

DNV GL PROMOTiON WP 16 Demonstration

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2019.08.14



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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

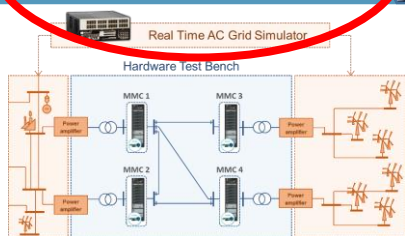
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- **Motivation for VSC Input-Admittance Measurement**
- **Concept of VSC Input – Admittance**
- **CHIL and PHIL Setup for WTG Input-Admittance**
- **Measurement Results**
- **Concept of CHIL Testbench for MMC-HVDC/MMC-STATCOM**
- **Update of CHIL Testbench of MMC-HVDC/MMC-STATCOM**

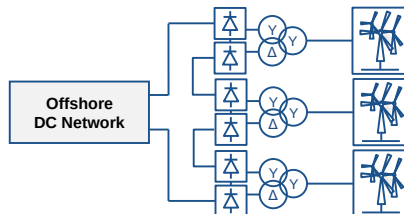


Cyber-physical Demos

MMC-HVDC



Grid-forming WTG



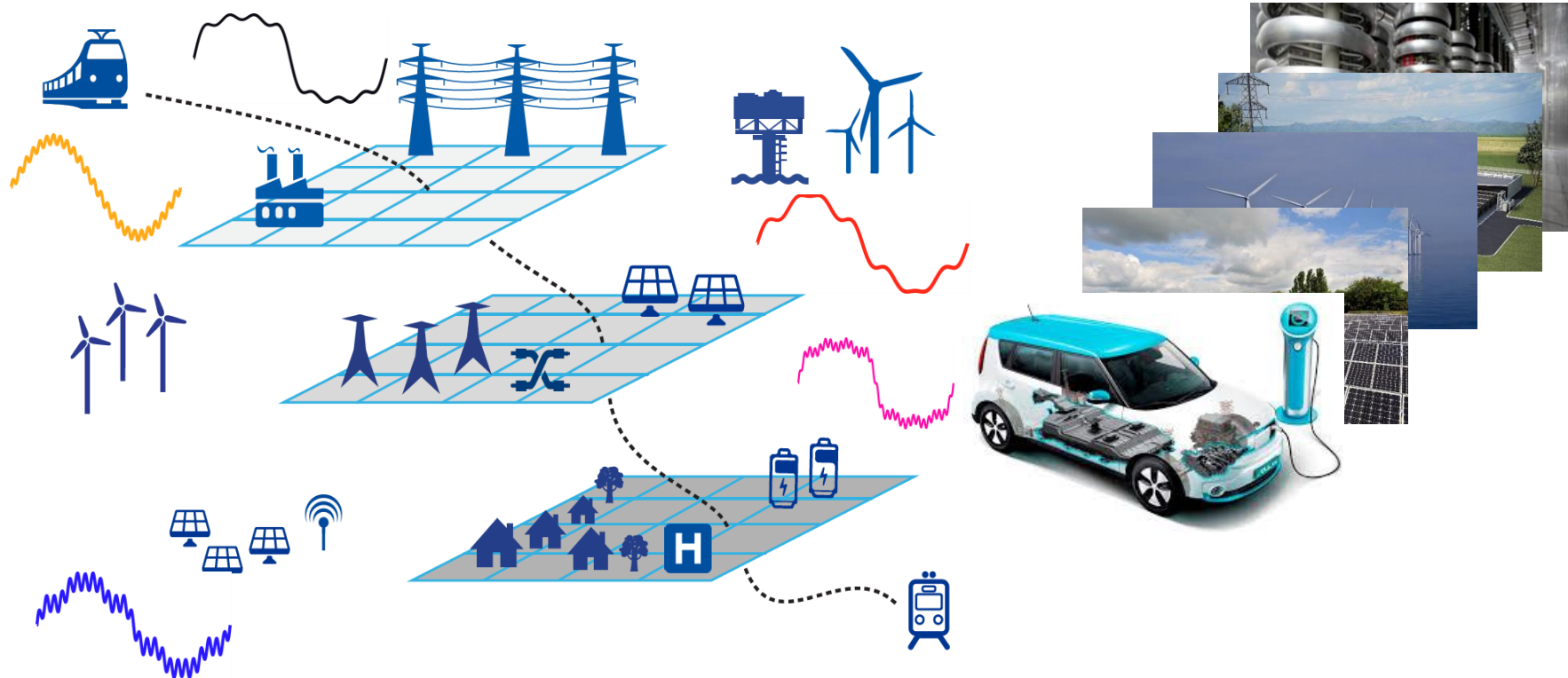
Grid-following WTG



Flexible Power Grid Lab

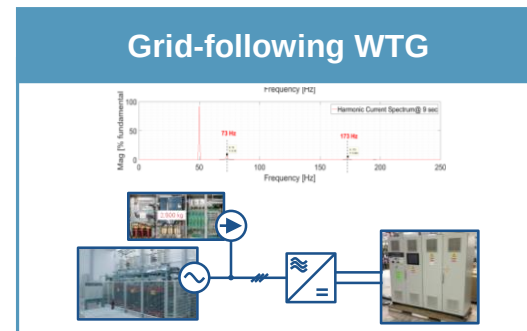
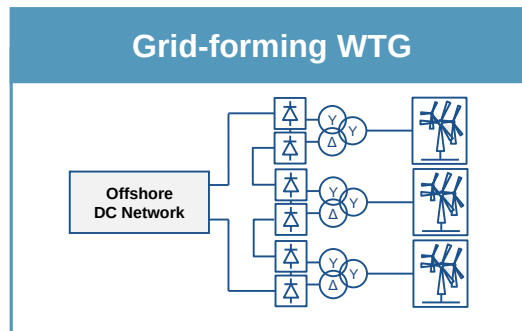
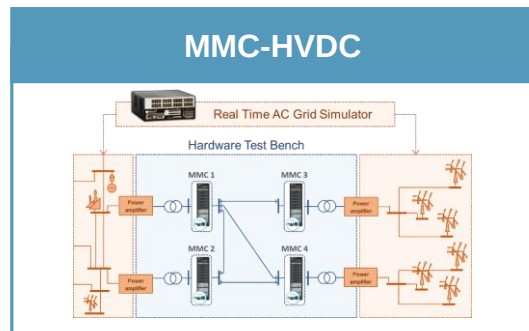


Motivation – Power Electronics Grid



Deliverable D16.5

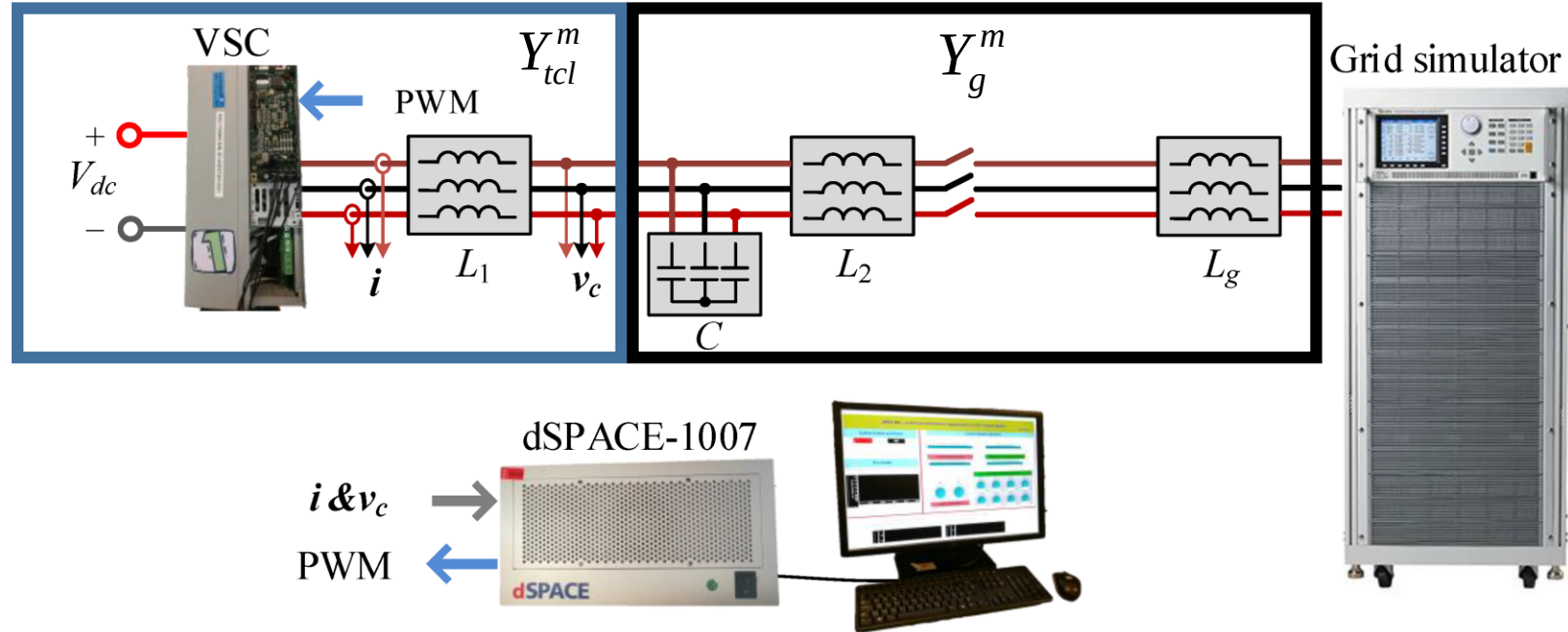
Implementation of an analytical method for analysis of harmonic resonance phenomena



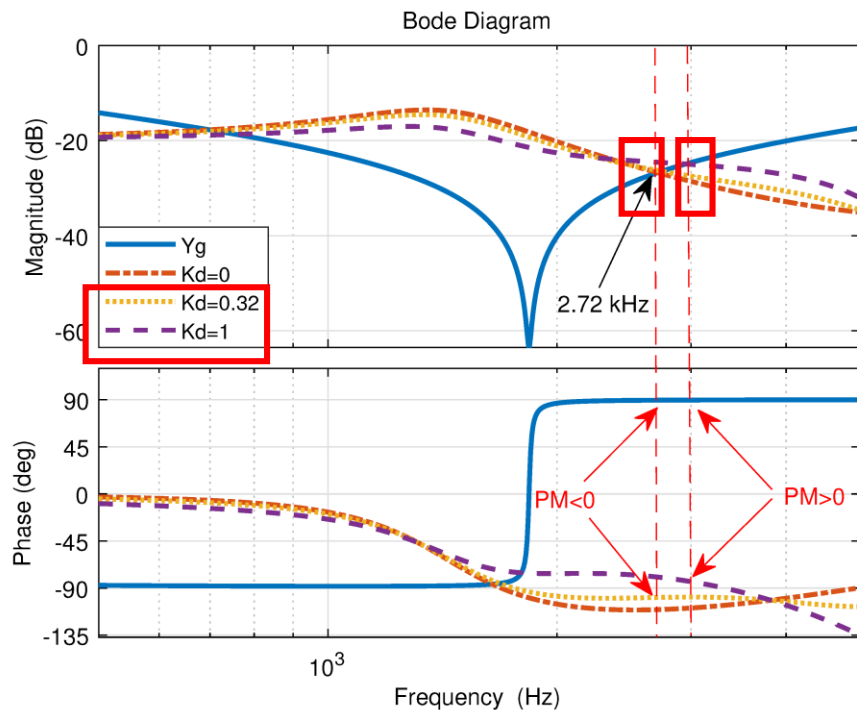
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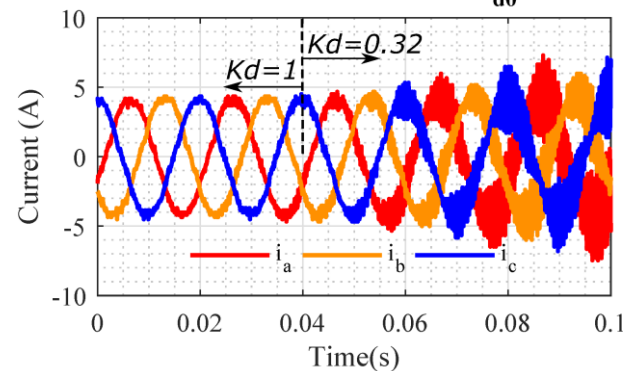
D16.5 – kW Lab Verification Test setup



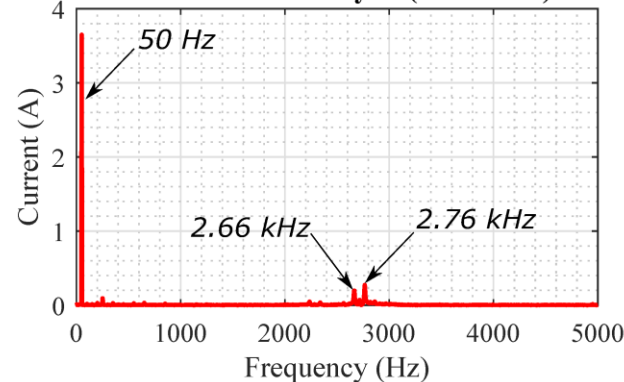
D16.5 – kW Lab Verification Test setup Results (1)



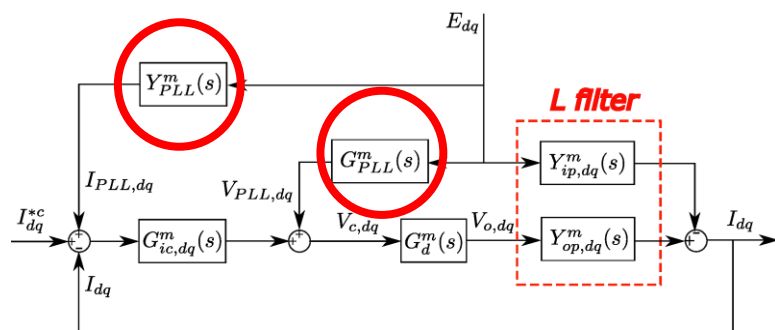
Current Output (AD to 0.32) - $I_{d0} = 4.1$ A



Current FFT Analysis (AD = 0.32)



D16.5 – Analytical Derivation of Input Admittance



DC Link



Phase Lock Loop



Current Control Loop

$$\begin{bmatrix} I_{PLL,d} \\ I_{PLL,q} \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & -H_{pll}(s)I_{1q} \\ 0 & H_{pll}(s)I_{1d} \end{bmatrix}}_{Y_{PLL}^m(s)} \begin{bmatrix} E_d \\ E_q \end{bmatrix} \quad \begin{bmatrix} V_{PLL,d} \\ V_{PLL,q} \end{bmatrix} = \underbrace{\begin{bmatrix} 0 & -H_{pll}(s)V_{1cq} \\ 0 & H_{pll}(s)V_{1cd} \end{bmatrix}}_{G_{PLL}^m(s)} \begin{bmatrix} E_d \\ E_q \end{bmatrix}$$

$$\begin{bmatrix} \Delta I_d \\ \Delta I_q \end{bmatrix} = G_{icl,dq}^m(s) \underbrace{\begin{bmatrix} \Delta I_d^{*c} \\ \Delta I_q^{*c} \end{bmatrix}}_{\Delta I_{icl,dq}^{*c}} - \underbrace{\left(-G_{icl,dq}^m(s)Y_{PLL}^m(s) + Y_{to,dq}^m \right)}_{Y_{icl,dq}^m(s)} \begin{bmatrix} \Delta E_d \\ \Delta E_q \end{bmatrix}$$

PLL-dynamics

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \underbrace{\begin{bmatrix} Y_{dd}(s) & Y_{dq}(s) \\ Y_{qd}(s) & Y_{qq}(s) \end{bmatrix}}_{Y_{icl,dq}^m(s)} \begin{bmatrix} E_d \\ E_q \end{bmatrix}$$

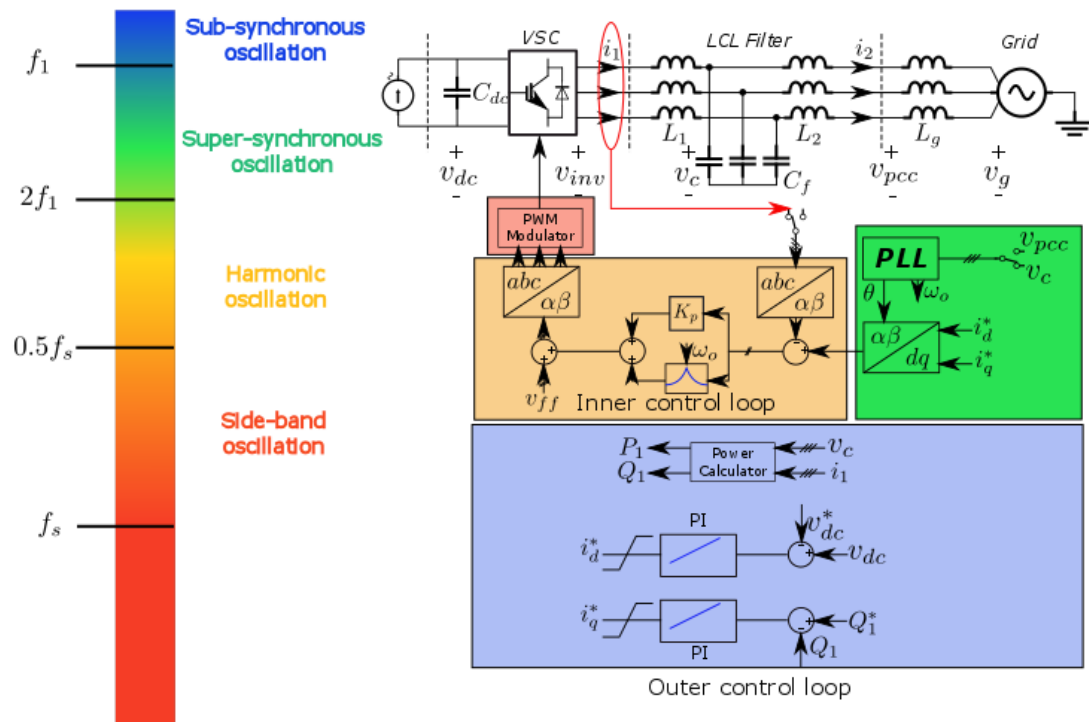


Concept of VSC Input-Admittance

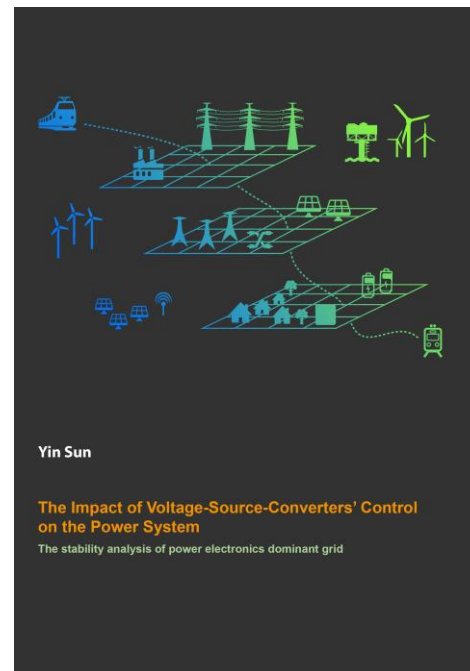


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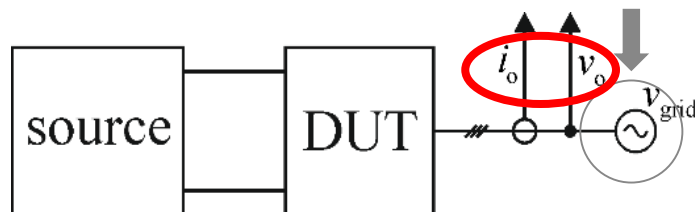
Control and Stability of VSC-Interfaced Devices



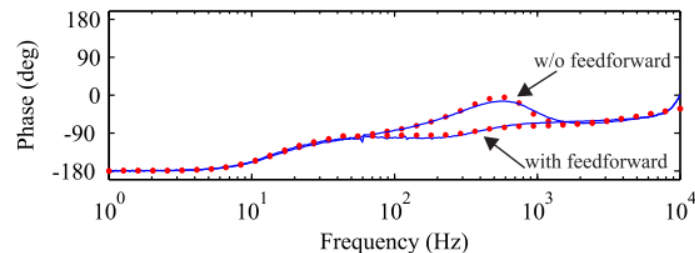
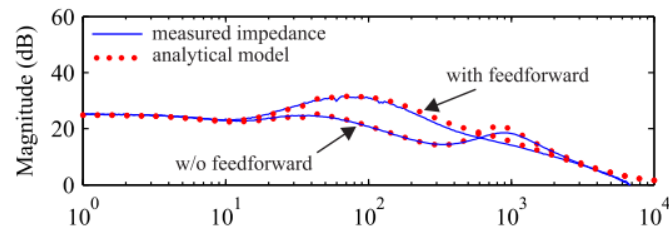
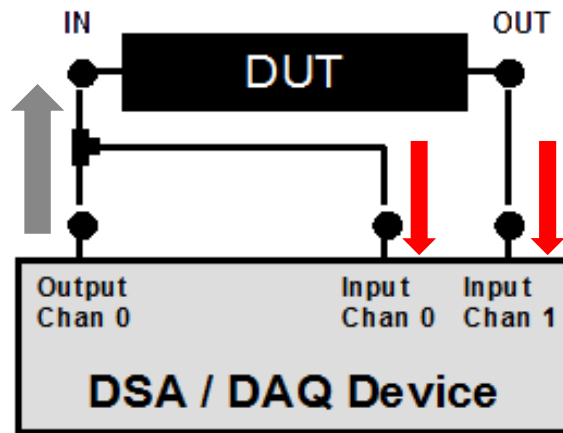
<https://research.tue.nl/en/publications/the-impact-of-voltage-source-converters-control-on-the-power-syst>



Concept of Input-admittance Measurement



Measurement setup – 10 kW DUT



Source: courtesy of Tampere University of Technology, Finland.



Wind Turbine Generator

Input admittance measurement

CHIL and PHIL Testbench

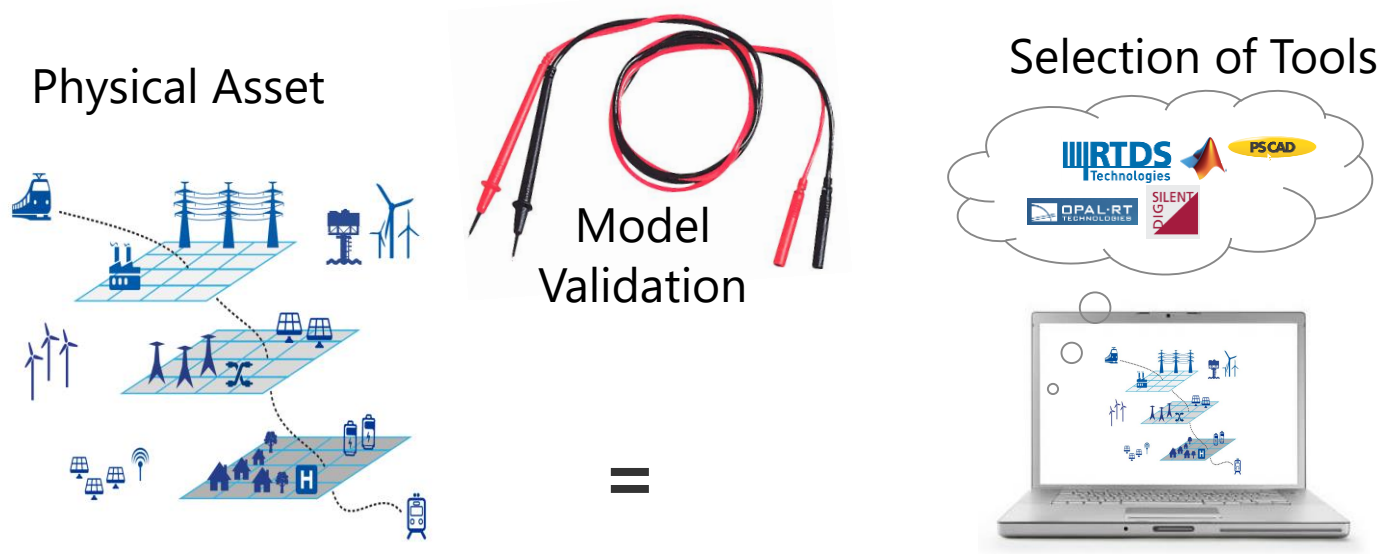


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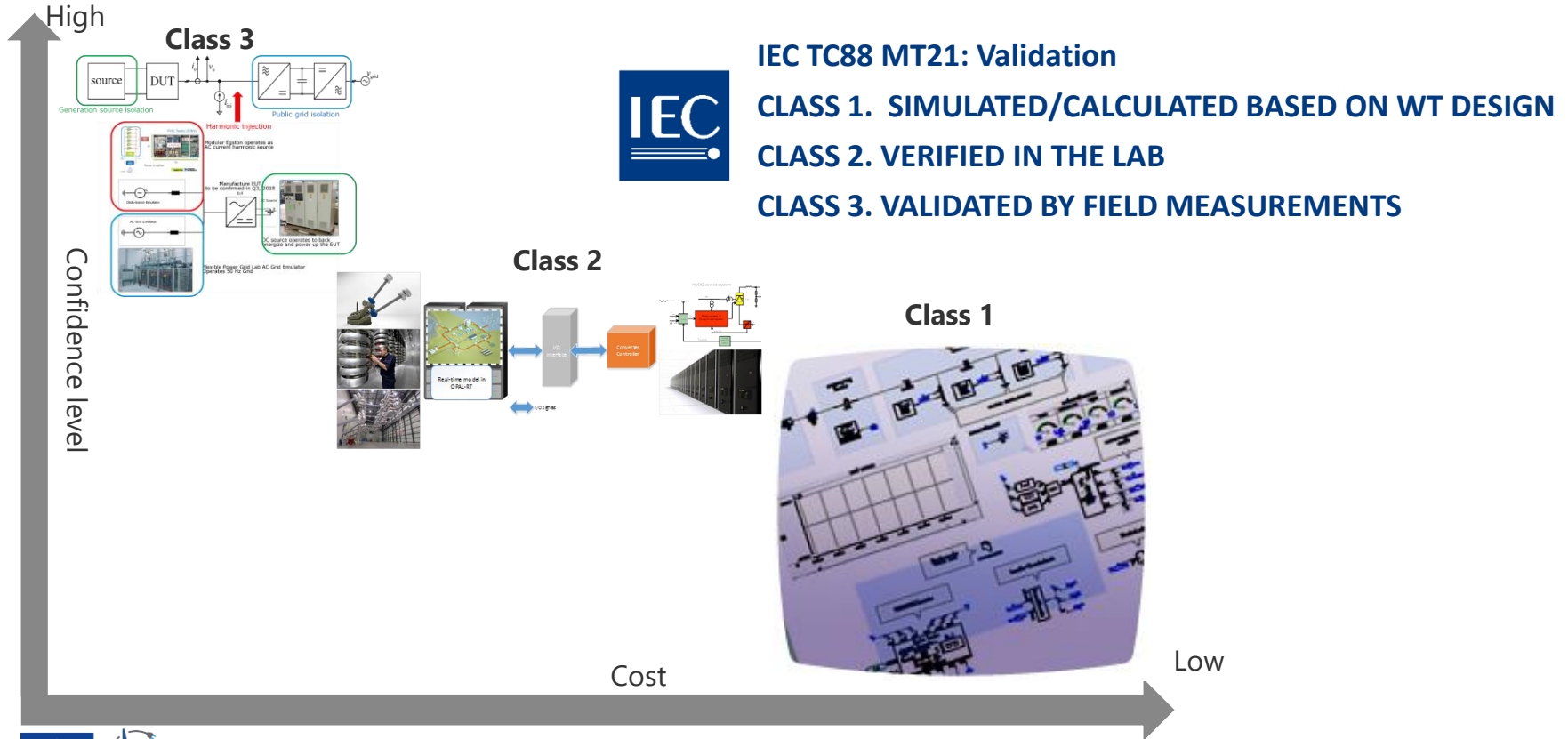
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Demo Objectives

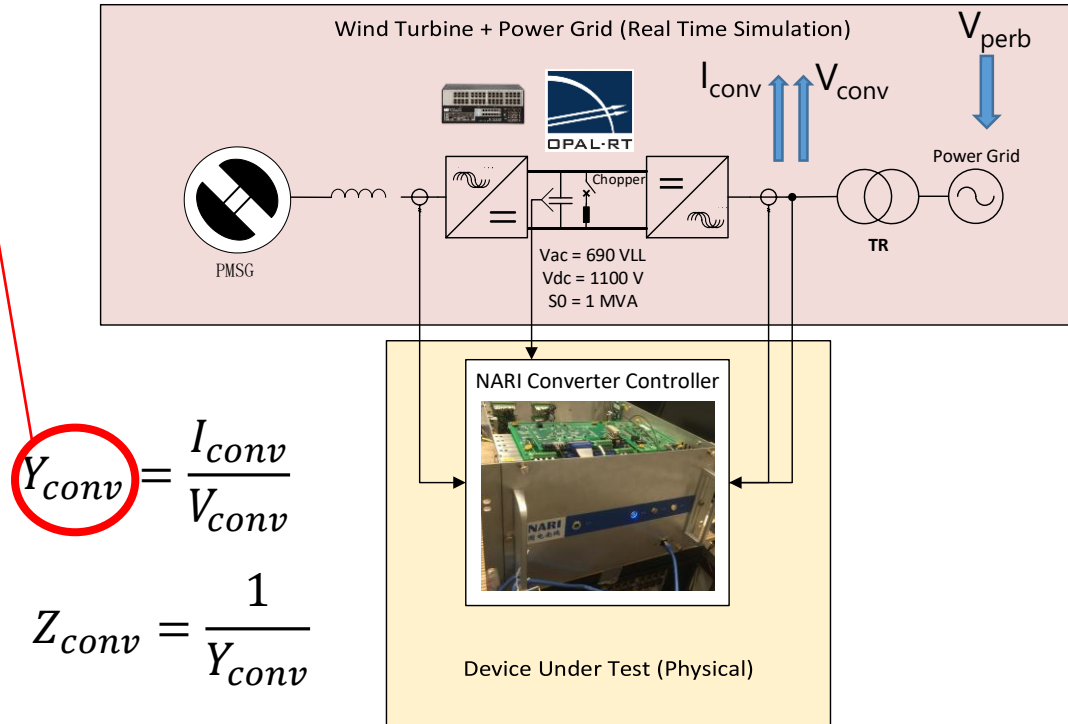
1. Assess active component without opening the “blackbox” (manufacture IP)
2. Compare CHIL and PHIL Input-Admittance Measurement Results



Model Validation – Classification

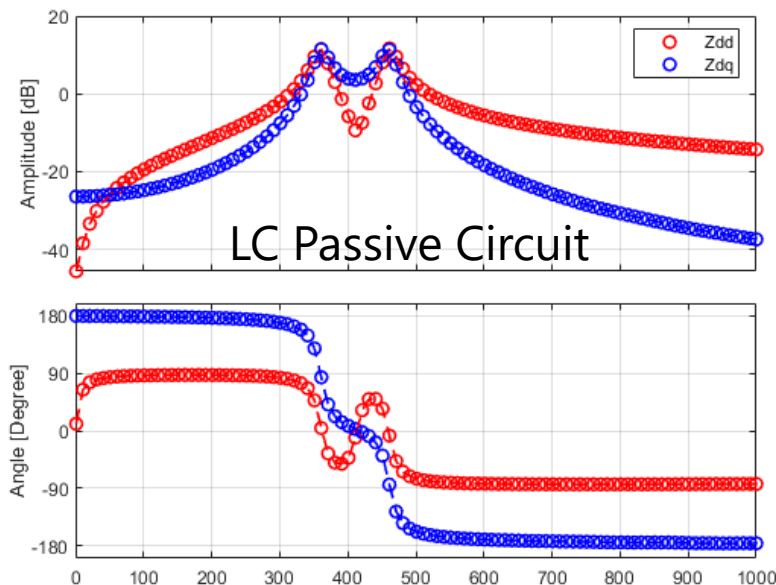
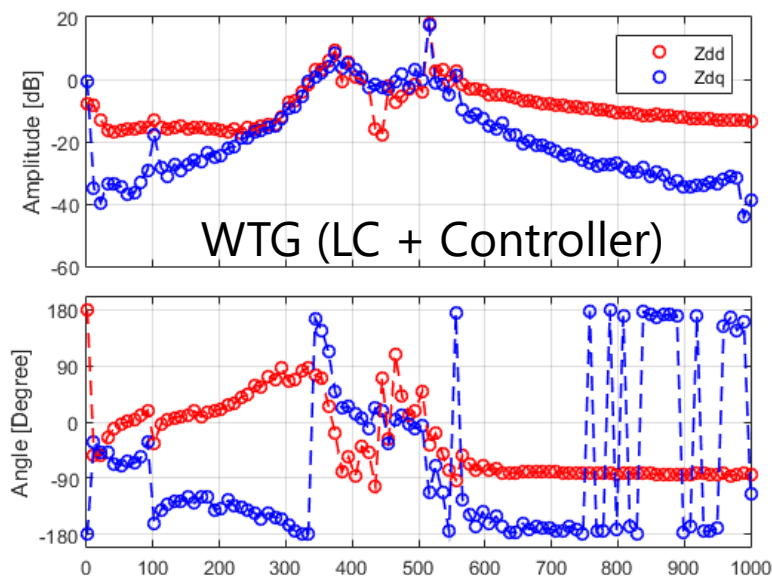


Input-admittance CHIL Test Setup



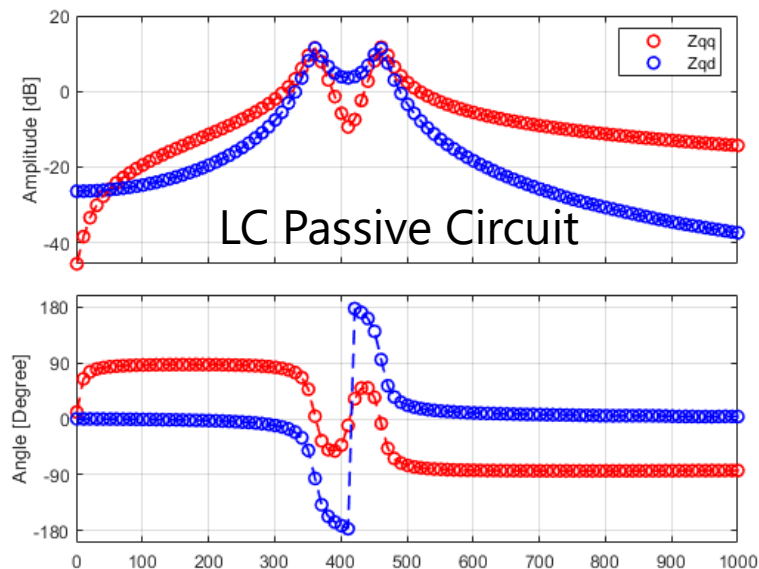
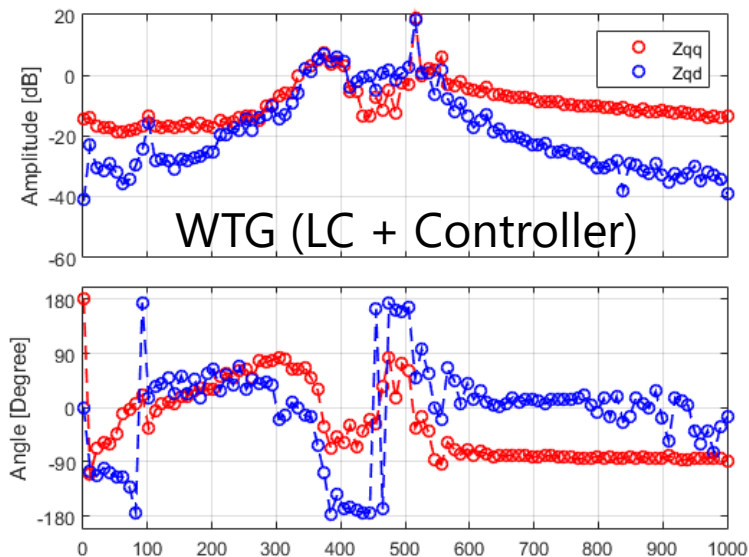


Results – WTG CHIL Measurement (WTG versus LC)



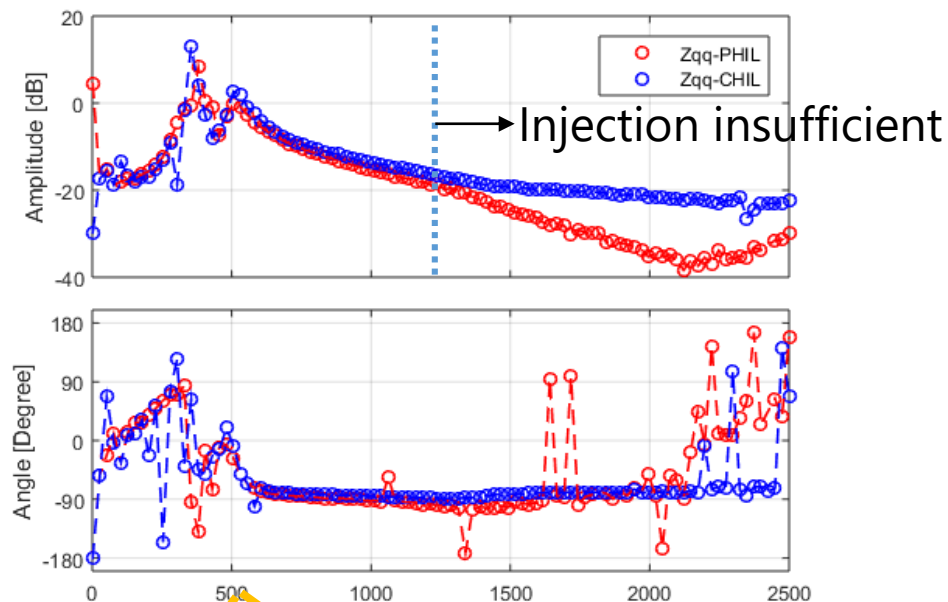
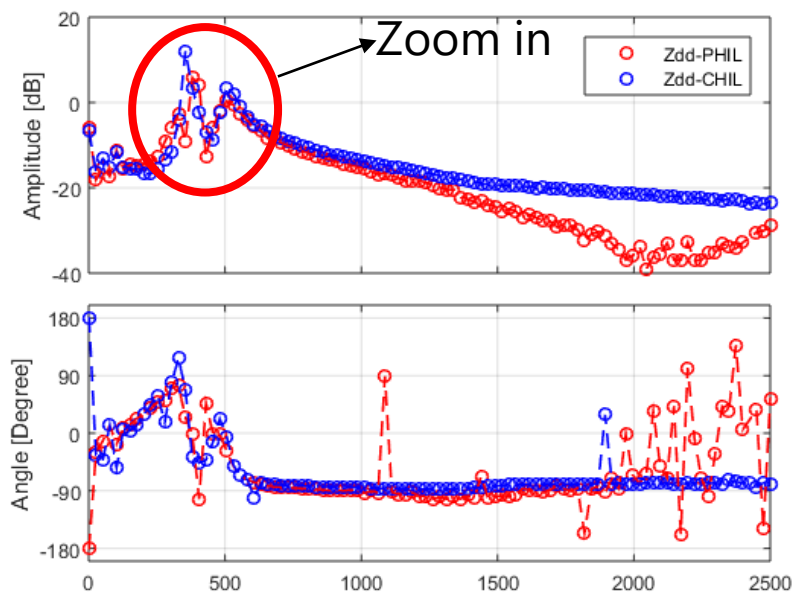
$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \underbrace{\begin{bmatrix} Y_{dd}(s) & Y_{dq}(s) \\ Y_{qd}(s) & Y_{qq}(s) \end{bmatrix}}_{Y_{icl,dq}^m} \begin{bmatrix} E_d \\ E_q \end{bmatrix}$$

Results –CHIL Measurement (WTG versus LC)



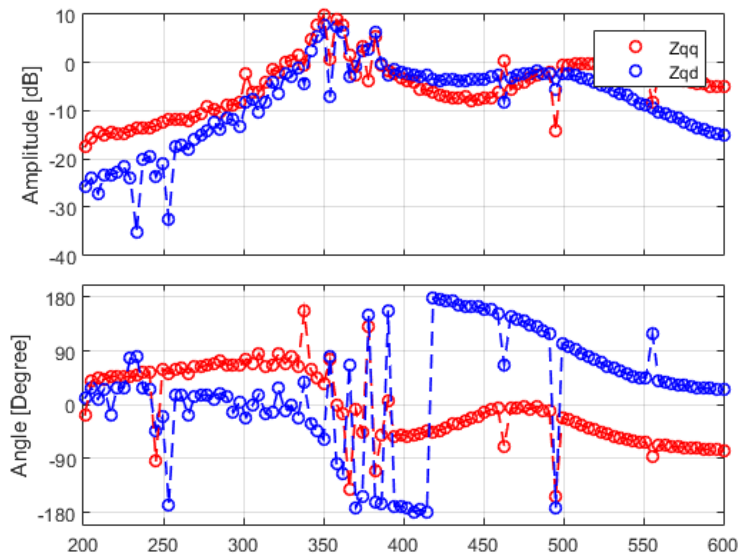
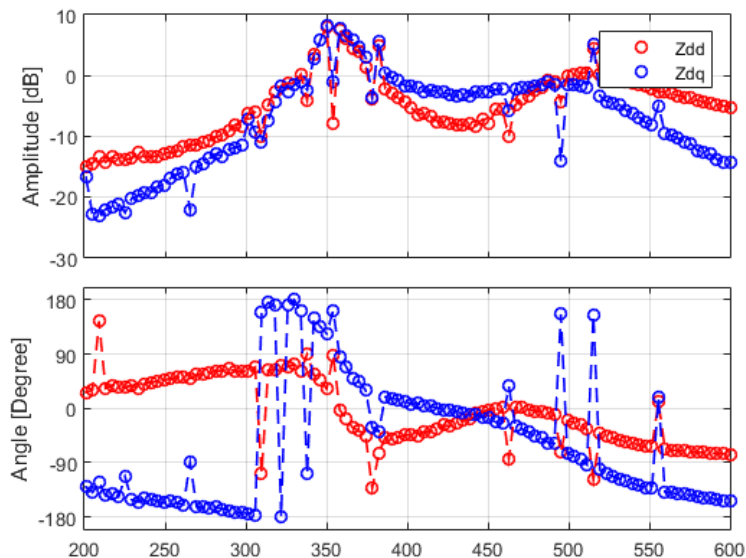
$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \underbrace{\begin{bmatrix} Y_{dd}(s) & Y_{dq}(s) \\ Y_{qd}(s) & Y_{qq}(s) \end{bmatrix}}_{Y_{icl,dq}^m} \begin{bmatrix} E_d \\ E_q \end{bmatrix}$$

Results – PHIL Measurement



$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \underbrace{\begin{bmatrix} Y_{dd}(s) & Y_{dq}(s) \\ Y_{qd}(s) & Y_{qq}(s) \end{bmatrix}}_{Y_{icl,dq}^m} \begin{bmatrix} E_d \\ E_q \end{bmatrix}$$

Results – PHIL Measurement



$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \underbrace{\begin{bmatrix} Y_{dd}(s) & Y_{dq}(s) \\ Y_{qd}(s) & Y_{qq}(s) \end{bmatrix}}_{Y_{icl,dq}^m} \begin{bmatrix} E_d \\ E_q \end{bmatrix}$$

Summary – Answer to the Objectives

1. **Assess active component without opening the “blackbox” (manufacture IP)**
 - Impedance measurement is identified as an effective method for the characterization of grid-connected VSC to prepare the grid for the electrification of future energy system.
2. **Compare CHIL and PHIL Input-Admittance Measurement Results**
 - CHIL has good match with PHIL for the mid and low range frequency
 - For high frequency range (above 1500 Hz), PHIL suffers from the measurement uncertainty as well as inability to inject sufficient perturbation from a current source coupling to the circuit through a transformer.
 - Verification of PHIL is necessary to provide confidence of using CHIL setup only.

Aalborg University is acknowledged for their pioneering work in the impedance-based stability analysis. Special thanks goes to Prof. Xiong Fei Wang, Dr. Dong Sheng Yang, Dr. Xiaolong Yue, Prof. Frede Blaaberg.



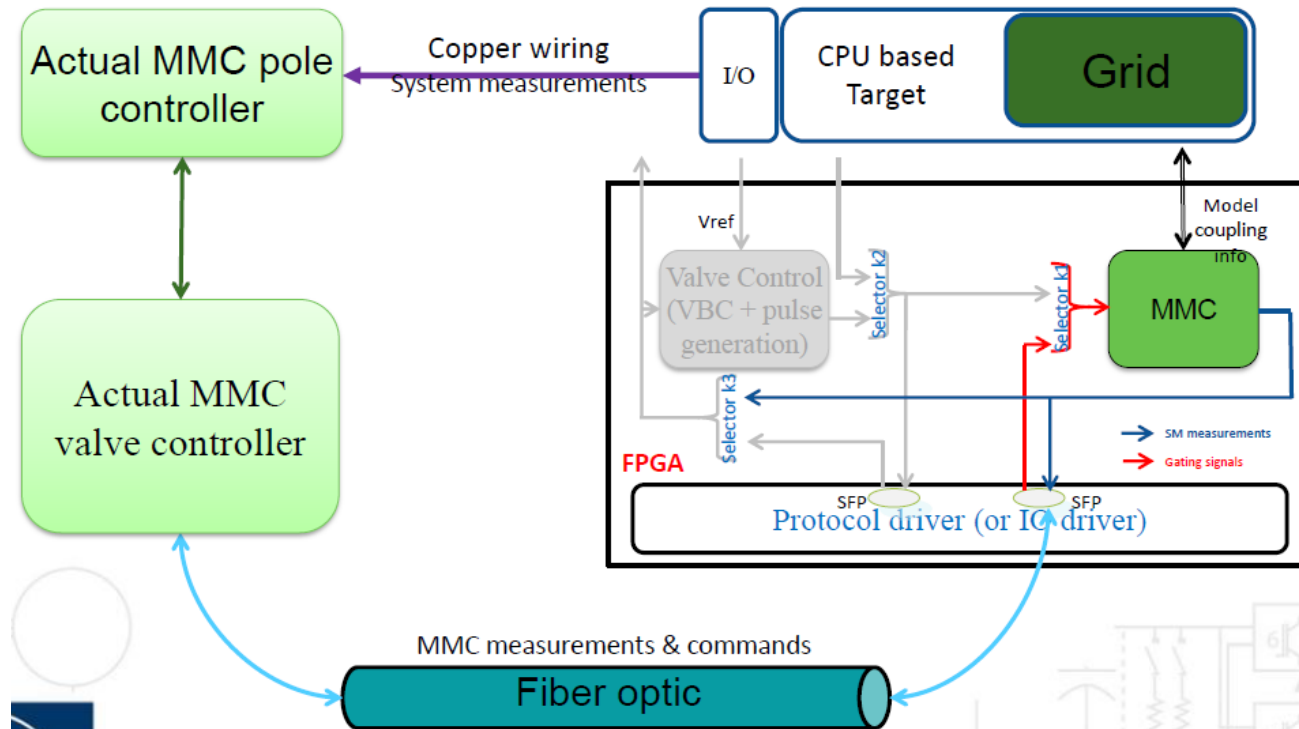


MMC HVDC CHIL Testbench

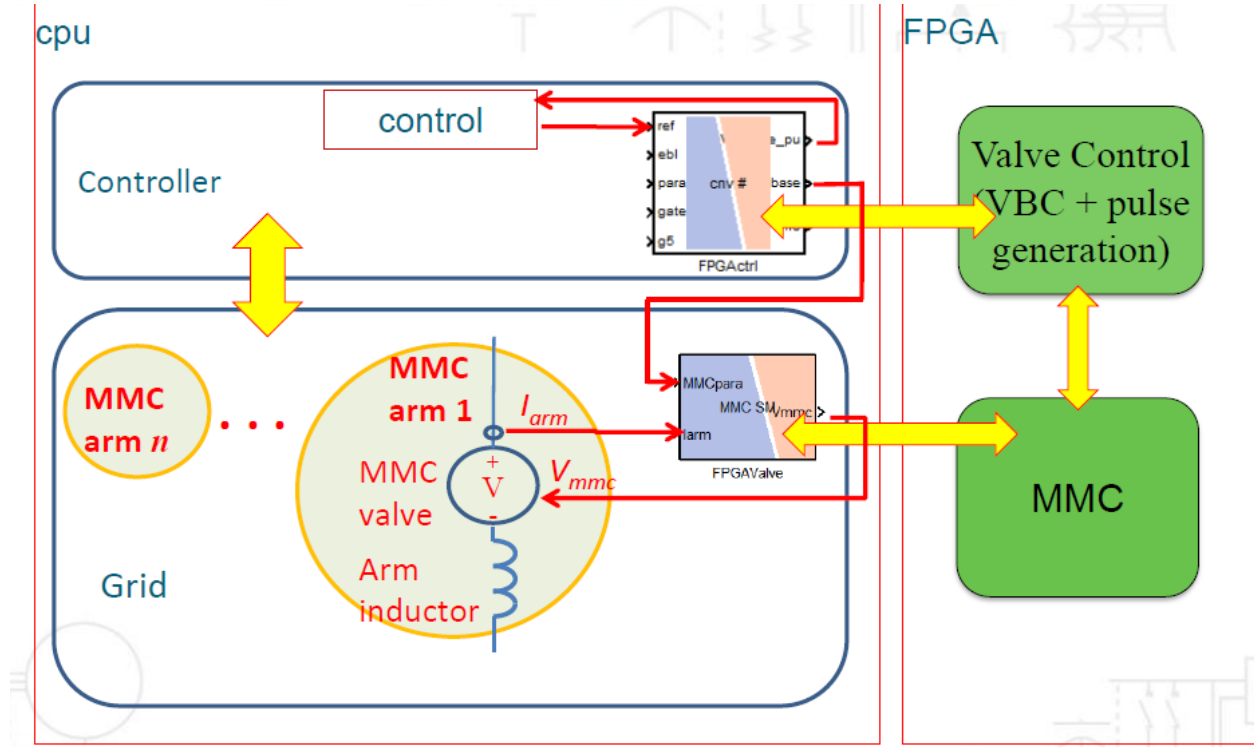


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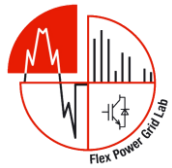
Concept of CHIL Test for MMC-based HVDC/FACTS



Concept of CHIL Test for MMC-based HVDC/FACTS

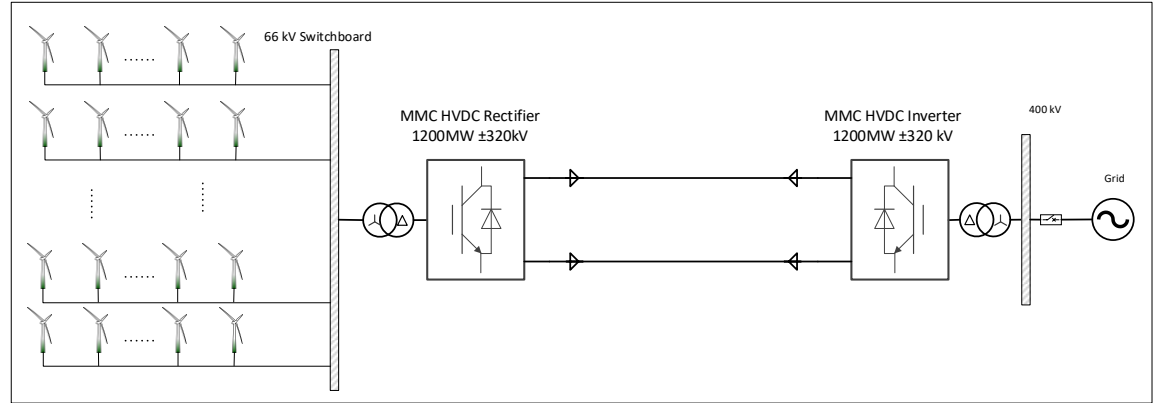


Objectives



Unit MMC resonance performance test

- Small signal perturbation test (injecting harmonic currents)
- Unit MMC converter operated as inverter/rectifier
- Validate the frequency domain performance measurement against theoretical models

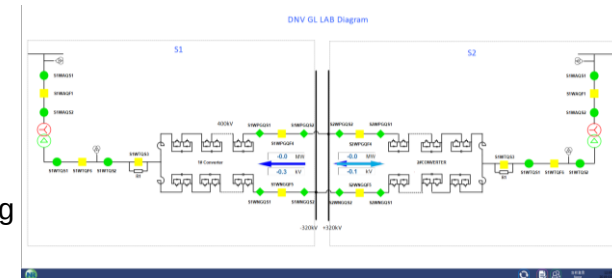


Offshore Wind Park (DC connection) Harmonic Resonance Analysis

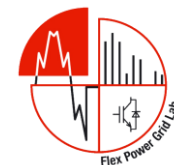
- Using WTG controller scaled up to represent the whole park
- Investigate system level risk of harmonic resonance
- Covering different operation states, e.g. number of connected wind turbines/collector radials, different power levels etc.

AC Grid Support (Optional)

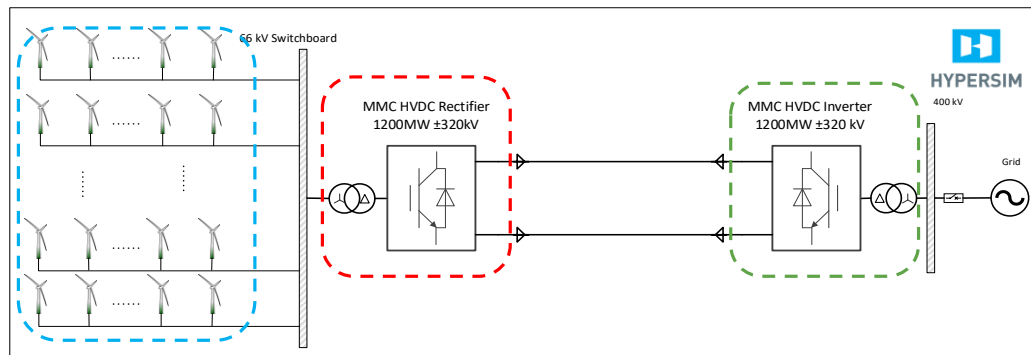
- Fault Ride Through (FRT) testing
- Frequency Support testing
- Power Oscillation Damping (POD) testing



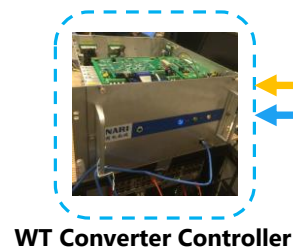
Demo 2.1 MMC HVDC CHiL Test bench



VBC – Valve Base Control
PCP – Pole Control & Protection



↔ Digital signals
 ↔ Analog signals



WT Converter Controller

Station 1



OP 5700

PCIe



OP 7000



VBC



PCP1



PCP2

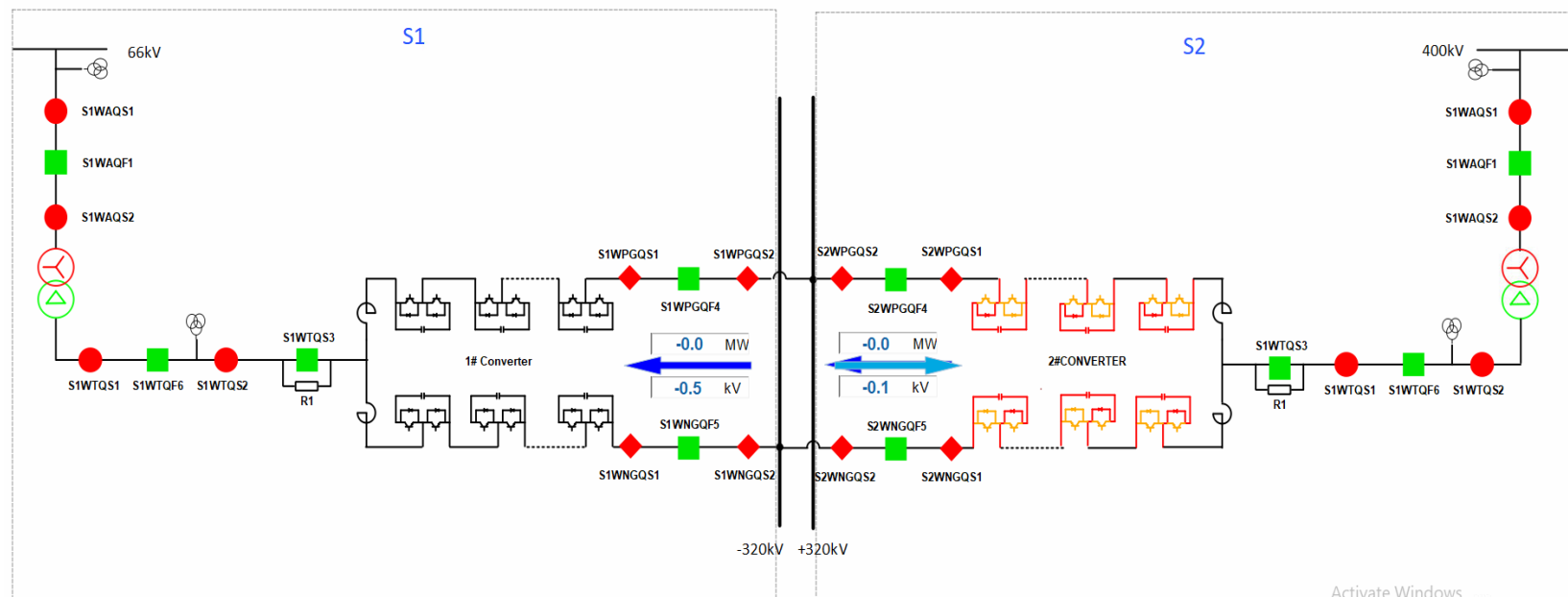
Station 2



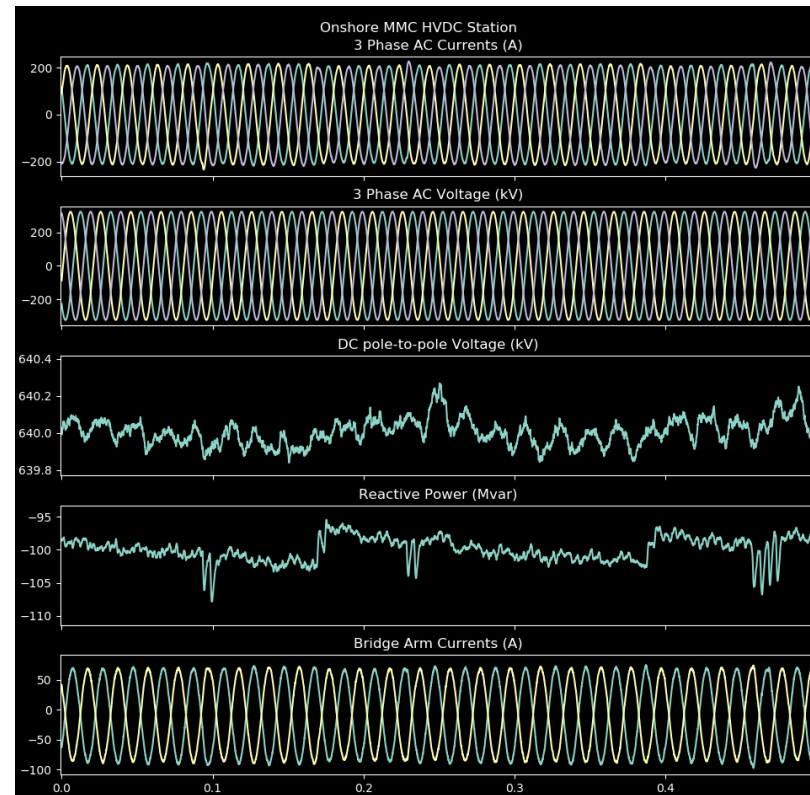
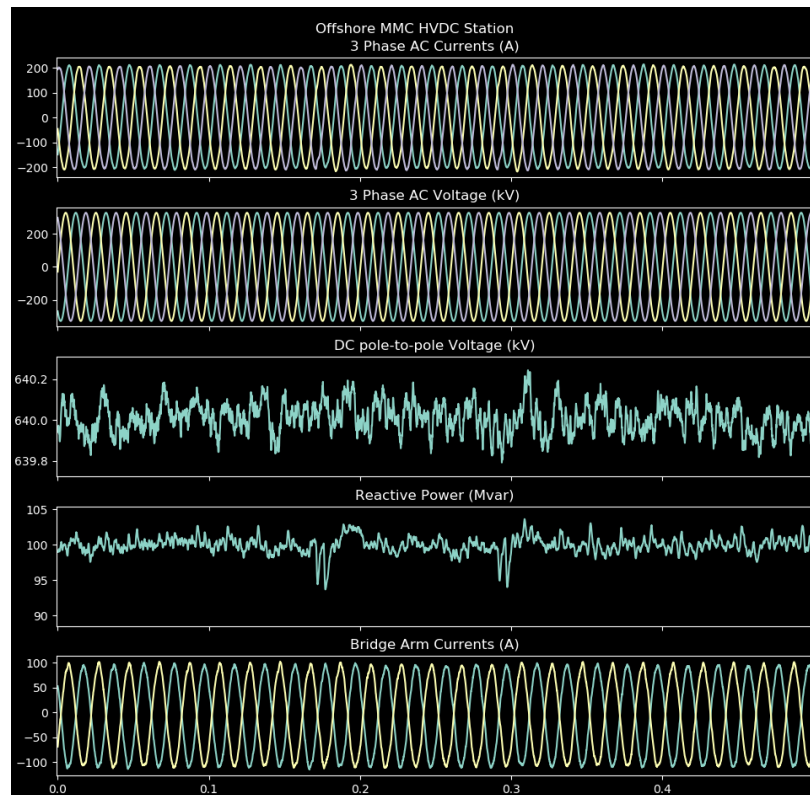
Diagram from the NREC SCADA



DNV GL LAB Diagram



CHIL Measurement Results on Both HVDC Station



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