Control of Grid-Forming Power Converters

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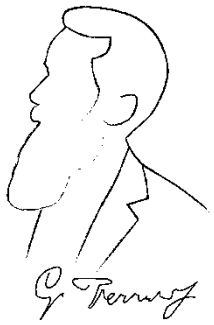

Dipartimento Energia "Galileo Ferraris"

Politecnico di Torino, Italy

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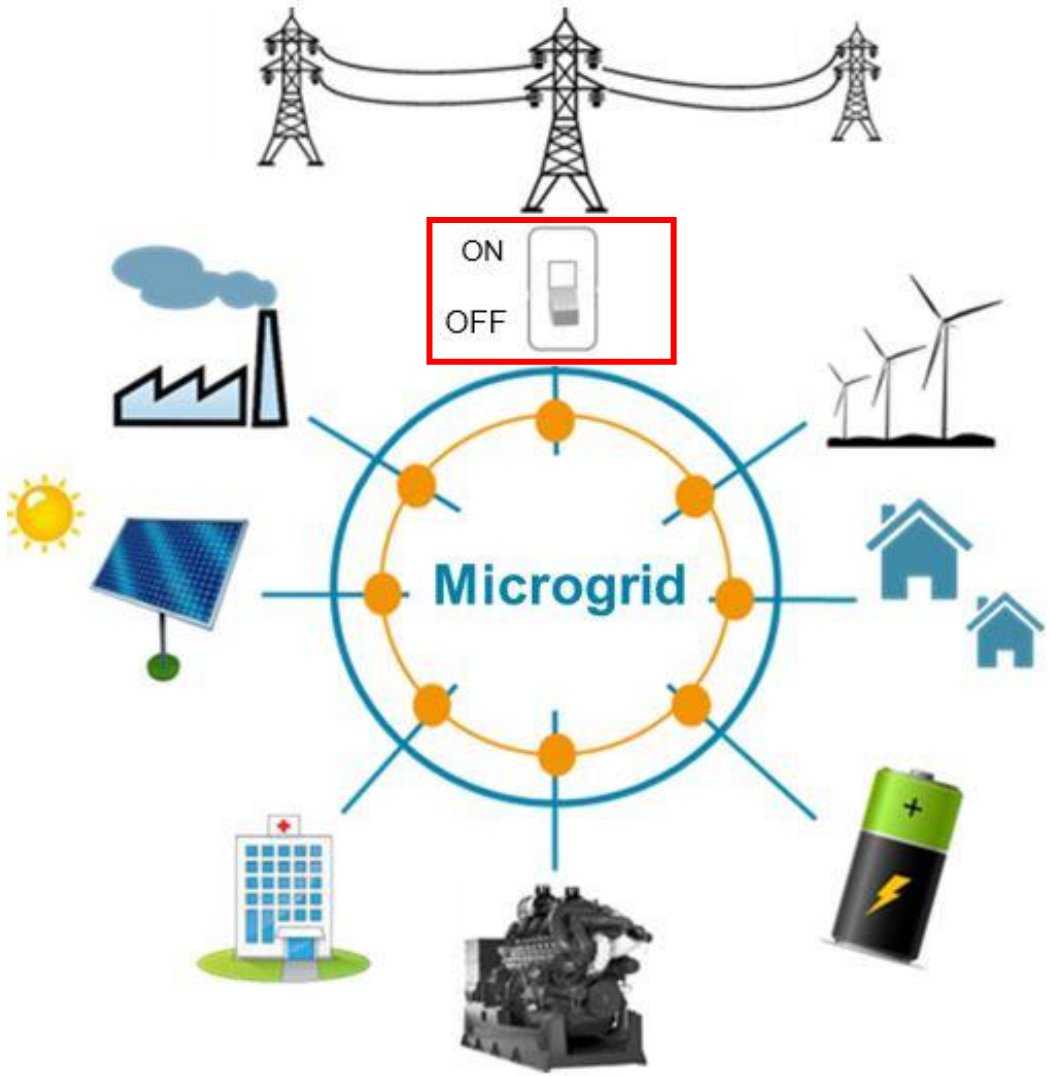
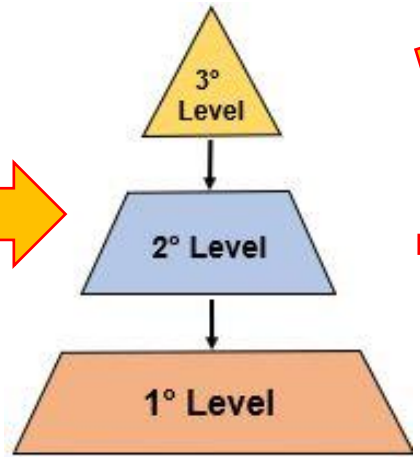
Outline

- Introduction
- Controls Analysed
- Simulations
- Experimental Validations
- New Test Bench Setup
- Conclusions

Introduction



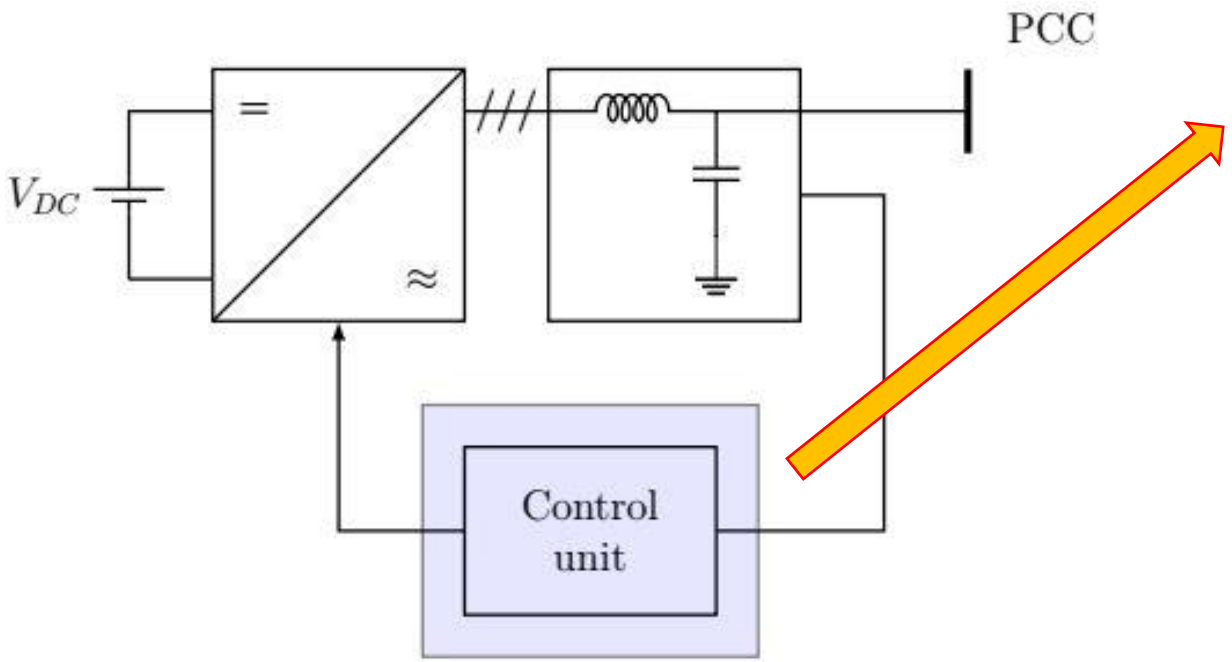


Power management among MGs and the Grid based on Economic Criteria

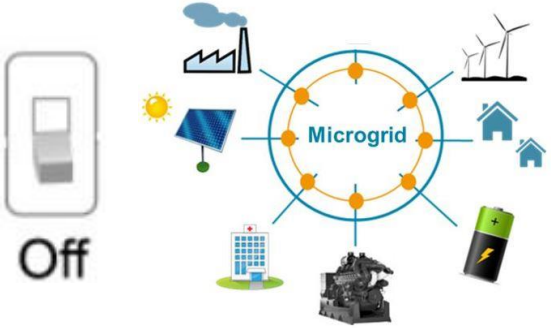
Power mismatch inside a MG

Local converter control
Voltage/frequency or current control

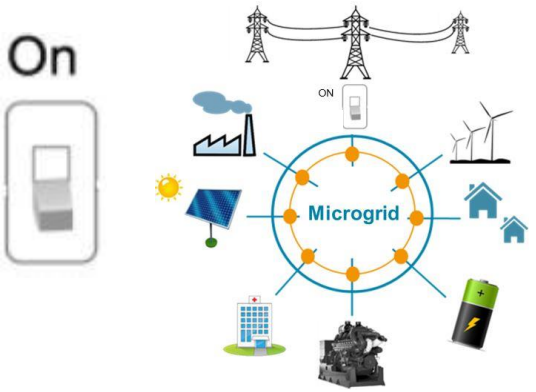
Goal of the Thesis



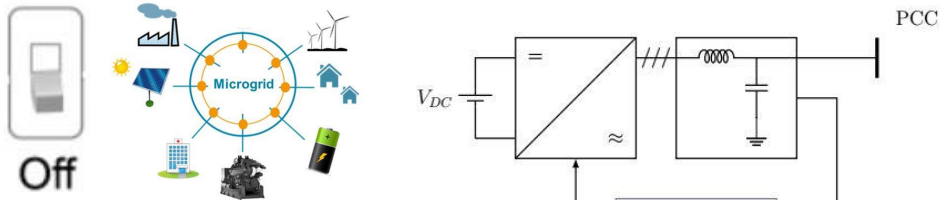
GRID-FORMING (GF)
sets V^*, f^*
at the
Point of Common Coupling
(PCC)

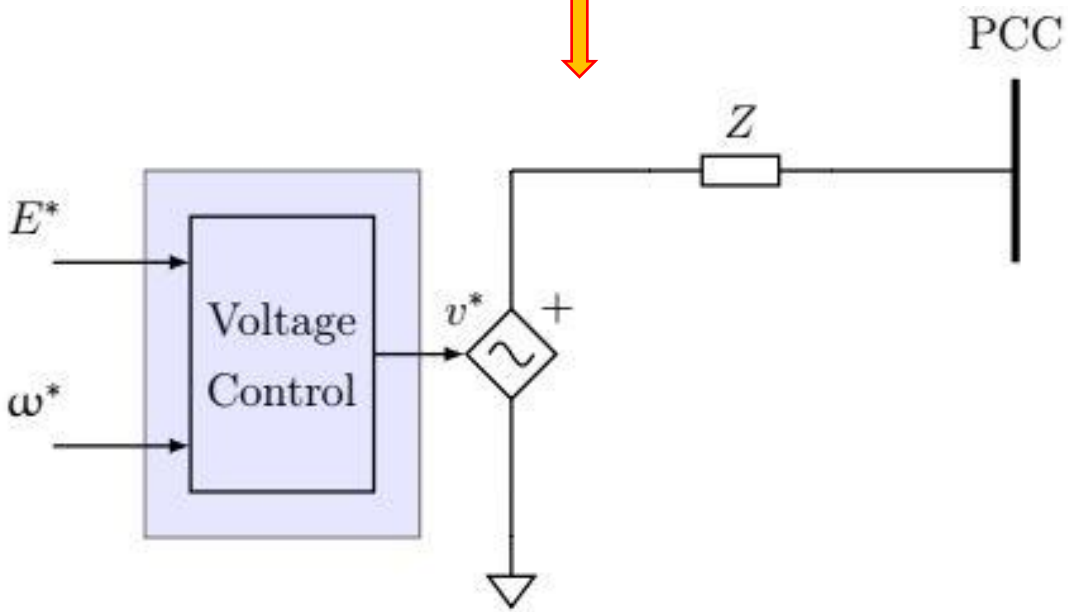


GRID-SUPPORTING (GS)
sets
V^*, f^* at PCC
according to power exchange
requirements



Grid-Forming Control Strategy





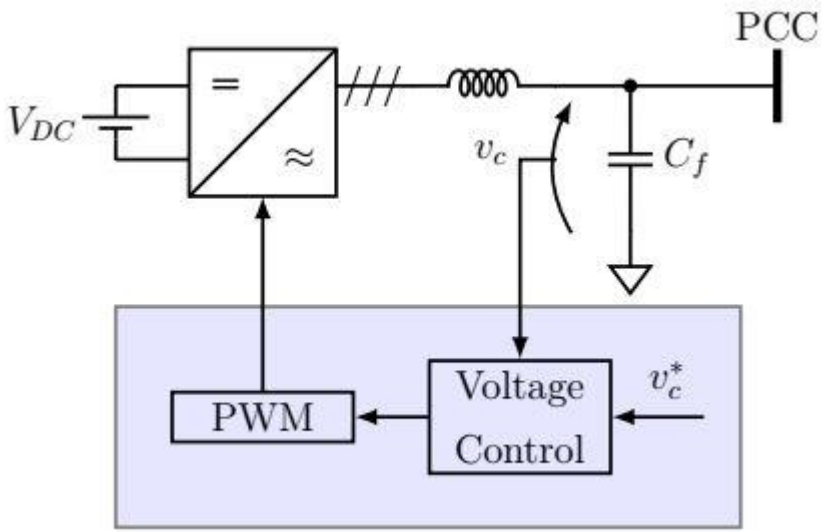
GRID-FORMING (GF) control Strategies Analysed:

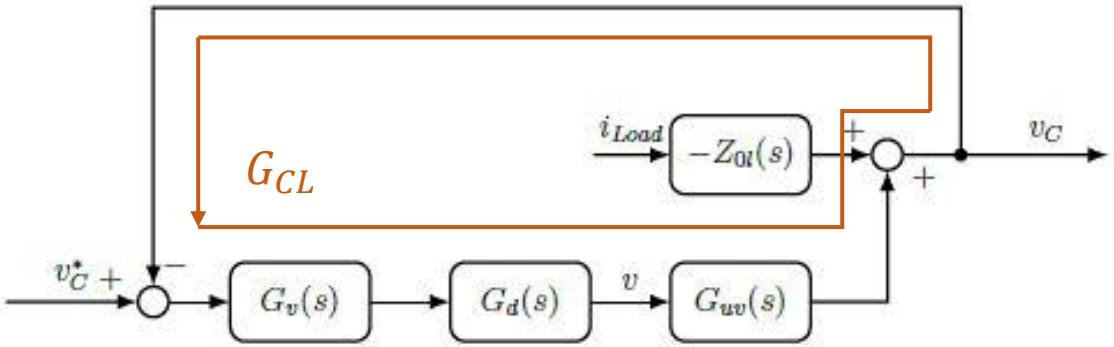
- ✓ Single loop voltage control (SL)
- ✓ Dual loop control(DL)

Controller type:

- in (d,q) frame ⟶ PI = $k_p + \frac{k_i}{s}$
- in (α,β) frame ⟶ PRES = $k_p + k_i \frac{s}{s^2+\omega_0^2}$

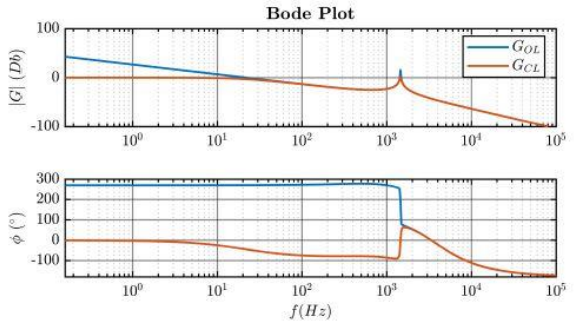
Single Loop Voltage Control

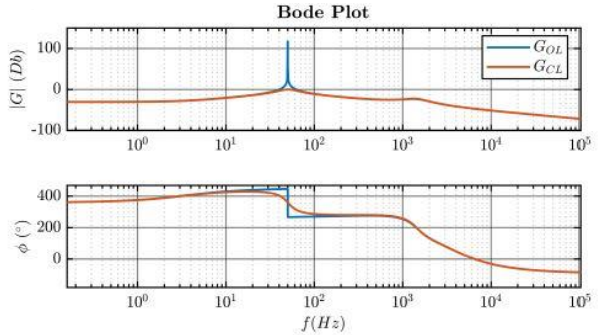




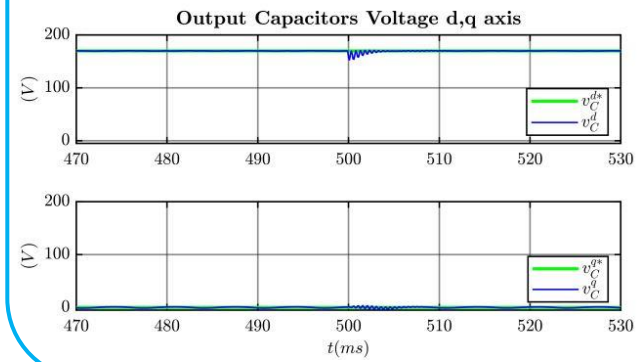
PI **PRES**

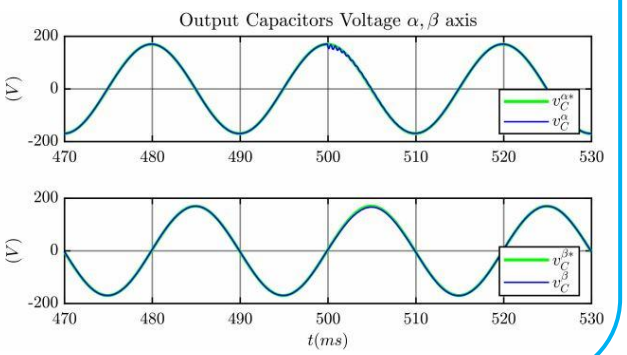
MATLAB



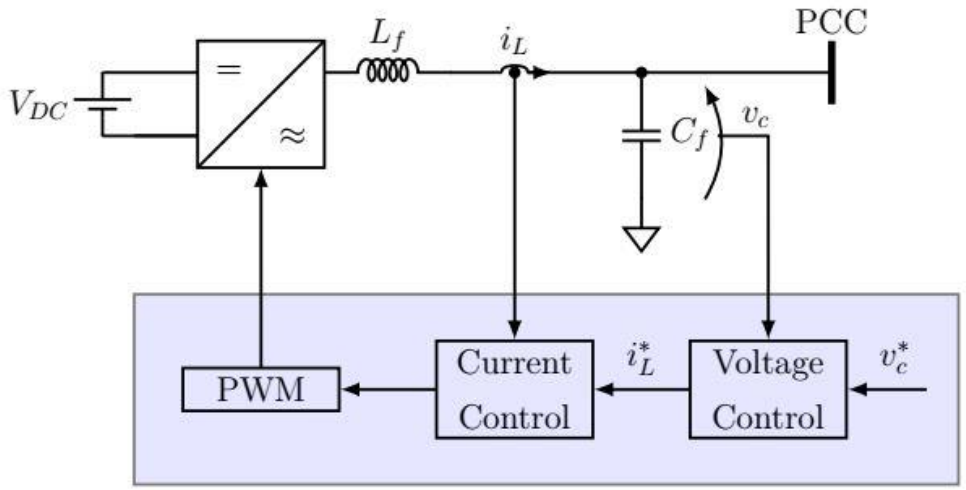


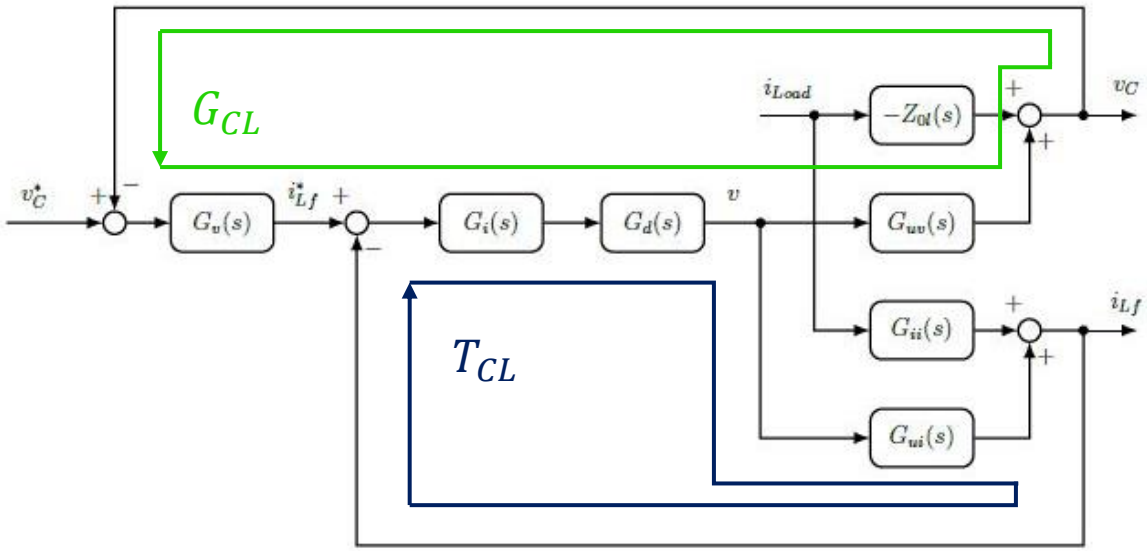
plecs



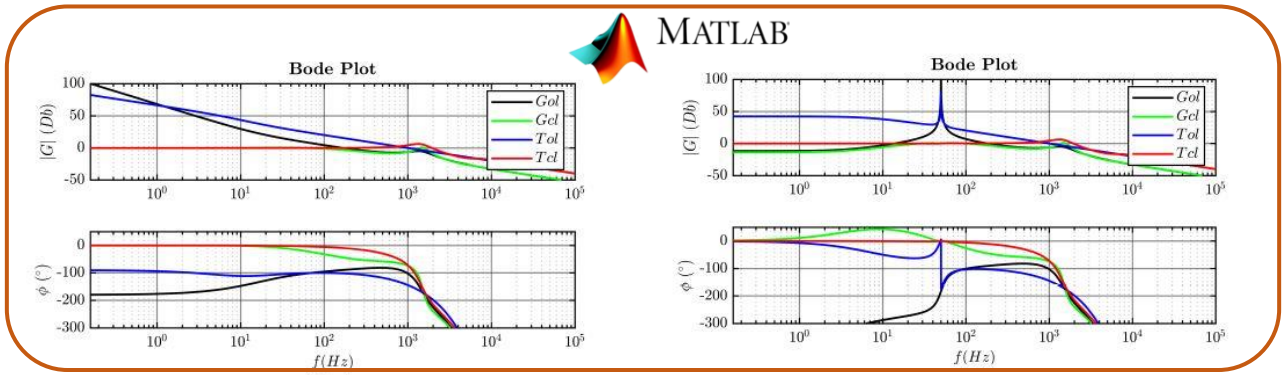


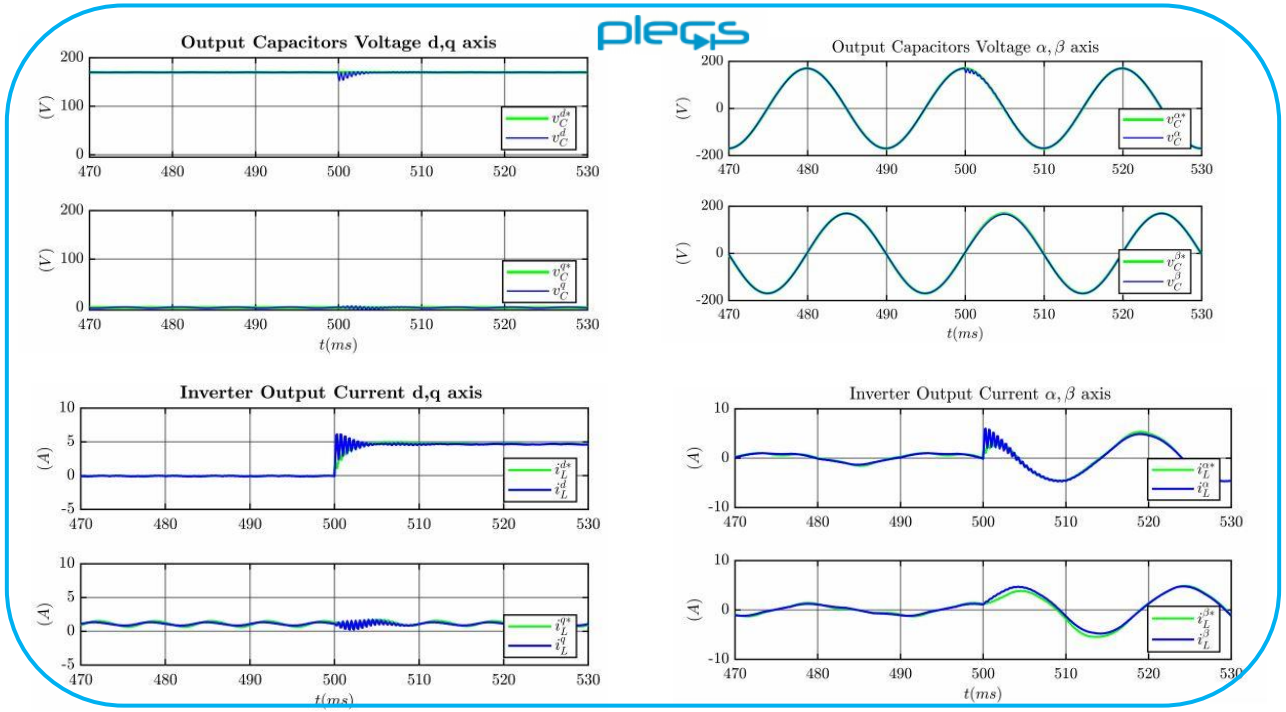
Dual Loop Control





PI **PRES**



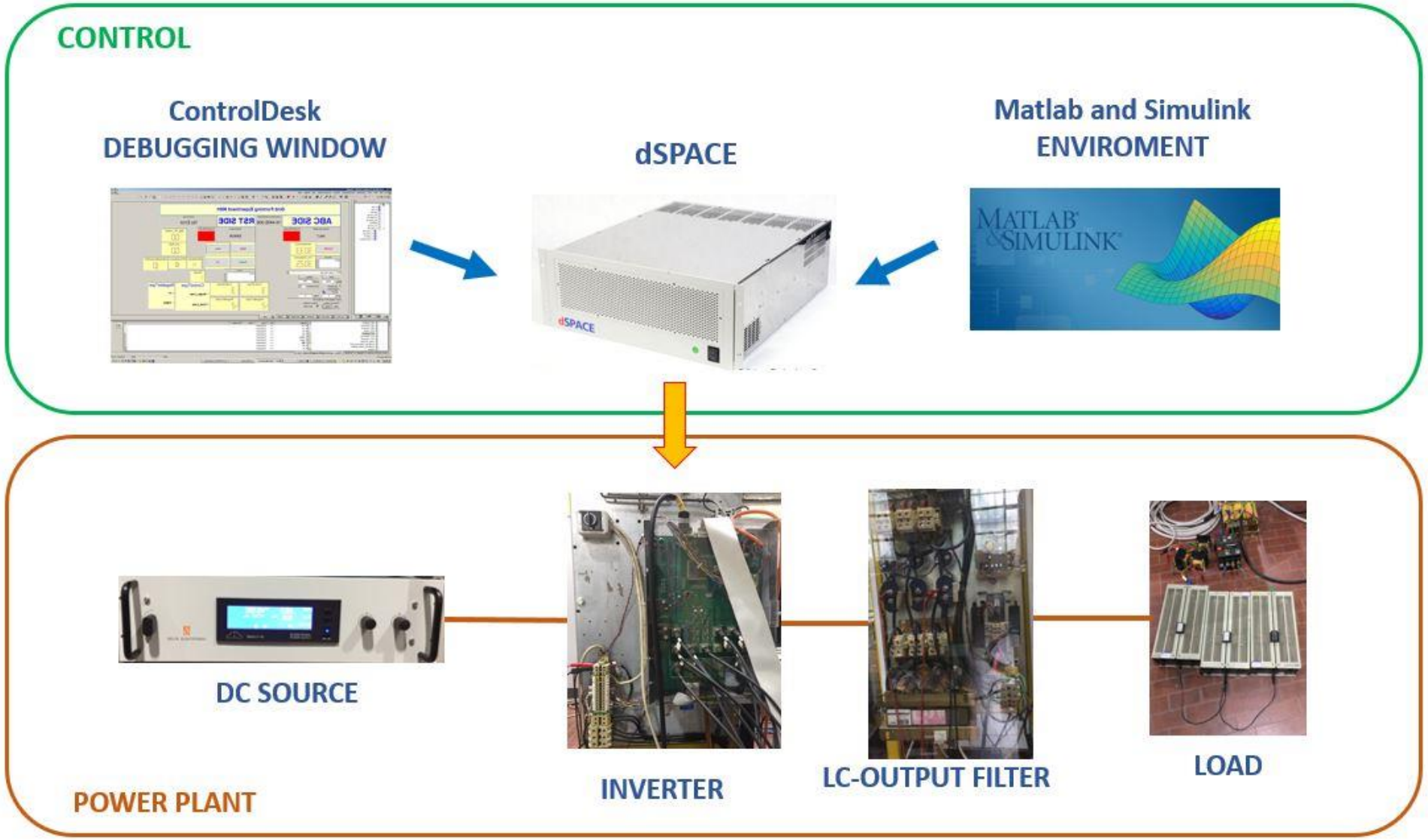


Grid-Forming C-code Implementation

- SL PI
- SL PRES
- DL PI
- DL PRES

Control Unit dSPACE

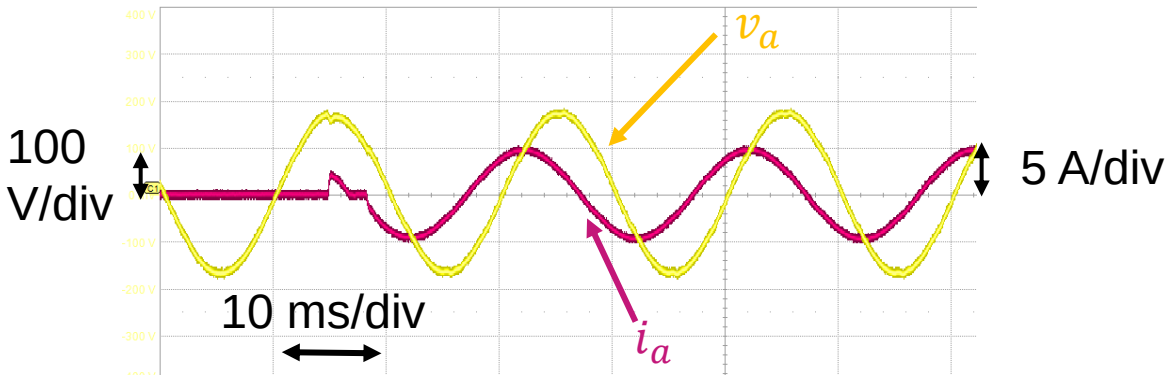
Experimental Setup



Experimental Results

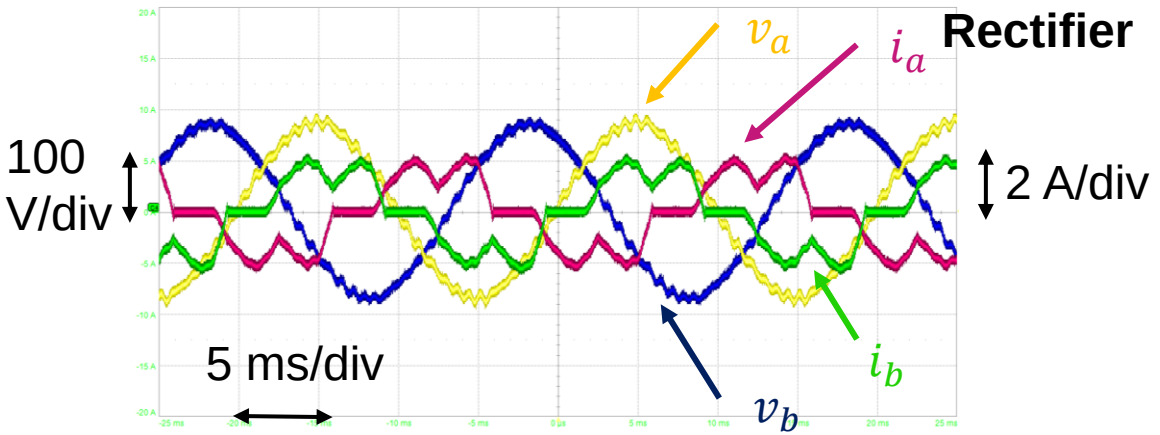
SL PI

RL load



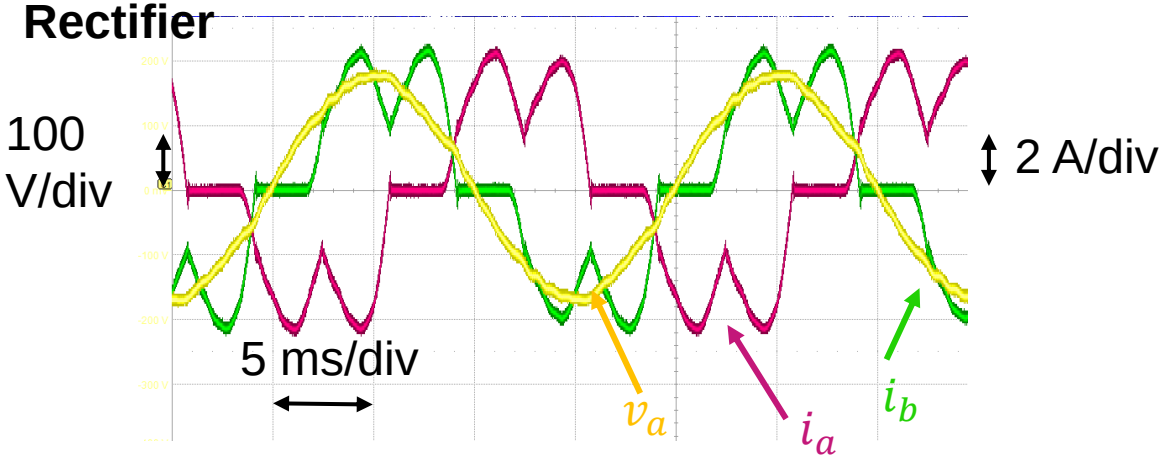
DL PI

Diode Rectifier



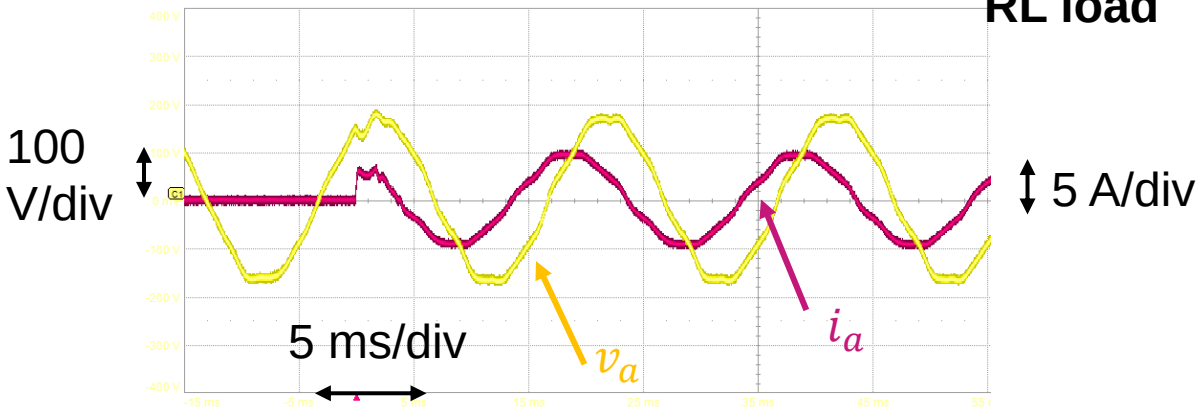
SL PRES

Diode Rectifier



DL PRES

RL load



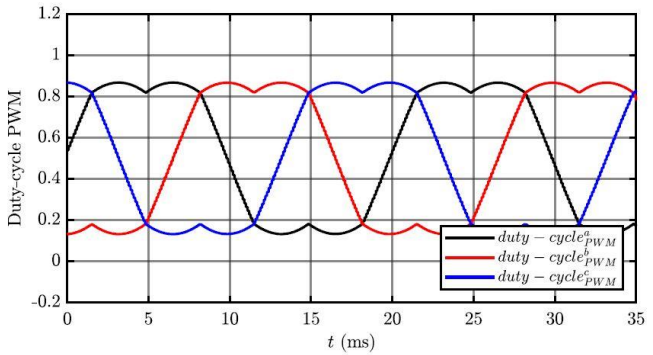
Grid-Forming: Further Analysis

- Two Different Modulation Techniques

$P_{Switching} = 0.38\%$

THD $v_{PCC} = 3.70\%$

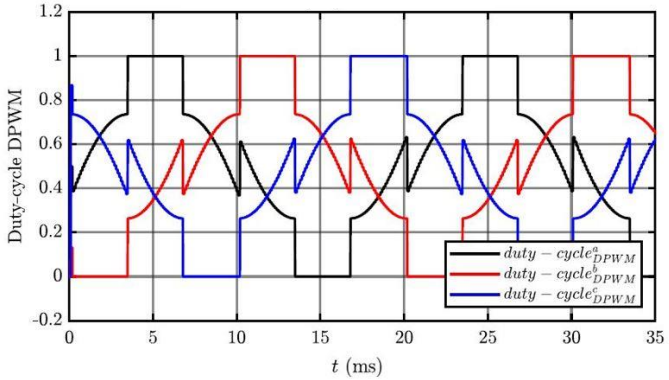
PWM BEM



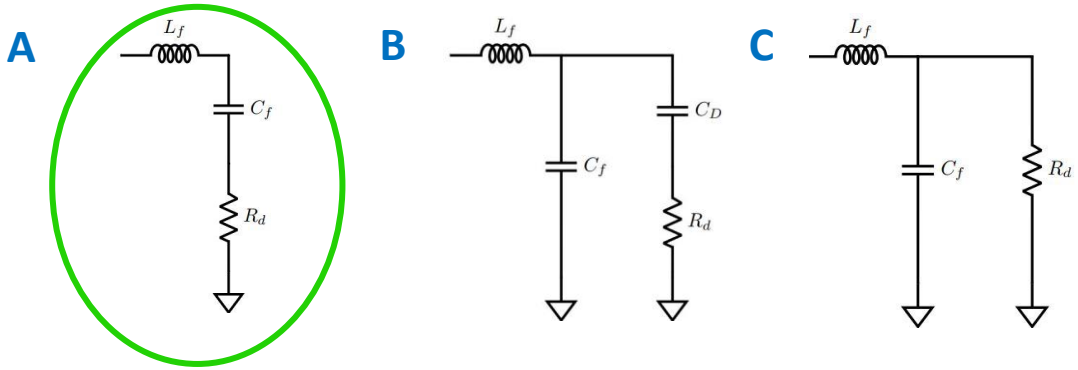
$P_{Switching} = 0.24\%$ -30 %

THD $v_{PCC} = 5.97\%$

DPWM



- Damping topologies of LC-output converter filter



(same ω_{LC})

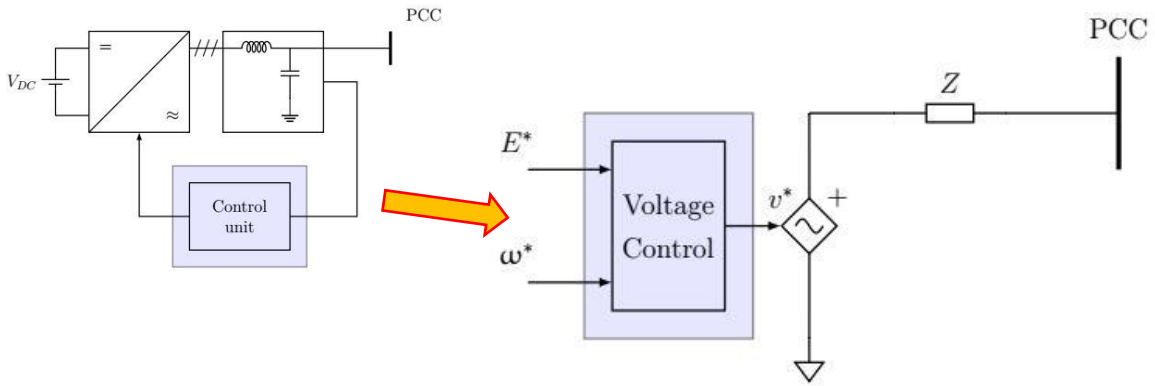
$P_{losses\ damping\ circuit}$: $C > A > B$

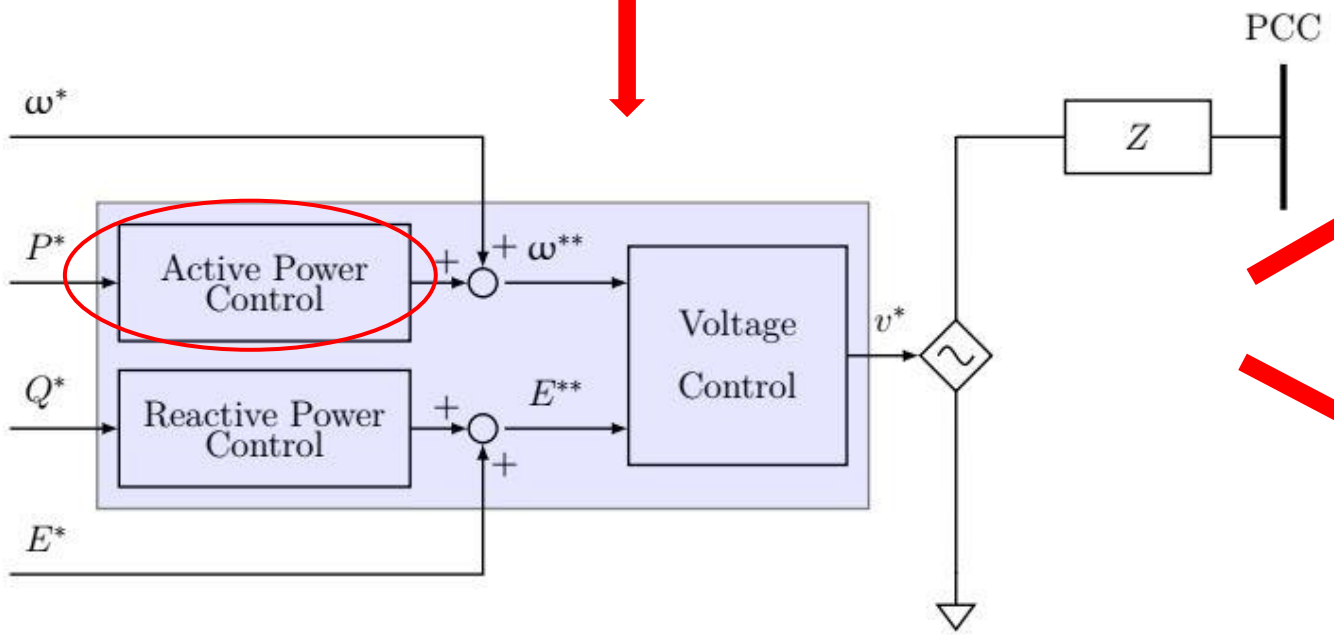
High frequency attenuation: $C > A > B$

- Dead Time compensation

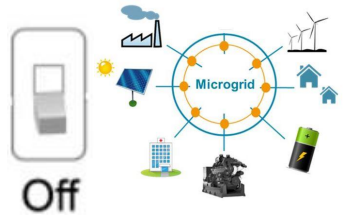
	IDEAL No Dead-Time added	REAL Dead-Time added	REAL Dead-Time Compensation Algotrithm
THD v_{PCC}	3.74%	4.35%	3.90%

Grid-Forming → Grid-Supporting



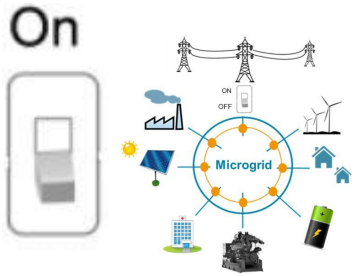


Power converter working in a *islanded* MG controlled as **Grid-Forming**

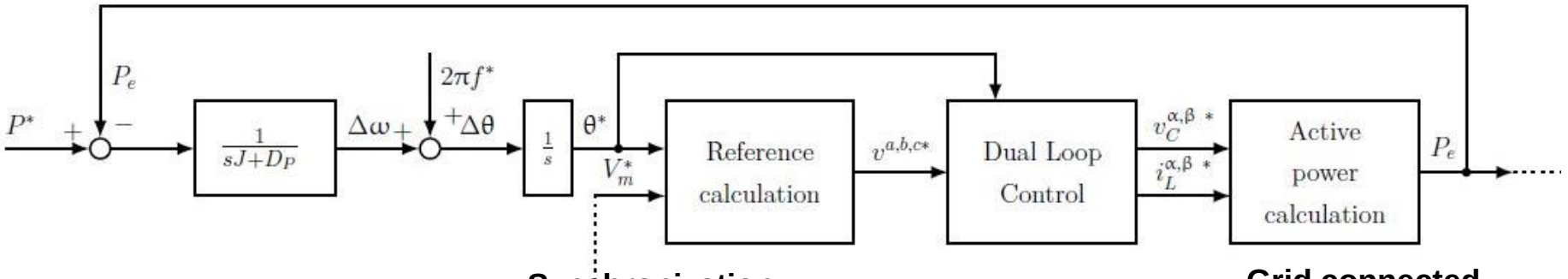


Synchronization Process to connect the MG to the main grid

Power converter work in a grid-connected MG controlled as **Grid-Supporting**



Power Synchronization Loop (PSL)

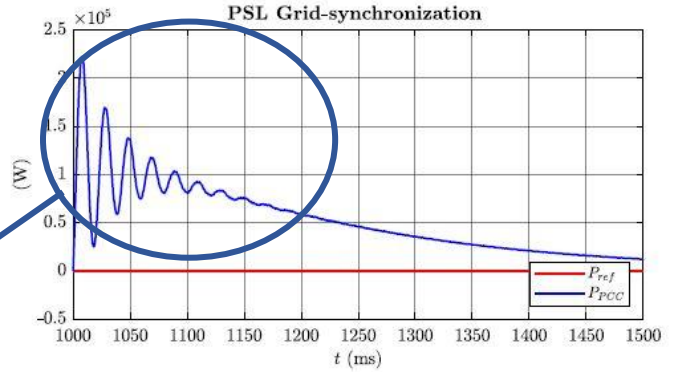


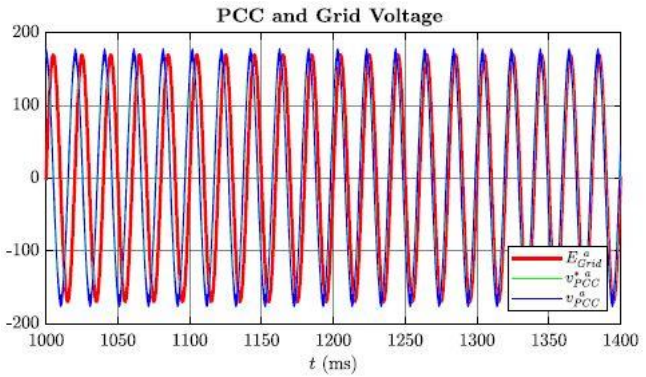
Synchronization

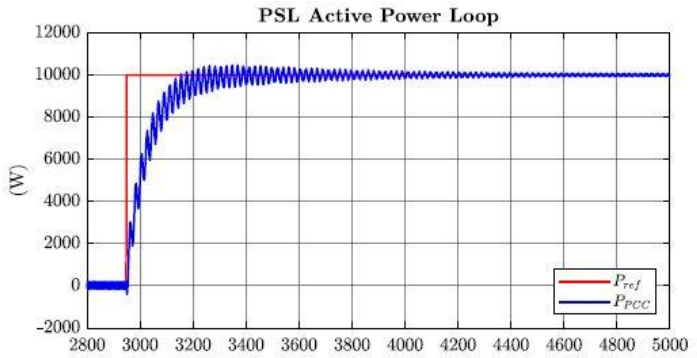
Grid connected

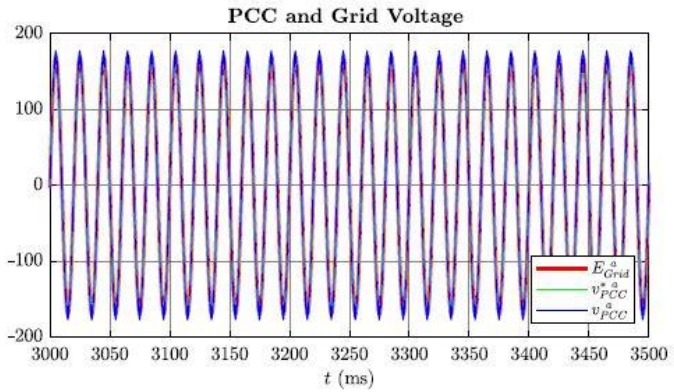
Not real !

During the synchronization process, P_{PCC} is calculated using a fictitious impedance that emulates the real one of connection to the grid

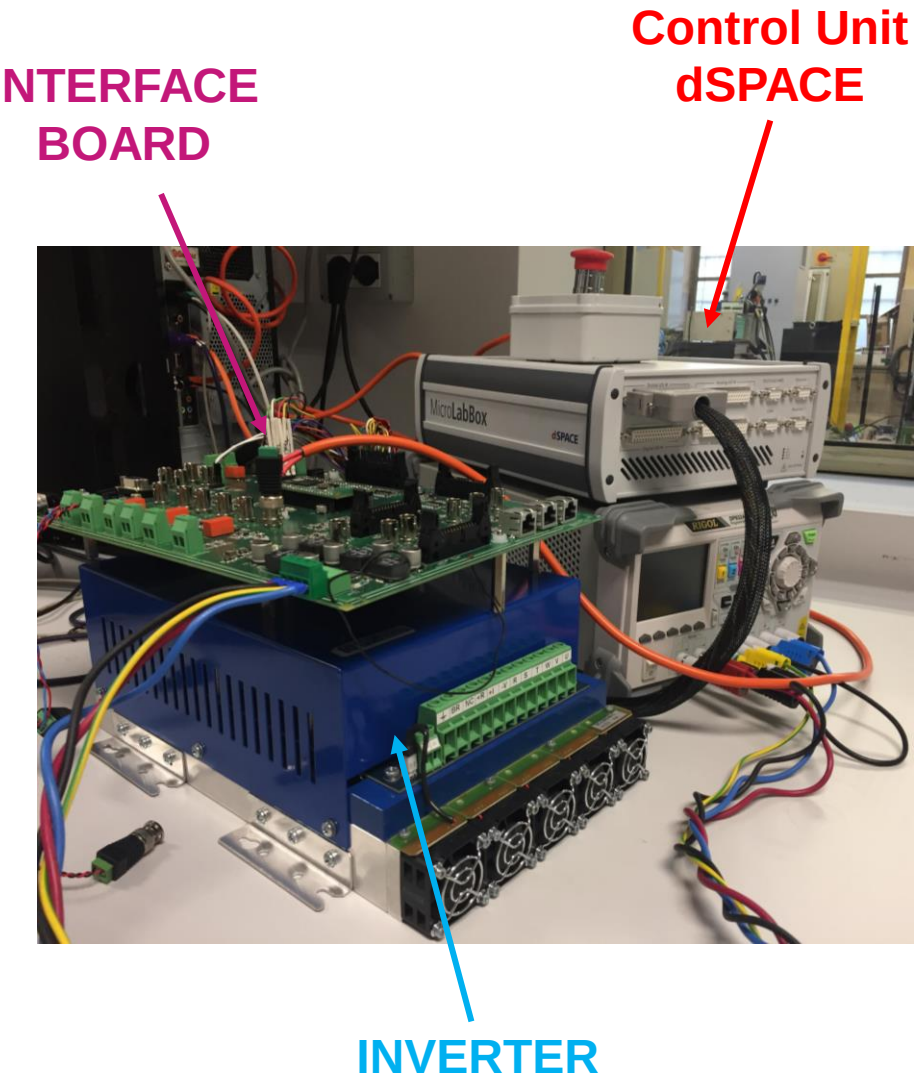


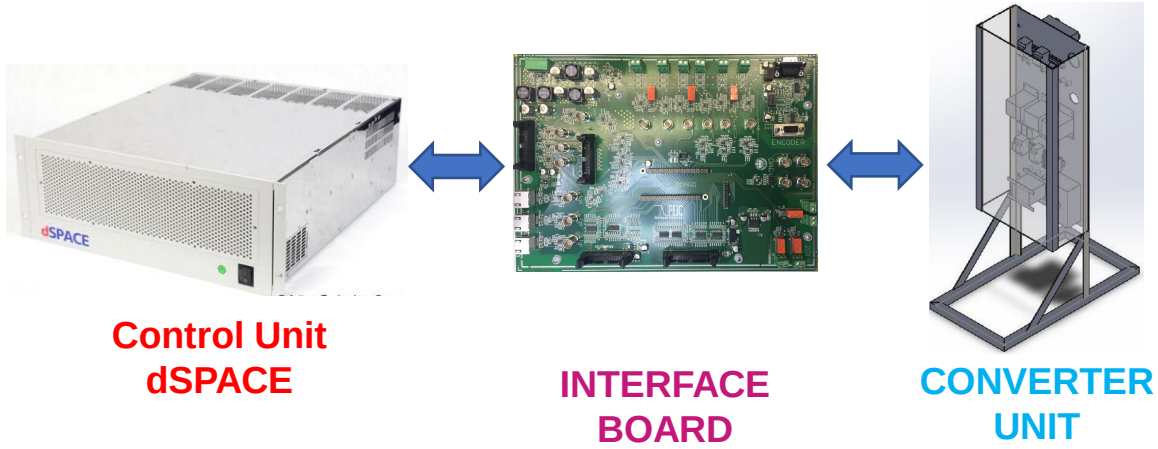






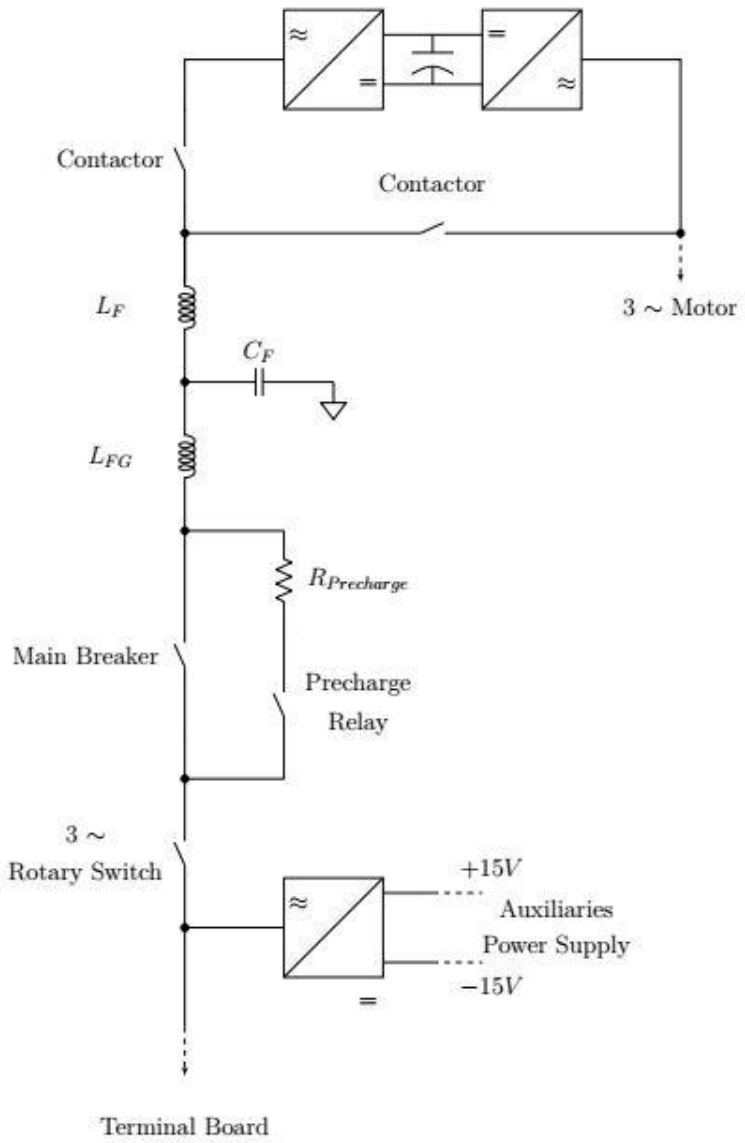
New Test Bench Setup

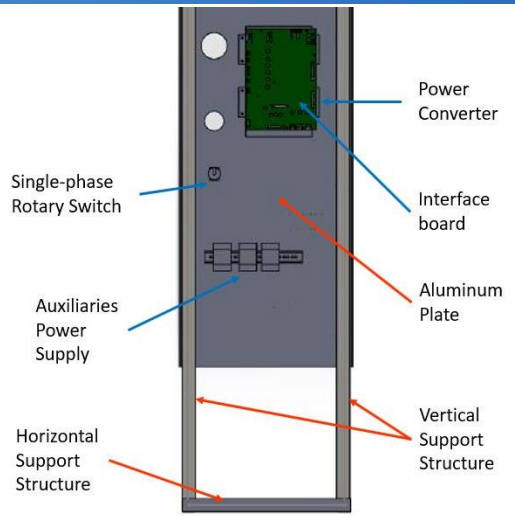


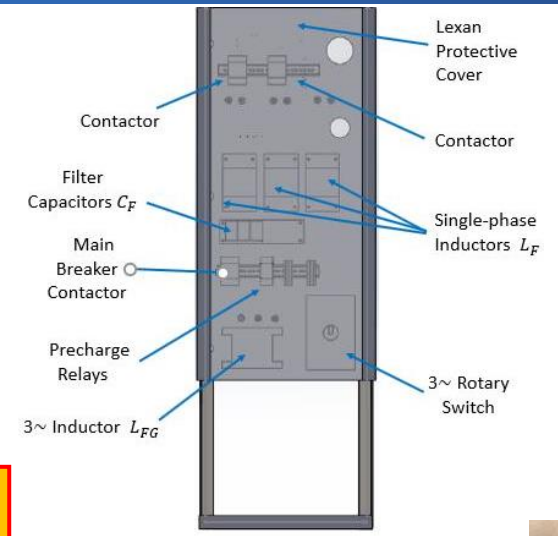


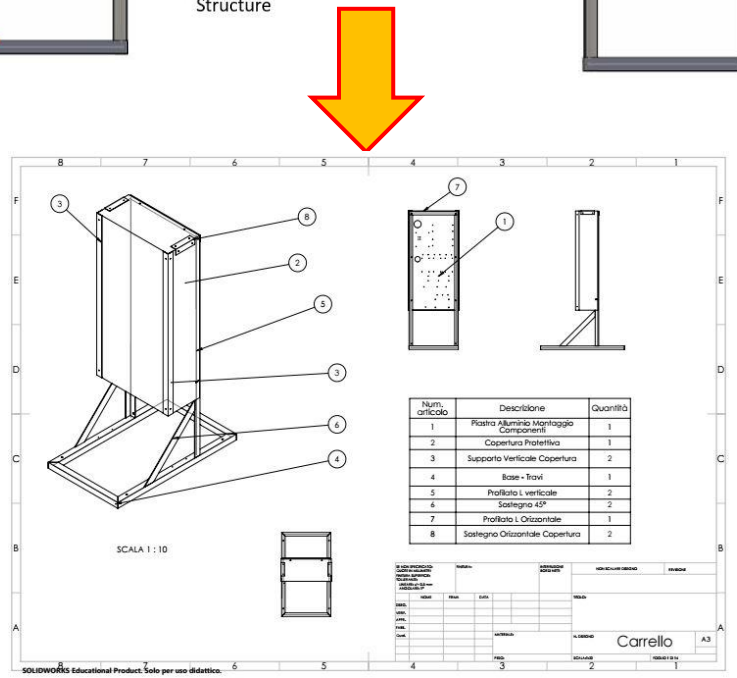
1. Mechanical Design of the support structure for the converter units
2. Assembly of two printed circuit board
3. Test to prove the functionality of the interface board
4. Firmware design of FPGA
5. Assembly of one of the converter units

New Converter Units Support Structure Mechanical Design

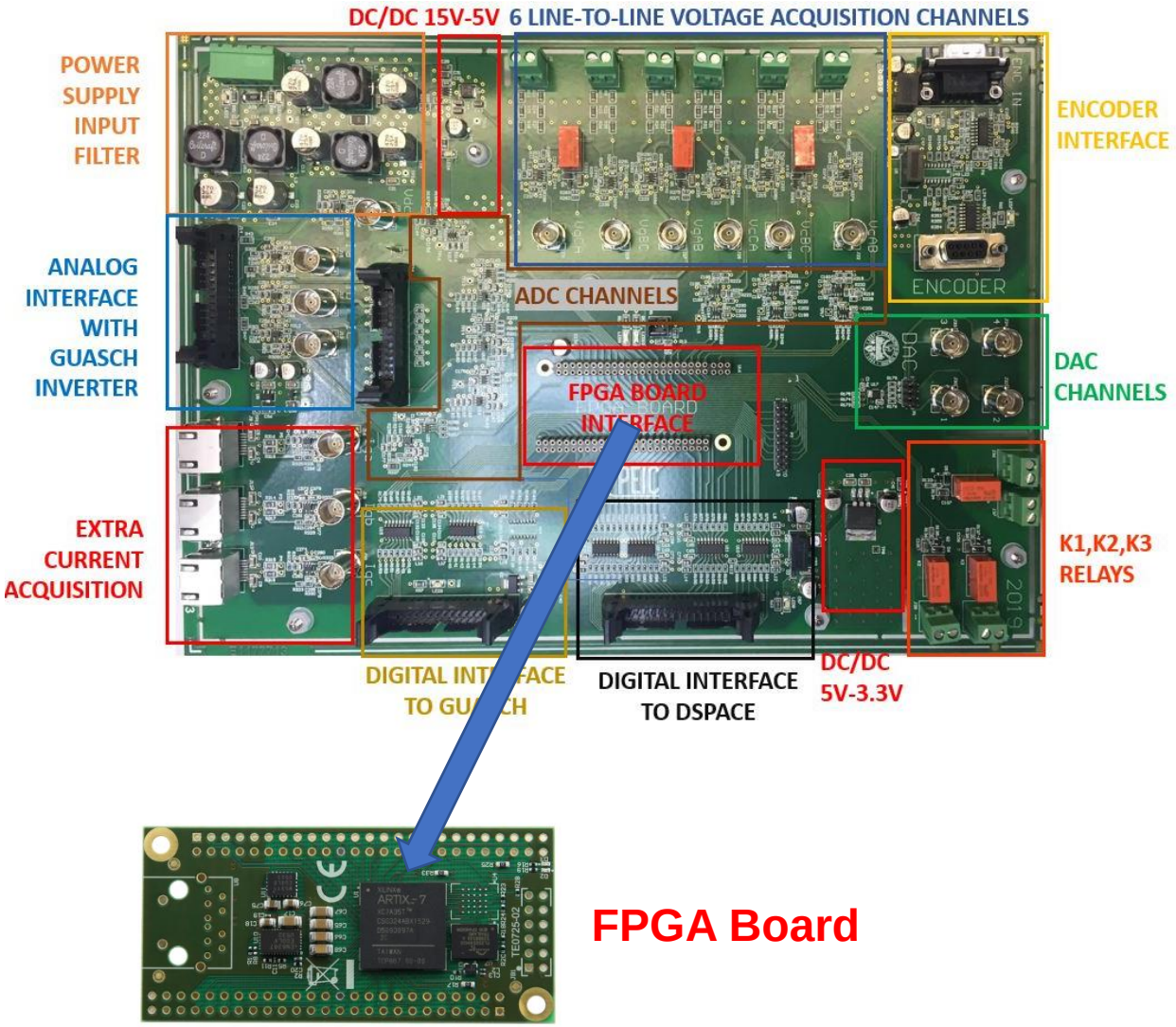








Interface Boards Assembly and Preliminary Tests



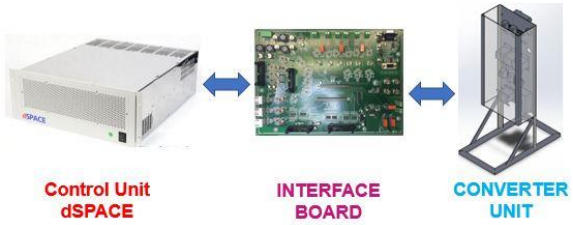
Preliminary Component Test:

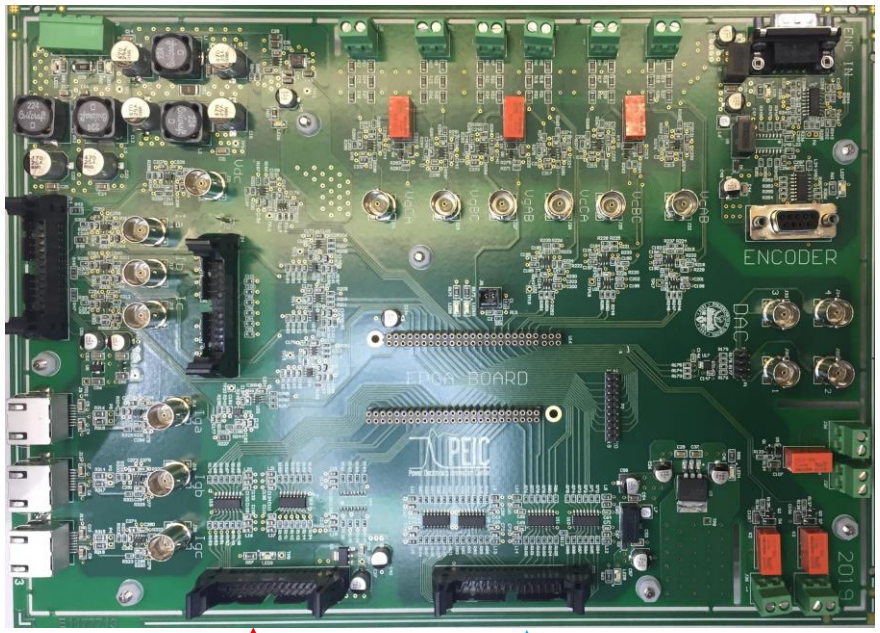
- Power Supply
- Relays
- Leds
- Digital Output Pins
- ADC
- DAC

VIVADO HLx Editions

FPGA Board

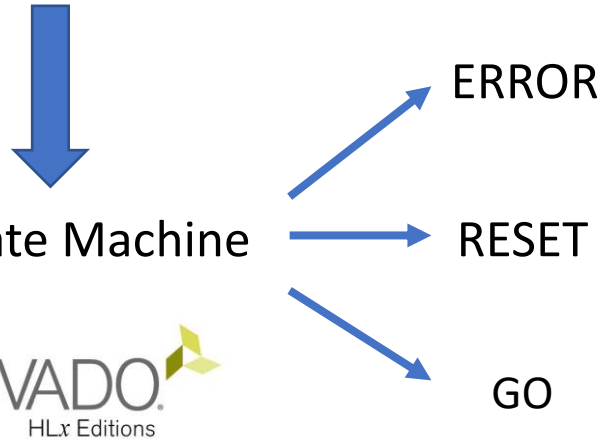
Interface FPGA Board





FPGA tasks:

- Analog acquisitions
- Analog protections
- Driver management
- Communication with dSPACE
- Redirection of the control signals to the power components (Inverter, Relays etc..)



Conclusions

The study of Microgrid Control Strategies is important to ensure their correct functionality.

AC Microgrid Converters Controls

Analysis and implementation of **Grid-forming** control strategies **SL** and **DL**

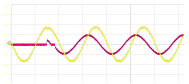
MATLAB

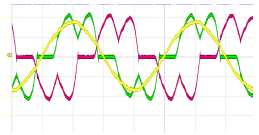
Controllers Design (PI, PRES)

PLECS simulations

Grid-forming C-code

Experimental validations





Analysis of **Grid-supporting** control strategy

MATLAB

Power Synchronization Loop (**PSL**) design and implementation

PLECS simulations

New Test Bench Setup

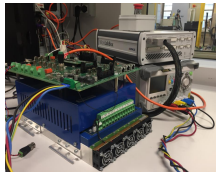
Mechanical Design of the support structure for the converter units

SOLIDWORKS

Assembly of two printed circuit boards

VIVADO HLx Editions

Test to prove the functionality of the interface board



Firmware design of FPGA

Assembly of one of the converter units

Thank you for your attention!