Update on the FSU-CAPS Megawatt Scale Power Hardware in the Loop Laboratory

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Clemson University Test Center
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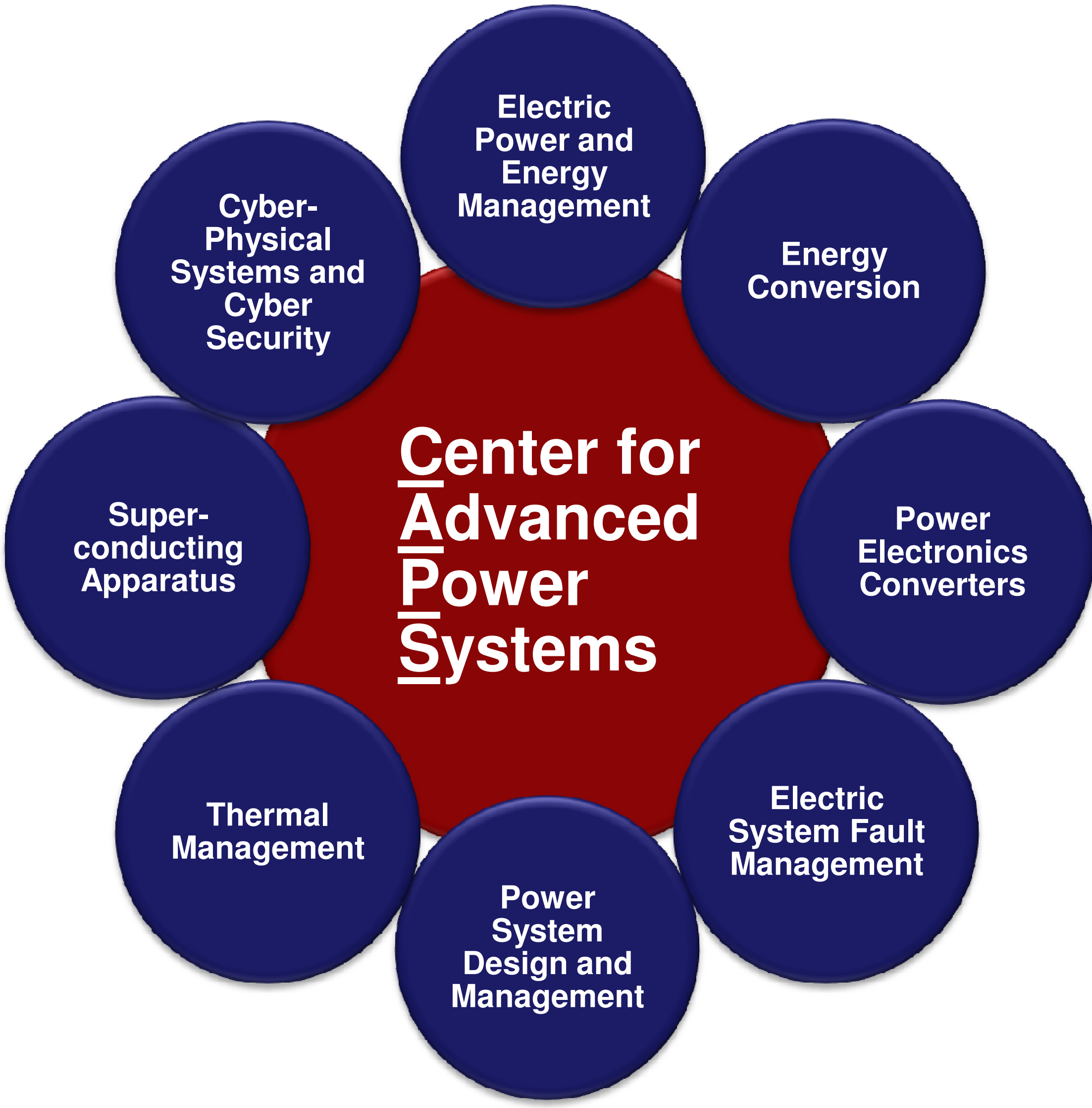
FSU Center for Advanced Power Systems

Center Highlights

Established at Florida State University in 2000 under a grant from the Office of Naval Research	
Focusing on research and education related to application of new technologies to electric power systems	
Organized under FSU Vice President for Research	
Affiliated with FAMU-FSU College of Engineering	
Member of ONR Electric Ship R&D Consortium - ESRDC	
~$5 million annual research funding from ONR, NSF, DOE, and Industry	
DOD cleared facility at Secret level	

CAPS Research Areas



11 Tenure track/Non-tenure track faculty

19 Staff Researchers and Technical Support

4 Post-doctorial Associates

25 Students (20 MS/PhD, 5 BS)

3 Visiting Scholars

4 Administrative Personnel

44,000 ft^2 laboratories and offices, located in Innovation Park, Tallahassee

Over $35 million specialized power and energy capabilities funded by ONR, DOE, NSF and Industry

FSU-CAPS Lab Capabilities

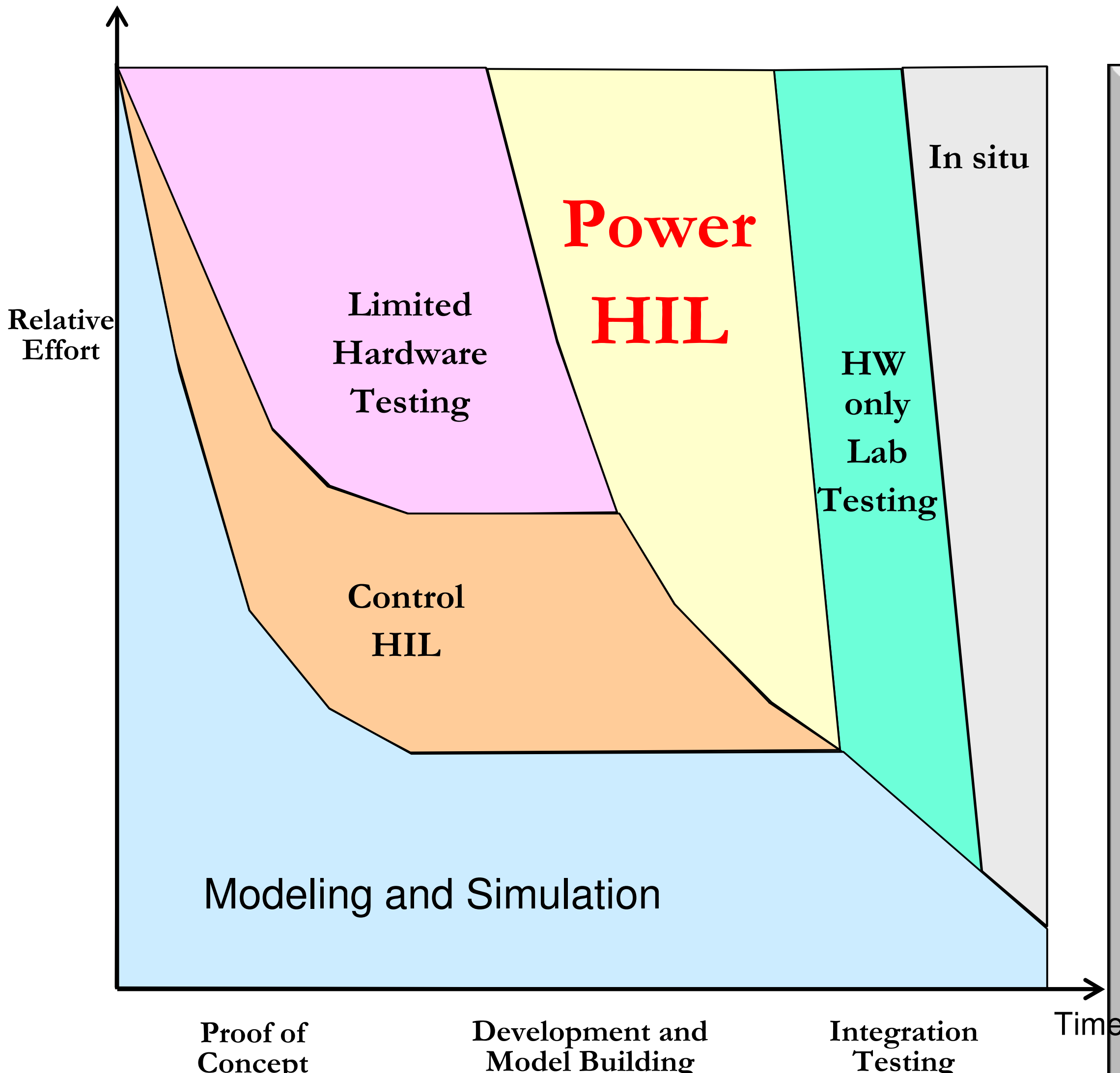
- **Integrated 5 MW HIL Testbed**
  - **5 MW variable voltage/frequency converter**
  - **5 MW dynamometers**
  - **5 MW MVDC converters (MMC)**
- **Real-time Digital Simulators**
  - **RTDS & OPAL-RT using typical time step sizes from 2 μs to 50 μs**
  - **Cyber-physical test bed**
- **Superconductivity and Cryogenics Labs**
  - **AC Loss and Quench Stability Lab**
  - **Cryo-dielectrics High Voltage Lab**
  - **Cryo-cooled Systems Lab**
- **Low Power and Smart Grid Labs**
- **Extensive non-RT simulation tools and expertise**
  - **PSCAD, PSS/E, Matlab, PLECS, OpenDSS, etc.**
  - **COMSOL, Magnet, etc.**





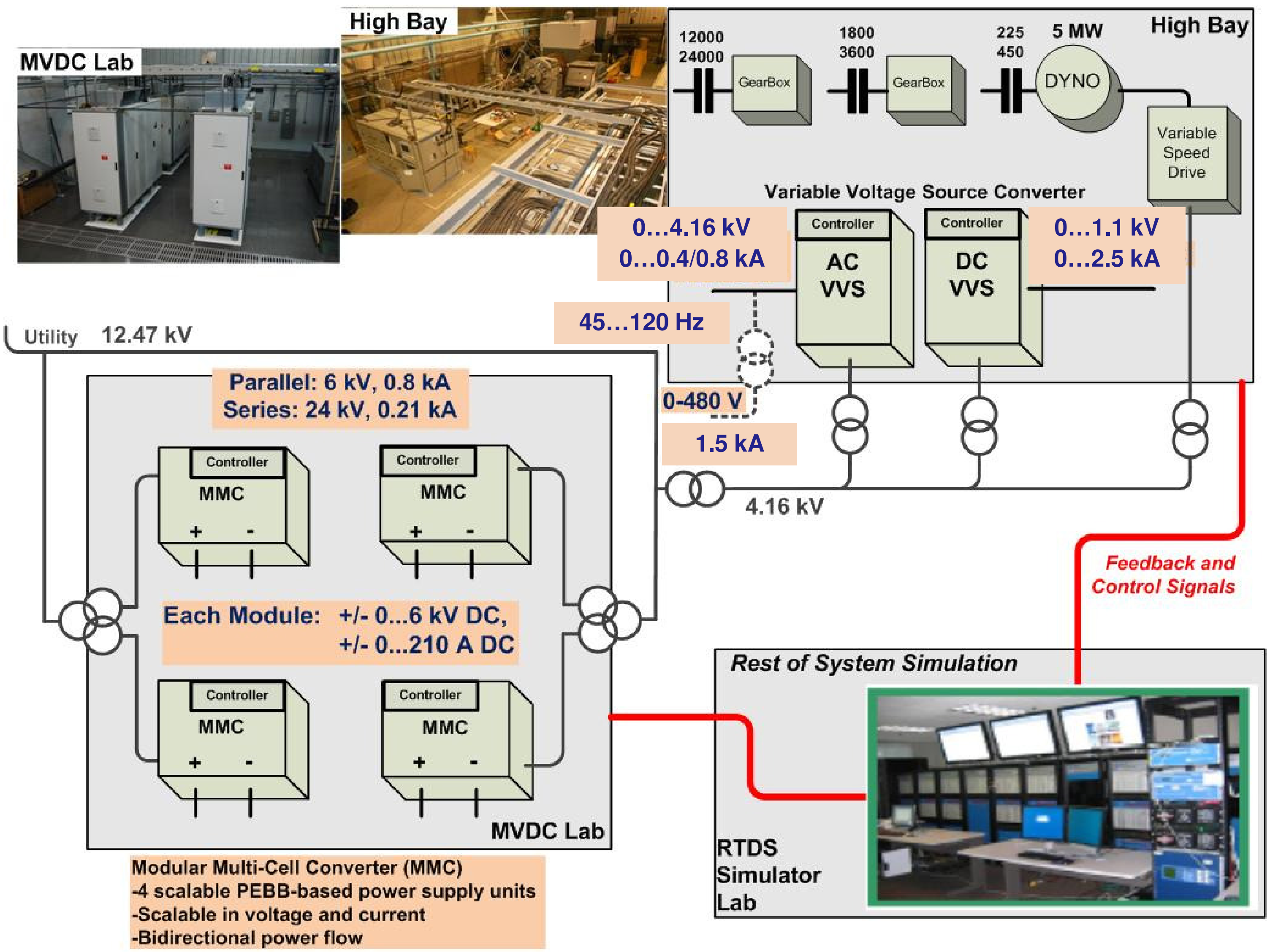



Role of HIL Simulation

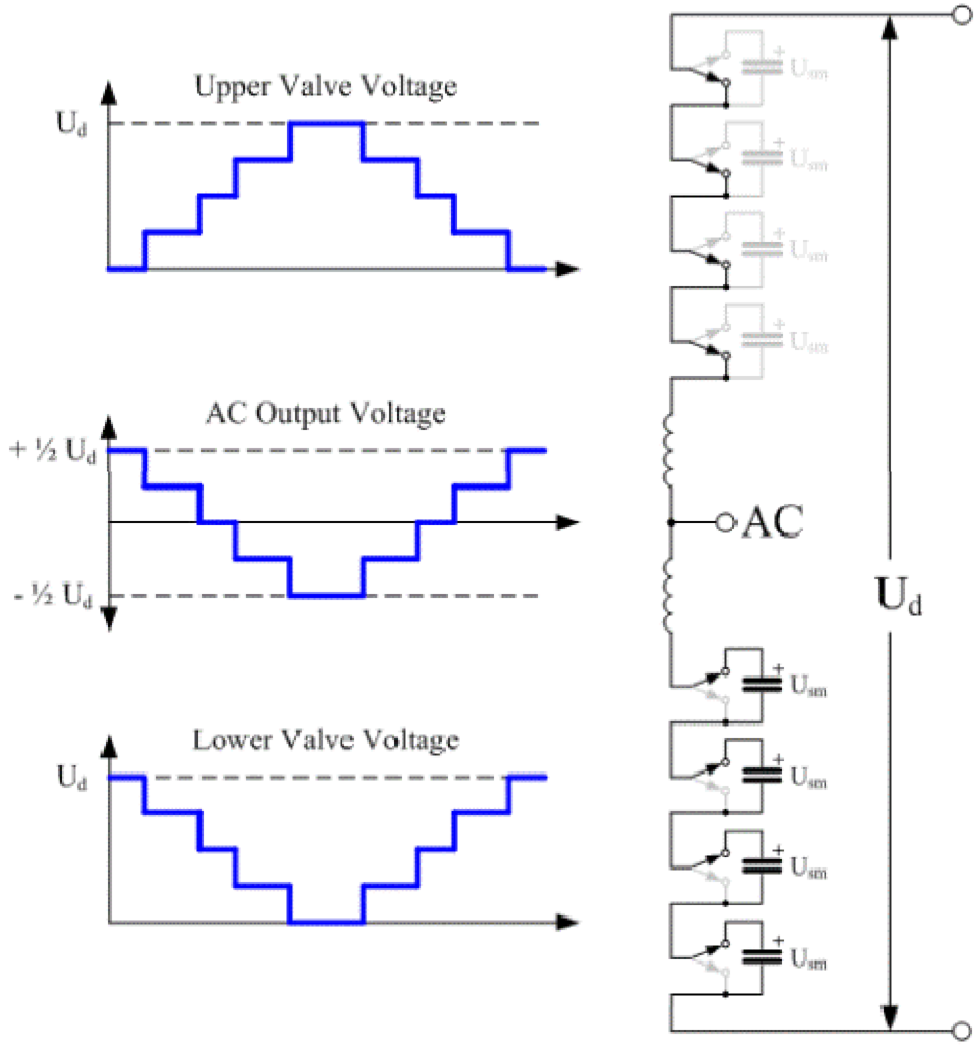


- Modeling and Simulation dominates the entire process
- CHIL contributes heavily from proof of concept through PHIL testing
  - De-risk early development of
    - Hardware (fast) controller
    - Application (slow) controller
  - De-risking PHIL experiments
- PHIL supports model building and integration phases
  - Experimental data for model construction and validation
  - Stimulation of component through controlled transients
  - Integration testing through emulation of the target environment(s)

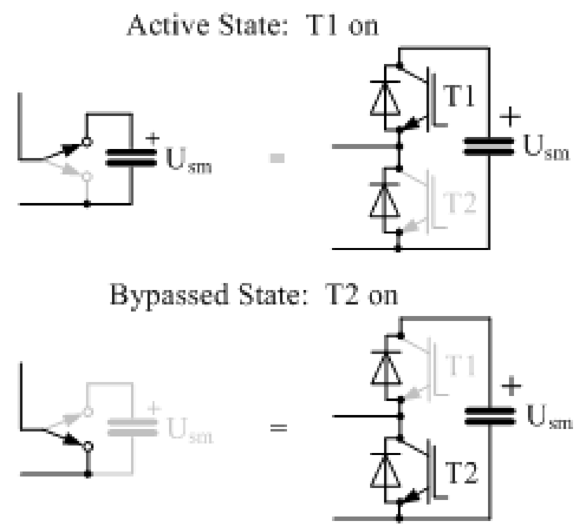
FSU-CAPS 5 MW Facilities



Modular Multi Cell (MMC) Converters

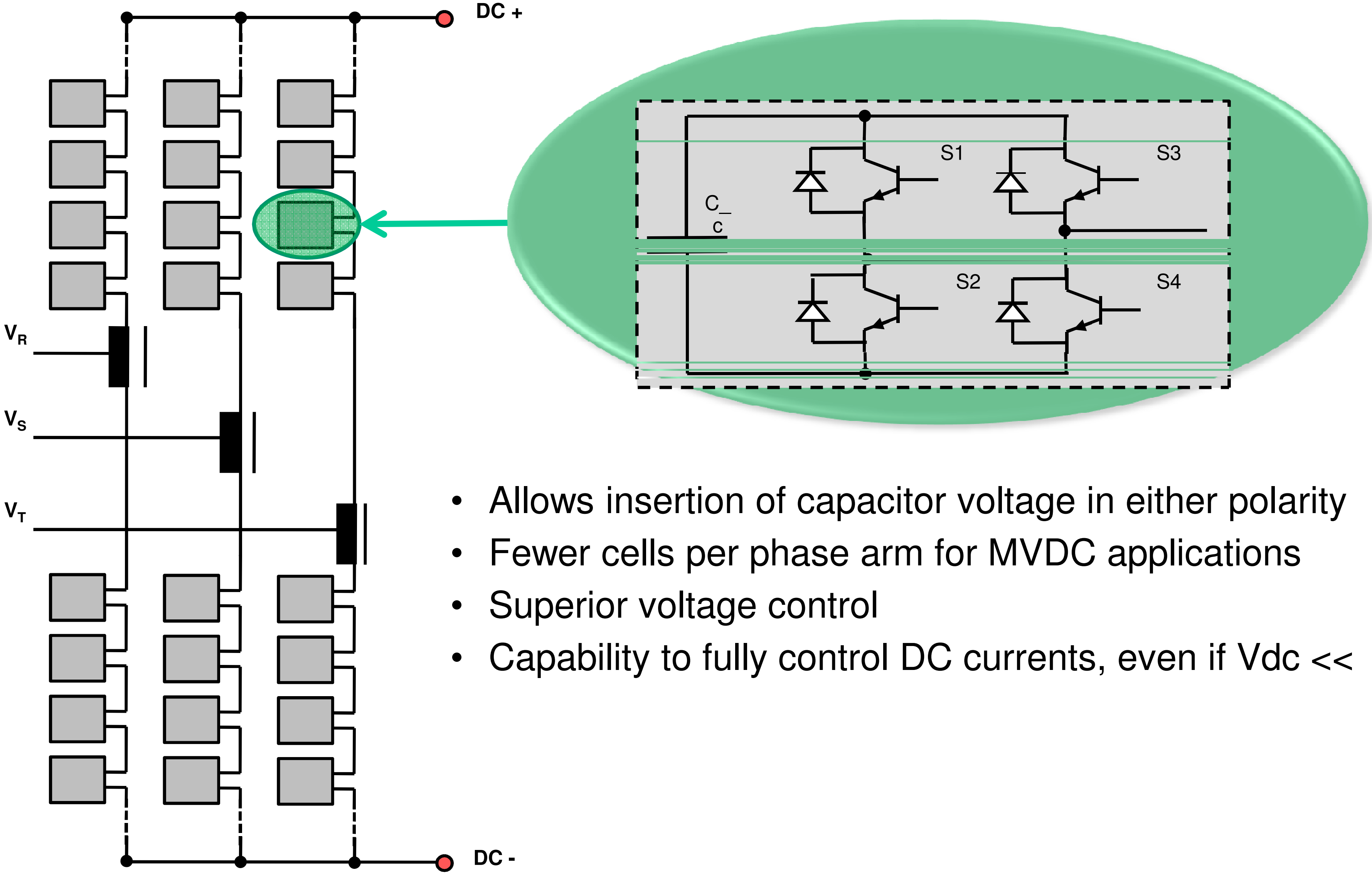


- Each MMC "cell" capacitor is a controllable voltage source
- Cell can be inserted or bypassed
- Complicated control (capacitor balancing)
- For HVDC, hundreds of (unipolar) cells per phase arm
- TransBay Cable, 400 MW, ±200 kV (2010, Siemens)



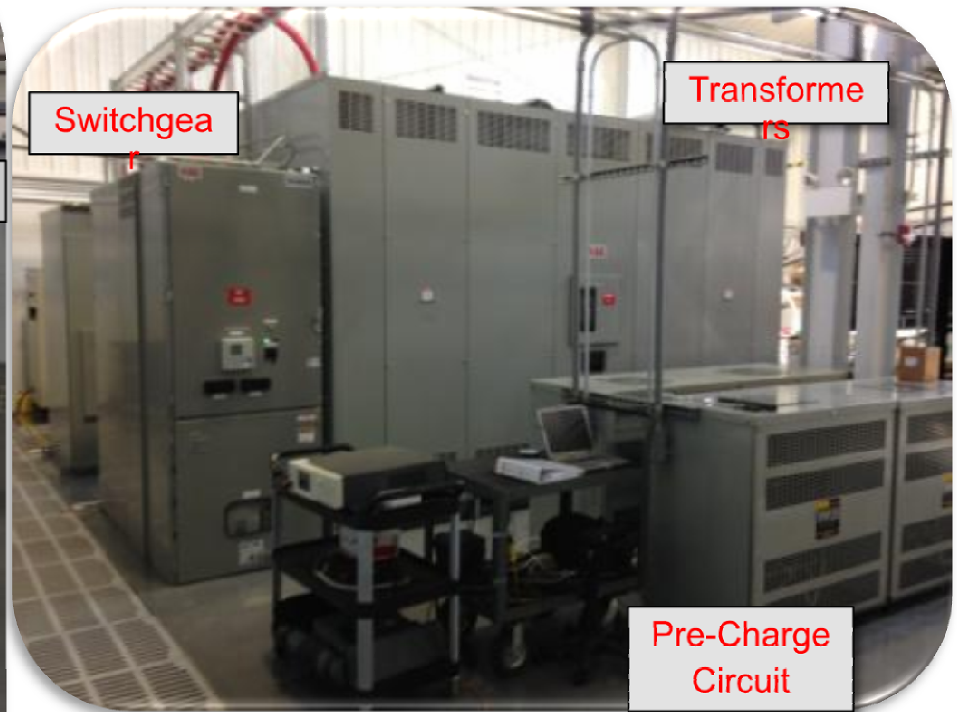
Wikimedia Commons, http://en.wikipedia.org/wiki/File:MMC-animation.gif

FSU-CAPS MMC – Full Bridge Cells



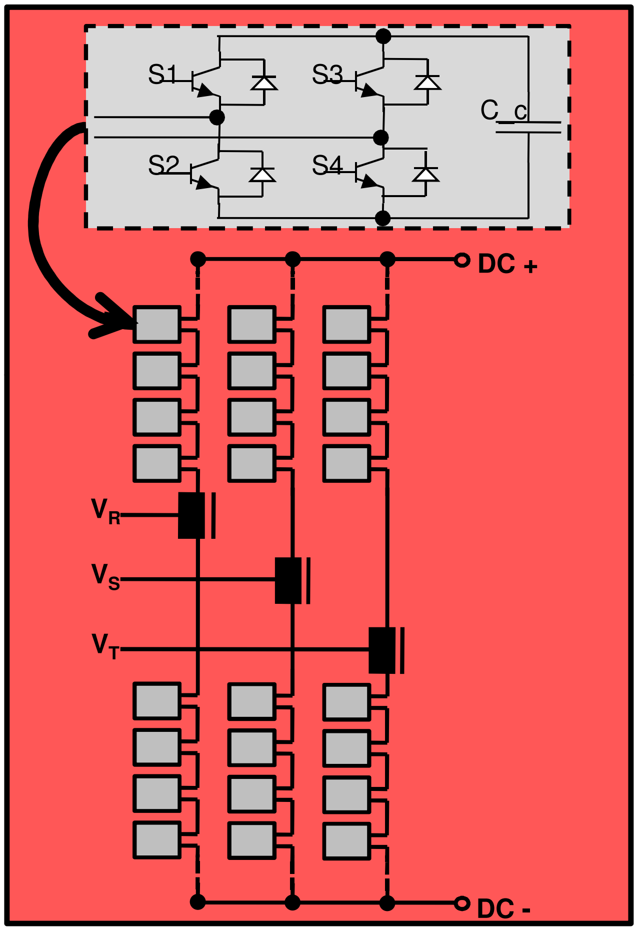
- Allows insertion of capacitor voltage in either polarity
- Fewer cells per phase arm for MVDC applications
- Superior voltage control
- Capability to fully control DC currents, even if Vdc <<

New CAPS MVDC Lab



MMC Controller HIL (CHIL)

CHIL of PHIL amplifier is an essential tools to derisk PHIL experiments



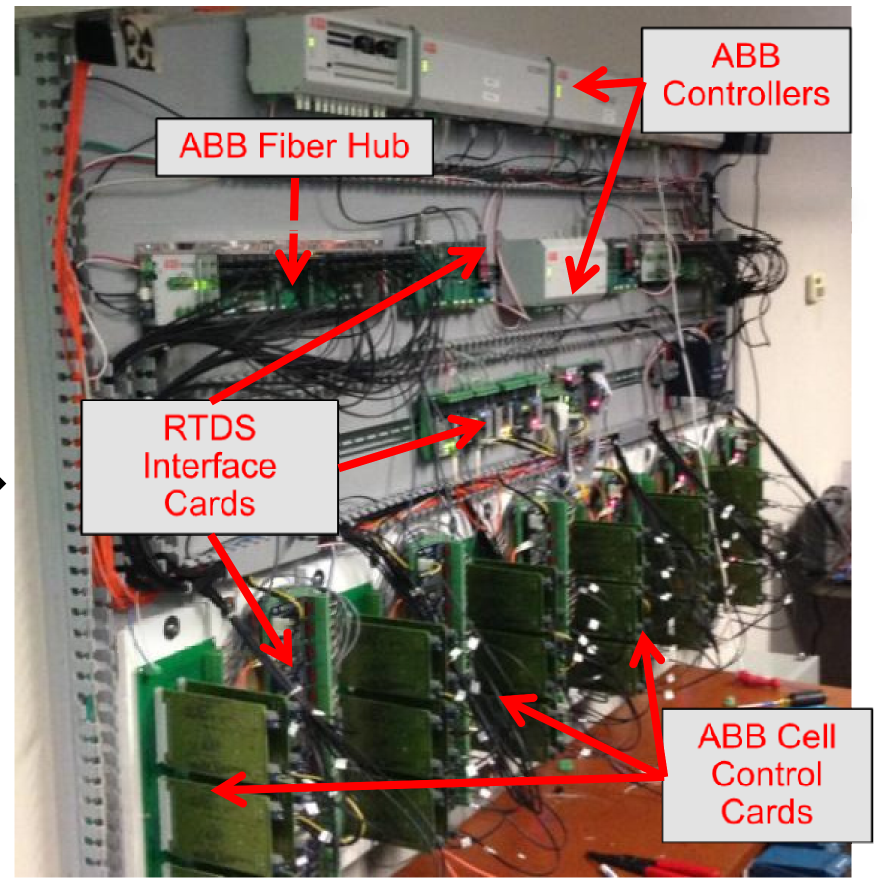
One of two converters modeled in RTDS

Voltages

Currents

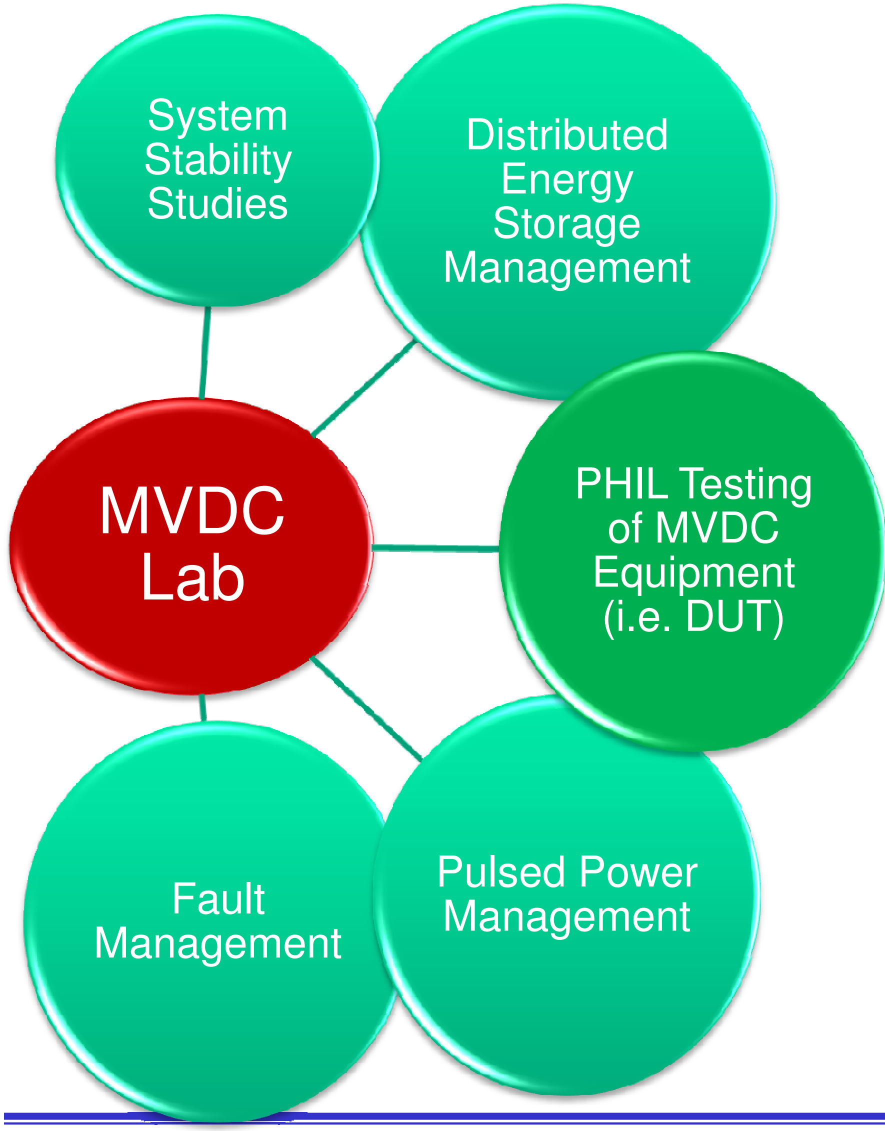
Firing

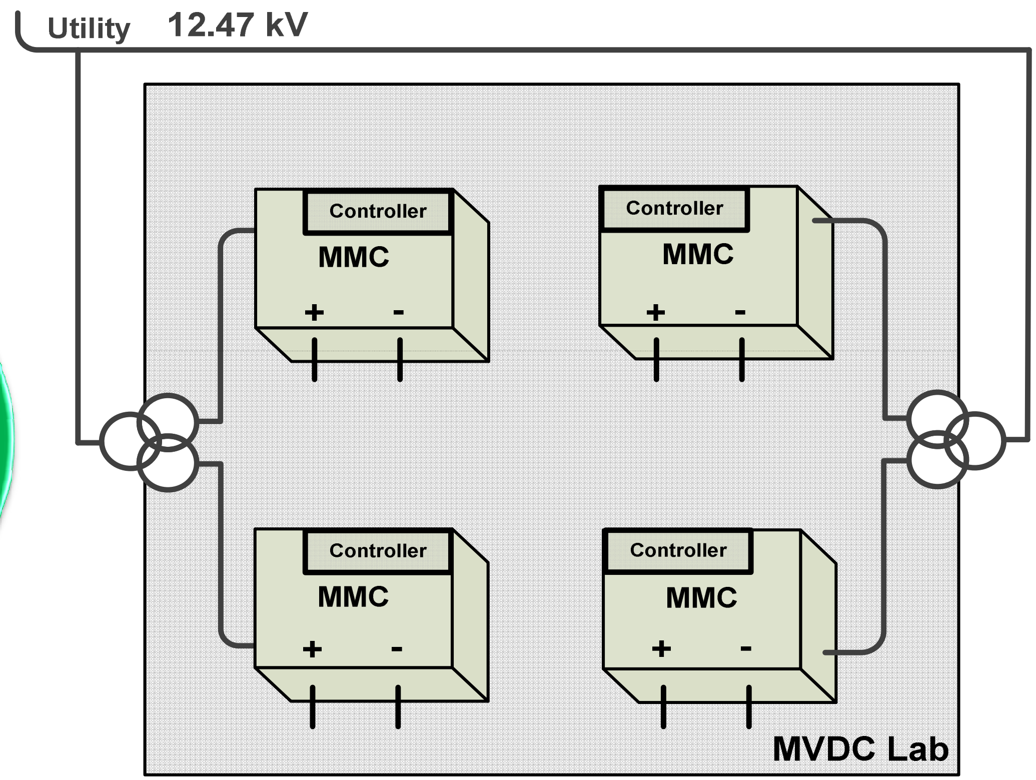
pulses



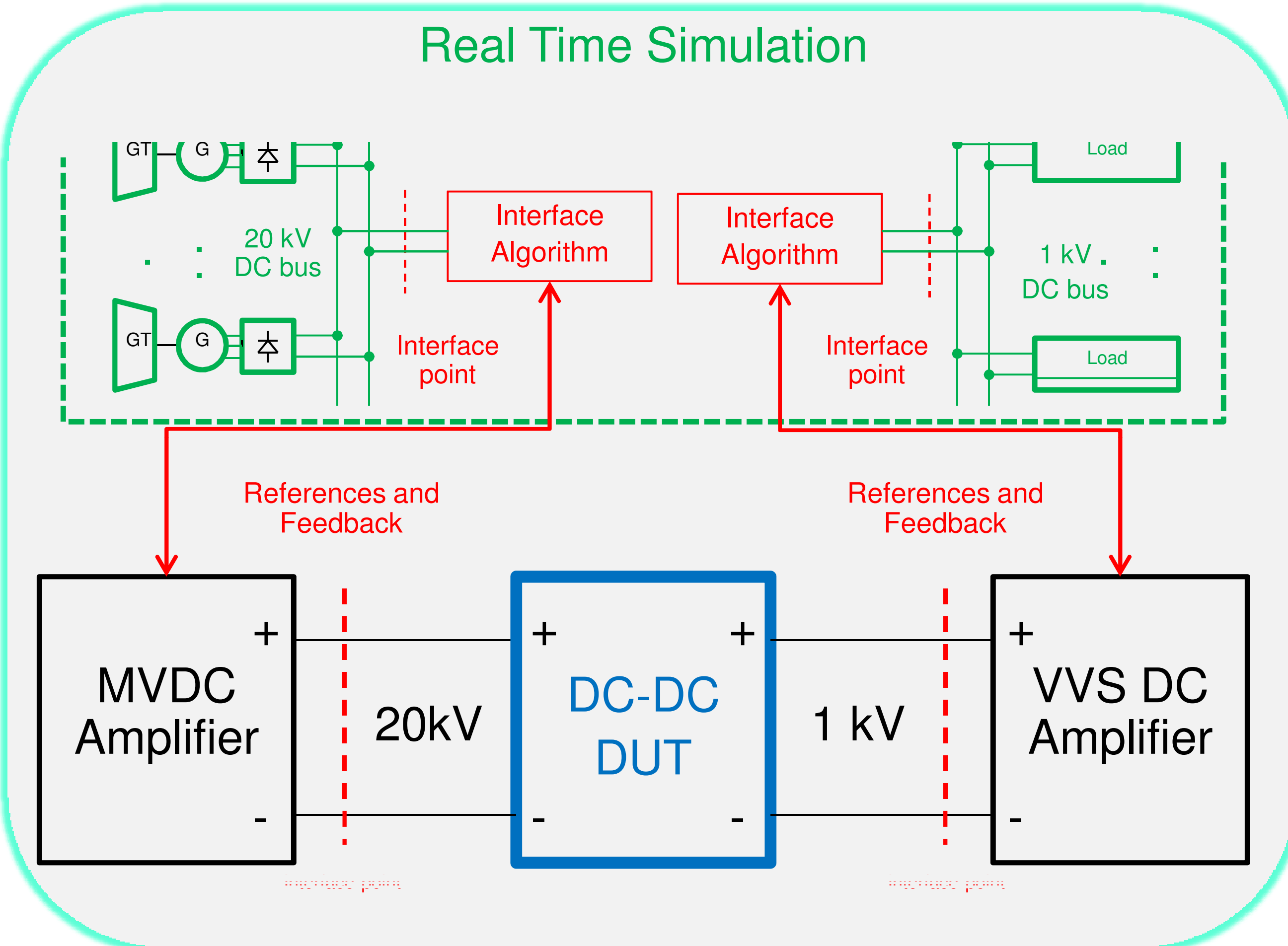
Two converter controls interfaced with RTDS

MVDC Lab
Experimental Possibilities

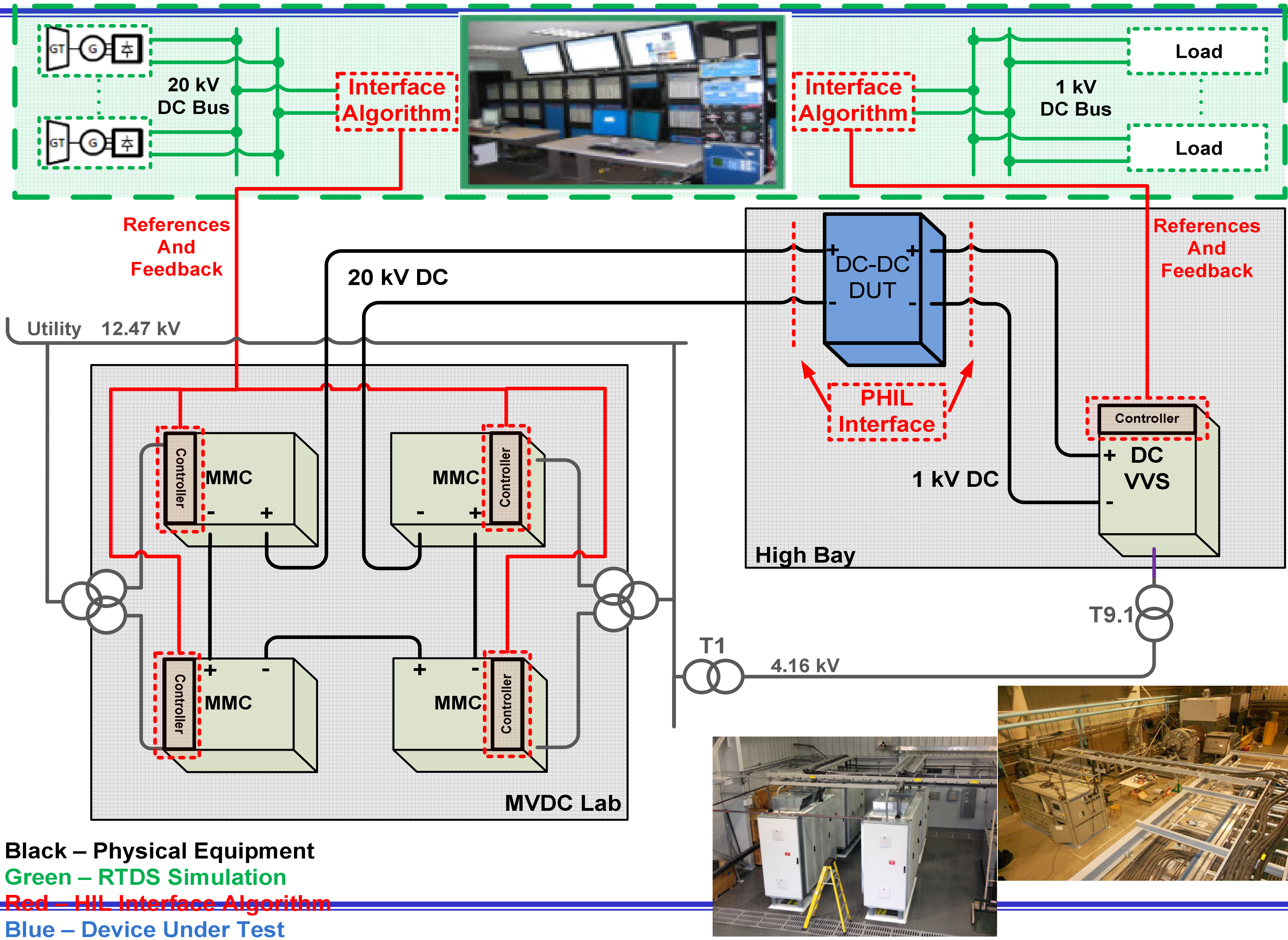




MVDC PHIL Application Example



MVDC PHIL Application Example



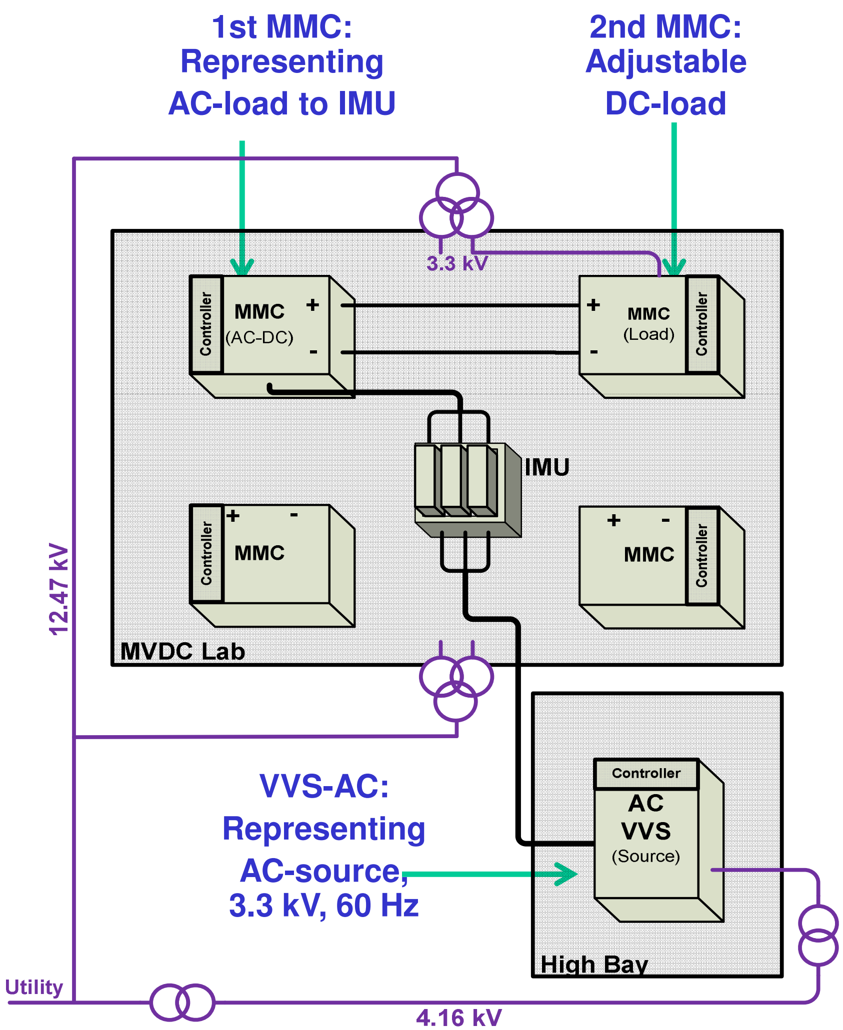
Black – Physical Equipment
Green – RTDS Simulation
Red – HIL Interface Algorithm
Blue – Device Under Test

Testing of VaTech's Impedance Measurement Unit

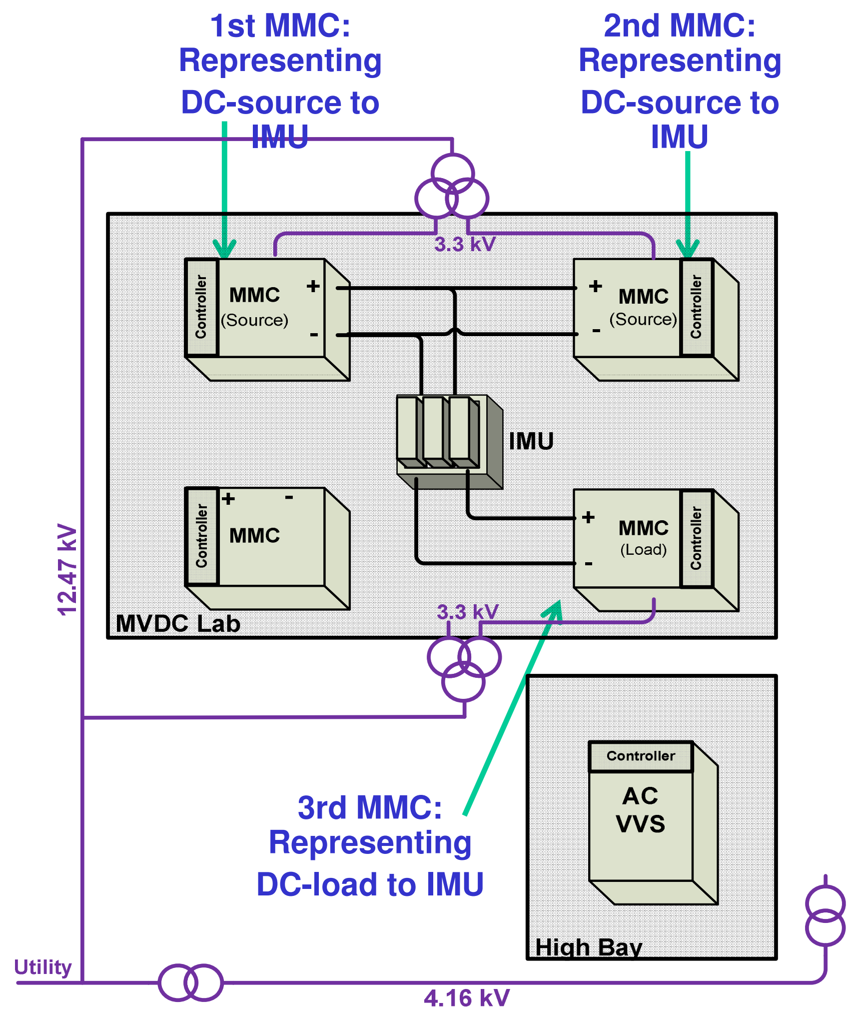
- Center for Power Electronics Systems (CPES) Virginia Tech (VT) developed Impedance Measurement Unit (IMU)
- Impedance measurement in AC and DC systems
  - Frequency range: 0.1 Hz – 1 kHz
  - Sources and Loads
  - Series or shunt connected (voltage or current injection)
- Medium voltage design
  - AC systems: 4.16 kV, 300 A, DC-400 Hz, 2.2 MVA
  - DC systems: 4 kV, 300 A
- Impedance measurement of converters at CAPS
  - Emulating source and load behaviors
  - Verification against model prediction
- System context: stability verification in systems based on
  - Model of power apparatus
  - IMU-derived model

IMU Test Setups

Measure AC impedances



Measure DC impedances



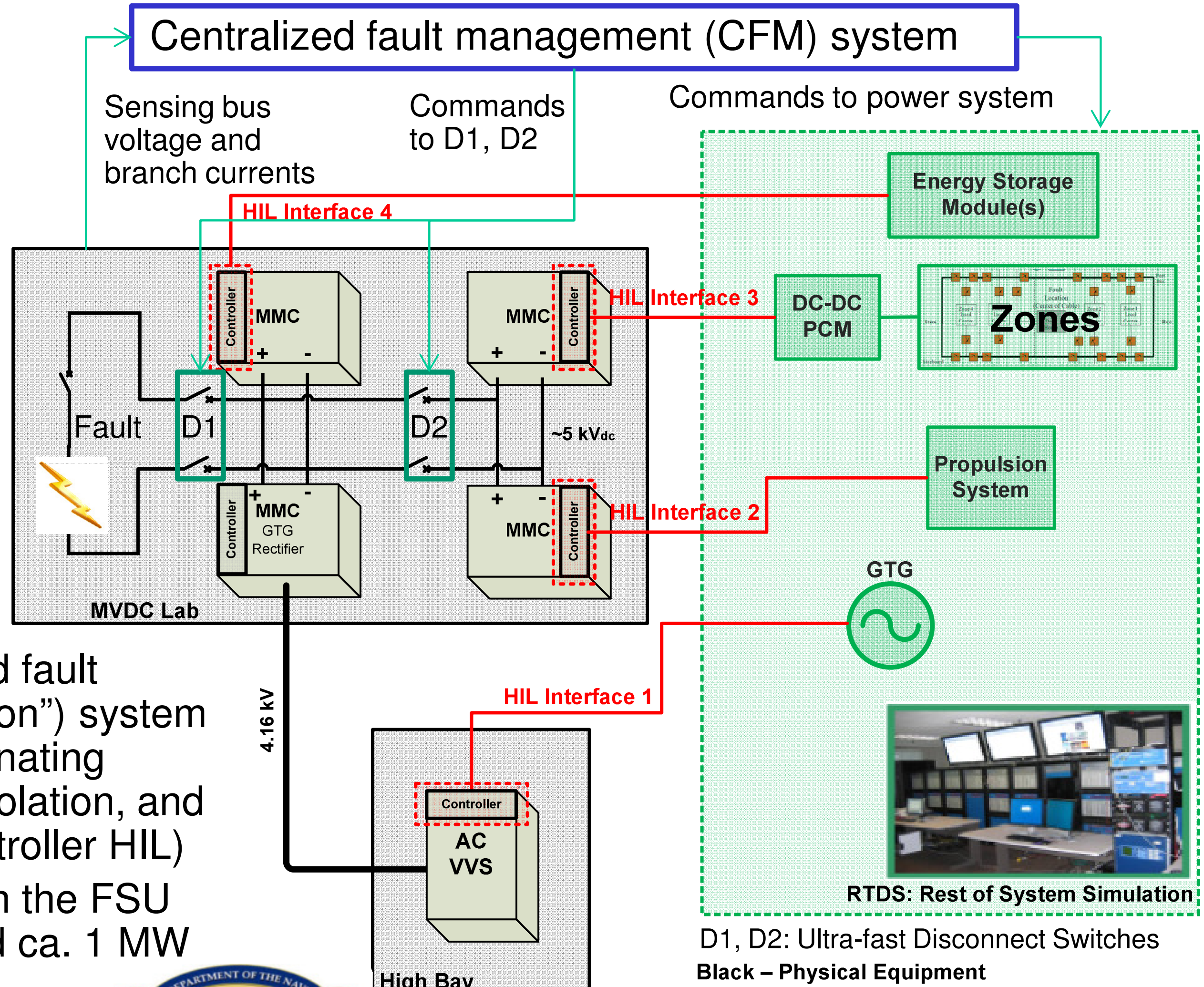
Fault Management in MVDC Systems

Challenges

- Scalability and robustness of fast centralized fault location system
- Availability of fast MVDC class (mechanical) disconnect switches
- Managing and coordinating rapid re-start of all load converters

Approach

- Design and test a centralized fault management CFM ("protection") system for locating faults and coordinating converter shut-down, fault isolation, and converter re-start (using controller HIL)
- Demonstrate the approach in the FSU MVDC lab (@ ca. 5kVdc and ca. 1 MW power level)



D1, D2: Ultra-fast Disconnect Switches

Black – Physical Equipment

Green – RTDS Simulation

Red – HIL Interface Algorithm

Concluding Remarks

- Established 5 MW MVDC PHIL simulation research facility using MMC converters
  - Includes MMC CHIL for de-risking PHIL experiments
- Scheduled for experiments
  - Testing of VaTech's Impedance Measurement Unit
  - Rapid Power Transfer in shipboard MVDC systems
  - Fault Management in fault current limited shipboard MVDC systems
- Commissioning ends Oct 2014