SUMMER SCHOOL "ENABLING DRES TO OFFER ANCILLARY SERVICES" 20TH – 24TH SEPTEMBER 2021

EXPERIMENTAL VALIDATION OF THE EASY-RES CONCEPT: PROTOTYPE UNITARY TESTING AND SYSTEM INTEGRATION TESTING

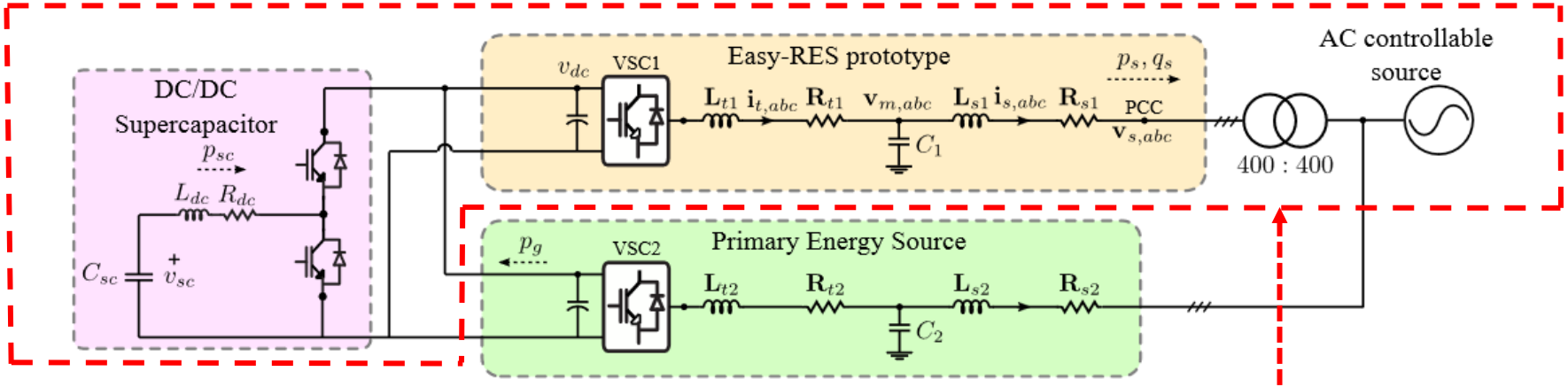
Manuel Barragán-Villarejo // 24/09/2021

This project has received funding from the European Union´s Horizon 2020 Programme for research and innovation under Grant Agreement no 764090.

Agenda

- Description of the EASY-RES prototype
- Control levels of the EASY-RES prototype
- Experimental Validation of EASY-RES functionalities in the EASY-RES prototype
- Description of the scaled-down distribution networks
- Control levels of the scaled-down distribution networks
- Experimental Validation of EASY-RES functionalities in the scaled-down distribution networks

Single-line diagramam of the EASY-RES prototype



- Main Power Components:
  - DC/AC converter
  - Supercapacitor
  - Bidirectional DC/DC converter
  - Primary energy source emulated by a second DC/AC converter
  - Power Filters

EASY-RES prototype

Description of the EASY-RES prototype

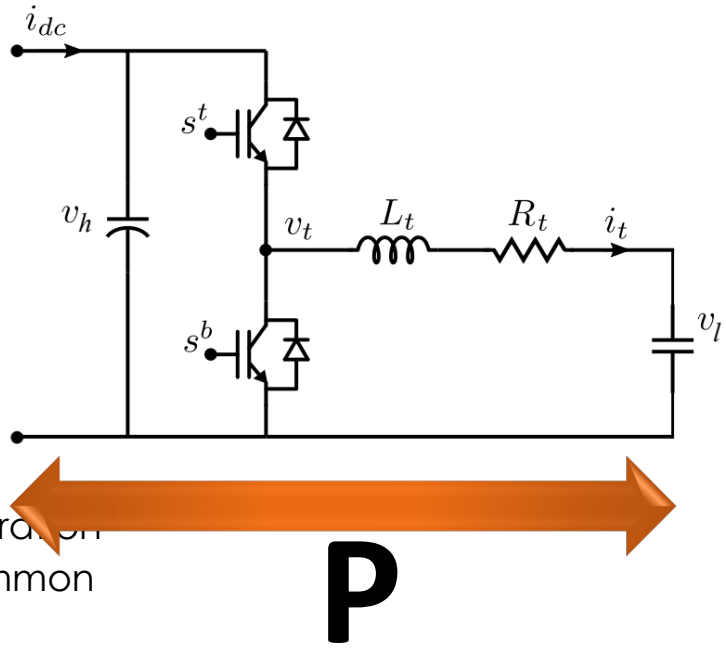
Supercapacitor

- Rated value:
  - Supercapacitor provide by Maxwell
  - Capacitance; 6 F
  - Voltage: 160 V
  - Rated current: 12 A
  - Energy: 76.8 kJ / 21.333 Wh
- Operation Condition in EASY-RES
  - Operation Voltage for EASY-RES: 130 V
  - Minimum Voltage for EASY-RES: 100 V
  - Maximum Voltage for EASY-RES: 155 V
  - Maximum Power: 2 kW

https://www.maxwell.com/products/ultracapacitors/160v-mod

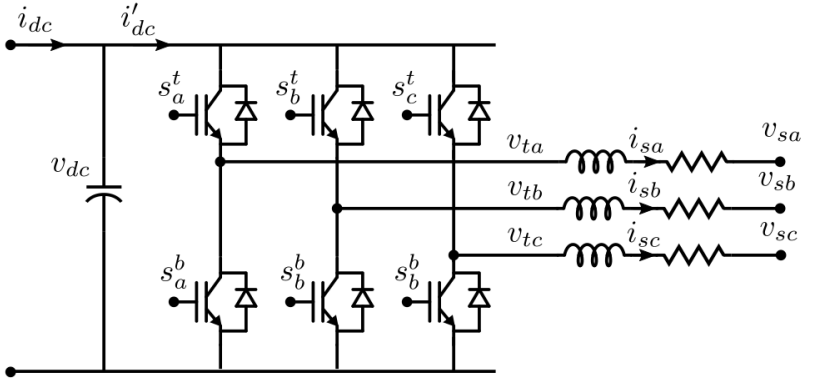
Bidirectional DC/DC converter

- Single column of IGBTs
- Rated value
  - DC voltage in High voltage side: 800 V
  - DC voltage in Low voltage side: 400 V
  - Rated current: 40 A
  - Biderectional power flow
- Operation Condition in EASY-RES
  - High Voltage side: 750 V. Common DC bus of EASY-RES prototype
  - Low Voltage side: 130 V. Supercapacitor integration
  - In charge of controlling the voltage of the common DC bus
  - Switching frequency: 10 kHz
  - Integrated in the DC/AC converter



DC/AC converter

- Three-phase three-wire and two level DC/AC converter
- Rated value
  - DC voltage side: 800 V
  - AC voltage side: 400 V rms
  - Rated current: 40 A
  - Rated power: 20 kVA
  - DC capactiance: 2200 μF
- Operation Condition in EASY-RES
  - DC voltage side: 750 V. Common DC bus

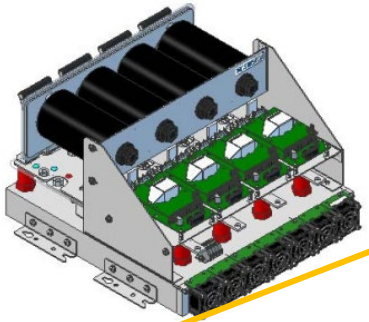


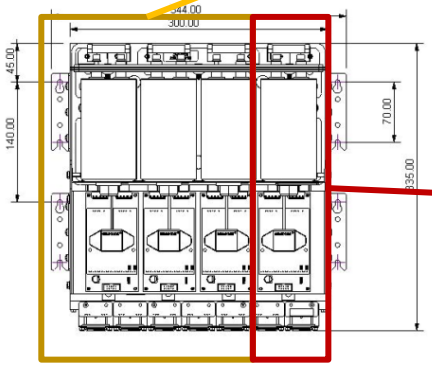
EASY-RES prototype

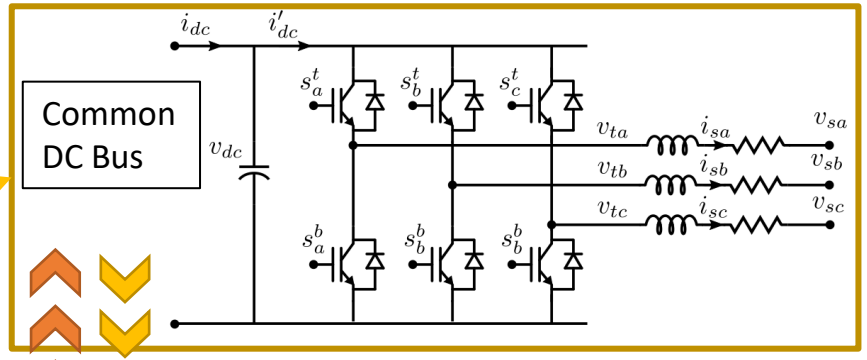
  - AC voltage side: Connected to a Controllable Voltage Source through a LCL filter and transformer
  - Switching frequency: 10 kHz
  - In charge of implementing the UVSG and EASY-RES functionalities

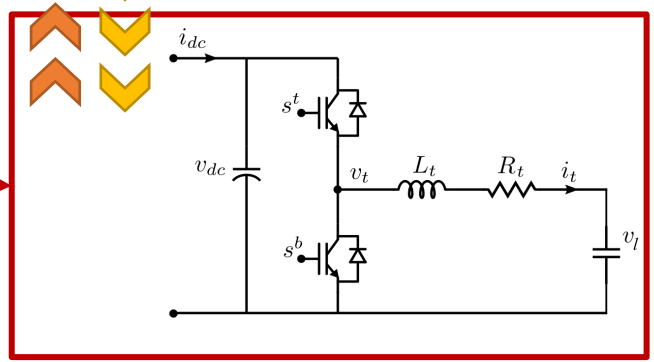
Description of the EASY-RES prototype

Integration of DC/DC and DC/AC converter





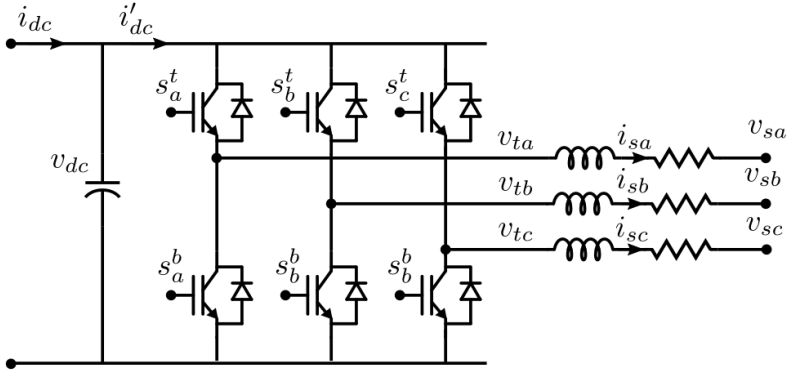




https://www.poweralia.com/products/6007

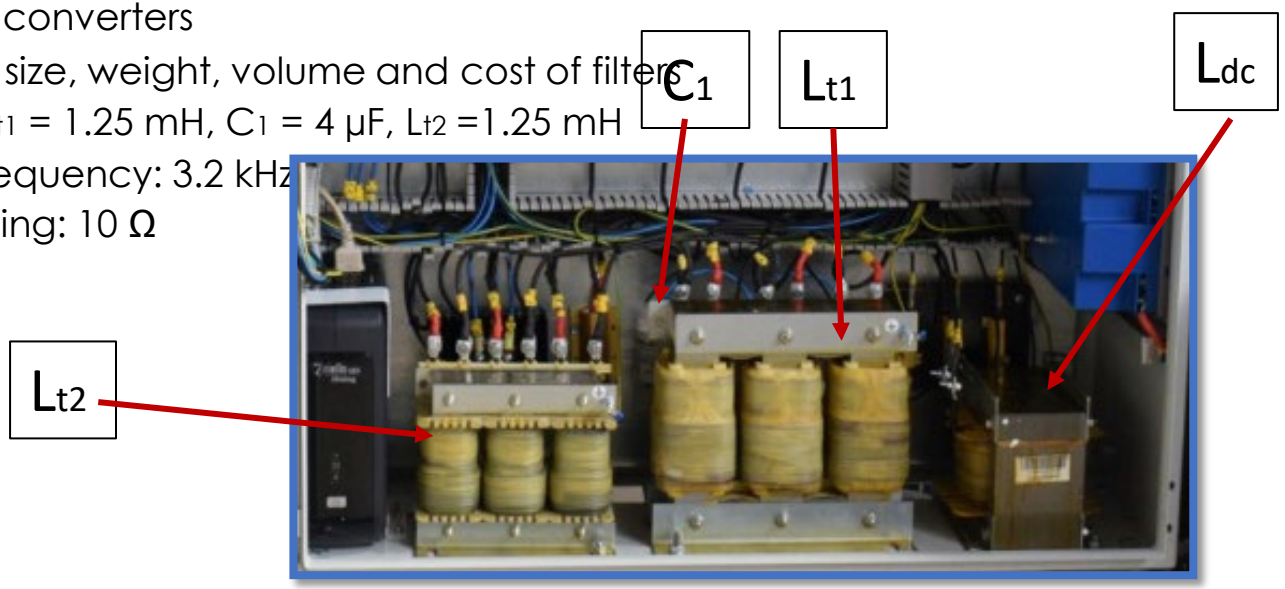
Primary energy source

- Three-phase three-wire and two level DC/AC converter
- Rated value
  - DC voltage side: 800 V
  - AC voltage side: 400 V rms
  - Rated current: 40 A
  - Rated power: 20 kVA
  - DC capactiance: 2200 μF
- Operation Condition in EASY-RES
  - DC voltage side: 750 V. Common DC bus of the EASY-RES prototype
  - AC voltage side: Connected to a Controllable Voltage Source through a LCL filter
  - Switching frequency: 10 kHz
  - In charge of emulating the active power of a primary energy source (PV or WT)
  - Classic Active and reactive power control of a grid-feeding power converter in *dq*



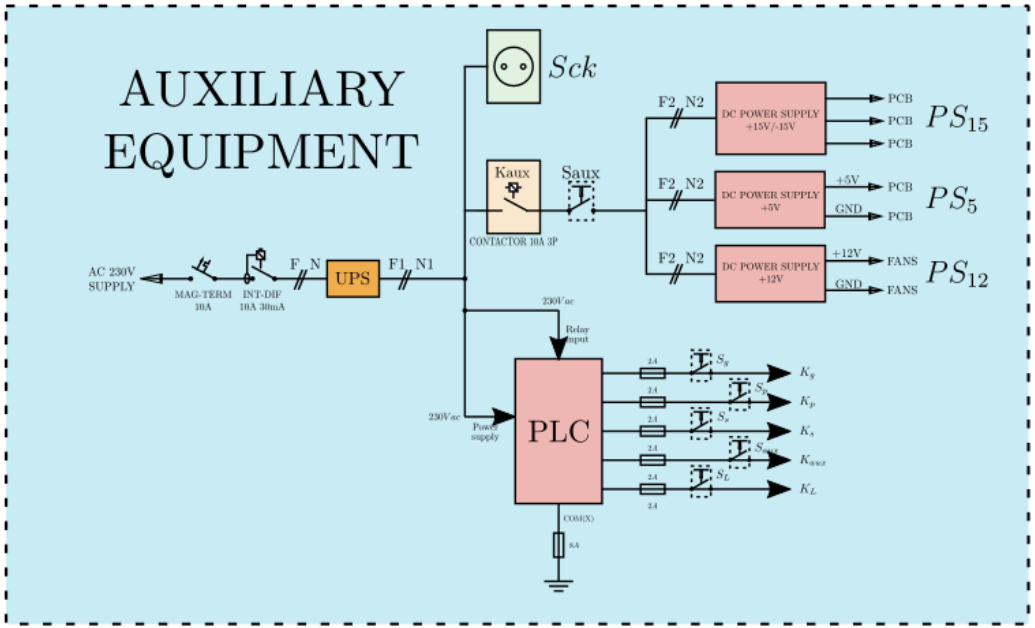
Power filters

- Inductive filter between the Supercapacitor and DC/DC converter
  - Reducing the switching frequency to avoid overtemperature in the Supercapacitor
  - Inductance: L_{dc} = 3 mH
- LCL filter for DC/AC converters
  - Reducing the size, weight, volume and cost of filters
  - Parameters: L_{t1} = 1.25 mH, C_1 = 4 µF, L_{t2} =1.25 mH
  - Resonance frequency: 3.2 kHz
  - Passive damping: 10 Ω



Description of the EASY-RES prototype

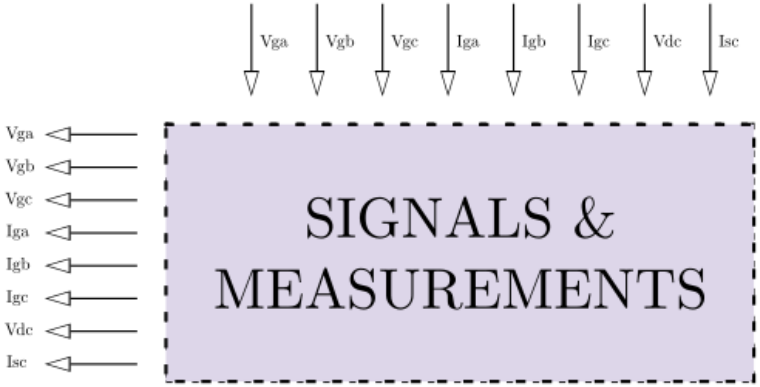
Control and auxiliary devices



- Electronics power supply
- Uninterruptible power supply for the control system
- PLC-controlled switchgear
- PLC-controlled Grid-former / Grid-feeder functionality switching

Description of the EASY-RES prototype

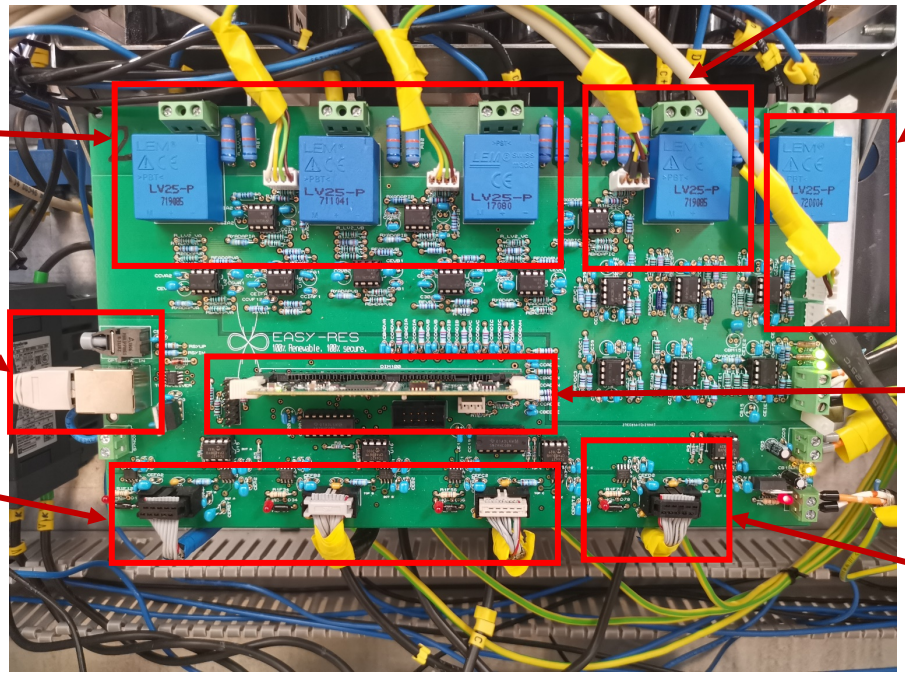
Measurements



Measurement	Type	M. Range	S. Range
V_{gabc}	Sinusoidal	$[-320V, +320V]$	$[-5V, +5V]$
I_{gabc}	Sinusoidal	$[-150A, +150A]$	$[-4V, +4V]$
V_{DC}	Constant value.	$[0V, +1.312kV]$	$[0V, +5V]$
V_{SC}	Constant value.	$[0V, +320V]$	$[0V, +5V]$
I_{SC}	Constant value.	$[-150A, +150A]$	$[-4V, +4V]$

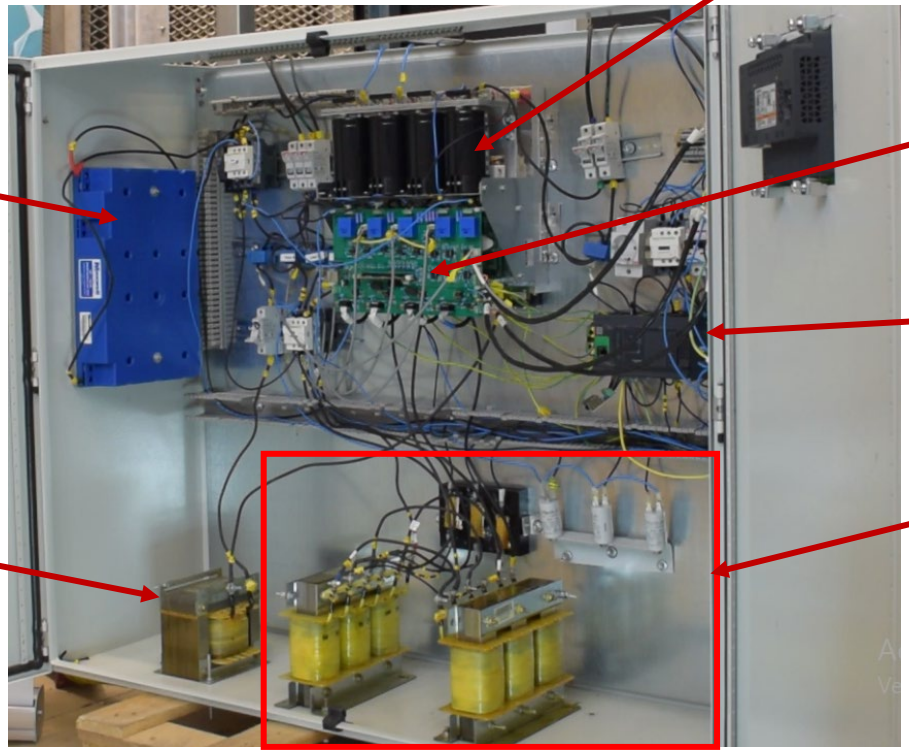
Description of the EASY-RES prototype

Control board



Description of the EASY-RES prototype

Final configuration

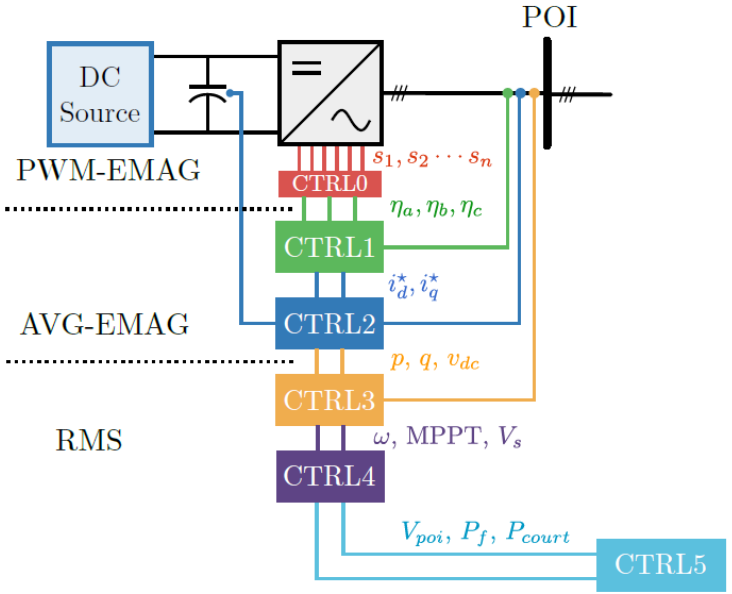


Description of the EASY-RES prototype

Final configuration

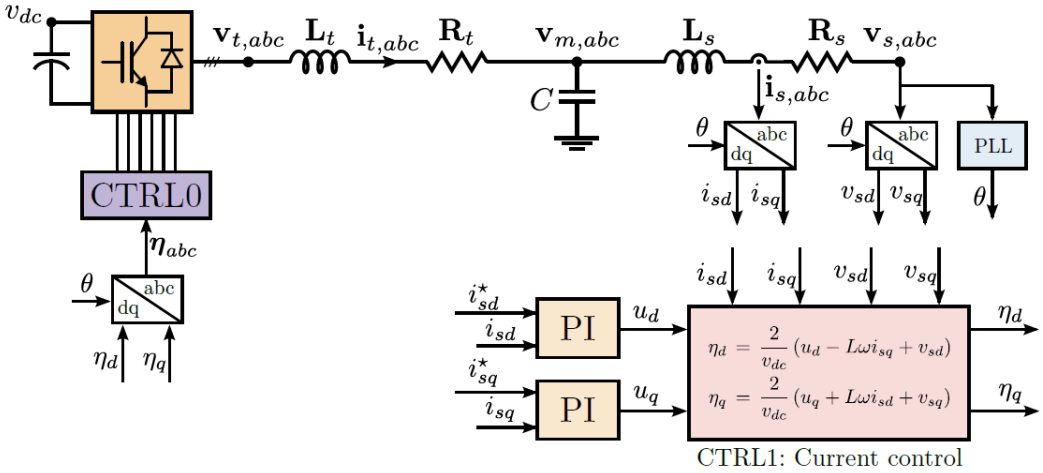
Control levels

- General overview of the Local Control System
  - Presented by Assoc. Prof. Juan Manuel Mauricio on Monday 20th



Control levels in the EASY-RES prototype

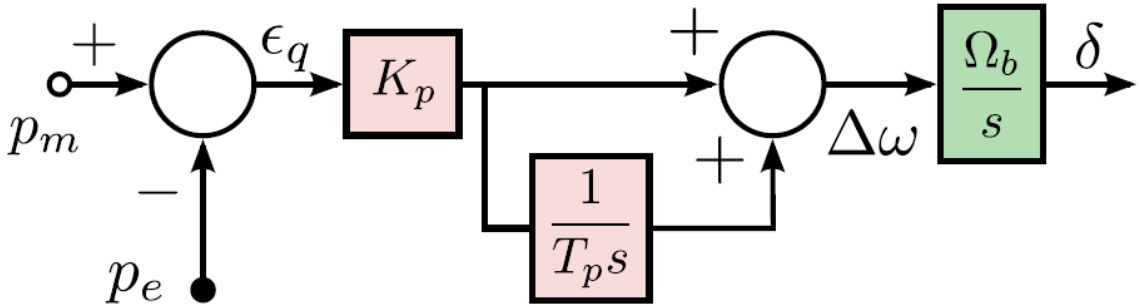
- Control Level 0
  - It corresponds to the generation of control signals to the IGBTs of the DC/DC and DC / AC converter. SPWM technique.
- Control Level 1 of the DC/AC converter
  - It is a current controller based on model in dq coordinates



CTRL1: Current control

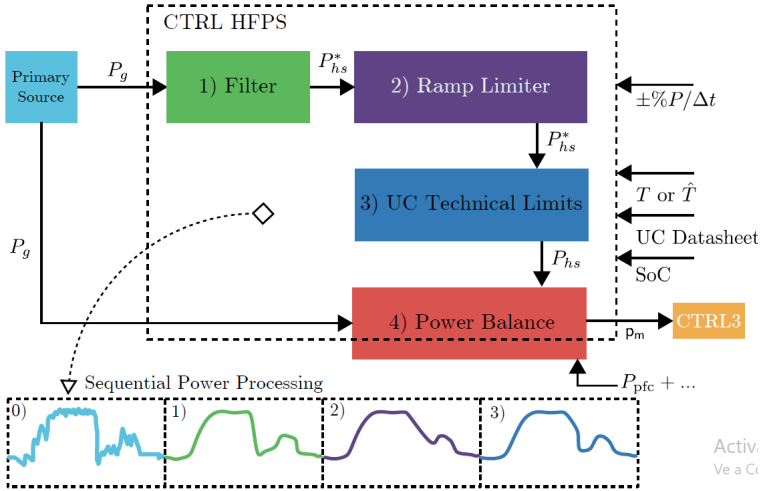
Control levels

- Control Level 3 of the DC/AC converter
  - UVSG approach for providing true controllable inertiapresented by Dr. Georgios C. Kryonidis on Monday 20th



Control levels

- Control Level 3 of the DC/AC converter
  - High Frequency Power Smoothing. Rampe Rate Limiter (RRL) approach presented by Kyriaki-Nefeli D. Malamaki on Tuesday 21th



Kyriaki-Nefeli D. Malamakia et al. "Ramp-Rate Control of DRES employing Supercapacitors in Distribution Systems", SEST'21, 6-9 Sept, Vaasa, Finlad

Control levels

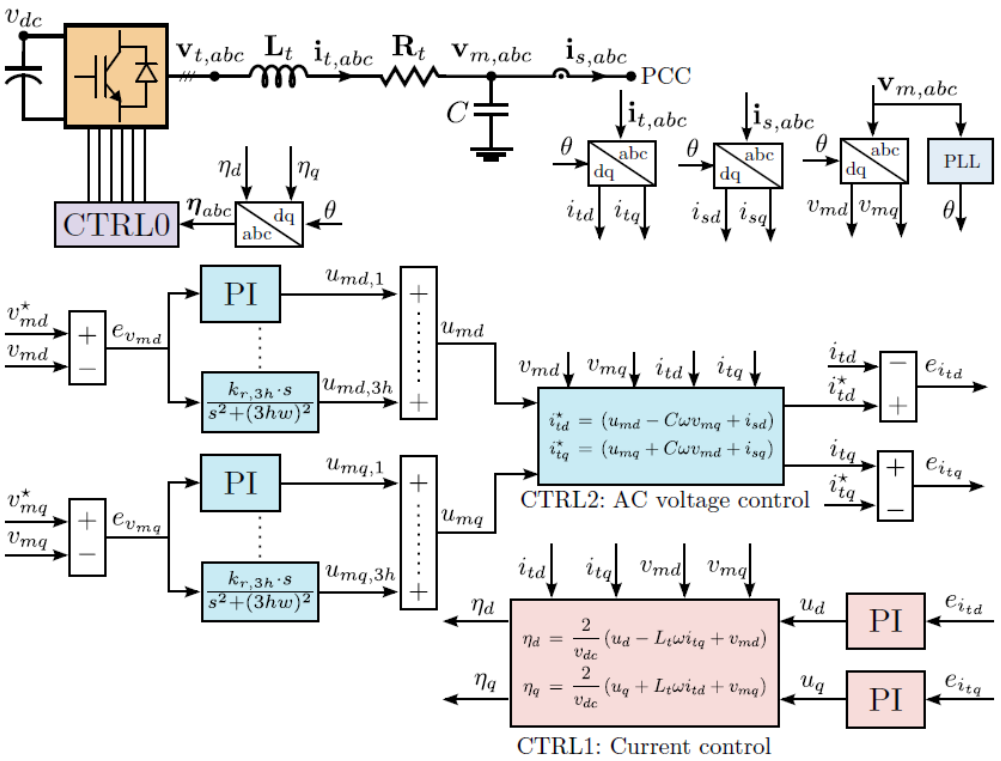
- Control Level 3 of the DC/AC converter
  - Reactive power provision by Dr. Georgios C. Kryonidis on Monday 20th and Tuesday 21th

Kryonidis, Georgios C. / Demoulias, Charis S. / Papagiannis, Grigoris K. (2019): A new voltage control scheme for active medium-voltage (MV) networks, Electric Power Systems Research, 169, pp. 53-64
Kryonidis, Georgios C. / Demoulias, Charis S. / Papagiannis, Grigoris K. (2019): A two-stage solution to the bi-objective optimal voltage regulation problem, IEEE Transactions on Sustainable Energy, April 2019.

Control levels of the EASY-RES prototype

Control levels

- Control Level 3 of the DC/AC conve
- Active Harmonic Filtering
  - Cascade controller to mitigate the harmomic voltage at the PCC
  - New control signals are addec Control Level 1

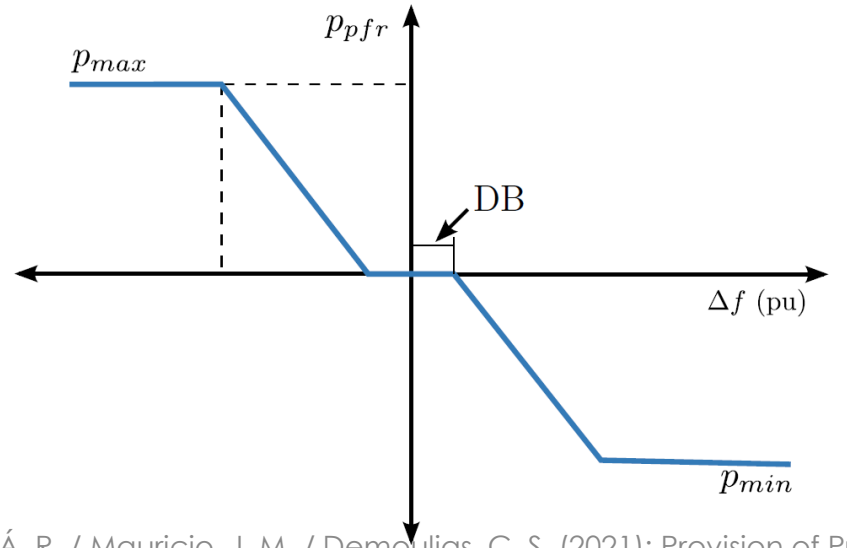


Barragán-Villarejo, M. / Mauricio, J.M. / Olives-Camps, J.C. / Matas-Díaz, F.J. / de Paula García-López, F. / Maza-Ortega J.M. (2020): Harmonic and Imbalance Compensation in Grid-Forming VSC, 2020 IEEE International Conference on Industrial Technology (ICIT), Buenos Aires, Argentina, pp. 757-762

Abstract Accepted in PSSC'22. Coordinated Active Harmonic Filtering in Distribution Networks with High RES Penetration

Control levels

- Control Level 4 of the DC/AC converter
  - Primary Frequency Response presented by Asist. Prof. Álvaro Rodríguez del Nozal



Kontis, E. O. / del Nozal, Á. R. / Mauricio, J. M. / Demoulias, C. S. (2021): Provision of Primary Frequency Response as Ancillary Service from Active Distribution Networks to the Transmission System, in IEEE Transactions on Smart Grid

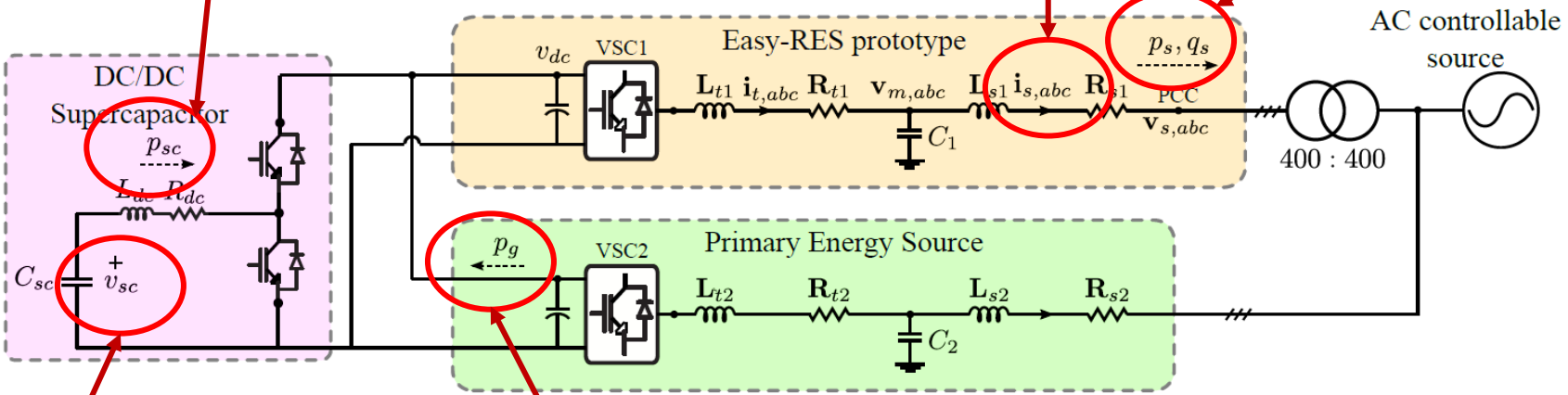
Mangitude to be analysed

- Control Level 4 of the DC/AC converter

Current injected by the DRES

Power injected by the DRES

Power injected by the SC



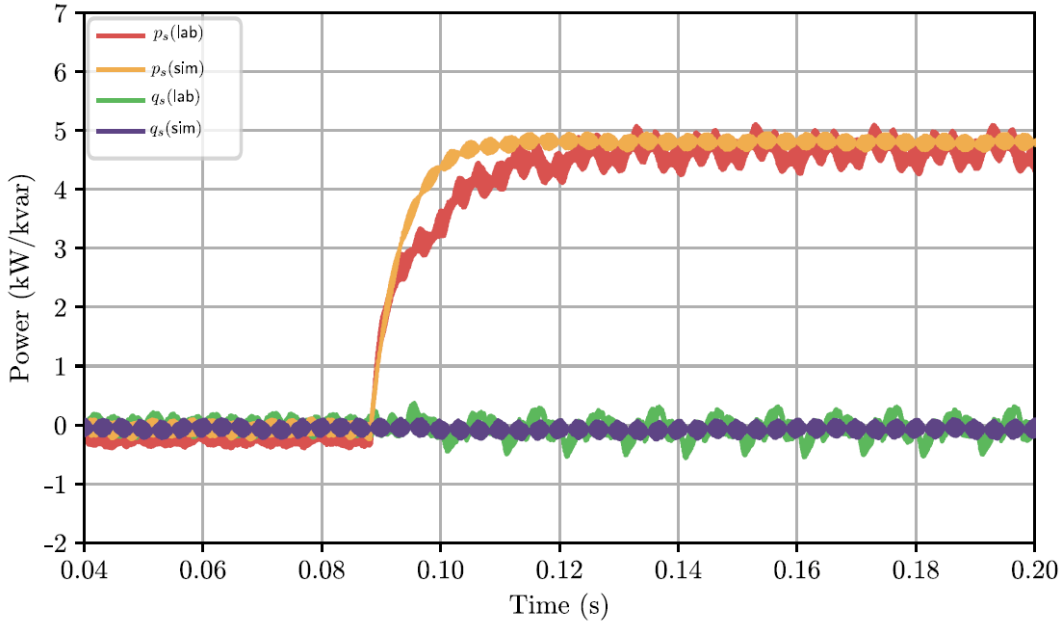
SC voltage

Power from the primary energy source

Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

Control Level 1. Current controller

- Transient state: Step change from i_{sq}*=0 A→ i_{sq}*=10 A ; i_{sd}*=0 A

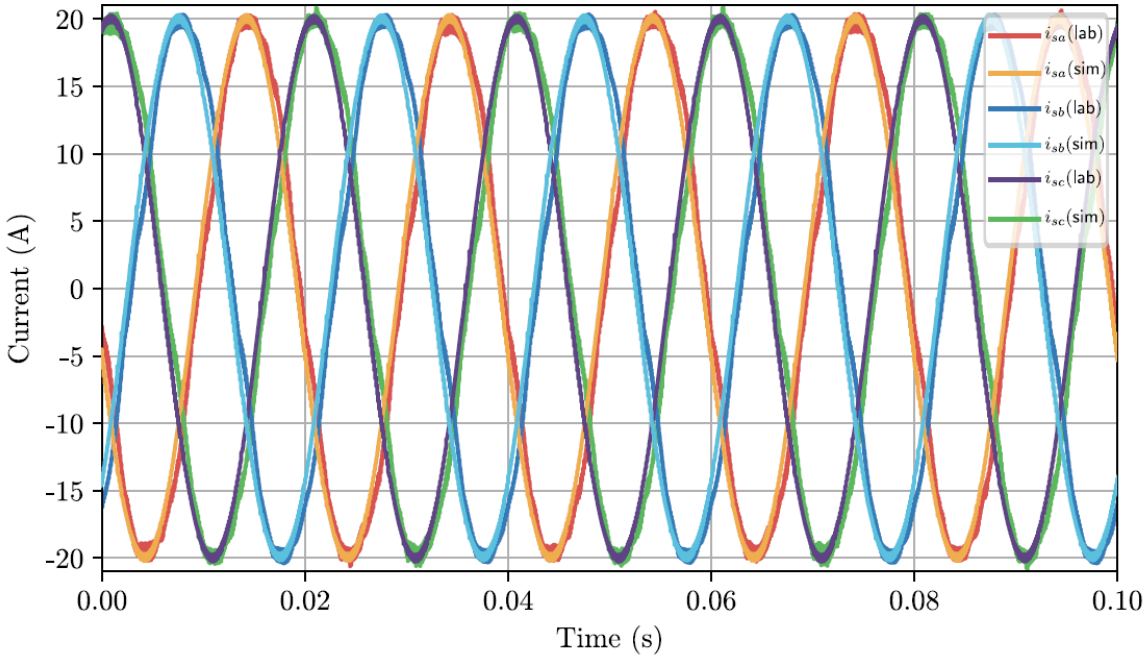


Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

Control Level 1. Current controller

- Steady-state: i_{sd}*=0 A; i_{sq}*=20 A

THD: 2.5%

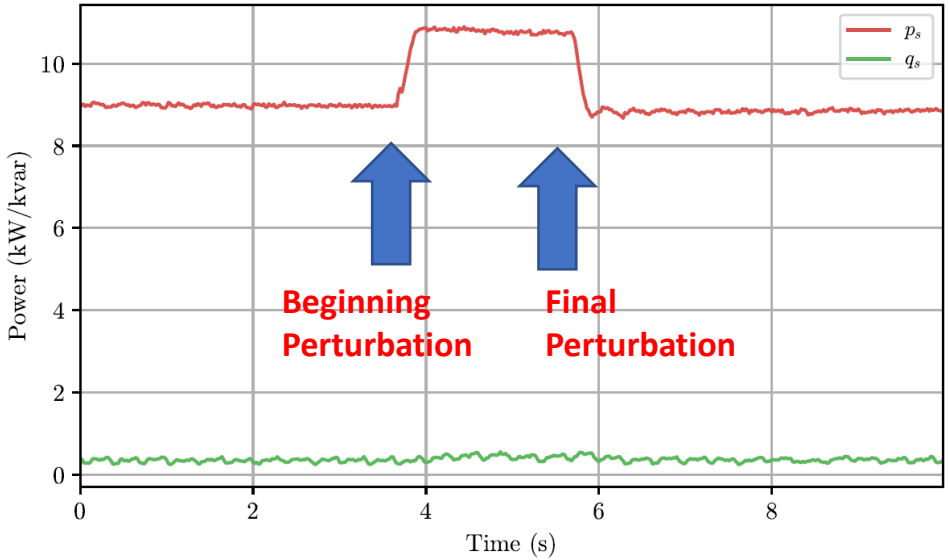


Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

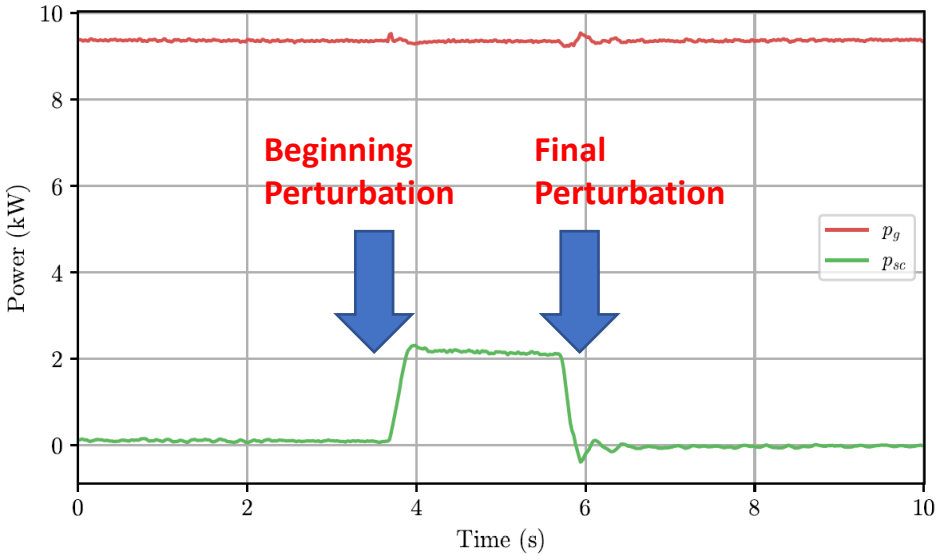
Inertia Provision

- Frequency perturbation. RoCoF: -0.5 Hz/s during 2 s. and H = 5 s

Active and Reactive Power injected at the PCC



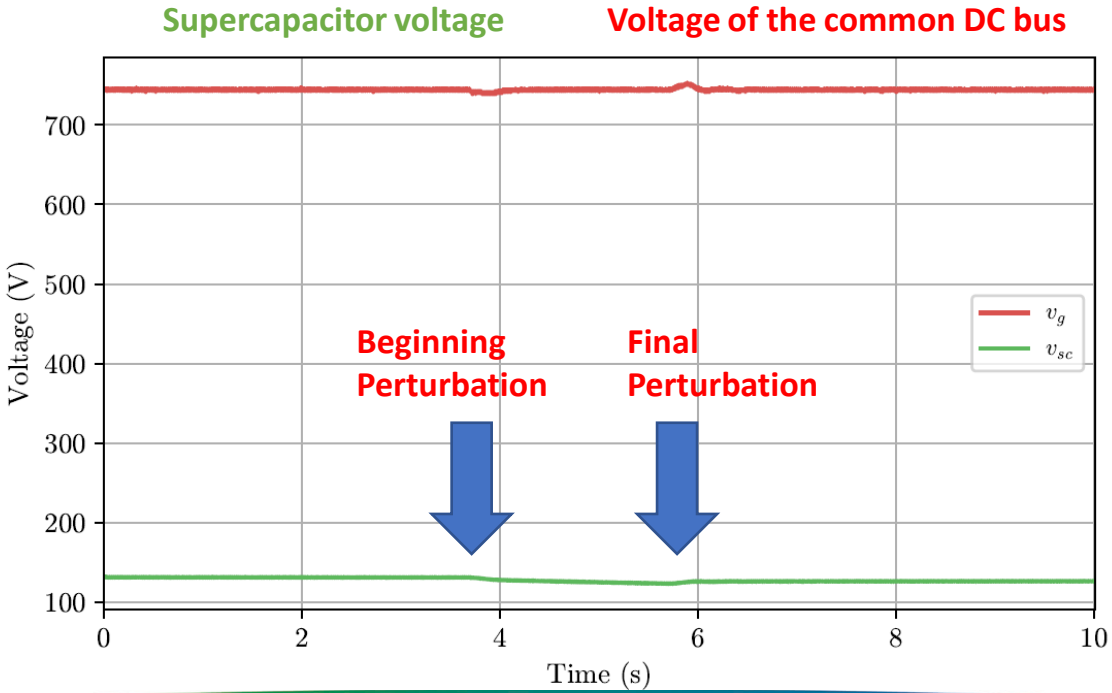
Active power from the primary energy source
Active power from the SC



Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

Inertia Provision

- Frequency perturbation. RoCoF: -0.5 Hz/s during 2 s. and H = 5 s

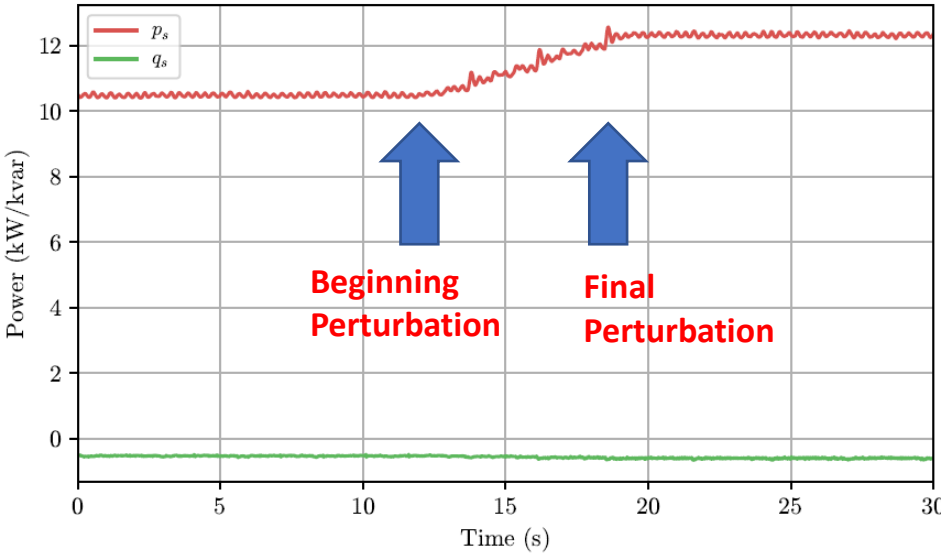


Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

Primary Frequency Response

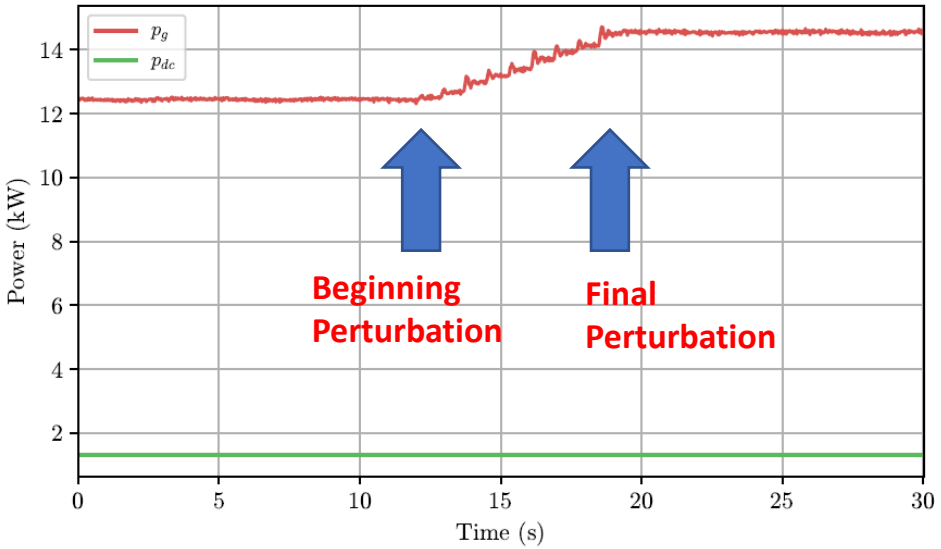
- Frequency perturbation. RoCoF: -0.5 Hz/s during 8 s. droop = -0.526 kW/Hz. Headroom = 2kW

Active and Reactive Power injected at the PCC



Active power from the primary energy source

Active power from the SC

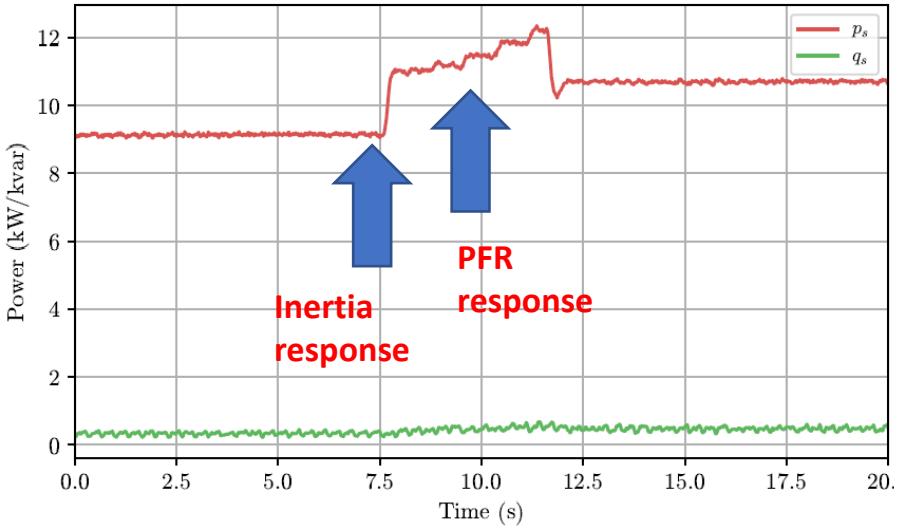


Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

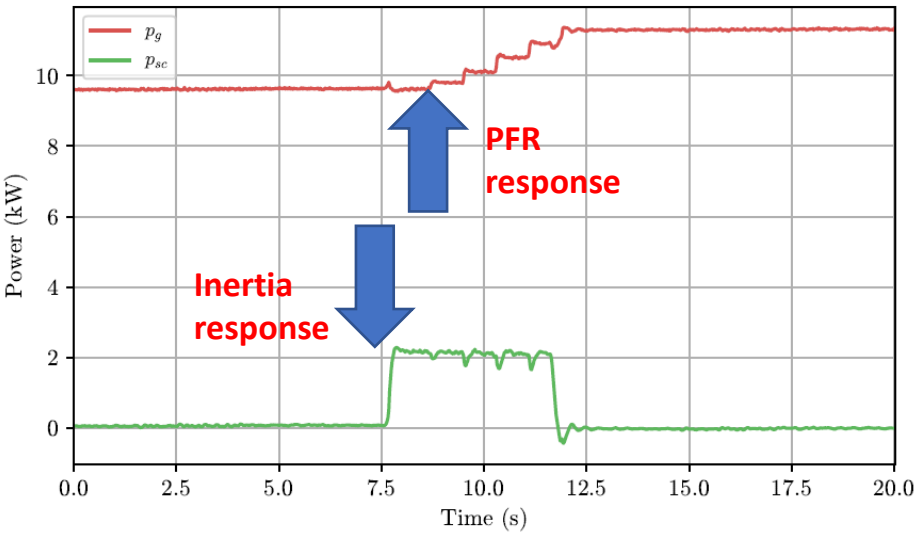
Inertia and Primary Frequency Response

- Frequency perturbation. RoCoF: -0.5 Hz/s during 4 s. droop = -0.526 kW/Hz. Headroom = 2kW. H= 5s

Active and Reactive Power injected at the PCC

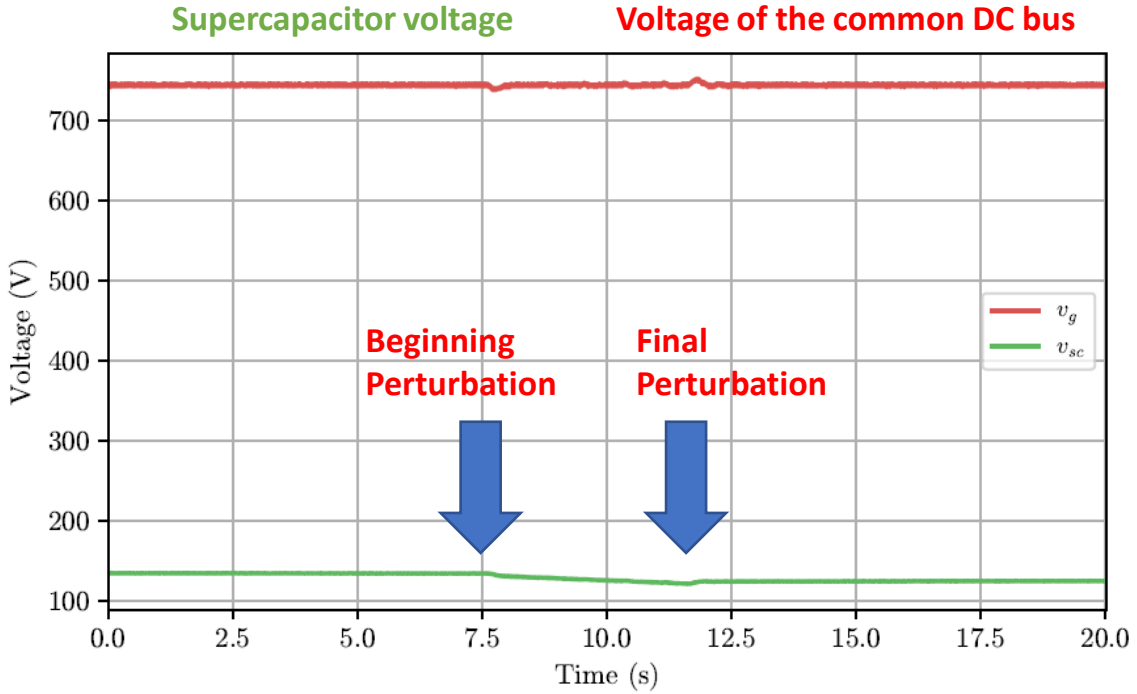


Active power from the primary energy source
Active power from the SC



Inertia and Primary Frequency Response

- Frequency perturbation. RoCoF: -0.5 Hz/s during 4 s. droop = -0.526 kW/Hz. Headroom = 2kW. H= 5s

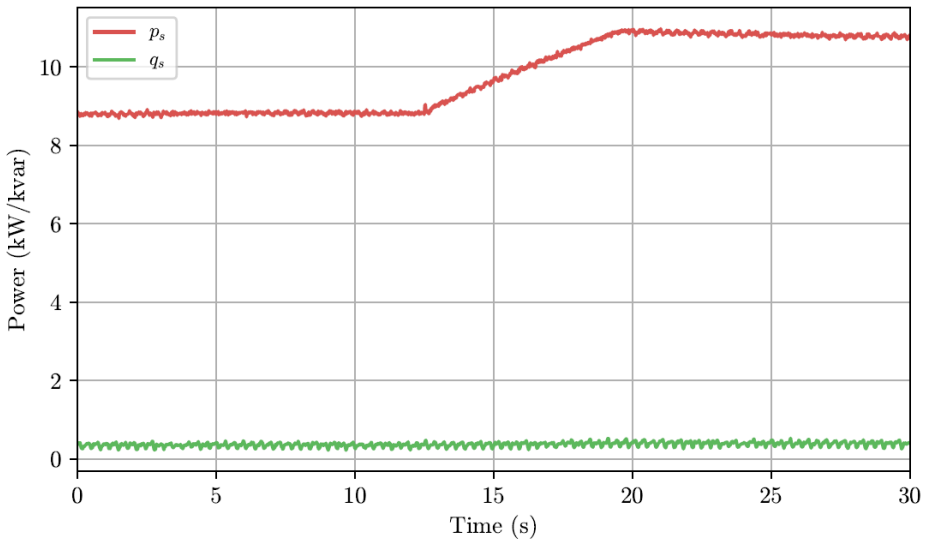


Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

High Frequency Power Smoothing.

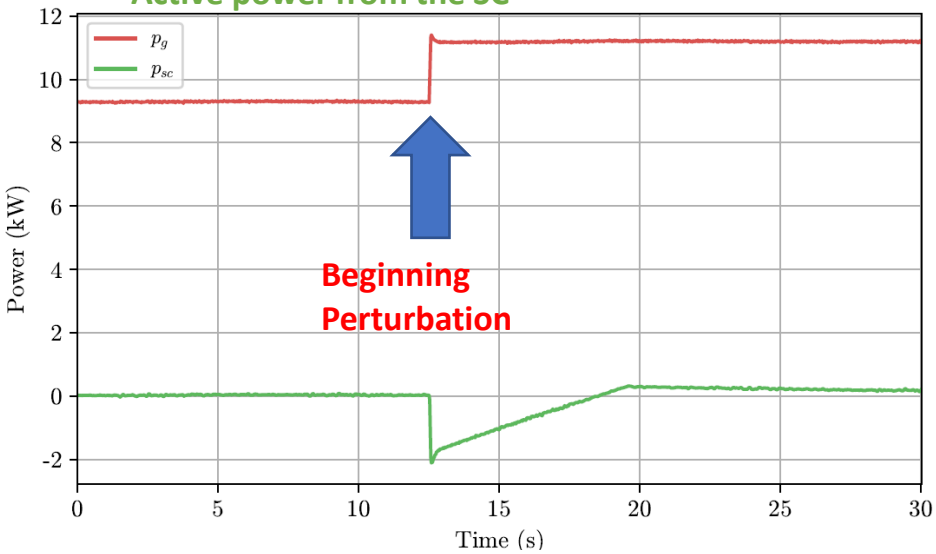
- Step change of 2 kW in the primary energy source. RRL= 300 W/s.

Active and Reactive Power injected at the PCC



Active power from the primary energy source

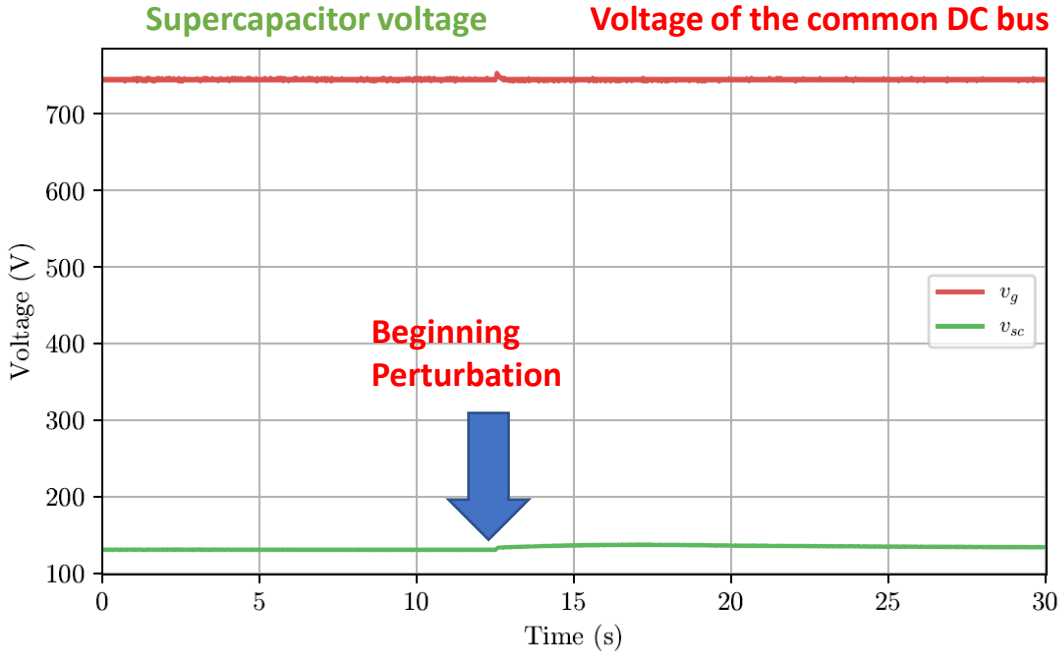
Active power from the SC



Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

High Frequency Power Smoothing.

- Step change of 2 kW in the primary energy source. RRL= 300 W/s.

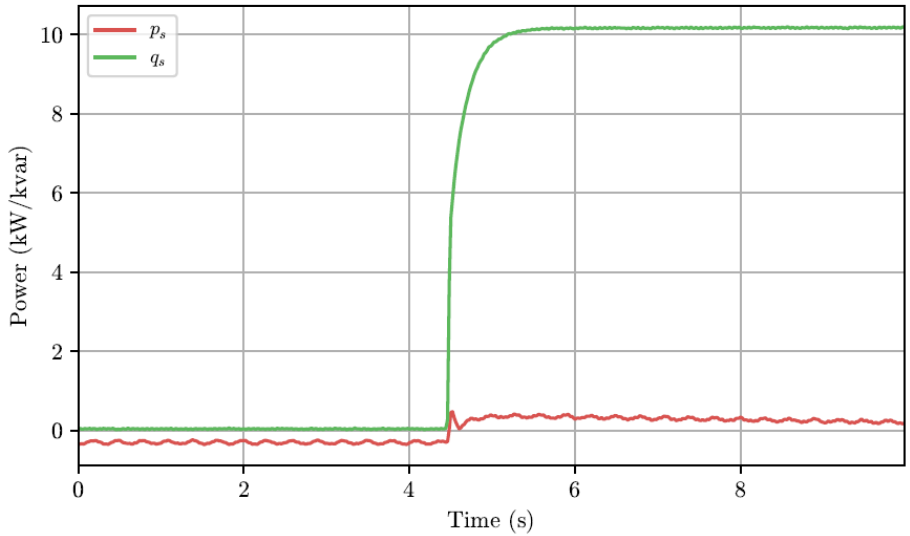


Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

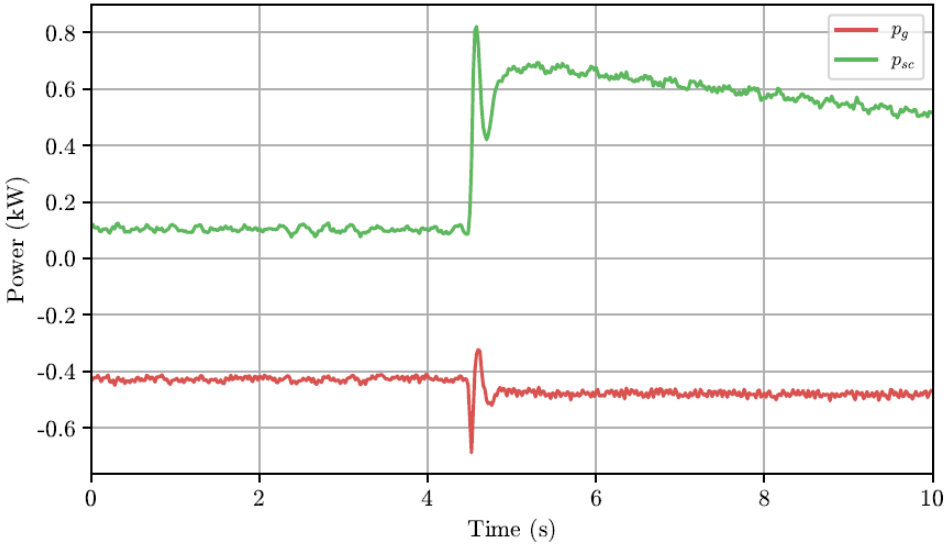
Reactive Power Provision

- Step change of 10 kvar

Active and Reactive Power injected at the PCC



Active power from the primary energy source
Active power from the SC

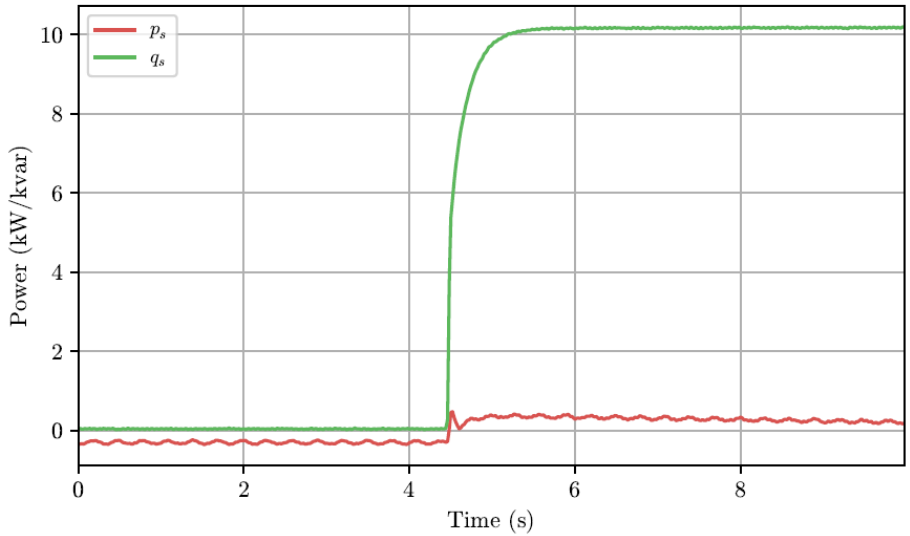


Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

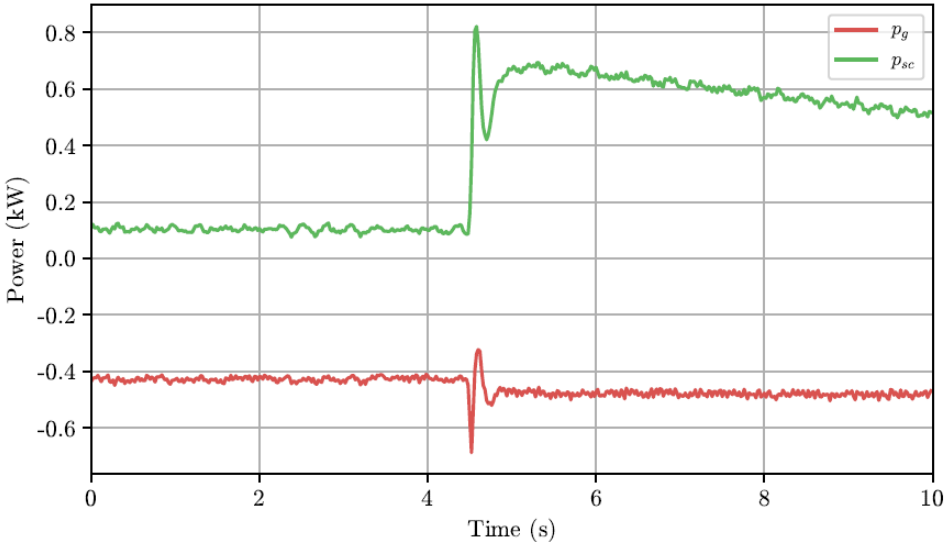
Reactive Power Provision

- Step change of 10 kvar

Active and Reactive Power injected at the PCC

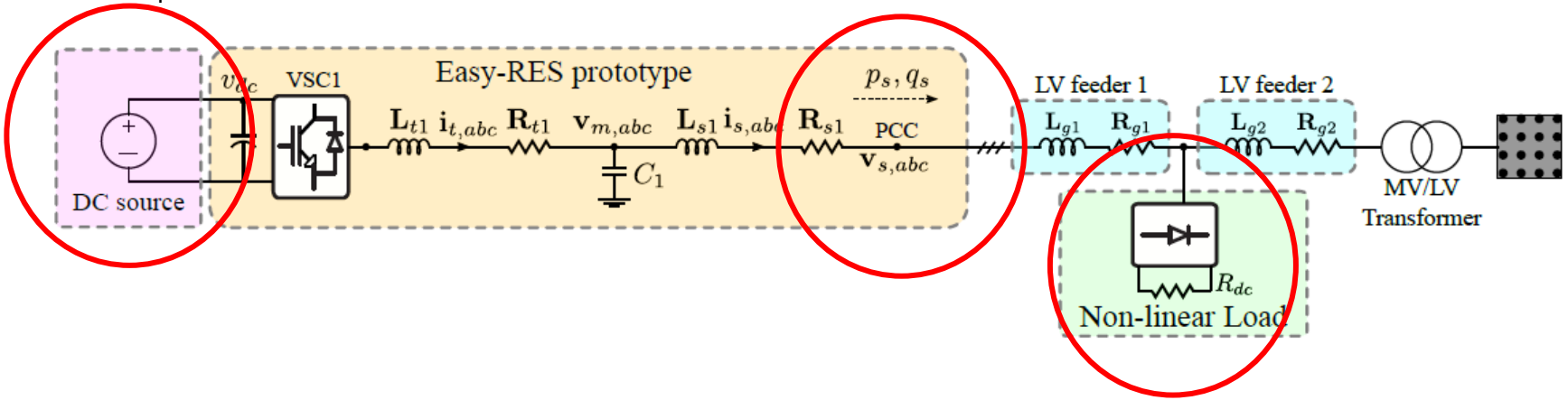


Active power from the primary energy source
Active power from the SC



Active Harmonic Filtering

- Experimental test



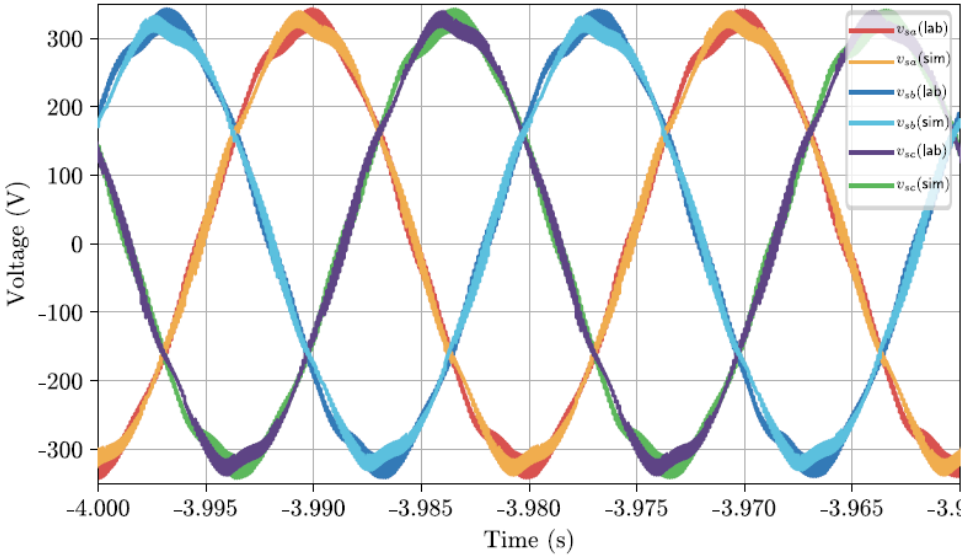
Parameter	L_{g1} (mH)	R_{g1} (Ω)	L_{g2} (mH)	R_{g2} (Ω)	R_{dc} (Ω)
Value	39.9479	0.24	10.0268	0.1	10

Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

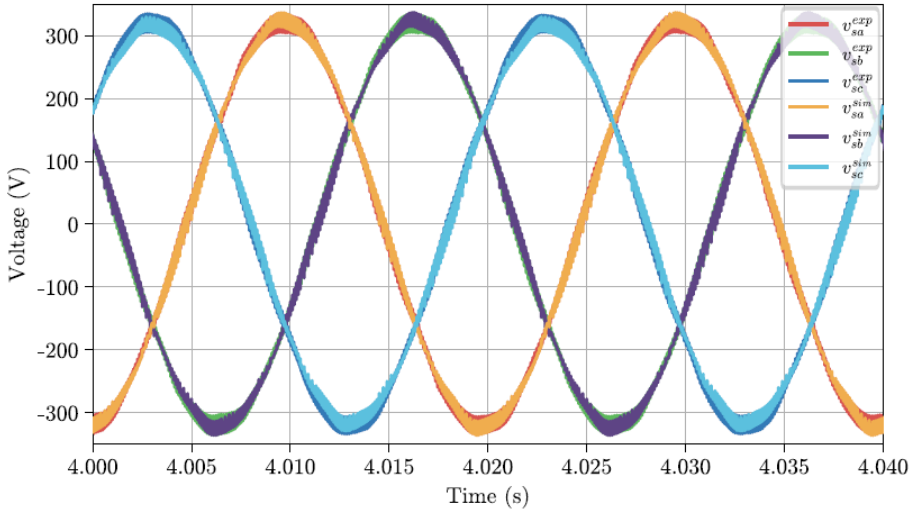
Active Harmonic Filtering (AHF)

- Voltage at PCC

Withouth AHF functionalty



With AHF



Active Harmonic Filtering (AHF)

- Power quality of voltages

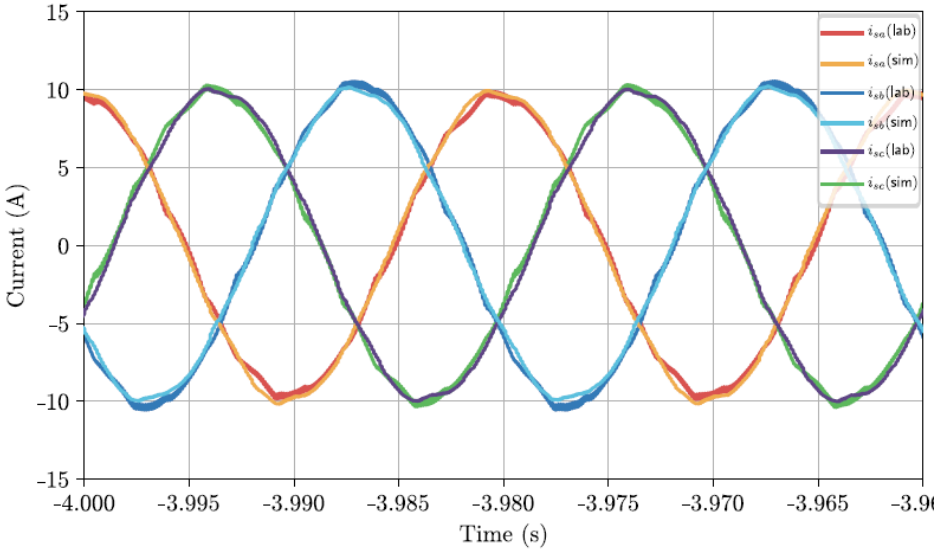
Test	V_5 (%)	V_7 (%)	V_{11} (%)	V_{13} (%)	THD (%)
Laboratory (No AHF)	1.03	2.08	0.62	0.35	2.43
Simulation (No AHF)	1.07	2.07	0.26	0.47	2.39
Laboratory (AHF)	0.43	0.84	0.47	0.23	1.09
Simulation (AHF)	0.3	0.61	0.27	0.46	0.87

Experimental Validation of EASY-RES functionalities in the EASY-RES prototype

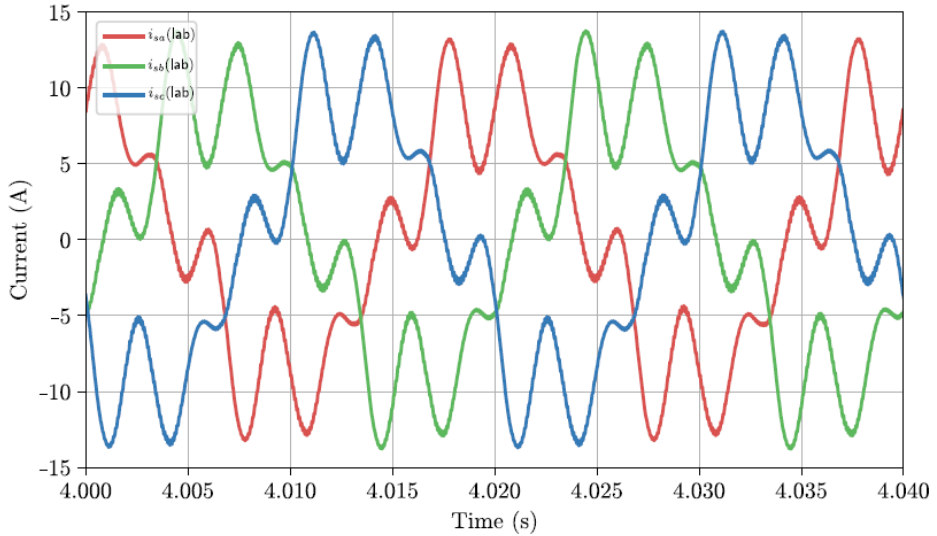
Active Harmonic Filtering (AHF)

- Current injected at PCC

Withouth AHF functionalty



With AHF



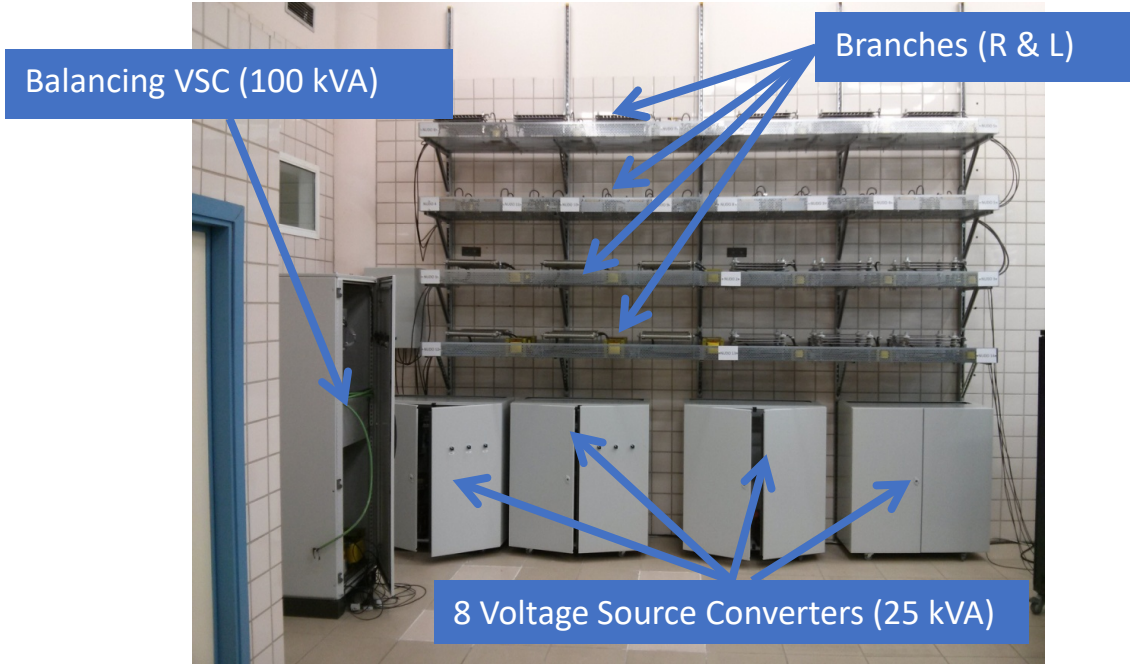
Active Harmonic Filtering (AHF)

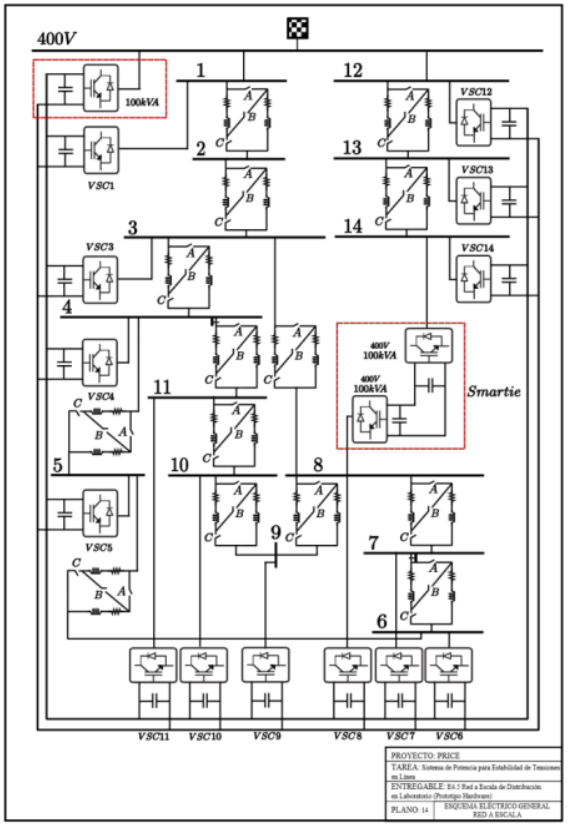
- Power quality of currents

Test	I_5 (%)	I_7 (%)	I_{11} (%)	I_{13} (%)	THD (%)
Laboratory (No AHF)	0.25	1.28	1.94	0.59	2.58
Simulation (No AHF)	0.91	1.42	0.18	0.53	2.01
Laboratory (AHF)	22.37	33.23	0.66	0.37	40.08
Simulation (AHF)	18.91	28.12	0.1	0.39	33.9

MV Scaled-down distribution network

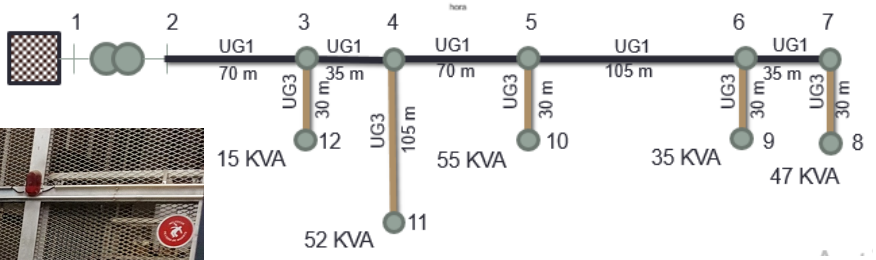
- MV Scaled-down distribution network





Description of the scaled-down distribution networks

LV Scaled-down distribution network



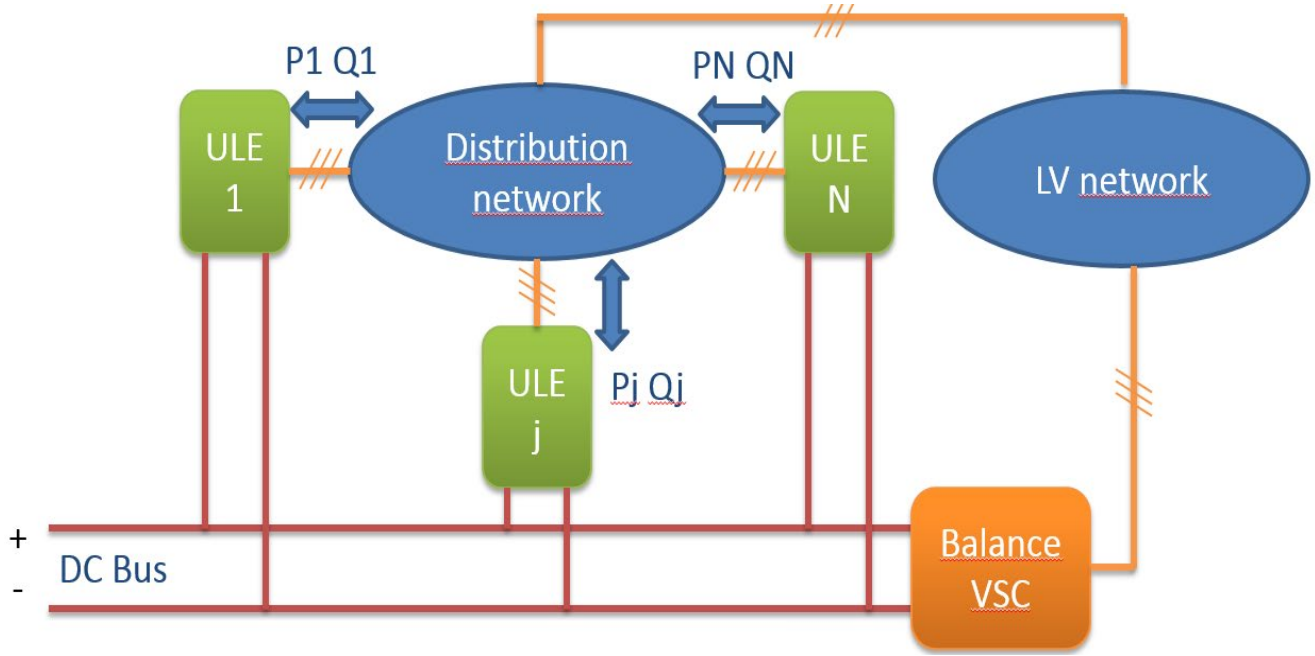
Balancing VSC

Branches (R&L)

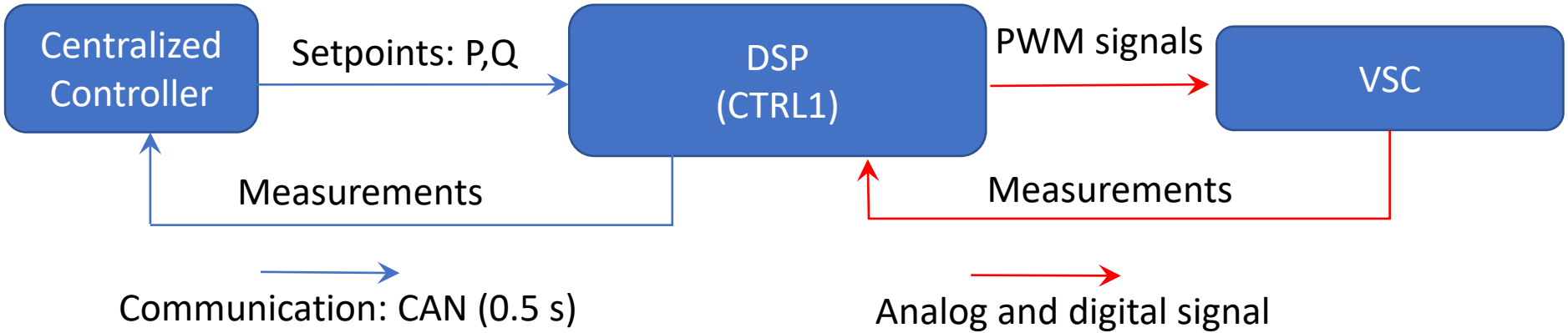
6 VSCs. Loads and
Primary Energy Sources

Transformer

Power balance in the scaled-down networks



Communication and control Layers

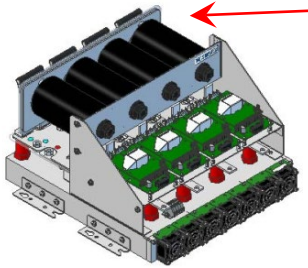


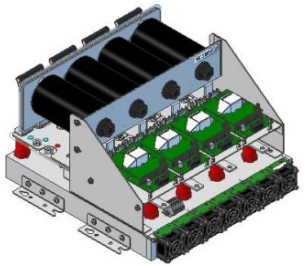
- Centralized Controller:
  - Real-time platform provided by SpeedGoat
  - Software environment: Matlab Simulink
  - Manage Power Profiles of Loads and Generators and Measurements from VSC

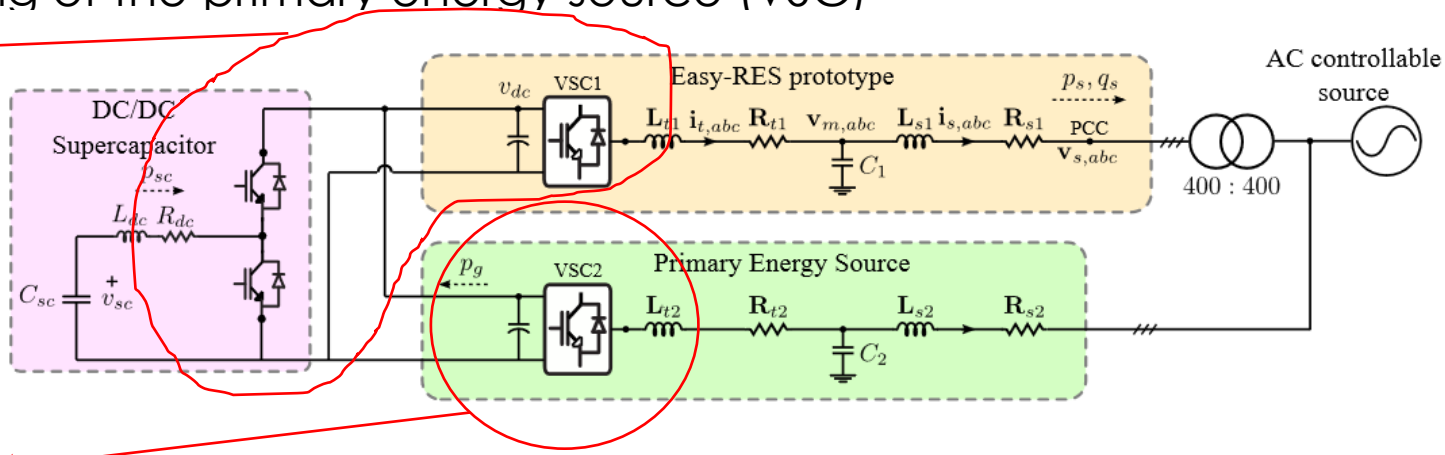
Description of the scaled-down distribution networks

VSC configurations

- Three EASY-RES prototypes ↔ Three VSCs
  - Unified Virtual Synchronous Generator (EASY-RES)
  - Emulating of the primary energy source (VSC)



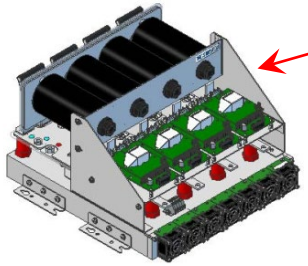


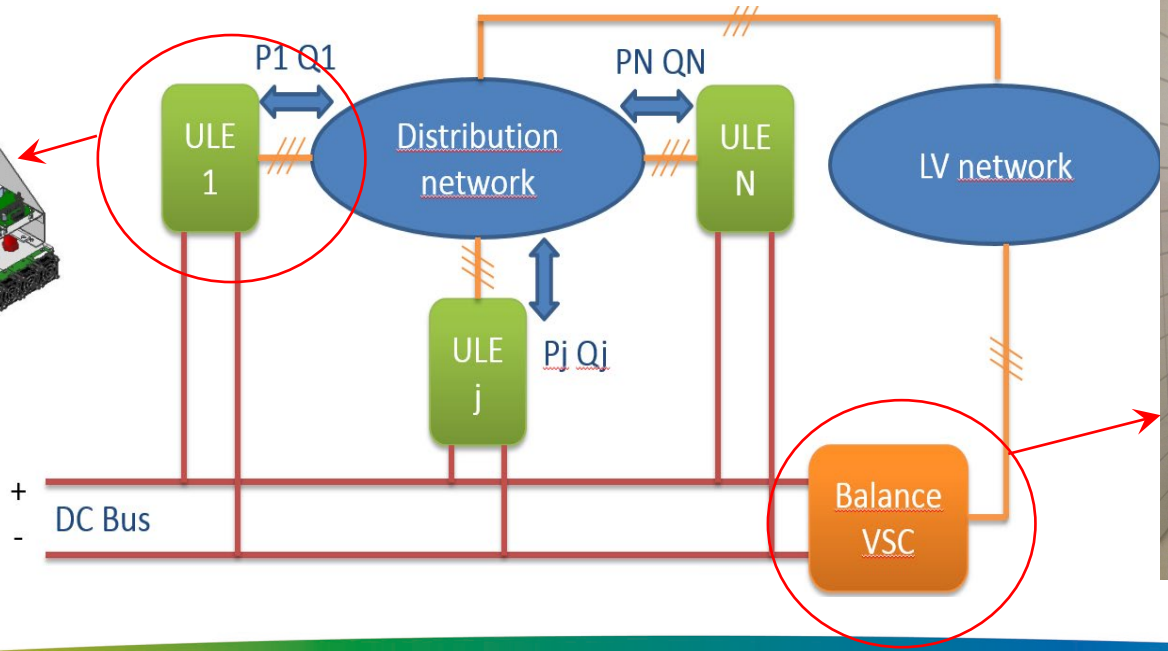


Description of the scaled-down distribution networks

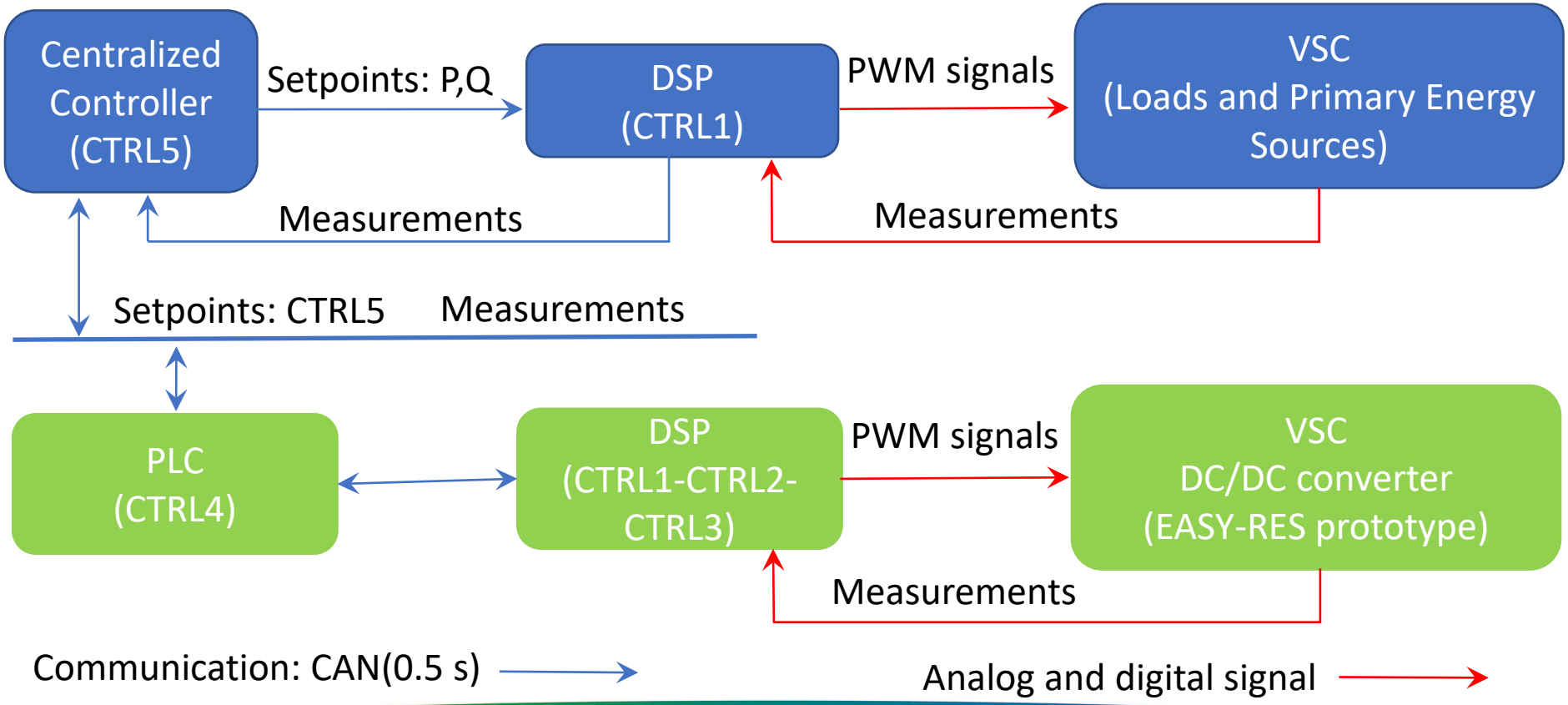
VSC configurations

- Three VSCs of the LV scaled-down Network emulating Loads
- Balancing VSC





Communication and Control Layers



Item 4: The EASY-RES Consortium

The Consortium

ARISTOTLE UNIVERSITY OF THESSALONIKI

UNIVERSIDAD DE SEVILLA

UNIVERSITÄT PASSAU

Lancaster University

TU Delft

stadtwerk haßfurt

ΑΔΜΗΕ
ΑΝΕΞΑΡΤΗΤΟΣ ΔΙΑΧΕΙΡΙΣΤΗΣ ΜΕΤΑΦΟΡΑΣ ΗΛΕΚΤΡΙΚΗΣ ΕΝΕΡΓΕΙΑΣ

elektro gorenjska

Stadtwerke LANDAU a.d.ISAR

fenecon
ENERGY ENGINEERING

ZD.B ZENTRUM DIGITALISIERUNG. BAYERN

This project has received funding from the European Union´s Horizon 2020 Programme for research and innovation under Grant Agreement no 764090.

Thank you!

Manuel Barragán-Villarejo

Affiliation: Universidad de Sevilla
Phone: +34 954481281
E-Mail: manuelbarragan@us.es
EASY-RES website: http://www.easyres-project.eu/