Advanced PHIL Applications using the RTDS™

NovaCor™
A revolution in real time.

RTDS Technologies
Introducing NovaCor™ – the new world standard for real time digital power system simulation

Presentation Outline

Introduction

PHIL for a PV Micro Inverter

PHIL Applications by RTDS Users

Key Factors for PHIL Simulation

Hardware Developments

Software Developments

Conclusions
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**Introduction**

- **Hardware In Loop (HIL)**
  - Control Hardware In Loop (CHIL)
  - Power Hardware In Loop (PHIL)
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**Introduction**

- In CHIL,
  - Entire power system is modeled in RTDS
  - No power exchanged over interface
  - Low level voltages and currents

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**Diagram:**

- Real Time Digital Simulator
- Digital In (GTFPI)
- D/A Converter (GTAO)
- Amplifier
- Device Under Test

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**Introduction**

- In PHIL,
  - A portion of the power system is modeled in RTDS
  - Power exchange via 4 quadrant amplifier
  - High level voltages and currents

![Diagram showing the components of NovaCor™ system](Image)
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Introduction

- Some applications might consider open loop as PHIL
- Challenges comes from closing the loop for kW to MW range
- All further discussions are referring to Closed Loop PHIL

Open Loop

- Testing tool
- Device under test
- Signals from power system

Closed Loop

- Testing tool
- Device under test
- Signals from power system
- Signals from device (voltage and/or current)
Introduction

• First RTDS PHIL application used to expand an Analogue HVDC Simulator

Introduction

• Motivation behind Power Hardware in Loop Applications
  • Power device under test is a “black box”
  • Difficult to obtain model for the power device under test
  • Testing increasingly complex control circuits

• Current PHIL Applications
  • Power converter testing (VSC, MMC etc.)
  • Distributed and Renewable Energy Integration
  • Micro grids
  • Shipboard Machine Drives
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PHIL Applications by RTDS Users


• **MW Scale Medium Voltage DC Test Bed on MMC** (M. Steurer et al., “Multifunctional megawatt scale medium voltage DC test bed based on modular multilevel converter (MMC) technology,” *2015 International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles (ESARS)*, Aachen, 2015, pp. 1-6.)

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PHIL for a PV Micro Inverter

• PHIL Simulation with a 255W PV Panel and 225W Micro Inverter

• Challenges with PHIL Interface (Stability, Accuracy)

• Check out our YouTube video: https://youtu.be/nnKHiEWDXJM

• Steady state operation

• Effect of noise filtering

• Effect of shading PV panel

• Closed loop fault operation

PHIL for a PV Micro Inverter

- PHIL Simulation with a 255W PV Panel and 225W Micro Inverter

Real Time Simulation

Hardware Device Under Test
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Key Factors for PHIL Simulation

- Delays in the PHIL interface affect simulation accuracy and stability

![Diagram of PHIL setup]

- Real Time Digital Simulator
- D/A Converter (GTAO)
- 4 Quad. Amplifier
- A/D Converter (GTAI)
- Power Device Under Test
- Sensors

Transformers

Inverters

Motors
Key Factors for PHIL Simulation

• Simulation time step of RTDS contributes to delay of PHIL interface

<table>
<thead>
<tr>
<th>Electromagnetic Transient Simulation</th>
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<td>Typical Time Step</td>
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<td>Frequency Range</td>
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Key Factors for PHIL Simulation

- Small Time Step Simulation in RTDS (1.4-3.5μs) improves stability and accuracy in PHIL simulation

Large Time Step (Unstable)

\[ \Delta t = 50\mu s \]

Small Time Step (Stable)

\[ \Delta t = 1.92\mu s \]
Key Factors for PHIL Simulation

- Amplifier Characteristics (Bandwidth, Frequency Response) impact stability of interface
- Type of Amplifier, Switched Mode or Linear type
- Linear amplifiers have fast dynamic response (<10μs)

SPS Linear Voltage Amplifier (1 kVA)
- Volt. Range: 60V, 150V, 300V, 630V (DC)
- Freq. Range: DC to 5kHz
- Dynamic response (T_d): < 6μs
Key Factors for PHIL Simulation

- Noise, wiring and measurement sensors all impact stability
- Noise can be filtered out but results in increased delay and loss of accuracy

![Image](image-url)

- Signal from RTDS
- Measurement Sensor
- Amplifier Output
- <6μs delay
- <8μs delay
Hardware Developments

• New generation of RTDS Simulator hardware - NovaCor
• Completely redesigned around IBM’s POWER8® RISC-based 10-core processor
  • OpenPOWER Foundation provided access and support
• Large $\Delta t$ reductions
• Small $\Delta t$ reductions
• Check out our YouTube video: [https://youtu.be/ByMlgNZ3_tg](https://youtu.be/ByMlgNZ3_tg)
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Hardware Developments

• Faster A/D converter sampling rate (1 million samples per second previously 167 thousand samples per second)

• Independent A/D converters for better channel isolation and more consistent results between channels

• Improved filtering on power supply inputs to reduce noise coupling

• New digital filtering capability and smaller form factor

• Improved error checking on internal states and processes
Hardware Developments

• Digital link between RTDS and Amplifiers with Aurora Protocol (SPS)
• Eliminates A/D and D/A converters
• Reduces delay
• 64 inputs and 64 outputs per port
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Software Developments

• Two and three level bridge VSC models running at a fraction of a small time step, also known as a sub time step

\[ \Delta t_{sub} = \frac{\Delta t_{small}}{N}, \quad N = \{2,3,4,5\} \]

• Multi-rate simulation model

• \( \Delta t_{sub} \) in the range of 750 nano seconds

• Allows for switching frequencies up to 40kHz (two level)
Conclusions

• Several Key Factors to consider in PHIL applications
  • Delays in interface
  • Size of simulation time step
  • Amplifier characteristics
  • Noise from transducers
  • Interface Algorithm

• Reducing the simulation time step (via small time step) can improve stability and accuracy of PHIL interface

• RTDS has continuously made hardware and software developments to enhance PHIL applications
Questions?
OpenPOWER Foundation

- The OpenPOWER Foundation is an open technical community based on the POWER architecture, enabling collaborative development and opportunity for member differentiation and industry growth.

- Member companies are enabled to customize POWER CPU processors and system platforms for optimization and innovation for their business needs.

- Opening the POWER architecture to give the industry the ability to innovate across the full Hardware and Software stack.