

AORC-CIGRE TECHNICAL MEETING

16th to 21st August 2015

The Magellan Sutera Resort, Kota Kinabalu, Sabah, MALAYSIA

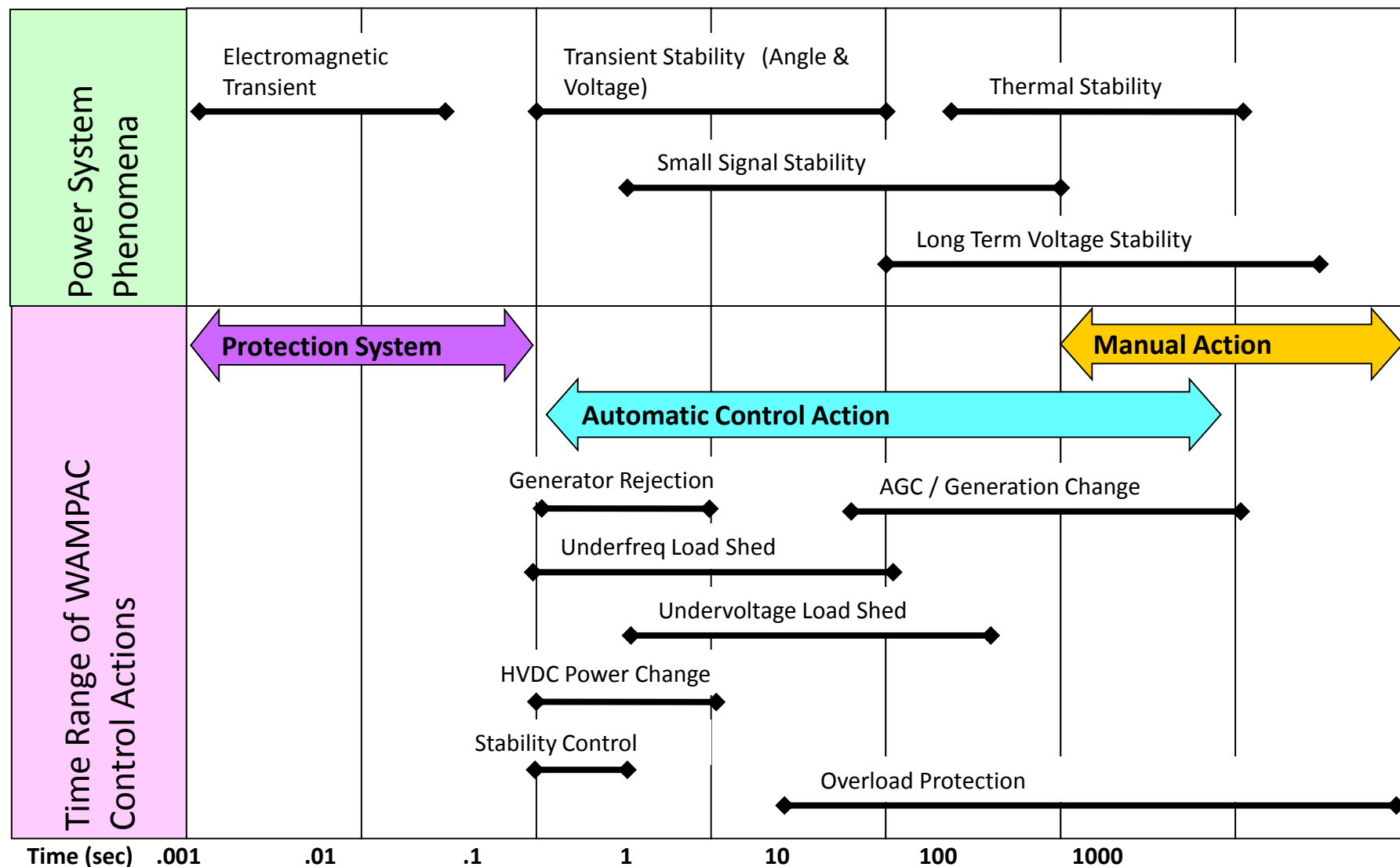


Application of Real-time Phasor Domain Simulation for Wide Area Protection in Large-Scale Power Systems

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Introduction: Application Time Frame

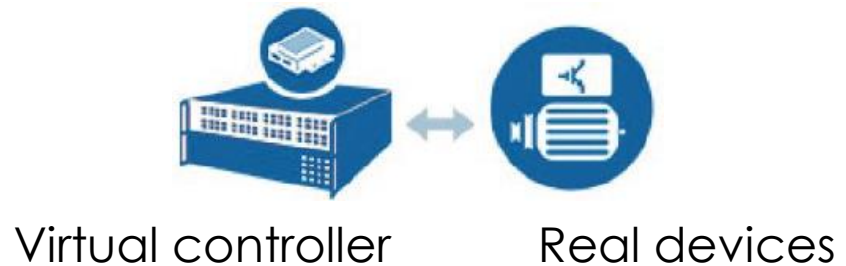


Highlights

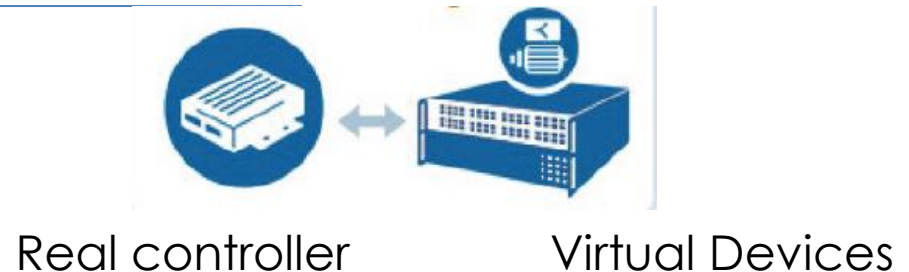
- Real Time Power System Simulator
- Features and Capability
- Example Hardware in Loop Testing

Why Real-Time Simulation?

- Rapid Control Prototyping
 - Motor Control
 - Power Electronics Control



- Hardware-In-the-Loop Testing
 - Power Electronics Controllers
 - (MMC, Drives, PV, Plugin Hybrid, Etc.)
 - WAMPAC system



- Real-Time Simulation of Power Systems & Power Electronics

Desktop Simulation



Real-Time Simulation Model Time Step



Application	Typical Frequency	Typical Time Step	Simulation Technology
Transient Stability Simulation (PHASOR)	100 Hz	1-10 ms	Intel CPU 3.3 Ghz
Robotics / Aircraft simulation	1 000 Hz	1 ms	
Electromagnetic Transient Simulation (EMT)	1 000 000 Hz	50 us	
Low frequency Power Electronics Simulation	100 000 Hz	10 us	
FEM PMSM Motor with Inverter	2 500 000 Hz	0,4 us	FPGA
High Frequency Power Electronics Simulation	5 000 000 Hz	0.2 us	

ePHASORsim

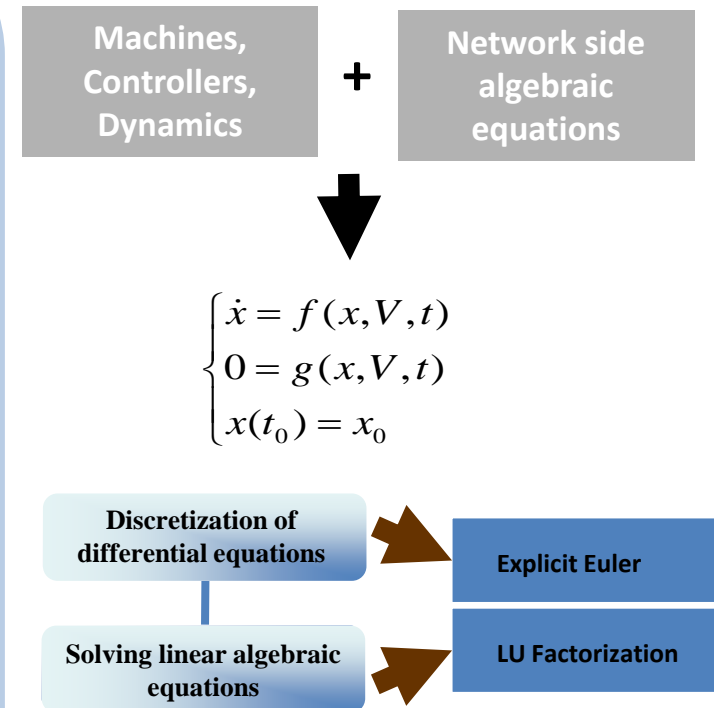
What is ePhasorSim?

Real-time transient stability simulator

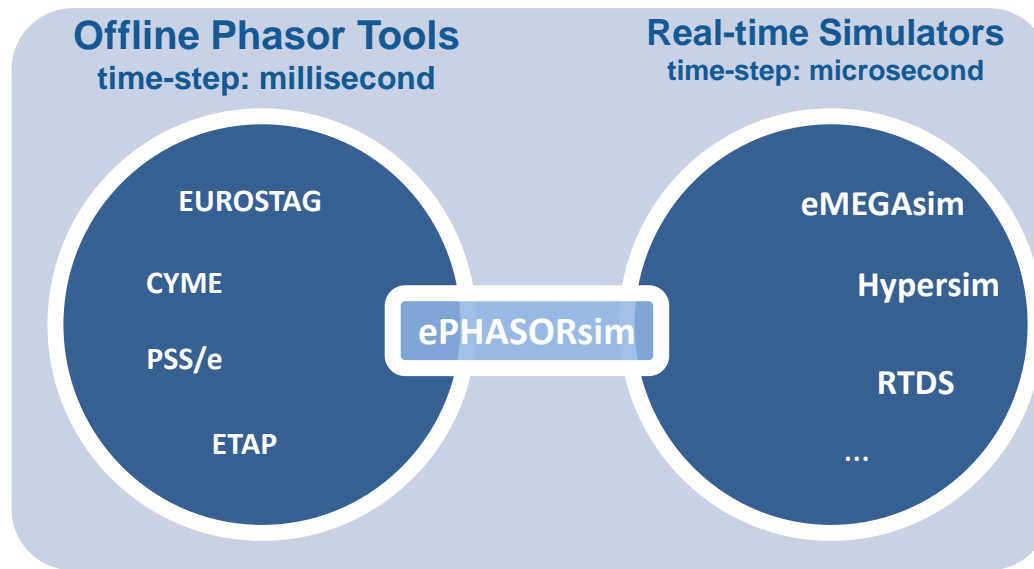
- Large-scale power systems
- Transmission, distribution and generation

Phasor domain solution

- Nominal frequency
- Positive sequence (balanced systems) OR
- 3-phase (unbalanced systems)
- Time-step in the range of few milliseconds



ePhasorsim...



ePHASORsim is a TS-type simulation tool that **not only** runs **offline** **but also** runs in **real-time** on RT-LAB enabled simulators

Features of ePhasorsim

- High performance computation:
 - systems in size of **20k buses** on single core CPU
- Built-in positive sequence and 3-phase library:
 - Machine, Sources, Transformers
 - Simulation of Transmission and Distribution Systems
- Flexible data input format:
 - **Excel** and **PSS/e**
- **Interactive, On-the-fly** changes of parameters: Loads, Generators, Create Faults, Transformer Taps etc
- Parallel processing
 - Automatic decomposition of network
- Ethernet protocols and I/Os
 - DNP3, C37.118, Modbus, IEC 61850, IEC 870-5-101 and 104
 - Analogue and Digital Input Output
- Support User Define Model , FMI: Functional Mock-up Interface

Functional Mock-up Interface

- FMI for

The screenshot displays the OMEdit - OpenModelica Connection Editor interface. The main window shows a hierarchical tree structure on the left, a central text editor with Modelica code, and a right-hand pane showing a block diagram of the system.

Libraries Browser (Left):

- Complex
- Modelica
- ModelicaReference
- ModelicaServices
- OpenModelica
- OpalRT
- Control
- Math
- Connector
- Electrical
- Machine
- GENROU_SM_T1
- GENCLS_SM_T2
- GENSAL_BASE
- GENROU_BASE
- Elements
- Events
- Measurements
- GenUnit

Text Editor (Center):

```

117 PSIq_s0 = (-ZSOURCE_RE * is_d0)
118 EFD0 = PSId_s0 + (Xd - Xd_s) *
119 SPEED0 = ws;
120 ANGLE = ANGLE0;
121 SLIP = 0;
122 der(Eq_p) = 0;
123 der(PSI1_d) = 0;
124 der(Ed_p) = 0;
125 der(PSI2_q) = 0;
126 equation
127 TRIPI = integer(TRIP);
128 when TRIPI == 1 then
129   reinit(SLIP, 0);
130   reinit(Eq_p, 0);
131   reinit(PSI1_d, 0);
132   reinit(Ed_p, 0);
133   reinit(PSI2_q, 0);
134   reinit(ANGLE, 0);
135 end when;
136 PMECH1 = if TRIPI == 0 then PME
137 EFD1 = if TRIPI == 0 then EFD e
138 if TRIPI == 0 then
139   Tdo_p * der(Eq_p) = EFD1 - Xa
140   Tdo_s * der(PSI1_d) = (-PSI1
141   Tqo_p * der(Ed_p) = (-Ed_p) +
142   + PSIq_s * ((Xq - X1) / (Xd - X1)
143   Tqo_s * der(PSI2_q) = (-PSI2
144   2 * H * der(SLIP) = (PMECH1 -
145   der(ANGLE) = ws * SLIP;
146 else
147   der(SLIP) = 0;
148   der(Eq_p) = 0;
  
```

Block Diagram (Right):

- OpalRT
 - Control
 - Excitation
 - I VOEX
 - EXST1
 - IEEEX1
 - SCRX
 - ESACSA
 - IEEET1
 - EX_T1
 - EXAC1
 - EXAC2
 - EXDC2
 - Turbine_Governor
 - GAST2A
 - GAST
 - IEEEG1
 - HYGOV
 - Stabilizer
 - IEEEST
 - STAB3
 - PSS2A
 - Math
 - Connector
 - Electrical
 - Machine
 - GENROU_SM_T1
 - GENSAL_BASE
 - GENROU_BASE
 - GENROE_BASE
 - GENCLS_BASE
 - GENSAE_BASE
 - Elements
 - Events
 - Measurements
 - FACTS
 - Branches
 - GenUnit

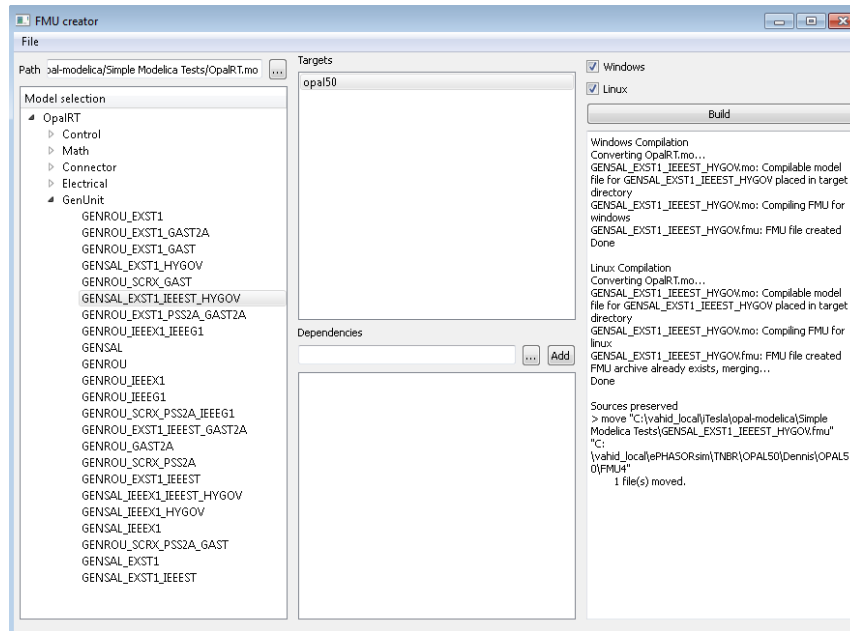
Equation (Bottom Right):

$$s) / (Xq_p - X1) ^ 2 * ((-PSI2_q) + (Xq_p - X1) *$$

Status Bar (Bottom):

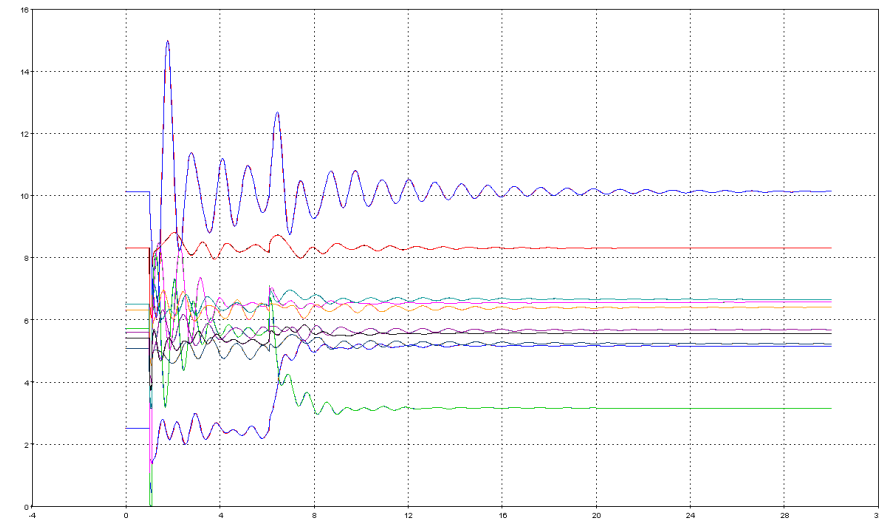
X: -150.72 Y: 50.56 Welcome Modeling Plotting

ePHASORsim FMU Creator

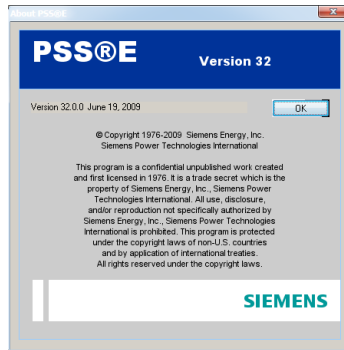


FMUs are loadable directly from

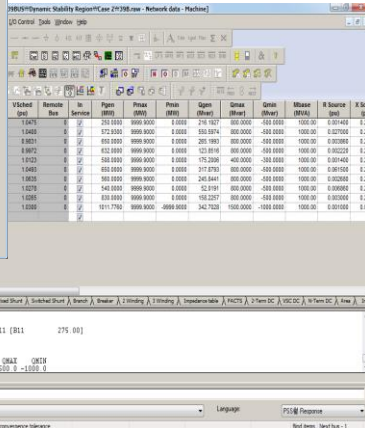
- Excel Template
- PSS/e *.dyr file



Preparing the Real Time Simulator



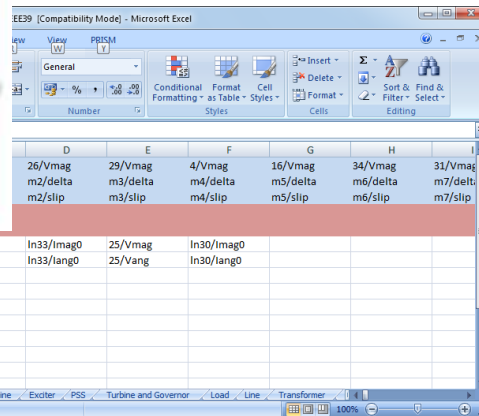
Offline tool



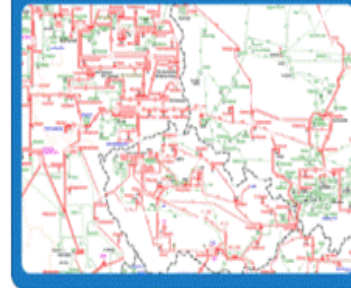
Network & Dynamic models

ePHASORsim

ePHASORsim



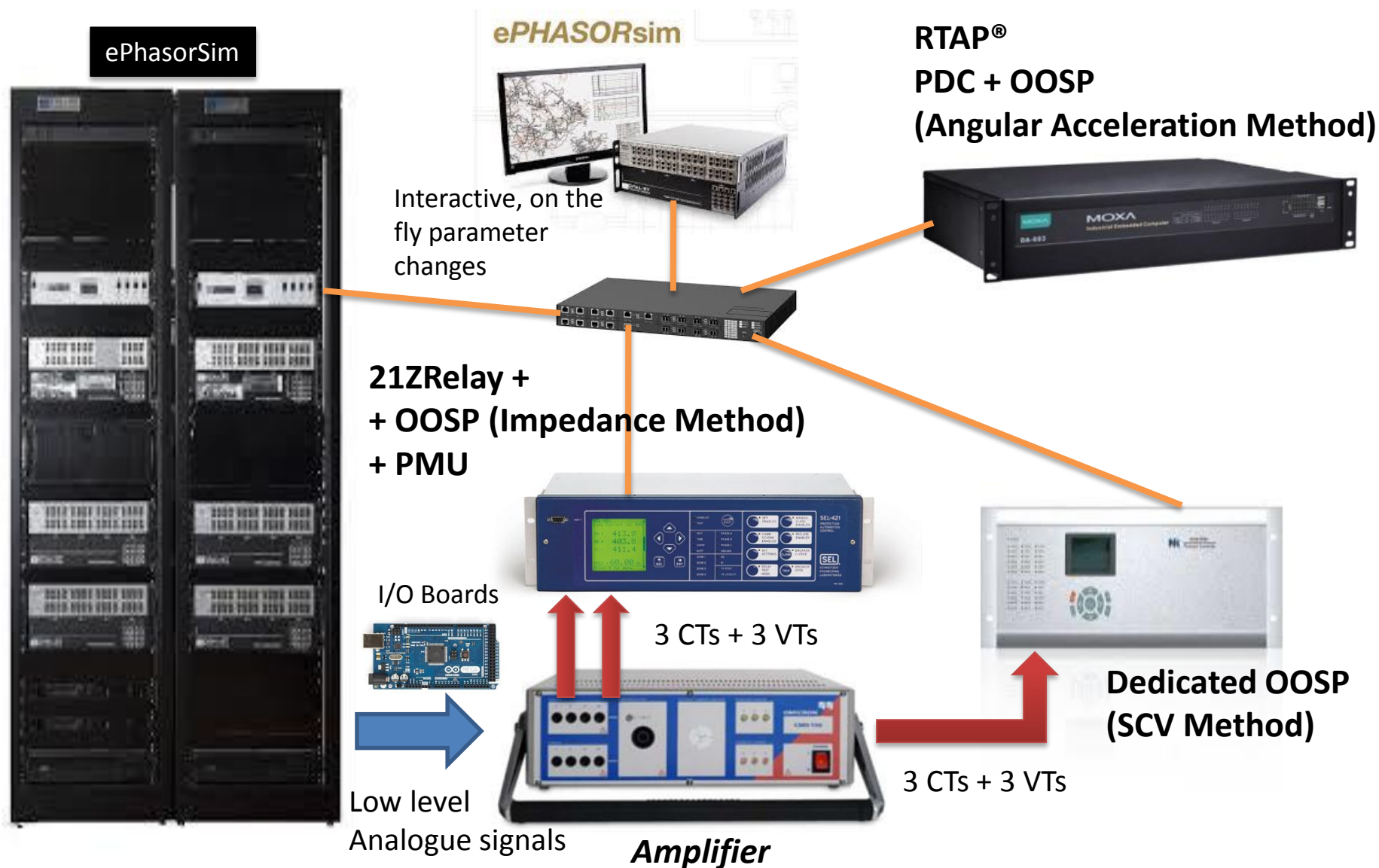
Wide Area Simulation



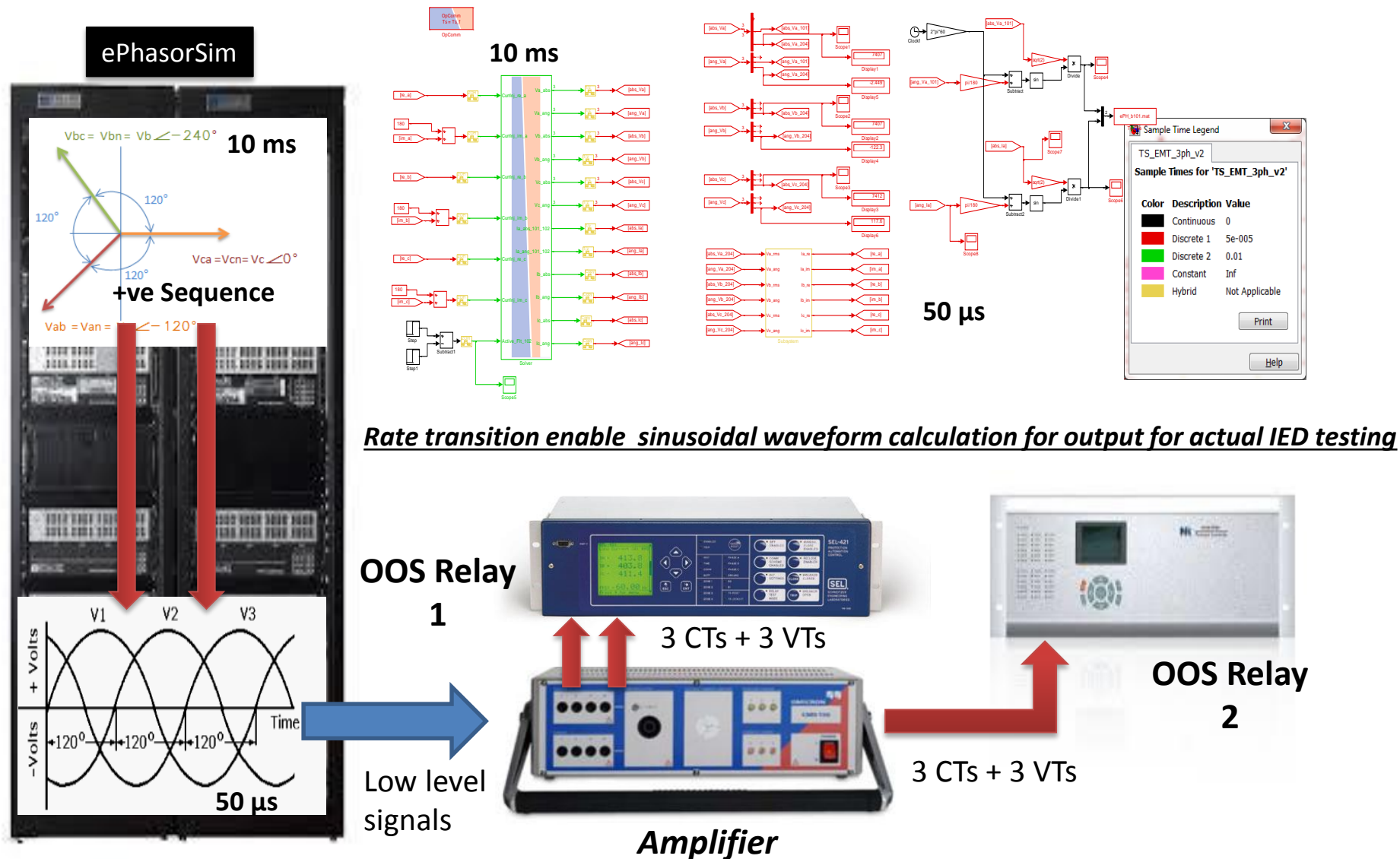
Interface pins



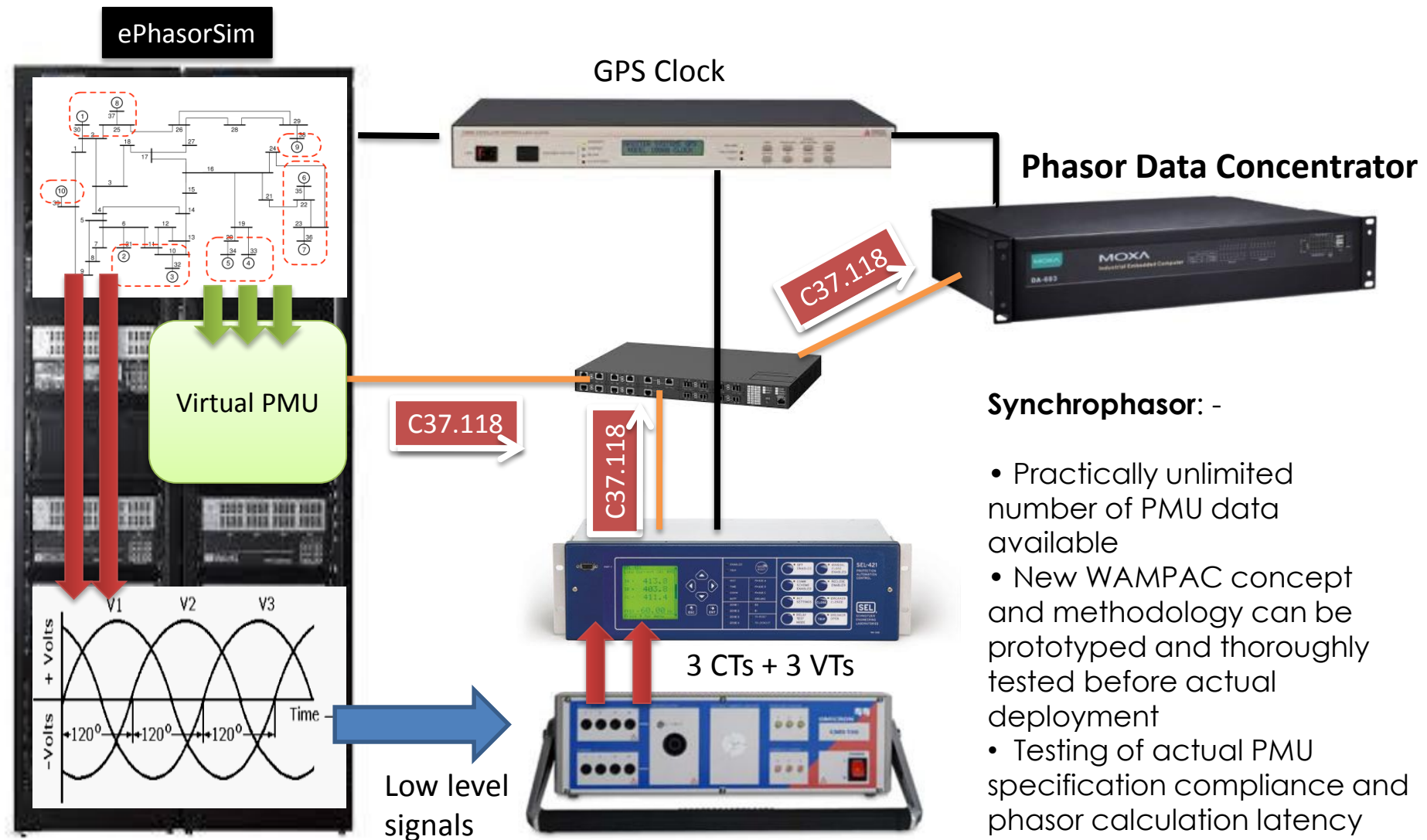
Out Of Step Protection System Test Setup



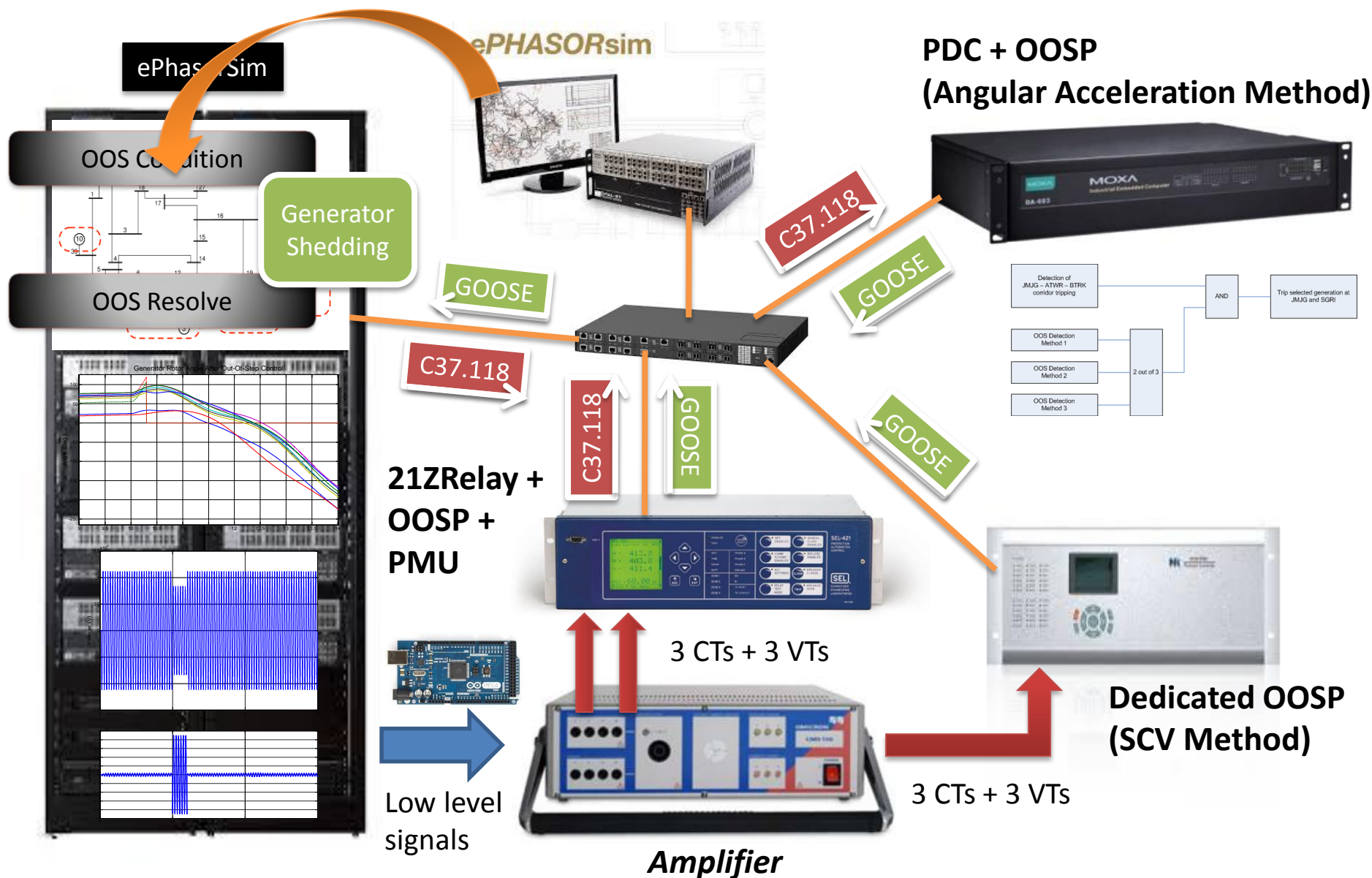
Phasor Domain to Time Domain Simulation



Testing a Synchrophasor-Based System



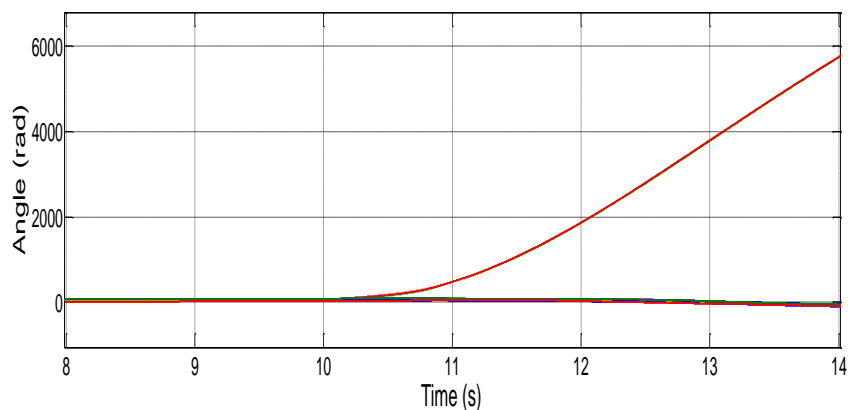
Out Of Step Protection System HiL Test



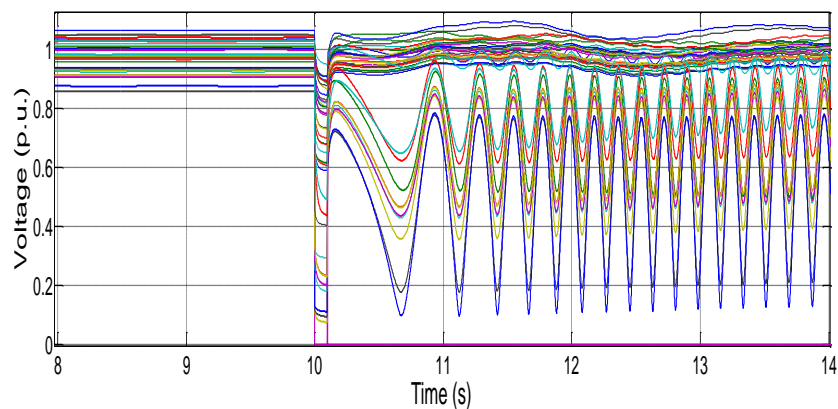
Sample Test Results

No Control Action

Rotor Angle Without Out-of-Step Control Measure

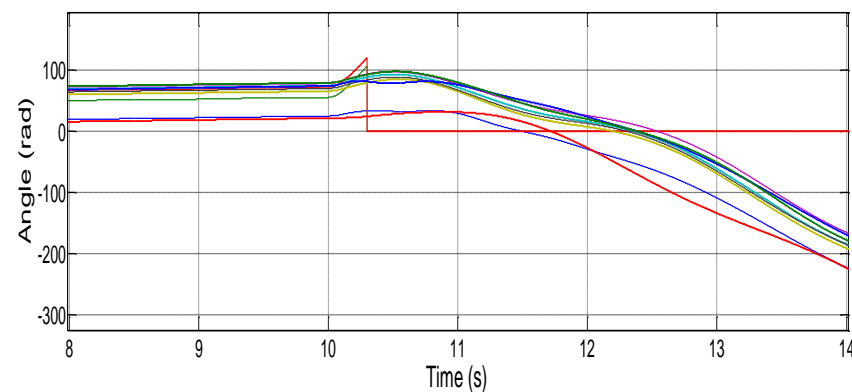


Bus Voltages Without Out-of-Step Control Measure

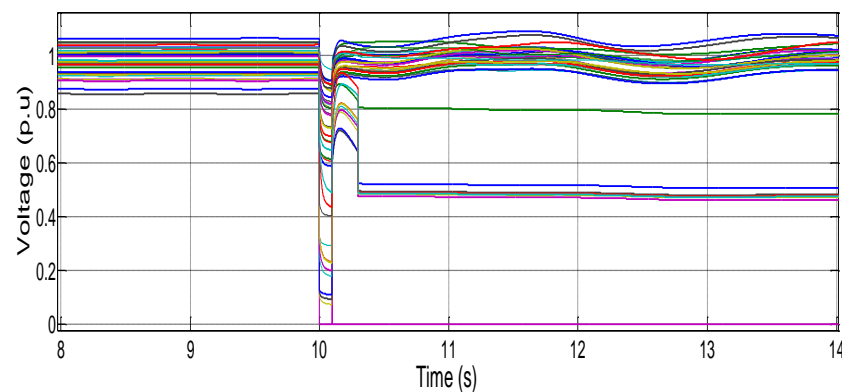


With Generator Shedding Action

Rotor Angle With Out-of-Step Control measure



Bus Voltages With Out-of-Step Control Measure



Summary

- Enable comprehensive functional and performance testing of WAMPAC under controlled environment
be actual deployment
 - Entire grid model can be included
 - Various grid conditions, loads and generation patterns
 - Testing scenarios not possible in actual system test
- Operator training on newly develop WAMPAC applications
- Rapid prototyping of new concepts or ideas
- Increase collaboration between utility and universities

Summary

- Continuous improvement and tuning of the models shall be carried out to ensure the simulation results are as close as possible to actual grid
 - Every time when grid disturbance occurs
 - Using data from PMU-Based dynamic recorder
 - Perform model and model parameters validation

THANK YOU

Q & A