

Naval hybrid propulsion and energy systems

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ITALY



Plural-fractionated energy system

APPLICATION

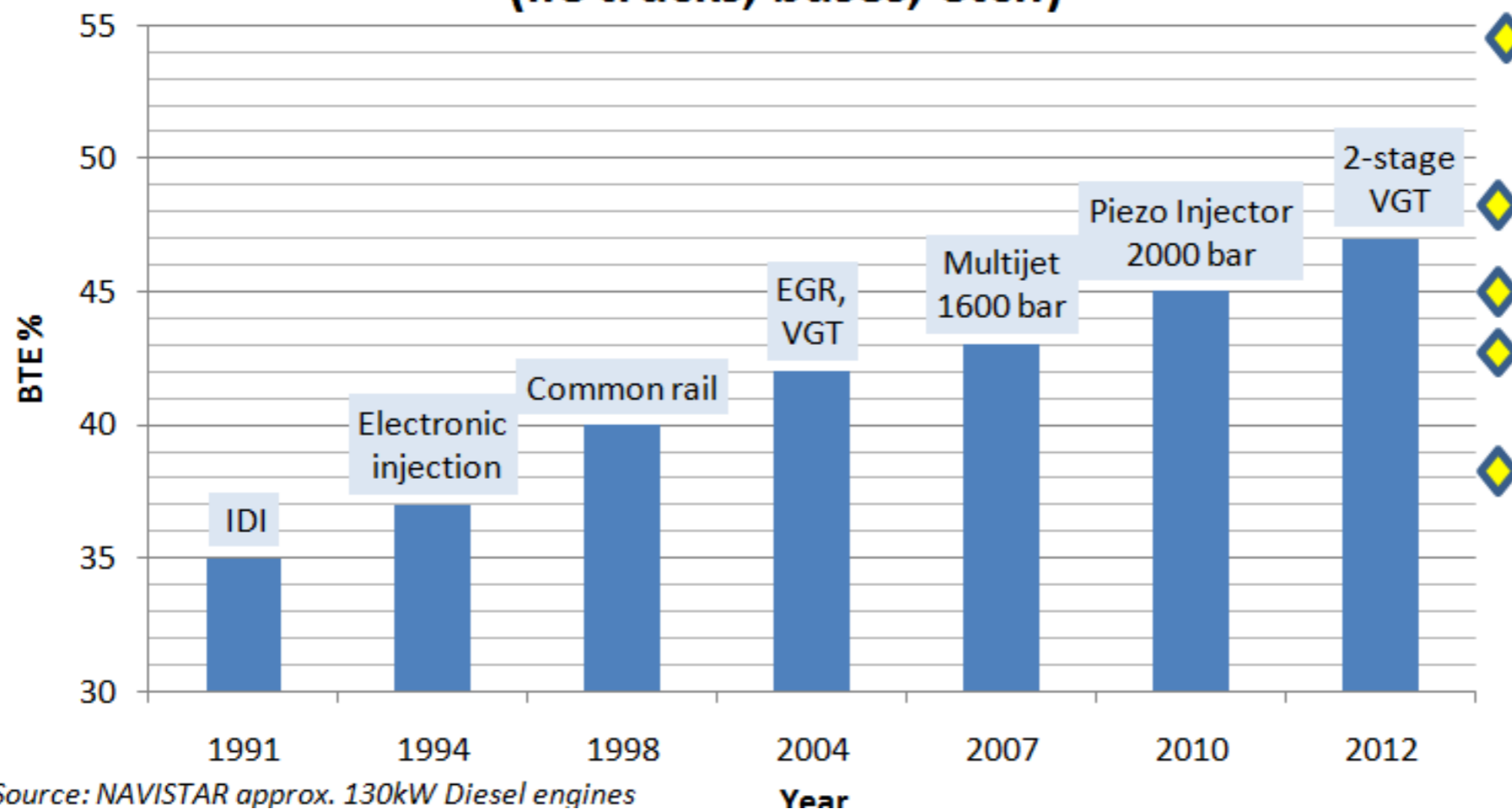
Naval propulsion and on board energy systems for ships operating at variable duty cycle, with a preponderant use at reduced power.

- ▶ **Patrol units**
- ▶ **Tugs, PSV**
- ▶ **Trawler fish boats**
- ▶ **War crafts**
- ▶ **Big yachts**
- ▶ **Ferries *for inner water***
- ▶ **....**

1. Plural-fractionated energy system

Prime movers: AUTOMOTIVE ENGINES

BTE Brake thermal efficiency for heavy duty Diesel engine (i.e trucks, buses, etc..)



DIESEL MARINE ENGINES

MAN S80ME-C Mk7 two-stroke , low speed
23 MW@250rpm

WÄRTSILÄ 18V32 medium speed
3 MW@750 rpm

WÄRTSILÄ 9L20, medium speed
1,8 MW@1000 rpm

MTU 12V4000M60R
1,05 MW@1600 rpm

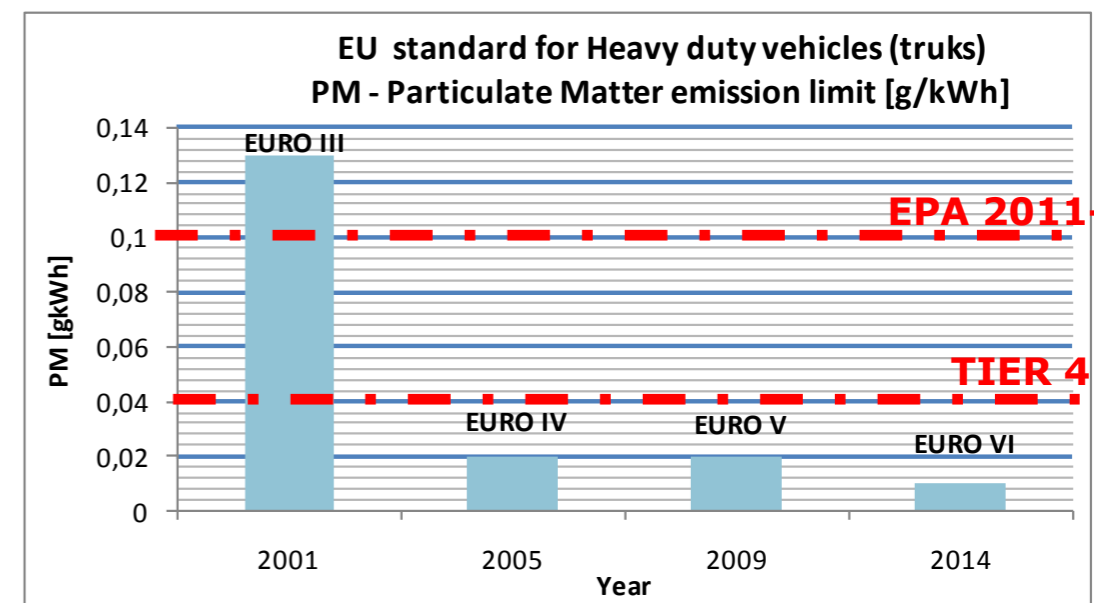
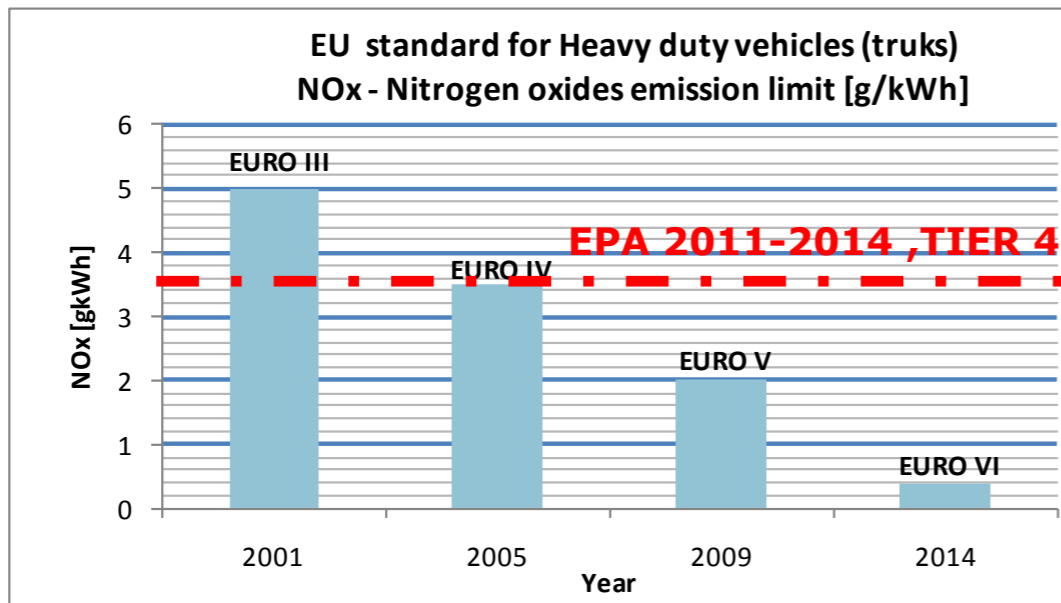
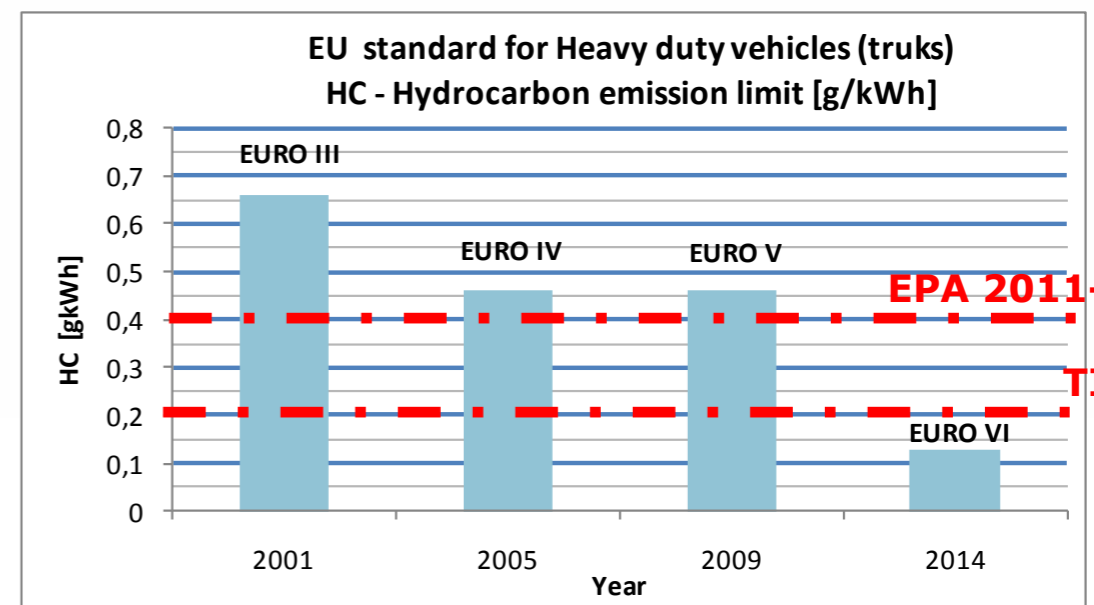
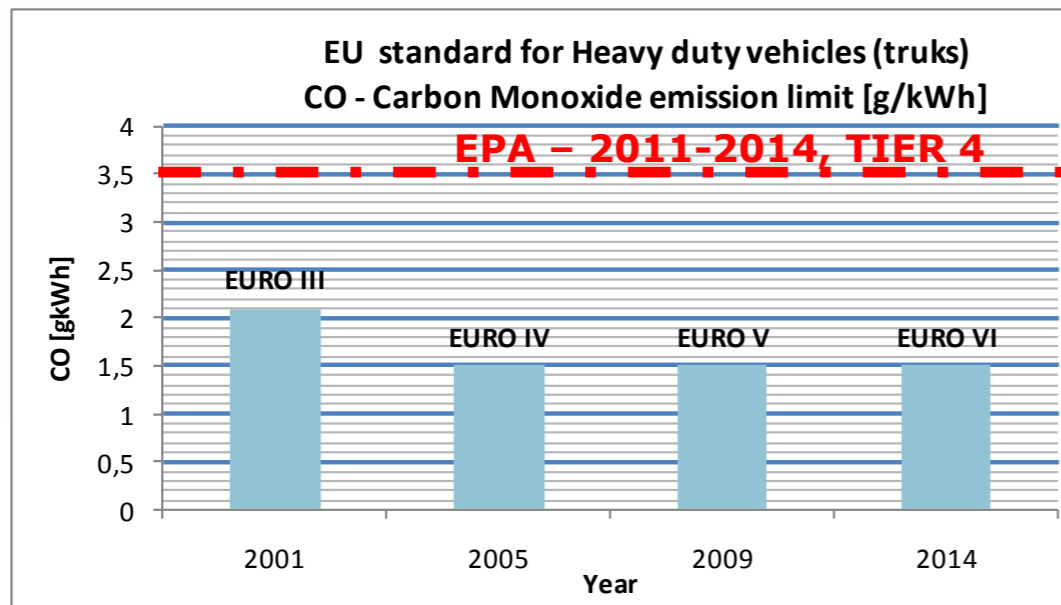
MAN V12 1360 Common rail, high speed
1 MW@2300rpm

1. Plural-fractionated energy system

AUTOMOTIVE ENGINES / EMISSION



US-EPA Standards for non road mobile equipment. P>560kW



1. Plural-fractionated energy system

Prime movers: AUTOMOTIVE ENGINES



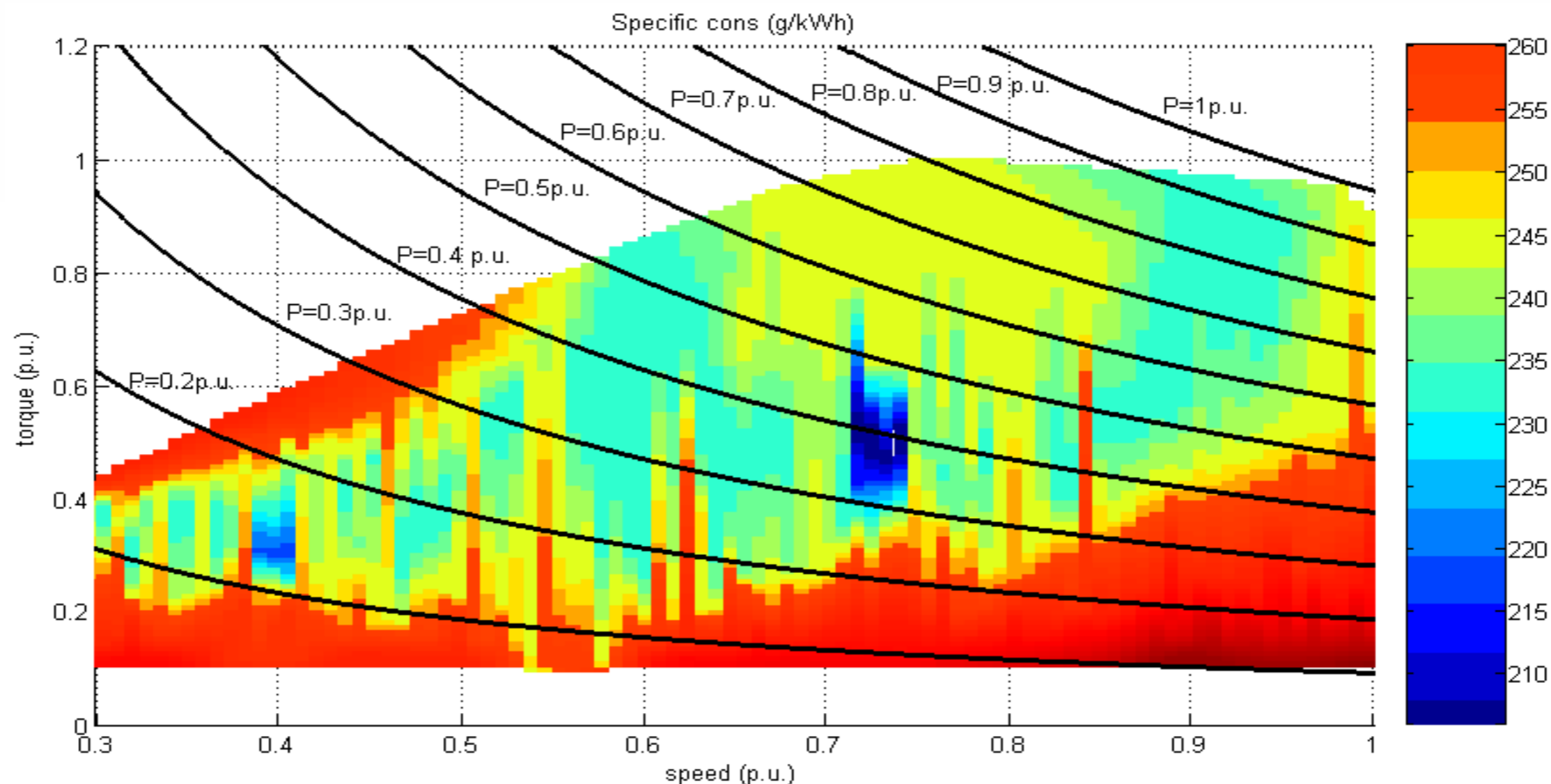
CUMMINS ISF 2.8
Heavy Duty
EURO4
110kW@3400rpm

NUMERIC EXAMPLE FOR **EURO 4, HEAVY DUTY, DIESEL ENGINE FOR LIGHTWEIGHT TRUCKS**

- **Weight:** 0.55 kW/kg
- **Volume:** 0,35 kW/l
- **Cost:** ~ 30 €/kW (~ 25£/kW)
- **Life exp.** 5000 h between major overhaul
- **Power range:** 100kW → 150kW

1. Plural-fractionated energy system

Variable speed GEN-SET: Optimal choice of the engine operating point for any given output power



1. Plural-fractionated energy system

System characteristics

1. Use of a high number of variable speed gen-set
2. Thermal engines from the automotive sector (i.e 100kW→150kW rated)
3. Very low cost of the engines per installed kW
4. Engines already compliant with the more stringent emission regulations from road transport sector (i.e EURO, TIER), through low cost devices (i.e. FAP, SCR, ..)
5. Engines already available for supplying with non conventional fuel (i.e. CNG, LPG and biofuels)
6. System operation at absolute minimum fuel consumption, including the possibility to operate with several gen-set switched -off.
7. Replacing of the existing engines across years with new and better models
8. Simplified maintenance and spare part availability guaranteed
9. Very low noise and vibration in the engine room
10. Generation system fully integrated with the on-board energy system
11. Propeller shaft driven by fractionated electric drive systems

1. Plural-fractionated energy system

Main research issues

1. Thermal engines

- 1.1 Engine mapping and control
- 1.2 Efficiency and emission trade-off

2. High level control algorithm

- 2.1 Gen-set switching -on and -off
- 2.2 Gen-set power sharing, torque and speed reference generator

3. Electric drives

- 3.1 Plural fractioning of the power electronic stages
- 3.2 High reliability, high redundancy topologies and control techniques
- 3.3 High torque density electric generators directly coupled to the engines
- 3.4 High torque density electric motor for propeller drive

4. System integration

- 4.1 Centralized heat transfer, fluids and gas management system
- 4.2 Rack assembly of the gen-sets

5. System assessment

- 5.1 Case study (ship, propulsion, on-board load, duty cycle) analysis
- 5.2 Design criteria
- 5.2 Fuel consumption estimation, comparison with concurrent solutions
- 5.3 Failure analysis

1. Plural-fractionated energy system

New technologies

1. Energy storage system

1.1 Introduction of Ion-Lithium batteries banks for real zero emission, silent mode operation (i.e war crafts, patrol crafts, big yachts...)

2. More electric ship loads

2.1 Substitution of many hydraulic loads with electric drives operated at variable speed by means of inverters (i.e. bow propeller, winches, ...)

3. Alternative fuel

3.1 CNG, LPG, biodiesel, etc....

3.2 Renewable energy (i.e. at the dock for recharging the batteries,)

4.

3. Skills at the University of Bologna

Research topics

Component and subsystems design:

- **Electric machine**
- **Power electronic converter**
- **Vehicle management system**
- **Battery Management system**

System design

- **Advanced full-electric powertrain**
- **Hybrid powertrain (series, parallel, power split)**

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1. Components and sub-systems

Electric machine



WR-SM wound rotor synchronous machine

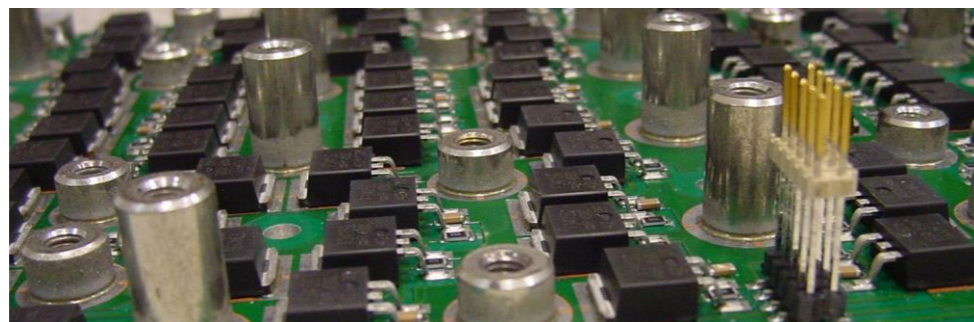


Outer rotor, high torque induction machine

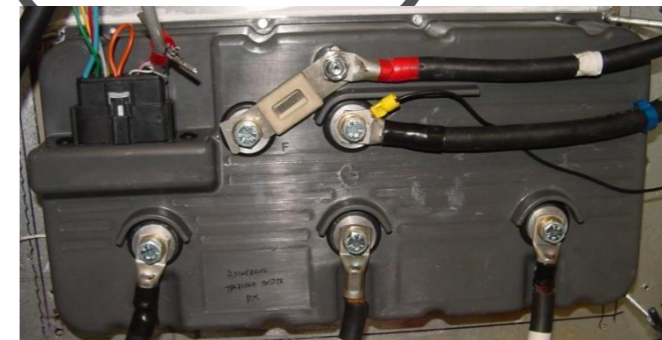


PM-SM permanent magnet synchronous machine

Power electronic (Inverter)



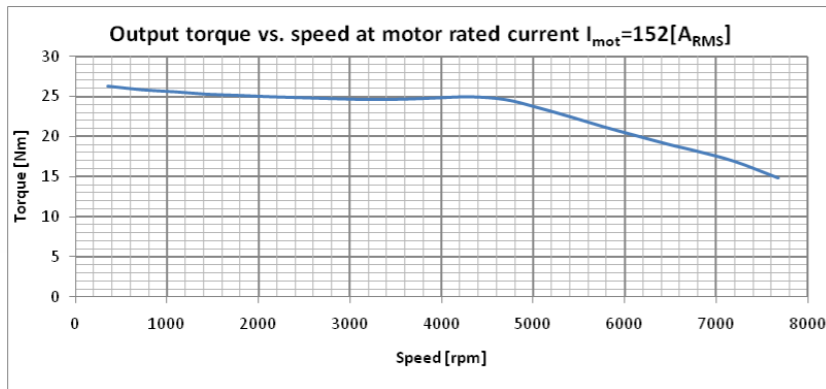
High current rating power stage



Complete assembly of a battery supplied inverter (up to 45kW)

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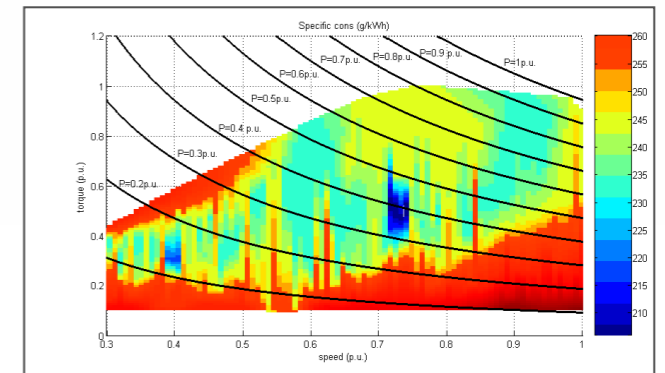
1. Components and sub-systems Electric drives and vehicle management



High performance electric drive control algorithms (brushless, induction)



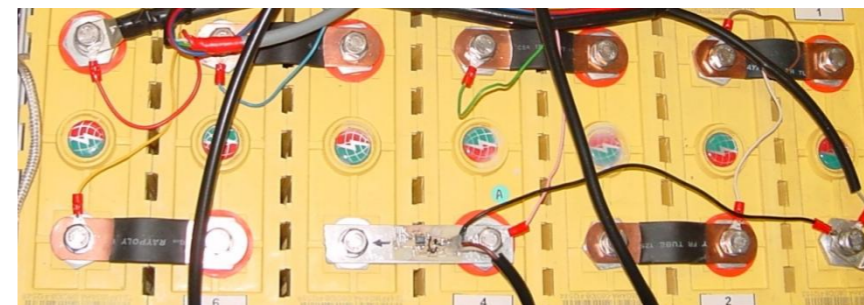
TCS – Traction control system for power split e-CVT hybrid transmission and thermal engine management



Energy storage systems



Ion lithium battery monitoring and equalizing module and control unit



24 cells, 160 Ah, Ion Lithium battery pack managed by BMS

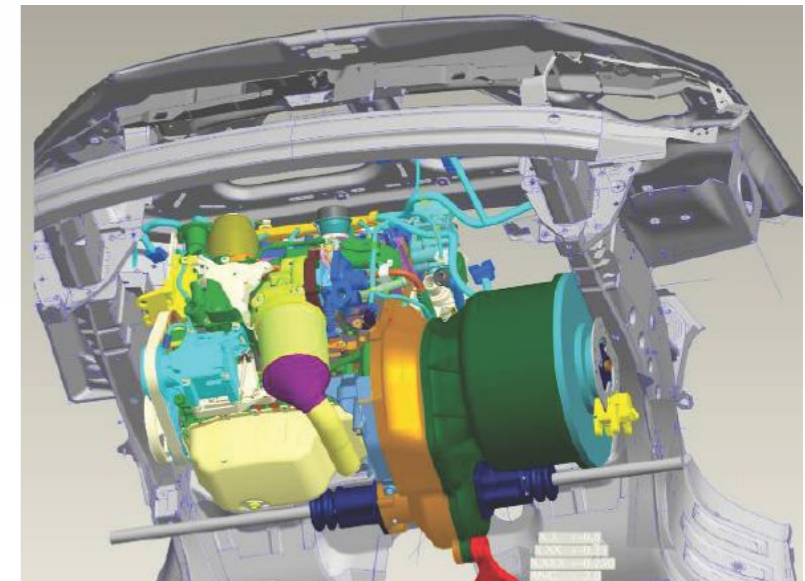
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Hybrid system

Hybrid power split e-CVT for passenger car



Company	MAGNETI MARELLI PWT
Project	Prestige
Year	2008
Application	passenger car
Type	power split
machine n.1	induction
Machine n.2	PMSM
Thermal engine	diesel, common rail
Pure electric	YES



Hybrid power split e-CVT for tractors

Company	BORDINI ENGINEERING
Project	EECVT
Year	2010
Application	100HP tractors
Type	power split + full electric
Thermal engine	diesel, common rail

Full electric traction system

Company	PICCHIO
Project	Belumbury
Year	2010
Application	full electric passenger car
Type	Lithium ion - full electric
Range	200km - urban cycle

3. Skills at the University of Bologna

STAFF & FACILITIES

Researcher

- | | | |
|-------------------------------|---------------------|-------------------------------------|
| • Electric machine: | Prof. G. Serra | <i>giovanni.serra@unibo.it</i> |
| • Power electronic: | Dr. L. Zarri | <i>luca.zarri@unibo.it</i> |
| • Vehicle management systems: | Prof. D. Casadei | <i>domenico.casadei@unibo.it</i> |
| • Battery management systems | Dr. C. Rossi | <i>claudio.rossi@unibo.it</i> |
| • Electric drives | Prof. A. Tani | <i>angelo.tani@unibo.it</i> |
| • Diagnostic systems | Prof. F. Filippetti | <i>fiorenzo.filippetti@unibo.it</i> |

Laboratory staff

- 2 Ph.D. student, 4 post-graduate
- 2 resident designer (1 for HW, 1 for SW)
- 1 external designer for mechanical systems and components

Laboratory equipment

- 200 sq. mt., 6 test bench for electric drives development and testing
- Batteries and dedicated supply system
- 1 test bench dedicated to power split e-CVT powertrain development

Thank you - GRAZIE



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