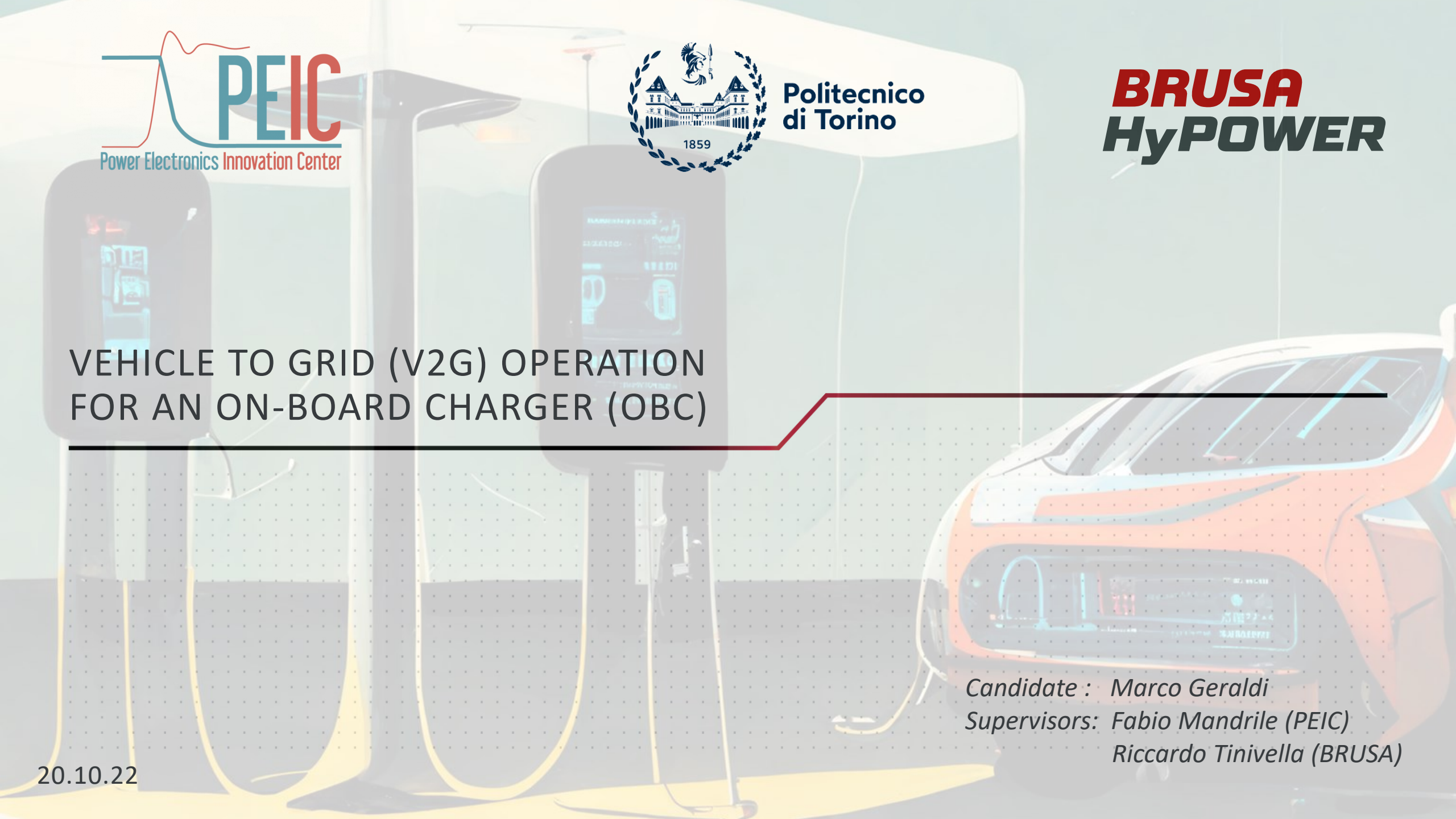
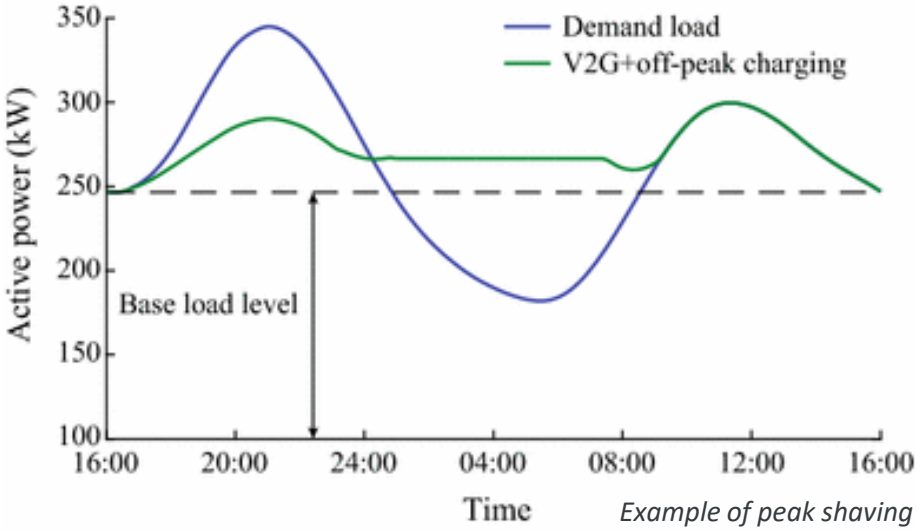


VEHICLE TO GRID (V2G) OPERATION FOR AN ON-BOARD CHARGER (OBC)

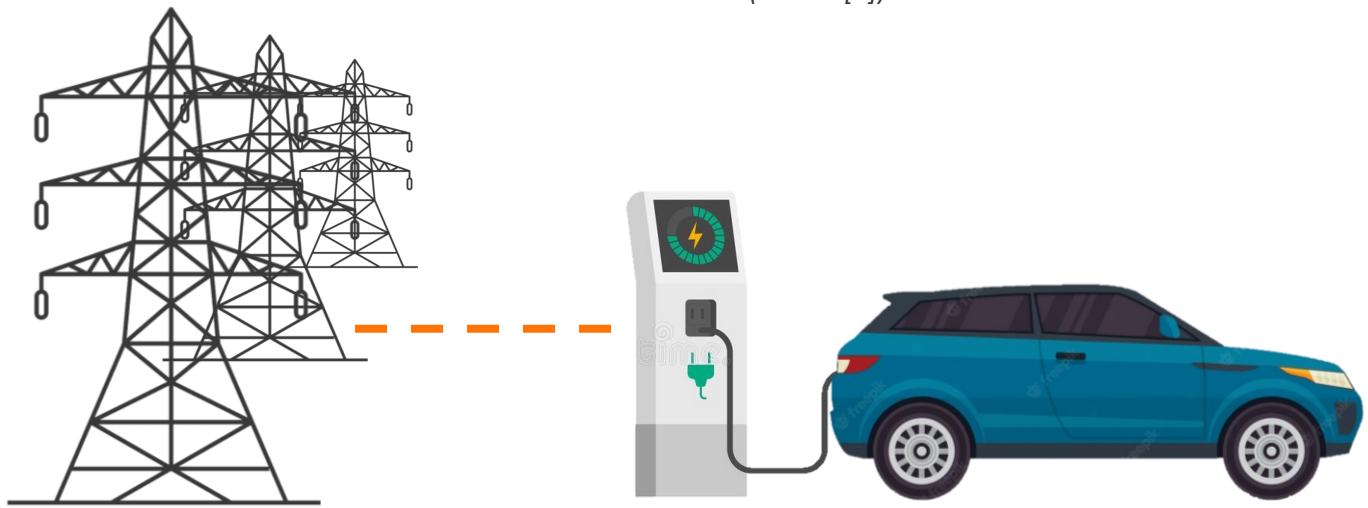
Candidate : Marco Geraldi
Supervisors: Fabio Mandrile (PEIC)
Riccardo Tinivella (BRUSA)

20.10.22

WHAT IS V2G



Example of peak shaving (Source [1])



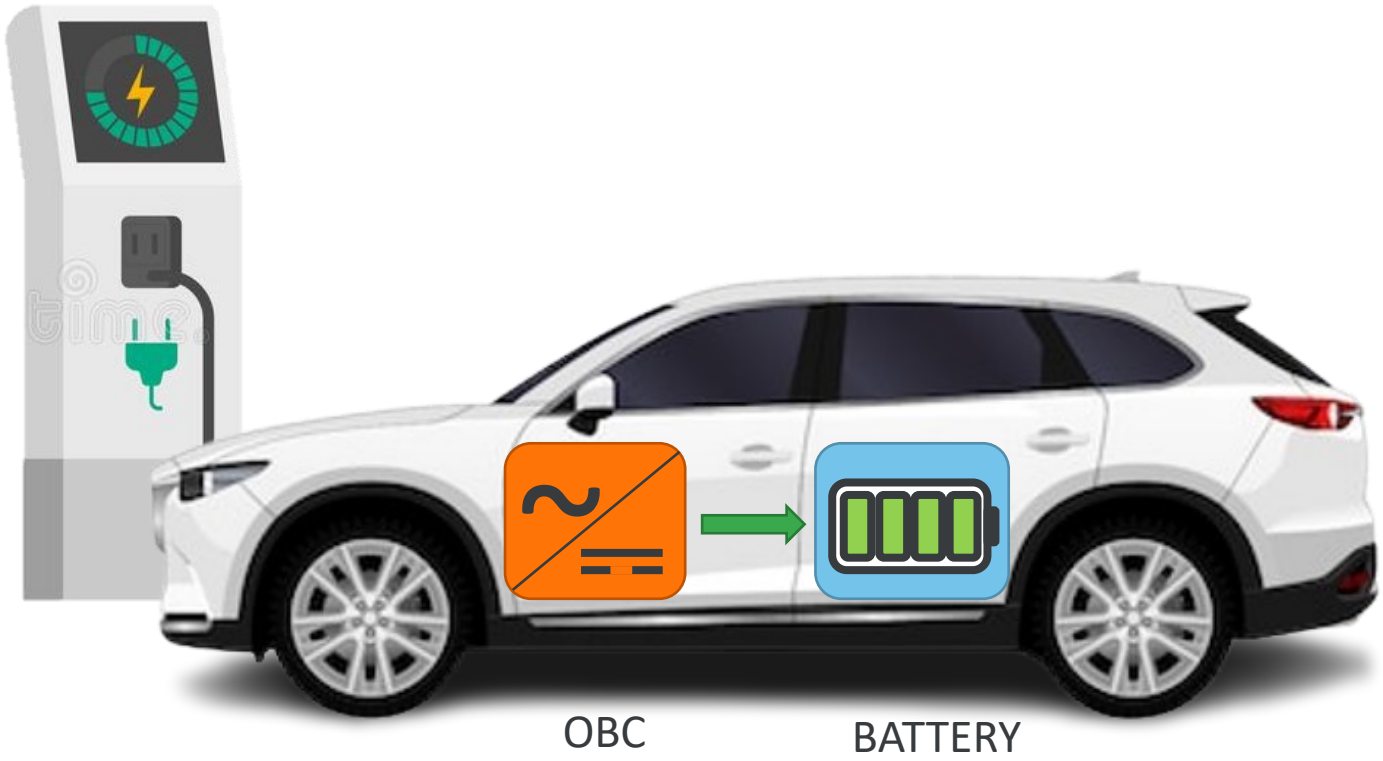
- ***Vehicle-To-Grid (V2G)*** is the capability to enable energy flow from the traction battery of the vehicle to the grid network.

Benefits :

- Vehicle owner can support grid services as:
  - Peak power delivery
  - Energy demand management
  - PF regulation
  - Grid stabilizing in smart grid
- Vehicle owner gets economic rewards by supporting the grid.

[1] Journal of Modern Power Systems and Clean Energy **volume 6**, pages555–566 (2018)

WHAT IS AN ON-BOARD-CHARGER (OBC) ?



- The role of the OBC in a BEV is to convert energy from AC sources (e.g., house outlet, Charging stations.) to DC form and charge the traction battery.
- Up to now, most of the OBC are only unidirectional, allowing the only flow of energy used to charge the EV battery.
- Different way of charging a vehicle
  - *Level 1*: mains outlets
  - *Level 2*: Wallboxes, AC chargers
  - *Level 3*: DC Fast Charge

THESIS GOAL

The final goal of the thesis is the realization of a prototype OBC capable of inverse power flow, opening the doors to V2G technology.

In summary, the focal point of the thesis are:

- Familiarizing with OBC concepts
- Research of applicable standards for V2G OBC
- PLECS Simulation of the power converter
- Realization of the actual prototype
- Test of the converter prototype in the lab

BRUSA OBC7 On-Board Charger

V2G-DC OR V2G-AC ?

V2G-DC

- Supported by CHAdeMO protocol only
- Few compatible vehicles
- Expensive DC Charging Stations required (off-board conversion)

CHAdeMO Plug

V2G-AC

- Potentially compatible with all already existing AC Charging stations (On-Board Conversion)
- Cheap Solution
- Lack of standards

Type-2 Plug

APPLICABLE STANDARDS

UL 1741* - EVSE safety and functionality

- EVSE are certified to UL 1741 to ensure grid conformance.

(*Not considered in this work).

NOT AUTOMOTIVE

IEEE 1547 - Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

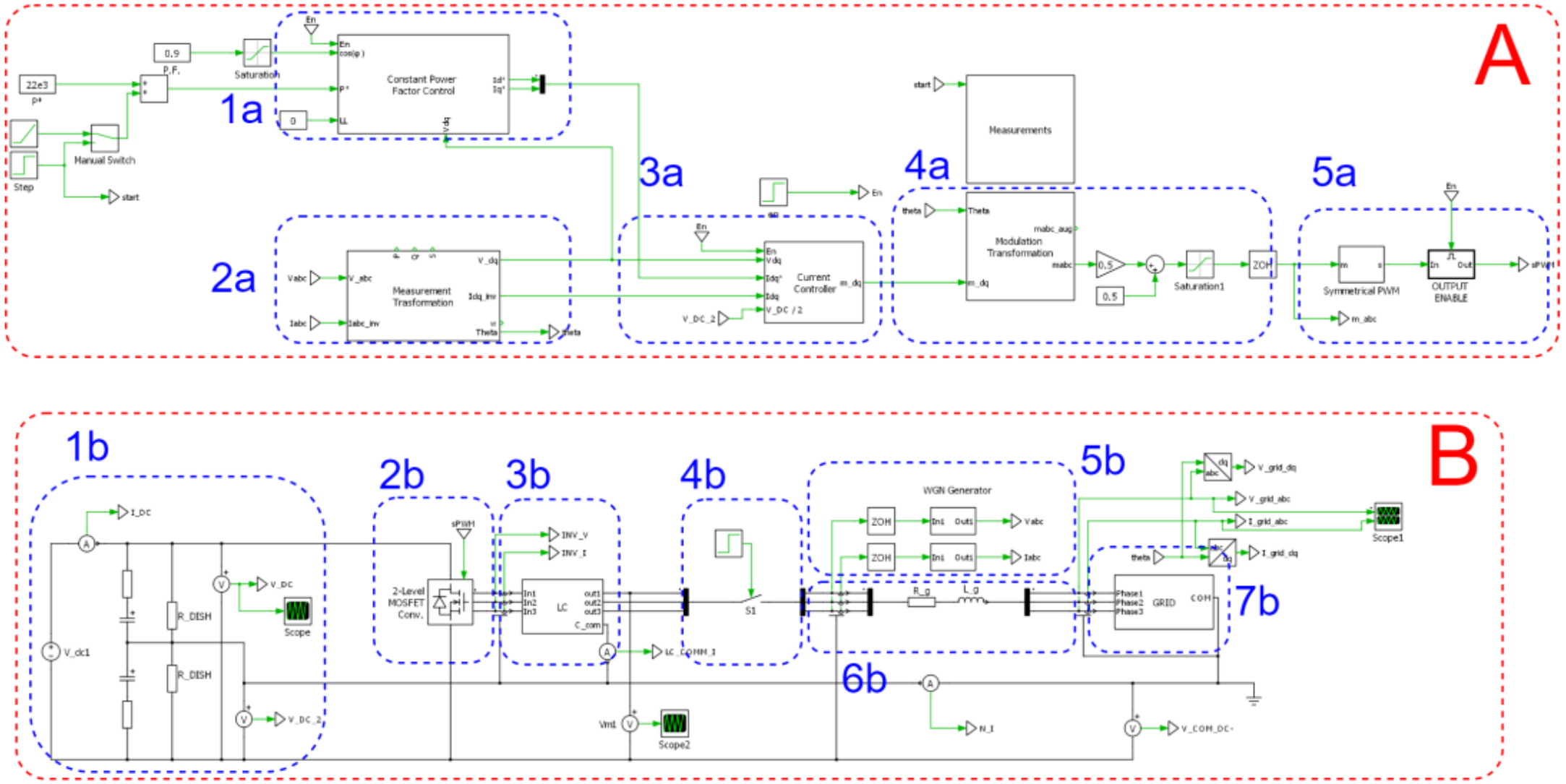
NOT AUTOMOTIVE

SAE J3072 - Interconnection Requirements for Onboard, Grid Support Inverter Systems

- UL 1741 SC has been developed to comply with not-stationary inverter and has been adopted in SAE J3072

AUTOMOTIVE but only for US

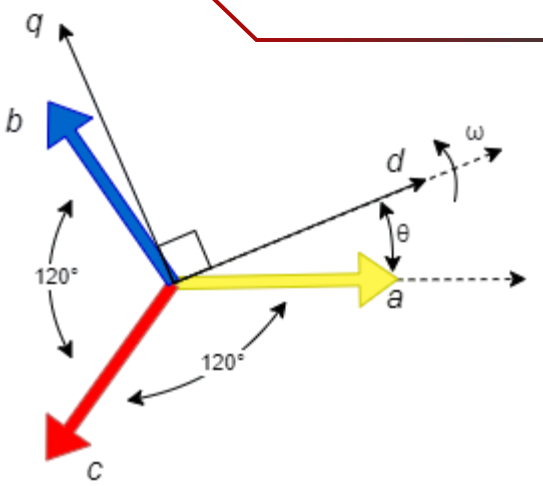
PLECS SIMULATION



DQ REFERENCE FRAME

3-Phase measurements of Voltage and current are transformed in *(d,q) Rotating Frame* via Clarke-Park Transformations, resulting in voltage and current of DC-form in steady-state conditions. Three-phase SRF-PLL is used to compute the reference phase angle.

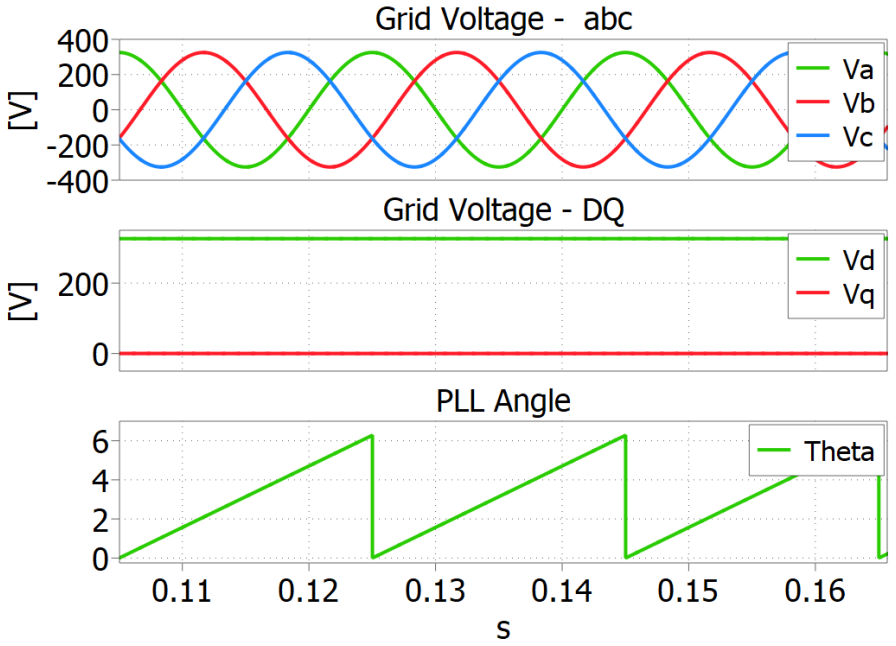
This method ensure a simpler control architecture, with only 2 controllers required, one for d-axis and one for q-axis.



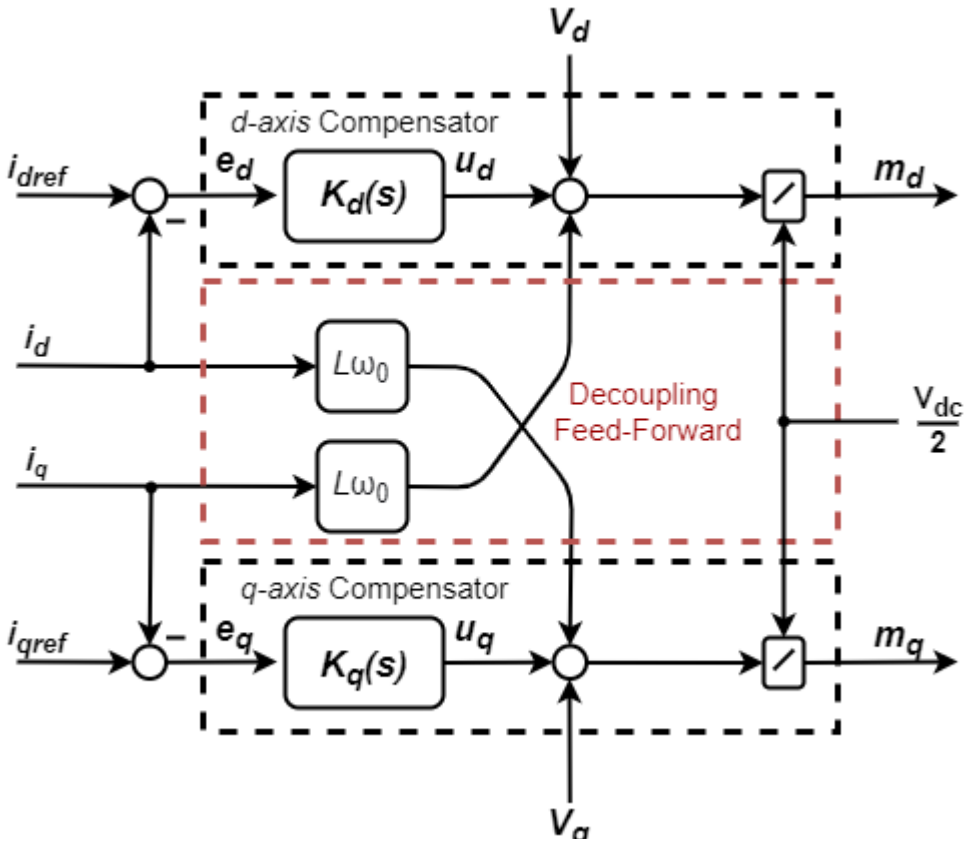
$$(V_{td} + jV_{tq})e^{j\varepsilon(t)} = \frac{V_{DC}}{2}(m_d + jm_q)\,e^{j\varepsilon(t)}$$

$$V_{td}(t) = \frac{V_{DC}}{2}m_d(t)$$

$$V_{tq}(t) = \frac{V_{DC}}{2}m_q(t)$$



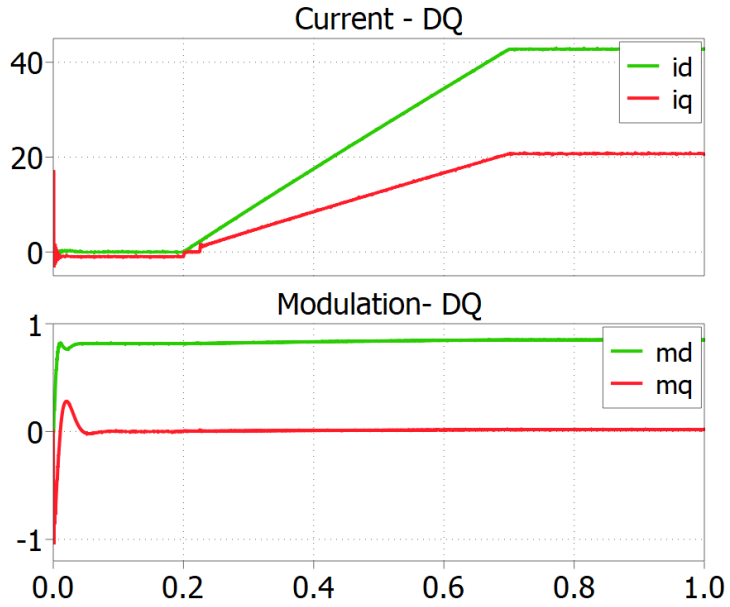
CURRENT CONTROLLER



$$m_d = \frac{2}{V_{DC}}(u_d - L\omega_0 i_q + V_{sd})$$

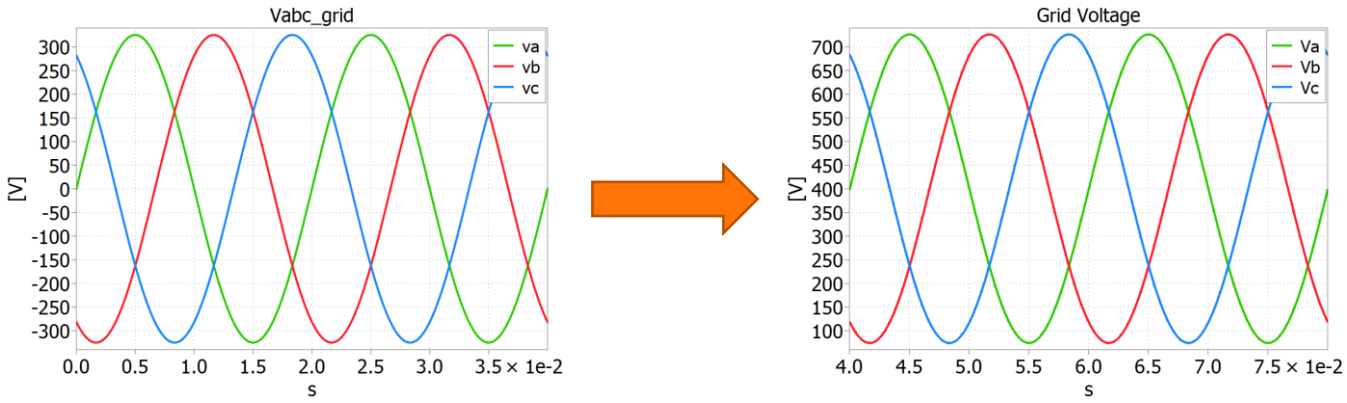
$$m_q = \frac{2}{V_{DC}}(u_q + L\omega_0 i_d + V_{sq})$$

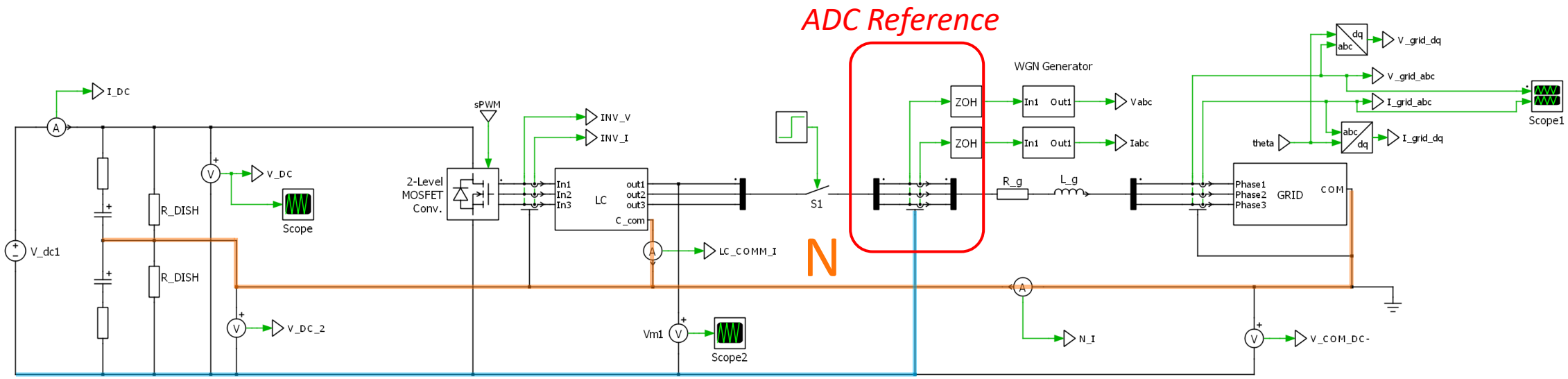
- The measured current is controlled via two PI Controllers, one per each axis.
- Given current references, a feedforward term is added to compute the modulation signals required for processing the switching pattern.



NEUTRAL POINT CONNECTION

- Voltage measurements are referred to DC- → **UNIPOLAR**
- It is necessary to connect the neutral line to the middle point of the DC-link to correctly measure the grid voltage.





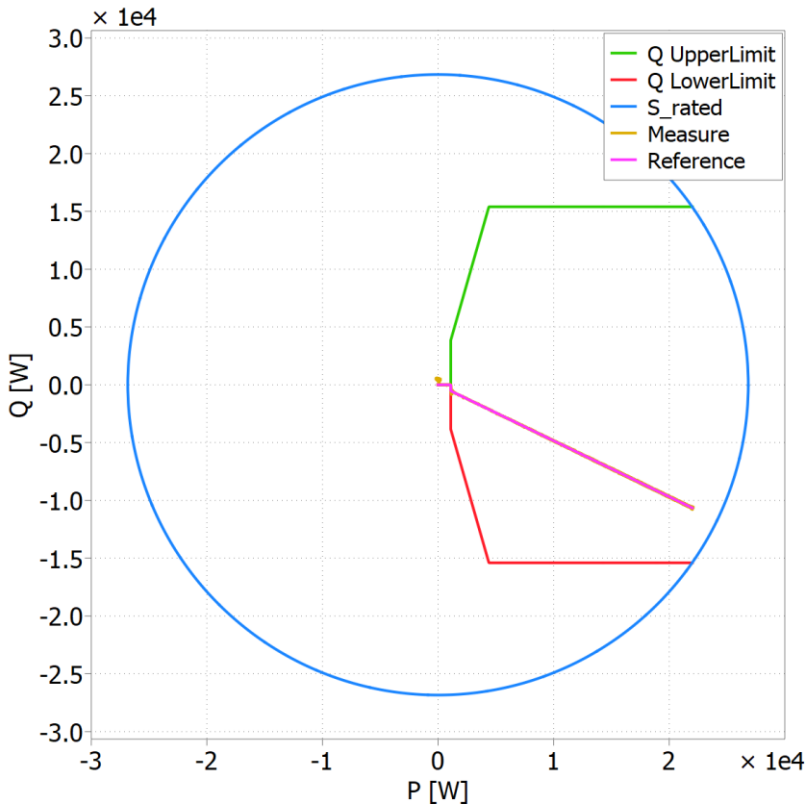
SIMULATION RESULTS

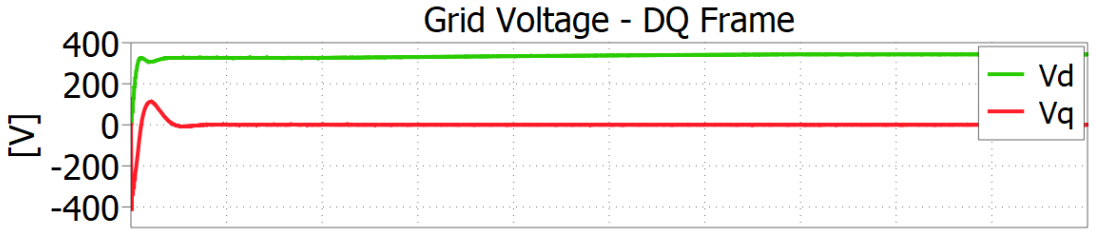
Simulation results shows a promising algorithm control for the current that requires to be precisely controlled.

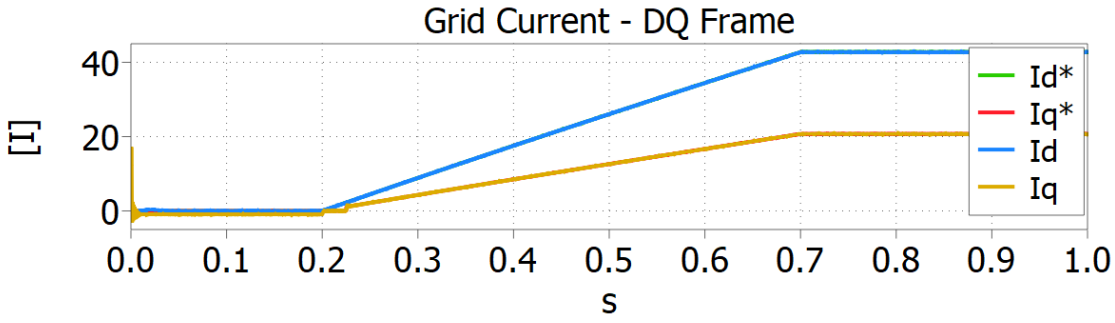
After the closing of the main switch, the requested active power is ramped up to 22KW.

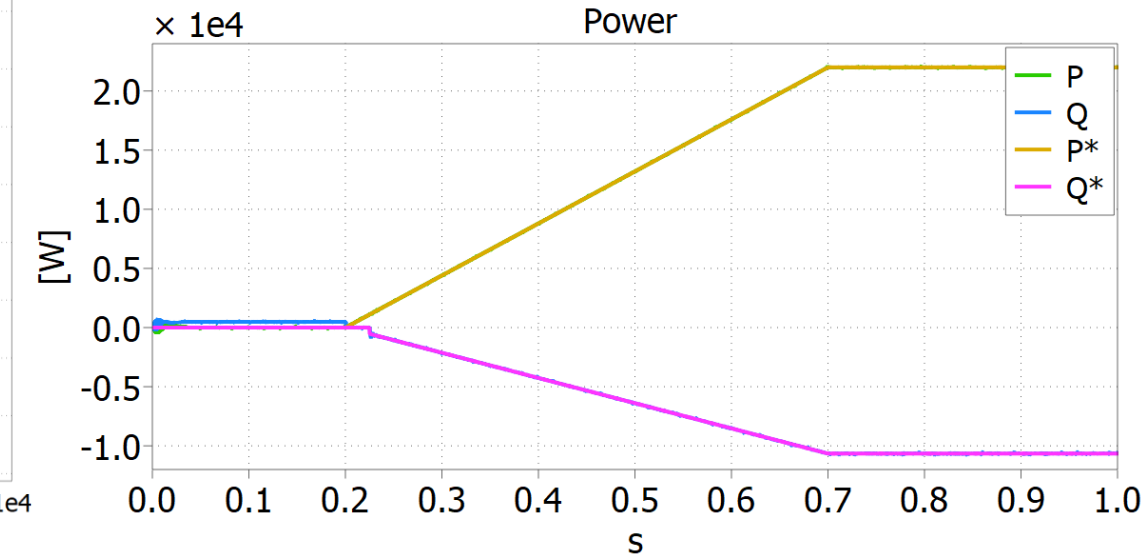
Simulation Specifications:

- $V_{DC} = 800V$
- $V_{rms} = 230V$
- $PF^* = 0.9$
- $P^* = 22kW$





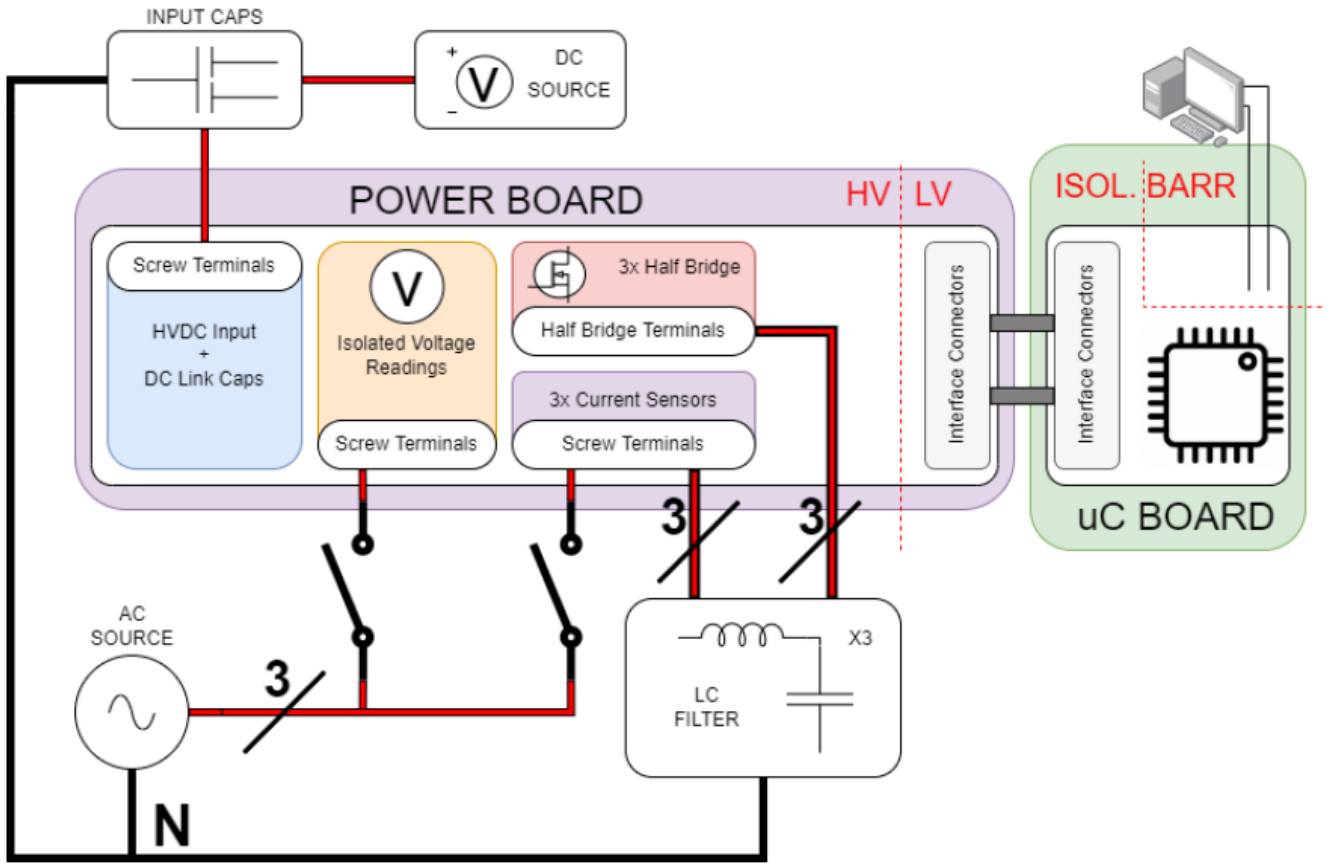




HARDWARE PROTOTYPE

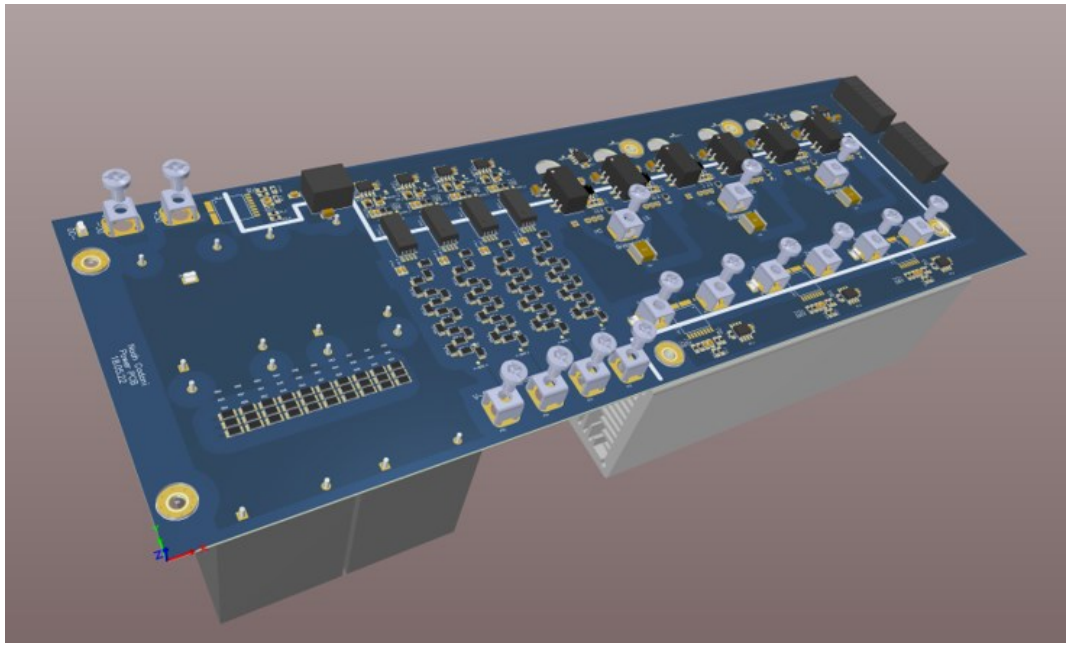
The Hardware prototype is made by the following components:

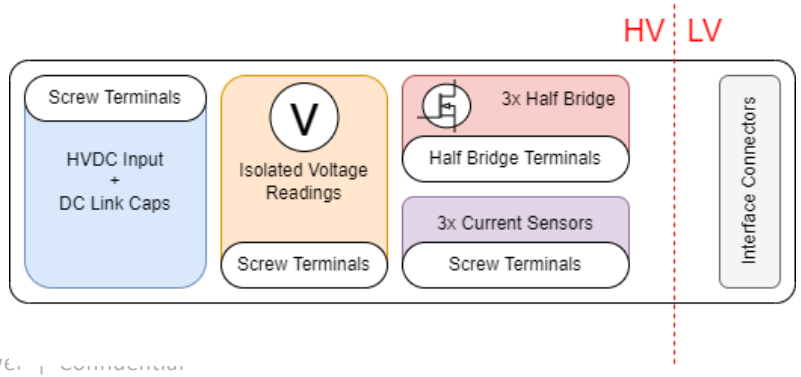
- ***Digital Board***: Reads measurements and compute switching pattern
- ***Power Board***: Consist of 2-level 3-phase converter with current and voltage measurement sensors
- ***LC Filter***: Low pass filter capable to reduce switching noise and harmonics
- ***Main Switch***: Disconnects the inverter output from the grid



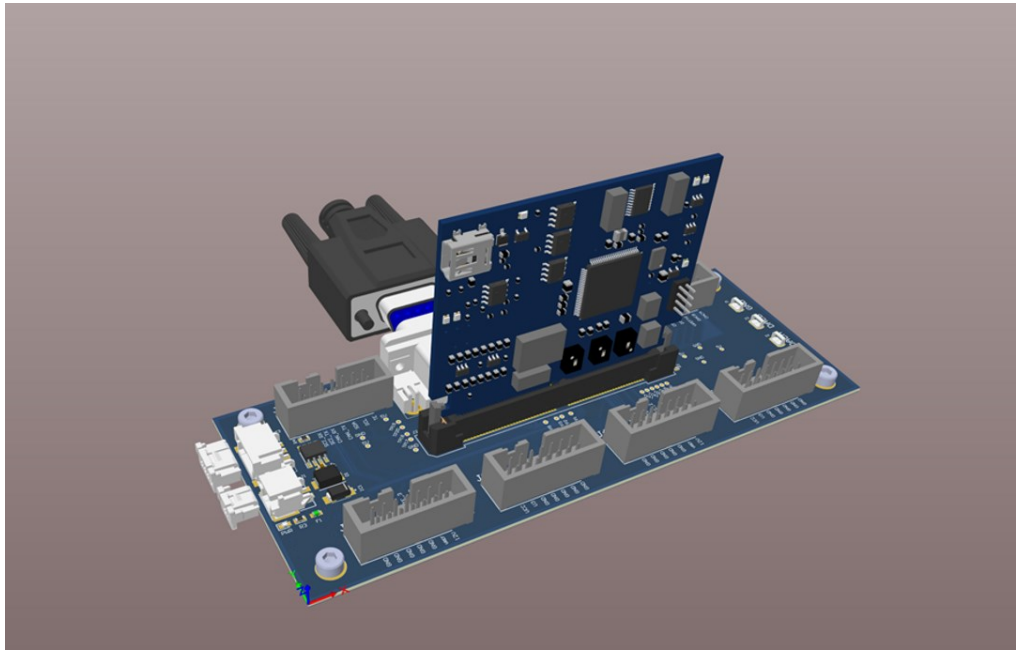
POWER AND DIGITAL BOARDS

Power Board





Digital Board



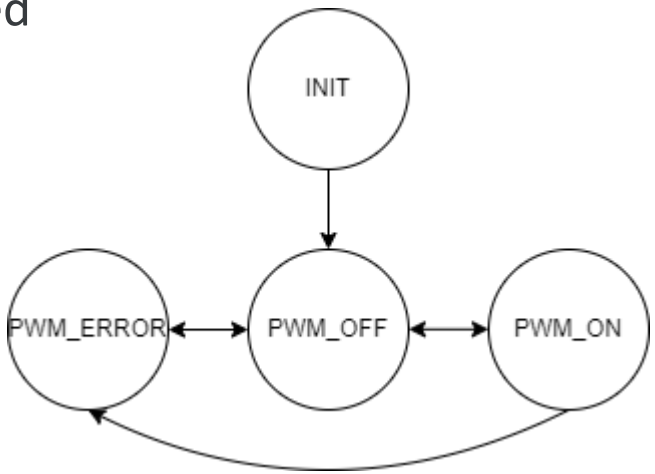
TI ControlCARD
EV-Board

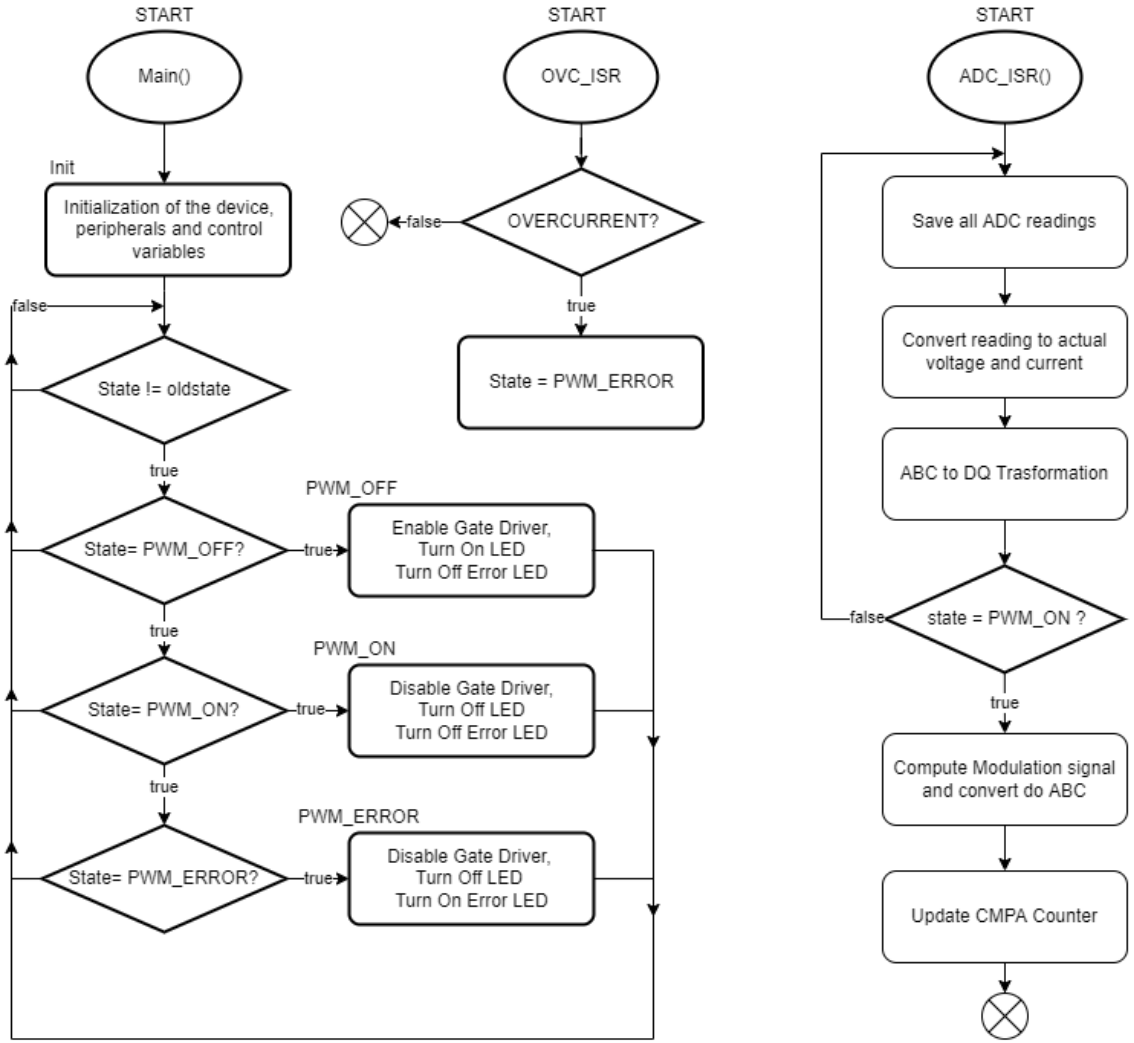
(TMDSCNCD280049C)

FIRMWARE

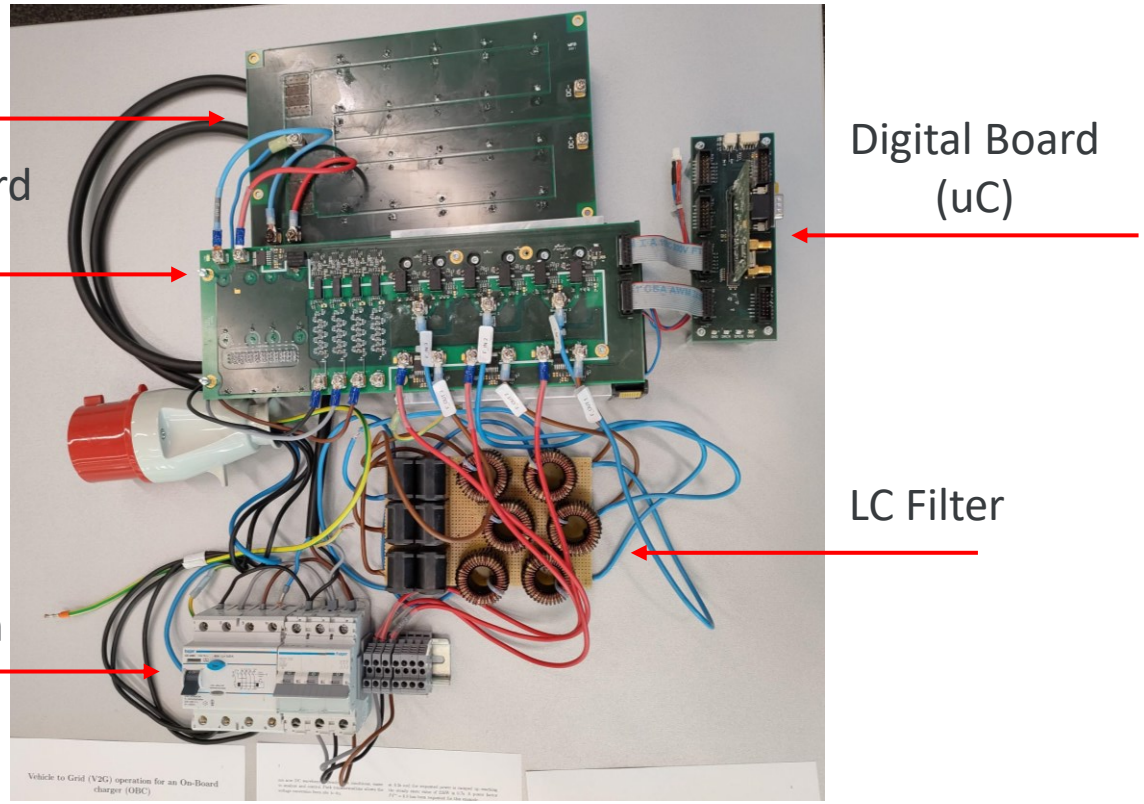
Four are the states in which the converter can operate:

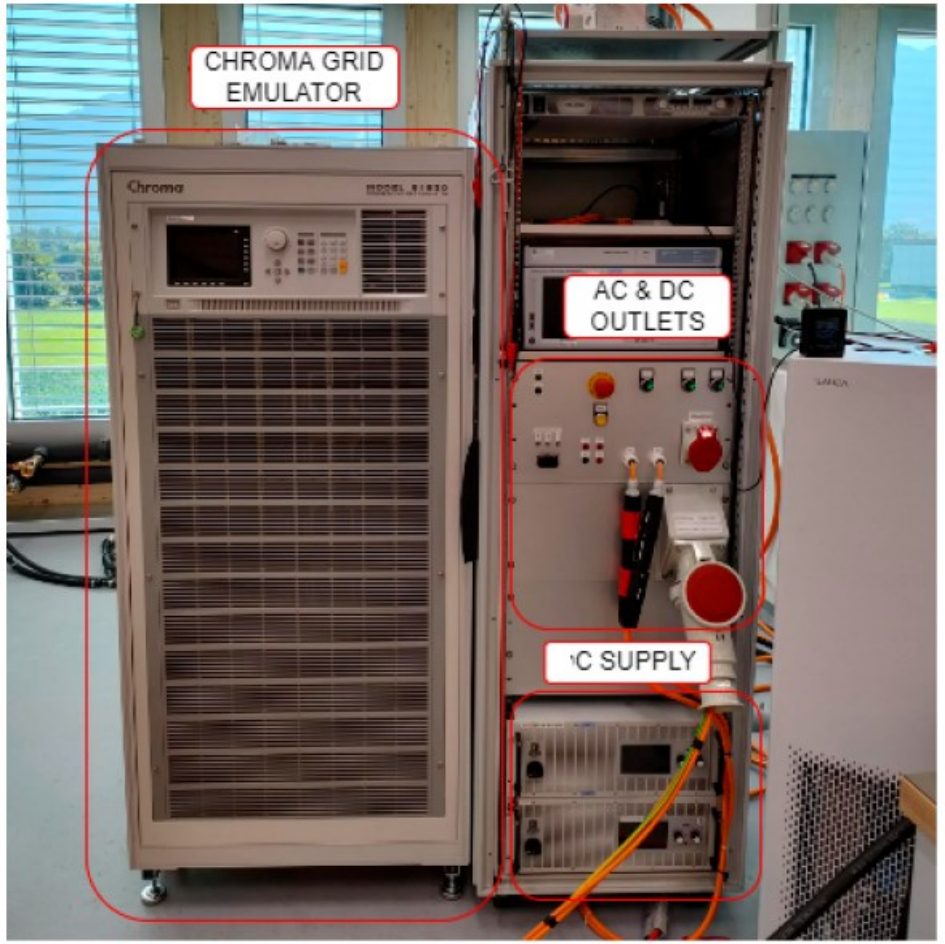
- ***INIT*: Initialization of all the peripherals**
- ***PWM_ON*: Normal Operation, gate drivers are enabled**
- ***PWM_OFF*: Output is disabled, no switching**
- ***PWM_ERROR*: Overcurrent event detected, Output is disabled**



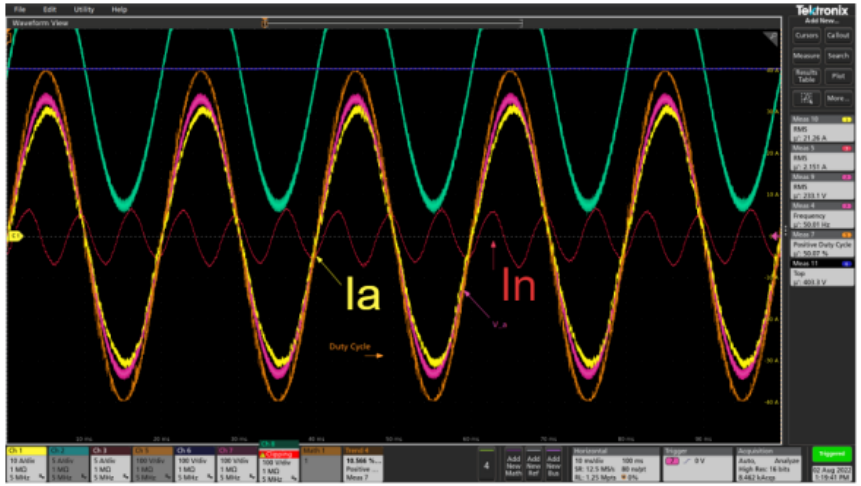


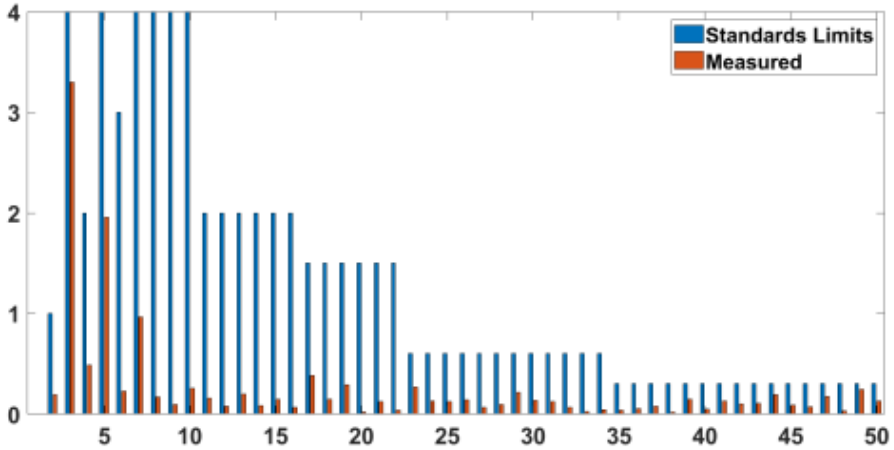
SYSTEM INTERCONNECTIONS





EXPERIMENTAL RESULTS





Experimental setup shown promising results:

- IEEE 1547 current distortion limitation satisfied
- High 3^{rd} harmonic distortion contribution
- Non-null current flow on neutral line

Test Specifications

- $V_{DC} = 800V$
- $V_{rms} = 230V$
- $PF^* = 1.0$
- $P^* = 18kW$

THD = 2.2%

CONCLUSIONS AND NEXT STEPS

In conclusion:

- V2G Technology will be fundamental in the next future
- V2G-AC will give the opportunity to widespread this technology
- Lack of Standards and compatible vehicles
- Simulation on PLECS and test of the prototype shown promising results, achieving active and reactive power control with harmonic emissions within the limits of IEEE 1547.

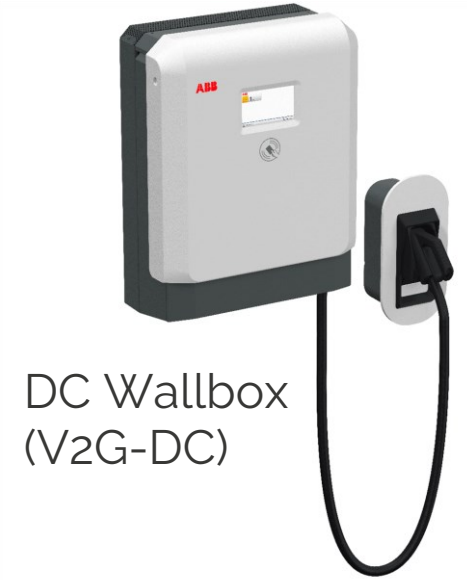
Next Steps:

- Firmware improvements and bug correction
- Add an additional leg to control neutral line (4-wire Converter)
- Dq0 modulation to compensate neutral current
- New PLL for advance performance

Possible Outcomes:

- Add “inverse” current flow capability to OBC7

OBC7 (V2G-AC)



DC Wallbox
(V2G-DC)

THANK YOU
FOR YOUR ATTENTION !