Design and Operation Strategies for a Low Cost Hybrid Electric Ship Propulsion System


development of a hybrid electric propulsion system for a small ship with a displacement of 200-10000 tons. The hybrid electric propulsion system is based on a conventional diesel engine as a main propulsion system and an electric motor as a supplement propulsion system. The system is designed to reduce fuel consumption and exhaust emissions.

The hybrid electric propulsion system is composed of a diesel engine, an electric motor, a battery system, and an energy management system. The energy management system is designed to control the operation of the diesel engine and the electric motor to achieve the optimal operation condition.

The ship's electrical system is also designed to be a hybrid electric system, which is composed of a main electrical system and a backup electrical system. The main electrical system is powered by the diesel engine and the electric motor, and the backup electrical system is powered by the battery system. The backup electrical system is used when the main electrical system is not available or when the main electrical system is in an emergency condition.

The ship's control system is also designed to be a hybrid electric system. The control system is composed of a ship's control system and a hybrid electric system control system. The ship's control system is designed to control the ship's motion and the hybrid electric system control system is designed to control the operation of the hybrid electric propulsion system.

The ship's propulsion system is also designed to be a hybrid electric system. The propulsion system is composed of a ship's propulsion system and a hybrid electric propulsion system. The ship's propulsion system is designed to control the ship's motion and the hybrid electric propulsion system is designed to control the operation of the hybrid electric propulsion system.

The ship's safety system is also designed to be a hybrid electric system. The safety system is composed of a ship's safety system and a hybrid electric safety system. The ship's safety system is designed to ensure the safety of the ship and the hybrid electric safety system is designed to ensure the safety of the hybrid electric propulsion system.

The hybrid electric propulsion system is advantageous over the conventional diesel engine propulsion system because it can reduce fuel consumption and exhaust emissions, and it can improve the ship's operation efficiency.

The design and operation strategies for the hybrid electric propulsion system are also developed. The design strategies are focused on minimizing the cost of the hybrid electric propulsion system and the operation strategies are focused on achieving the optimal operation condition of the hybrid electric propulsion system.

The hybrid electric propulsion system is expected to be used for small ships in the future.

Abstract

The hybrid electric propulsion system for small ships is designed to reduce fuel consumption and exhaust emissions. The system consists of a diesel engine, an electric motor, a battery system, and an energy management system. The ship's electrical system and control system are also designed to be hybrid electric systems. The propulsion system and safety system are also designed to be hybrid electric systems.

1. Introduction

The hybrid electric propulsion system is designed to be a low cost system for small ships. The system is expected to be used for small ships in the future.
of Rules was established, also in coordination with other international competition and the participating teams have been progressively increased.

1.2 The structure of the competition

Three Classes of research exhibits are demonstrated in the events:
- Class 1: sport prototype cars, with formula style body, with Electric or Hybrid propulsion systems
- Class 2: vehicles without structural constraints, including two or three wheelers, with electric or hybrid or fuel cell systems
- Class 3: vehicle concepts, components and projects, addressing new technology ideas and considered as bases for future developments.

The competition is deployed in Static Presentation and Dynamic Events.

The evaluation of the outcomes is operated by a jury of experts and the scoring is performed on the basis of merits according to the following criteria:
- Operational performance
- Energy and environmental effectiveness
- Innovation level
- Industrial and marketing aspects

Formula EHI 2009 took place in Roma, at the Center ENEA “Casaccia” and registered the participation of 14 Teams out of 7 international Countries [1]:
- Formula Hybrid Team, from ETH Zurich, with a plug-in hybrid car (Class 1)
- Squadra Corse, from Politecnico di Torino, with a plug-in hybrid car (Class 1)
- Drexel Formula Hybrid, from Drexel University, U.S.A. with a hybrid car with supercapacitor
- TUFHT, from Thapar University, India, with a plug-in car (Class 1)
- ENEA Urbe, from Roma La Sapienza – Roma TRE, with a battery electric vehicle (Class 2)
- CroLITH, from Linkoeping University, Sweden, with a battery electric scooter (Class 2)
- TrecoLITH, from Linkoeping University, Sweden, with a battery electric threewheeler (Class 2)
- PicoFarad Racing Team, from Politecnico di Torino, with an electric vehicle (Class 2)
- H2poliO, from Politecnico di Torino, with a low motion resistance fuel cell vehicle (Class 2)
- HyTeam, from Università di Pisa, with a project on advanced fuel cell system (Class 3)
- Hyke, from Università di Padova, with a prototype of electrically assisted fuel cell bicycle (Class 3)
- SYNECTRIC, from Erasmus College Brussels & Vrije Universiteit Brussel; with a project on hybrid car (Class 3)
- PED TEAM, from Roma TRE, with a wheel chair integrating motors in wheel electronically controlled (Class 3)
- ENEA Ginko, from Roma La Sapienza, with a concept car integrating an advanced electric power train (Class 3)

1.3 Innovative technology results

The prototypes and the projects, which have been presented and demonstrated, have offered a wide range of innovative solutions for systems integrated in various types of vehicles and structures, which are here summarized:

1.3.1 Hybrid propulsion systems

Two vehicles externally chargeable (plug-in), with parallel system architecture, and different management concept have been demonstrated:
- Prototype of Squadra Corse of Politecnico di Torino, with manually shifted gear and clutch power transmission (see scheme in Figure 1 and the car in Figure 2)

![Figure 1: scheme of parallel hybrid architecture with gear box control and clutch](image1)

![Figure 2: Squadra Corse car during the competition](image2)
Two main differences characterize the systems:
- The power/speed control
  In the first case it is performed by variable ratio mechanical gearbox and clutch, operated by the driver. In the second case it is performed through the only control of electric traction motor and clutch. In this case the electric drive covers the function of variable speed transmission and is automatically actuated by the electronic control. The electric drive is based on a permanent magnet brushless motor with an efficiency of over 96% for full load and speed from 2000 and 11000 rpm [1].
- The sharing strategy between fuel and electricity
  The plug-in concept offers the opportunity to establish the appropriate sharing between the use of the two energy vectors through the appropriate management control.

The energy use sharing involves, at the level of system design, the trade-off related to the energy sizing of the battery and relevant weight, tied to mission requirement, the cost of the fuel and the electricity at the utilisation level and also the consideration of the impact on the use of the primary energies and on the environment.

These two cases of hybrid systems are examples of the various approaches that can be considered in the design of the architecture and of the utilisation strategy.

Summarising, the trade-off to be considered are:
- Weight/Efficiency/Cost of the power train and storage system
- Performance/control ergonomic
- Balance between energy vectors use

The following constraints are meanwhile to be considered:
- The utilisation conditions with respect to the environment area of operation
- The mission profile
- The availability of infrastructure for energy supply
- The priority given to the best utilisation of the primary energy sources

Two hybrid vehicles with series architecture have been presented and demonstrated.

- Prototype by Drexel University, in Class 1 (Figure below)

- Prototype by University of Roma La Sapienza – Roma TRE – ENEA, in Class 2 (Figure 6)

Both systems, with series architecture, are making use of supercapacitors as energy storage system.

Also in accordance with the vehicle presentation, the following consideration can be made:
The choice of a supercapacitor bank in a hybrid system, as an alternative to a battery, to be used as a buffer to smooth the power dynamic supplied by the Internal Combustion Engine and to recover the braking energy, involves a trade-off analysis among the parameters characterising the performance and the use feature of the energy storage and the mission and road profile:
- Efficiency of the energy storage over the working duty cycle
- Weight/Volume/Cost
- Cell balancing system
- The continuous use of the generating unit with ICE, including the necessity of start charging the supercapacitors.

### 1.3.2 Power train

The participating vehicles integrated different types of electric drive and power train.

The electric drive are based on synchronous motors:
- Permanent magnet brushless (ETH Zurich, Squadra Corse Politecnico di Torino)
- DC brushed (Drexel)
- Synchronous reluctance (PicoFarad)

The following vehicles integrate double motors, individually driven by electronic control:
- Series hybrid of Drexel University
- Electric car PicoFarad of Politecnico di Torino (presented as concept in Class 3)
- E - Snack three wheeler of University of Padova (presented in previous editions of EHI) [2].

The system design approach with two electric motors offers the opportunity of releasing the structure from the mechanical transmission constraints and also of contributing to the vehicle handling, through the appropriate coordinated management of the two drives.

### 1.3.3 Vehicle structure

Formula EHI opens the way to innovations in various technology fields, including the vehicle structure itself.

Class 1 vehicles, which are more oriented to high performance and handling, with constraints related to body structure and dimensions, can offer the opportunity of particular studies on suspensions and lightweight chassis design.

Class 2 vehicles, which are free from body constraints, can stimulate the initiative for studies on structure and body configuration.

Examples in this field are given by the three wheelers, which were presented and demonstrated in the edition EHI 2010 and in previous editions.
- The university of Linkoeping presented a battery electric three wheeler characterised by a tilting body (Figure 7), with an electric motor driving the rear wheel and the two front wheels connected to hydraulic motors, for recovering the braking energy into an hydraulic accumulator.
- The University of Padova demonstrated in previous EHI editions the E – Snack, a three wheeler with tilting body, with two electric motors directly integrated in the rear wheels [2].

### 1.3.4 Studies on low motion resistance

The emphasis given in the competition evaluation to performance and energy efficiency stimulate the teams to give high priority in the design criteria of their prototypes every possible factor to reduce the motion resistance.

A special test is provided in the evaluation to measure the rolling resistance of the vehicles, by making use of a dynamometer and the results are taken into account in the evaluation frame of the Engineering Design.

The aerodynamic resistance is in particular considered in by special structure vehicles demonstrated in the Formula EHI 2010 and in previous events [3].

The team H2politO demonstrated the IDRA 08, propelled by fuel cell system, supplied with compressed hydrogen, with light weight chassis and low aerodynamic drag body (Figure 9)

Consistently with the new body shape, the steering system and the control command have been studied to match the constraint of the body shape and the light weight with the requirement of safety and ergonomic aspect.
as basis for possible development follow up.

1.4 Technology validation

The demonstration given by the competing vehicles offered a validation regarding functional behaviour and reliability of various elements of the electric vehicle technology and regarding the electric and hybrid vehicles operation; in particular:

- Lithium – Ion storage batteries
  Lithium – Ion batteries with different types were use in the majority of vehicles, either battery electric or hybrid., showing good level of reliability and management response.

- Plug-in system practice
  The externally chargeable hybrid vehicles demonstrated the viability of the plug-in operation procedure and the consequent flexibility of energy management with sharing between electricity and fuel utilisation.

- Electric motors
  Design application examples of different types of synchronous motors, with single or double motor solutions, including direct integration of the motor in wheel.

- Supercapacitors
  Design solutions and operation for hybrid systems with only supercapacitors as buffer energy storage ere successfully demonstrated.

- Fuel cell systems
  Vehicle operation with fuel cell supplied by compressed hydrogen were demonstrated, as a confirmation also of previous demonstrations, showing the functional and energy potential of Hydrogen supplied systems.

2. Conclusion

Formula Electric and hybrid Italy, which is yearly organised by ATA since 2005, has been progressively enriched by significant technology results as innovative solutions and validations, demonstrated in vehicles developed by Universities and Technical Institutes student teams.

Formula EHI scope is basically addressing the formation of students and young engineers, in the field of the technology for the sustainable mobility, as a completion of the education in technical and economical disciplines, which are dealt out in the academic courses.

On the other hand, the demonstration of the research efforts and results produced by the Academic World, in coordination with the Industry is a way to increase the sensitiveness and the interest for the ecological vehicles in preparation of their future diffusion.

The challenging targets of the competition constitute important stimulus for the innovation to be pursued in the design and realisation of the prototypes.

Working in team is an effective and productive way for a fertilisation of initiative and the confrontation context of the competition is a hint to further progress in the research.

The various editions of Formula EHI offer an overview on the technology status and on the evolution trends in the area of electrically propelled vehicles.

The technology solutions which are proposed and demonstrated can produce follow-up for industrial application and give indication for future developments.

References

[1] Brusaglino Giampiero, Advanced Power train Concepts demonstrated in Formula Electric and Hybrid Italy 2009, IAMF, Geneva, March 2010.
[2] G. Brusaglino, A. Doria, P. Guglielmi, L. Martellucci, M. Razzetti, Innovation for Ecological Sustainable Mobility in Formula Electric & Hybrid Italy 2007, EET-2008 / IAMF, Geneva, March 2008.
[3] G. Brusaglino, G. Buja, M. Carello, A.P. Carlucci, C.H. Onder, M. Mazzetti, New technologies demonstrated at Formula Electric and Hybrid Italy 2008, EVS 24, Stavanger, May 2009

Author

Ing. Giampiero Brusaglino

ATA-Associazione Tecnica dell’Automobile
E-mail: giampiero.brusaglino@crf.it
Tel: +39 011 9083085
Fax: +39 011 9080400

Electrical and Aeronautical Engineer
He has been Vice Director at Centro Ricerche Fiat and President of A.V.E.R.E.
He is chairman of the Technical Committee CEI-CIVES and CEI TC 69, Electric Vehicles