

WP16

MMC Test Bench Demonstrator – Introduction

Demonstration of Converter & Controller
Model Validation

15.08.2019 – Arnhem

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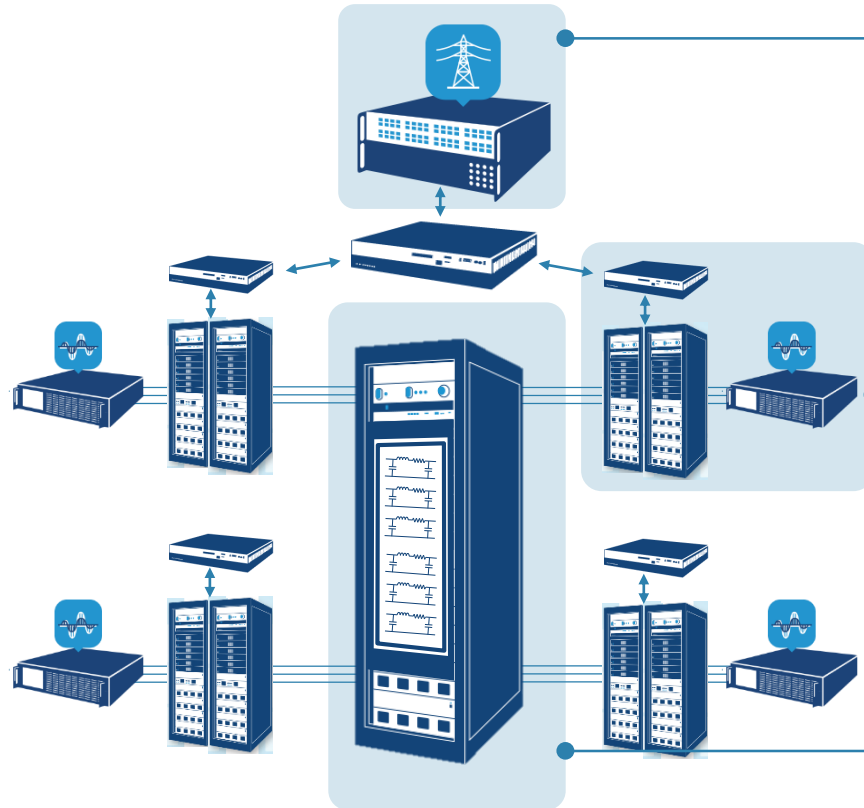


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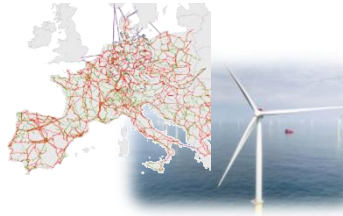
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MMC Test Bench Overview



AC system and component modelling



Source: www.windpoweroffshore.com

- OP5707 real-time simulator for AC grids (up to 3000 nodes) and wind farms
- OP4510 real-time simulator as DC grid controller
- 4x Puissance Plus power amplifiers (21 kVA, 4-Q operation, -3 dB at 50 kHz)

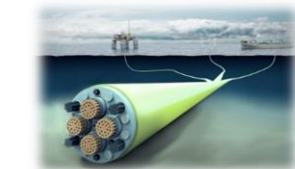
MMC converter stations



Source: ABB

- Hardware representation of Modular Multilevel Converters with half-/full-bridge submodules (10 levels per converter arm) at laboratory scale: $V_{dc,r} = 400 \text{ V}$, $I_{dc,r} = 15 \text{ A}$
- Possibility to investigate DC grids with up to 8 converter stations in sym. monopole or up to 4 converter stations in bipolar configuration

DC-line models



Source: www.offshore-technology.com

- 32x Pi-Line models
- Up to 800 km in bipolar grid configuration
- Up to 1,600 km in monopolar grid configuration
- Different DC topologies can be represented with hardware components at laboratory scale

MMC Test Bench

Lab Setup



MMC Test Bench

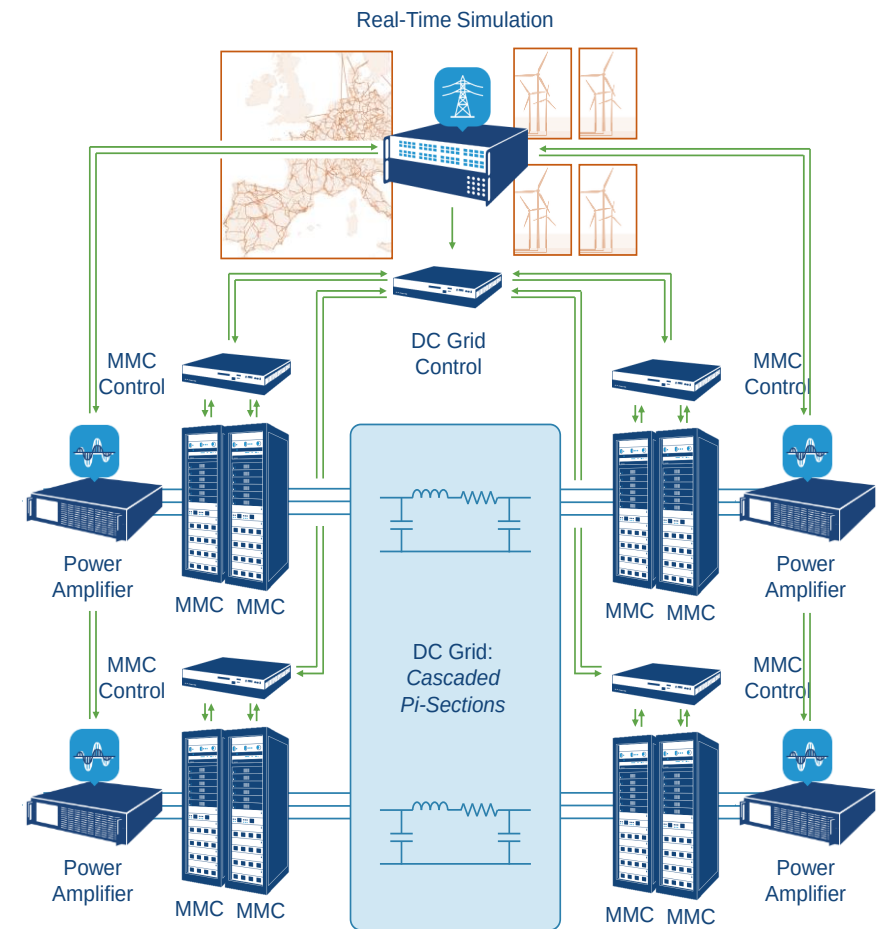
Parameters

Detailed description of MMC Test Bench:

- Converters, transmission line, transformers, ...
- Real-Time Simulators
- Power Amplifiers
- Laboratory Facilities

➤ Update after commissioning of the MMC Test Bench lab

Nominal DC Voltage	$V_{DC,n}$	400 V
Nominal DC Current	$I_{DC,n}$	15 A
Nominal Output Power	$P_{DC,n}$	6 kW
Nominal AC Voltage per phase	$V_{AC,1}/V_{AC,2}$	400/208 V (3ph-LL)
Nominal AC RMS current at fundamental frequency	I_{AC}	16.7 A
MOSFET Switching Frequency	f_{sw}	0-10 kHz
Number of Cells (Submodules)	n_{SM}	10
Nominal Cell Voltage	$V_{c,n}$	40 V
Cell Capacitor	C_{SM}	4.92 mF
Arm inductor	L_{Arm}	2.5 mH



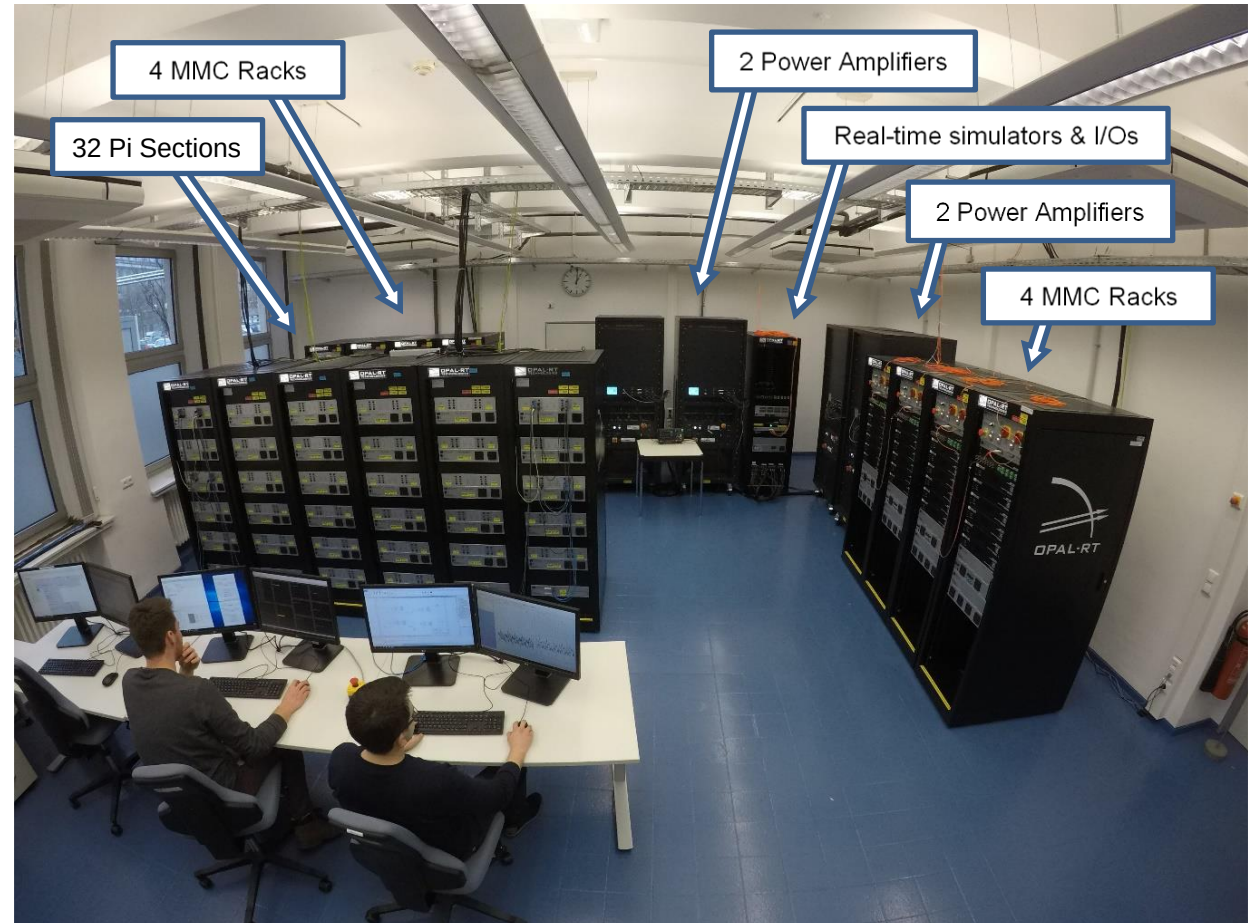
MMC Test Bench

Accomplishments:

- ✓ Physical assembly completed
- ✓ Tested with RWTH/PROMOTiON controls
- ✓ First Power-Hardware-in-the-Loop (PHiL) tests completed
- ✓ Milestone M75: First comparison between MMC Testbench and Simulations

Ongoing Work

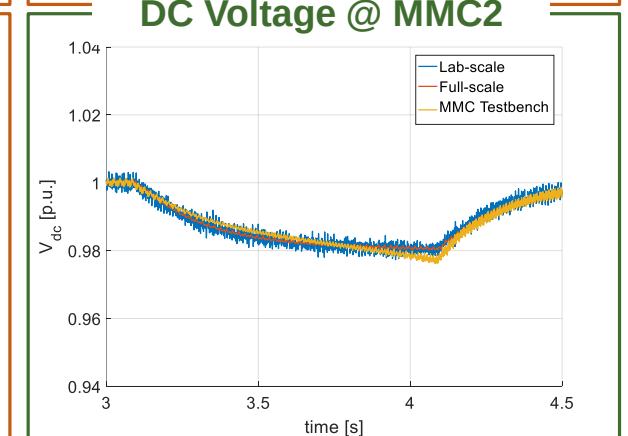
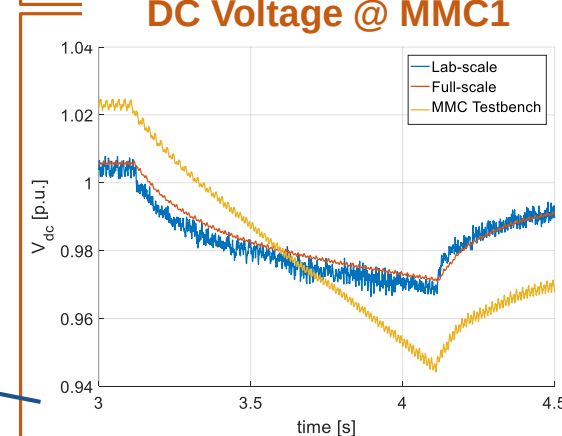
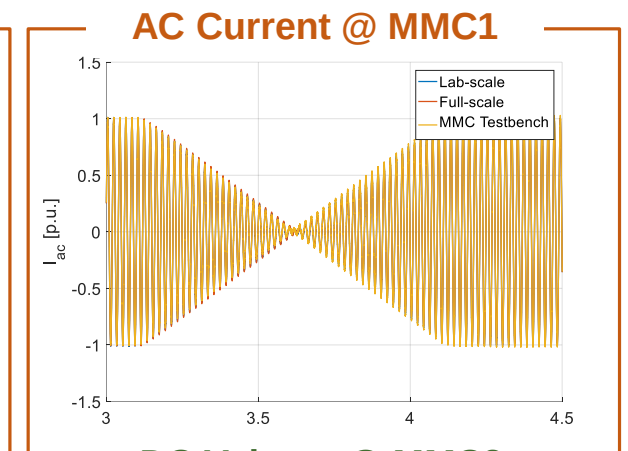
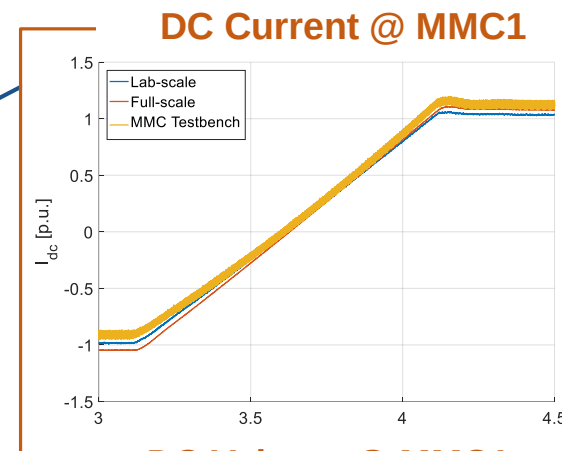
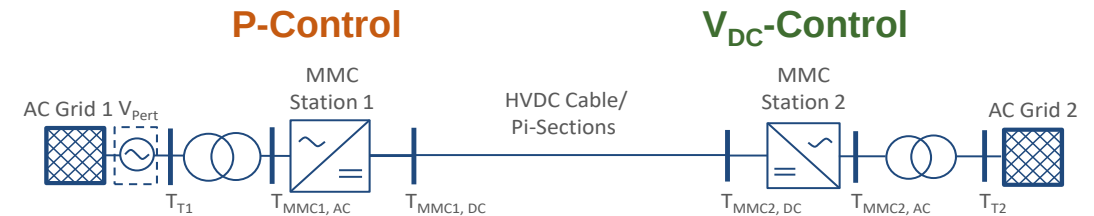
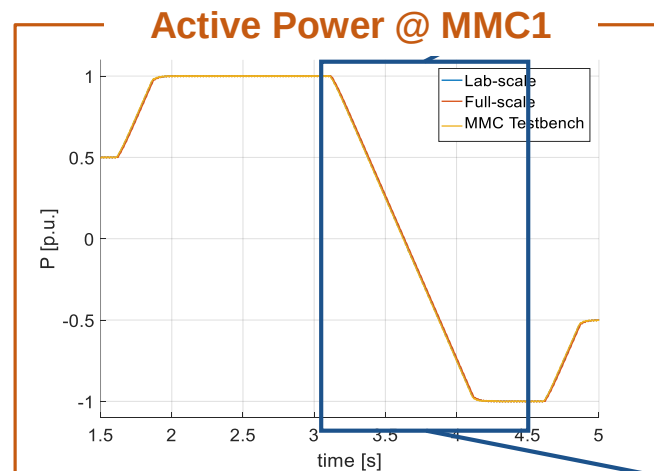
- Investigation of PHiL methods for OWP integration
- Integration of AC grid data to RTS (OWP and AC transmission grids)
- Impedance measurement of the MMCs
- **Testcases defined in D16.1**



Active Power Set-Point Change

First Test Results of the MMC Test Bench

- First test results with the MMC Testbench
- Comparison between simulation and MMC Testbench
- Here: Exemplary set-point change in active power



Harmonic Stability Assessment



PROMOTioN
PROGRESS ON MESHED HVDC
OFFSHORE TRANSMISSION
NETWORKS



PROMOTioN Arnhem

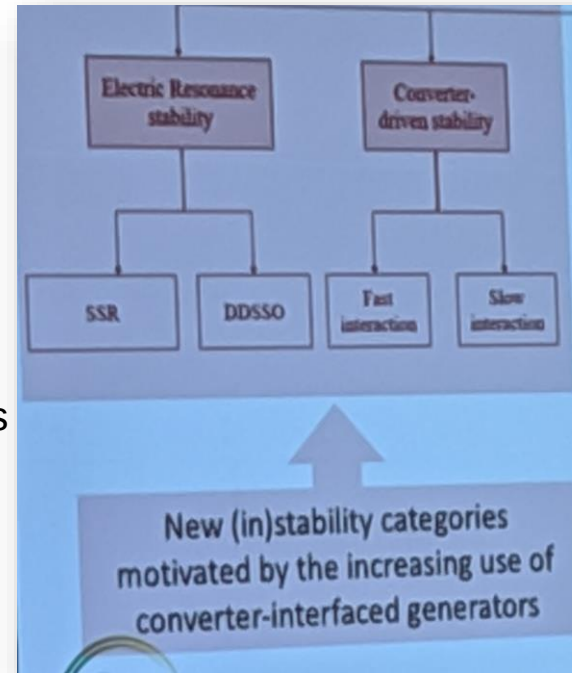
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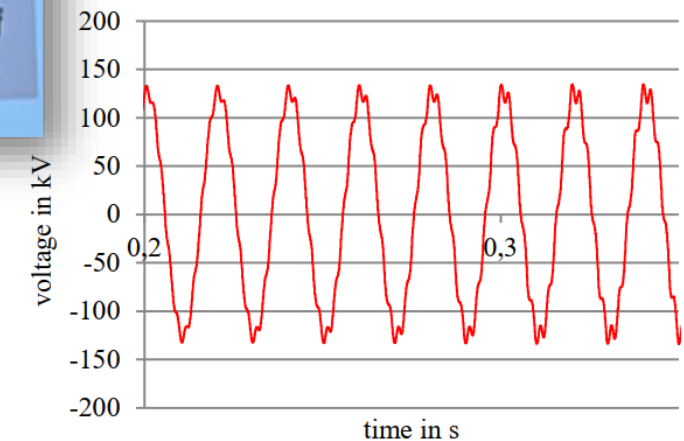
© PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks
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Harmonic Stability Assessment

- Sustained oscillations have been observed in power systems with VSCs
 - VSC and AC grid
 - Offshore HVDC link and wind farm
 - Related to resonance interactions
 - Caused by interactions of a converter controllers with grid resonance
 - Not to be mistaken as steady state harmonics
- Often referred to as harmonic instability
 - Converter driven stability



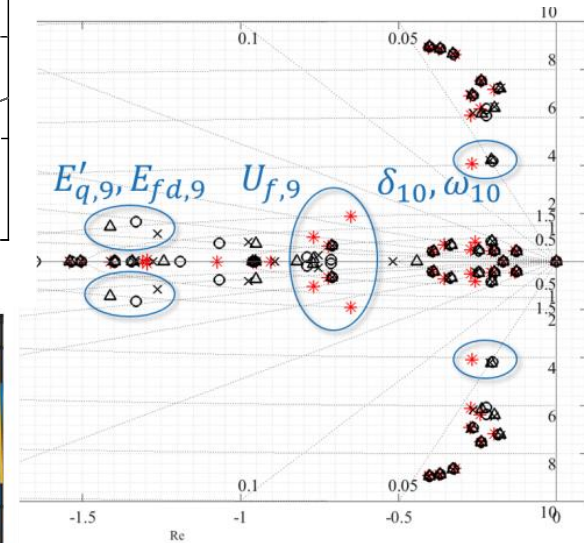
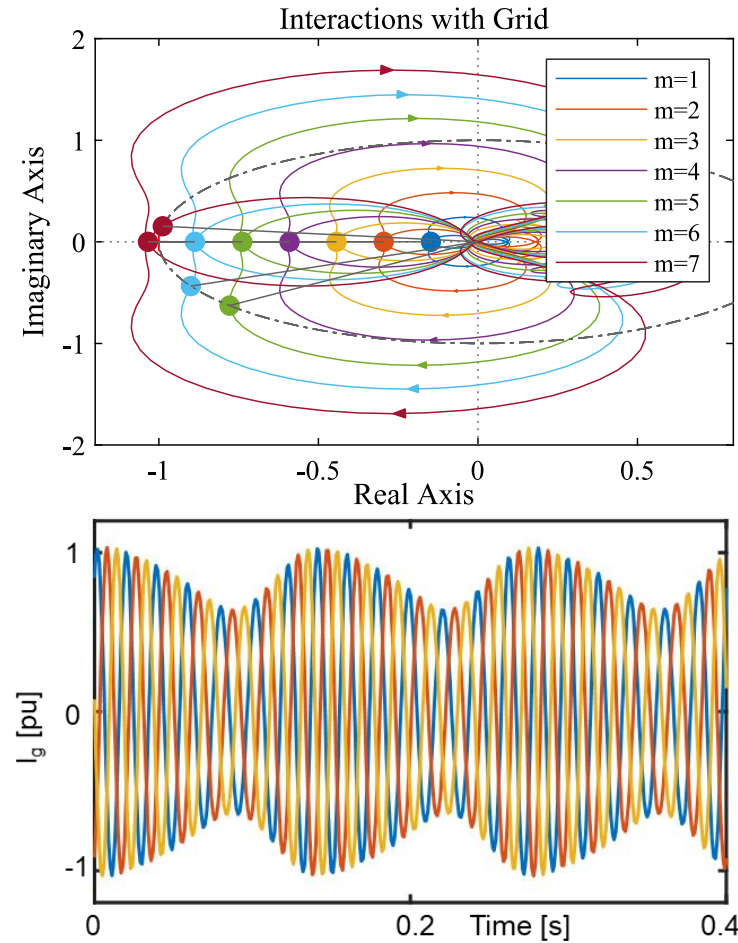
Source: PES General Meeting 2019, Atlanta



Source: TenneT

Harmonic Stability Assessment

- Stability analysis methods
 - State-space modeling
 - Time domain
 - Frequency domain
- No consensus yet which method is applicable
- Focus here on impedance-based approach



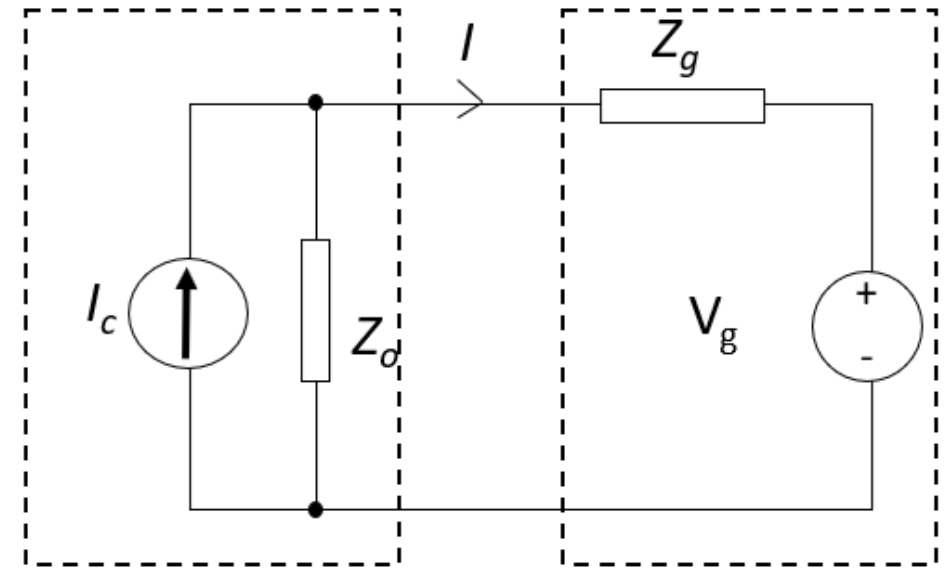
Harmonic Stability Assessment

Impedance-based approach

- Harmonic stability is assessed in the frequency domain
- System is modelled as two subsystems having frequency dependent impedances
- Stability is assessed by analyzing the loop gain $G_o(s)$ of the system:

$$I(s) = \left[I_c(s) - \frac{V_g(s)}{Z_o(s)} \right] \frac{1}{1 + \frac{Z_g(s)}{Z_o(s)}}$$

- System is stable if $G_o(s) = \frac{Z_g(s)}{Z_o(s)}$ satisfies Nyquist stability criterion



Harmonic Stability Assessment

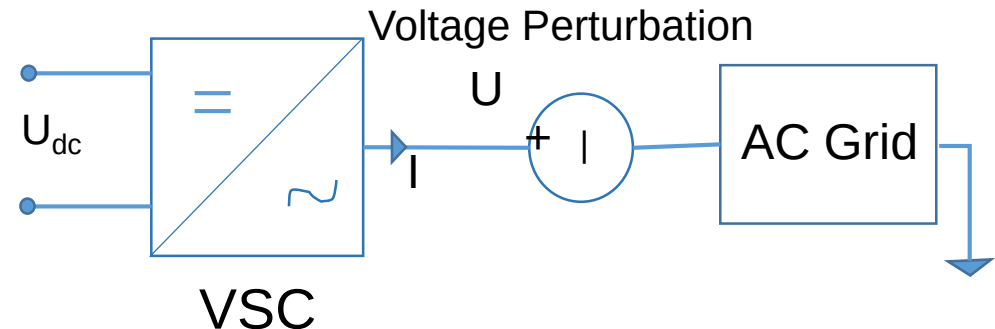
Analytically

- Impedance derived by linearizing MMC model including controls
- Gives insight about root causes of instabilities
- Full knowledge about converter & controllers needed

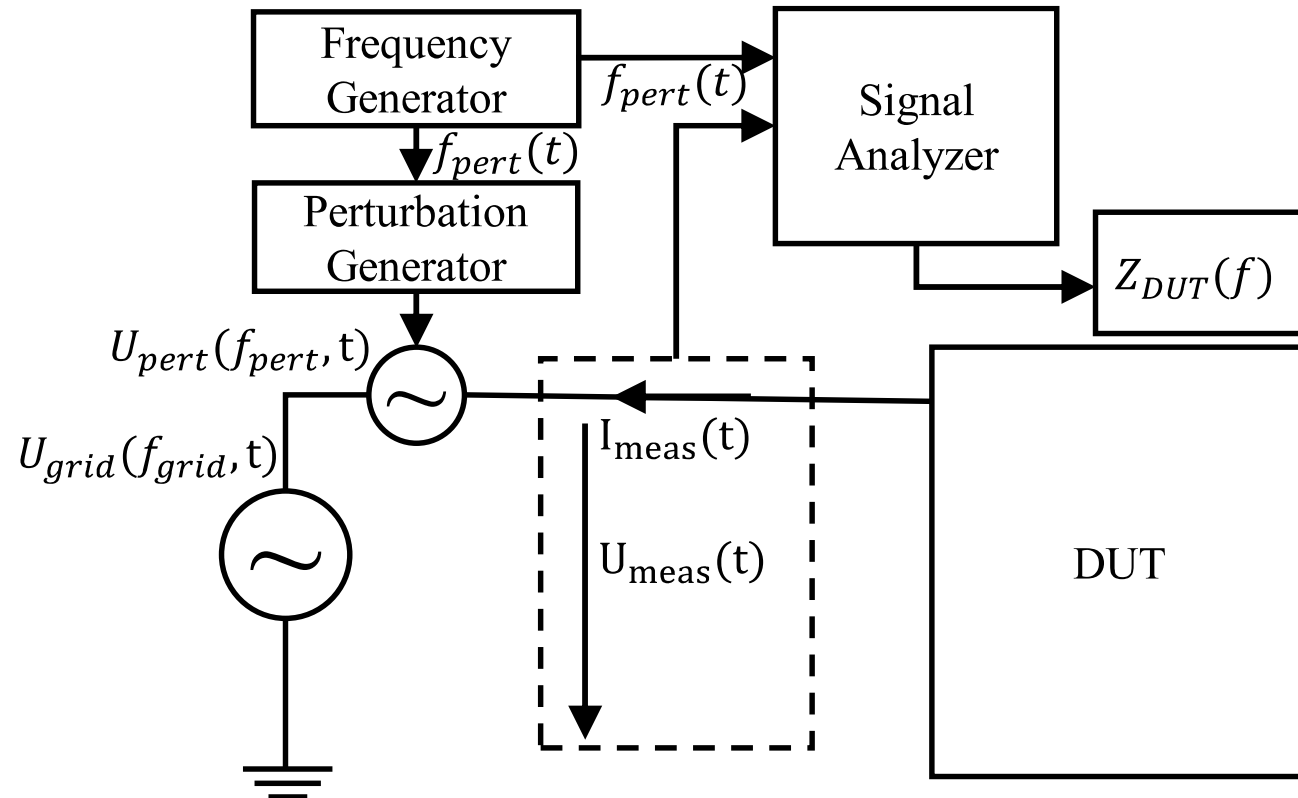
$$Z(s) = \frac{K_m V_{dc} [H_i(s - 2\pi f_1) - jK_d] + sL}{1 - K_m V_{dc} [(H_i(s - 2\pi f_1) - jK_d)I_1 + M_1]T_p(s - 2\pi f_1)}$$

Measurement based

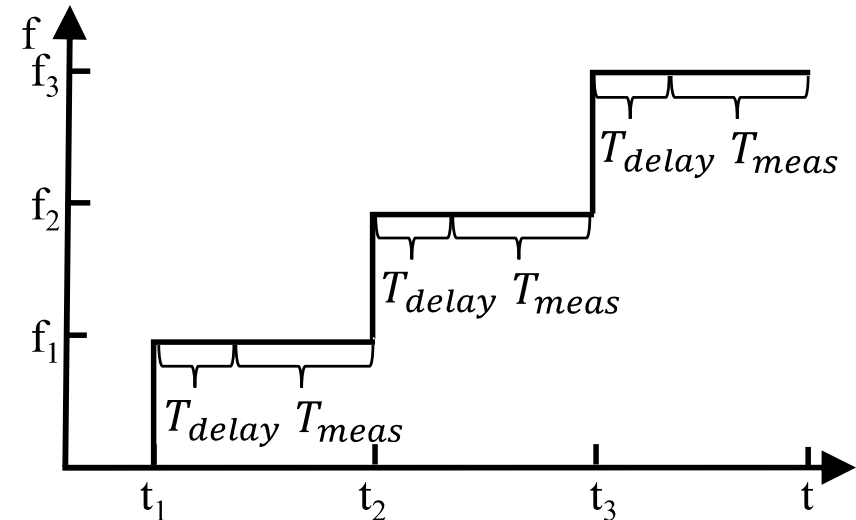
- Impedance derived by injecting perturbation voltages or currents
- Impedance given by $Z(j2\pi f) = \frac{U(j2\pi f)}{I(j2\pi f)}$
- Black box models can be applied
- Only valid for measured system



Impedance Measurement

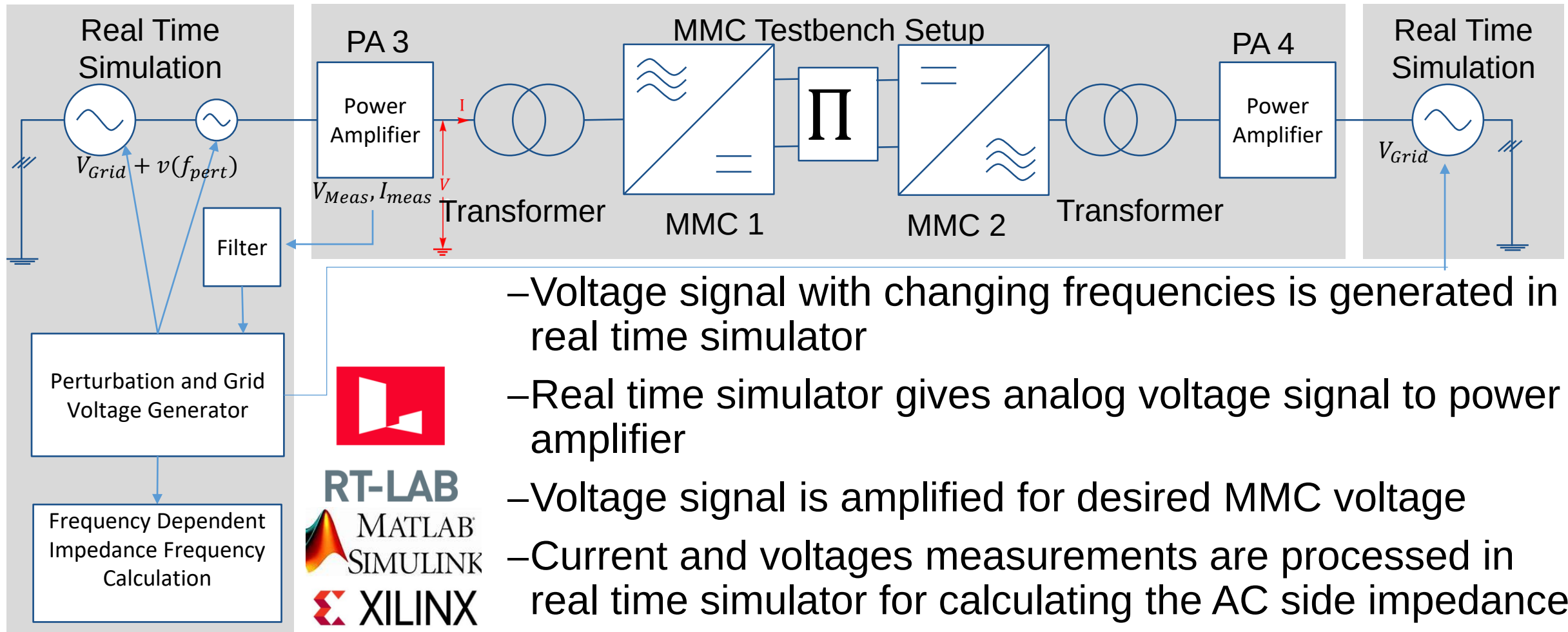


Source: Quester, Online Impedance Measurement of a Modular Multilevel Converter, ISGT 2019



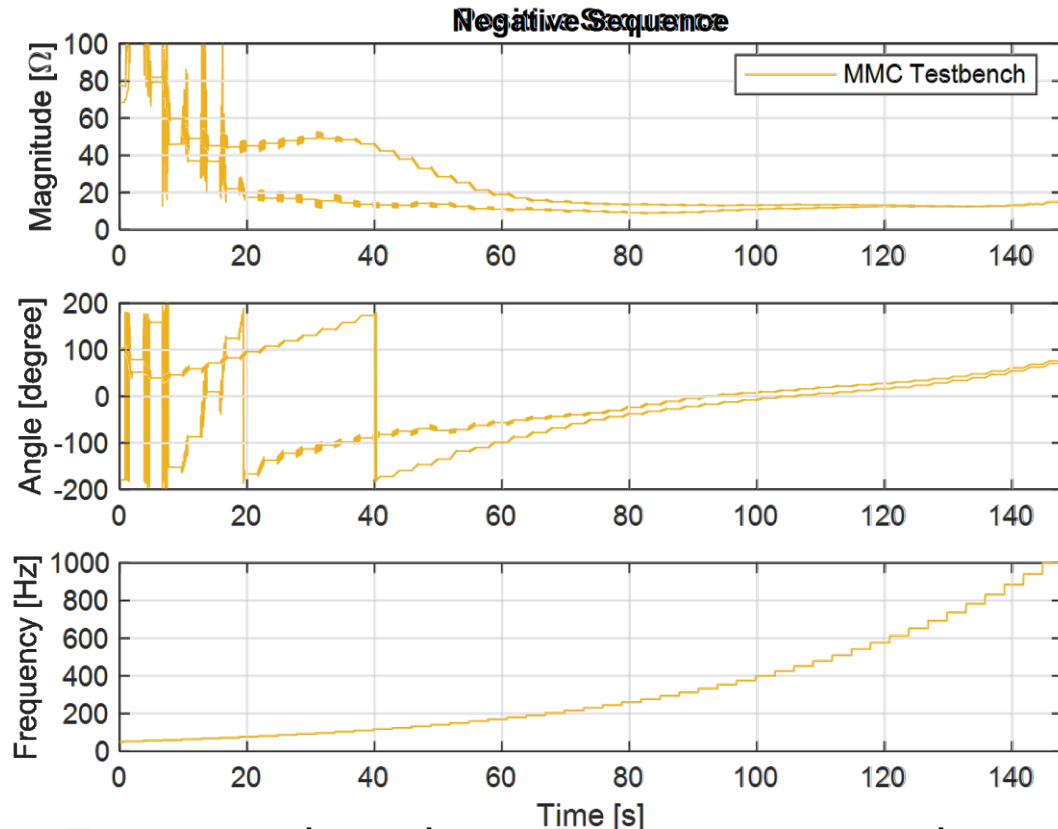
- Sequence of $f_{pert}(t)$ is generated and applied
- $U(t)$ & $I(t)$ measured and evaluated for $f_{pert}(t)$ for impedance calculation
 - Delay to wait until system is in steady state
- Impedance is calculated in real time
 - No need for further post-processing of data

MMC Impedance Measurement Setup

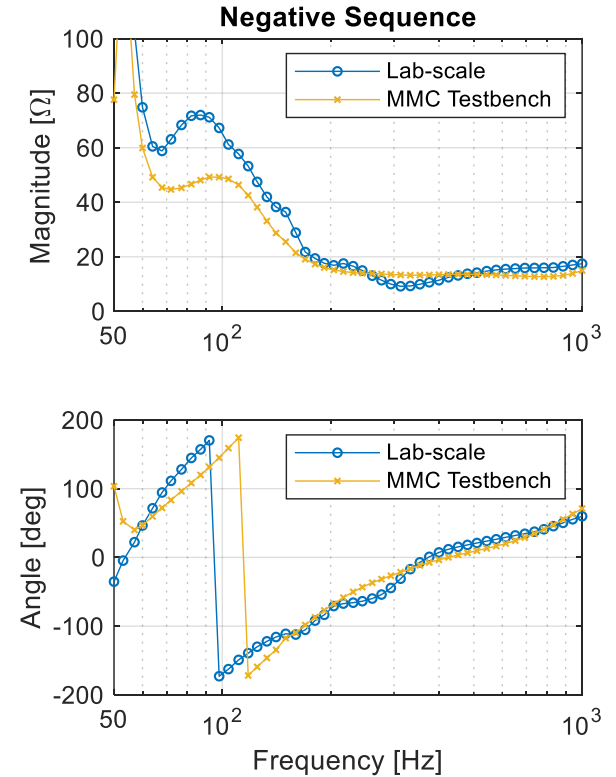
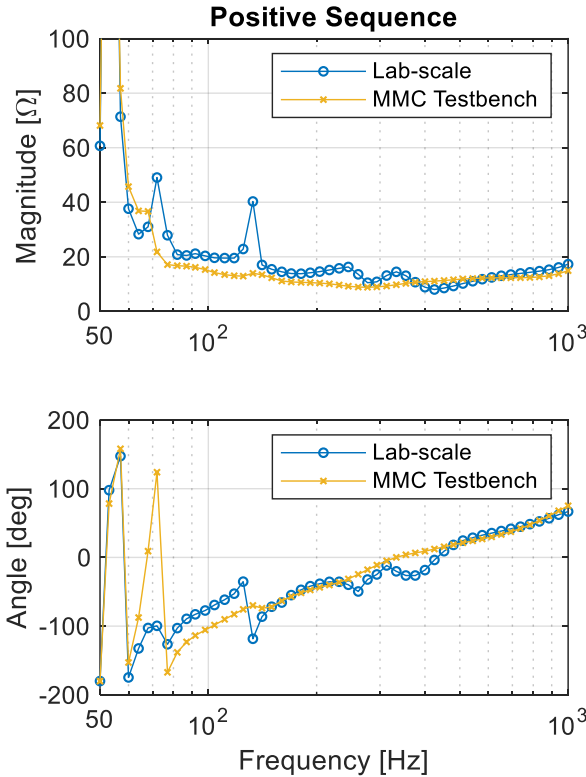


- Voltage signal with changing frequencies is generated in real time simulator
- Real time simulator gives analog voltage signal to power amplifier
- Voltage signal is amplified for desired MMC voltage
- Current and voltages measurements are processed in real time simulator for calculating the AC side impedance

Impedance Measurement: U_{DC} Control



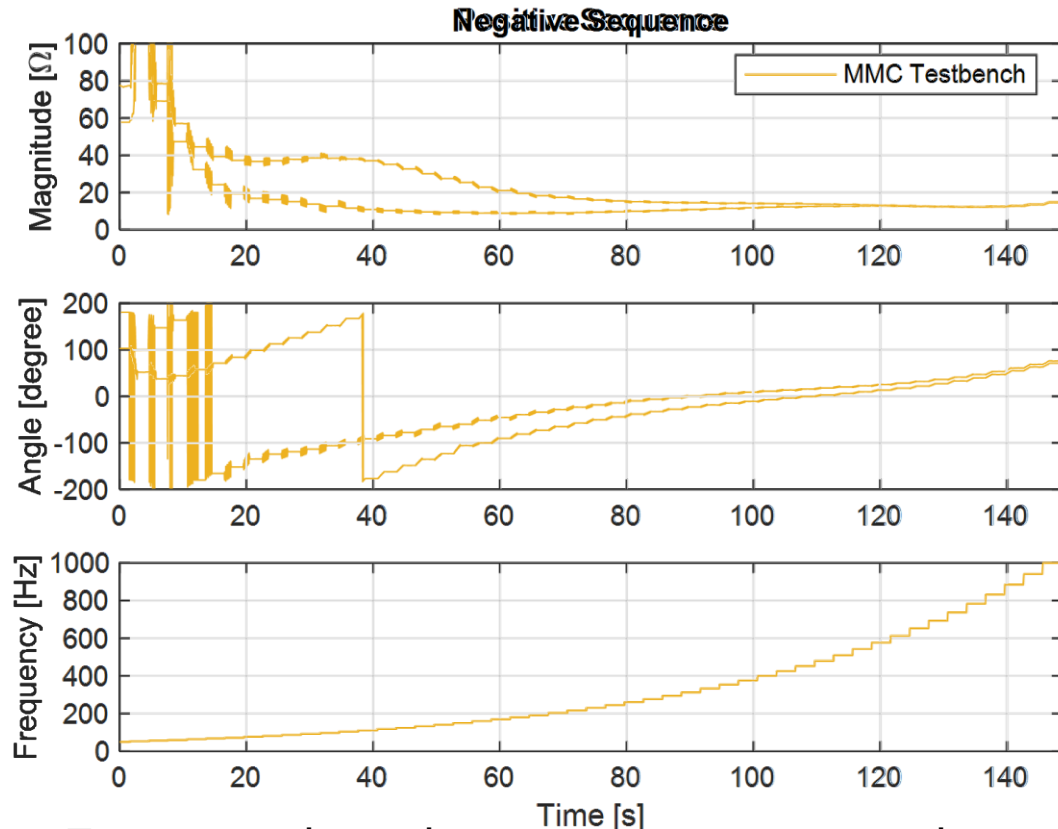
- Frequency impedance measurement settings
 - 50 Hz to 10 kHz with 50 measurement points,
 - FFT fundamental: 0.1 Hz; Measurement period: 3 s,
 - Data points based on mean of last 1.5 s for each perturbation frequency



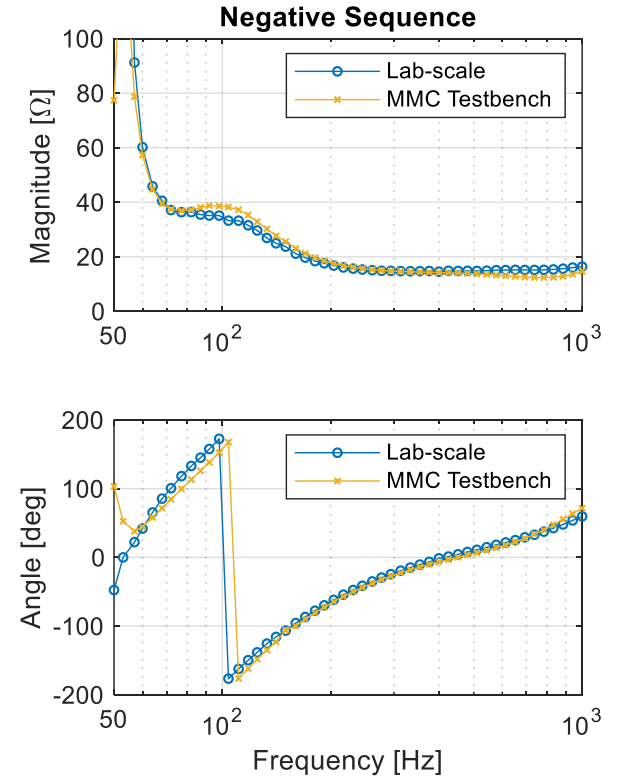
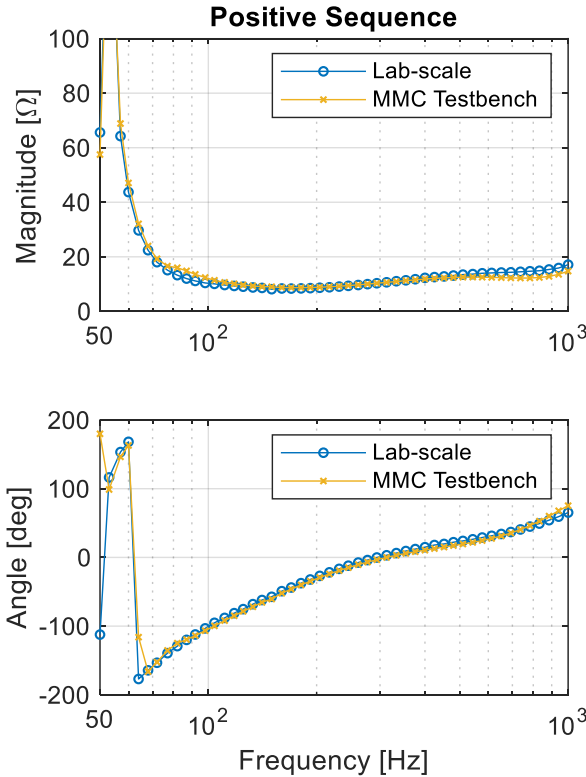
- MMC settings
 - IFHT control
 - $P = 3$ kW, $Q = 0$
 - PA 4 absorbs power
 - MMC 1 controls U_{DC} , MMC 2 controls P

Source: PROMOTiON MS 75

Impedance Measurement: P Control



- Frequency impedance measurement settings
 - 50 Hz to 10 kHz with 50 measurement points,
 - FFT fundamental: 0.1 Hz; Measurement period: 3 s,
 - Data points based on mean of last 1.5 s for each perturbation frequency



- MMC settings

- IFHT control
- $P = 3$ kW, $Q = 0$
- PA 4 absorbs power
- MMC 1 controls P , MMC 2 controls U_{DC}

Source: PROMOTiON MS 75

Now: Demos in the Lab



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APPENDIX

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