



UNIVERSITÀ  
di CATANIA



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**DOTTORATO DI RICERCA NAZIONALE IN INGEGNERIA DEI  
SISTEMI, ENERGETICA, INFORMATICA, E DELLE  
TELECOMUNICAZIONI XXXII CICLO**

Dipartimento di Ingegneria Elettrica Elettronica e Informatica

**ANALYSIS AND DEVELOPMENT OF HIGH PERFORMANCE  
ELECTRONIC CONVERTERS WITH WIDE BAND GAP  
DEVICES**

Advanced digital control techniques of SiC  
based Front-End Power Converters

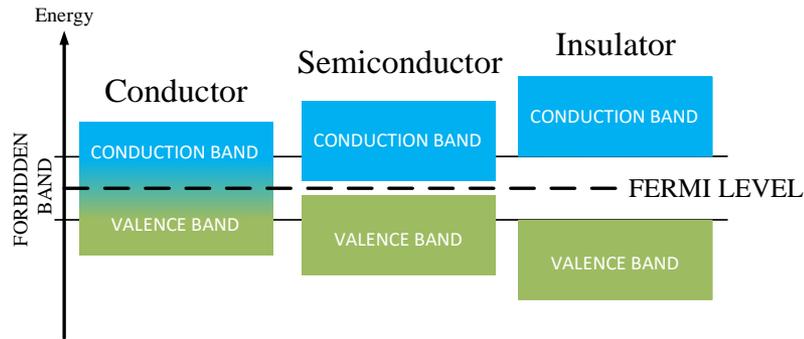
**AIELLO GIUSEPPE**

**ACADEMIC YEAR**

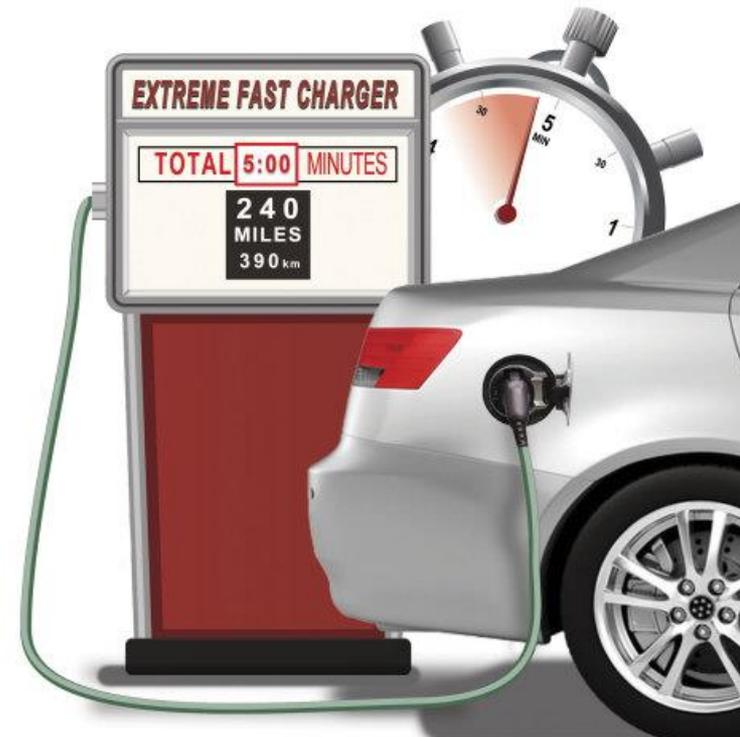
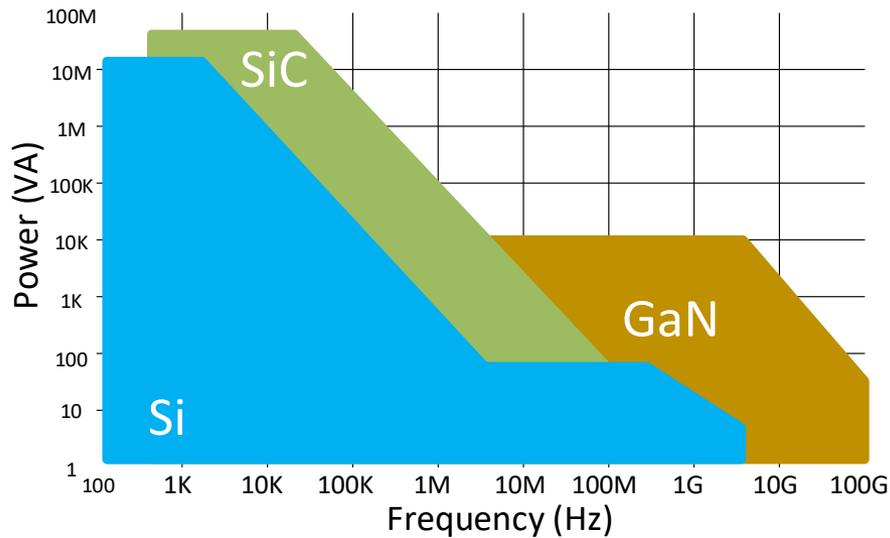
**2018-2019**

*Tutor: Prof. Mario Cacciato*

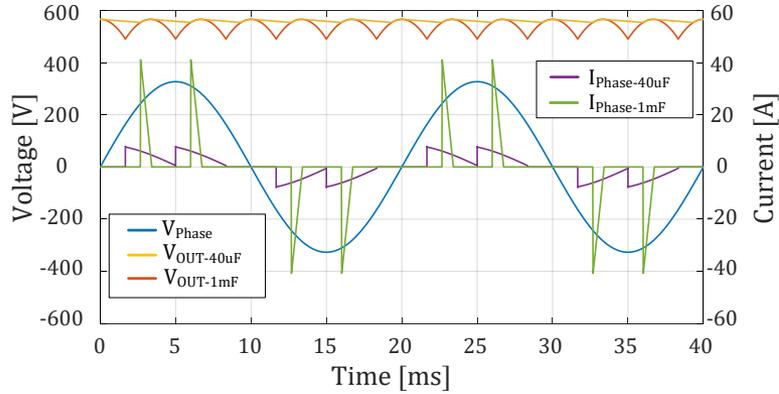
# ANALYSIS AND DEVELOPMENT OF HIGH PERFORMANCE ELECTRONIC CONVERTERS WITH WIDE BAND GAP DEVICES



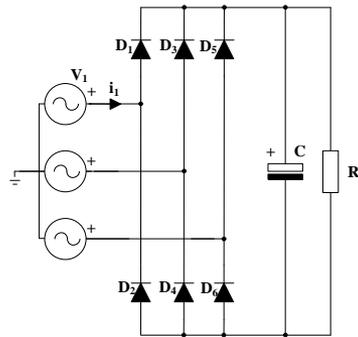
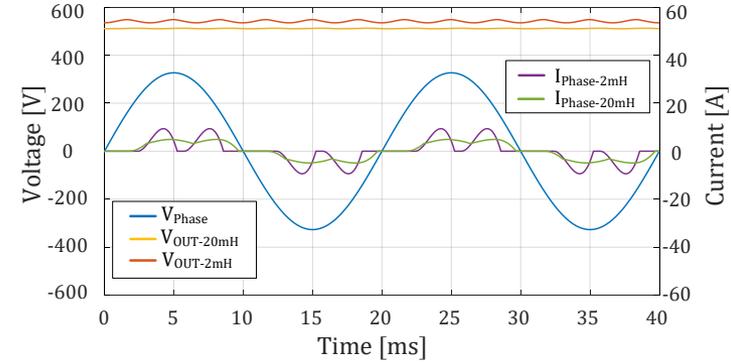
- Lower  $R_{on}$ ;
- Higher breakdown voltage;
- Operability at high temperature;
- Greater reliability;
- Best Recovery;
- Operability at high frequency.



# FRONT-END POWER CONVERTERS

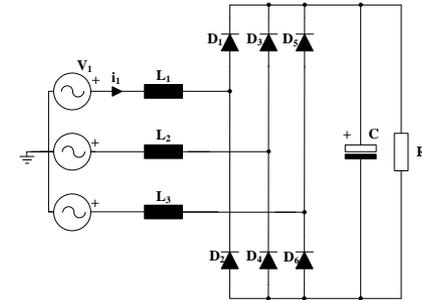


NO PFC

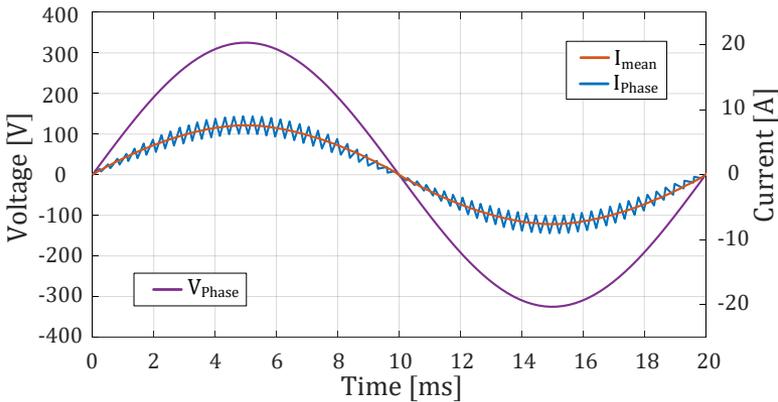


$$CF = \frac{I_{peak}}{I_{rms}} = \text{HIGH}$$

$$PF = \sqrt{\frac{\cos^2 \varphi}{1 + THD^2}} = \text{LOW}$$

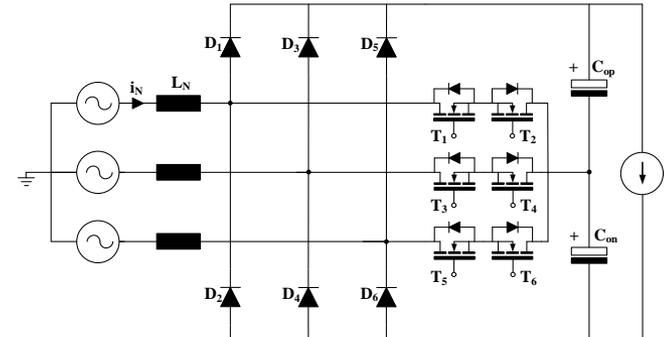


PFC



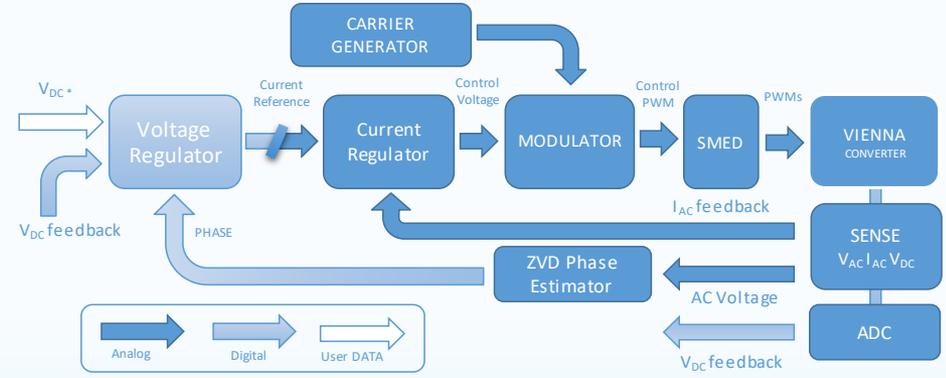
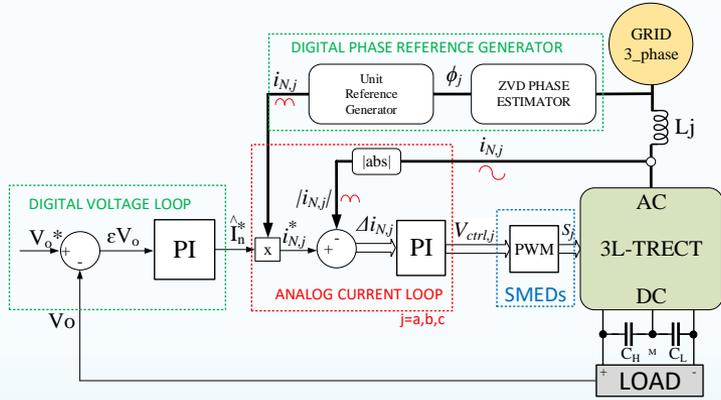
$$CF = \frac{I_{peak}}{I_{rms}} = 1,41$$

$$PF = \sqrt{\frac{\cos^2 \varphi}{1 + THD^2}} = 1$$



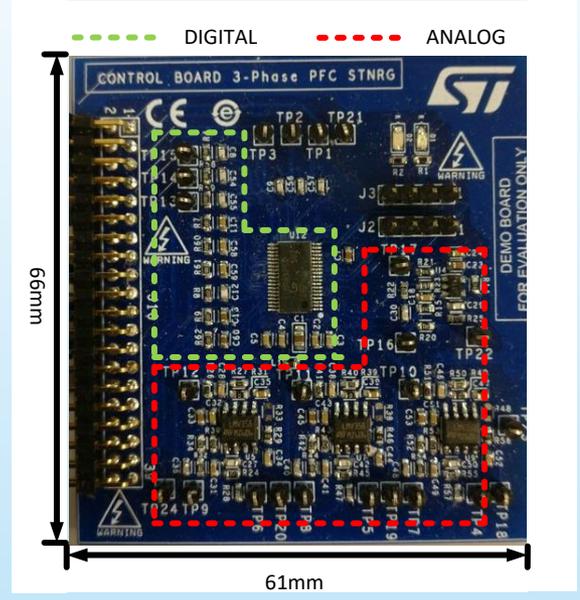
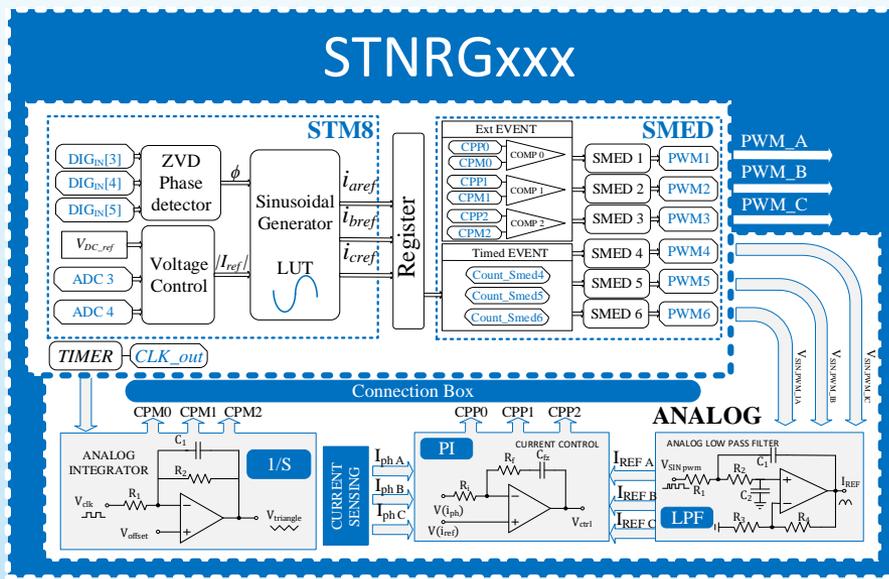
# Mixed Signals Based Control of a SiC Vienna Rectifier for On-Board Battery Chargers

Mixed Signal Control: that use an external electronics and a state machine to minimize the microcontroller computational effort, using low cost uC without compromising the "custom functionality" of the control

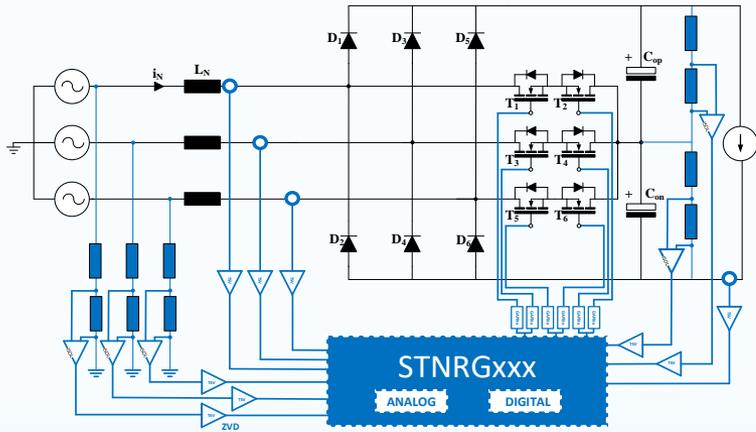


PROPOSED CONCEPT

IMPLEMENTATION



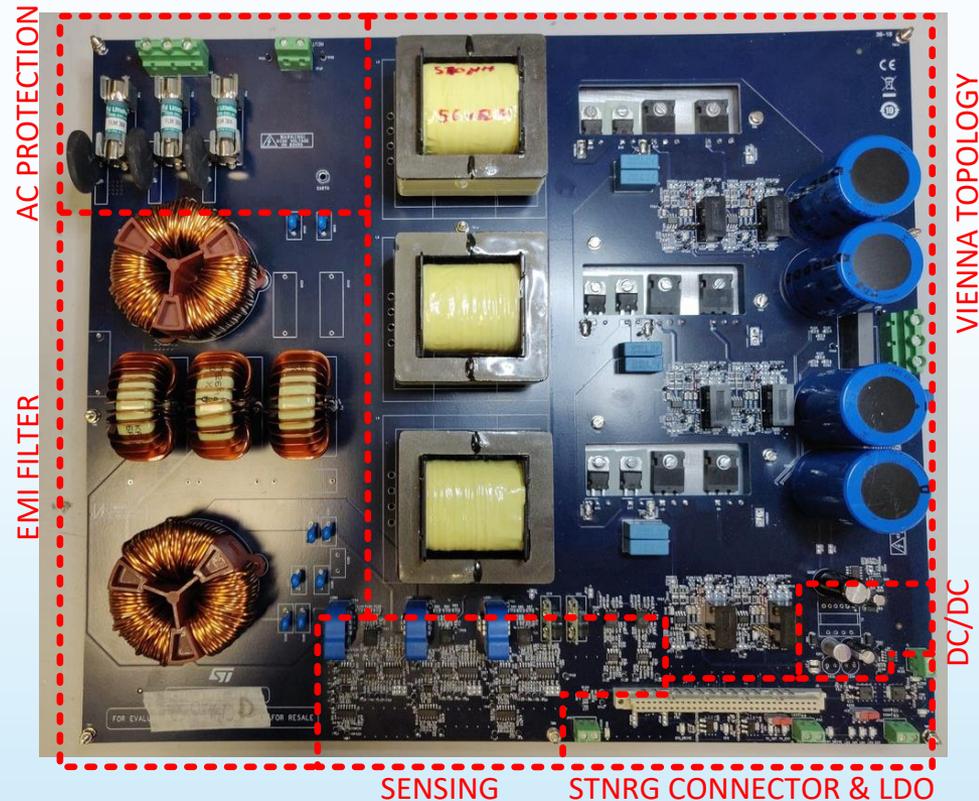
# Mixed Signals Based Control of a SiC Vienna Rectifier for On-Board Battery Chargers



## Main specs

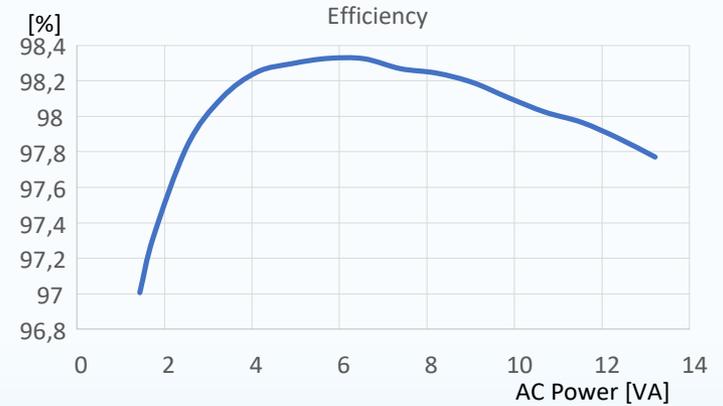
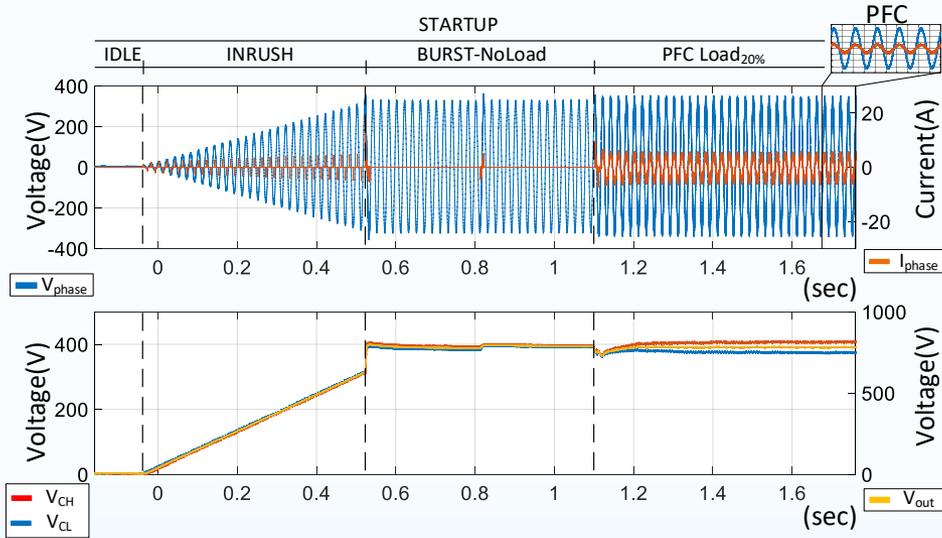
- $P_{out} = 12kW$  @  $V_{in} = 380Vac$  &  $V_{out} = 800V$
- $PF > 0.98$  @ 20% load (target)
- $THD < 5\%$  @ 20% load (target)
- $\eta > 97\%$  @ 20% load (target)
- CCM decoupling current control loop
- Active & Reactive power control
- Grid Connection capability
- Switching frequency = 70kHz
- $I_{ripple} = 2.5A$
- $V_{DC\_ripple} = 10V_{pp}$

## Power converter prototype

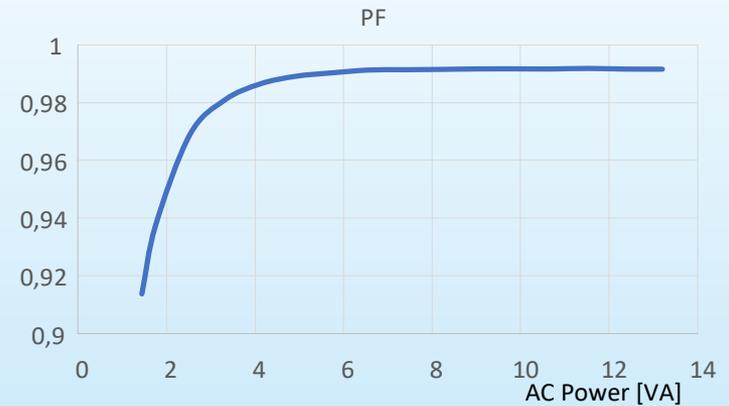
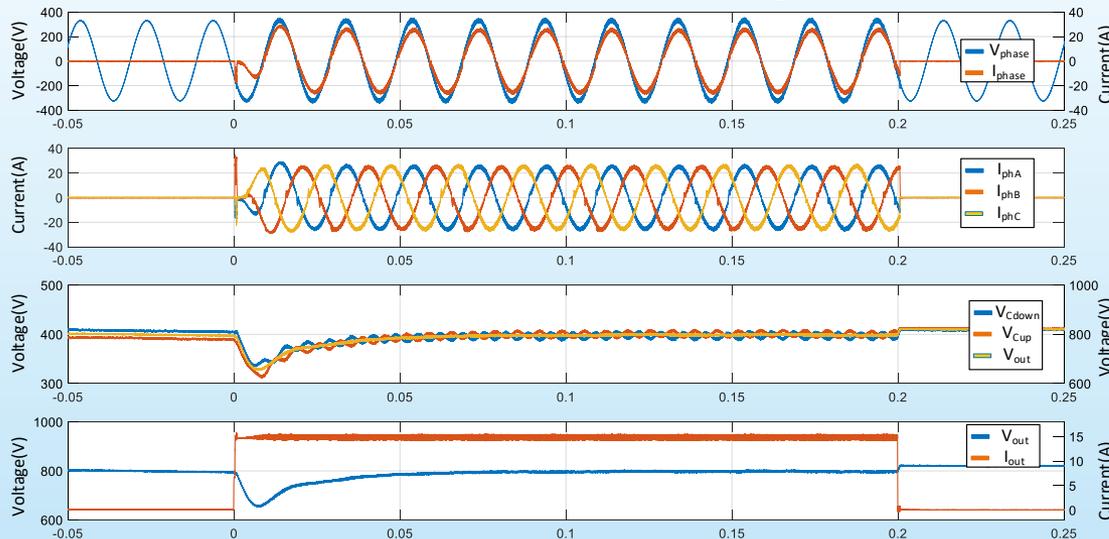


It has been made a full 3 phase 12kw converter with an alternative mixed signal control approach

# Mixed Signals Based Control of a SiC Vienna Rectifier for On-Board Battery Chargers

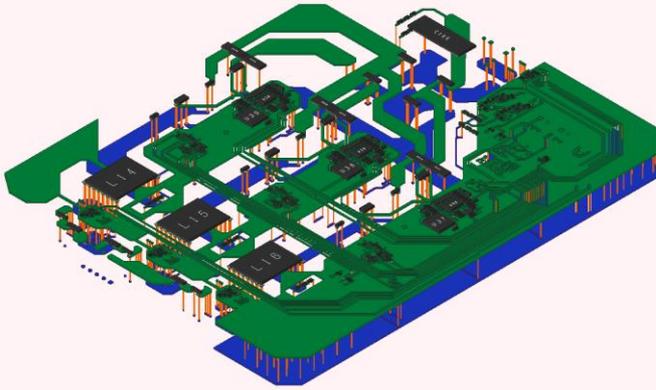


Load Transient [0% - 100% - 0%] @230Vrms 800V

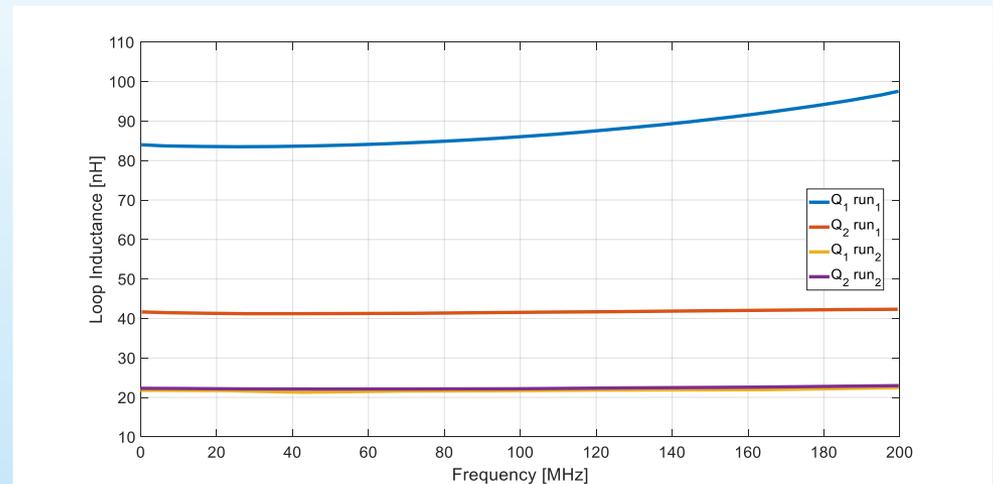
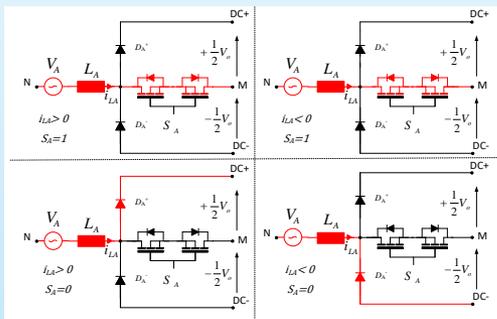
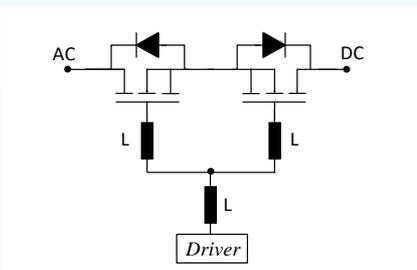
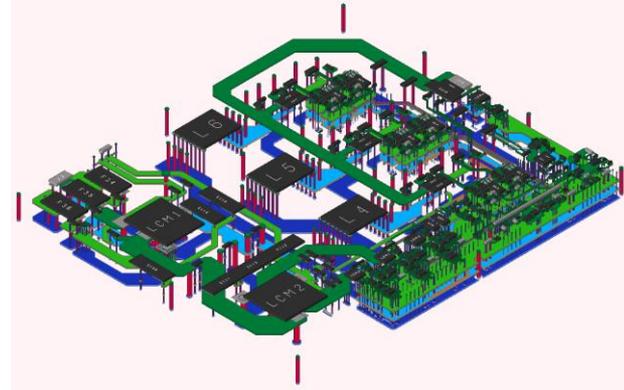


# Analysis of PCB parasitic effects in a Vienna Rectifier for an EV battery charger by means of Electromagnetic Simulations

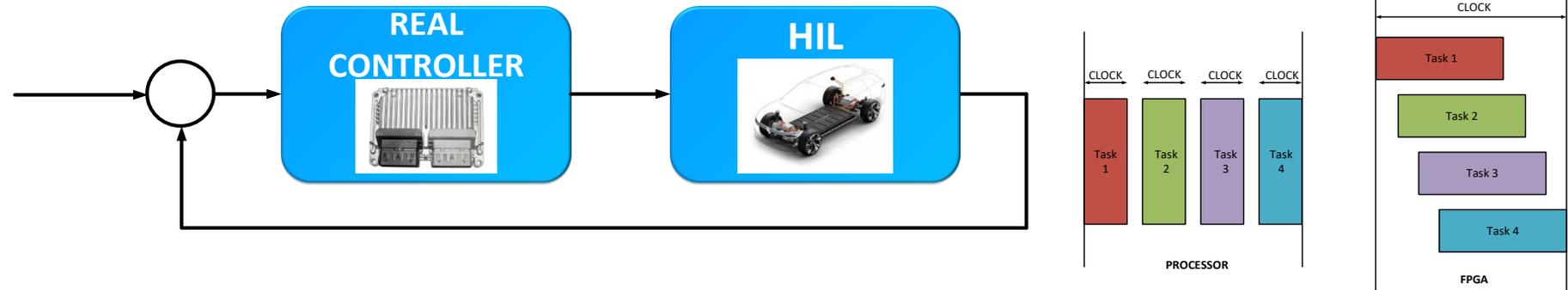
## Prototype REV1



## Prototype REV2



# HIL STUDY AND DEVELOPMENT



**MECHANICAL**

VS

**ELETRO MECHANICAL**

Realtime Plant  
150Hz

$\mu$ C - PC  
Platform  
Task 100kHz



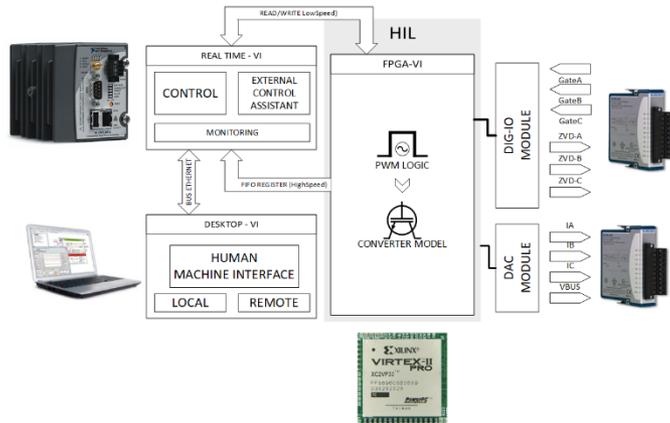
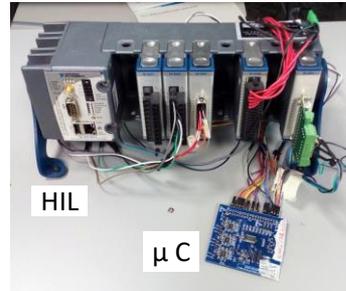
Realtime Plant  
150KHz

FPGA  
Platform  
Task 100MHz

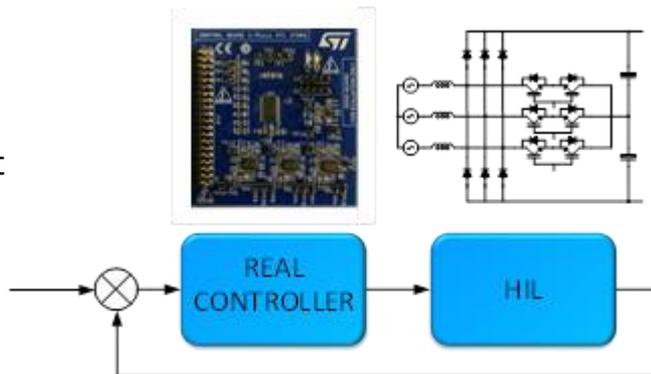


# REALTIME EMULATION OF A THREE-PHASE VIENNA RECTIFIER WITH UNITY POWER FACTOR OPERATIONS

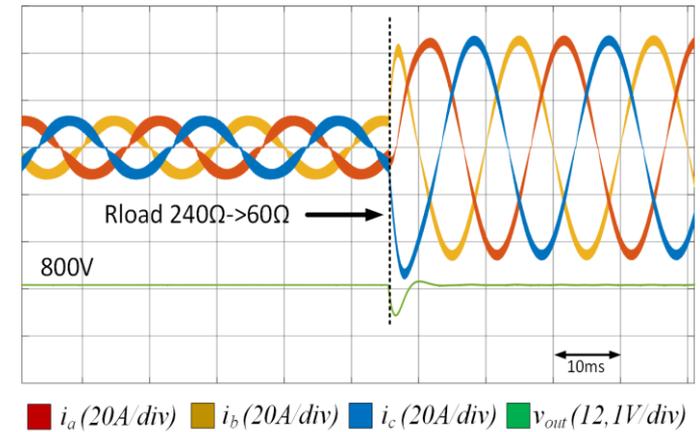
Such a model has been developed for Hardware In the Loop (HIL) implementation of a test rig where the power converter is replaced with an embedded system using a FPGA board.



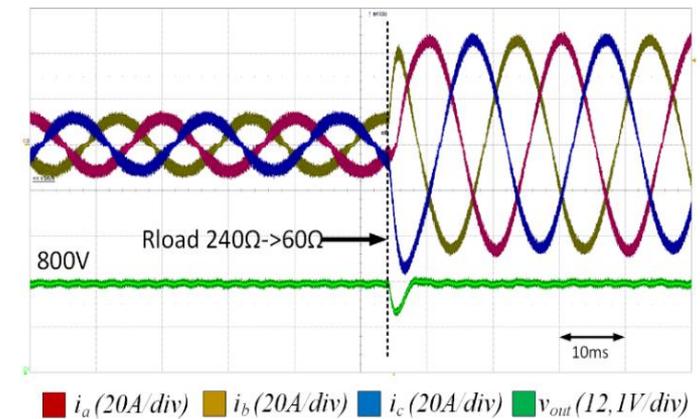
“The proposed approach has been fostered mainly to test different converter control algorithm in a fast and safe way”



## RESULTS



## Offline Simulation



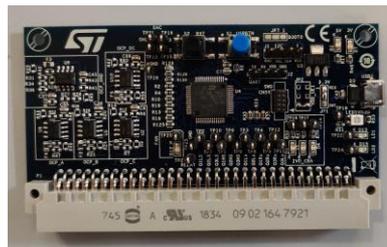
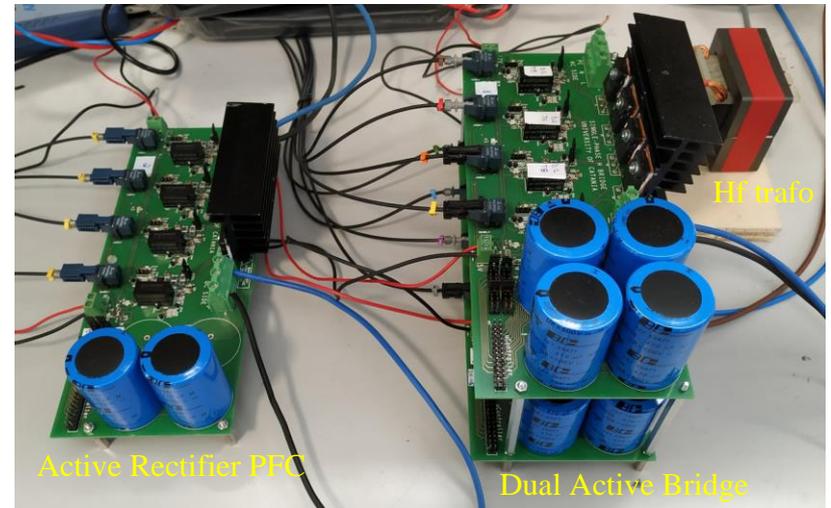
HIL

# OTHER PROTOTYPE

SiC 3Phase Multilevel converter based on high performance mixed-signal MCU for bidirectional Vehicle to Grid automotive applications in SiC technology



Bidirectional SiC-based Battery Charger for V2G applications



# My Bibliography

- Hardware in the loop for failure analysis in AC motor drives G Scelba, G Scarcella, M Cacciato, G Aiello 11<sup>th</sup> International Conference ELEKTRO 2016 May 16-18,2016 Štrbské Pleso – High Tatras, 364-369 (**BEST PAPER AWARDS**)
- Failure analysis of AC motor drives via FPGA-based hardware-in-the-loop simulations G Aiello, M Cacciato, G Scarcella, G Scelba Electrical Engineering 99 (4), 1337-1347
- A high efficiency interleaved PFC front-end converter for EV battery charger Giuseppe Aiello - Mario Cacciato - Sebastiano Messina - Marco Torrisi COMMUNICATIONS 1/2018 86-91
- Real-time emulation of induction machines for hardware in the loop applications G. Aiello and G. Scelba and G. Scarcella and M. Cacciato and L. D. Tornello and A. Palmieri and E. Vanelli and C. Pernaci and R. Di Dio 2018 International SPEEDAM
- RealTime Emulation of a Three-Phase Vienna Rectifier with Unity Power Factor Operations G. Aiello, M. Cacciato, G. Scarcella, G. Scelba, F. Gennaro, N. Aiello 12<sup>th</sup> International Conference ELEKTRO 2018 May 21-23,2018 Mikulov, Czech Republic (**BEST PAPER AWARDS**)
- RealTime Emulation of a Three-Phase Vienna Rectifier for the Development of Control Unit with PFC Capability G. Aiello, M. Cacciato, G. Scarcella, G. Scelba, F. Gennaro, N. Aiello Electrical Engineering 2018 – Springer
- Modelling and Simulation of a Bidirectional SiC-based Battery Charger for V2G Giuseppe Aiello · Mario Cacciato · Alex La Cognata · Giacomo Scelba · Giuseppe Scarcella · Alessandro Allegra Electrimacs 2019 21-23 May, Salerno (Italy)
- FPGA-Based Design and Implementation of a real Time Simulator of Switched reluctance motor Drives Aiello G., Tornello LD, CACCIATO M., DI DIO R., PALMIERI A, PERNACI C,SCARCELLA G., SCELBA G., VANELLI E. EPE19 2-6 2019 Genova (Italy)
- Mixed Signals Based Control of a SiC Vienna rectifier for On-Board Battery Chargers, AIELLO G., AIELLO N., CACCIATO M., GENNARO F., SCARCELLA G., SCELBA G.,EPE19 2-6 2019 Genova (Italy)
- Analysis of PCB parasitic effects in a Vienna rectifier for an EV battery charger by means of Electromagnetic Simulations, PALOMBA F., AIELLO G., AIELLO N.,CACCIATO M., GENNARO F., PAVONE M.,EPE19 2-6 2019 Genova (Italy)
- Analyse der parasitären Leiterplatteneffekte eines EV Batterieladesystems mit Gleichrichter durch Simulation , PALOMBA F., AIELLO G., AIELLO N.,CACCIATO M., GENNARO F., PAVONE M,Muff S. DESIGN & ELEKTRONIK (submitted)
- Modelling and Simulation of a Bidirectional SiC-based Battery Charger for V2G applications, Aiello G.,Cacciato M., Scelba G., Scarcella G., Gennaro F., MATCOM (submitted)

# AWARDS



# Training & Courses

- **EUROPEAN PHD SCHOOL** «Power Electronics, electrical machines Energy control and Power Systems 21-25 May 2018 Gaeta (Italy)
- **ECPE Tutorial** «Power semiconductor devices and technologies» 4-5 October 2018 STMicroelectronics Catania (Italy)
- **ISI&DCN** «International school on Informatics and Dynamic Complex Systems» 15-19 October 2018 Catania (Italy)
- **PCIM Tutorial** «High performance Control of Power Converters» 6 May 2019 Nuremberg (Germany)
- **EPE Tutorial** «Model predictive Control of Power Converters: Principle, Design and Applications» 2 September 2019 Genova (Italy)
- **CMAEL** «Riunione annuale congiunta GUSEE-CMAEL» 16-17 Settembre 2019 Cagliari (Italy)



THANK YOU