

Power Hardware-in-the-Loop testing for the Inverter-based Distributed Power Source



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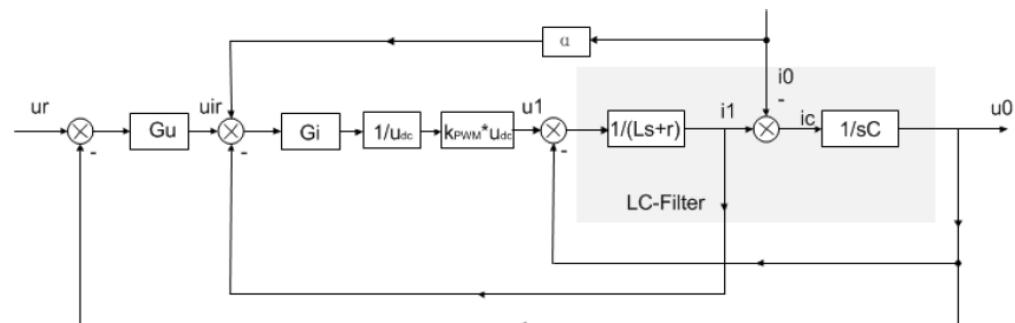
Cyber-physical grids

Cyber-physics in power systems

- Influence from power electronics-based power source to grid
 - Dynamic behavior
 - No induction motor/generator load model
 - No rotating equipment
 - Very fast response-controlled current source
 - Power Quality
 - power fluctuations
 - Harmonic wave
 - Unstable of parallel sources
 - Reaction of a power failure/interference

Power Electronic – Hardware and software

- Power electronic components
 - IGBT
 - MOSFET
 - over-current damage
- Software signal processing
 - Control algorithm
 - Program efficiency
 - Bug...



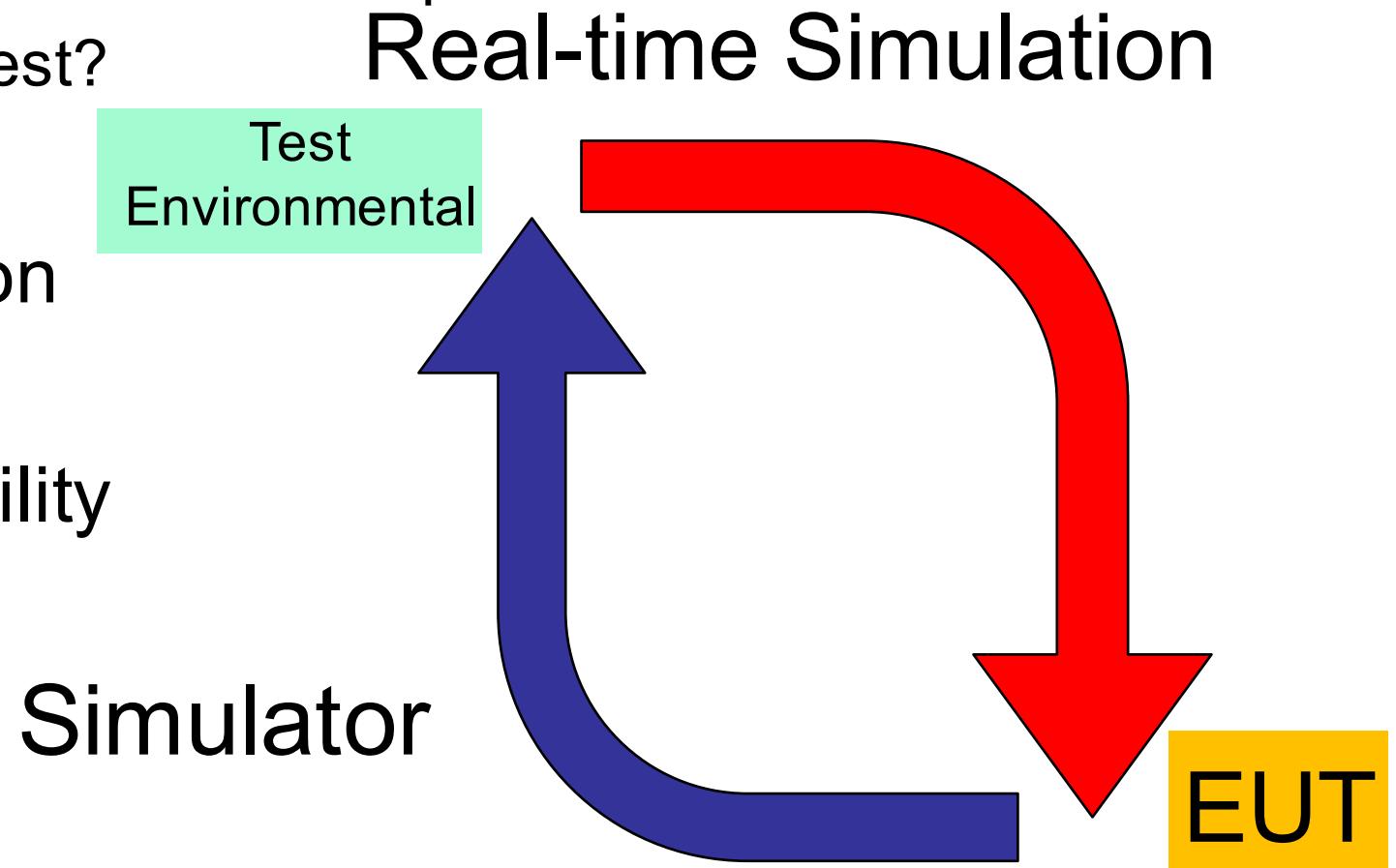
Power Hardware in the loop

Hardware in the loop Test Concept

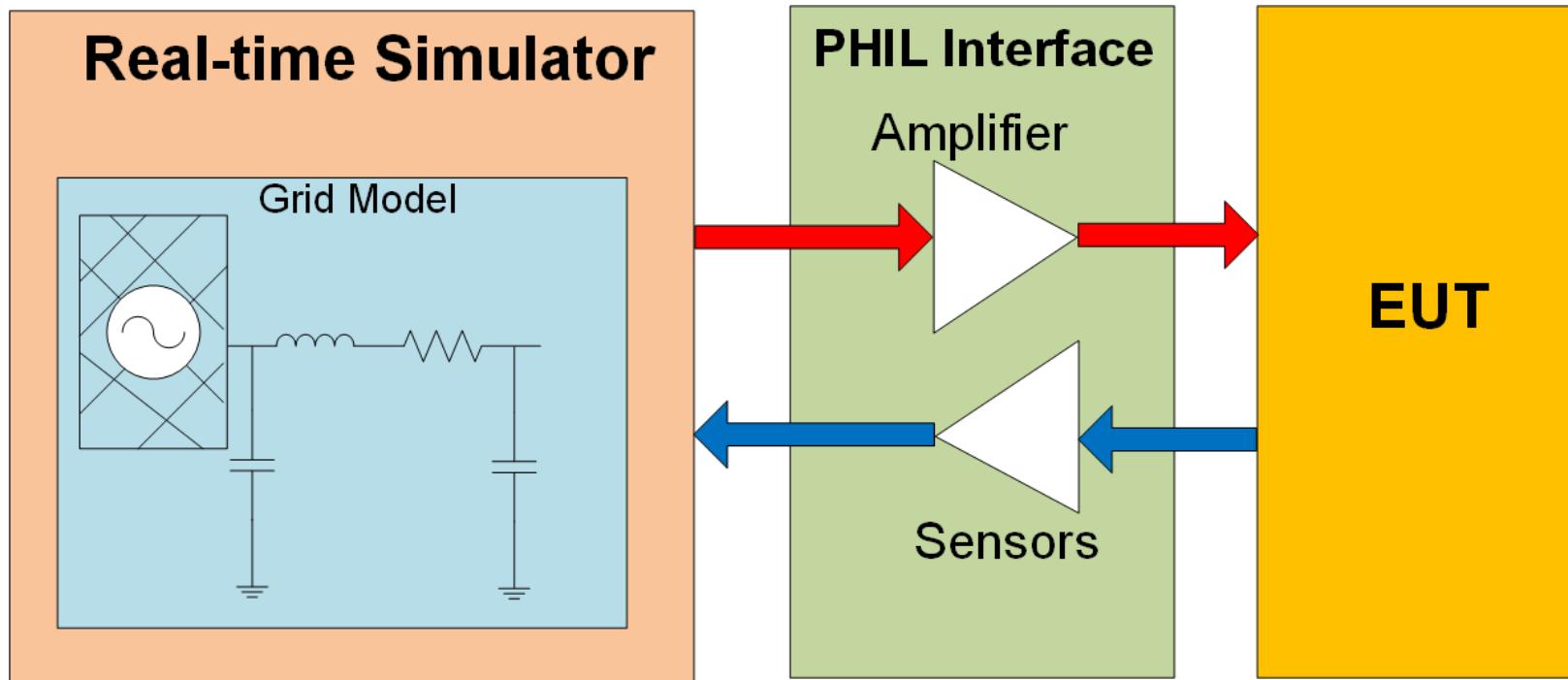
- HIL = Hardware in the loop

- Why HIL Test?

- Cost
- Duration
- Safety
- Feasibility

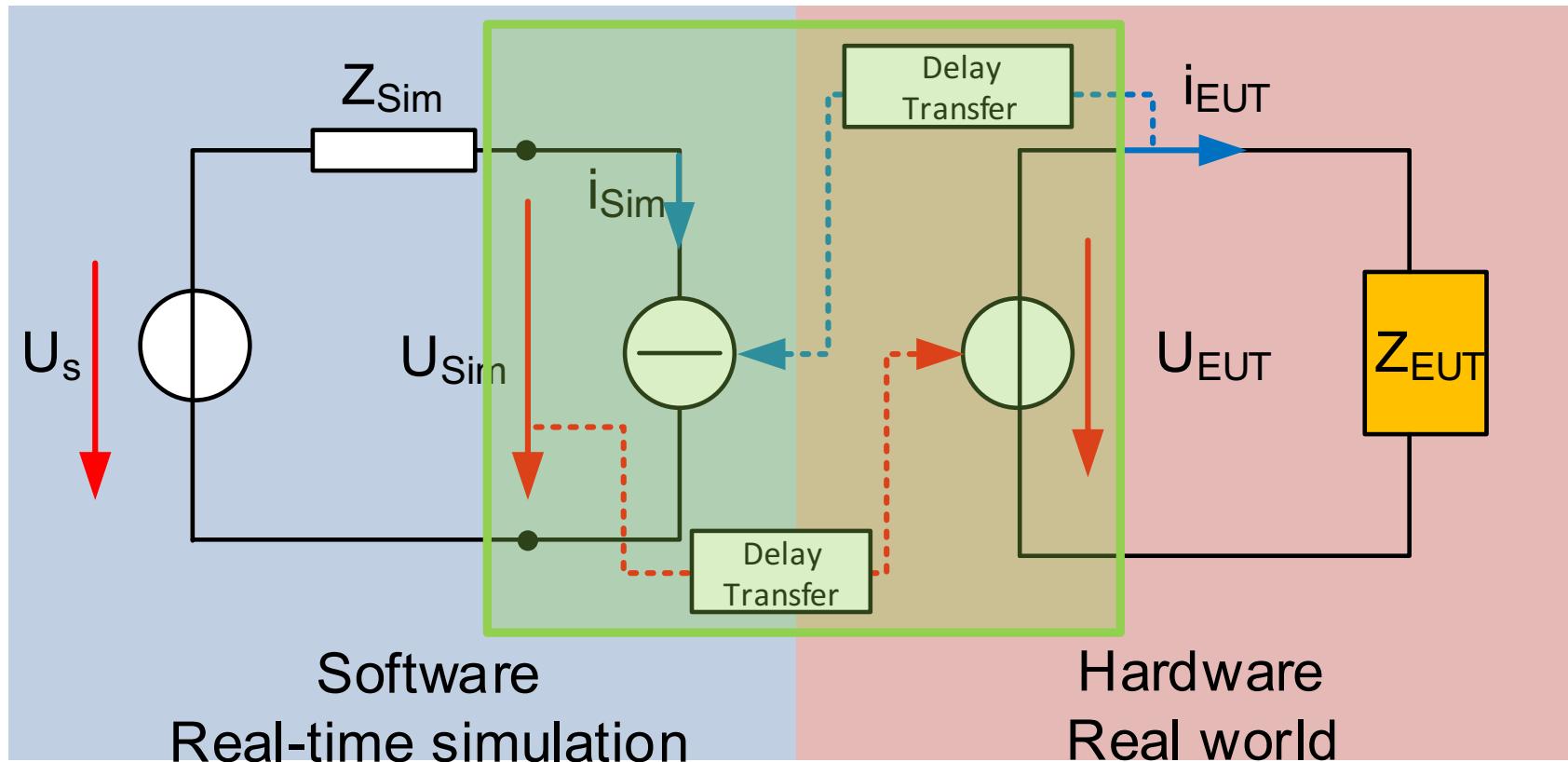


Power Hardware in the Loop



The signal exchange between the EUT and an RTS is through high-power signals, the PHIL Interface is required.

PHIL Interface Algorithmus



- Z_{Sim} is the grid impedance of the grid model
- Z_{EUT} is the impedance of the real world
- i_{Sim} is represents the influence of the EUT current upon the grid in the form of a current source.
- U_{EUT} is the output voltage of the power amplifier.

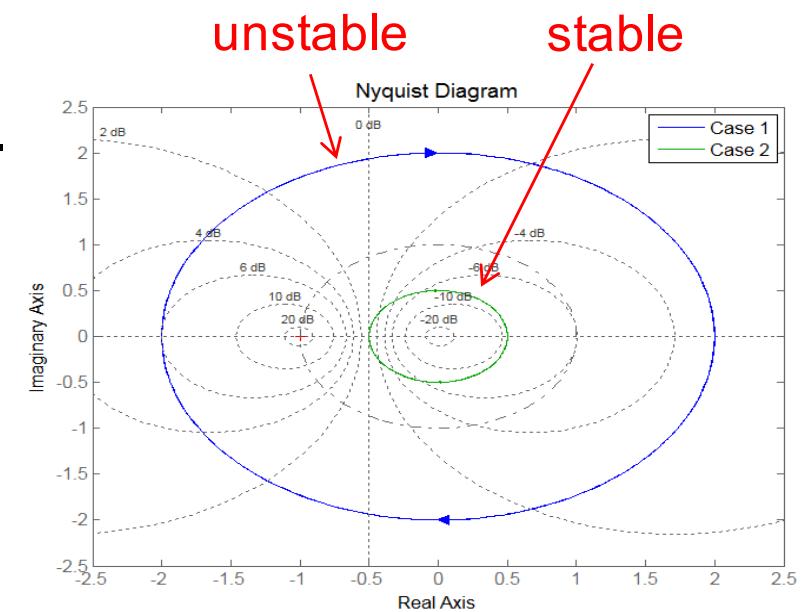
Stability of PHIL

- The open loop transfer function of PHIL:

$$G_{ITM_OL}(s) = -e^{t_d} \frac{Z_{Sim}(s)}{Z_{EUT}(s)}$$

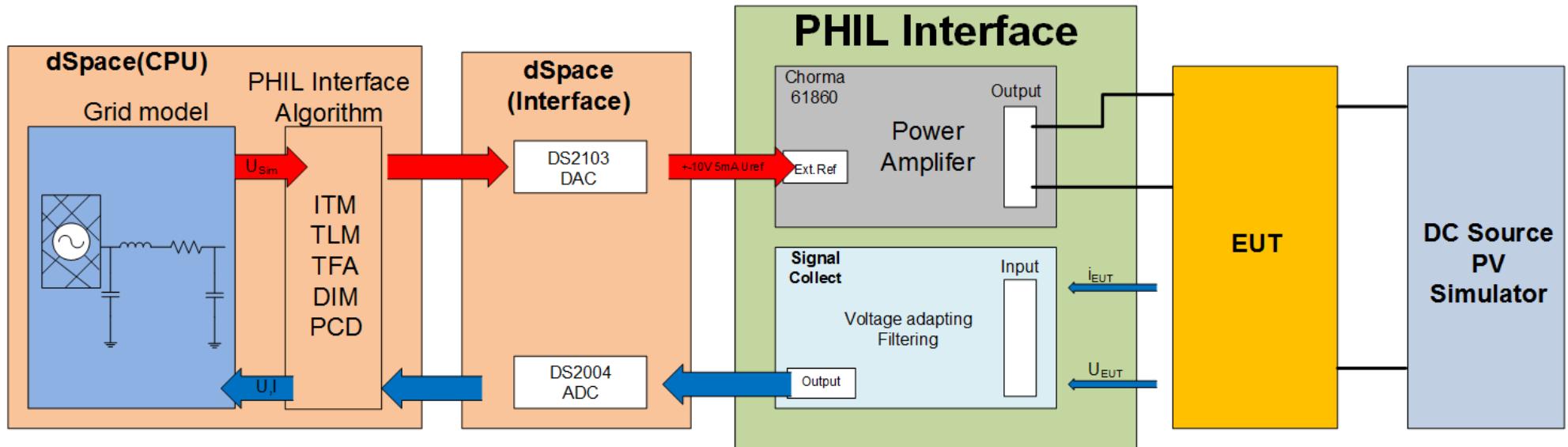
- With nyquist stability criterion can get:

When $\left| \frac{Z_{Sim}}{Z_{EUT}} \right| < 1$, the system is stable.



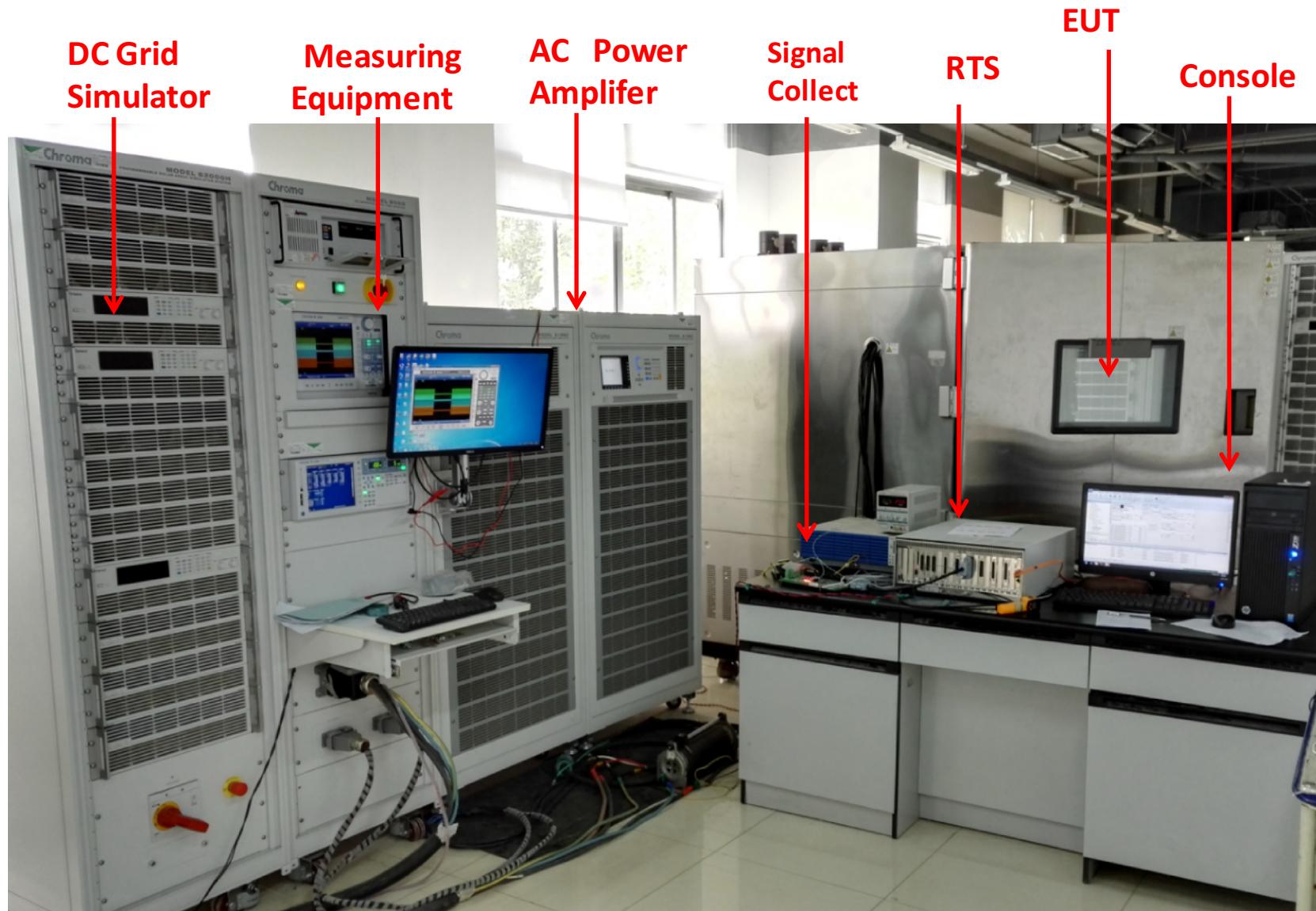
PHIL Laboratory Setup

Hardware-in-the-loop interface Setup



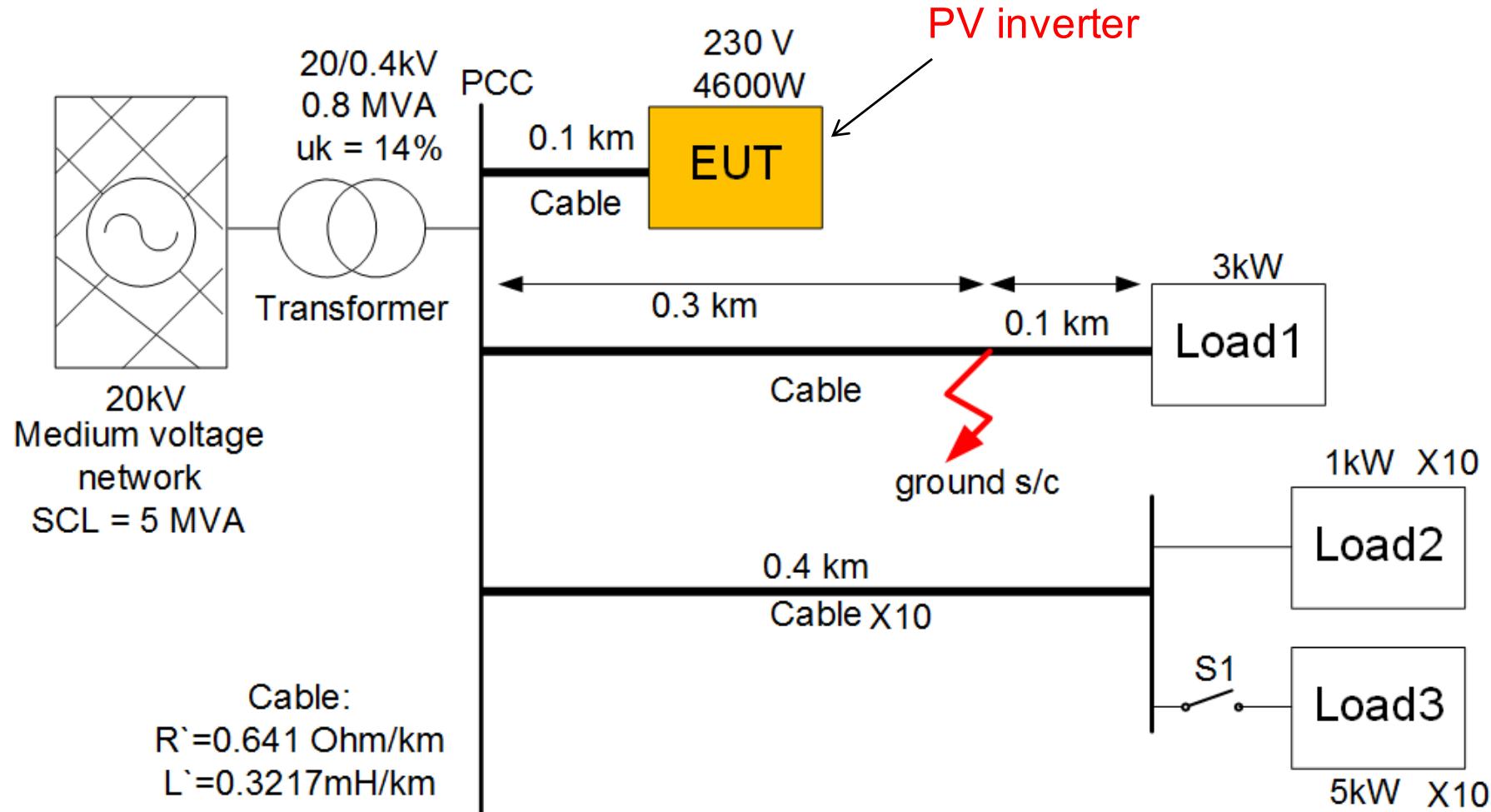
- The real-time simulator is the product from dSpace.
- The output voltage of the PV cell is simulated by DC source (PV Simulator), and is supplied to the EUT (PV inverter).
- Output voltage of the power amplifier used to simulate the grid voltage.

Hardware-in-the-loop interface Setup in Laboratory



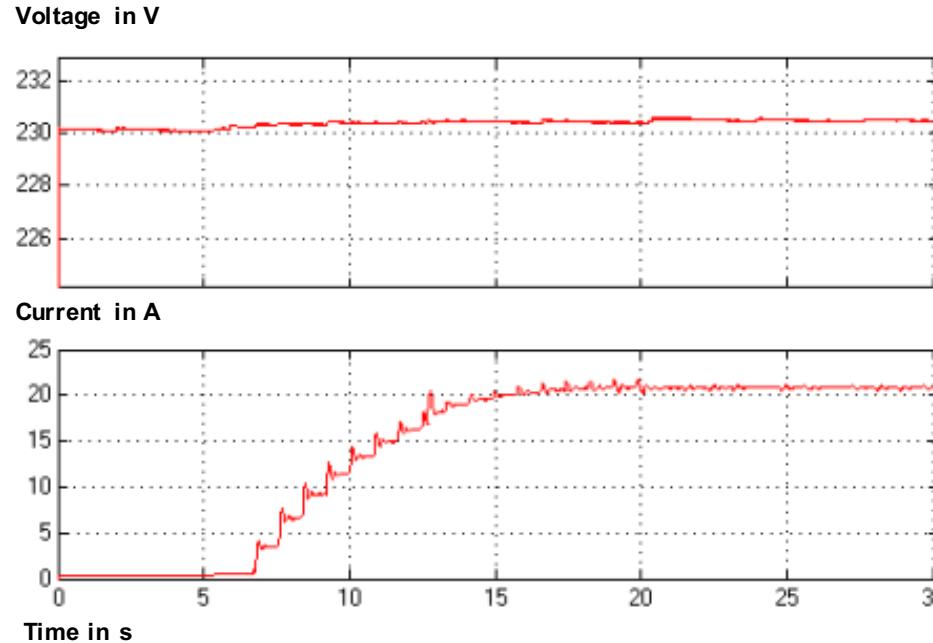
PHIL Test

Test Grid Model

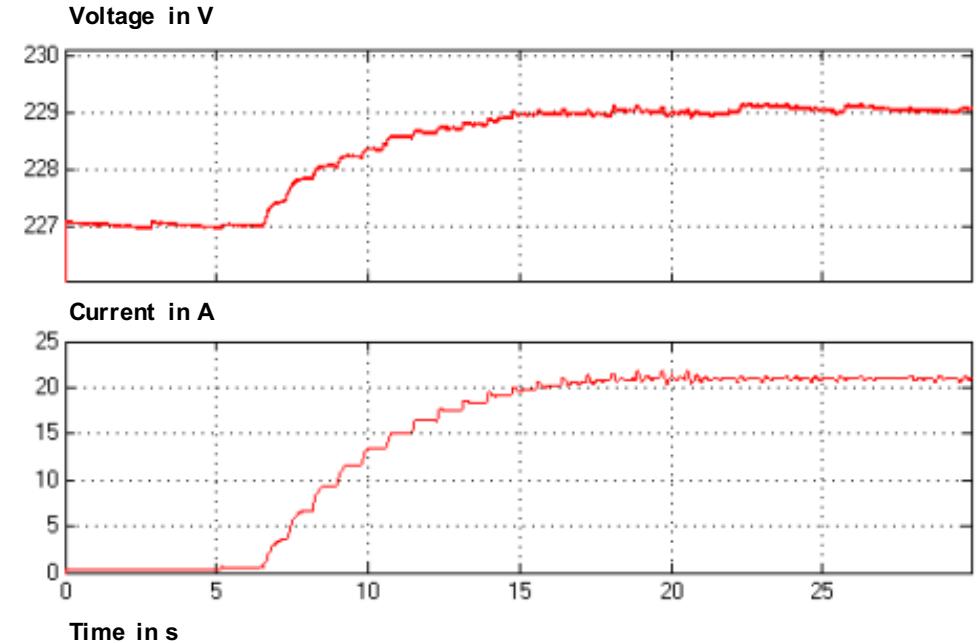


Grid Retroactive Effects

Non PHIL Test Without Grid Model



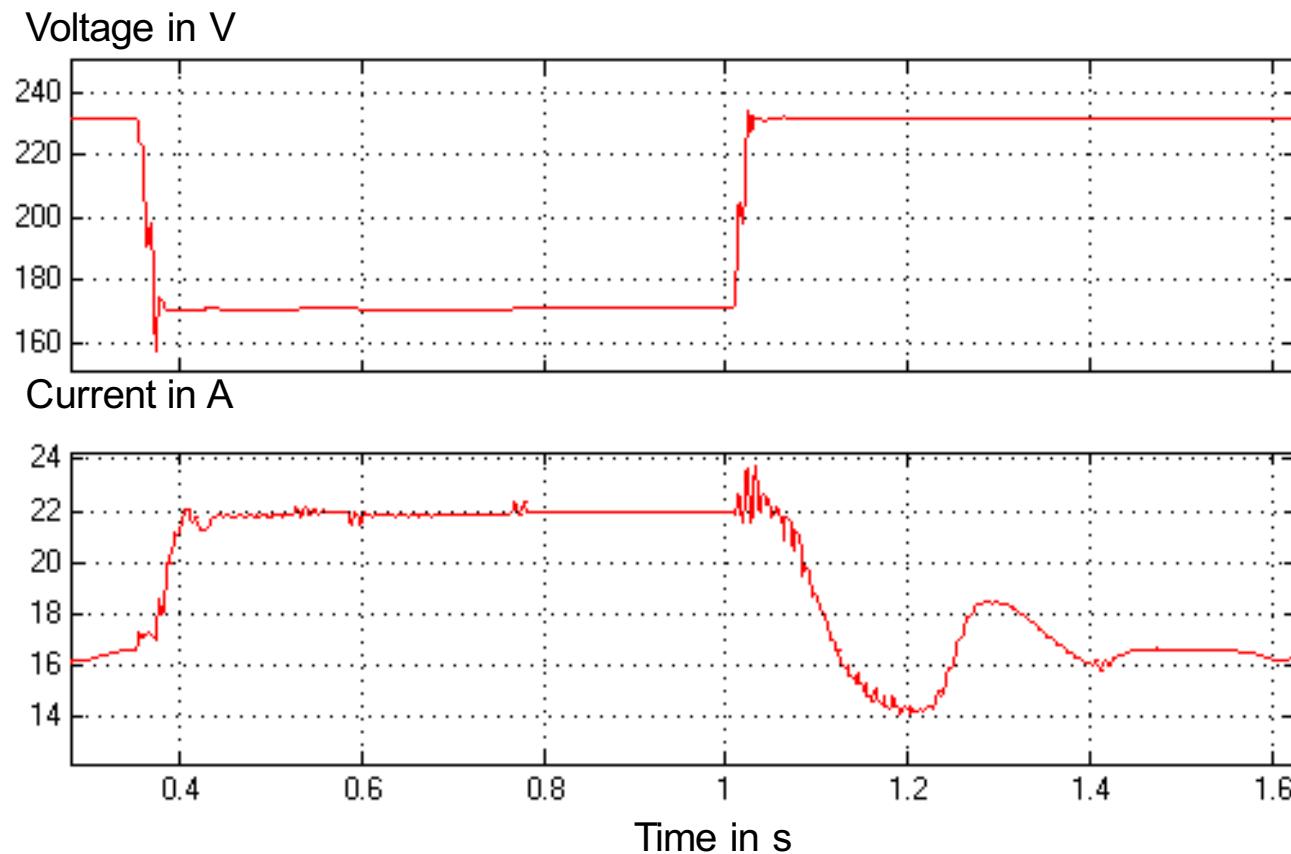
PHIL test With Grid Model



- This EUT will increase the output current from 0A to the rated current (22A) in 15 seconds.
- When we set the output voltage of the AC source fixed at 230V, which is the non-PHIL test, the output voltage will not change with the increase of EUT current .
- In PHIL test with the above grid model, the output voltage will change with the increase of EUT current .

Test of the Low Voltage Ride Through Capability

The voltage dip will be realized by a short circuit fault, its duration is **650ms**. The fault point is **100m from the PCC** and circuit breaker S1 is close.



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