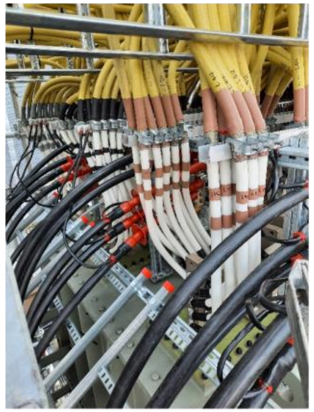
SIEMENS Gamesa
RENEWABLE ENERGY

Grid-Converter Test Rig

An Industrial Approach to Validation of Wind Energy Converter Systems



SGRE TE EL Grid Connection
October 2024

7th International Workshop on Grid Simulator Testing of Energy Systems and Wind Turbine Drivetrains

Fraunhofer
IWES

AGENDA

- INTRODUCTION G-CTR
  - SYSTEM SETUP
  - POWER HARDWARE & CONTROL
  - DYNAMIC TEST CAPABILITY
- PROJECT PLAN
- DETERMINATION OF HARMONIC CHARACTERISTICS
- OUTLOOK

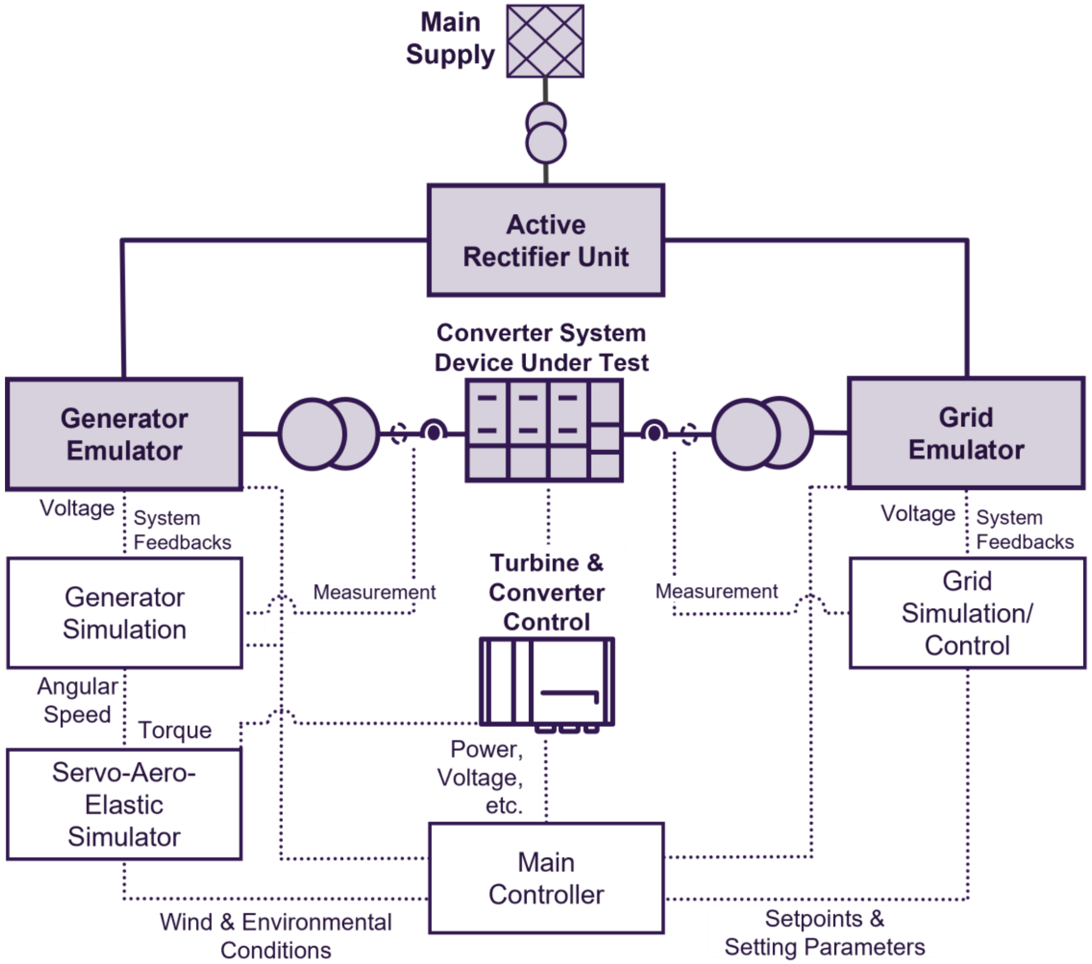
GRID-CONVERTER TEST RIG (G-CTR)

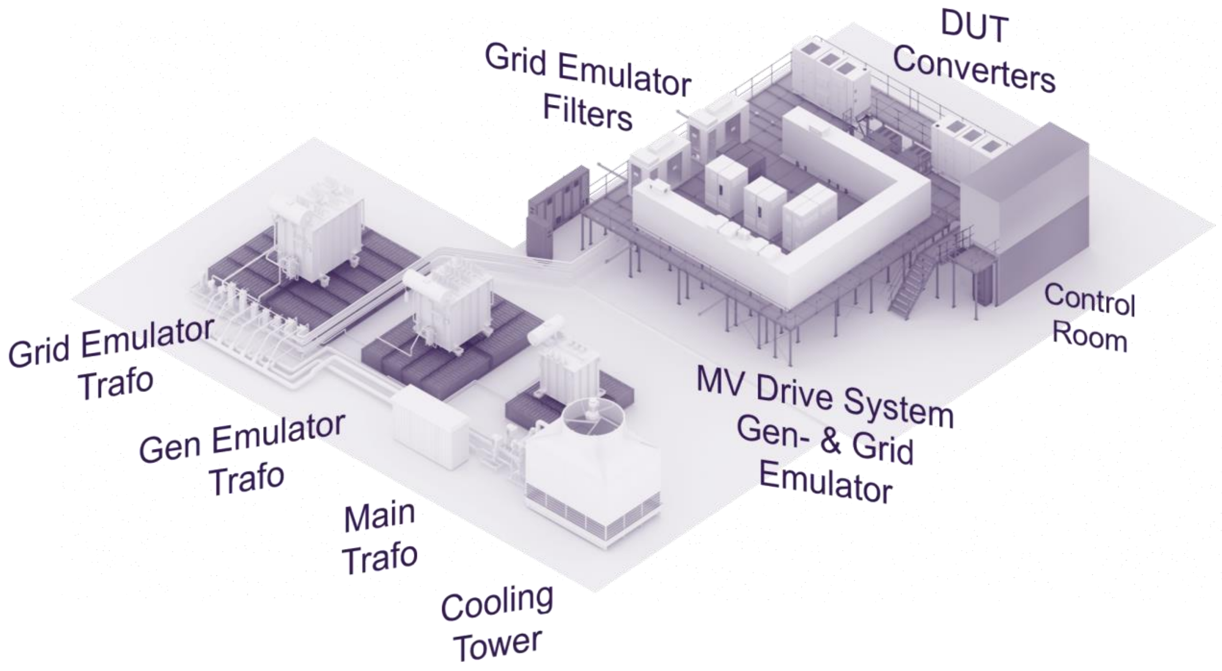
SIEMENS Gamesa
RENEWABLE ENERGY

- Commissioned 2023
- Located at SGRE facility in Brande
- Prototype early-stage model validation
- RMS & EMT model validation
- Frequency Domain Model Validation
- Converter Harmonic Modeling

GRID-CONVERTER TEST RIG

System Setup

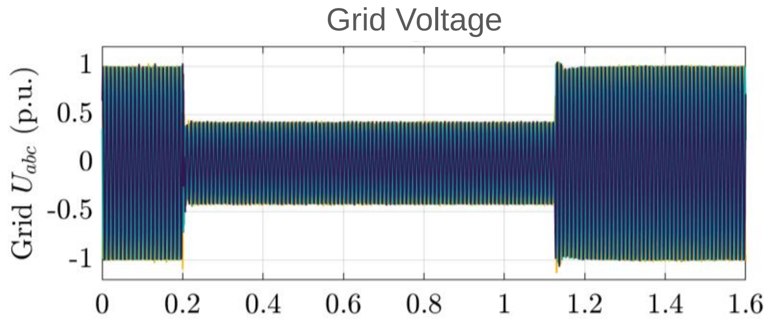


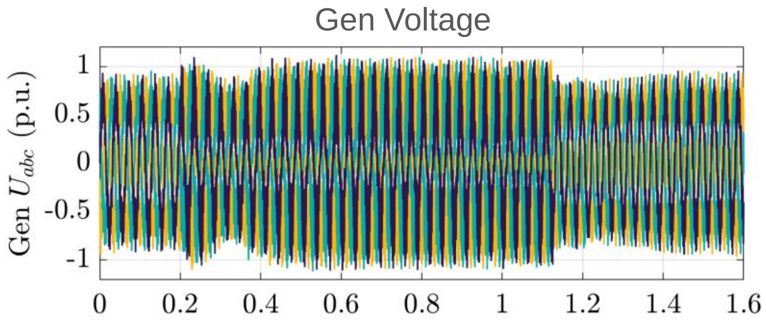


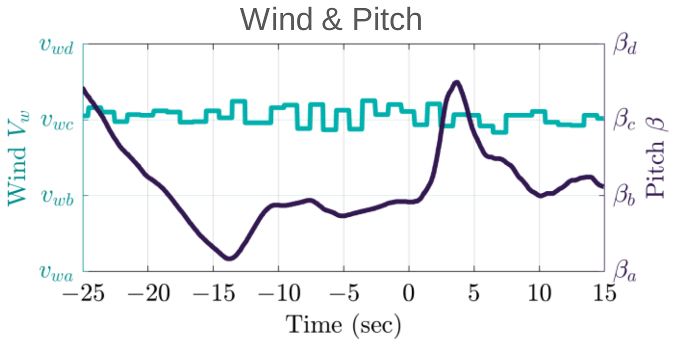
UVRT SYSTEM PERFORMANCE

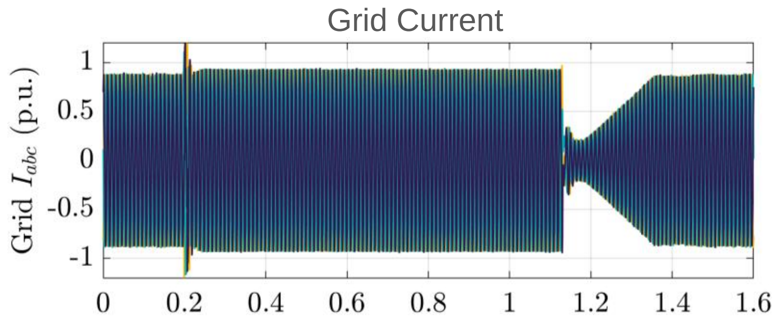
SIEMENS Gamesa
RENEWABLE ENERGY

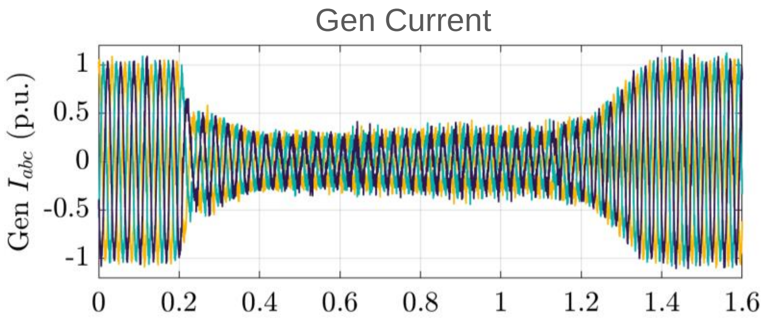
Measurement Result - 20% retained voltage at 100% power

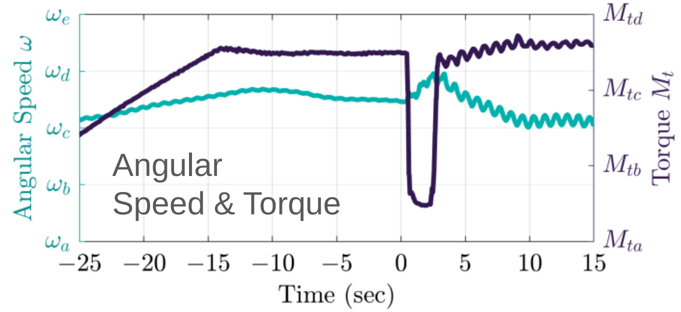


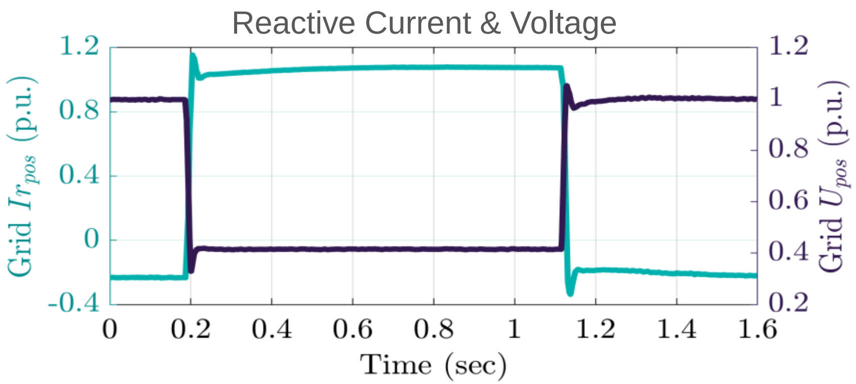


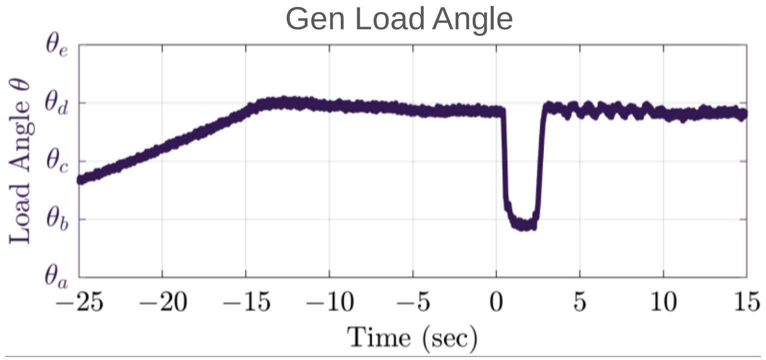












Neshati et al., Grid Connection Testing of Wind Energy Converters with Medium Voltage Generator- and Grid Emulators on a Multi-Megawatt Power Hardware-in-the-Loop Test Rig Wind Integration Workshop 2023, Copenhagen, Denmark.

MEASUREMENT SYSTEM

SIEMENS Gamesa
RENEWABLE ENERGY

High Precision and High Sampled

- 80 high precision & high sampled measurements
- Measurements on low-voltage as well as medium-voltage side
- Extensive DUT measurements on net-bridge converter

- LEM ITZ ULTRASTAB high precision current measuring device
  - DC and AC current with a bandwidth > 10kHz

- Dewesoft SIRIUS XHS: high-speed data acquisition system
  - Up to 15 MS/s sampling rate with 5 MHz bandwidth
  - Direct voltage measurement up to 2000V peak
  - Medium voltage measurement using differential probes
  - Field bus interfaces to acquire setpoints & feedback signals

TEST RIG VALIDATION

SIEMENS Gamesa
RENEWABLE ENERGY

Comparison Field vs. G-CTR Measurements

vs.

Accomplished 2024

Curran et al., WTG Grid Compliance Testing and Validation Part 1: Grid-Converter Test Rig Measurement and Verification based on the IEC 61400-21-4.
Wind Integration Workshop 2024, Helsinki, Finland.

	No-load Tests	Component Validation	Type Test Validation	Measurement Reports
Aim	Demonstrate fulfilment of technical specification on 50/60 Hz.	Prove fidelity of models used and reduce uncertainty. Validation of emulated components.	Assess G-CTR performance acc. to IEC 61400-21-4. Transferability analysis with DEWI-OCC.	Measurement report for each test type.
Task	Test G-CTR technical specs acc. to IEC61400-21-4.	Field and G-CTR tests which focus on emulated components representation.	Type tests performed in field and repeated on G-CTR.	Analysis of measurement results with UL International.

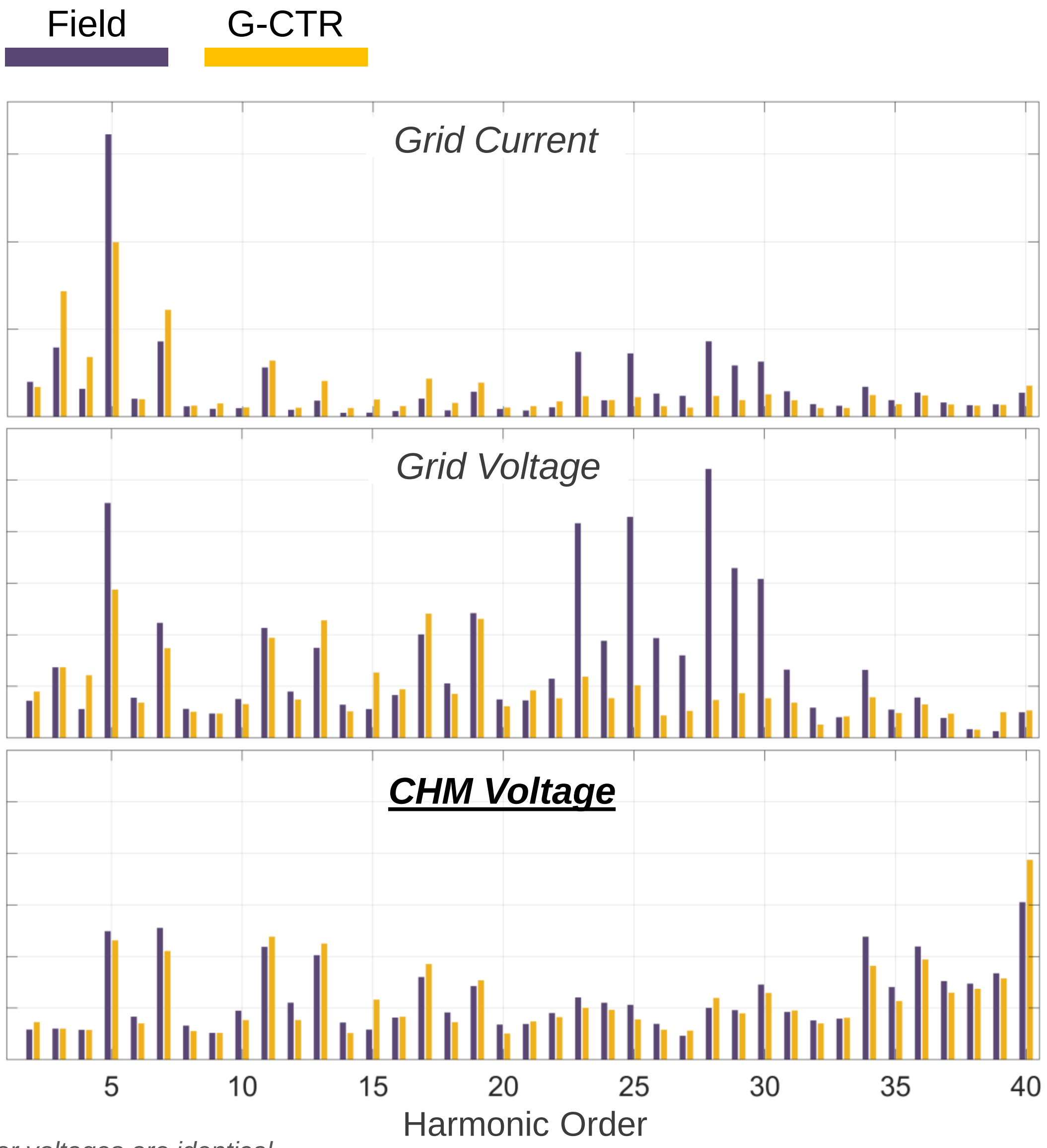
Contribution to Power Quality Analysis

Harmonic Characteristics

- ✓ Converter Harmonic Model
- ✓ Frequency Domain Model Validation
- ✓ Dual-Scheme Impedance Scan

HARMONIC CHARACTERISTICS

- Up to now there is a lack of experience regarding harmonic analysis on test rigs
- Power quality analysis from different sites not comparable
- Method required to increase immunity to grid background harmonic
- Test rigs provide an advantage in combination with mathematical tools
- Best practice required to explore the effect of converter operating conditions on harmonic characteristics
- Converter Harmonic Model (CHM): Field independent analysis & representation

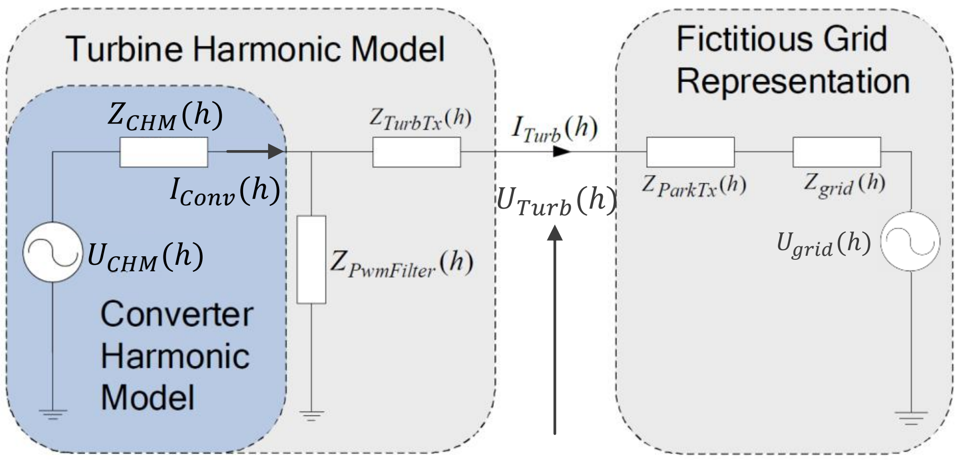


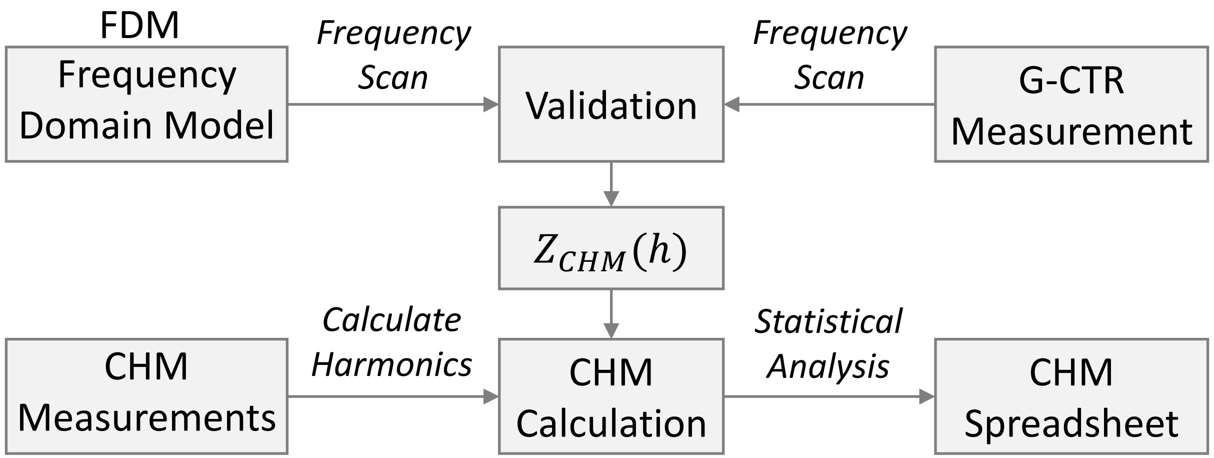
Note: y-axis scaling for voltages are identical

CONVERTER HARMONIC MODEL (CHM)

Brogan et al.,
Wind Integration Workshop 2012.

- Thevenin equivalent representation of the converter
- Utilized for harmonic compliance studies
- Measurement& calculation in accordance with IEC 61400-21-1 and -3
- Converter current measurement (non-filtered)
- Voltage measurement at the point of common coupling
- Equivalent converter impedance characteristics from validated frequency scan results (FDM)
- Statistical analysis to export CHM

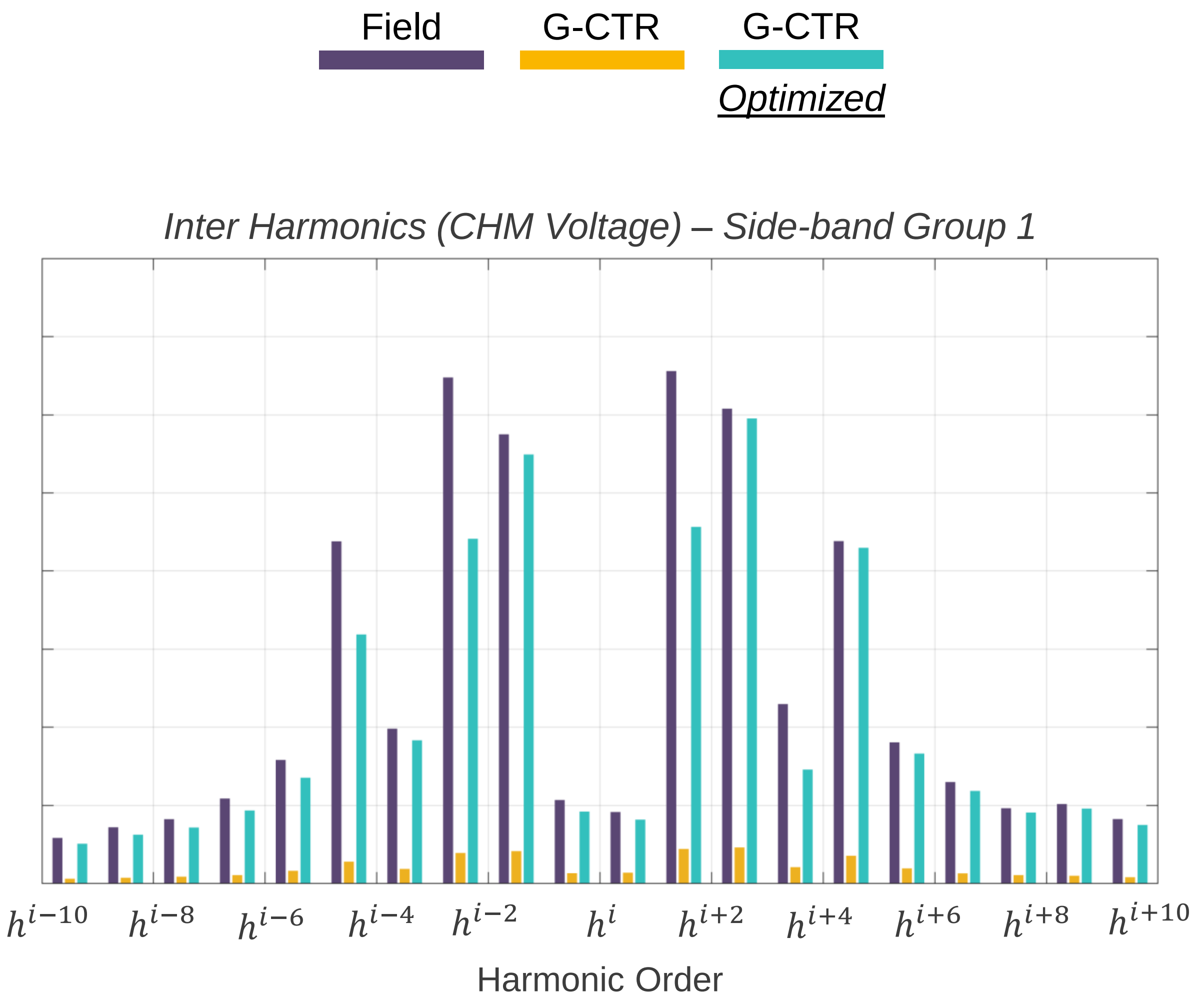




SIEMENS Gamesa RENEWABLE ENERGY

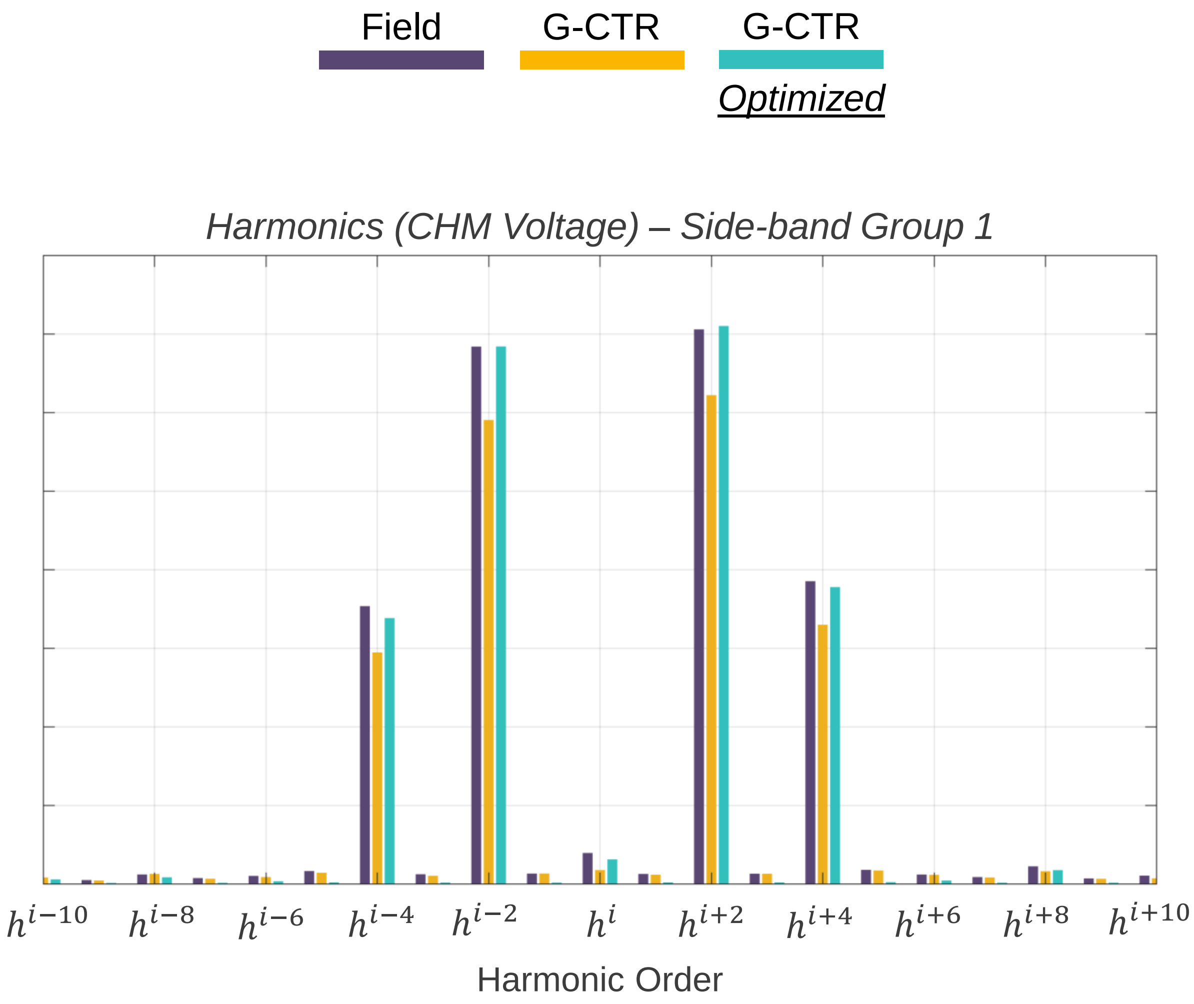
MEASUREMENT & OPTIMIZATION

- Detailed Test & Analysis on Test Rig
  - Individual measurements at each 10% power bin
  - Reactive import and export conditions as well as various modulation depth conditions
  - Various grid strength conditions as well as 50/60 Hz operation
  - Various grid emulator switching frequency and modulation schemes
  - Analysis of lower-order baseband harmonics as well as high-order sideband harmonics
- Best practice to increase comparability
- Variable fundamental frequency influences results specially in the sideband and for interharmonic characteristics
- Periodic or constant deviation of ± 0.025Hz



MEASUREMENT & OPTIMIZATION

- Best practice to increase comparability
- Modifications on the modulation depth by modifying voltage operating point
- Variations in both baseband and sideband harmonics observed
- E.g. an increase in the modulation depth increases harmonics in the side band range (more dominant)
- Controllability of grid voltage on test rig provides an additional possibility to maintain voltage and reactive operating point in a wider range



CONVERTER IMPEDANCE SCAN

Calculate converter dq-frame *input* impedance:

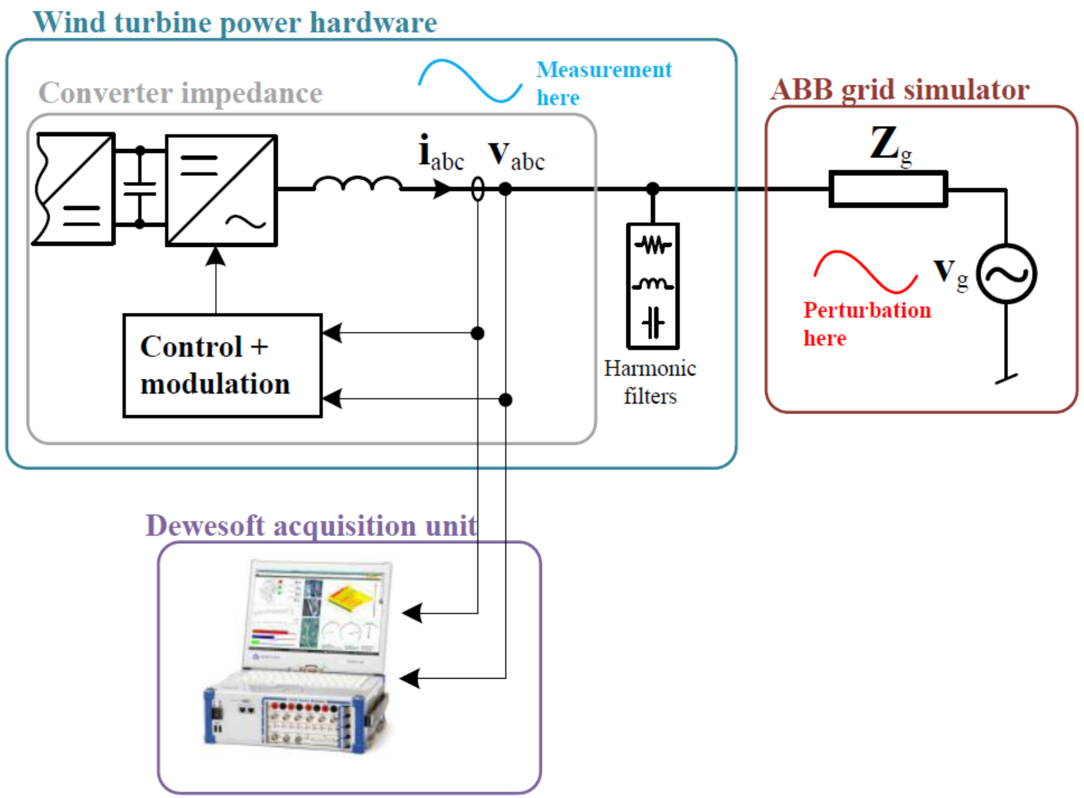
$$\begin{bmatrix} V_q \\ V_d \end{bmatrix} = \begin{bmatrix} Z_{qq}(j\omega) & Z_{qd}(j\omega) \\ Z_{dq}(j\omega) & Z_{dd}(j\omega) \end{bmatrix} \begin{bmatrix} I_q \\ I_d \end{bmatrix}$$

Perturbation:

- Frequency perturbation added to the grid simulator voltage thereby invoking a response from the WT converter.
- Each perturbation is performed at frequency f_p and $f_p - 2f_1$

Measurements:

- Converter main reactor three-phase current $i_{abc}(t)$.
- LV three-phase voltage measurement $v_{abc}(t)$



Frequency Domain Model (FDM) Validation

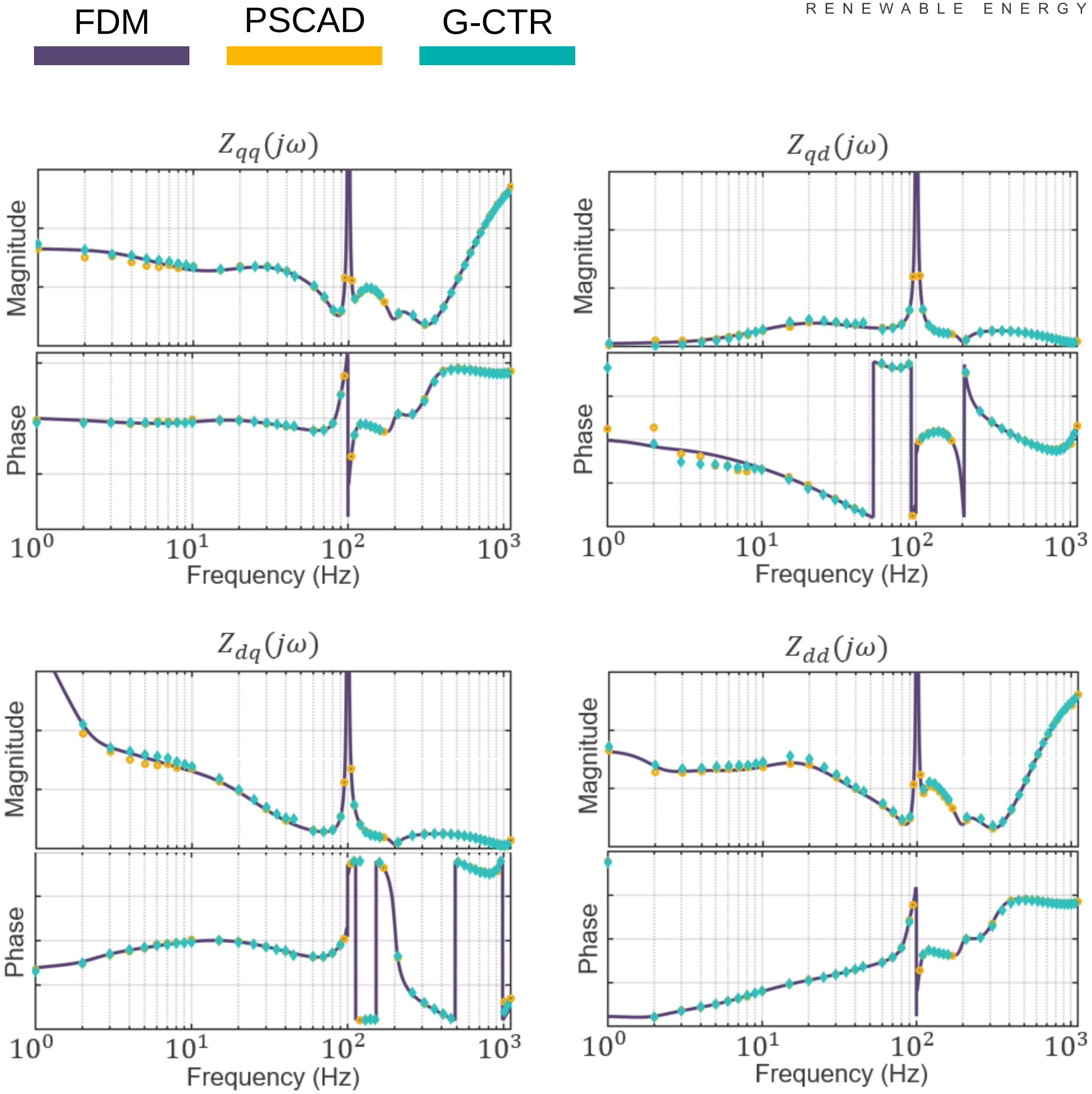
DUAL-INJECTION METHODOLOGY

- Calculated converter dq-frame *input* impedance:

$$\begin{bmatrix} V_q \\ V_d \end{bmatrix} = \begin{bmatrix} Z_{qq}(j\omega) & Z_{qd}(j\omega) \\ Z_{dq}(j\omega) & Z_{dd}(j\omega) \end{bmatrix} \begin{bmatrix} I_q \\ I_d \end{bmatrix}$$

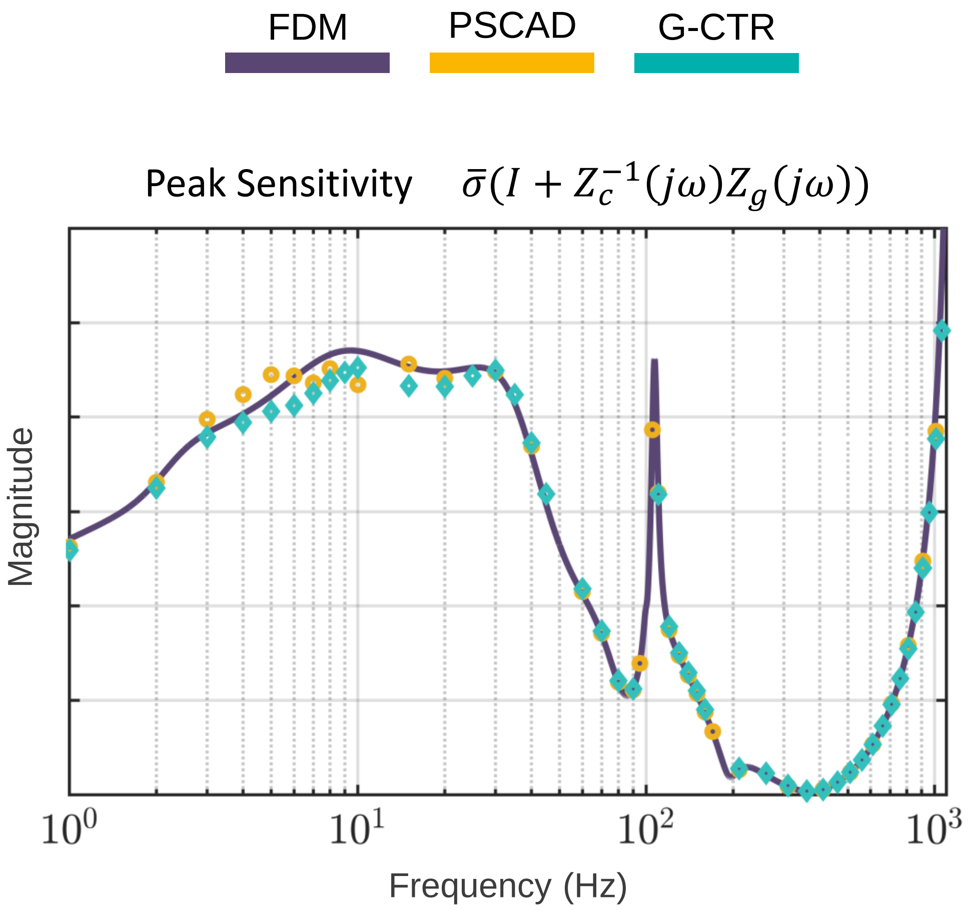
- Dual-scheme scan to capture frequency-couplings
- Impedance model obtained as a transfer function matrix (MIMO representation)
- Further transformation into stationary-frame with complex valued transfer matrix possible

- Capture full dynamic response enabled by independent injection of pos. and neg. sequence
- Separate injection of f_p and $f_p - 2f_1$ perturbations required to calculate impedance matrix
- Benchmarking FDM, PSCAD & test rig measurements up to 1000 Hz



SUPPORT SYSTEM LEVEL STABILITY ANALYSIS

- Calculated converter impedance matrix can be applied to impedance-based stability analysis.
- Stability properties of the converter-grid system can be compared to analytical or PSCAD models.
- The example shows the peak sensitivity calculated from the MIMO minor loop formed by the converter and grid impedances for an SCR = 1.55 – higher peak sensitivity indicates lower damping/stability margin.



Conclusion & Outlook

INTEGRATION	Adapt Internal Processes	Optimize Test Rig Operation	Grid Compliance Testing
EVALUATE TRANSFERABILITY	Test Rig Capabilites	Component Validation	Type Test Validation
TEST RIG UTILIZATION	Early Model Validation	Advanced Test Methods	Project Application

SIEMENS Gamesa
RENEWABLE ENERGY

Thank You for Your Attention!

SGRE TE EL Grid Connection
Grid Compliance & Testing

Mohsen.Neshati@siemensgamesa.com
October 2024

Grid-Converter Test Rig (G-CTR)