Laboratory research activities on advanced energy storage systems for electric mobility

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Istituto Motori – National Research Council of Italy

The Istituto Motori is one of the largest research Institutes of the CNR. The 22 laboratories are organised in test cells for propulsion and energy conversion systems, distributed on an area greater than 4000 m^2.

Staff:

- 45 Researchers and Technologists
- 25 Technicians and Administrative Employees

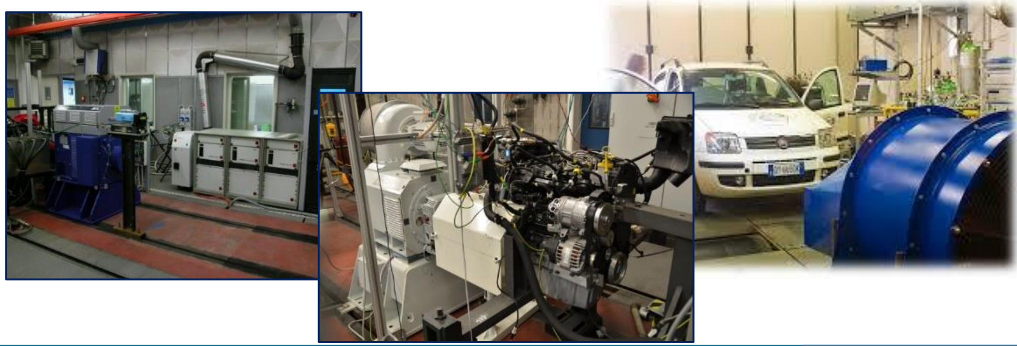
Director: Dr. Gerardo Valentino

ISTITUTO MOTORI
National Research Council of Italy

- Public Research Projects
- Industries
- Education

Main Research Fields:

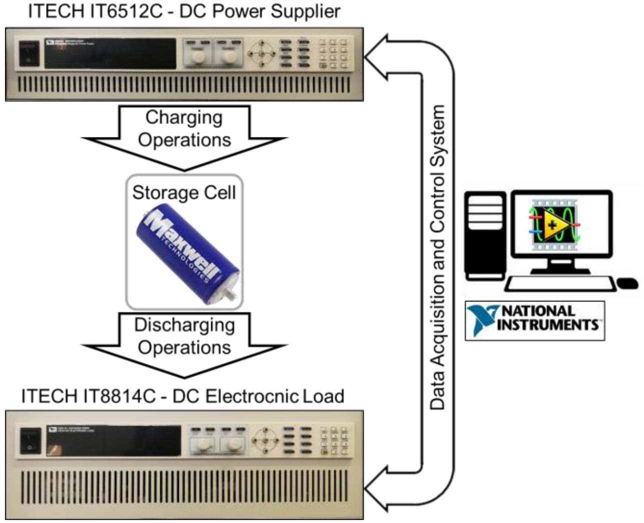
- Integrated methodologies for propulsion and energy systems
- Methodologies and technologies for sustainable transport
- Advanced systems for thermal engines optimization
- Advanced technologies and systems for efficient energy conversion with low environmental impact
- Technologies for propulsion and energy systems



CNR Istituto Motori : Main Laboratory Facilities for Electric Mobility

Storage System Test Bench

The preliminary experimental tests on batteries performed using a laboratory test bench, mainly composed by life cycle testers and climate chamber connected to a computer for the system control and data acquisition.

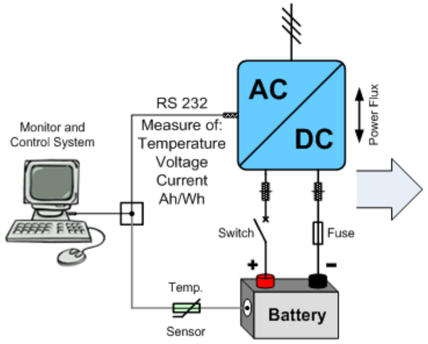


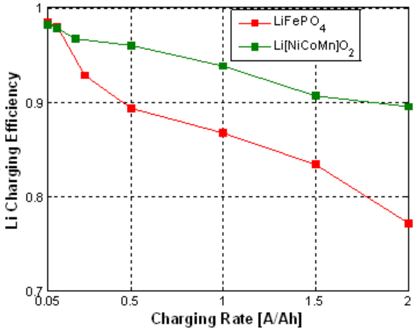
Charging/Discharging devices for Storage Systems

- Voltage Range: 0 - 12 V, 0-120 V
- Maximum Charging Current: 120 A
- Maximum Discharging Current: 240 A
- Operative Modes: CC/CV/CR/CP/Custom Cycles

Climate Chamber

- Temperature Range: -40 +180°C
- Humidity Range: 0 95%
- GN2 inlet for safe battery tests

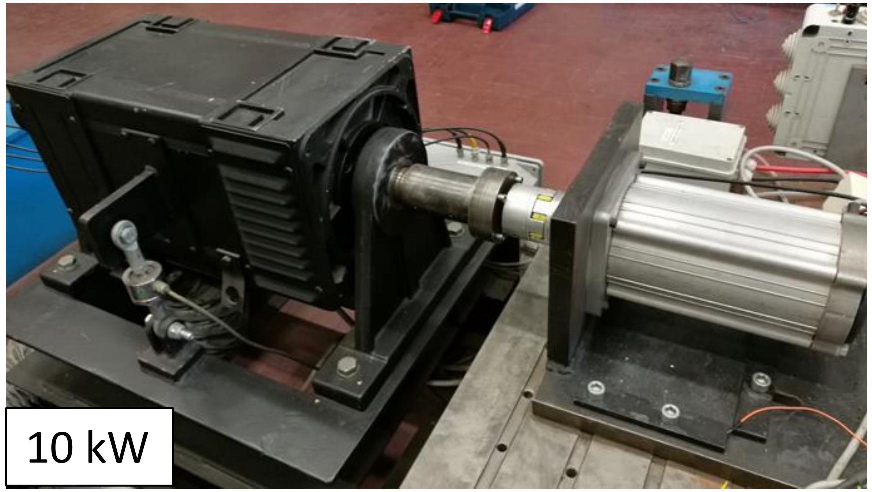


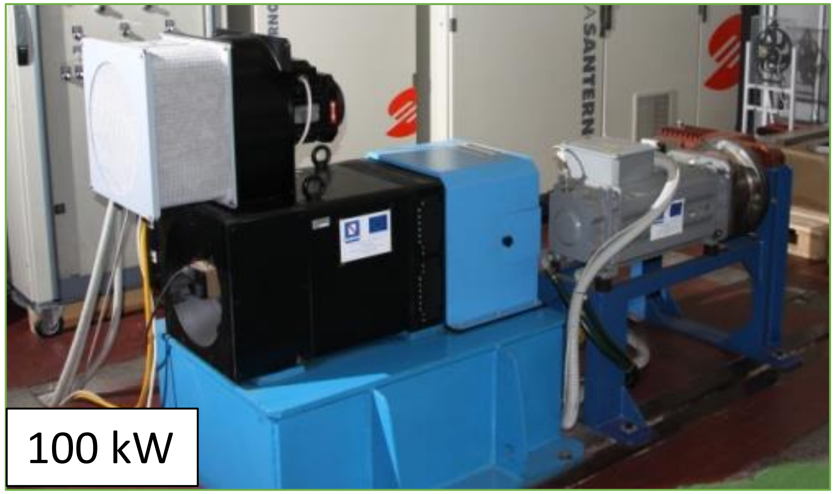


(*) C. Capasso, O. Veneri "Experimental analysis on the performance of lithium based batteries for road full electric and hybrid vehicles" Applied Energy 2014

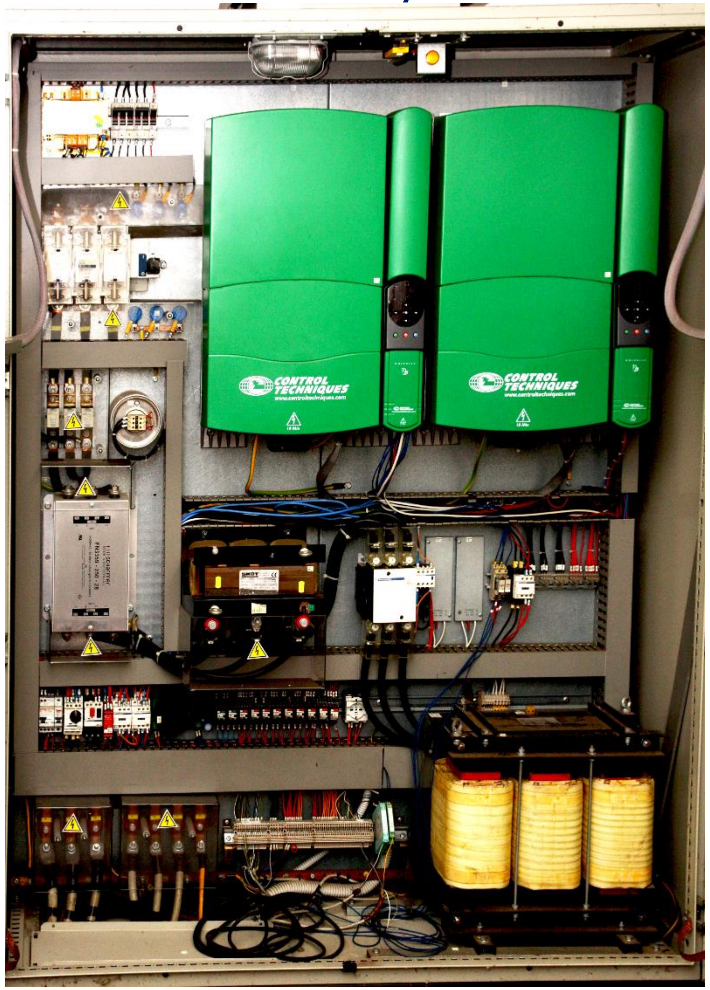
Laboratory Test Benches for Electric Drive up to 230 kW

4-quadrant Dynamic Brakes

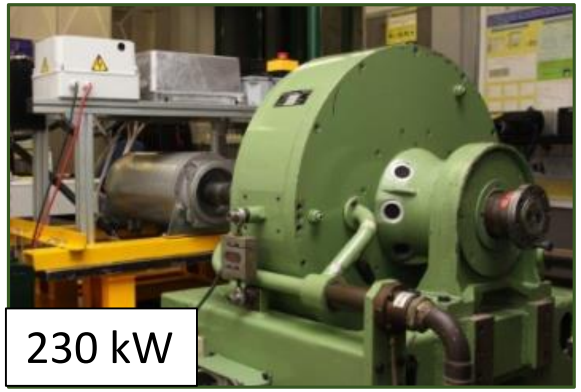

10 kW

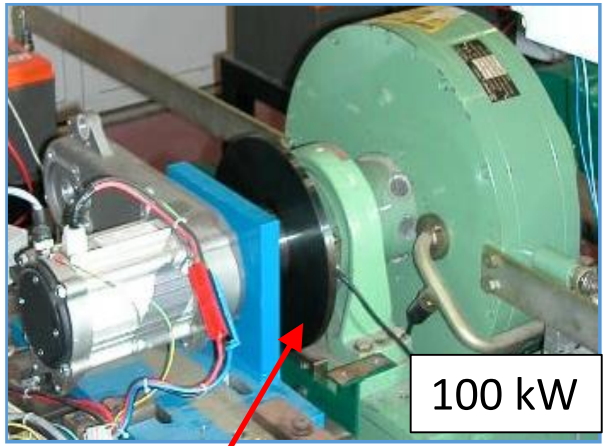

100 kW

Dynamic Brake Control System



Eddy Current Brakes

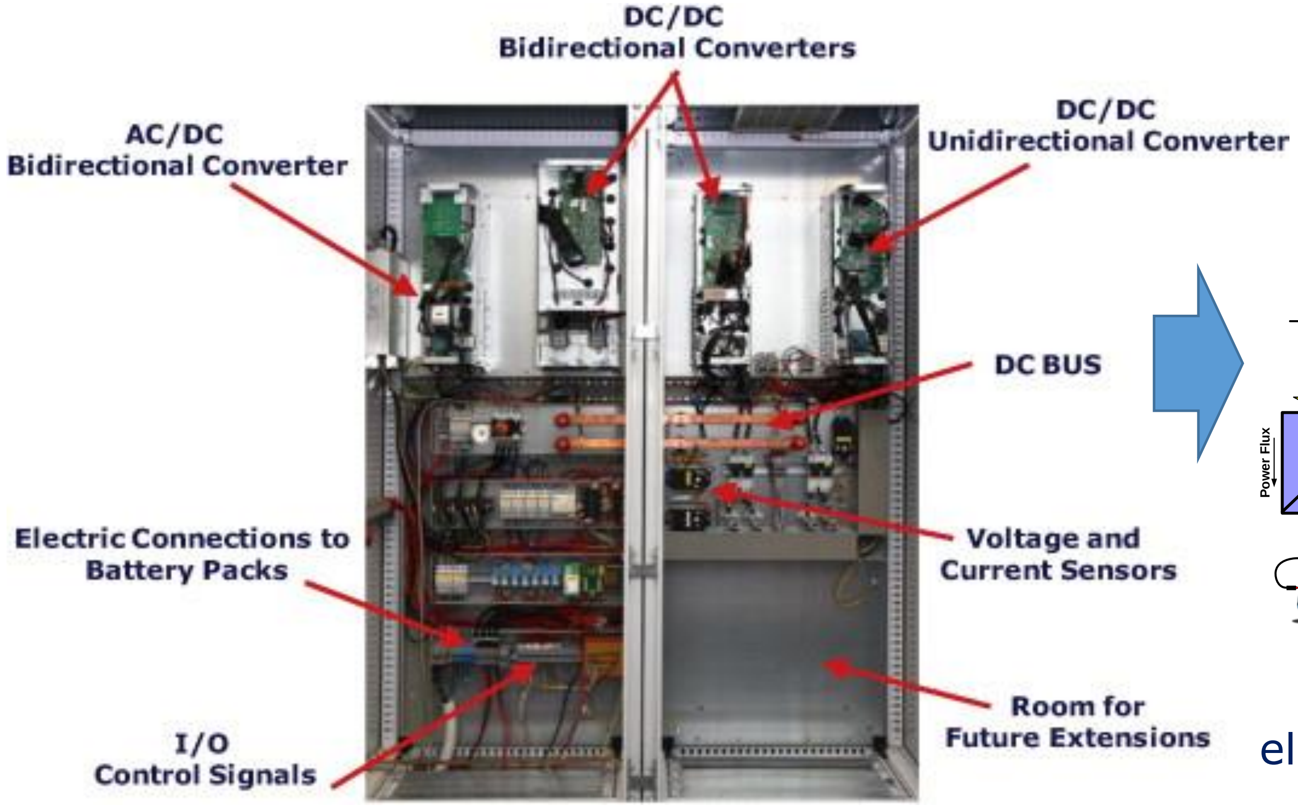

230 kW

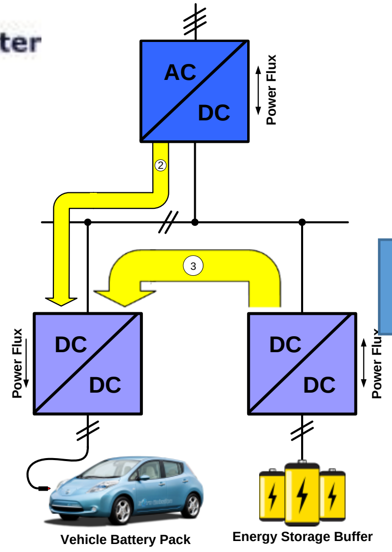

100 kW

Flywheel for the simulation of vehicle inertia

Charging Architectures for Electric Vehicles

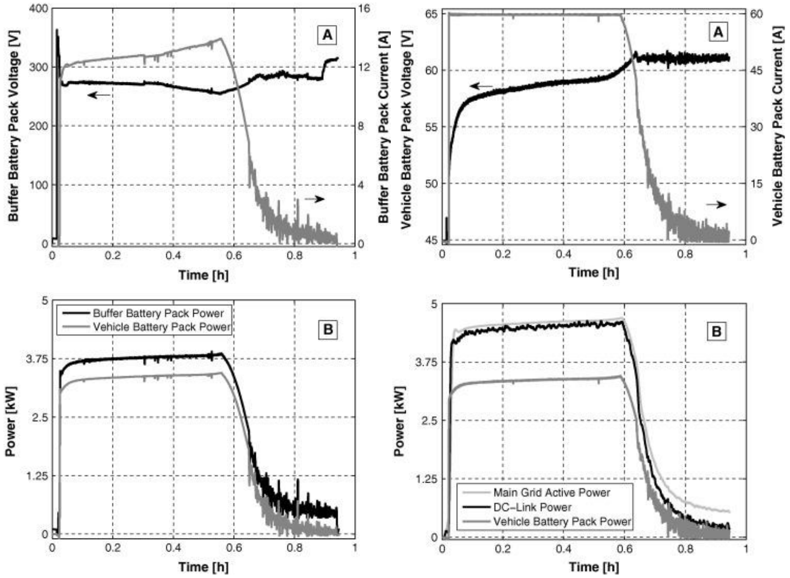
Prototype of 800 V DC bus fast Charging Station





Management of
electric power flows

Experimental Results (*)



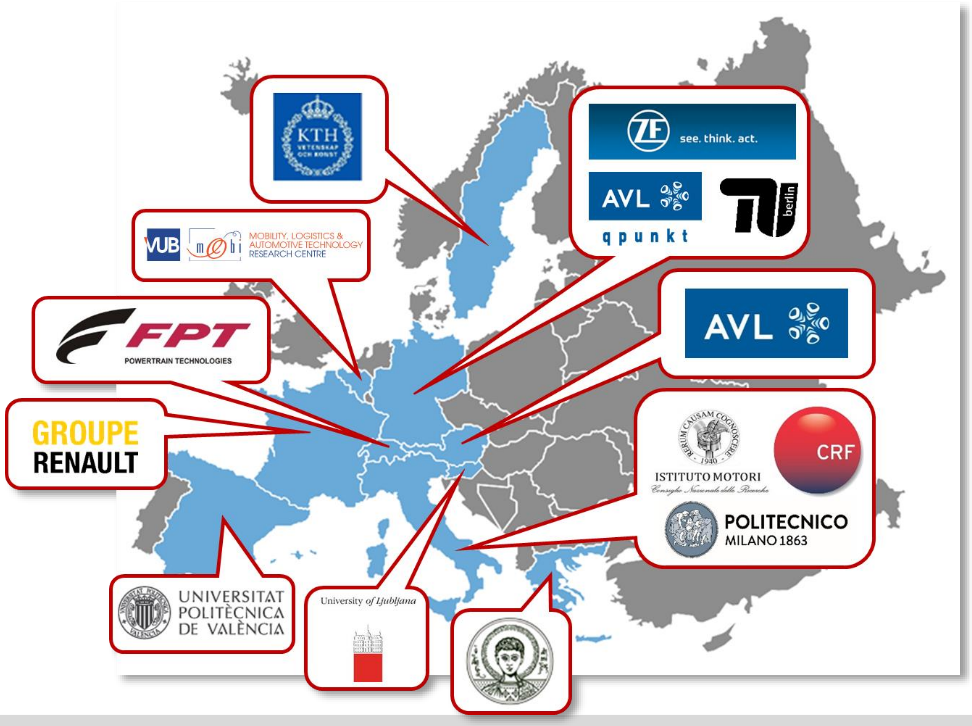
(*)
L Rubino, C Capasso, O Veneri "Review on plug-in electric vehicle charging architectures integrated with distributed energy sources for sustainable mobility" Applied Energy 2017
O Veneri, C Capasso, D Iannuzzi "Experimental evaluation of DC charging architecture for fully-electrified low-power two-wheeler" Applied Energy 2016
C Capasso, O Veneri "Experimental study of a DC charging station for full electric and plug in hybrid vehicles" Applied Energy 2015

Main Activities on Super-Capacitors and Hybrid energy Storage Systems for Sustainable Mobility

VISION-xEV

Project Coordinator: AVL

Objective: Development and demonstration of a **generic virtual component and system integration framework** for efficient development of all kinds of future electrified / hybrid vehicles

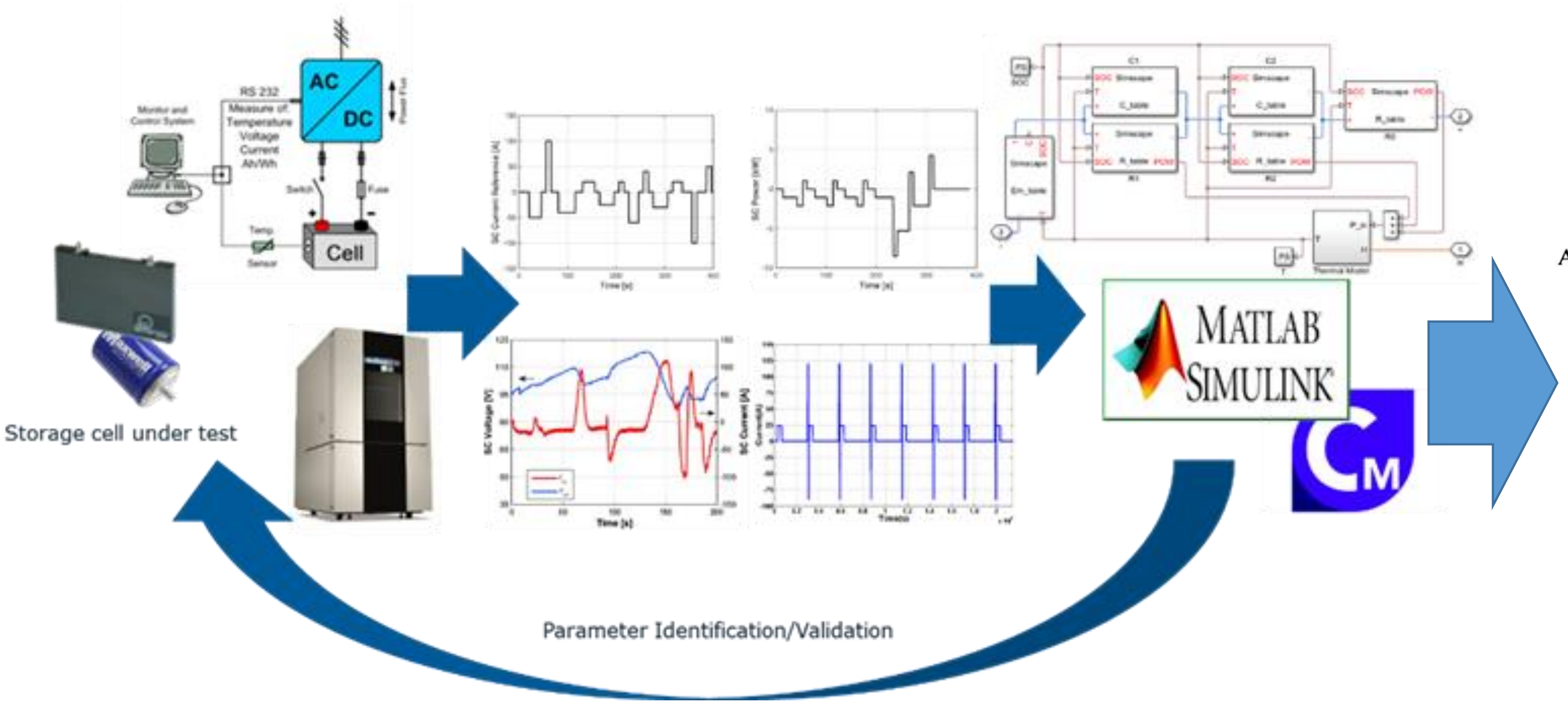


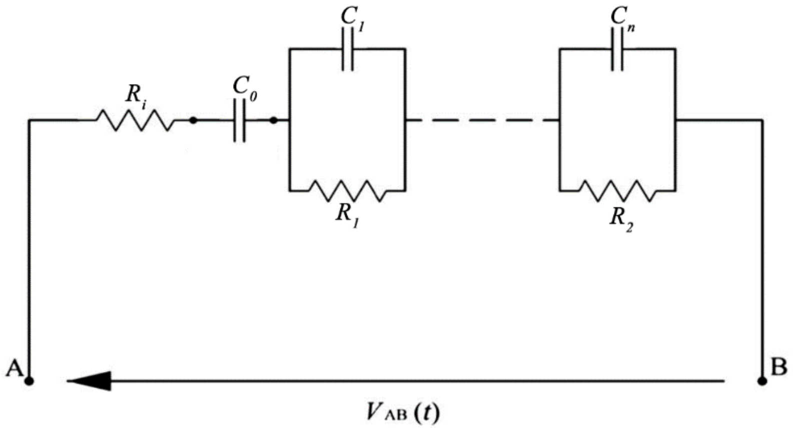
- 14 partners from 10 different countries
- Overall budget / funding: 3,995,061.25 €
- Overall capacity: 472 MM
- Project start: 1.1.2019
- Duration: 36 months

European Commission

Activities of IM-CNR

- Development and integration in xEV virtual platforms of Super-Capacitor models;
- Complete experimental characterization of various Super-Cap technologies under different ambient and operating conditions.





n-orther capacitor model

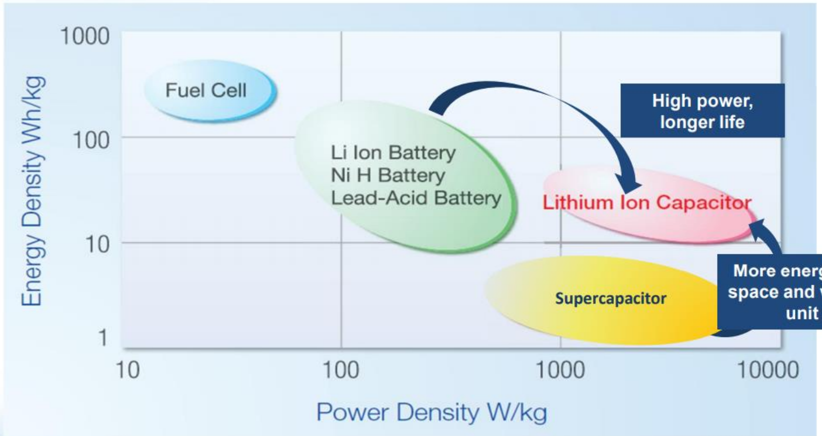
Storage Technologies Under Test

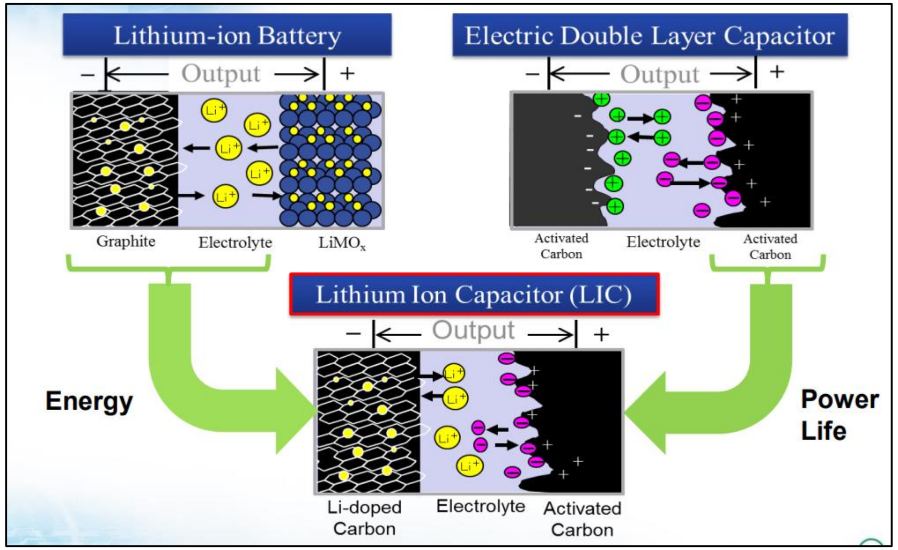
EDLC cells

Maxwell BCAP EDLC 3000 cell

Parameter	Value
Rated Capacitance (F)	3000
Shape	Cylindrical
Nom. Voltage (V)	2.70
DC Equivalent Series Resistance (mΩ)	0.29
Weight (g)	510
Maximum Leakage Current (mA)	5.20
Stored Energy (Wh)	3.04
Specific Energy (Wh/kg)	6.00
Usable Specific Power (W/kg)	5900

Lithium Ion Capacitor cells





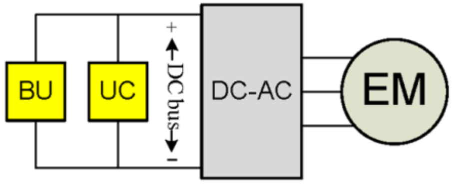
Parameter	ULTIMO 3300F LR
Range of Operating Temperatures (°C)	-30~70
Maximum Voltage (V)	3.8
Minimum Voltage (V)	2.2
Capacitance (F)	3300
ESR (mΩ)	0.7mΩ
DC-IR (mΩ)	1.0mΩ
Weight E-density (Wh/kg)	13
Volume E-density (Wh/L)	20
-20°C Capacitance ratio(vs 25 °C)	85 %
70°C Capacitance ratio(vs 25 °C)	100 %
Cell size (mm)	150x93.0x15.5
Cell weight (kg)	0.350

Hybrid Energy Storage Systems (HESS)

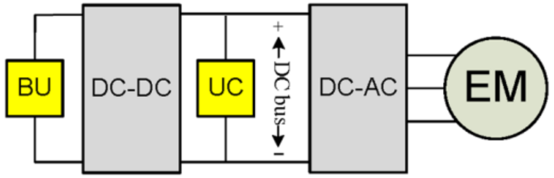
Battery Packs with High Energy Density

Ultra-Cacpacitors with High Power Density and long lifecycle

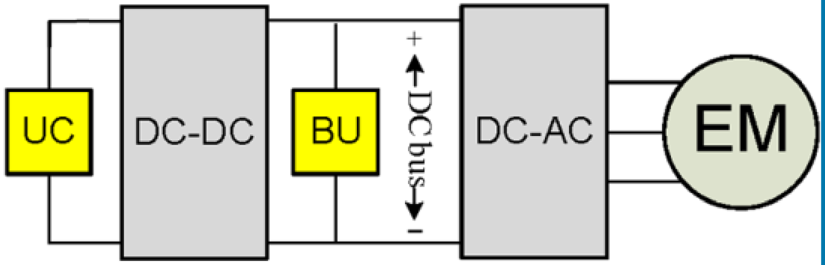
Power Architectures for Storage Units Integration



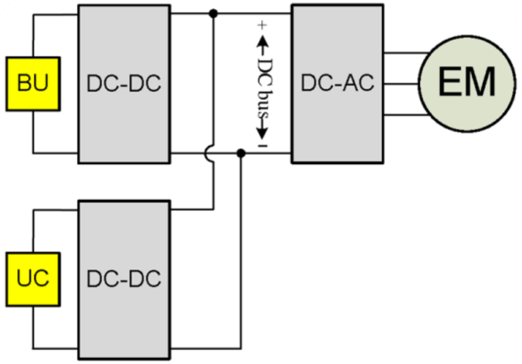
(a)



(b)

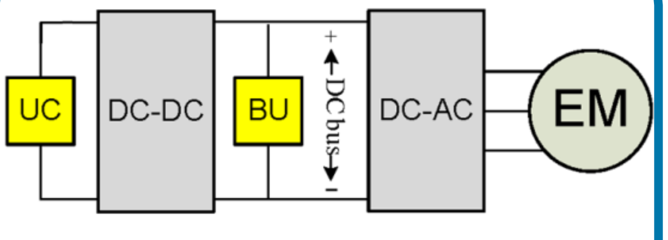


(c)



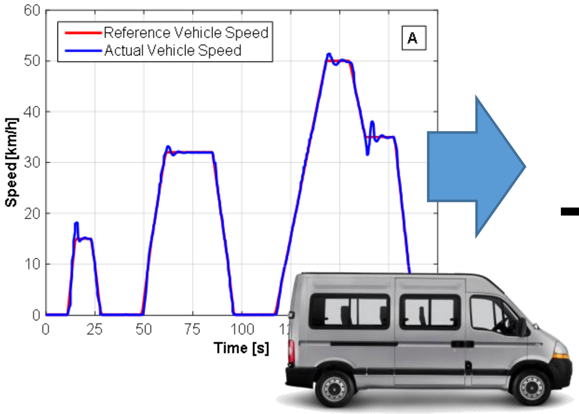
(d)

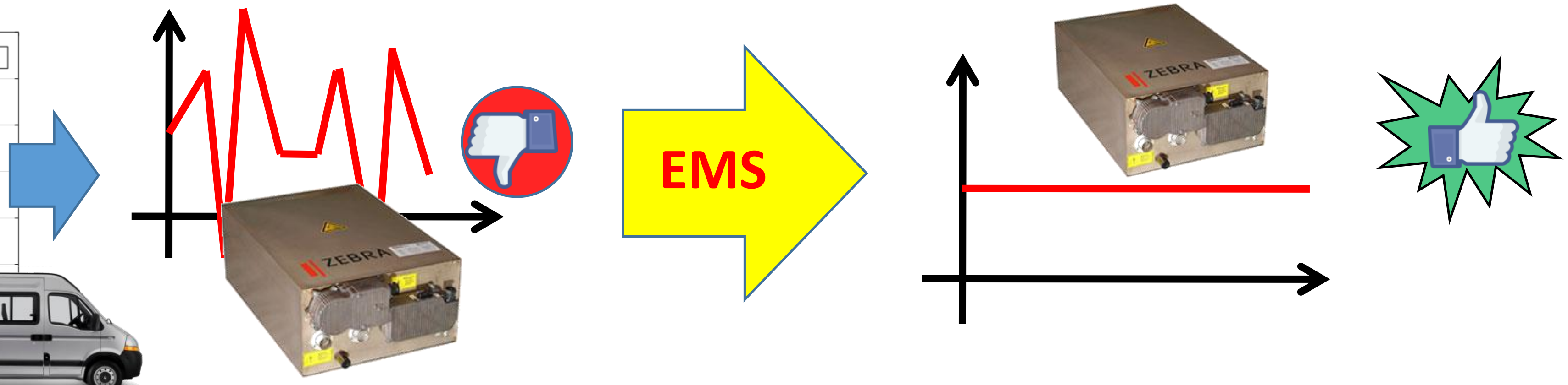
Energy Management Strategies (EMS)



(c)

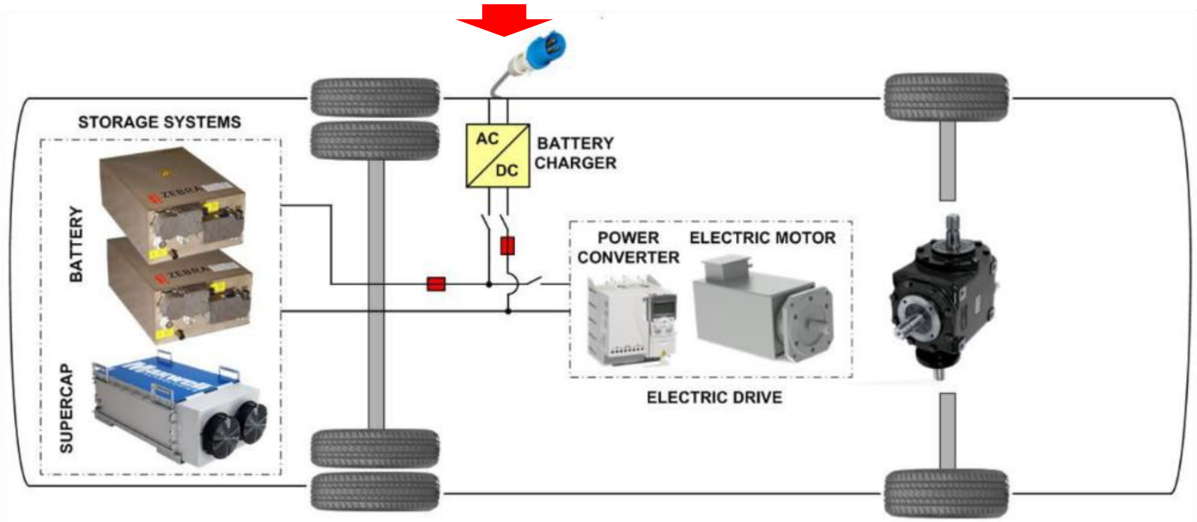
Main Objective of EMS: *Reduction of battery pack charging/discharging peak current through the use of ultra-capacitors in order to increase the expected battery lifetime*





Comprehensive example of Case Study in Istituto Motori: Electric Urban Bus Architecture

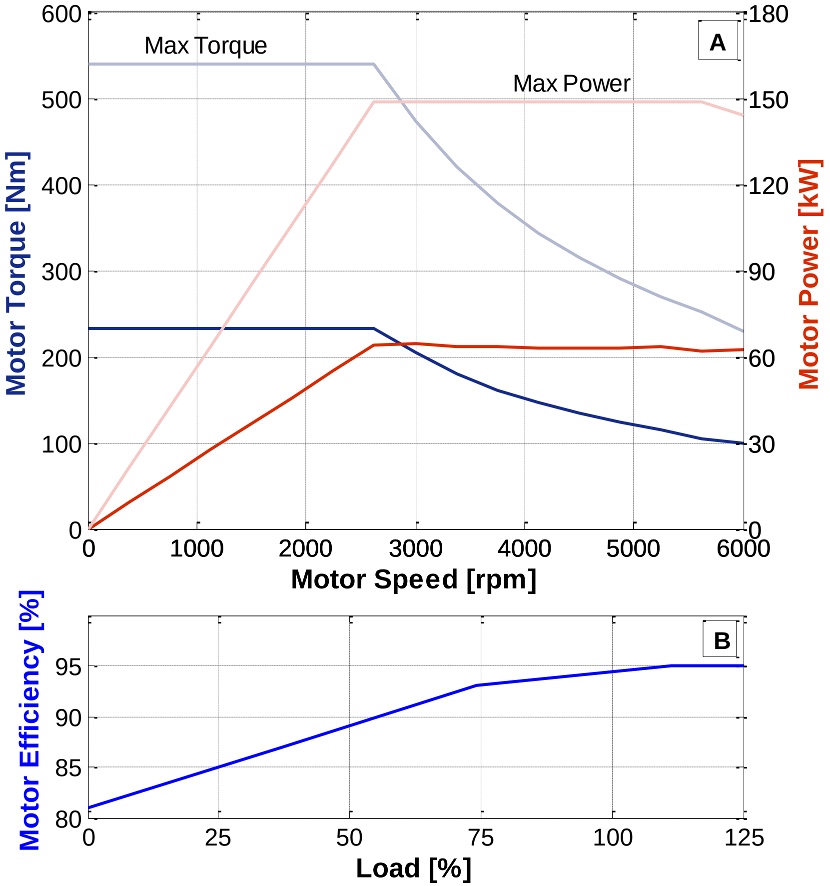
Urban bus – Full Electric Architecture



Weight (without passengers)	1820 kg
Numbers of Passenger + Bus Driver	8
Total Weight (with an average passenger weight of 70 kg)	2380 kg
Aerodynamic Drag Coefficient	0.7
Front Surface	3.664 m^2
Tires	225/75 R17.5
Transmission Ratio	1/3.17 - 1/6
Max Speed	6000 rpm
Nominal Battery Capacity (with two Zebra batteries connected in parallel)	42.4 kWh
Storage System Weight	362 kg
Electric Propulsion System Weight	730 kg

Main Characteristics of the Electric Motor

Motor	Three-phase Asynchronous
Cooling	Liquid cooled
Nominal Power	63.4 kW
Max Power	147 kW
Nominal Torque	233 Nm
Max Torque	540 Nm
Nominal Speed	2600 rpm
Max Speed	6000 rpm
Inertia	0.151 kg m^2
Weight	150 kg

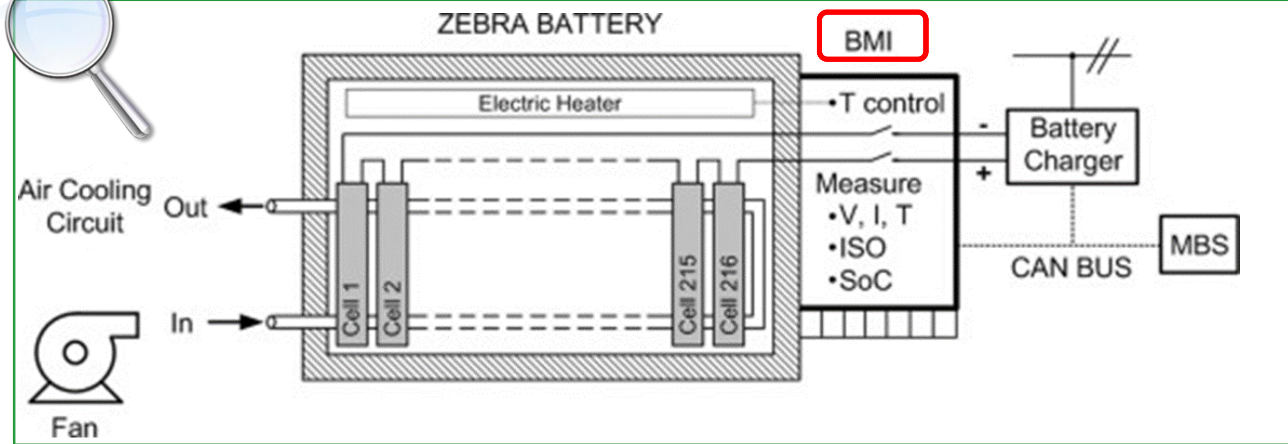


Electromechanical characteristics in terms of torque and power versus motor speed (A) and motor efficiency vs mechanical load (B)

Main Characteristics of Storage Units

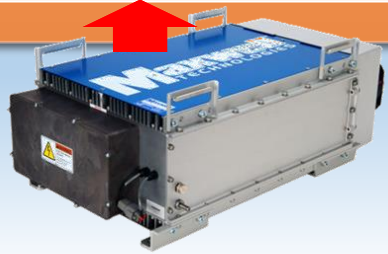
ZEBRA Battery Pack

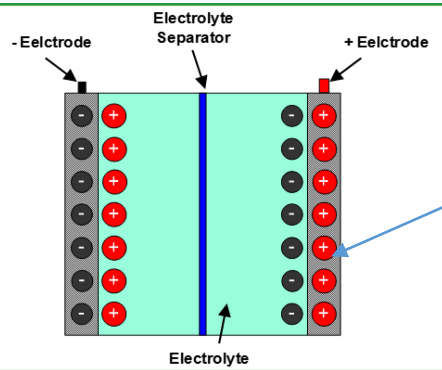
Capacity	38 Ah
Nominal Energy	21.2 kWh
Open Circuit Voltage	557 V
Peak Discharging Current	112 A
Numbers of Cells	216
Weight (with BMI)	184 Kg
Specific Energy (Without BMI)	118 Wh/kg
Energy Density (Without BMI)	181 Wh/l
Specific Power	179 W/kg
Power Density	273 Wh/l
Working temperature range (K)	508–613



Ultra-Capacitor Module

Rated Capacitance [F]	63
Max Equivalent Series Resistance (in DC) initial [mΩ]	18
Rated Voltage [V]	125
Maximum Voltage [V]	136
Max Continuous Current @ ΔT = 15 K[A]	140
Max Continuous Current @ ΔT = 40 K [A]	240
Max Peak Current [A]	1900
Maximum Series Voltage [V]	1500
Operative Temperature [K]	263 ÷ 340
Cooling System	Air



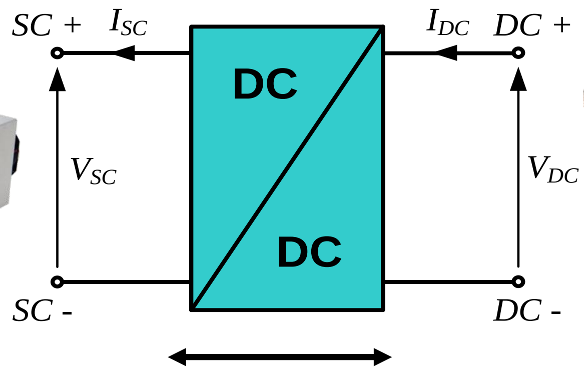


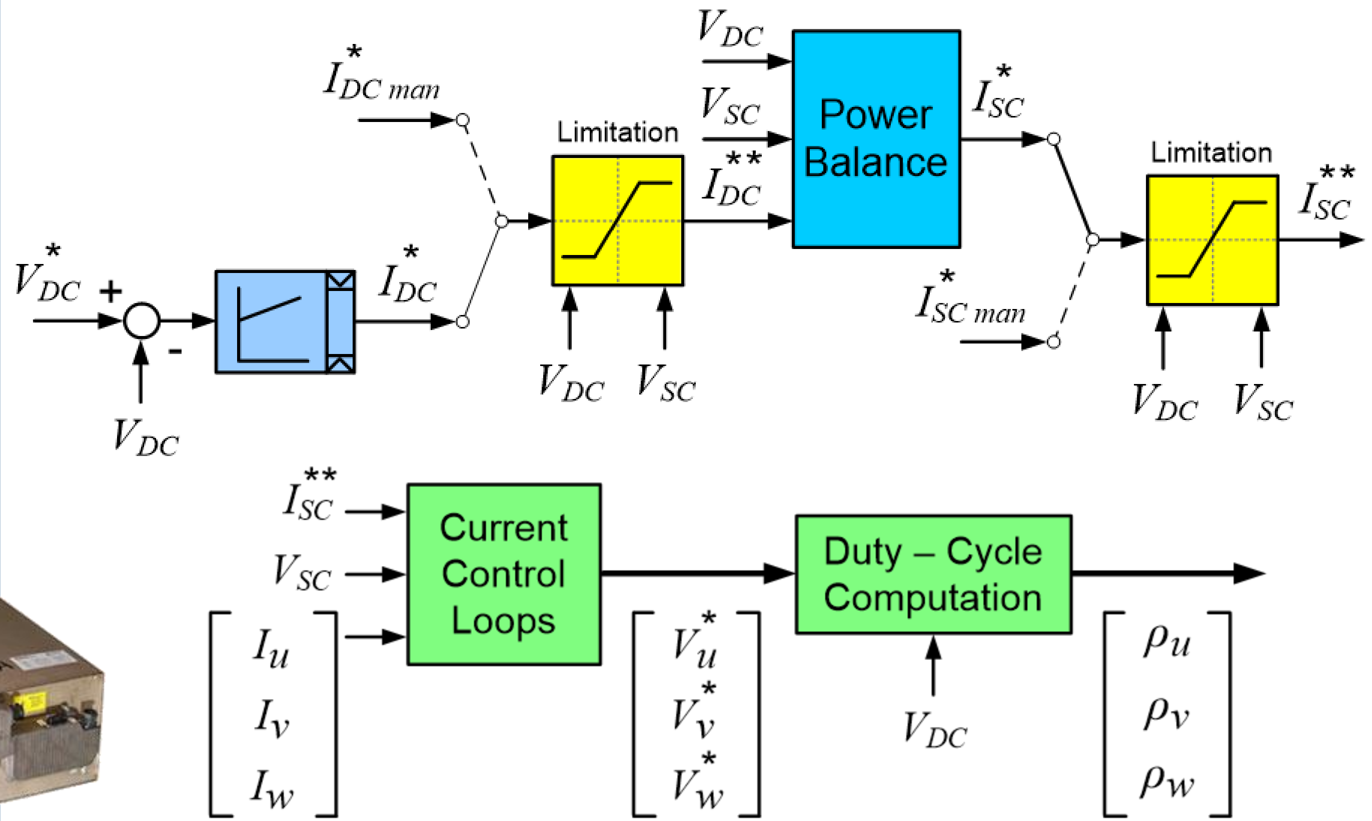
Porous structures of the EDLCs electrode surface, realizing equivalent areas up to 2000 m^2/cm^3 with a consequent increase in capacitance $C=\varepsilon_0 A/d$

DC/DC Power Converter – Control Modes

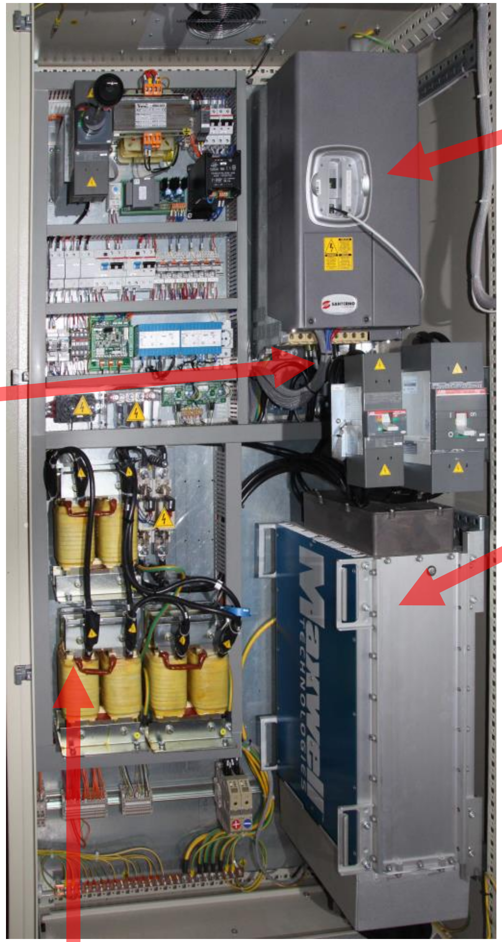
DC/DC Converter control modes:

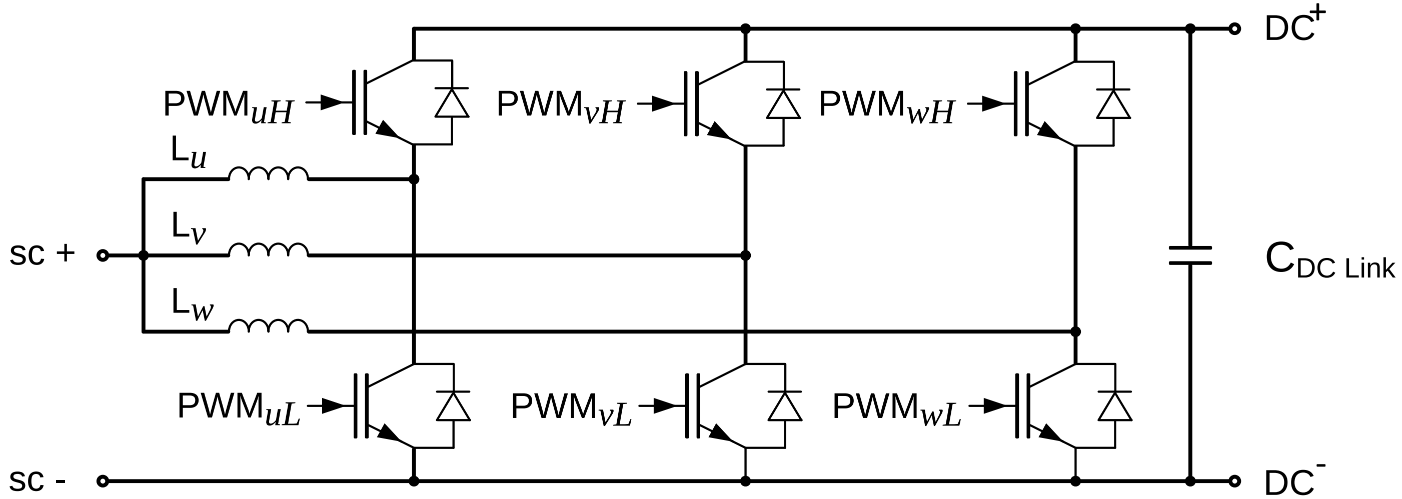
- **SC current reference = $I^*_{SC\ man}$**
- **DC link current reference = $I^*_{DC\ man}$**
- **DC link voltage reference = V^*_{DC}**





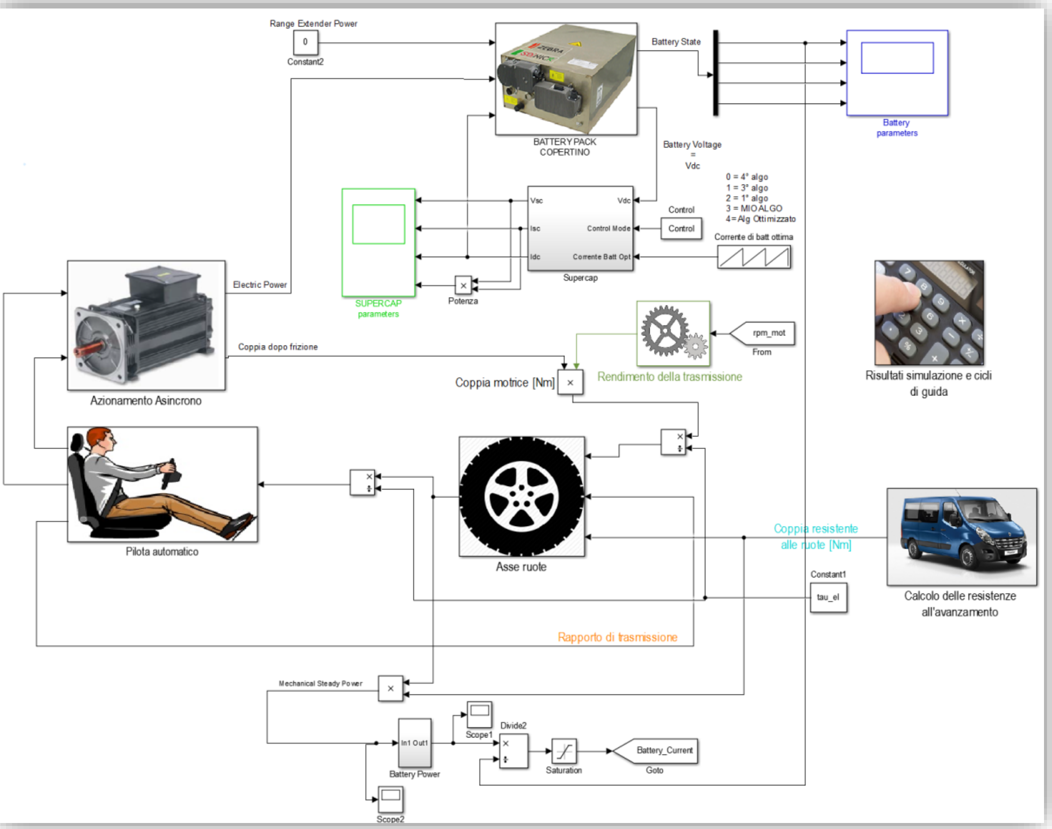
DC/DC Bidirectional Power Converter



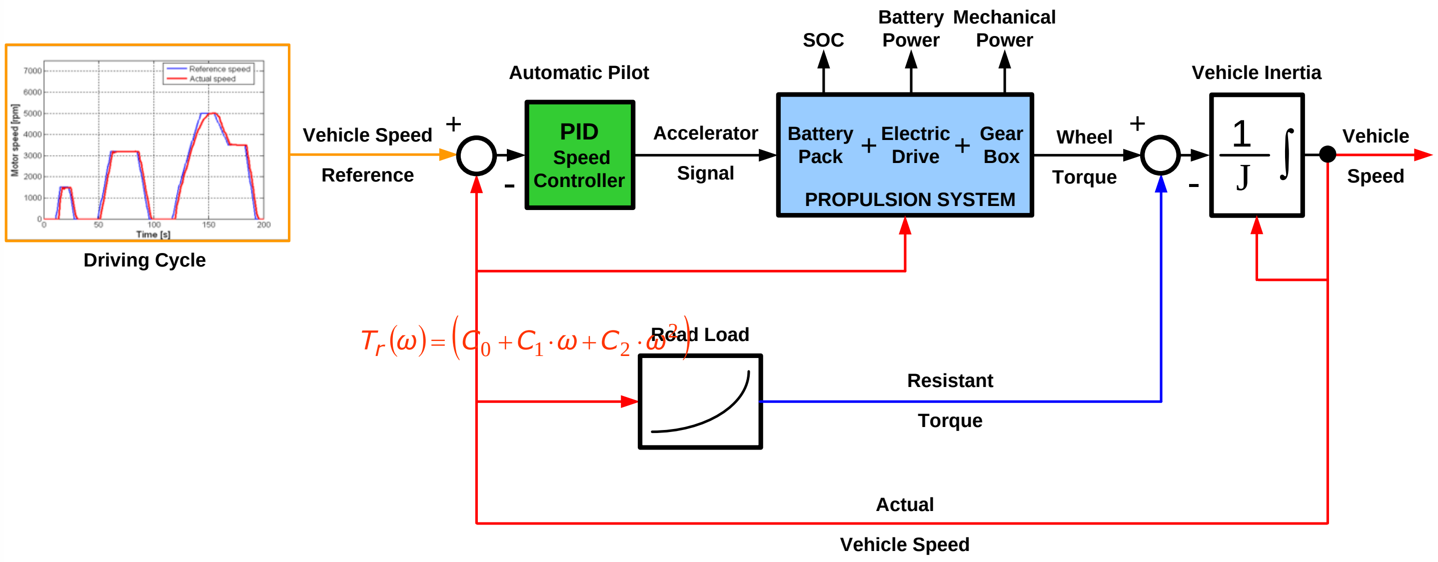


Min Voltage/DC Link-side [V]	333
Max Voltage/ DC Link -side [V]	828
Rated current/ DC Link -side [A]	150
Rated current/SC-side [A]	286
Max current/SC-side [A]	328
Switching frequency [kHz]	2.5 ÷ 5

Simulink Model of the Urban Bus

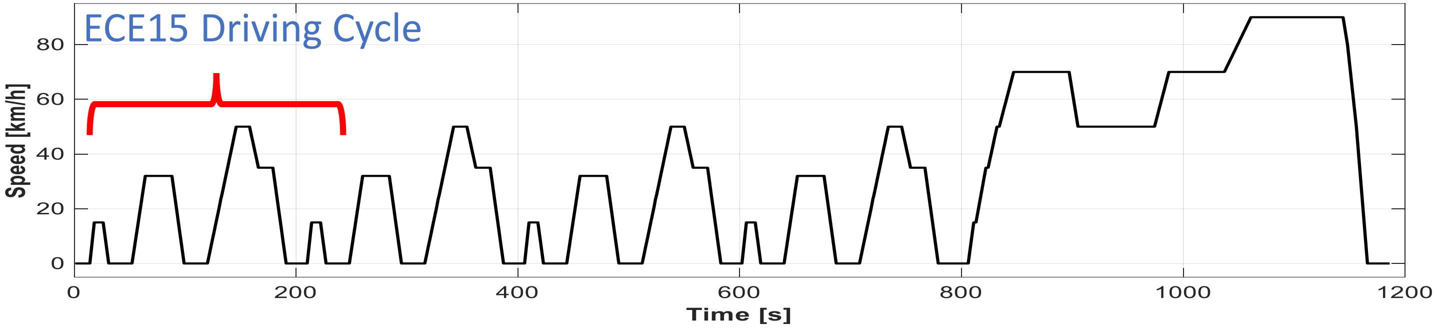


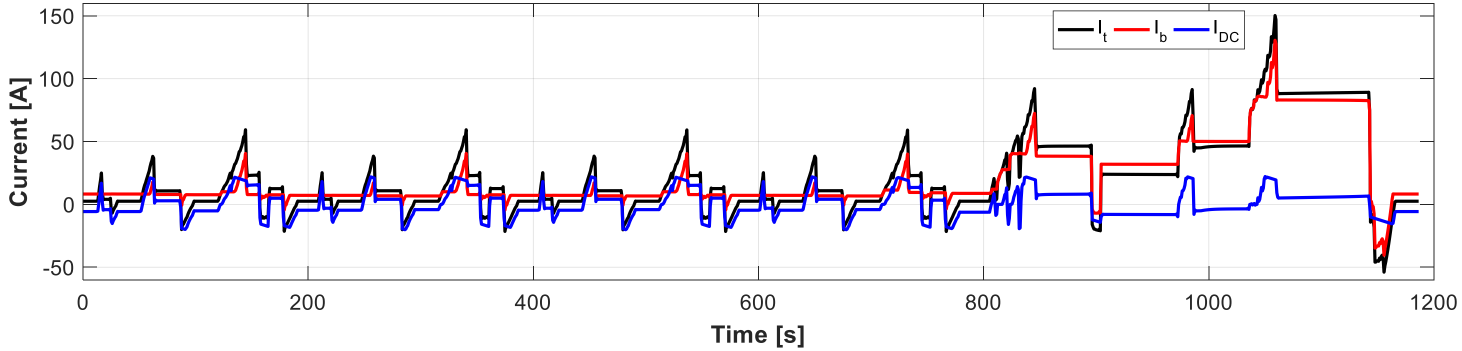
- Speed and torque control scheme



Preliminary Simulation Results

NEDC Driving Cycle

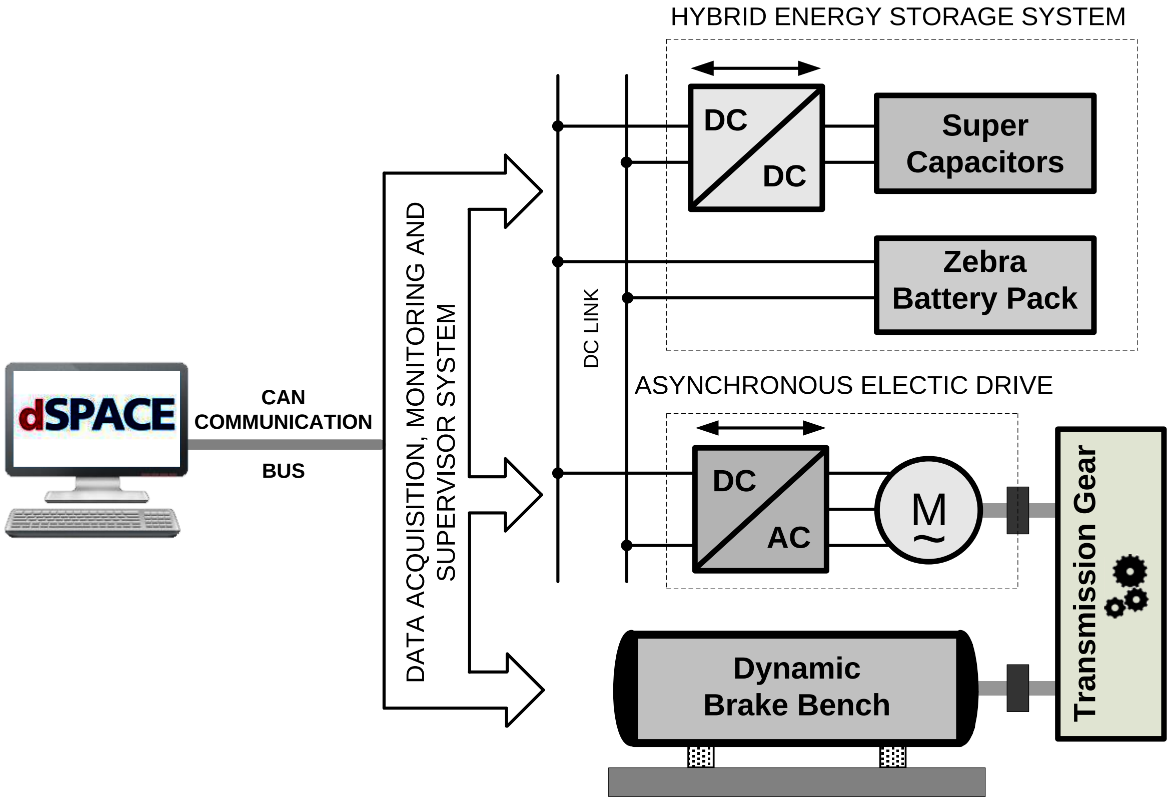


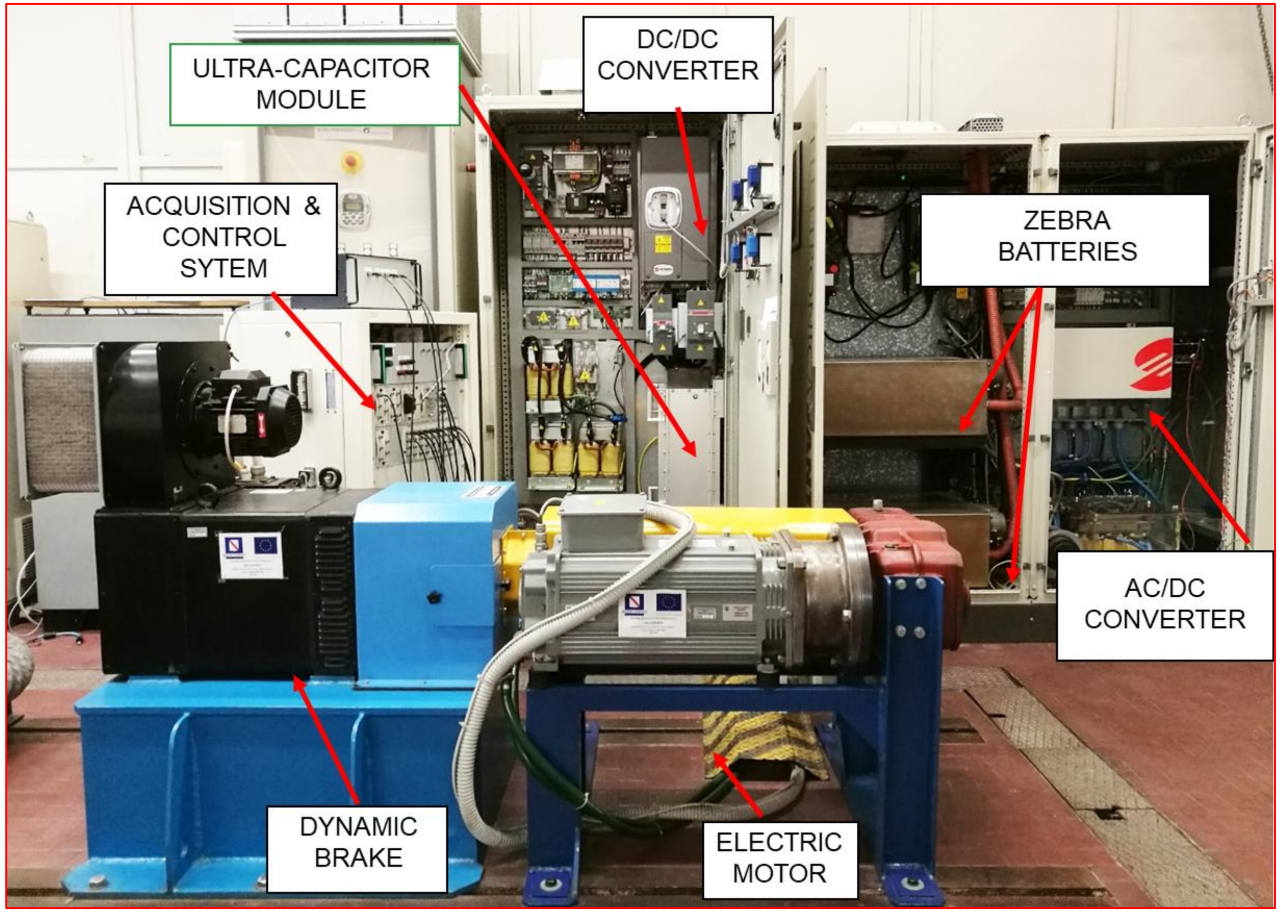


Ultra-capacitor Current on DC-Link side
Battery Current
Total DC-Link Current

Driving Cycle	EMS Efficacy%	
	Filter-based	Lambda-control
ECE15	60.4%	64.4%
NEDC	11.6%	17.2%
WLTC low	60.0%	59.6%
WLTC high	16%	15.9%

Scheme and Picture of the Laboratory Dynamic Test-Bench





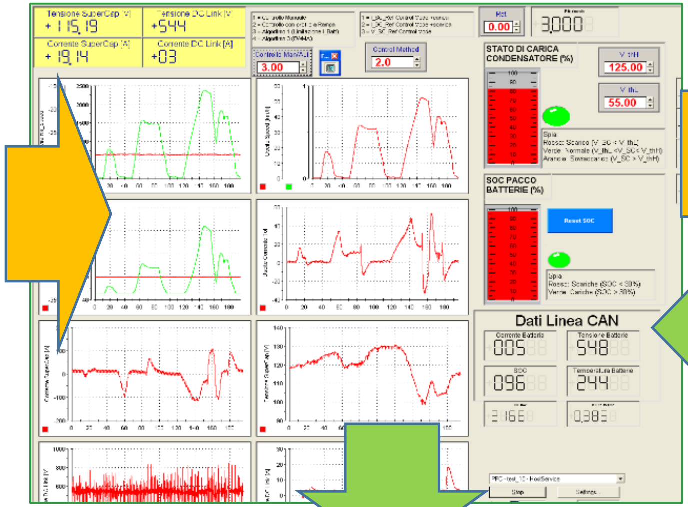
Laboratory implementation of EMS

Simulink Model Built in “.ppc” format

MATLAB SIMULINK

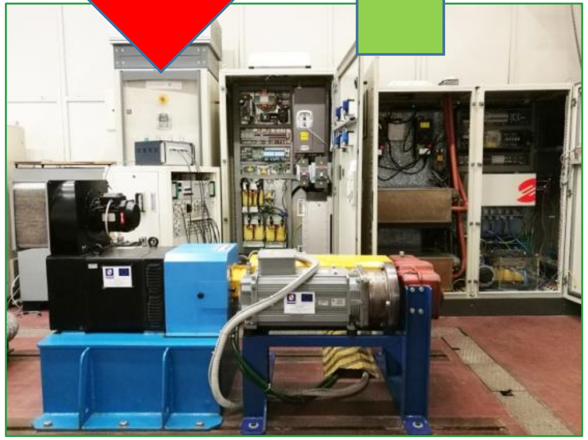
dSPACE

Control Desk



dSPACE

Hardware



Data acquisition “.mat”

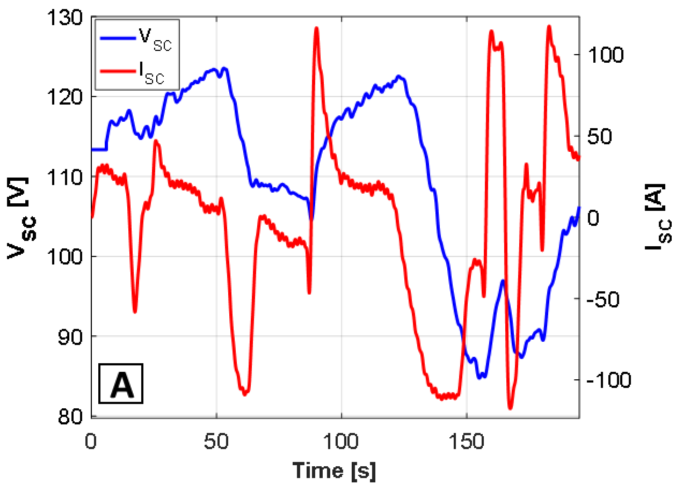
Measurement Acquistion

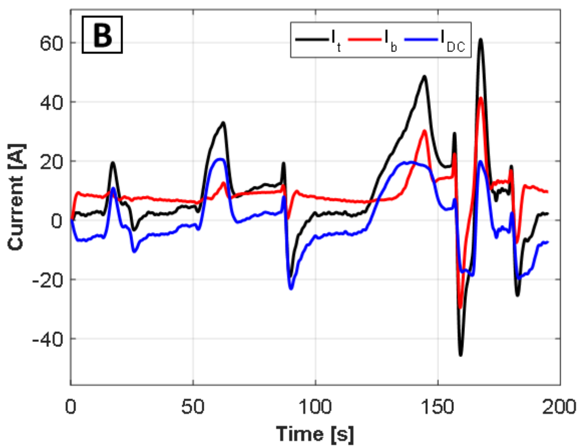
Software Flows

Real Time Control

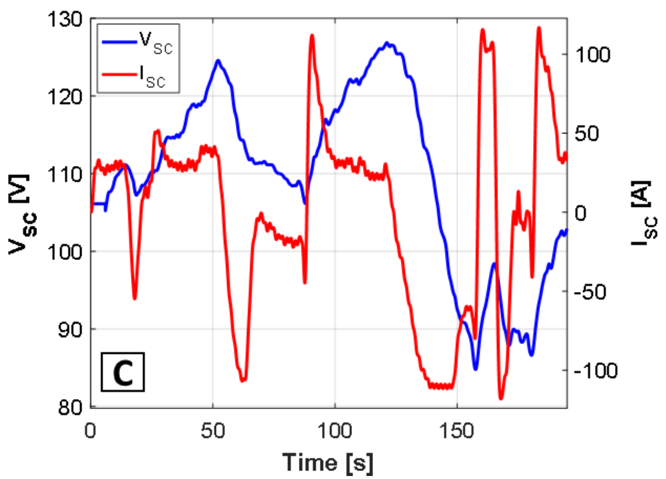
ECE 15 Driving Cycle: Example of Experimental Results (*)

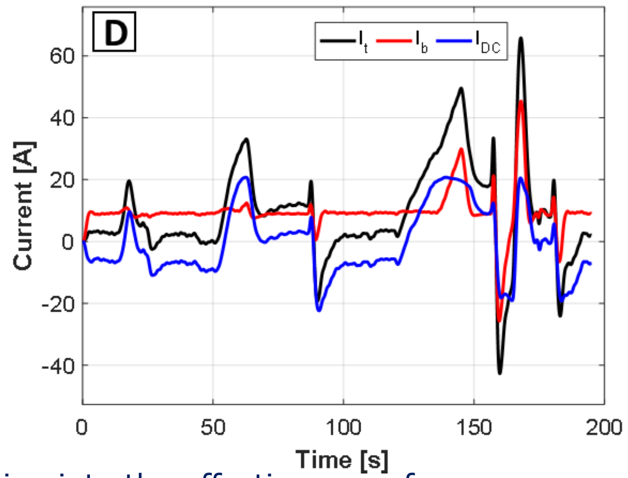
Filter Based EMS





Lambda Control EMS





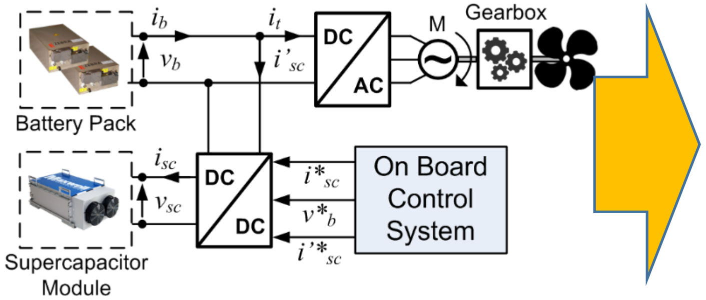
Ultra-capacitor Voltage
Ultra-capacitor Current

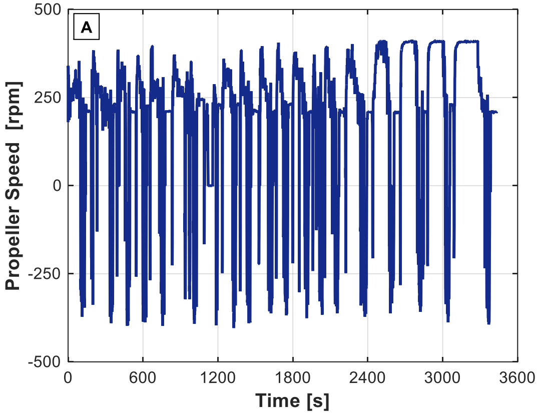
Ultra-capacitor Current on DC-Link side
Battery Current
Total DC-Link Current

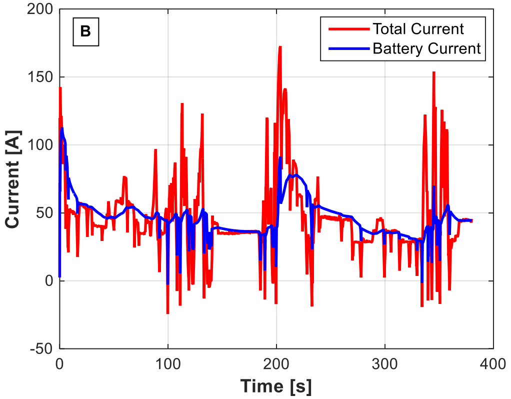
(*) O. Veneri, C. Capasso, S. Patalano "Experimental investigation into the effectiveness of a super-capacitor based hybrid energy storage system for urban commercial vehicles" Applied Energy 2017
C. Capasso, D. Lauria, O. Veneri "Experimental evaluation of model-based control strategies of sodium-nickel chloride battery plus supercapacitor hybrid storage systems for urban electric vehicles" Applied Energy 2018

Ongoing Activities on Hybrid Energy Storage Systems

- ❑ Perfomance evaluations of hybrid energy storage systems for marine applications.(*)



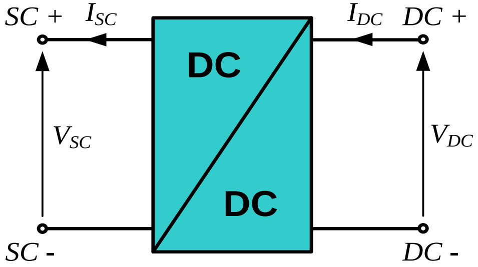




- ❑ Experimental Study of hybrid energy storage system based on Lithum Capacitors.

Rated Voltage	Max	3.8 V
	Min	2.2 V
Capacitance		3300 F
Weight E density		12 Wh/kg
Volume E density		20 Wh/l

LiC



Lithium Battery Pack

Number of Cells	13
Nominal Capacity C_{10}	20 Ah
Battery Pack Nominal Voltage	46.8 V
Max Charging Current	50 A (2.5 C)

(*) F.Balsamo, C. Capasso, O. Veneri "Performance evaluation of an all-electric waterbus supplied by hybrid energy storage systems" Speedam 20018

National Research Council of Italy

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