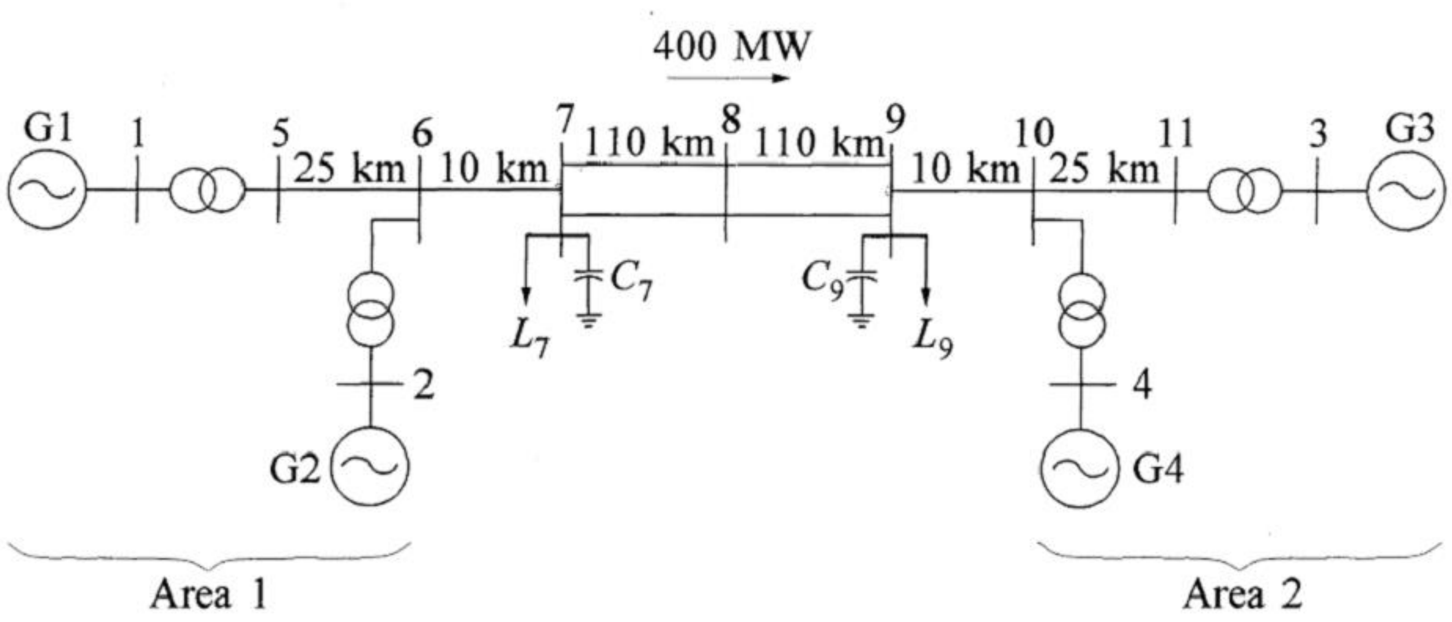
Development of a modified Kundur two-area system with Solar PV farm for Typhoon HIL simulation

DYCOS

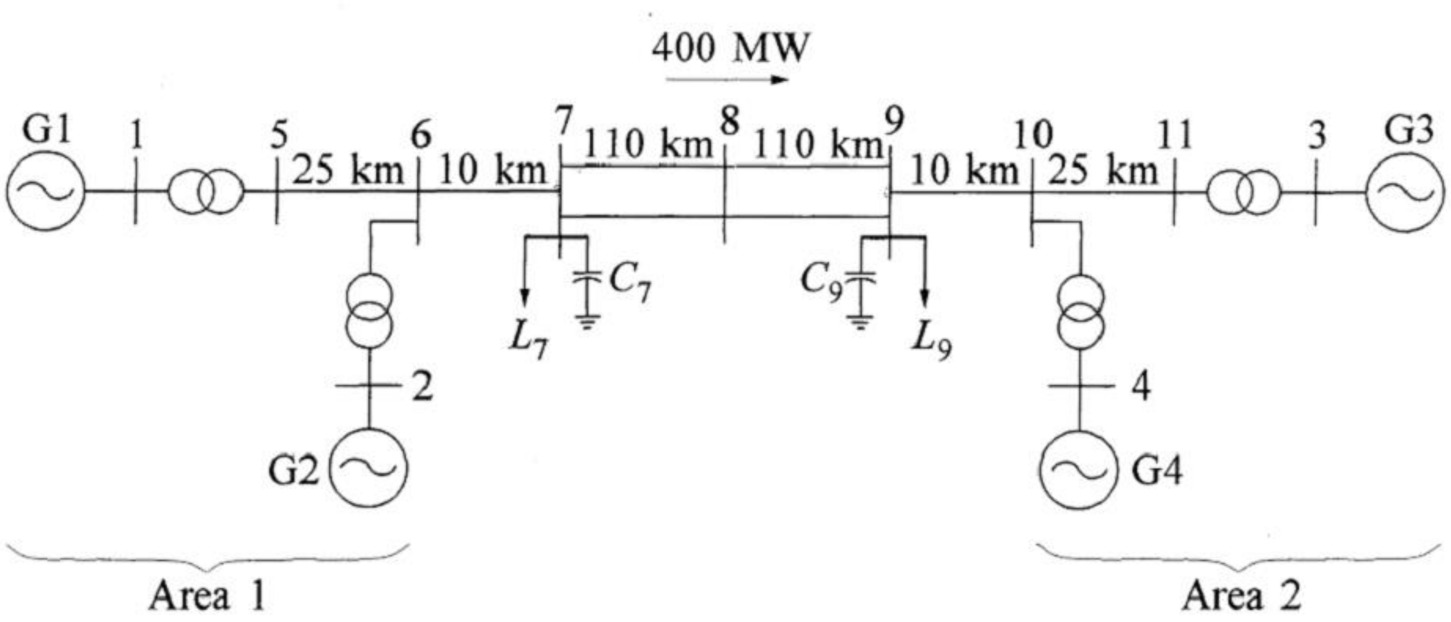
Background

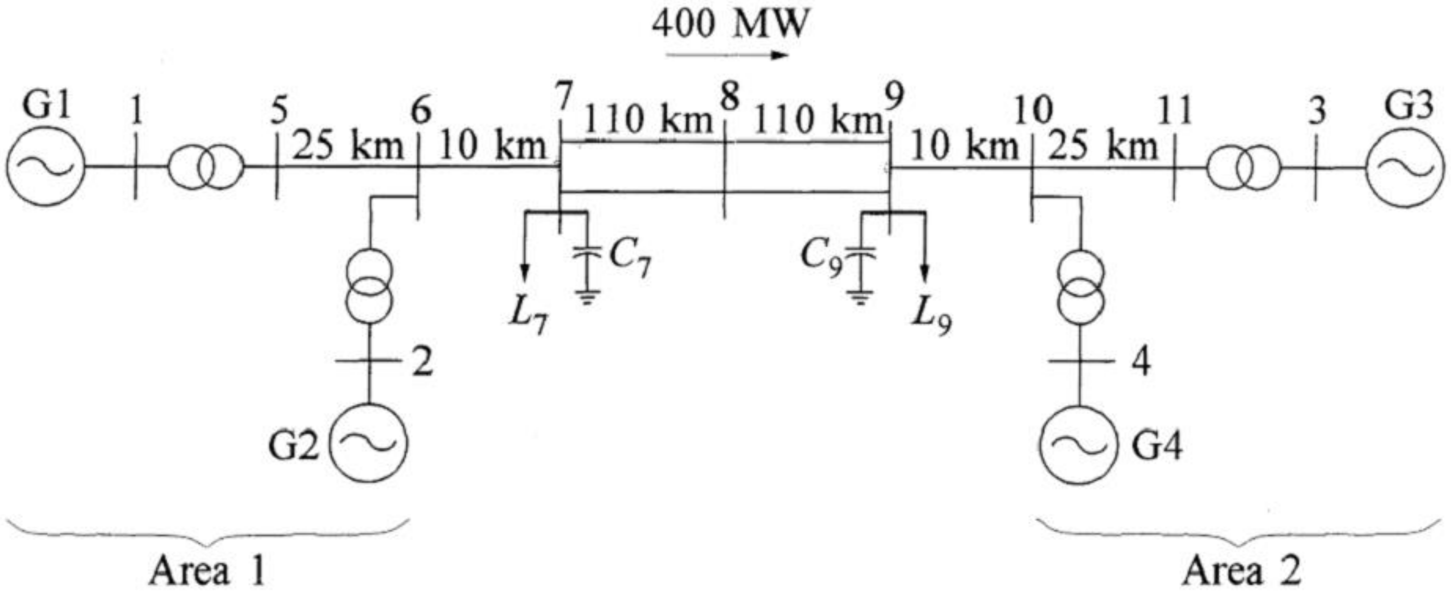
- The two-area system test case is from Prabha Kundur's textbook *Power System Stability and Control* [1], Chapter 12
- It is a test case used for studies on dynamic stability, power interchange, oscillation damping, etc.
- The system contains 11 buses, four generators, and two areas.



Objective

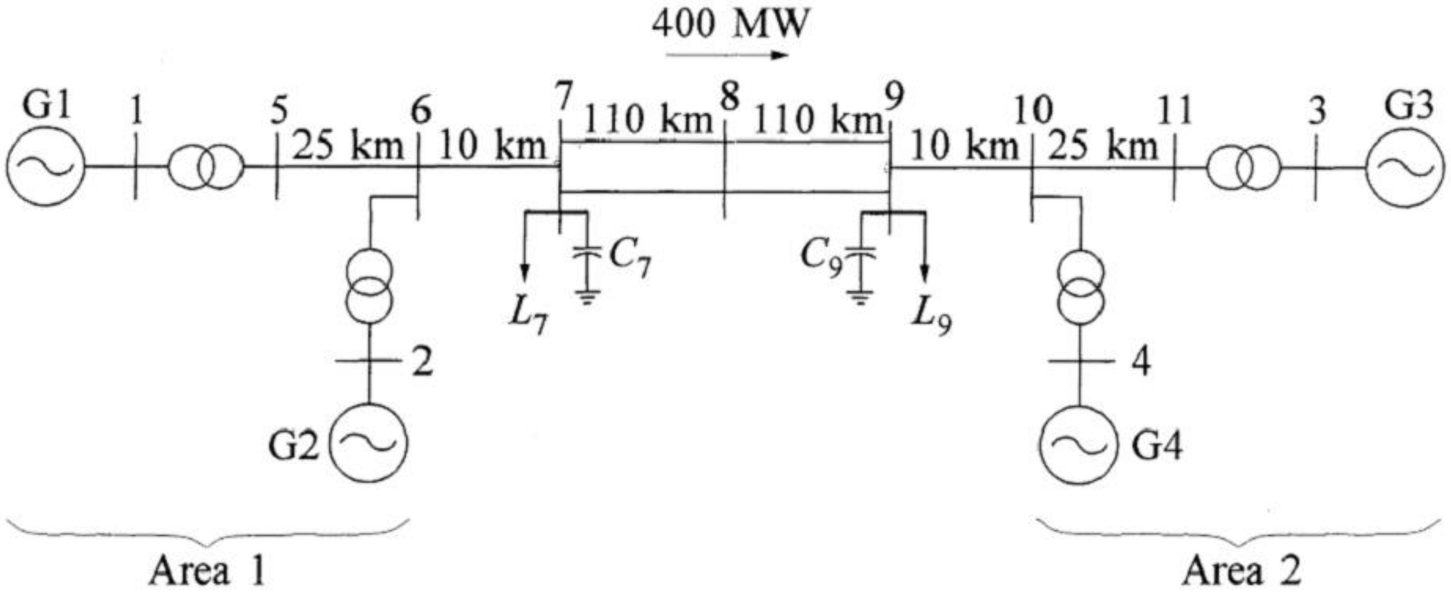
- To make a model of the two-area system to be implemented in Typhoon Hardware in the loop simulator
- To develop a modified model with 1 generator replaced by a solar PV farm of similar power capacities





The system consists of two similar areas connected by a weak tie. Each area consists of two coupled units, each having a rating of 900 MVA and 20 kV. The generator parameters in per unit on the rated MVA and kV base are as follows:

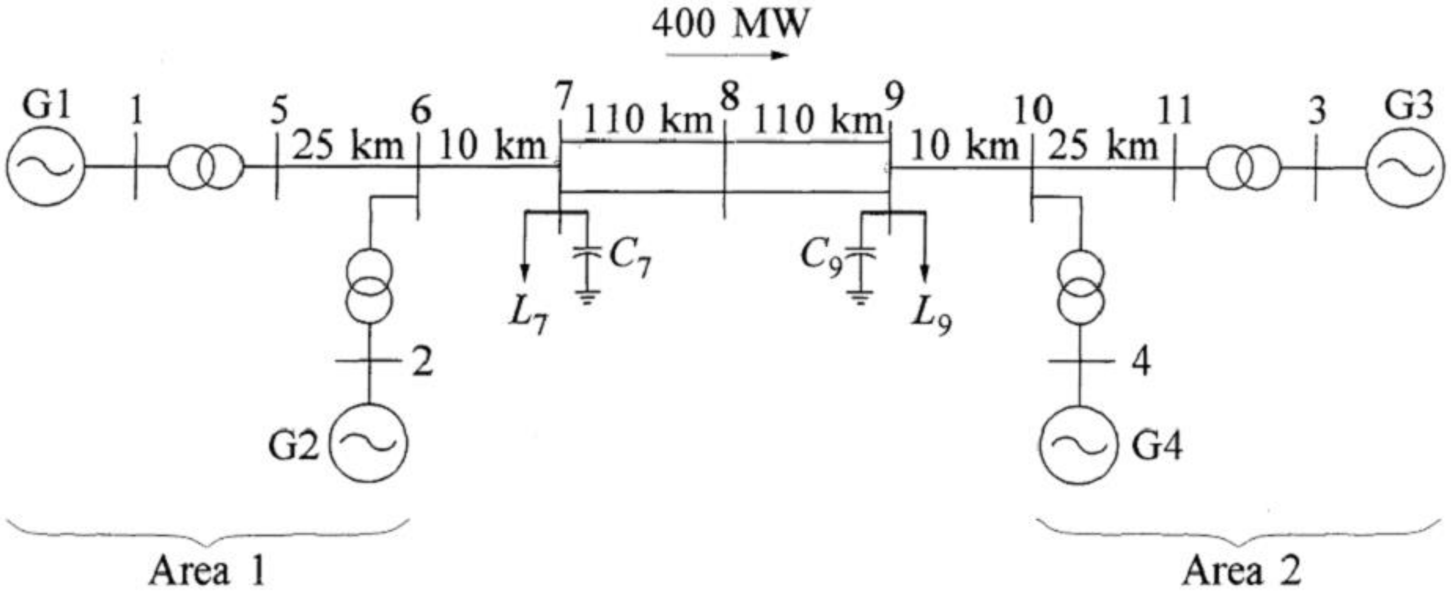
$X_d = 1.8$	$X_q = 1.7$	$X_l = 0.2$	$X'_d = 0.3$	$X'_q = 0.55$
$X''_d = 0.25$	$X''_q = 0.25$	$R_a = 0.0025$	$T'_{d0} = 8.0$ s	$T'_{q0} = 0.4$ s
$T''_{d0} = 0.03$ s	$T''_{q0} = 0.05$ s	$A_{Sat} = 0.015$	$B_{Sat} = 9.6$	$\psi_{T1} = 0.9$
$H = 6.5$ (for G1 and G2)		$H = 6.175$ (for G3 and G4)		$K_D = 0$



Each step-up transformer has an impedance of $0+j0.15$ per unit on 900 MVA and 20/230 kV base, and has an off-nominal ratio of 1.0.

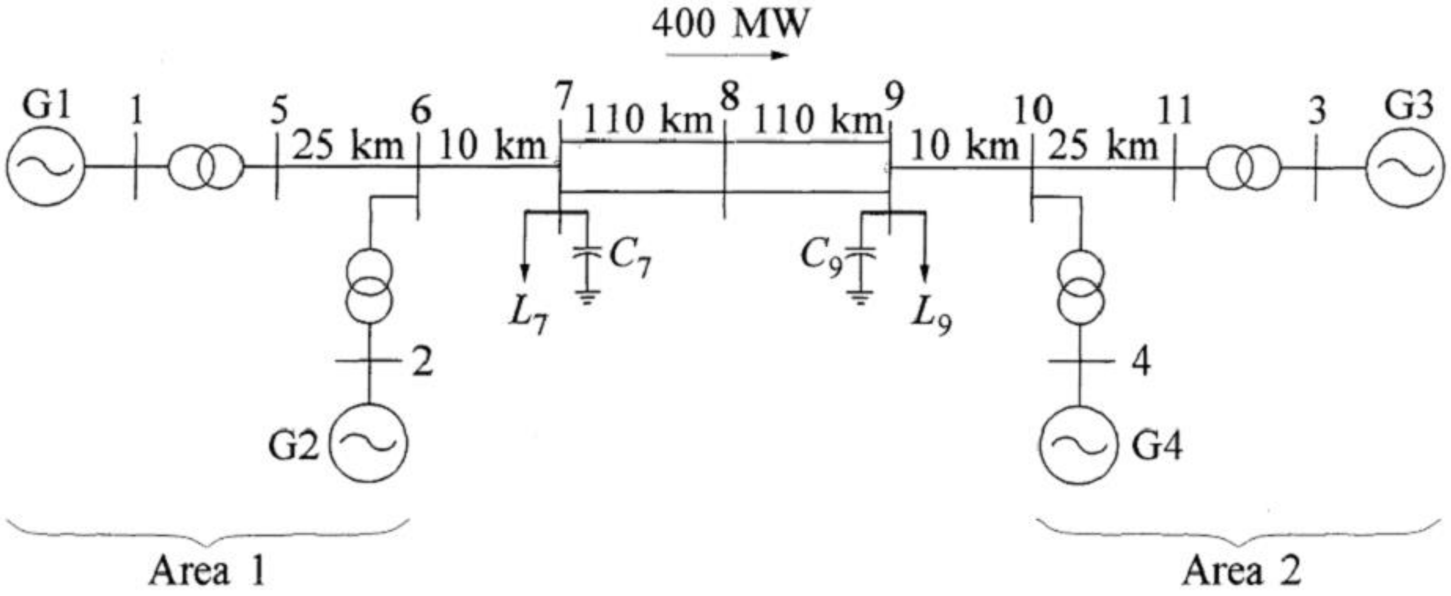
The transmission system nominal voltage is 230 kV. The line lengths are identified in Figure E12.8. The parameters of the lines in per unit on 100 MVA, 230 kV base are

$$r = 0.0001 \text{ pu/km} \qquad x_L = 0.001 \text{ pu/km} \qquad b_C = 0.00175 \text{ pu/km}$$



The system is operating with area 1 exporting 400 MW to area 2, and the generating units are loaded as follows:

G1:	P = 700 MW,	Q = 185 MVAr,	$E_t = 1.03\angle 20.2°$
G2:	P = 700 MW,	Q = 235 MVAr,	$E_t = 1.01\angle 10.5°$
G3:	P = 719 MW,	Q = 176 MVAr,	$E_t = 1.03\angle -6.8°$
G4:	P = 700 MW,	Q = 202 MVAr,	$E_t = 1.01\angle -17.0°$



The loads and reactive power supplied (Q_C) by the shunt capacitors at buses 7 and 9 are as follows:

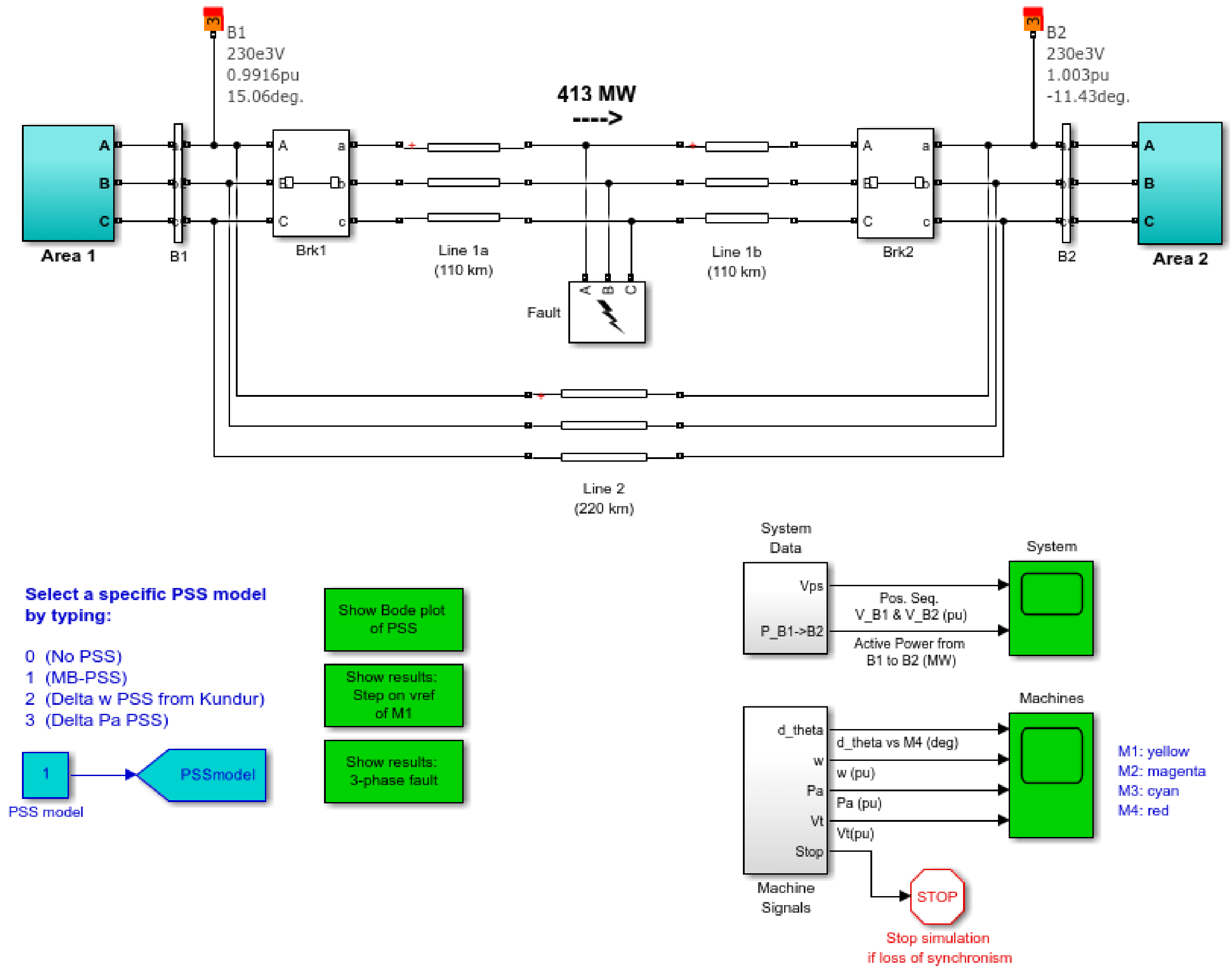
Bus 7:	P_L = 967 MW,	Q_L = 100 MVAr,	Q_C = 200 MVAr
Bus 9:	P_L = 1,767 MW,	Q_L = 100 MVAr,	Q_C = 350 MVAr

Possible references

Performance of Three PSS for Interarea Oscillations

This example shows three Power System Stabilizers (PSS) models using Kundur's four-machine two-area test system.

I. Kamwa (Hydro-Quebec)



https://fr.mathworks.com/help/sps/ug/performance-of-three-pss-for-interarea-oscillations.html

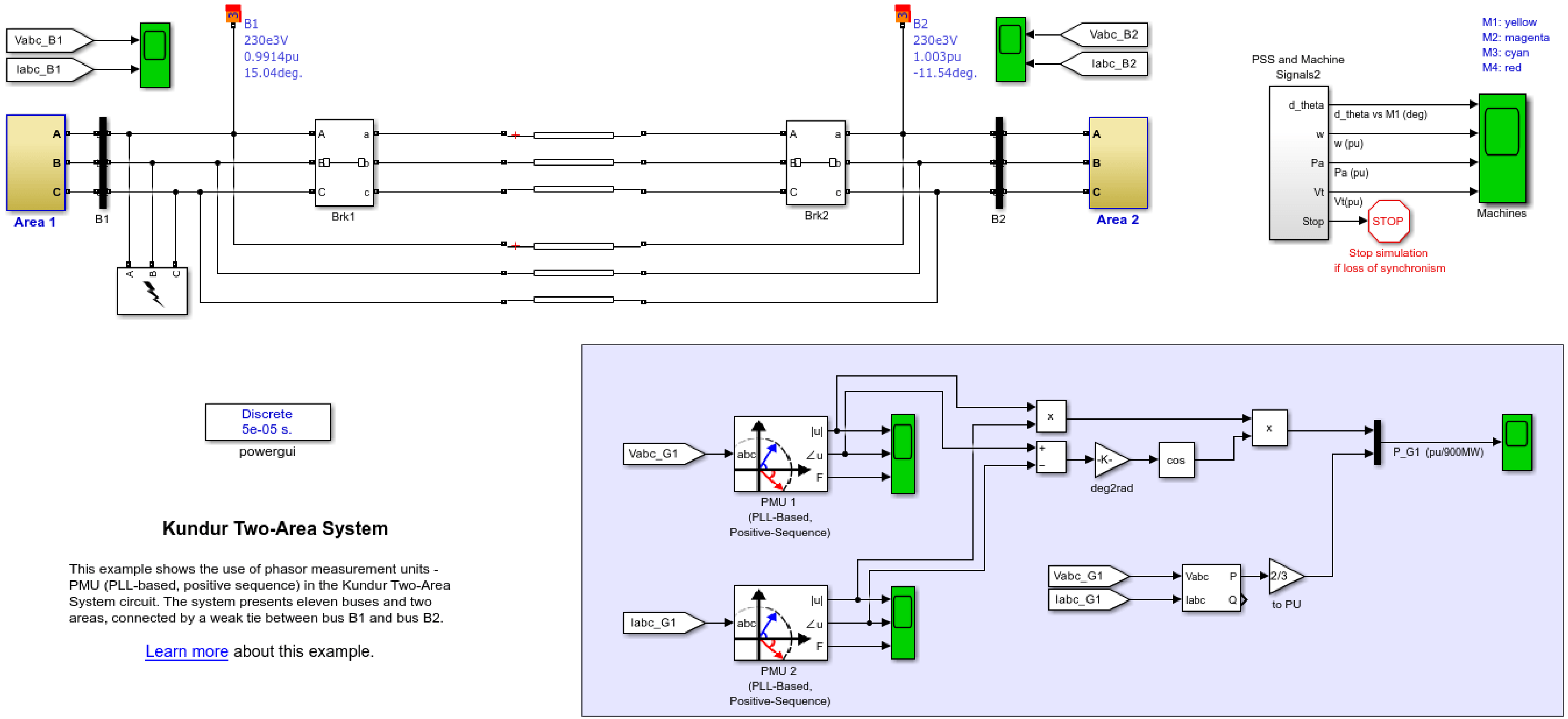
Possible references

Kundur's Two-Area System with PMU

R2023b

Copy Command

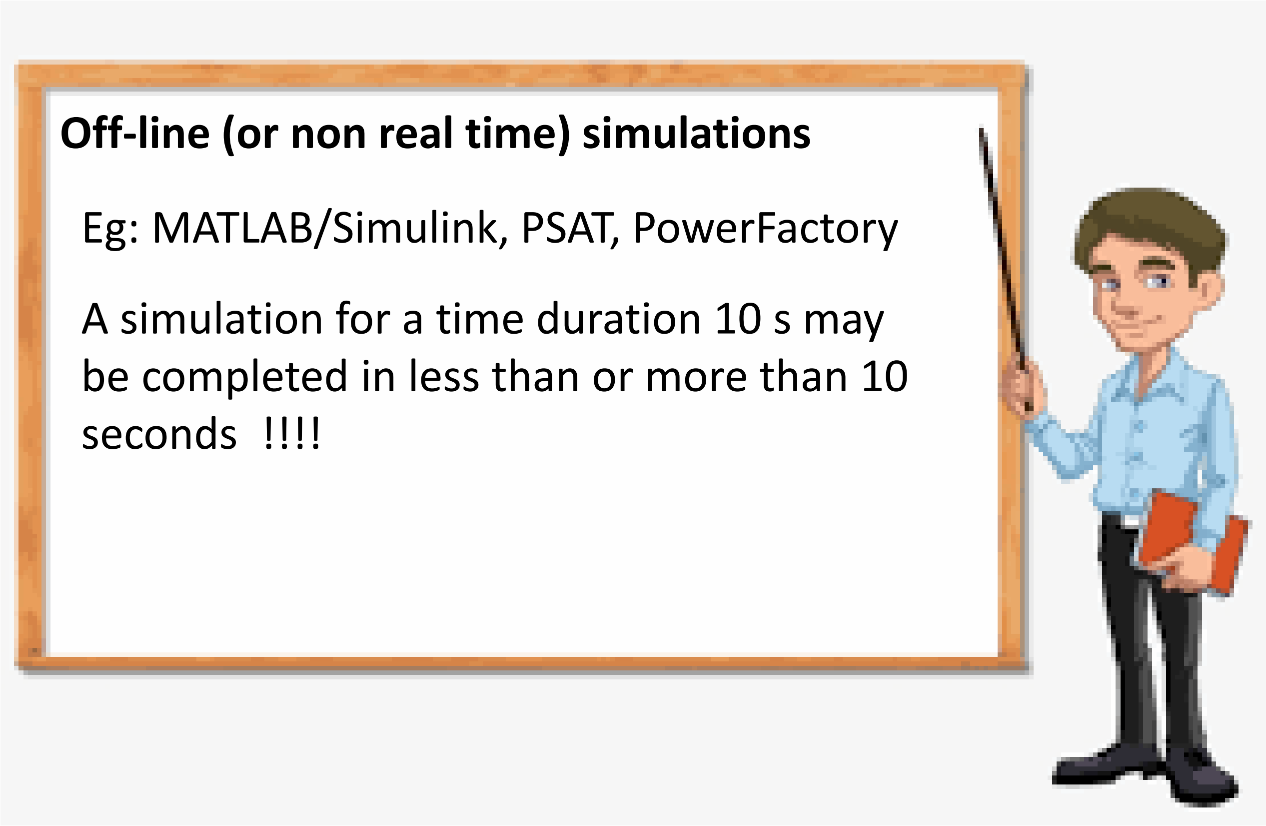
This example shows the use of the PMU (PLL-Based, Positive-Sequence) block within the Kundur's Two-Area System.



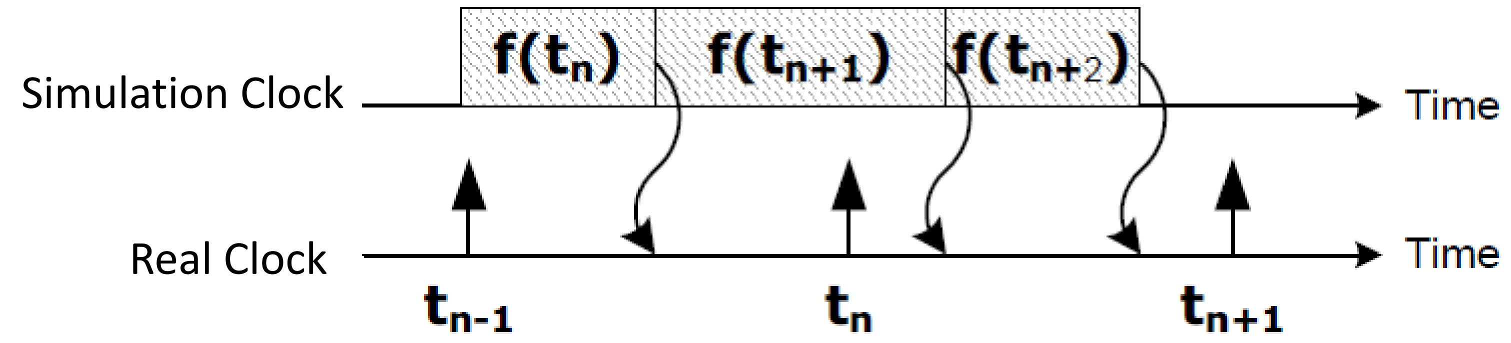
https://fr.mathworks.com/help/sps/ug/pmu-pll-based-positive-sequence-kundur-s-two-area-system.html

Digital Simulation

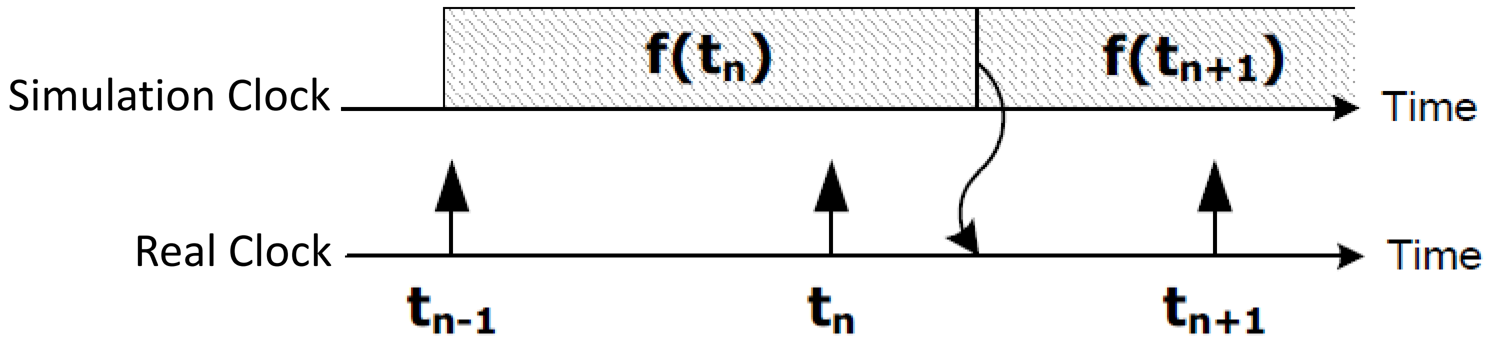
- Used extensively to analyse larger and complex systems
- Digital simulation typically involves the solving of the mathematical model (differential equations) describing the system by the use of proper numerical integration techniques and time steps
- The implementation is done through a high-level language code on a digital platform, such as a computer but newer softwares allow the use of GUI blocks to build up the system



Digital Simulation



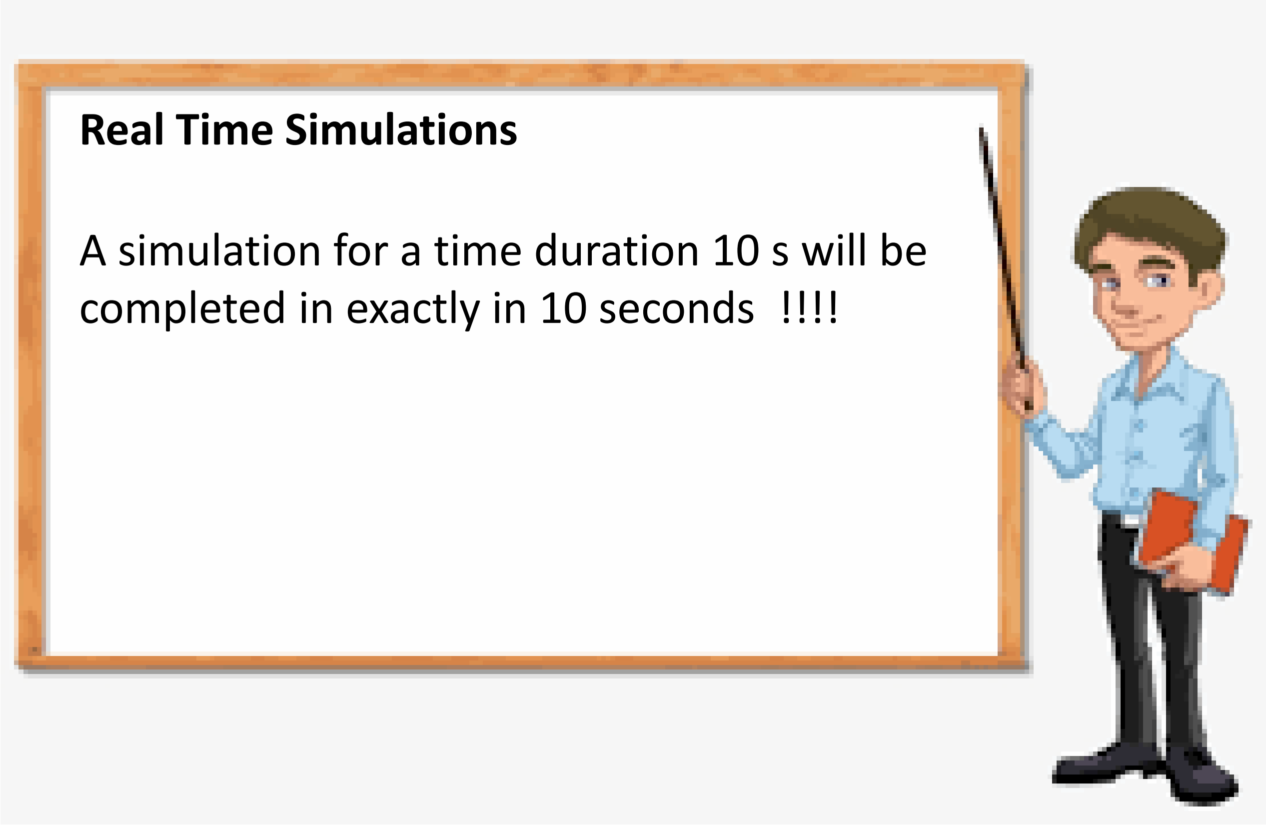
Case 1: FASTER THAN REAL-TIME



Case 2: SLOWER THAN REAL-TIME

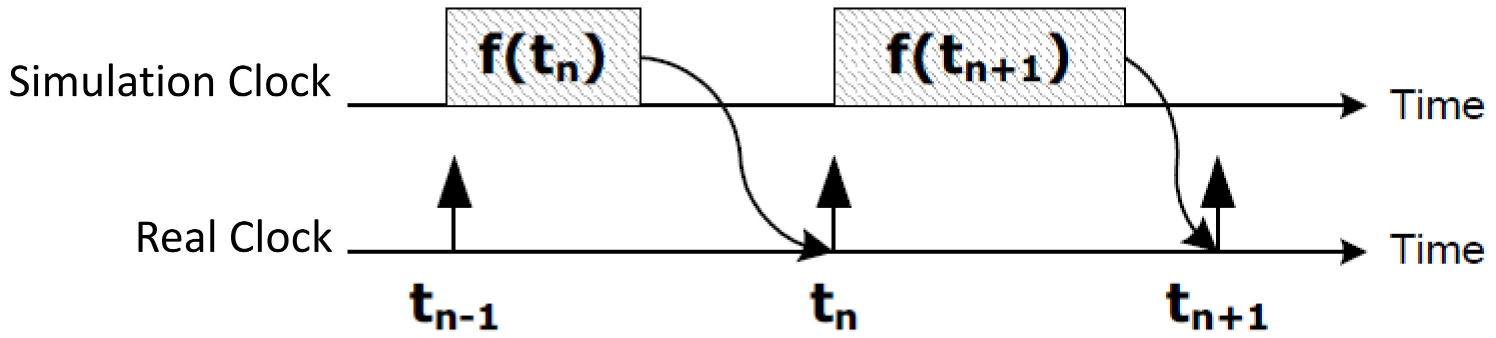
Real Time Simulation

- Refers to a computer model of a physical system that can execute at the same rate as actual "wall clock" time.
- In other words, the computer model runs at the same rate as the actual physical system
- Performed in a discrete time with constant step also known as fixed step simulation



- Time required to solve the internal state equations and functions representing the system must be less than the fixed step.
- If calculation time exceeds the time of the fixed step, an over-run is said to have occurred

Real Time Simulation



Real-Time Simulator- Manufacturers

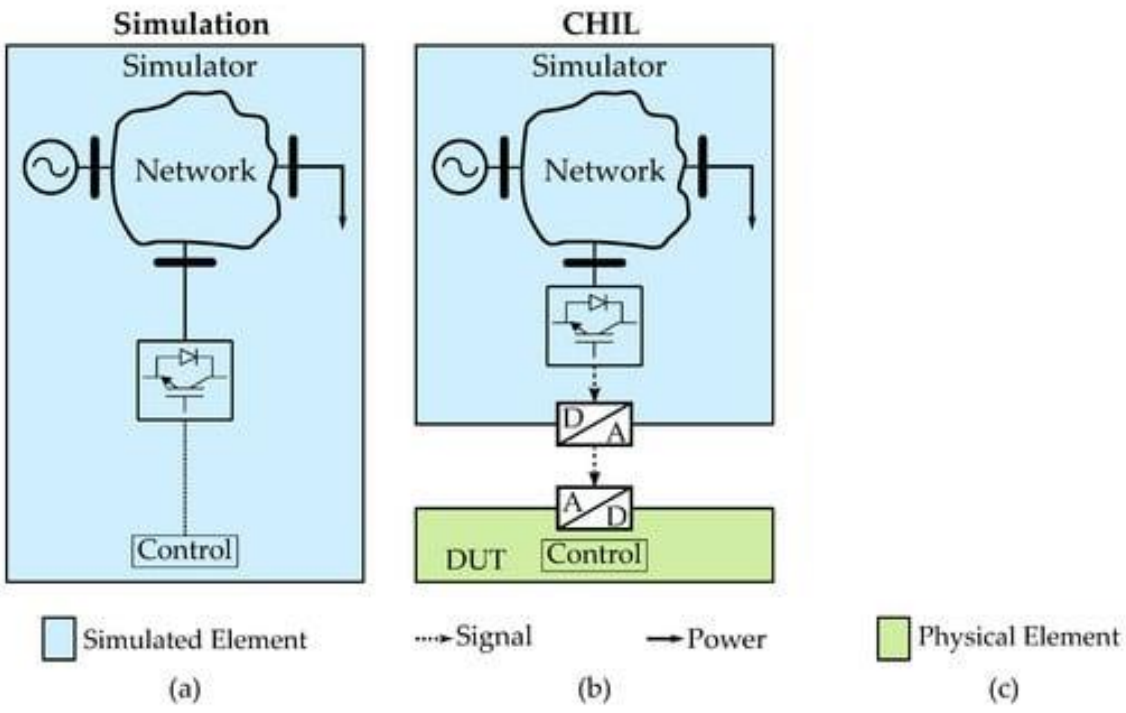
OPAL-RT	Typhoon	RTDS	Speedgoat	dSPACE
 OPAL-RT TECHNOLOGIES 	 Typhoon HIL 	 RTDS Technologies 	 speedgoat 	 dSPACE 

Hardware-in-the-loop Simulation

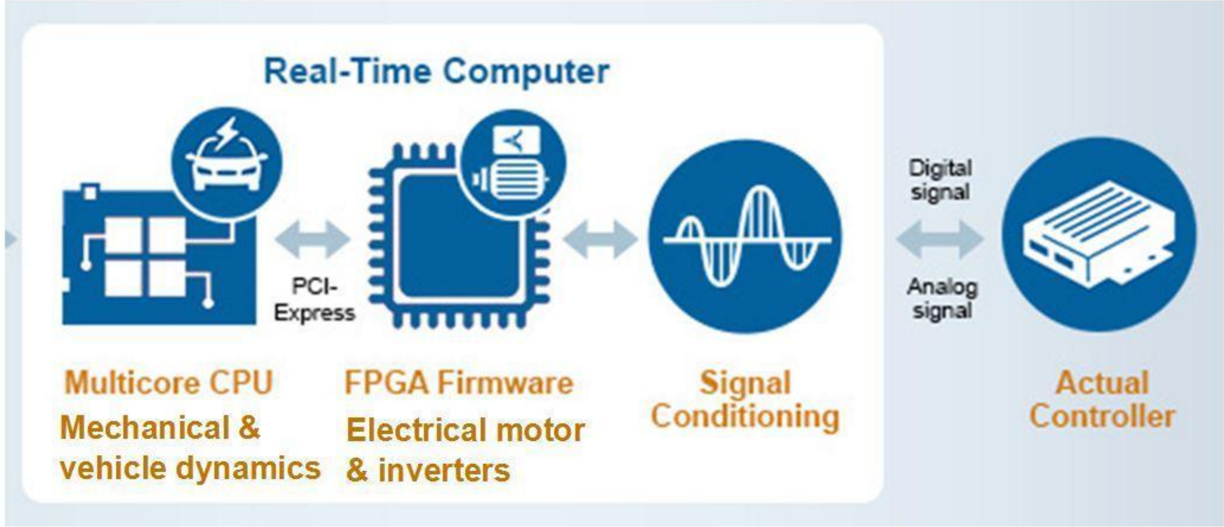
- In Hardware-in-the-Loop(HIL) simulation, a hardware device is interfaced to a Real-Time-Simulator(RTS) which models the rest of the system used to test the device operation.
- HIL simulation is a cost-effective and flexible method to test hardware devices under various operating conditions.
- HIL simulations can be open loop where signals are sent from the RTS to the device or most commonly closed-loop where the response of the device is feedback to the RTS.
- HIL simulation can be divided into two types: Control HIL and Power-HIL

Controller-HIL (CHIL)

- HIL or CHIL or CIL (Controller-in-the-Loop) simulation is a real-time plant model (grid …) interfaced to a piece of hardware under test **usually with low-power signal interfaces**



C-HIL Testing of an inverter connected to a grid

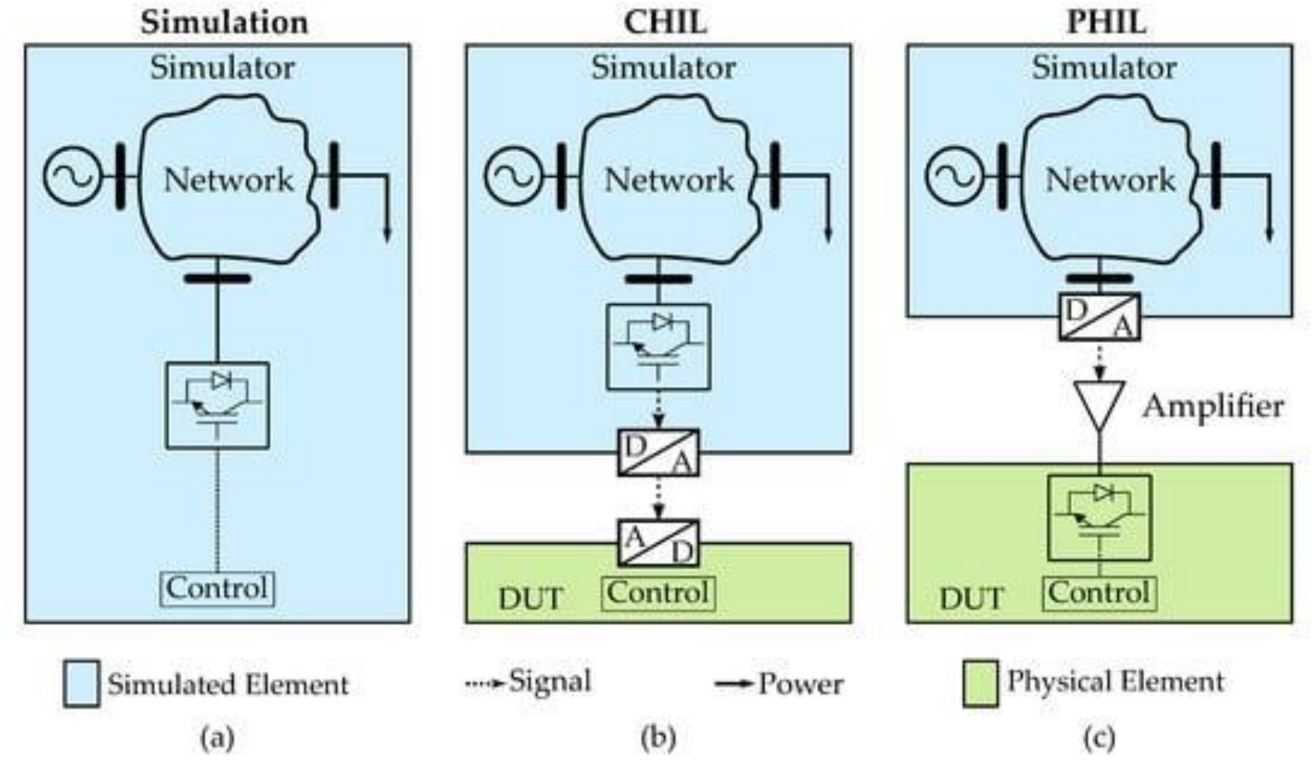


C-HIL Testing of Electrical Vehicles

https://tec.ieee.org/newsletter/september-2013/hardware-in-the-loop-hil-for-electric-drive-applications

Power Hardware-in-the-loop Simulation

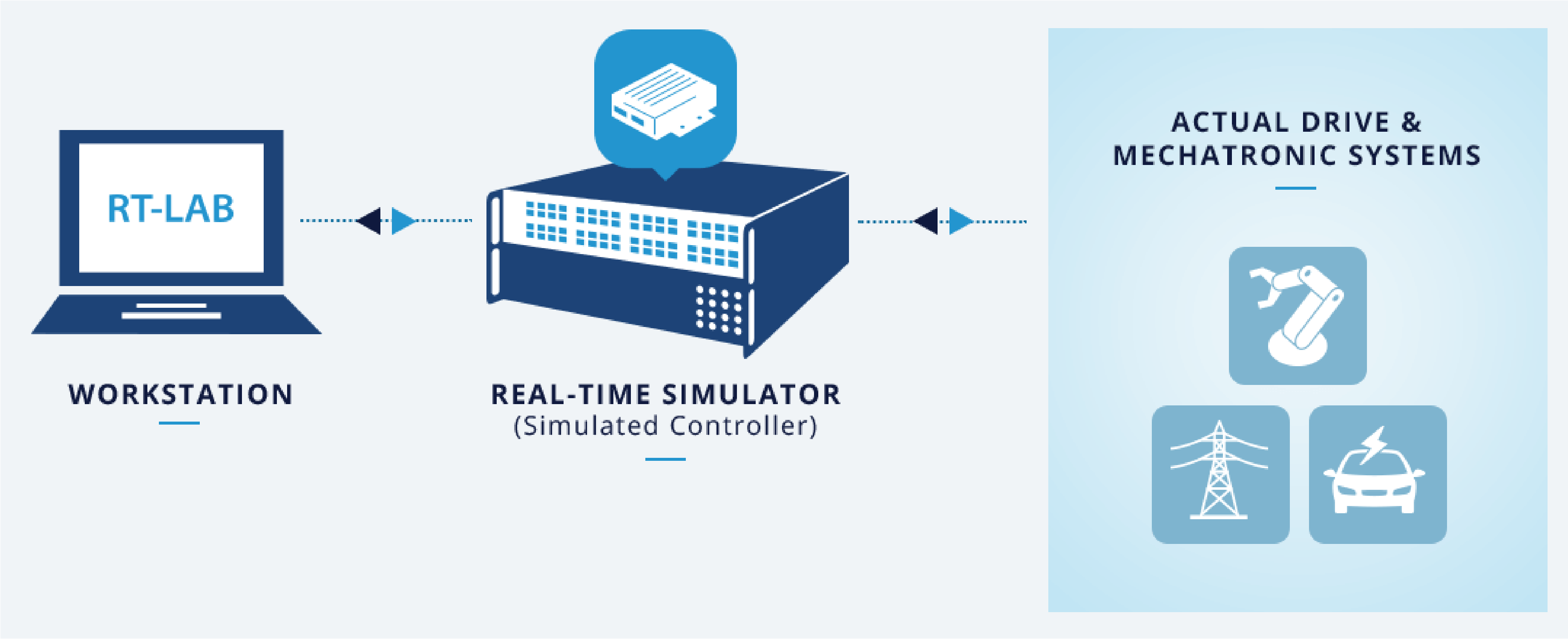
- PHIL simulation is the **integrated simulation of a complete system** with **one part simulated numerically** and the **other part using real devices.**
- Need power amplifiers (Bidirectional programmable DC sources or Grid emulators)
- The power amplifier must have the capability to feed the device under test and to absorb power generated by the devices



PHIL Testing of an inverter connected to a grid

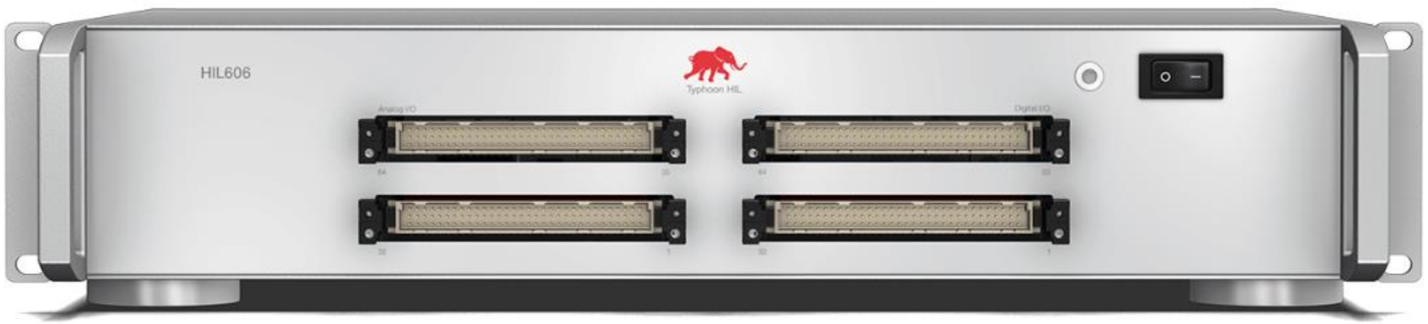
Rapid Control Prototyping (RCP)

- Rapid control prototyping differs from Hardware-in-the-Loop in that the control strategy is simulated in real-time and the plant, or system under control, is real.



Typhoon HIL platform

- https://www.typhoon-hil.com/videos/learn-to-use/typhoon-hil-microgrid-testbed/



HIL606 technical details

0.2 μs	3.5 ns	24 (3PH)*	16/8 (1PH/3PH)*	16 units
Min. Simulation Step	DI Sampling Resolution	Detailed DER Models	Detailed Converter Models	Paralleling

Processor	ZU9EG Zynq UltraScale+ MPSoC up to 8 processing cores
Channels	32 x Analog inputs (AI) 64 x Analog outputs (AO) 64 x Digital inputs (DI) 64 x Digital outputs (DO)

Work Plan – Period 1 (2 weeks)

- Literature Review on the topic
- Exploring Typhoon HIL platform
- Elementary simulation with simple systems in Typhoon virtual HIL

Work Plan – Period 2 (3 weeks)

- Implementation of the two area system in Typhoon Virtual HIL

Work Plan – Period 3(2.5 weeks)

- Implementation of solar PV part in the simulation model (partial)

Work Plan – Period 4 (2.5 weeks)

- Implementation of solar PV part in the simulation model (complete)
- Testing the overall model

Work Plan – Period 5 (4 weeks)

- Testing the overall model (final)
- Consolidation of the results
- Preparation of final report and presentation (16 Jan 2024)

References

[1] Prabha Kundur. *Power System Stability and Control*. McGraw-Hill Professional, 1994.

[2] https://www.typhoon-hil.com/