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XXXVI Cycle

Next Generation Inverters for Energy Production with Virtual Synchronous Machine Features for Grid Services and Grid Support

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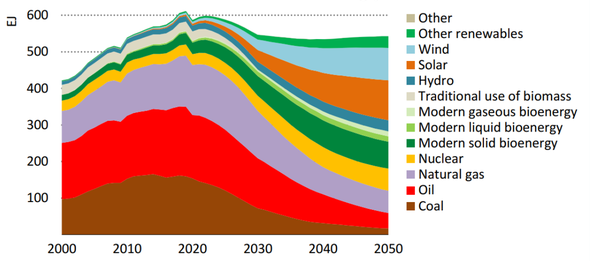
Research context and motivation

- Future decommissioning of thermoelectric power plants (especially coal-based)

Reduction of the synchronous generators number

- Widespread penetration of power electronic interfaced renewable energy sources



Lower system inertia

Decrease of the total power system inertia

Grid frequency and voltage stability will be compromised

Addressed research questions/problems

According to recent grid codes, renewable power plants will be required to provide ancillary services

- **Virtual Synchronous Machines (VSMs):** grid-tied inverters can behave as conventional synchronous machines to support the grid by providing:
  - Inertial Behavior
  - Frequency/Active Power Regulation
  - Voltage/Reactive Power Regulation
  - Harmonic/Unbalance Sink Capability
  - Support during faults
  - Black start/Island Capability

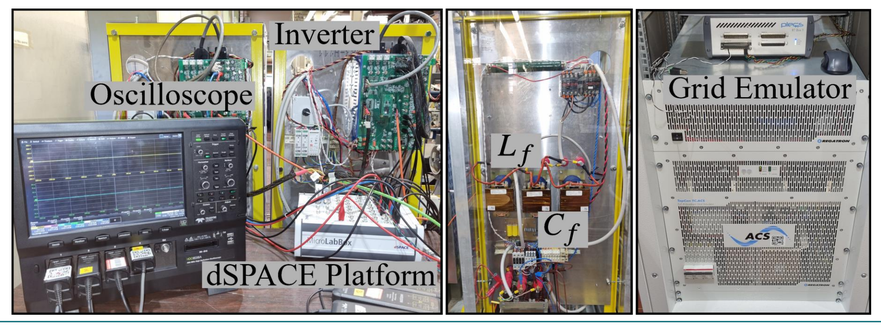
Goal

Propose and investigate advanced control solutions for grid-connected inverters for the fulfillment of the next generation grid codes for the integration of renewable energy sources

VSMs in microgrids	VSMs + battery chargers	Stability analysis of parallel VSMs/multi-VSMs systems	VSMs behavior under non-ideal conditions

Starting Point

- Research of **VSM solutions** in the literature and **implementation** of several existing VSMs
- **Simplified Virtual Synchronous Compensator (S-VSC)**: VSM developed at the Politecnico di Torino
- Experimental setup



Adopted methodologies

Theoretical study
- Small-Signal Analysis

MATLAB® & SIMULINK®

Simulations
- Continuous-time ⇒ Laplace
- Discrete-time ⇒ C-script

plecs

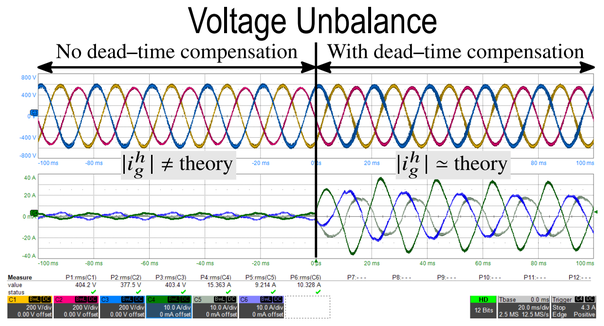
Experimental Validation
- dSPACE Platform
- 3x15 kVA Inverters
- 15/90 kW dc Sources
- 50 kVA Grid Emulator

Novel contributions

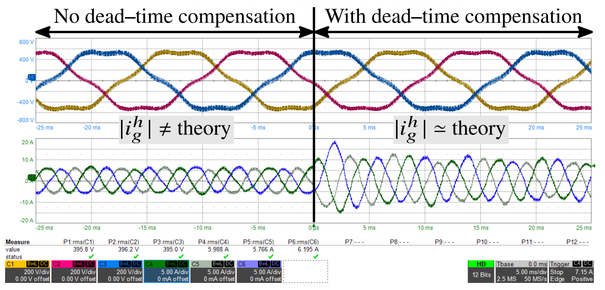
- **Dead-Time Effect on Two-Level Voltage Source Virtual Synchronous Machines**

Dead-time compensation is needed to match the theoretical harmonic and unbalance sink capability of voltage source VSMs

Voltage Unbalance

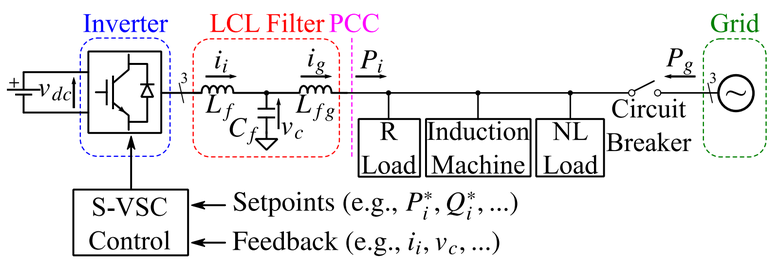


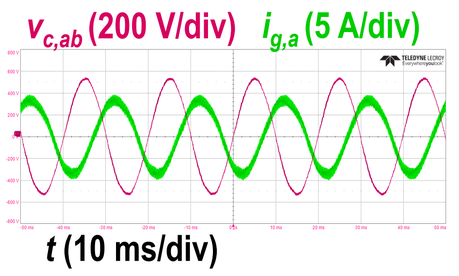
Fifth Harmonic Distortion



- **Extension of the original S-VSC algorithm to grid-forming converters**

Islanding capability and microgrid control preserving the virtual compensator performance

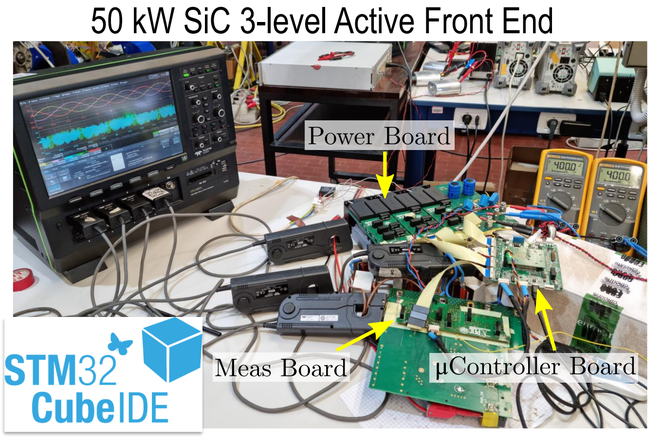




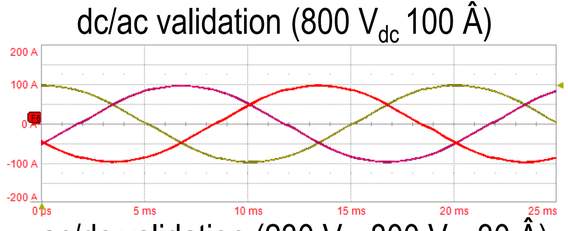
- **Evaluate the possibility to make battery chargers able to provide ancillary services**

Bidirectional battery chargers can provide ancillary services for V2G applications

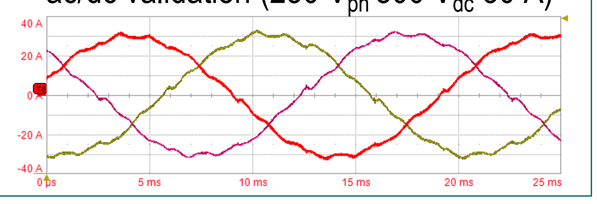
50 kW SiC 3-level Active Front End



dc/ac validation (800 V_{dc} 100 Â)



ac/dc validation (230 V_{ph} 800 V_{dc} 30 Â)



Future work

- Operation and **stability** of parallel **converters** using S-VSC algorithm and operated in **grid-mode** or **islanded** in a microgrid configuration
- **Integration** of the **S-VSC** algorithm into the **Active Front End** prototype
- Evaluation of novel strategies to **limit** the inverter **current** under symmetrical and asymmetrical **faults**

Submitted and published works

- V. **Mallemaci,** F. Mandrile, E. Carpaneto and R. Bojoi, "*Dead-Time Effect on Two-Level Voltage Source Virtual Synchronous Machines*", 2022 IEEE Energy Conversion Congress and Exposition (ECCE), *In Press*.
- V. **Mallemaci**, F. Mandrile, S. Rubino, A. Mazza, E. Carpaneto, and R. Bojoi, "A comprehensive comparison of Virtual Synchronous Generators with focus on virtual inertia and frequency regulation," Electric Power Systems Research, vol. 201, p. 107516, Dec. 2021.
- Mandrile, F.; Cittanti, D.; **Mallemaci**, V.; Bojoi, R. Electric Vehicle Ultra-Fast Battery Chargers: A Boost for Power System Stability? World Electr. Veh. J.2021,12, 16.
- F. Reissner, V. **Mallemaci**, F. Mandrile, R. Bojoi and G. Weiss, "Virtual Friction: Experimental Validation in a Microgrid of 3 Virtual Synchronous Machines," 2022 IEEE 23rd Workshop on Control and Modeling for Power Electronics (COMPEL), 2022, pp. 1-6.
- F. Mandrile, V. **Mallemaci**, E. Carpaneto and R. Bojoi, "A Lead-Lag Filter for Virtual Synchronous Machines with Improved Electromechanical Damping", 2021 IEEE Energy Conversion Congress and Exposition (ECCE), Vancouver, BC, Canada, 2021, pp. 583-589.
- V. **Mallemaci**, E. Carpaneto and R. Bojoi, "Grid-Forming Inverter with Simplified Virtual Synchronous Compensator Providing Grid Services and Grid Support," 2021 24th International Conference on Electrical Machines and Systems (ICEMS), Gyeongju, Korea, Republic of, 2021, pp. 2323-2328.
- D. Cittanti, V. **Mallemaci**, F. Mandrile, S. Rubino, R. Bojoi and A. Boglietti, "PWM-Induced Losses in Electrical Machines: An ImpedanceBased Estimation Method," 2021 24th International Conference on Electrical Machines and Systems (ICEMS), Gyeongju, Korea, Republic of, 2021, pp. 548-553.

List of attended classes

- 02LCPRV – Experimental modeling (9/2/2021, 7 credits)
- 02ITTRV – Generatori e impianti fotovoltaici (19/4/2021, 5 credits)
- 01LEVRV – Power system economics (14/7/2021, 3 credits)
- 02SFURV – Programmazione scientifica avanzata in MATLAB (27/4/2021, 6 credits)
- 01TSLRO – Soluzioni innovative per veicoli elettrici e/o ibridi (19/5/2021, 3 credits)
- 01QORRV – Writing Scientific Papers in English (18/2/2021, 3 credits)
- European PhD School: Power Electronics, Electrical Machines, Energy Control and Power Systems 2021 (12/7/2021, 30 hours)
- European PhD School: Power Electronics, Electrical Machines, Energy Control and Power Systems 2022 (23/5/2022, 40 hours)
- WinGrid PhD School 2022 (4/7/2022, 24 hours)

POLITECNICO DI TORINO

PhD program in
Electrical, Electronics and Communications Engineering