CIGRE US National Committee

2015 Grid of the Future Symposium

Investigation and Correction of Phase Shift Delays in Power Hardware in Loop Real-Time Digital Simulation Testing of Power Electronic Converters

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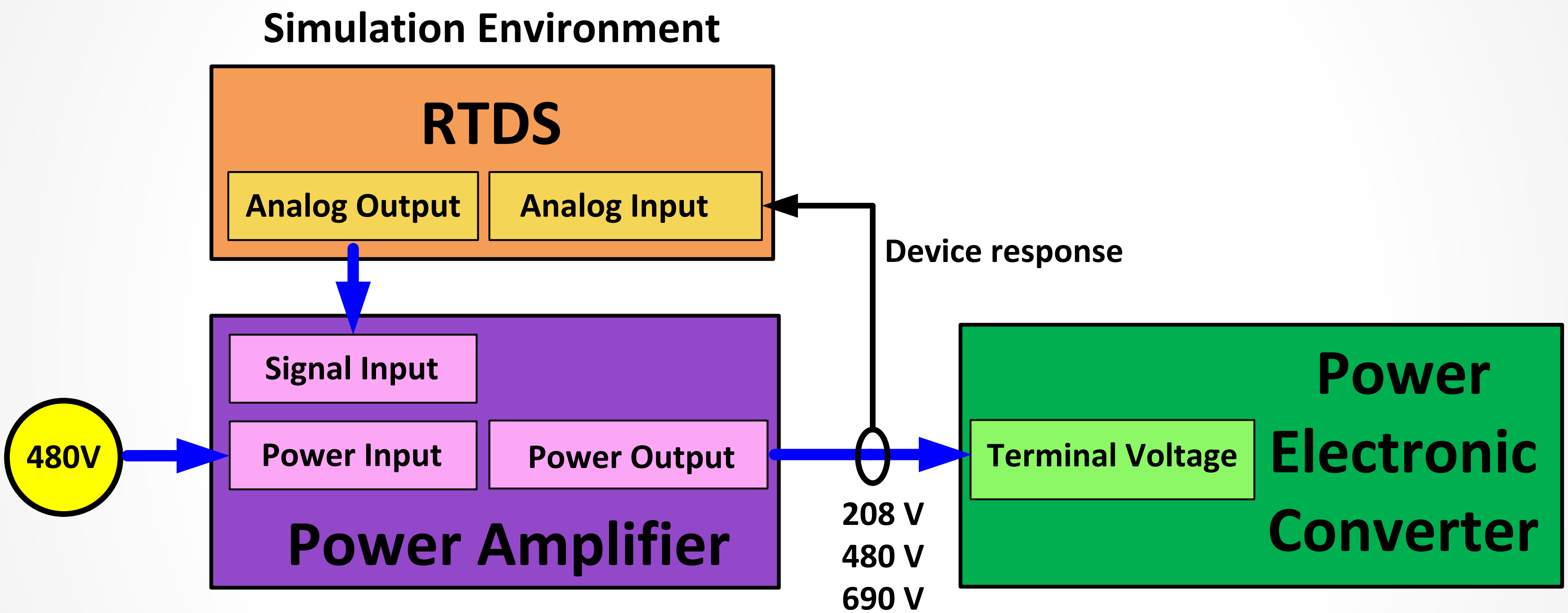
Introduction

Industry Challenges – Emerging Technologies

Power Electronics	Energy Storage	Microgrids	PMUs
• High penetration issues (PQ, stability and protection) • Smart inverter controls • Anti-islanding	• Performance evaluation • Control functions • Integration	• Design & Protection • Safety • Control & Operation	• Application evaluations • Communications infrastructure (especially for Distribution)

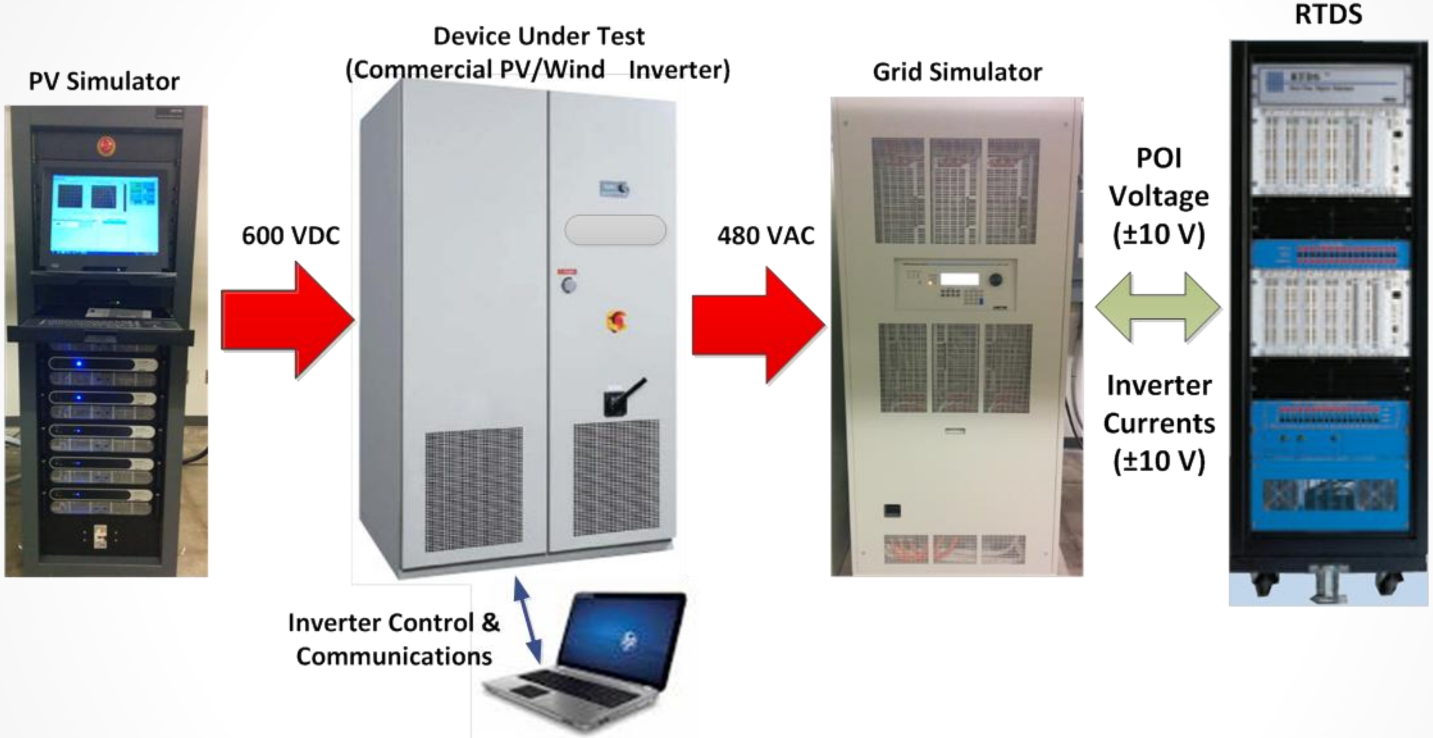
Modeling, Analysis, Testing, and Diagnostics become the key requirement prior to field deployment of a new technology and wide scale utilization

Power Hardware in Loop (PHIL) Digital Simulation



- An advanced simulation and test platform to evaluate performance of single or multiple Power Electronic Devices in interaction with the grid (faults, switching transients, control function)

Power Hardware in Loop (PHIL) Digital Simulation



- Alternative approach to traditional methods of high power/high voltage device level testing
- Cost effective and highly accurate for performance evaluation of power electronic apparatus – using **Actual Hardware** as device under test **(DUT)** rather than model

Key Considerations in PHIL Testing

Main challenges are:

- **Stability and performance problems introduced by Phase Shift (delay) or Non-Linearity on the Input or Output signals through amplifiers and sensors – Resonance**

- ***Existing Solutions:***

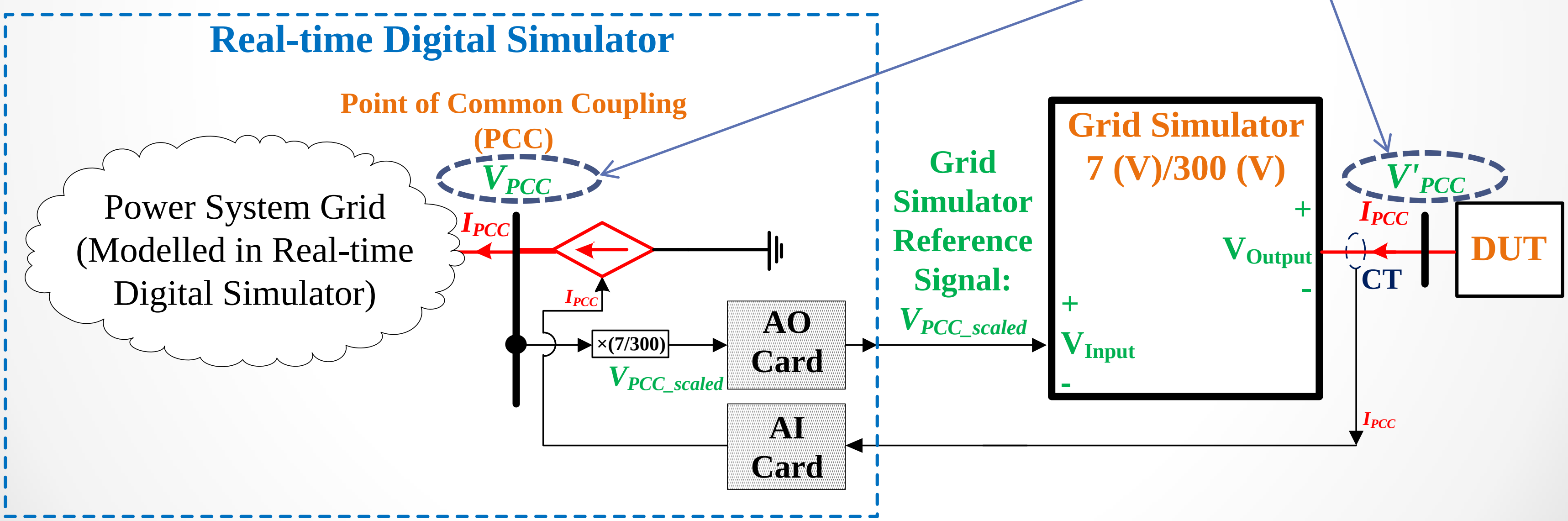
  1) Finding and adding an equivalent resistance and a current source in the modeling
  2) Employing high level of current signal filtering
  3) Converting to DC signals (dq0 frame) and reconverting to AC after injection

- ***Problems Associated with Existing Solutions:***

  Loosing accuracy and important signal content when dealing with Time-Domain Simulation and Transients / Harmonics

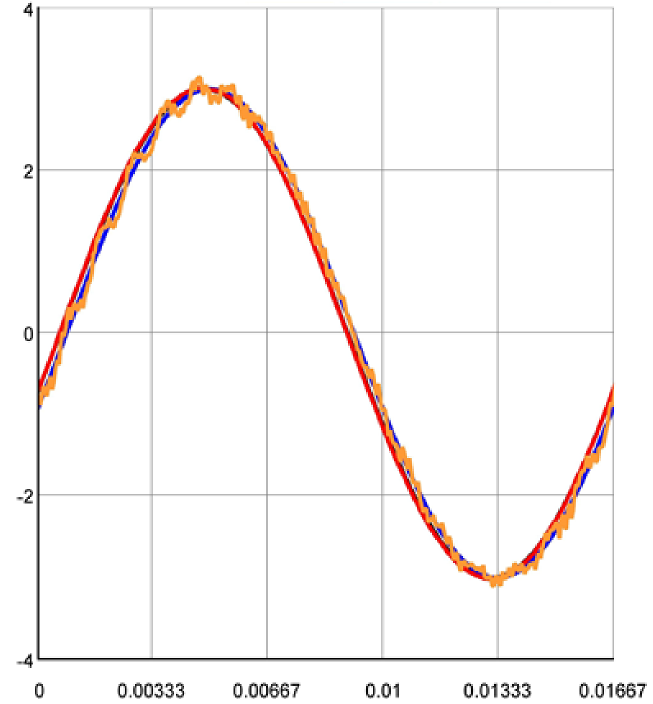
General Configuration of PHIL Simulation

V_{PCC} and V'_{PCC} should be ideally the same, but it is not the case because of existing delay in either AO/AI Cards or Grid Simulator, mainly because of Amplifier (Grid Simulator)



Sources of Phase Shift

Voltage Sent out by AO, Phase Shifted Reference by 3.456˚, Amplifier Output After Scaling Back



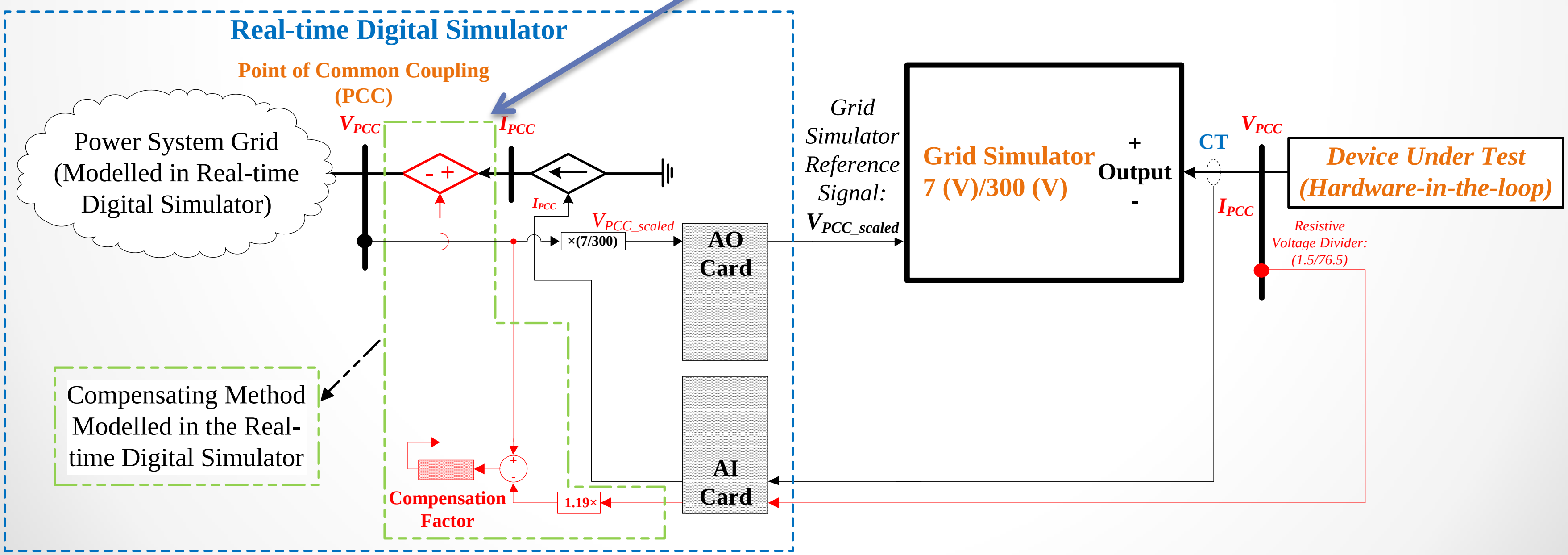
3.456˚ phase shift for the 60 Hz sinusoidal input signal, comprising:

2.706˚ phase shift is generated by the **Grid Simulator**, and

0.750˚ phase shift, is generated by the interface cards, i.e. **AI & AO**

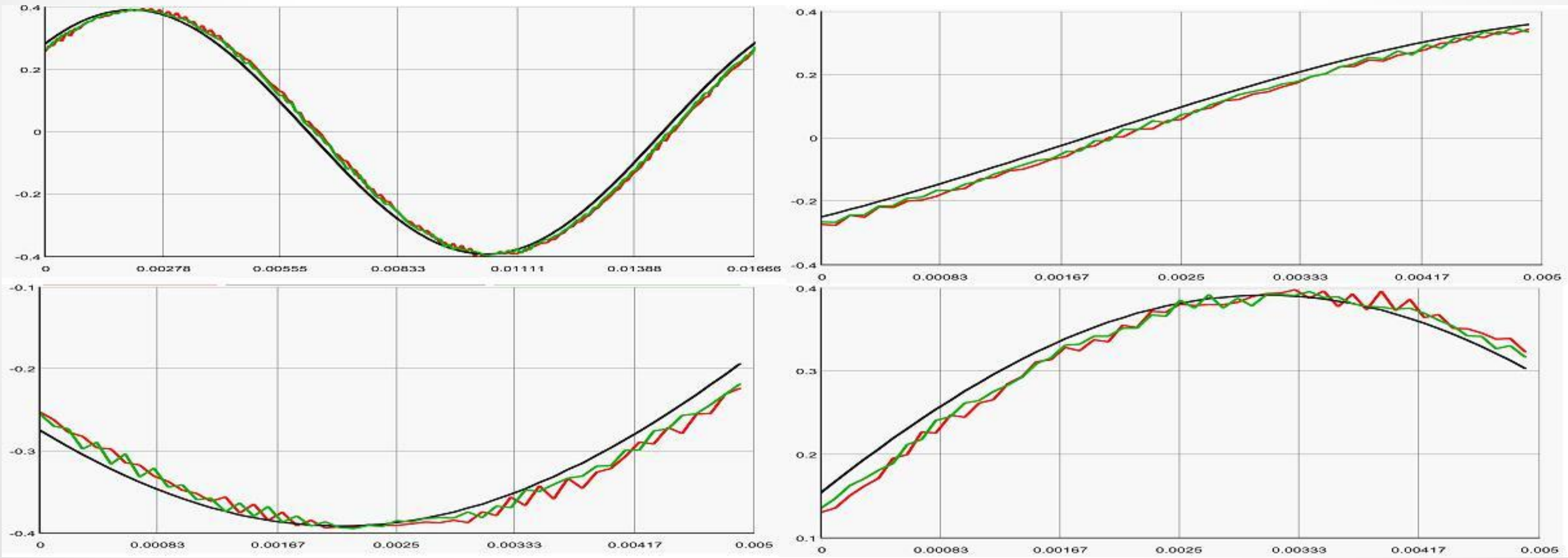
Proposed Compensated Solution

Voltage Feedback Compensation Method **WITHOUT** Adding Additional Dynamics

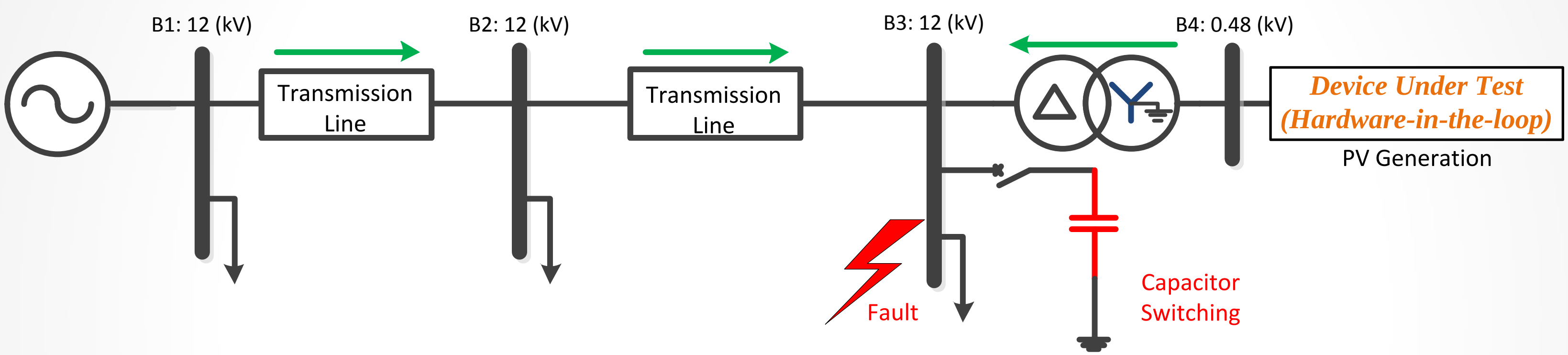


Experimental Results of Measuring V_{PCC} and V'_{PCC} After Compensating with Voltage Feedback

Voltage Sent out by AO, Grid Simulator's Output After Scaling Back, Voltage Employed in Real-time HIL Simulation after Compensation

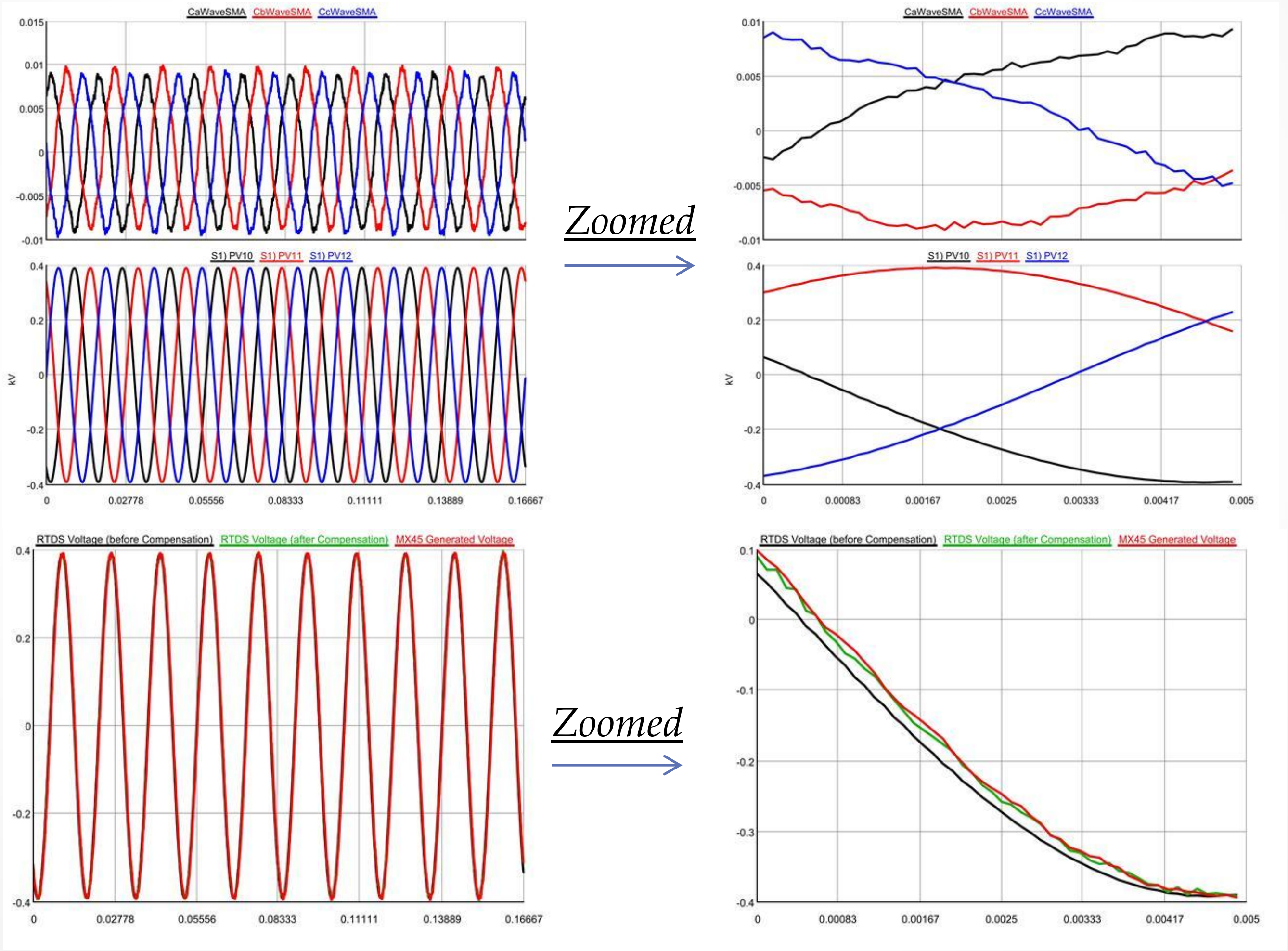


PHIL Simulation Results of a Given Power System

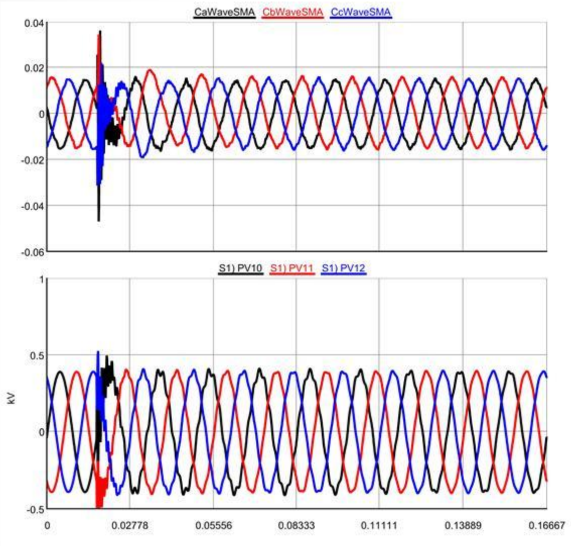


- **Cases Under Study for PHIL Simulation:**
  - ✓ PHIL Simulation for the case of **normal operation**
  - ✓ PHIL Simulation for the case of a **capacitor switching @ bus B3**
  - ✓ PHIL Simulation for the case of a **line to ground fault @ bus B3**
  - ✓ PHIL Simulation for the case of a **three phase fault @ bus B3**

PHIL Simulation for the case of normal operation



PHIL Simulation for the case of a Capacitor Switching @B3



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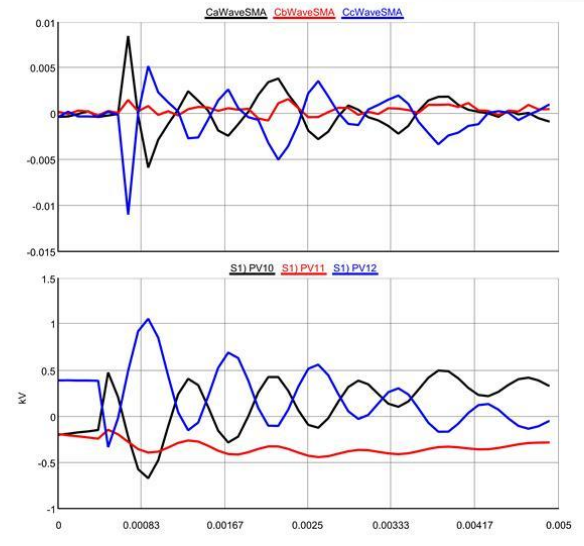

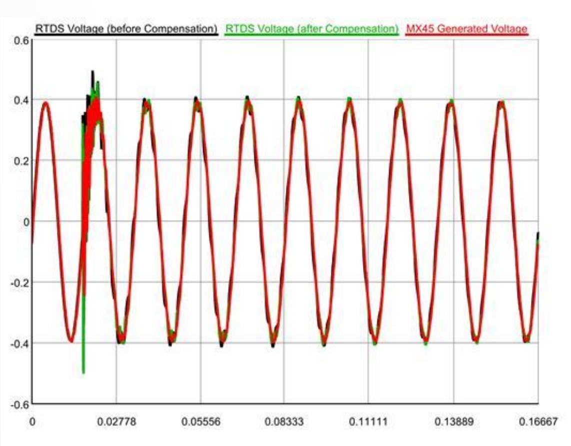

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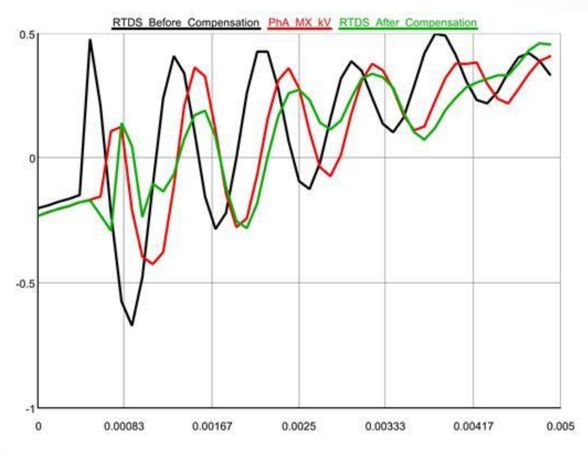
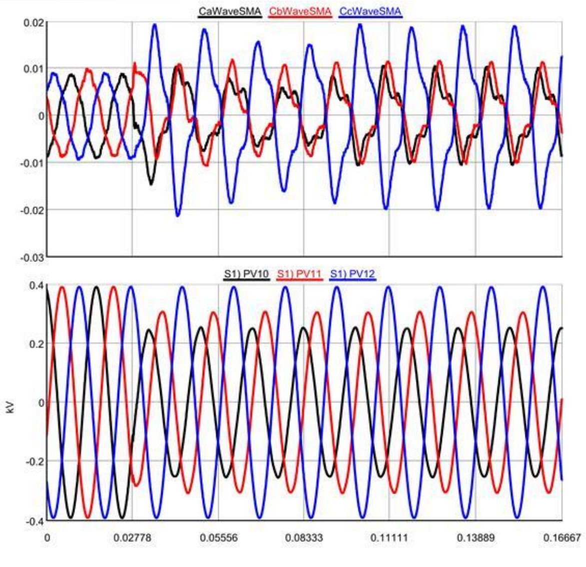


PHIL Simulation for the case of a Line to Ground Fault @B3



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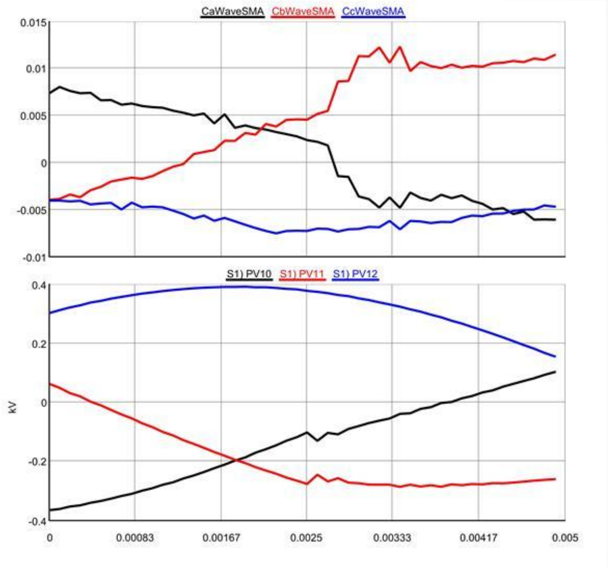

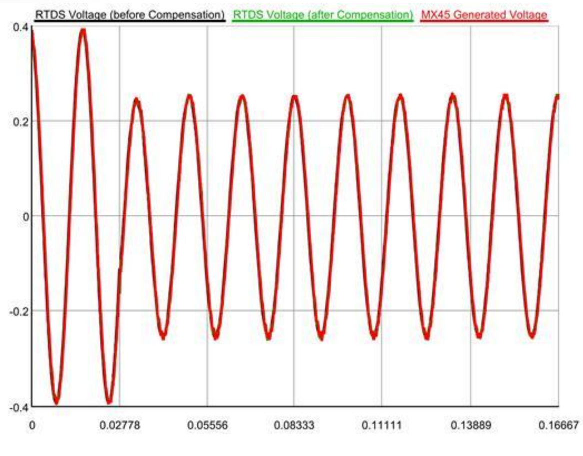

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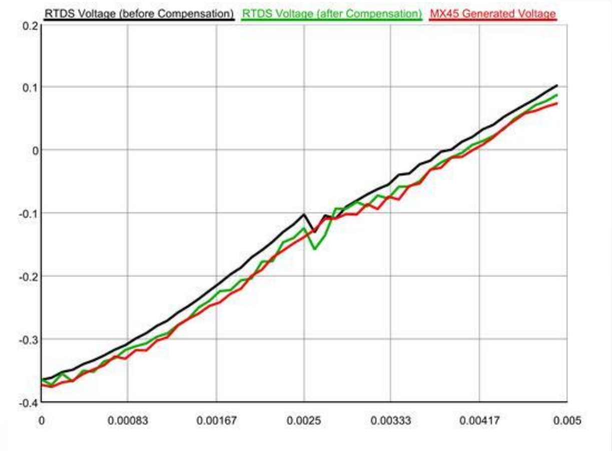
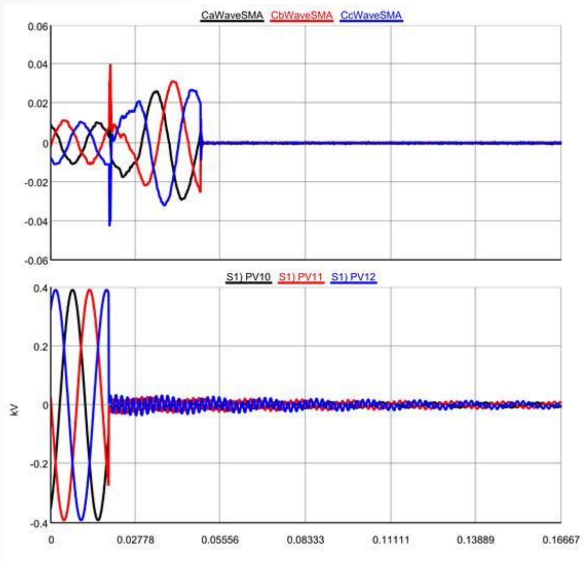


PHIL Simulation for the case of a Three Phase Fault @B3



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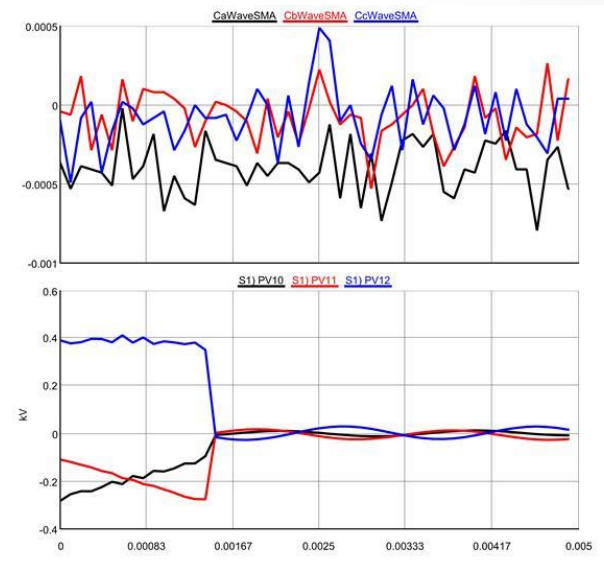

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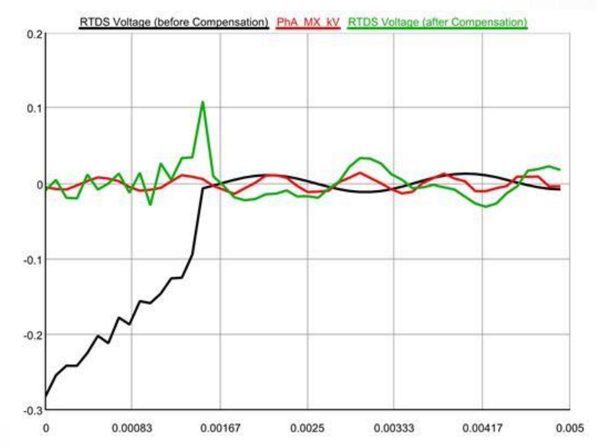

Conclusions

As the penetration of the power electronic devices are increased in the power system, alternative testing methods are required to evaluate performance of the devices before deploying in the field

PHIL is introduced as an alternative and accurate solution for high voltage and high power testing of power electronic devices

PHIL can be utilized for testing of dynamic or transient events, with proper signal conditioning and compensation methods

Several inverters and converters are tested on the PHIL setup for fault evaluations, switching transient response and performance

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Thanks

Questions?

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