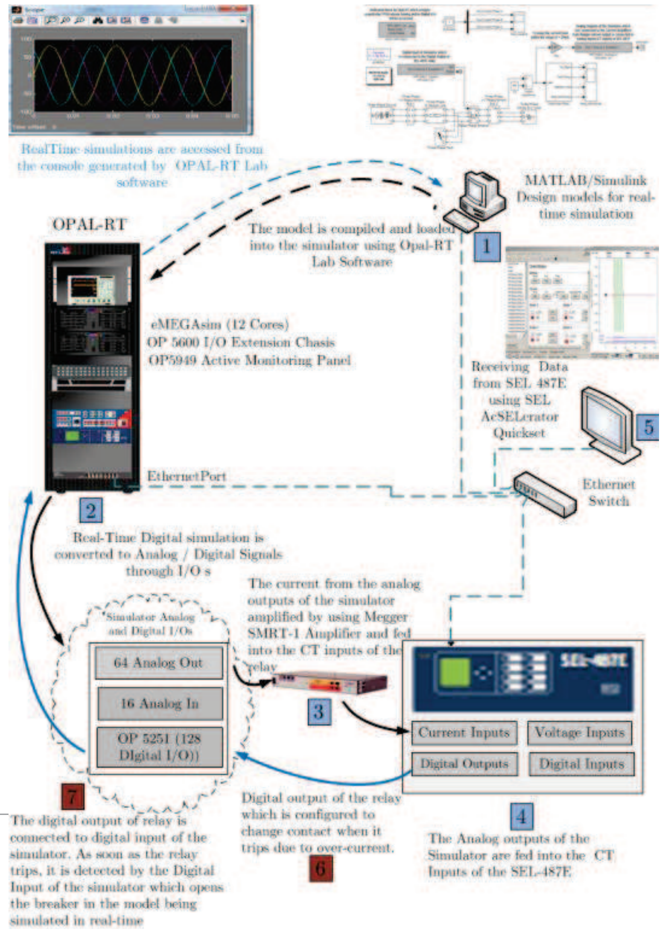
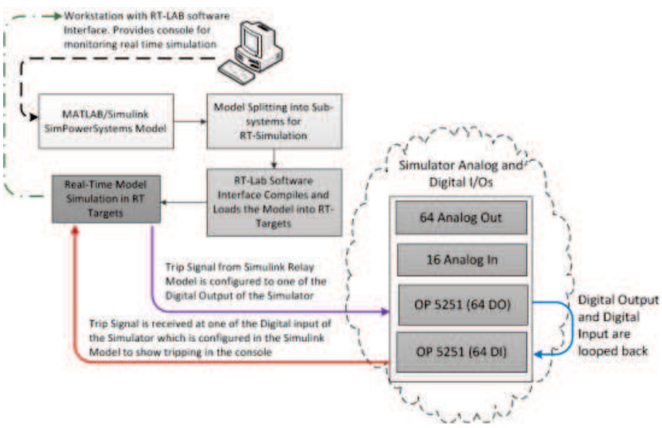
Comm. and Synchronization Architecture and Implementation
Process Bus
(IEC 61850-9-2)
Station Bus
(IEC 61850-8-1)
SYNCHROWAVE Central
SEL
IRIG-B
Synchrophasor Bus
(IEEE C37.118)
GPS - Signal
SEL
PDC

Model-to-Data Workflow

Hardware-in-the-Loop Validation

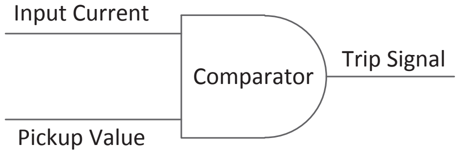


Software-in-the-Loop Validation



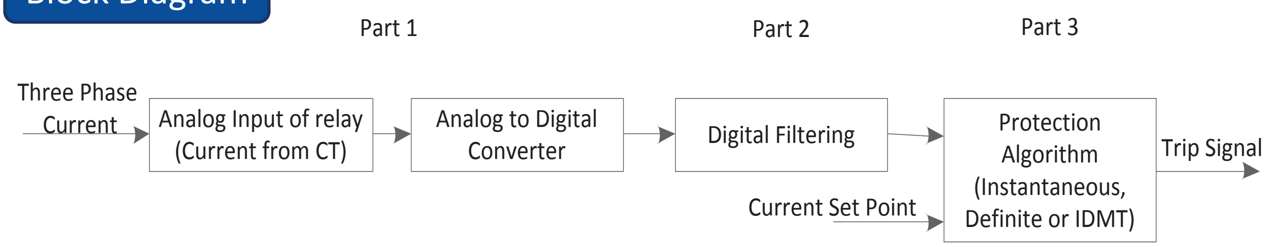
Recent Projects at SmarTS LAB

1. Model Validation of an Over-Current Relay



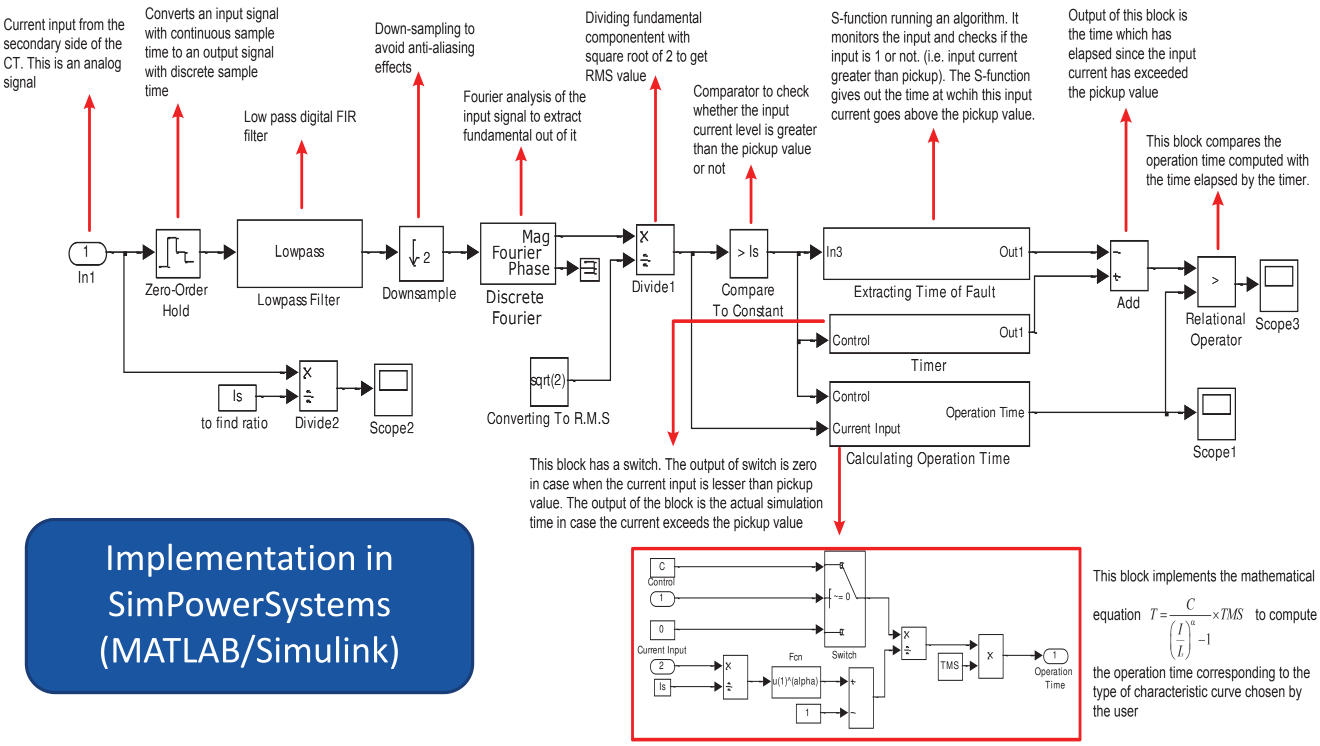
- Instantaneous
- Definite Time
- Inverse Definite Minimum Time (IDMT)

Block Diagram



1. Model Validation of an Over-Current Relay (contd.)

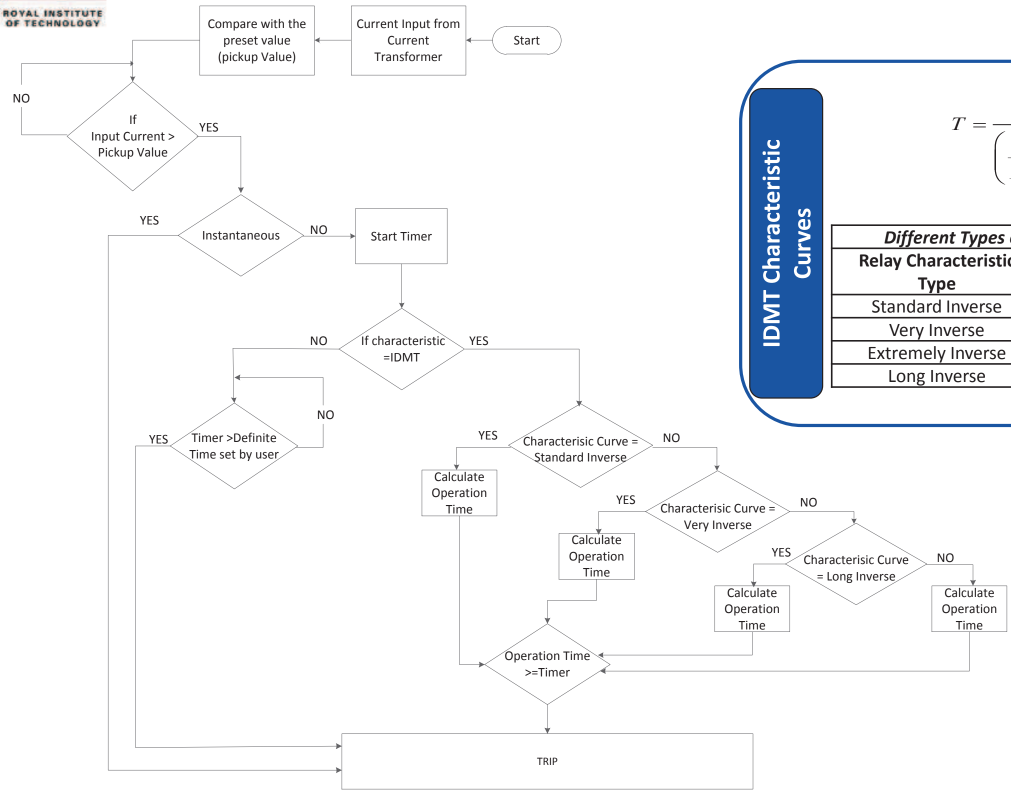
Modeling and Implementation for RT Simulation



Implementation in SimPowerSystems (MATLAB/Simulink)

1. Model Validation of an Over-Current Relay (contd.)

Protection Algorithm Implemented in the Overcurrent Relay Model



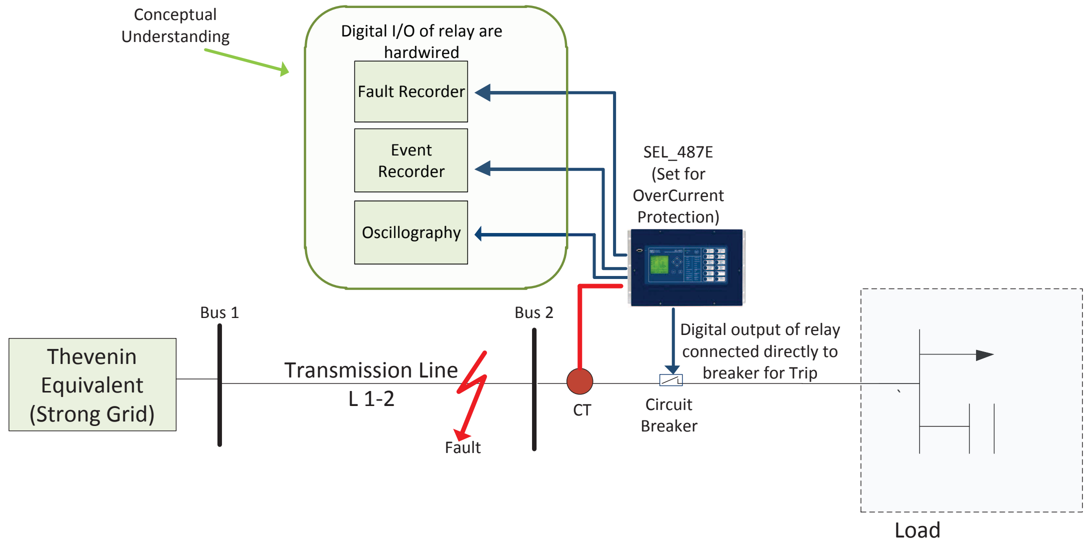
IDMT Characteristic Curves

$$T = \frac{C}{\left(\frac{I}{I_s}\right)^{\alpha} - 1} \times TMS$$

Different Types of Inverse Characteristics		
Relay Characteristic Type	**α**	**C**
Standard Inverse	0.02	0.14
Very Inverse	1	13.5
Extremely Inverse	2	80
Long Inverse	1	120

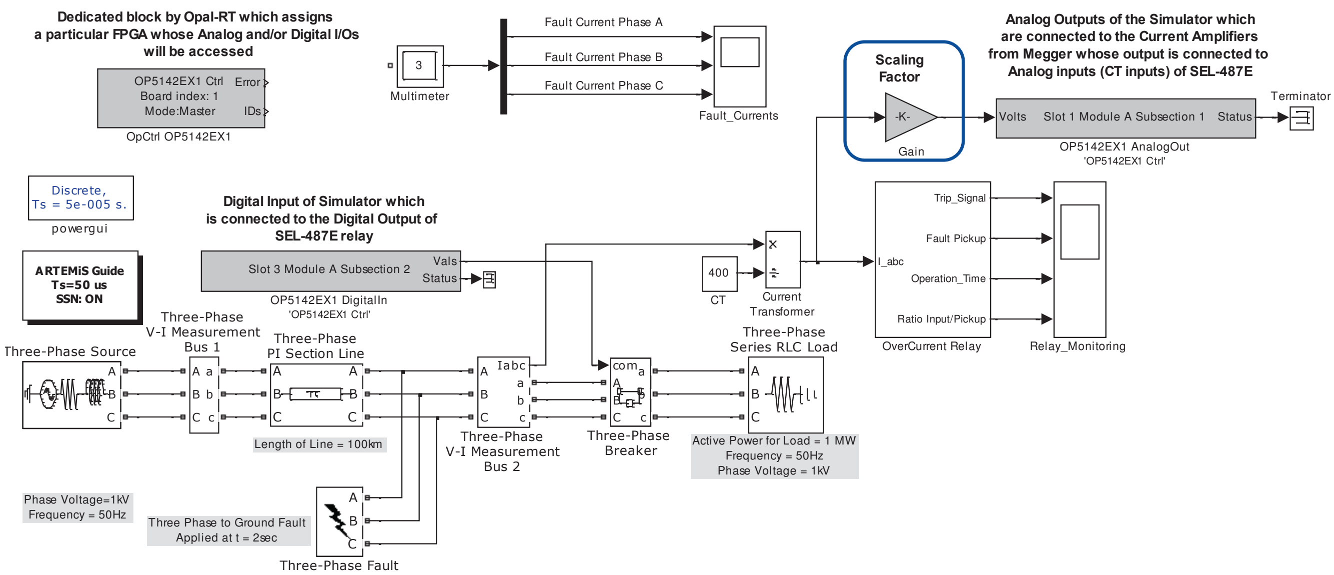
1. Model Validation of an Over-Current Relay (contd.)

Test Case Model Developed in SimPowerSystems (MATLAB/Simulink)



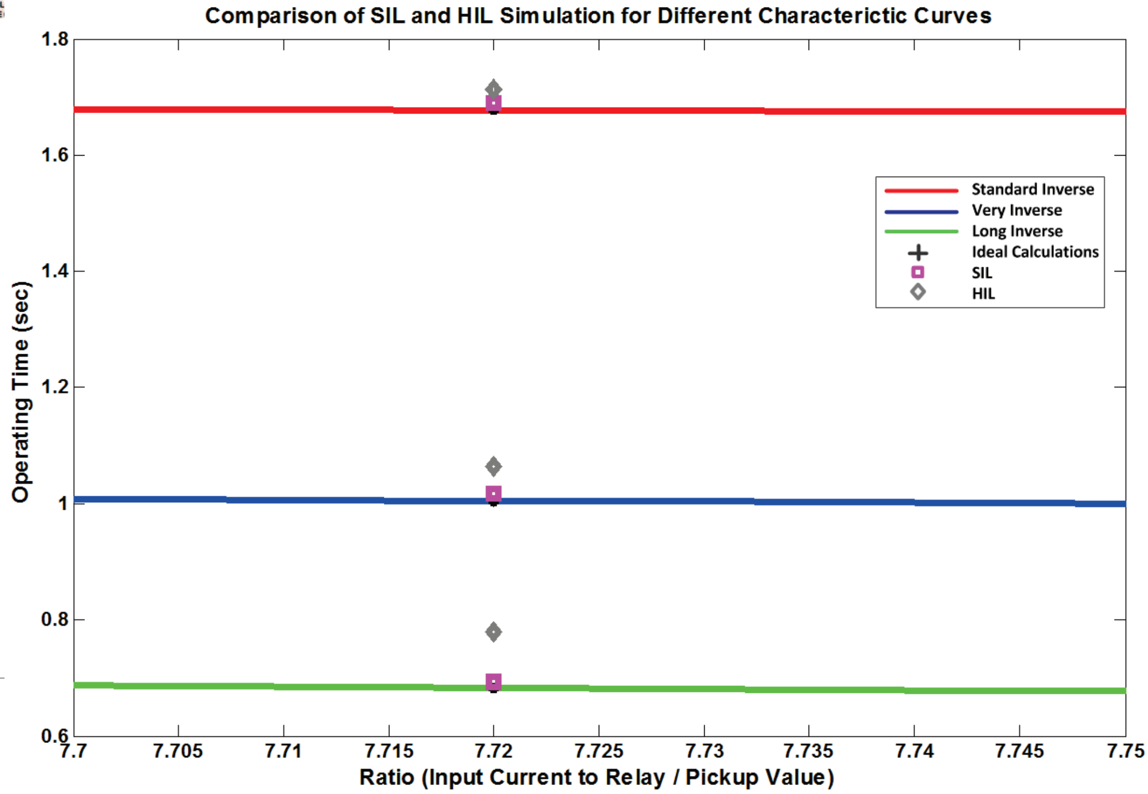
1. Model Validation of an Over-Current Relay (contd.)

Test Case Model Developed in SimPowerSystems (MATLAB/Simulink) HIL Implementation



1. Model Validation of an Over-Current Relay (contd.)

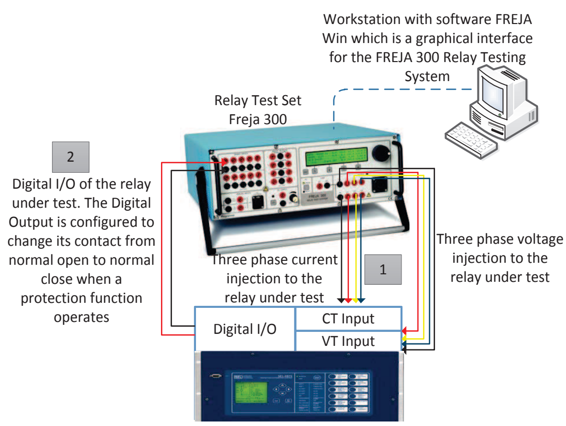
Validation Results



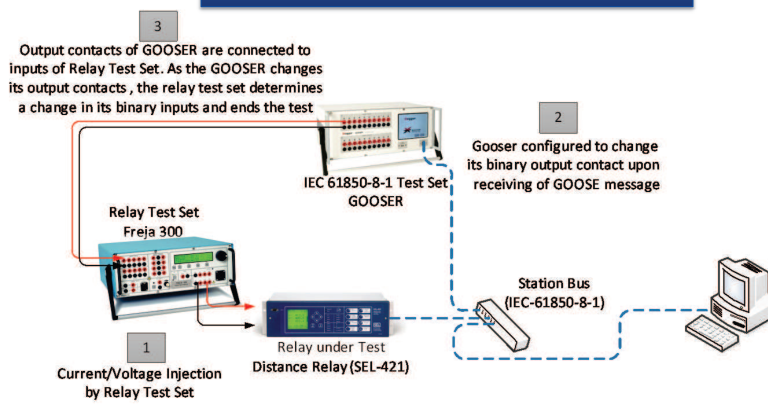
2. Power System Communication (Station & Process Bus Implementation

Comparison of the Real-Time Results with Stand Alone Testing Using Freja-300 (Relay Test Set)

Stand-Alone Testing Hardwired



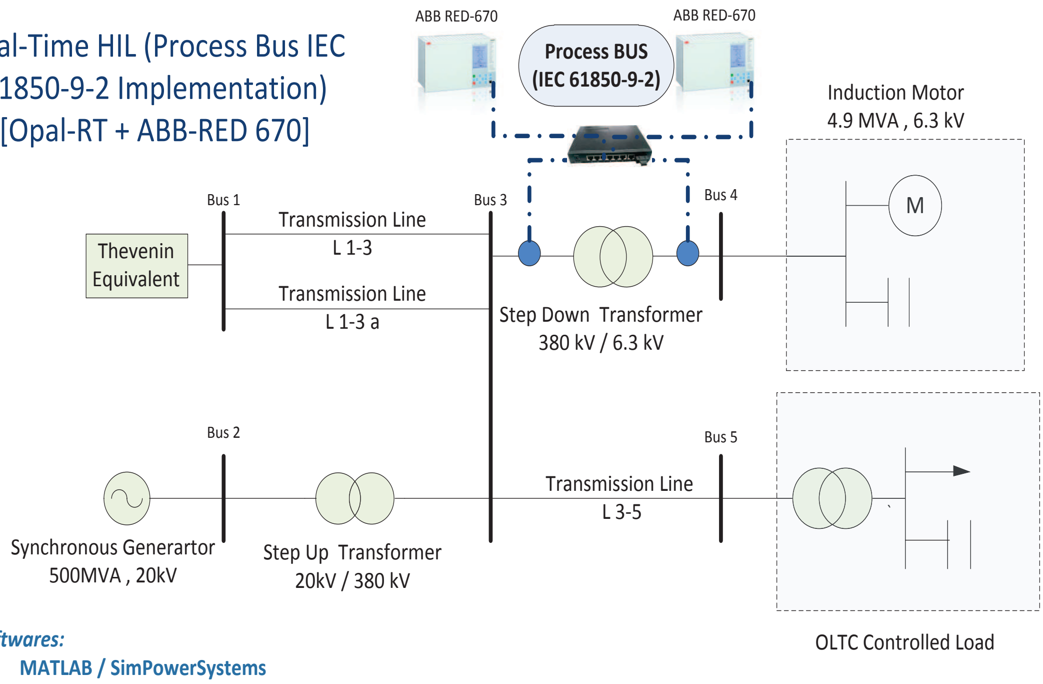
Stand-Alone Testing GOOSE (IEC 61850-8-1:Station Bus)



The only way to validate the RT-HIL results for protection IEDs is to compare results with existing technology (stand-alone tests)

2. Power System Communication (Station & Process Bus Implementation (contd.)

Real-Time HIL (Process Bus IEC 61850-9-2 Implementation) [Opal-RT + ABB-RED 670]

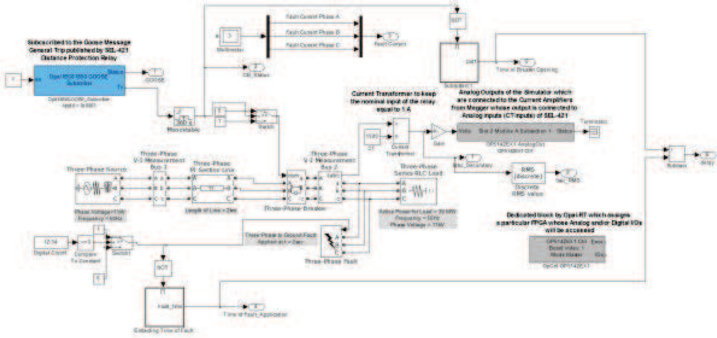


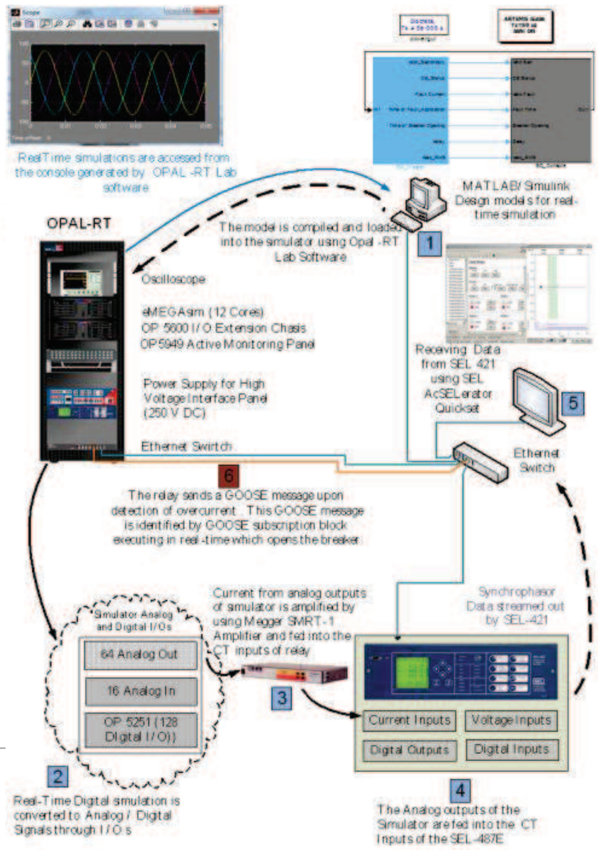
Softwares:

- MATLAB / SimPowerSystems
- ABB PCM 600: Relat Settings
- RT-LAB: Real-Time Execution
- WireShark: Network Analyzer
- ABB IET 600: Substation Automation Architecture

No Hardwires for CT and VT connections
No need of Amplifiers for RT-HIL execution

3. Comparison of Standalone and RT-HIL Testing Approach

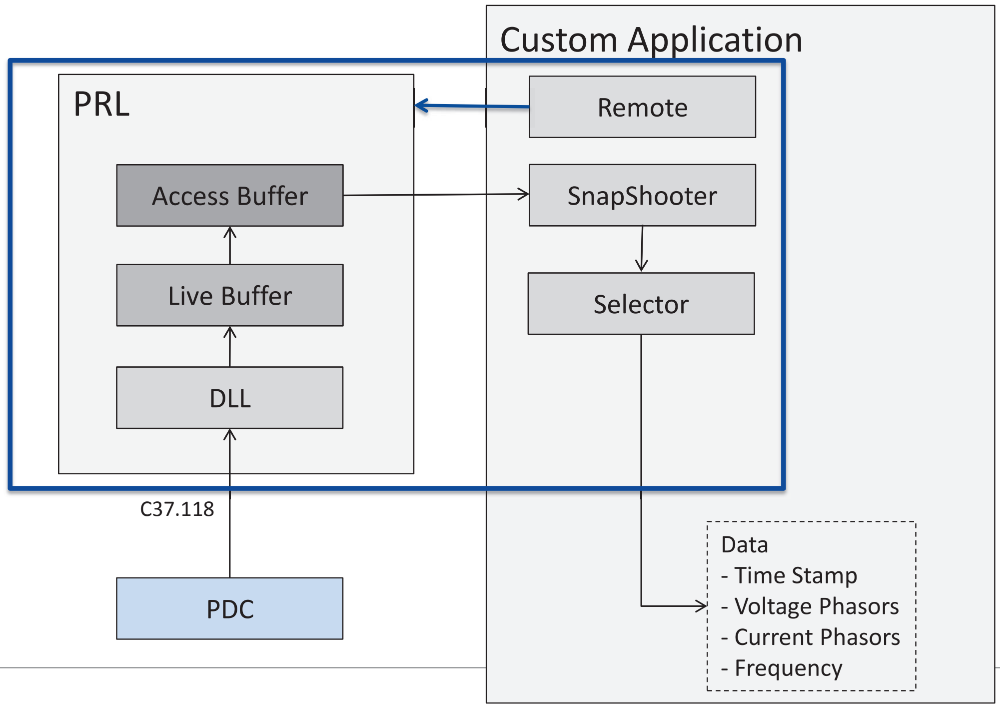




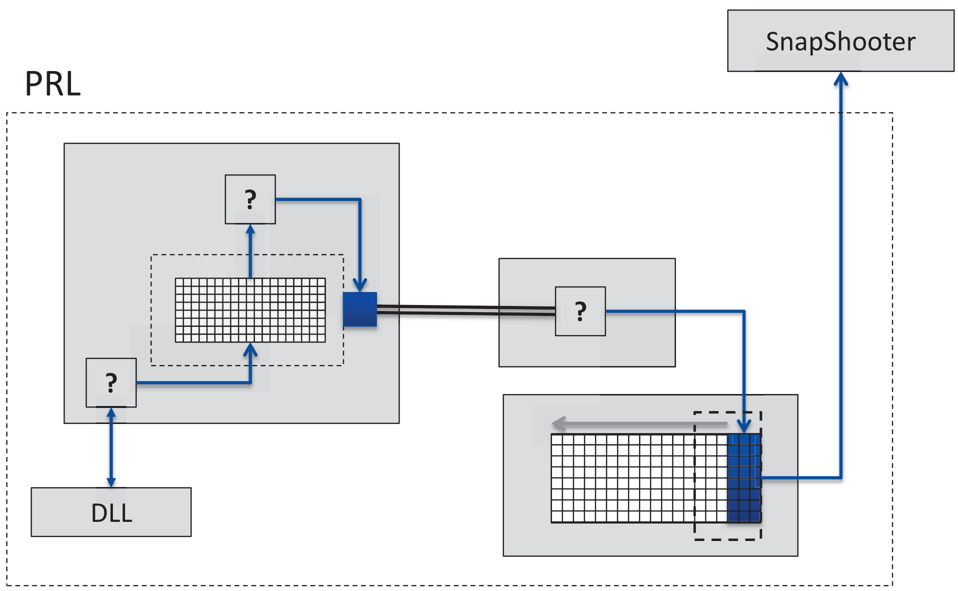
Comparison of Results from Standalone and RT-HIL Testing Fault Applied at t=2 sec, protection tested=instantaneous overcurrent

Testing Methodology	Feature	Tripping Time (sec)	Delay (msec)
Standalone	Hardwired	2.0083	8.30
	GOOSE	2.0060	6.00
RT-HIL	Hardwired	2.0085	8.50
	GOOSE	2.0062	6.20

PMU App. SDK
A LabView-Based PMU Application SDK



PMU Recorder Light (PRL)



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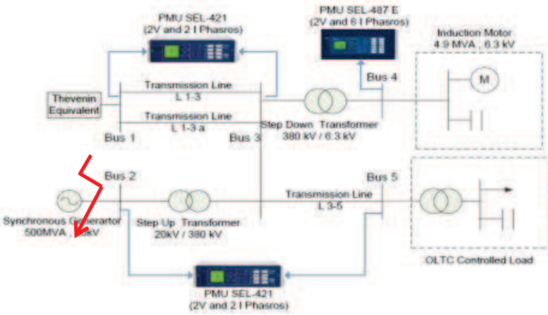
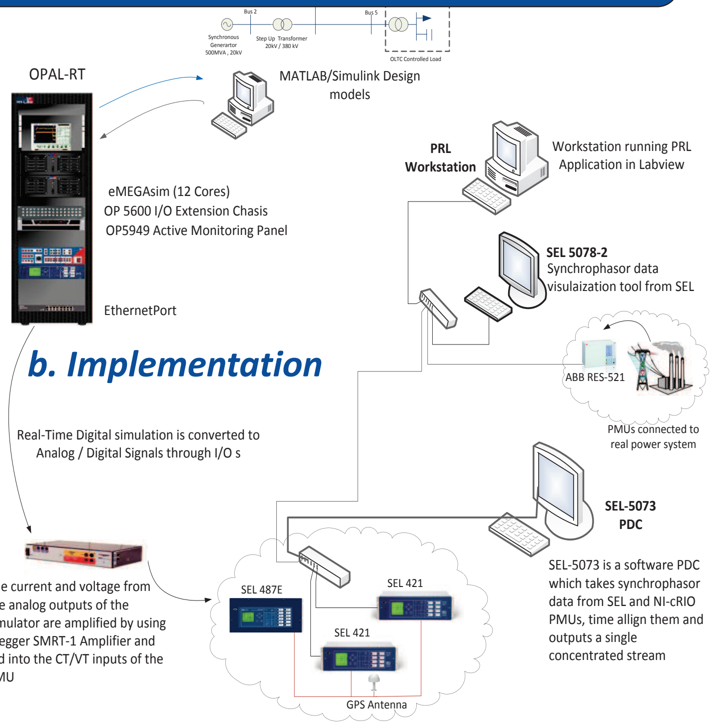
PMU App. SDK
A LabView-Based PMU Application SDK

a. Model





b. Implementation

The amplified current and voltages are connected to the CT and VT inputs of the PMUs. The PMUs acquire these analog quantities, computes the phasors and time tags them, and streams out the synchronized phasor data in C37.118 format.

c. Results from PMU based monitoring Application

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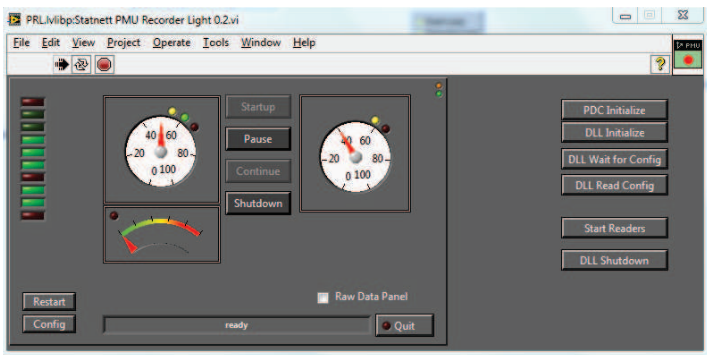
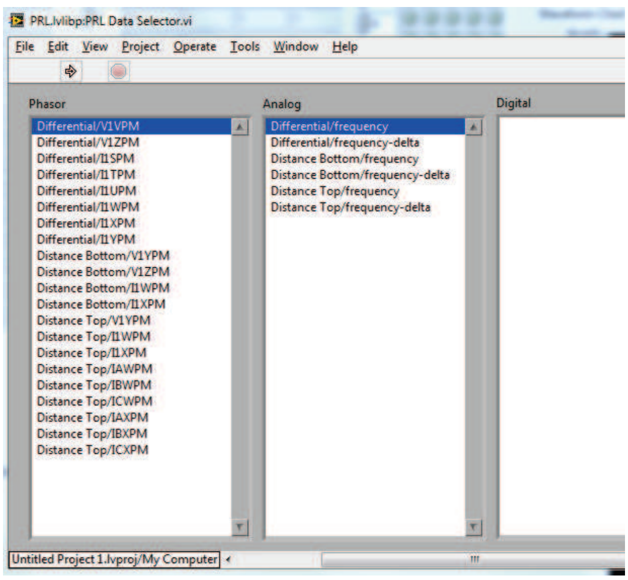
Prototype Implementation (PMU App. SDK *Beta)*





Connection with PDC
Configuration
PC Loading Monitor

Data Channel Selection

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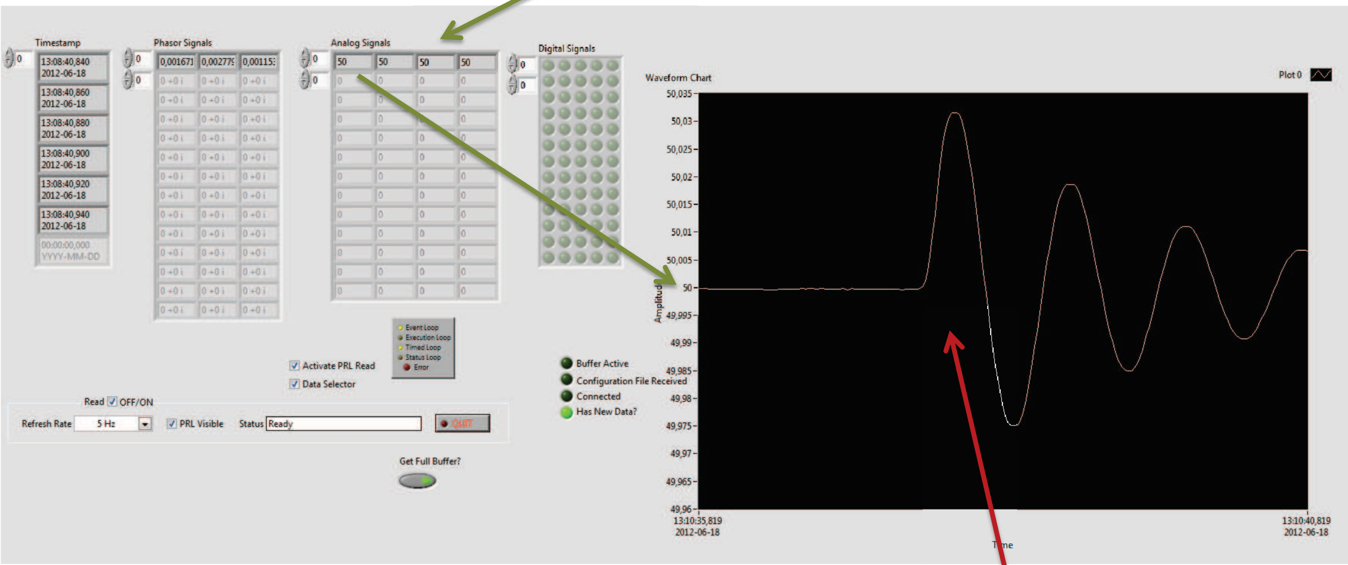
Real-Time Data Access



Straightforward Development of Monitoring Application

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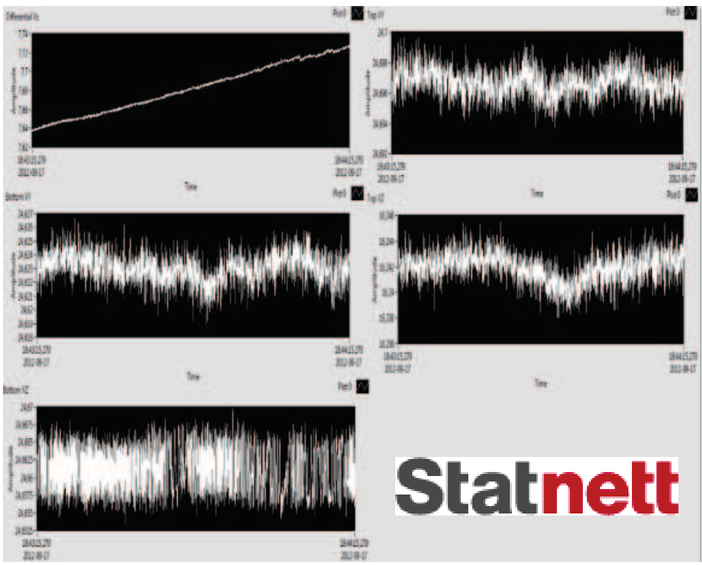
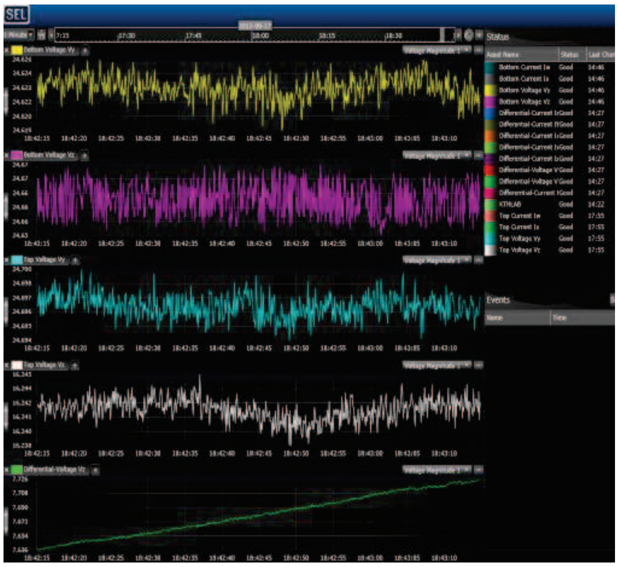
Comparison with a commercial monitoring tool



a. Results from developed synchrophasor based monitoring application (with Statnett)



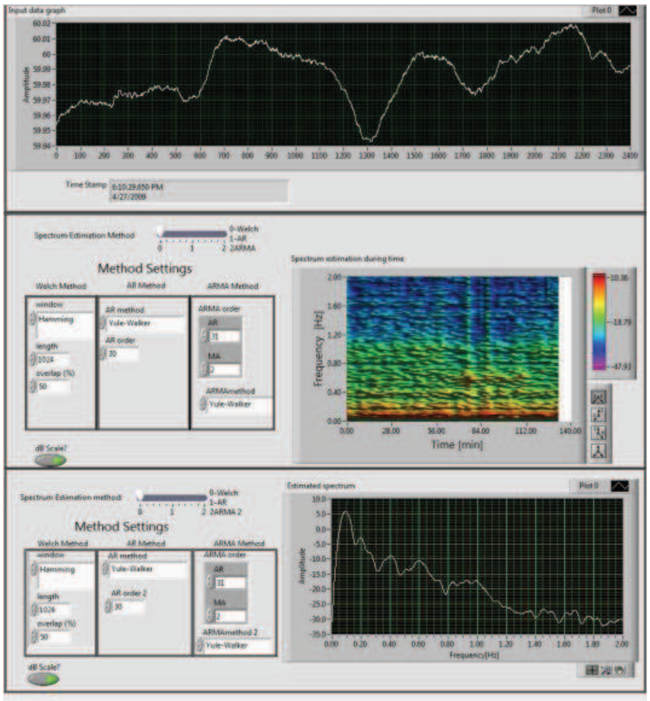
b. Results from vendor specific (SEL-5073 PDC monitoring) tool

PMU Based Application Example
Real-Time Mode Meter

Estimates frequency of the electromechanical modes of the power system

Three different spectral estimators are used ensuring accurate signal spectrum estimation:

- Welch's method,
- Auto-Regresive (AR)method
- Auto-Regresive Moving Average (ARMA) method



Conclusions and Further Work

- Smart Transmission Grids will benefit from RT HIL simulation for developing new technologies.
- Modeling for real time simulation is necessary:
  - Developing more models for protection functions like Distance protection, differential protection, over/under voltage, over/under frequency protection etc. to have available a library for protection functions.
- Consideration of actual measurement and automation streams is necessary:
  - Exploiting IEEE C37.118 (Synchrophasors from PMU) and IEC 61850 (Substation Automation) can be useful to develop applications which can serve as online oscillation detection, mode estimation, power oscillation damping, etc.
- PMU-Based applications can enable flexibility:
  - Developing a Real-Time controller which can read data from power system / substation components irrespective of the vendor protocol and can translate it to take either distributed or global control actions.
- RT HIL simulation can help us to achieve broader goals:
  - Power system which is more reliable and more flexible

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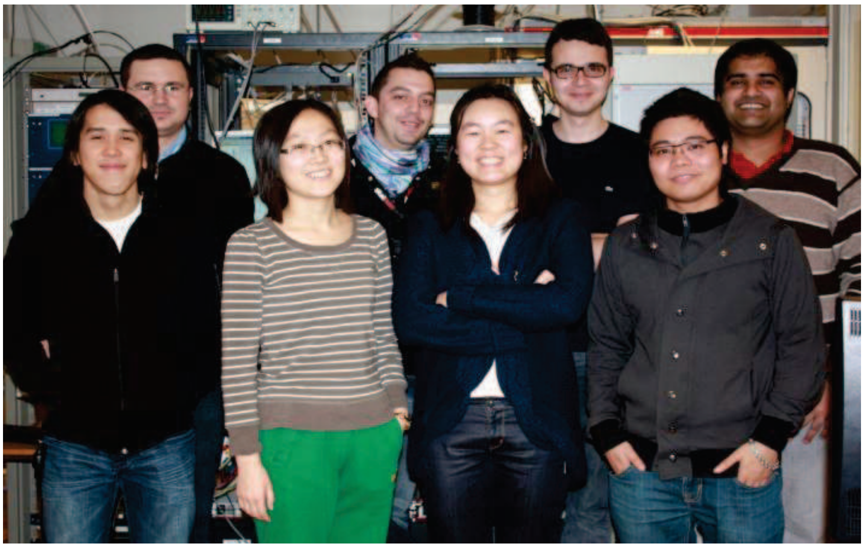

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Thank you!