



NTNU – Trondheim
Norwegian University of
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Hardware-In-the-Loop (HIL) test lab and Applications

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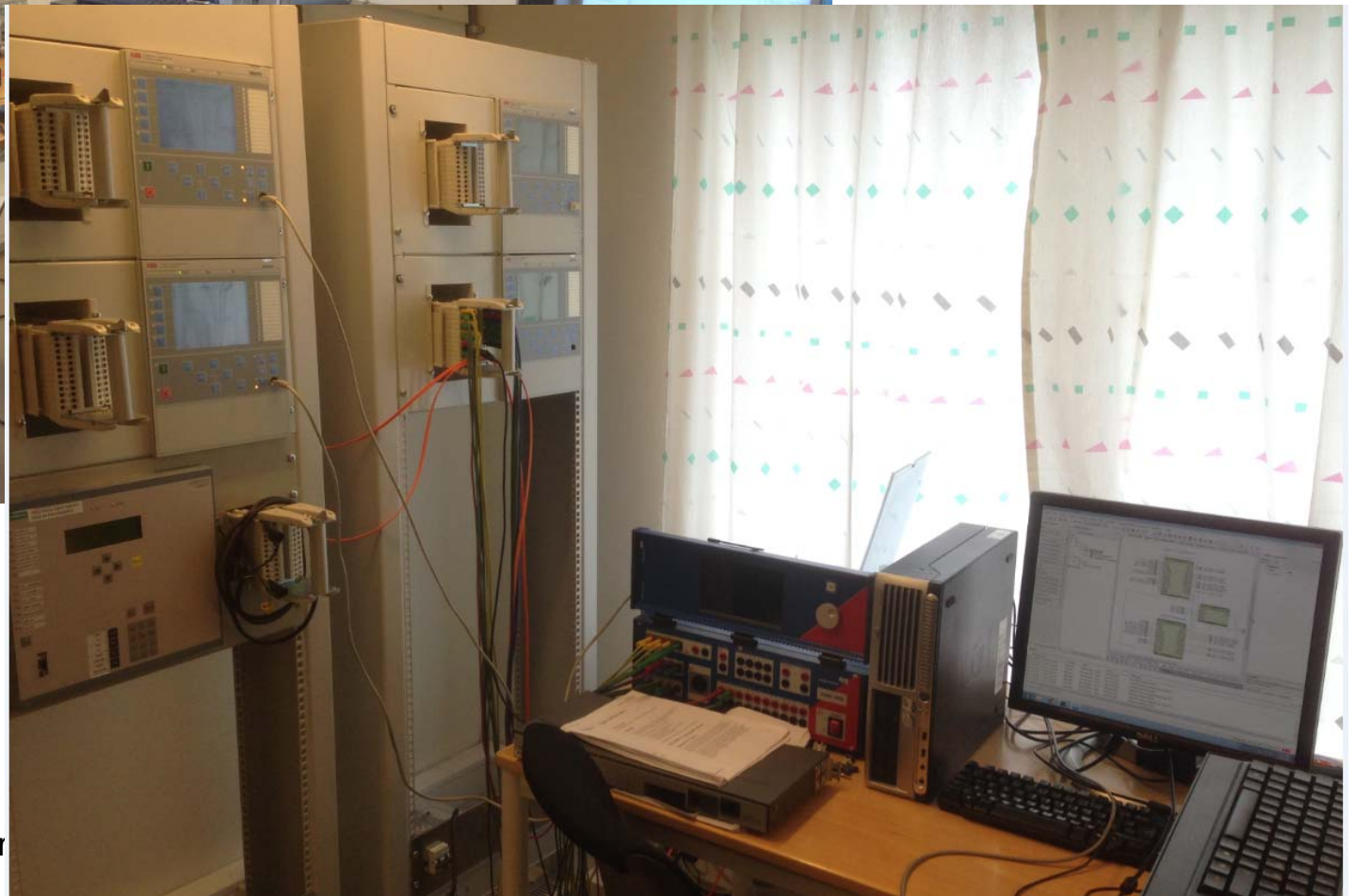
NTNU- Electric power engineering

2016-05

Outline

- **NTNU HIL test lab**
- **HIL applications on power system protection**

NTNU HIL test Lab - photos



NTNU HIL test lab

Motivations:

- **HIL relay testing for research and education**
- Powerful real time simulation capability for power system
 - Modern power networks
 - Complex faulty scenarios
 - Communication network
- *Interoperability to ensure integration of IEDs from different vendors*
- *Implementation and verification of wide area monitoring, protection and control*

NTNU HIL test lab

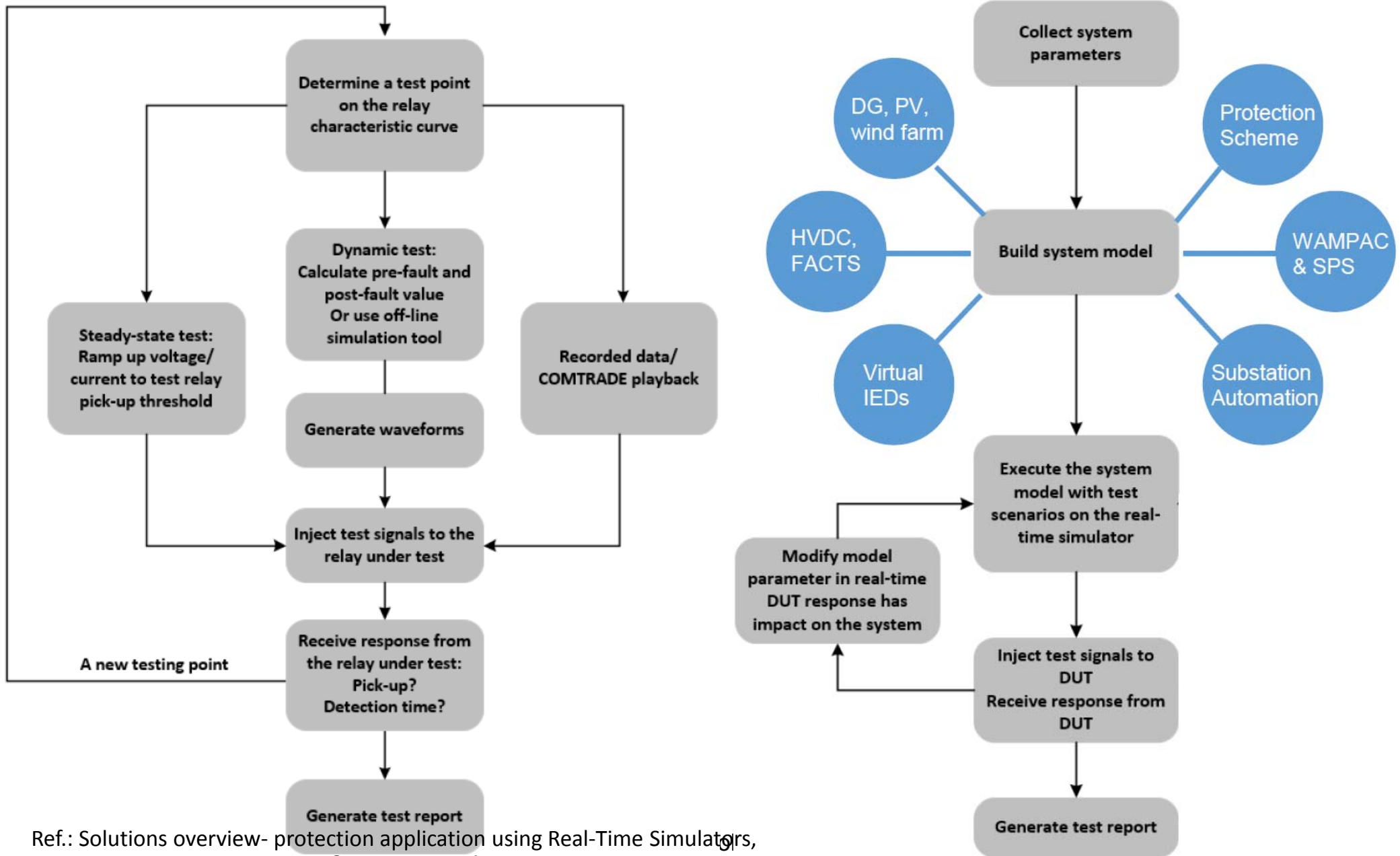
The laboratory project is divided in three phases:

- **Phase 1:** Establish a test bench for relay setting and testing, including use of high speed data from the local process bus for transformer and bus differential, over-current, and distance protection;
- *Phase 2: Establish a SCADA interface with data concentrators and protocol converters to connect with the relay test bench;*
- *Phase 3: Establish a communication system to share remote synchrophasor data for wide-area protection and control*

Phase 1 is an important part for the normal protection courses.

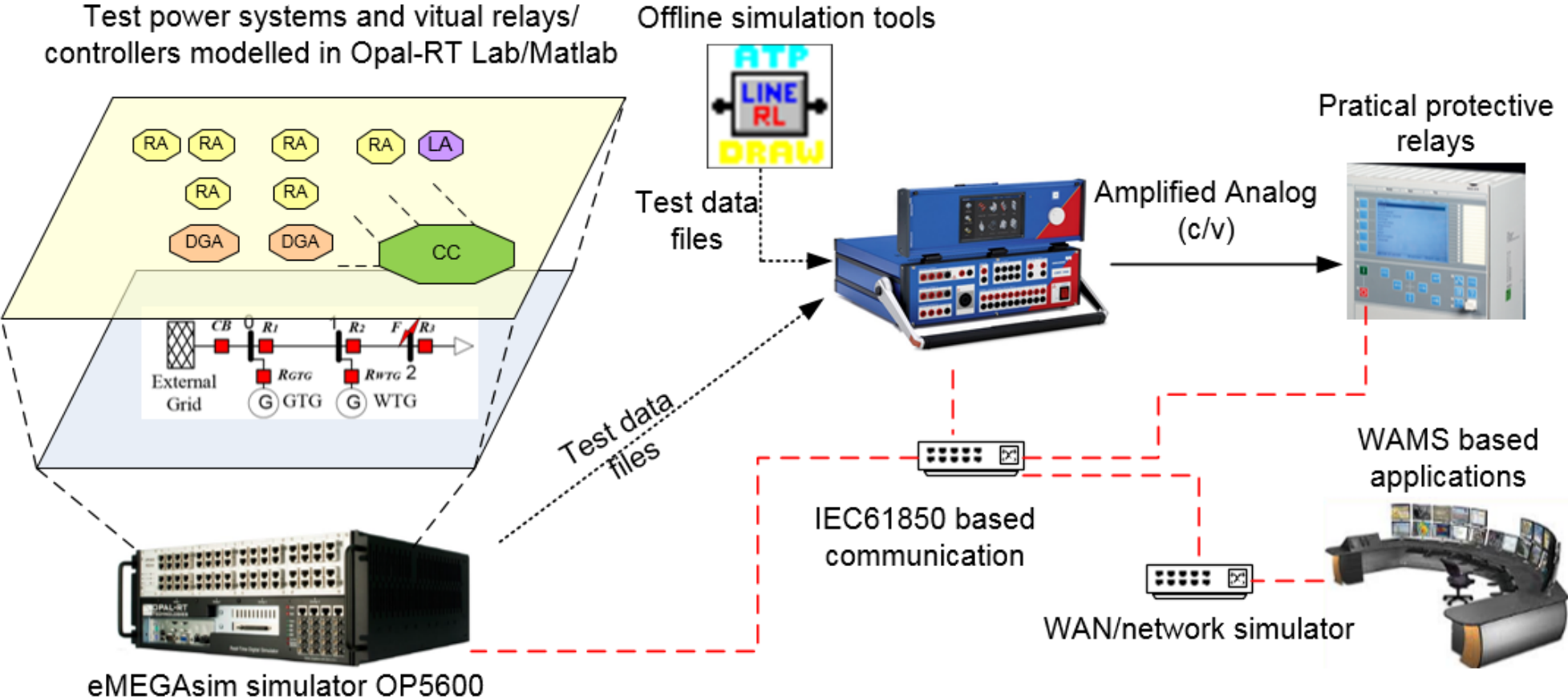
And Phase 2 and Phase 3 are advanced and extended parts related to wide area protection and control against big disturbances.

Conventional relay testing VS HIL



Ref.: Solutions overview- protection application using Real-Time Simulators, by Francois Berthelot & Shijia Li, OPAL-RT.

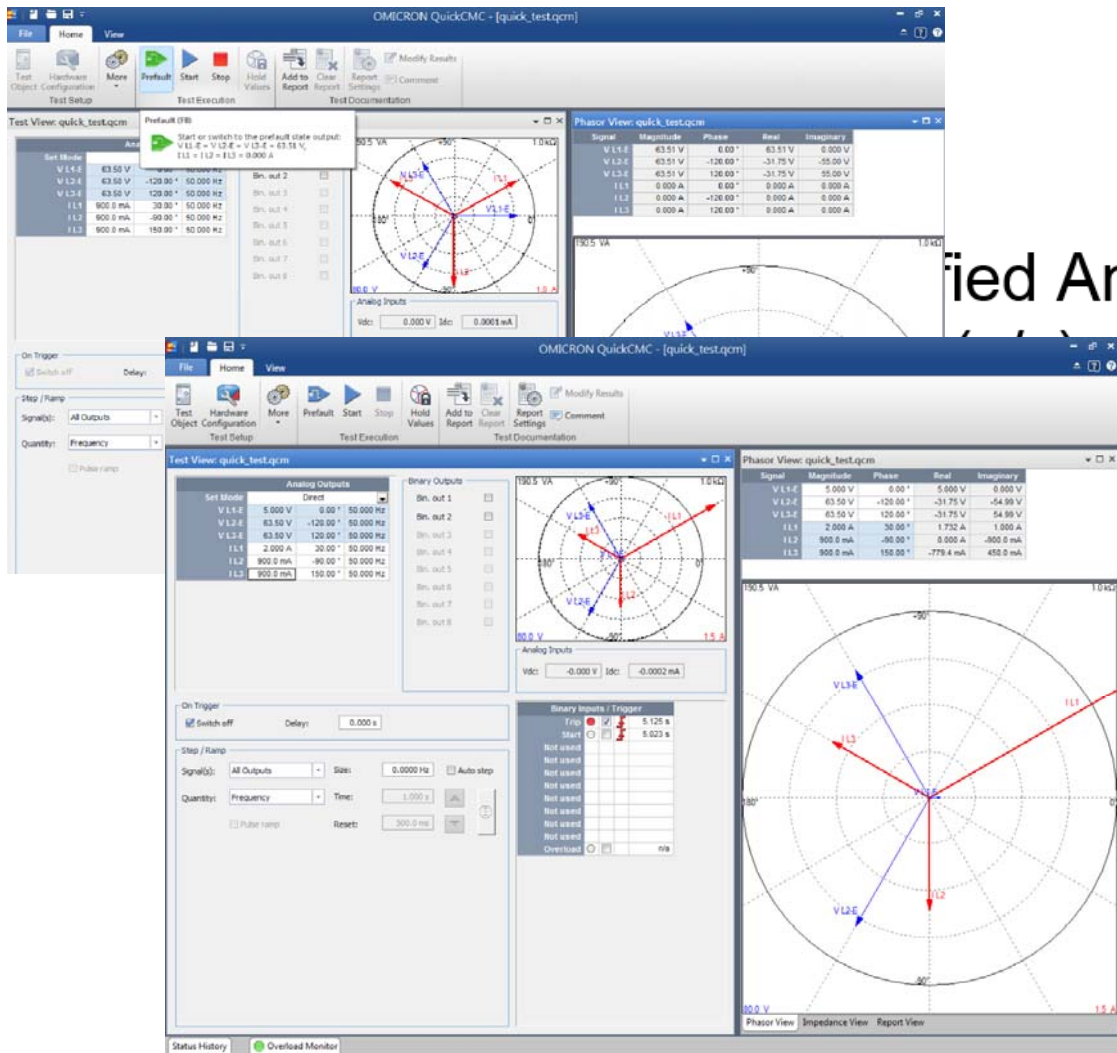
NTNU HIL test lab



Outline

- NTNU HIL test lab
- **HIL applications on power system protection**
 - Simple test case
 - Adaptive distance relay and testing

Simple test case in traditional way



ified Analog

RET 670



Simple test case (Process Bus - Sample Value)

- 61850-9-2 process bus between Opal simulator and Relays
- Normal operation mode 22kV, 180.6A.

The screenshot shows the OPAL simulator interface on the left with two voltage and current signal plots. The top plot is labeled 'Voltage' and the bottom 'Current'. Both show sinusoidal waveforms. On the right, a Wireshark capture window displays an IEC61850 Sampled Values frame. The frame details include:

- Frame 110238: 122 bytes on wire (976 bits), 122 bytes captured (976 bits) on interface
- Ethernet II, Src: Iec-Tc57_04:e3:5f, Dst: Iec-Tc57_04:e3:5f
- IEC61850 Sampled Values
- APPID: 0x4000
- Length: 108
- Reserved 1: 0x0000 (0)
- Reserved 2: 0x0000 (0)
- seqASDU: 1 item
- ASDU:
 - sVID: OPAL_MU003
 - smpCrt: 1847
 - confRef: 1
 - smpSynch: none (0)
 - seqData: ffffdd7a20000000000003e0b000000000ffffe47af00000000...

Below the Wireshark window, a hex dump shows the raw data bytes, with a portion highlighted in blue.

Test signals generated by OPAL

Raw data on process bus seen by Wireshark

The PCM monitoring interface displays real-time data for two relays: RED 670 and REG670. The data is organized into two columns of digital displays.

Relay	Parameter	Value	Unit
RED 670	IL1	180.672	A
	IL1ANGL	4.1871	deg
	IL2	180.662	A
	IL2ANGL	78.130	deg
	IL3	180.663	A
	IL3ANGL	16.1874	deg
REG670	UL12	22.081	kV
	UL12ANGL	93.089	deg
	UL23	22.081	kV
	UL23ANGL	26.915	deg
	UL31	22.082	kV
	UL31ANGL	156.002	deg

PCM monitoring interface

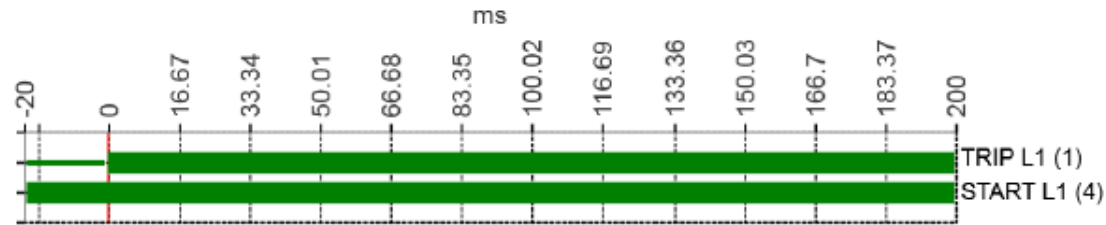


Sim

- Sing

Binary Time Diagram

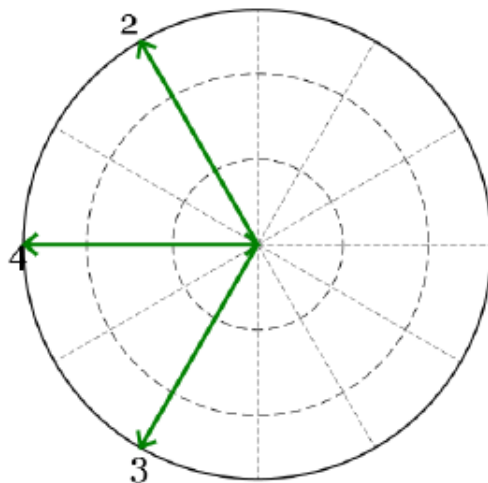
Trig Date Time: 12/26/2014 7:01:16:891 AM



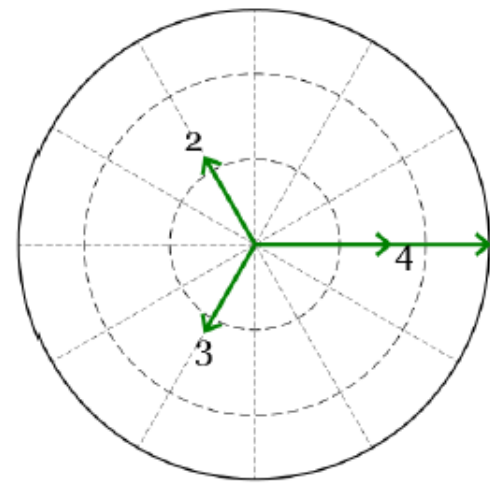
Vector Diagrams

Calculation Interval : 1.26599999999996 ms to 16.26 ms

Voltages



Currents

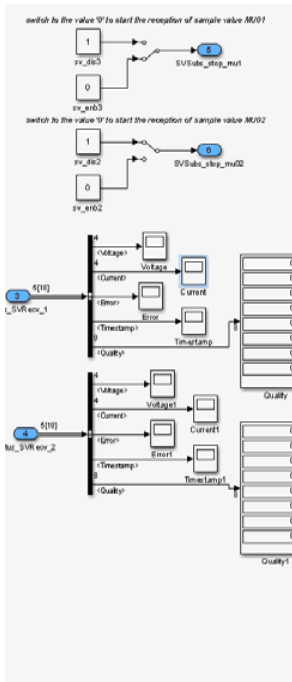
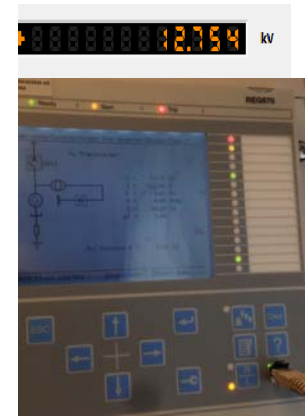


No.	Name	RMS	Angle
1	LINE_UL1	12.744(V)	0.0°
2	LINE_UL2	12749.02(V)	120.0°
3	LINE_UL3	12748.55(V)	240.0°
4	LINE_UN	12736.08(V)	180.0°

No.	Name	RMS	Angle
1	LINE_IL1	425.838(A)	0.0°
2	LINE_IL2	180.671(A)	120.0°
3	LINE_IL3	180.665(A)	240.0°
4	LINE_IN	245.169(A)	0.0°

Events List

Channel Number	Name	Status	Time
1	TRIP L1	On	12/26/2014 7:01:16:891 AM
4	START L1	On	12/26/2014 7:01:11:891 AM



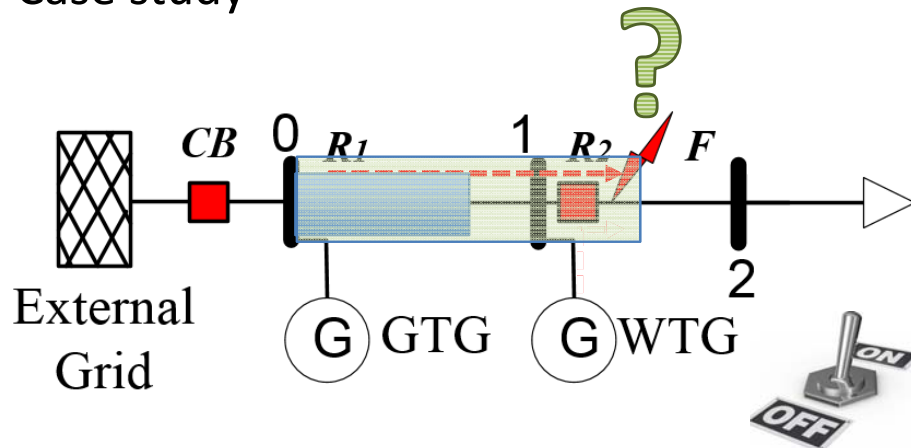
Test si
gener

play HMI



Adaptive distance relay testing

Case study



DG integration **VS** protection setting requirement



IEC61850 based communication



RED 670

Setting group 1



Setting group 2

Ref.:

Z. Liu, H. K. Høidalen, An adaptive inverse time overcurrent relay model implementation for real time simulation and hardware-in-the-loop testing, DPSP 2016

Z. Liu, H. K. Høidalen, A. Ling, M. M. Saha, An adaptive distance relay model implementation for hardware-in-the-loop testing, PAC World 2016.

Conclusion and future possibilities

HIL testing is an excellent solution for advanced protection researches

- Increase simulation and testing speed
- Help researchers to improve their protective algorithms and devices
- Substation automation design based on communication protocols, e.g. IEC61850
- Scalability and flexibility allow adaptation to various study complexity and power system type and size.
- WAMS based applications, e.g. situation awareness, system protection and control, cyber security, etc.

It is a good platform to cooperate with utilities, academics and industries for knowledge sharing and updating as well as professional training.

Live case in the lab.
Meet you there 😊