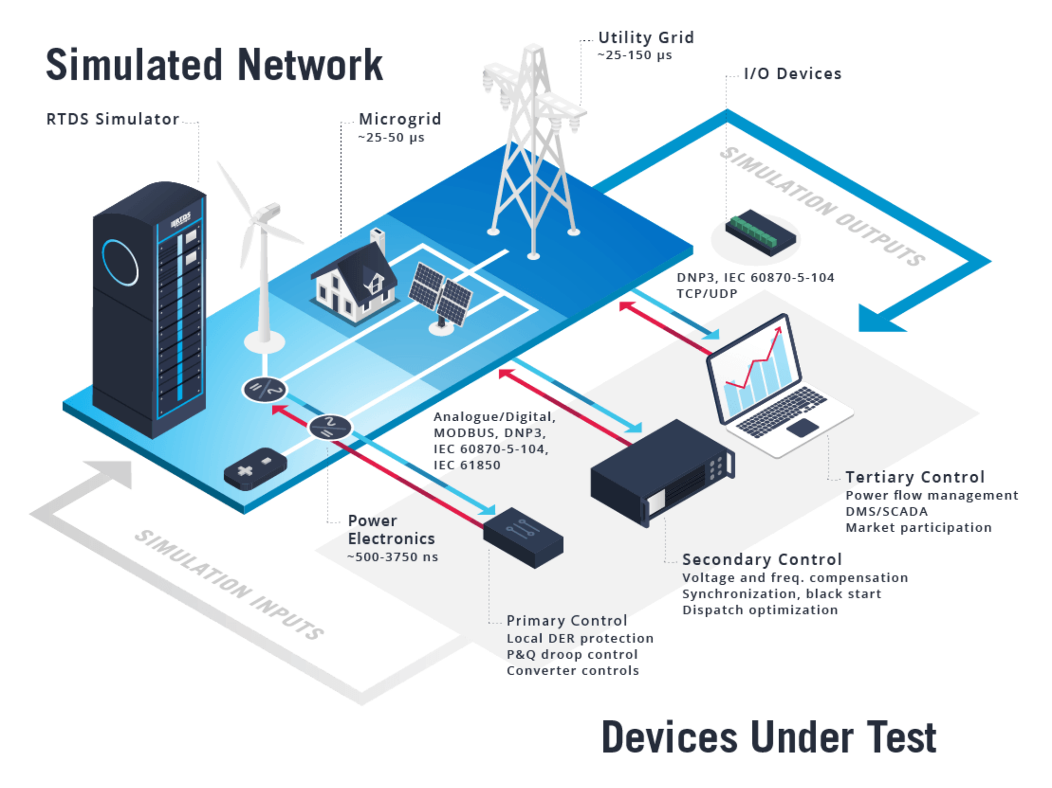
REAL TIME BLACK BOX MODELING OF VENDOR PROPRIETARY CONTROLS

RTDS TECHNOLOGIES INC.

Why are Black Box Controls Important?

- Customers want models that accurately reflect the real control and protection equipment provided by vendors
- The same code base used by vendors can be used to create the black box model
- Vendor’s IP must be protected
- Generic models have their limitations
- Tuning generic models can be very time consuming

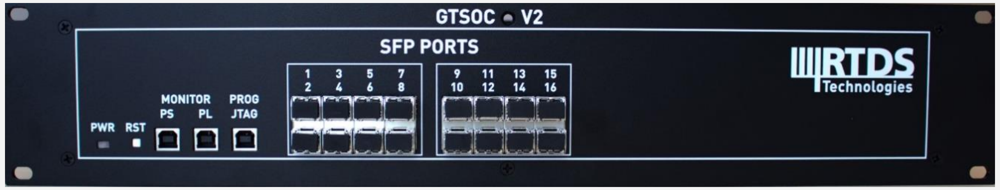


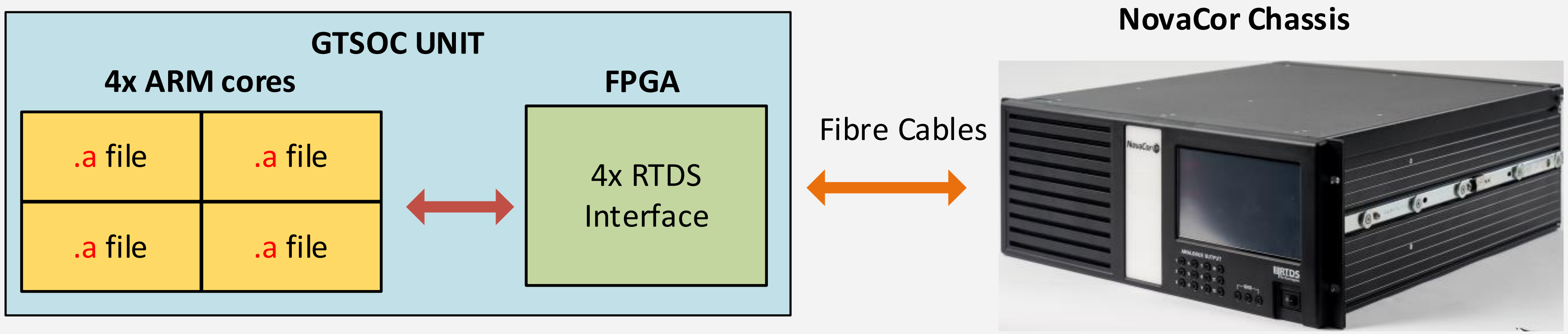
Black Box Controller Options in RTDS

- Component Builder (Cbuilder)
  - Develop own component model
- Compiled Hierarchy Box
  - Use standard control blocks and/or Cbuilder and pre-compile
- GTSOC
  - Auxiliary hardware platform that run vendor source code
  - Recommended options for complex controllers such as HVDC and IBR control and protection

GTSOC

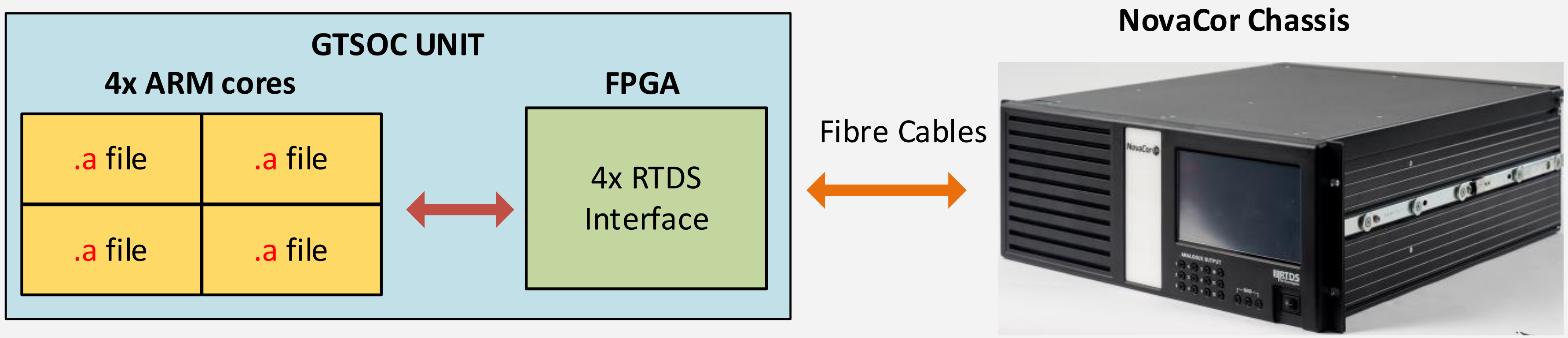
- Hardware Platform to run the black box controller
- Combination of FPGA and Multi-Processor System-on-Chip (MPSoC)
- Supports Bare Metal Execution of Static Library (*.a) Files containing Vendor Source Code
- 4 ARM cores available to develop applications
- Interconnects with NovaCor via Fiber Optic Cables





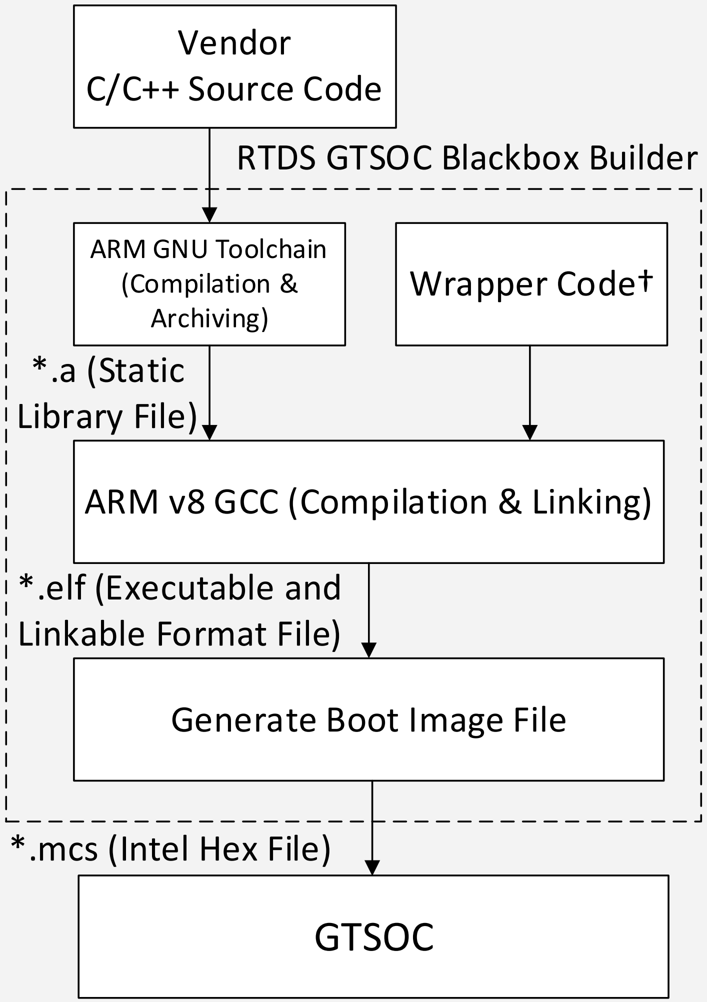
GTSOC

- Run the vendor controller on the ARM cores
  - Each ARM core can model different controllers
  - Controller code can be distributed across multiple ARM cores
  - Each core can run at a different time step,
  - Each core time step can run at a time step different from the RTDS
- FPGA fabric used for communication with NovaCor
- GTSOC runs in parallel with the simulation, mimics how actually control operates.



Deploying Blackbox Controls on the GTSOC

- Vendor C/C++/Fortran Source Code
  - Written by Hand
  - Generated via MATLAB/Simulink
- **RTDS GTSOC Blackbox Builder Tool**
  - Source code compiled into Static Library (*.a)
  - Wrapper code is used for mapping inputs/outputs and parameters
  - Generates Firmware (*.mcs) for GTSOC

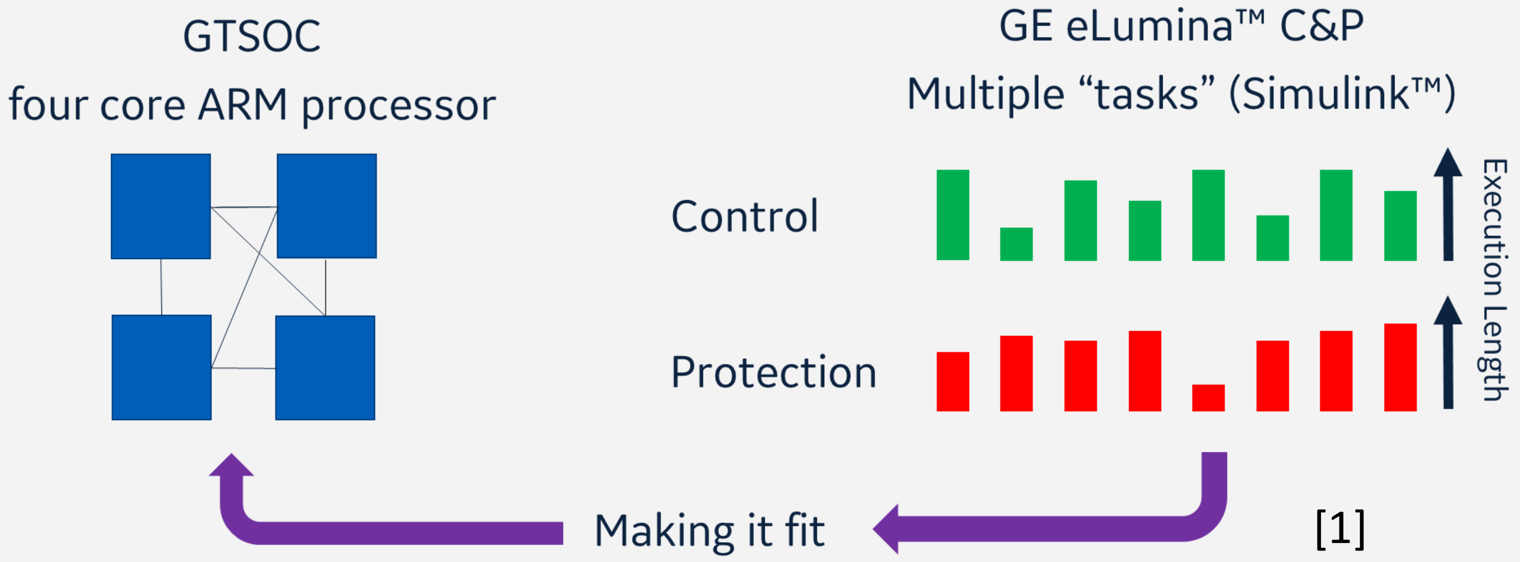


GTSOC

- Comprehensive document available
- Aids in the development of GTSOC applications

GE Vernova HVDC control and protection on GTSOC

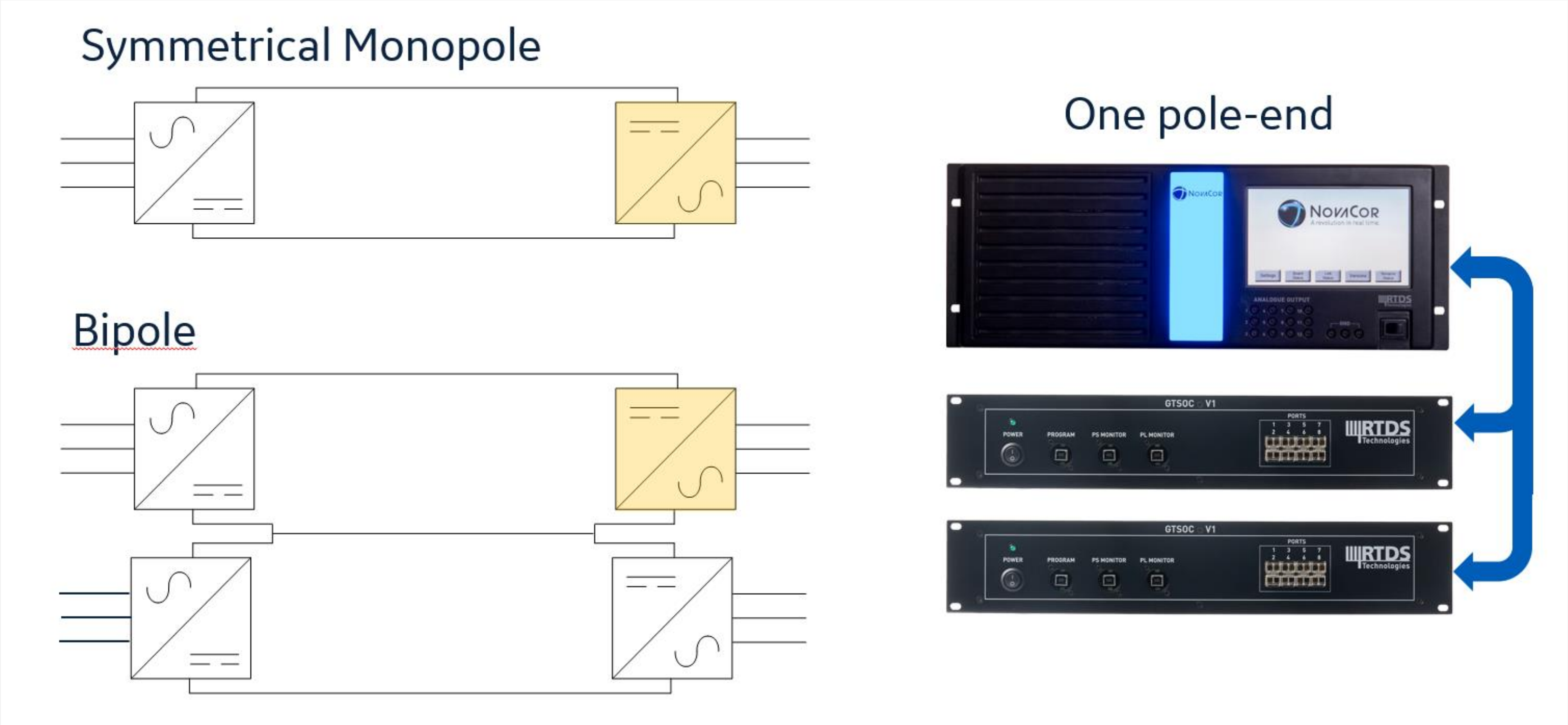
- Runs complete control and protection code from the original source model
- First challenge was determining number of GTSOC ARM cores required to model the control and protection system and assure real time performance
- Second challenge was evaluating the latency in the simulation setup



[1]

GE Vernova HVDC control and protection on GTSOC

- Four ARM cores required for Control
- Four ARM cores required for Protection

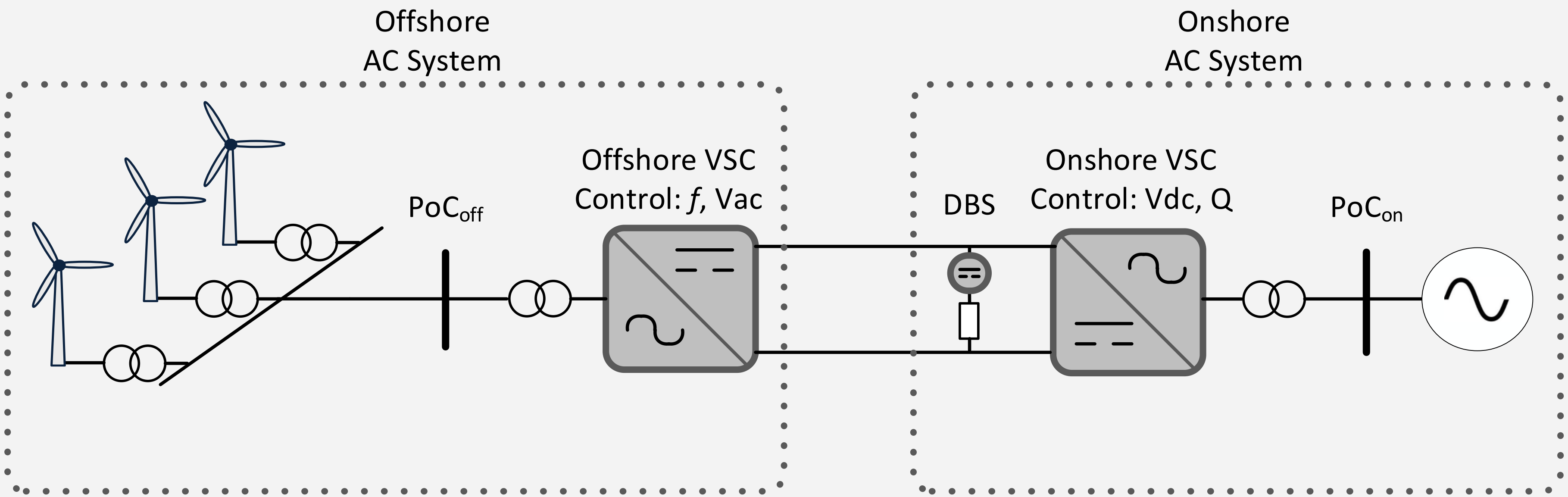


[2]

GE Vernova HVDC control and protection on GTSOC

Test Model

- Used for benchmarking against offline model
- Onshore and Offshore converters' control and protection modelled on GTSOC
- 4 GTSOC units - 16 ARM cores
- 1 NovaCor Chassis – 2 cores
- Main goal was comparing results to offline model, C&P not optimized



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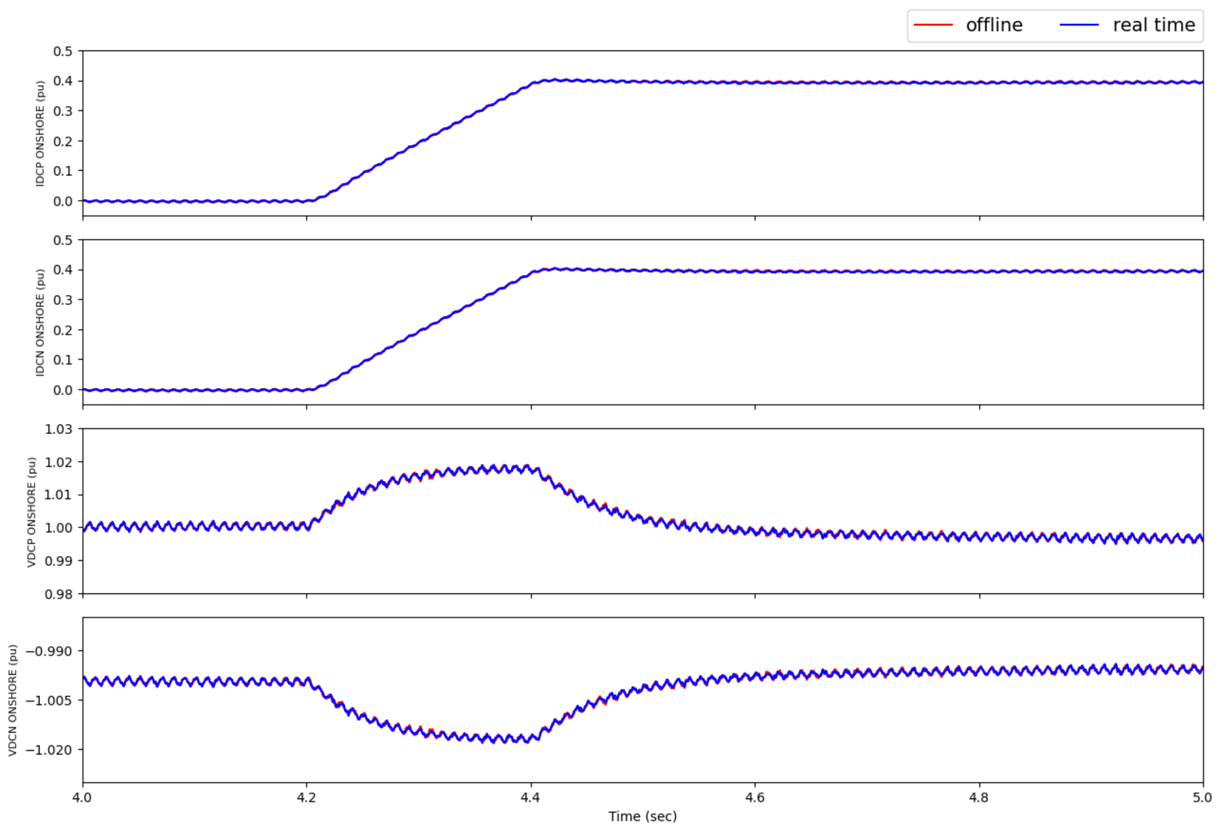
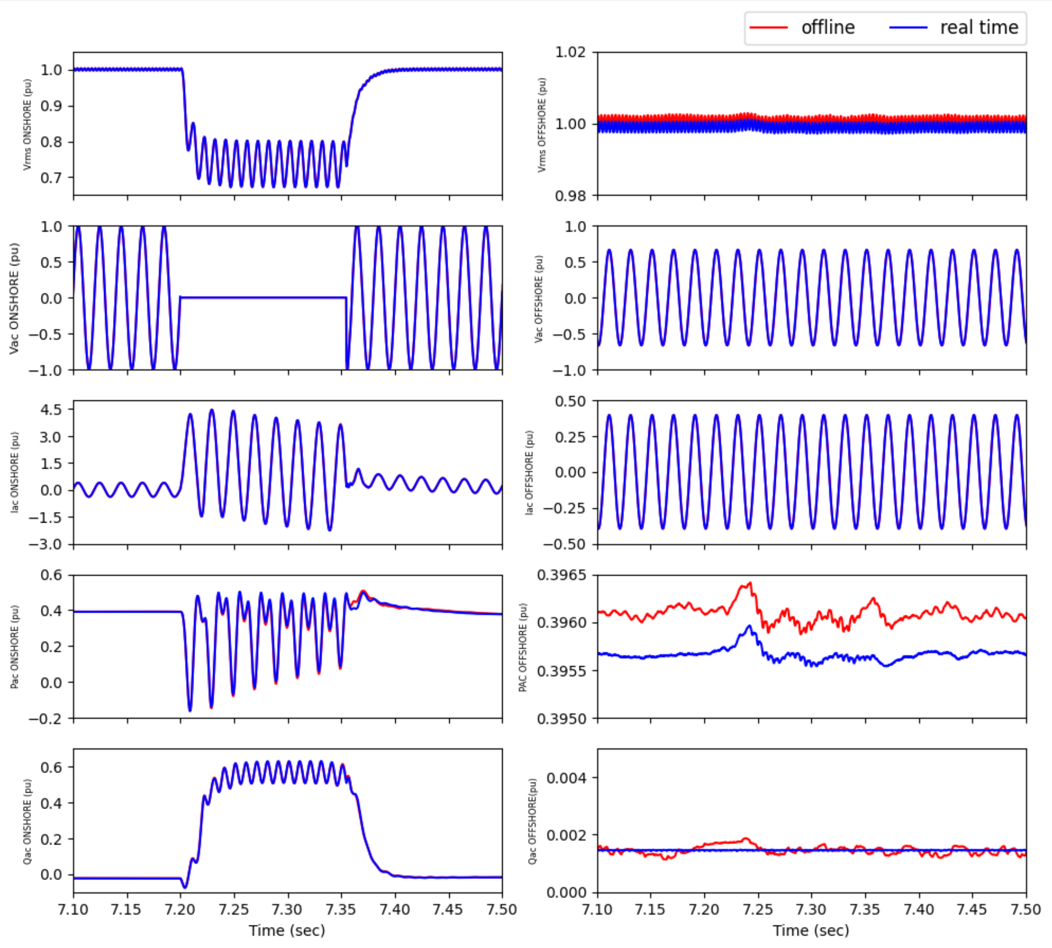
GE Vernova HVDC control and protection on GTSOC

Test Results



Power Ramp (DC signals)



150 ms 1-phase fault at Onshore POC

Frequency Scan

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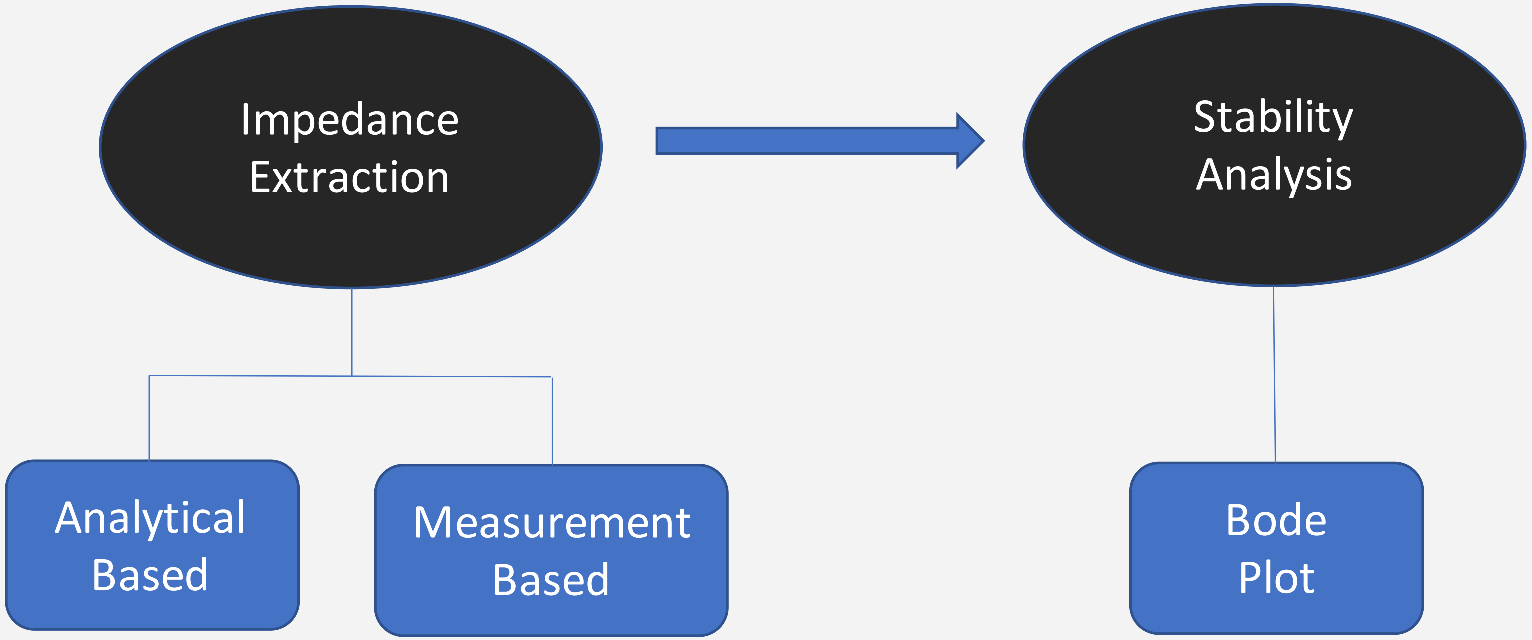
Impedance Based Analysis



Measurement Based Scan

- MMC system feature a significant number of dynamic elements
- Introduces wideband frequency interactions with nearby systems, both AC and DC, and their control systems.
- Analytical methods are complicated and ignores details of the vendor controls
- Frequency Scan tool developed to analyze the frequency characteristics and assist in the stability analysis of the system.
- Suitable for applications with Hardware in the Loop (HIL), Software in the Loop (SIL) with GTSOC, or a combination of both HIL and SIL.

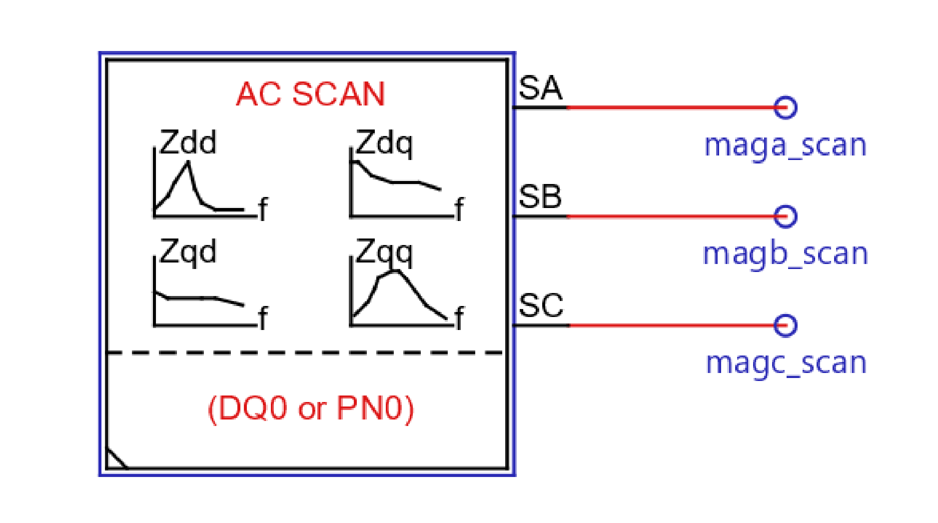
Impedance Extraction

Measurement based

1. Inject harmonic to the system at an equilibrium
2. Small signal multi-sine perturbation
3. Measure the harmonic current and voltage for a subsystem
4. DFT and calculation

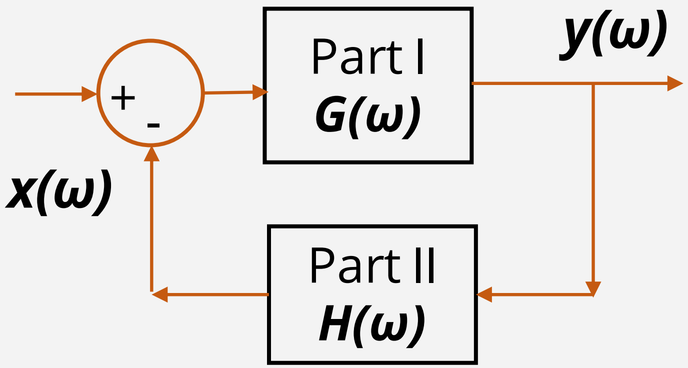
Stability Analysis

- Import scan results
- Create Bode plot



RSCAD Frequency Scan Component

Bode Plot



$$\frac{y(\omega)}{x(\omega)} = \frac{G(\omega)}{I + G(\omega) * H(\omega)}$$

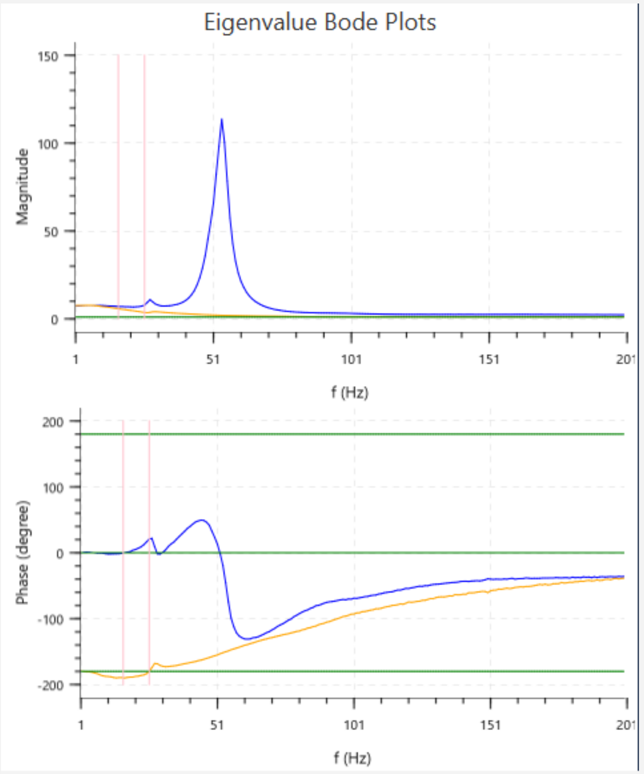
Closed loop representation

$$\lambda(\omega)$$

$$\uparrow$$

$$eig[G(\omega)H(\omega)]$$

Open loop gain eigenvalues



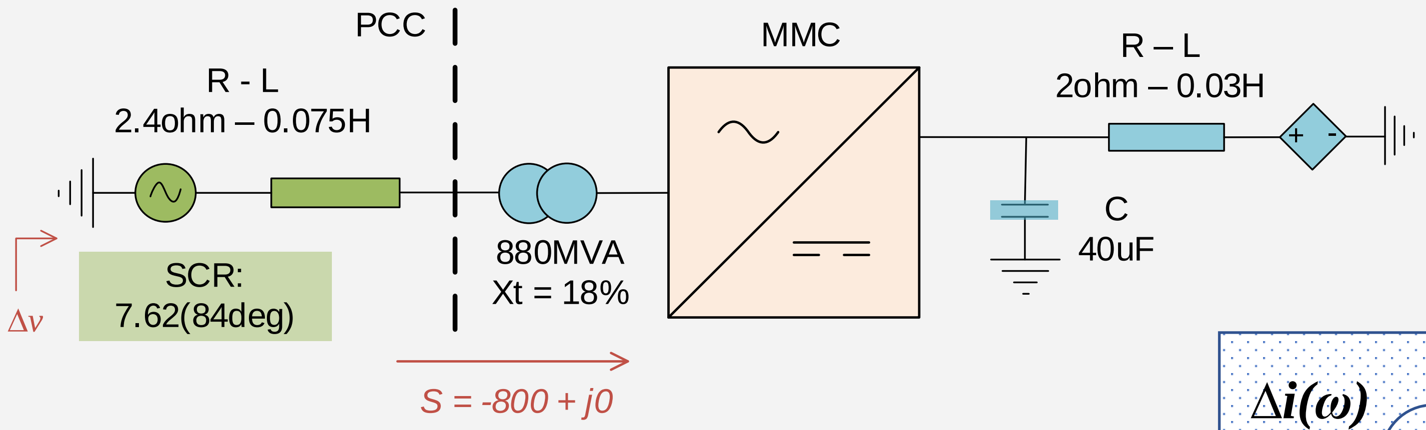
Bode Plot

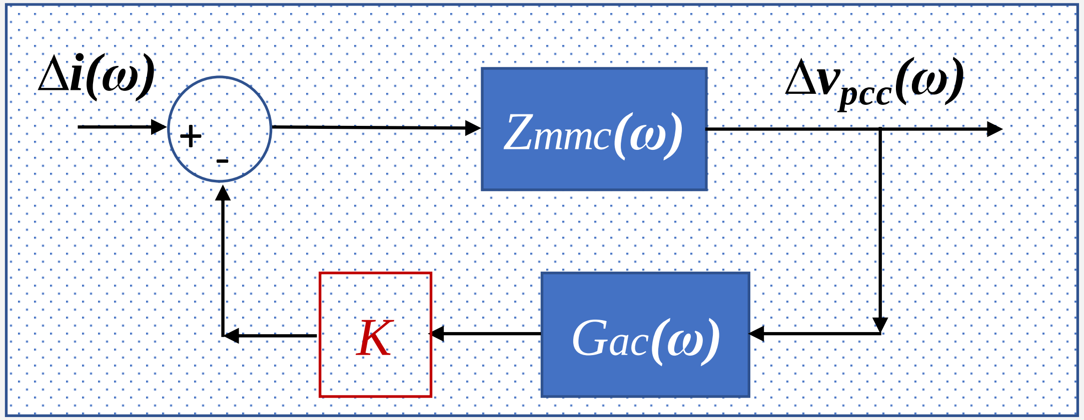
(1,180deg)

Example Case

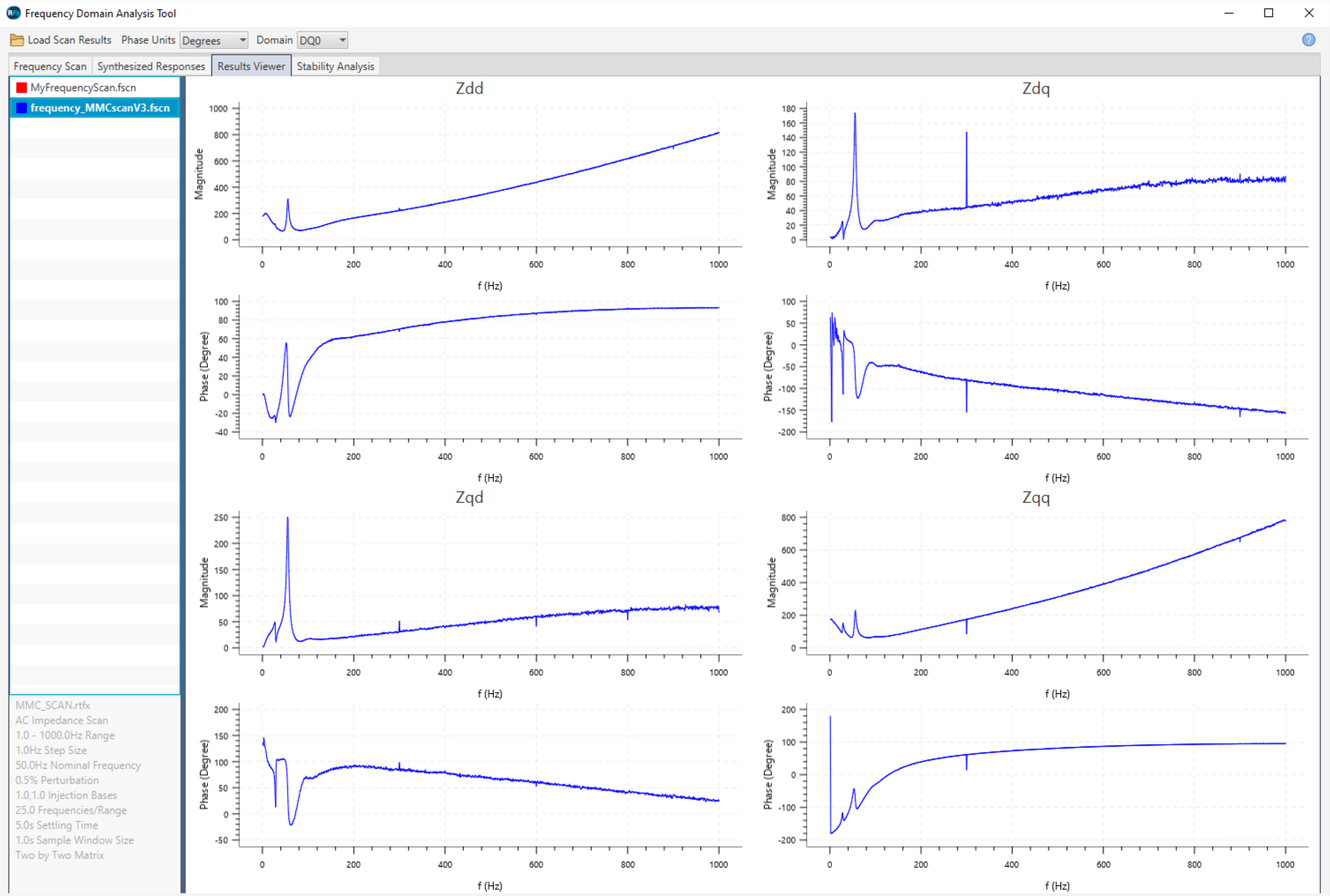
Circuit Block and Close-Loop System

MMC Systems Interaction with AC Network



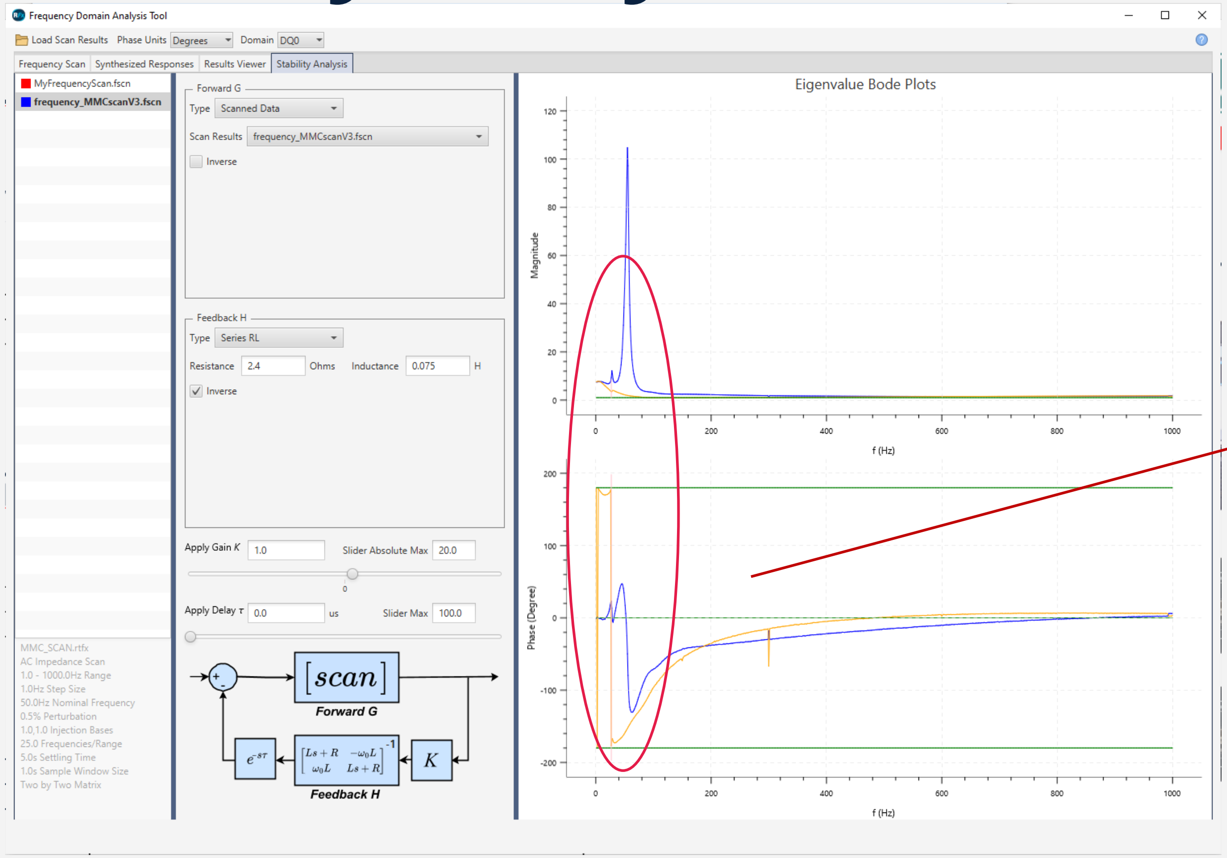


Impedance Scan of MMC system

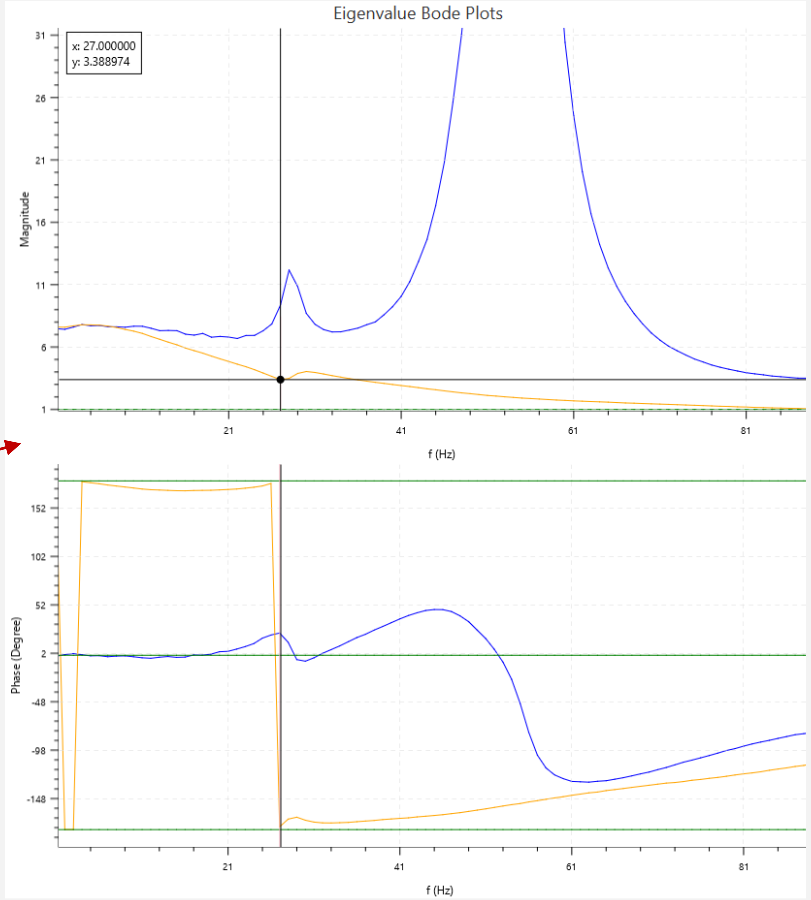


Frequency Scan of the MMC system (DQ domain)

Stability Analysis



"Stability Analysis" Tab in FDA for the MMC Scan Case (SCR=7.62)



Phase Angle Crossing ±180 for the MMC Scan Case

Two frequencies where angle crosses +/- 180 degrees

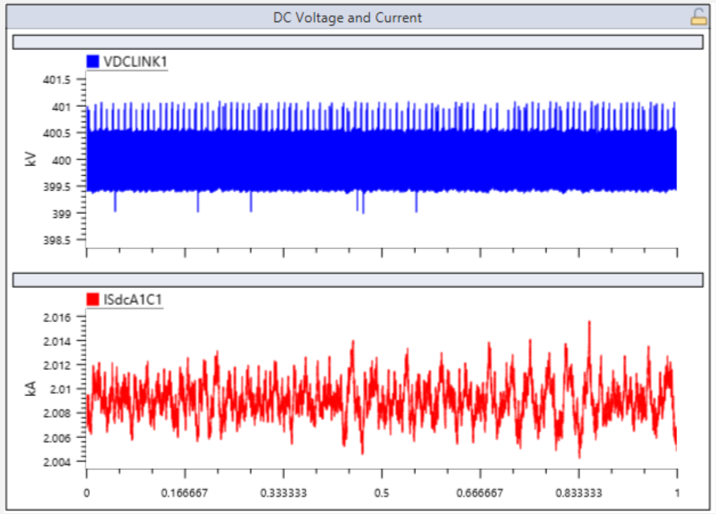
~3hz → magnitude is 7.70

~26-27 Hz → magnitude is ~3.46 (Critical Freq.)

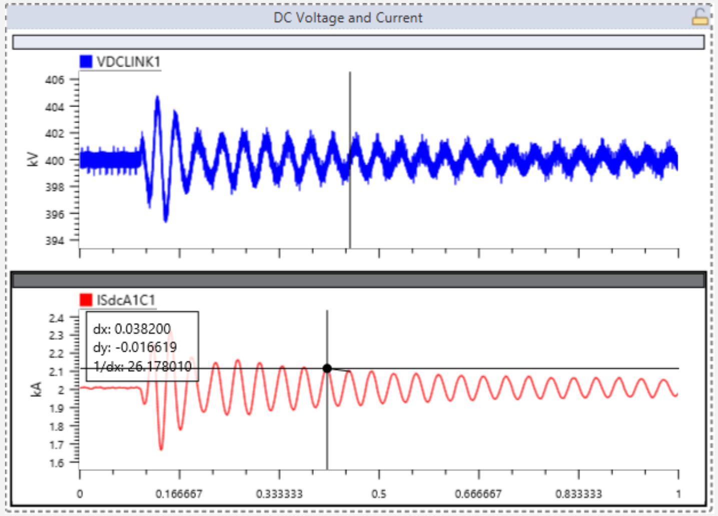
$$CSCR = \frac{SCR}{GM}$$

→ CSCR ~= 2.2

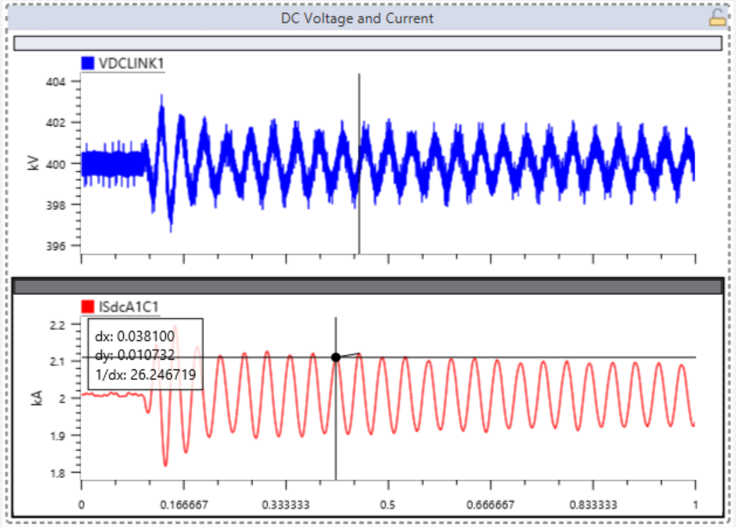
Dynamic Response from different SCR



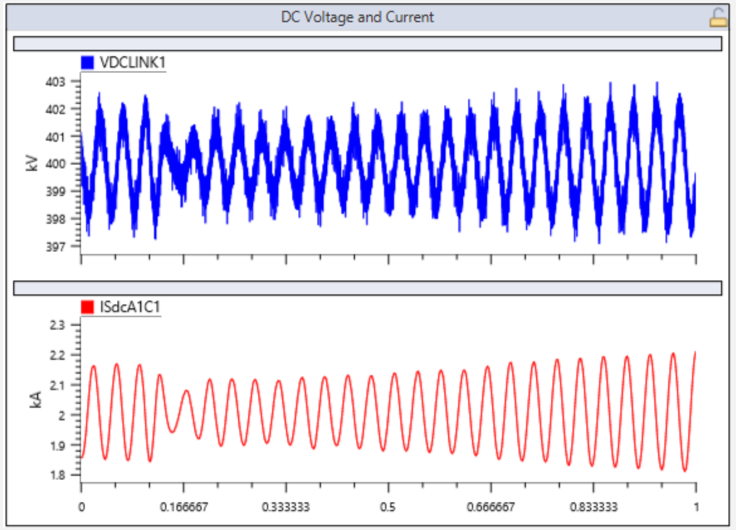
SCR: 7.62



SCR: 2.5 -> 2.3



SCR: 2.3 -> 2.2



SCR: 2.2 -> 2.15

- From simulation, it is observed that marginal stability point is around **SCR 2.2** and the oscillation frequency is around ***26-27 Hz***
- Matches to frequency scan result of marginal stability

Oscillation magnitude rises and eventually blows up!

CONCLUSIONS

- GTSOCV2 supports integration of vendor blackbox controls for RTDS simulation
- Frequency Scan tool can aid in stability analysis for HVDC system with HIL and/or SIL (i.e. GTSOC) controls

Thank you!

[1] Implementation of GE Vernova MMC Controls on GTSOC platform, RTDS Technologies, Aug 2023
[2] C. Barker et al. “Software in the Loop Real Time Simulation of a HVDC Terminal”, CIGRE Paris 2024

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