

*EVS26*  
*Los Angeles, California, May 6-9, 2012*

## **Technology Evolution in Formula Electric and Hybrid Italy**

*Giampiero Brusaglino*  
*ATA (Associazione Tecnica dell'Automobile), Strada Torino, 32/A, 10043 Orbassano (Torino)*  
*E-mail: giampiero.brusaglino@crf.it*

---

**Abstract** – The international event, in form of competition among student teams of University and Technical Institutes, which demonstrate self-developed innovative vehicles, can present an assessment of the advanced technology and trends in the domain of Battery electric, Hybrid and Fuel cell systems. The Formula Electric and Hybrid Italy was initiated in 2005, under the denomination Formula TECH and was run yearly, with progressively increased interest at the international level. The technology achievements have been progressively increased in the field of Hybrid propulsion system, Electric drives, Battery and Super capacitors management. These findings can be a hint to industries for engineering development of the concepts, whose validation is demonstrated in these competitions. The paper presents the major findings from the beginning of the various Formula EHI editions up to now.

In particular the various solutions of hybrid systems is discussed, based on the demonstration given by the realized vehicles and the tests on track. The various solution of electric drive is presented, with different types of motors and power train architectures.

The development of the prototypes, which are yearly presented for the competitions and which are the result of working in team by students can be a strong component of their cultural and skill formation, in view of their professional involvement in the industries dealing with electric vehicle technologies. The research outcomes presented by the teams are evaluated and awarded, by an expert Jury, on the basis of criteria addressing the innovation level, the energy effectiveness, the environmental quality and the industrial potential applications.

*Keywords: Education, Electric drive, Energy storage, fuel cell, PHEV (plug in hybrid electric vehicle).*

---

### **1 Introduction**

Formula EHI was initiated in 2005 by ATA, the Italian Technical Association of Automobiles, with the denomination of Formula TECH, at the Fiat proving Ground In Balocco (VC), Italy, at the same time as the Formula SAE Italy.

The scope was to define the technologies in the field of electric and hybrid vehicles, to be developed and demonstrated in the future competitive events, which the University student teams were invited to adhere to.

The yearly event was held in different circuits in Italy. A set of rules was set up and progressively

enriched and harmonized with those of other international competitive events for hybrid and electric vehicles, which were being established in other Countries.

The technology achievements demonstrated have been progressively grown up, as well as the participating teams to the competitions.

Three Classes of research exhibits were established:

- Class 1: sport prototype cars, with formula style body equipped with Electric or Hybrid propulsion systems
- Class 2: vehicles without structure constraints, including two and three

wheelers, with electric or hybrid or fuel cell systems

- Class 3: vehicle concepts, systems, components and projects, addressing new ecological technology ideas, as a basis for future developments.

## 2 Technology developments

Formula TECH offered a range of potential technologies, worthy for possible future developments, such as:

- An electric car “Solaria”, with photovoltaic cells, produced by Università dell’Aquila
- A Hydrogen –Electric Hybrid scooter, shown by Environmental Park of Torino
- A Hybrid/dual mode scooter, from Università di Pisa
- A Hybrid sport car, with ultra-capacitor storage system, by Università di Roma La Sapienza.

In the field of Systems:

- A Fuel cell system, demonstrated at bench, with hydrogen stored in metal hydride tank and with super-capacitor buffer.
- A Wheel-motor system electronically controlled, applied on a wheel chair, by Università di Roma TRE.
- Synchronous electronically commutated motor, with wound rotor, featuring very high field weakening range, by Università di Bologna.

In the field of Studies:

- A project on an electric city car, with a flexible multi-body and multi-system solution, by Università di Firenze
- Innovative components for electric and hybrid systems, by University of Sheffield
- New Transportation technologies, by Vrije Universiteit Brussel.

### 2.1 The evolution

In 2006 the vehicle exhibited started to be demonstrated on the test track.

Three prototypes were tested according to the procedures of the ISO Standards:

- A parallel hybrid developed by Università di Roma La Sapienza, with a super capacitor as buffer unit, featuring a

top speed of 220 km/h and an acceleration time 0 – 100 km/h of 6,3 s.

- A series hybrid prototype, developed by Università del Salento. This vehicle was an example of “plug-in” hybrid, featuring a range in pure electric and a battery recharging from the mains or from a range extender generating unit.
- A high technology two seater electric scooter, developed by Politecnico di Torino, with lithium-ion batteries and synchronous reluctance electric motor, with a field weakening ratio 2800 – 9000 r.p.m., 90% efficiency, maximum speed 90 km/h and range up to 130 km.



Fig. 1 The three prototypes of edition 2006, on the test track: the “Magica” parallel hybrid, the electric “ECOSCOOTER” and the series hybrid prototype, with members of the evaluating Jury

For the edition **2007**, to better identify the character of the event, as addressing the ecological technologies, the denomination was chosen “Formula Electric and Hybrid Italy”.

The 2007 event was held in the Grand Place of Pollein (Aosta).

For this edition emphasis was given to the competitive tests on track, for which rules were established consistently with those of the “Formula Hybrid”, which was started in USA at that time.

The evaluation of the teams were based on: Static Events, in which the quality of the research outcomes took into account the engineering design in terms of innovation and energy efficiency, and on Dynamic Events, in which the performance, handling and reliability, other than the measure of the energy consumption, were taken into account [1].

An innovative concept, among other research outcomes, was presented by Università di Padova, with an electric three wheeler, with front tilting body and two rear in-wheel motors (fig. 2)

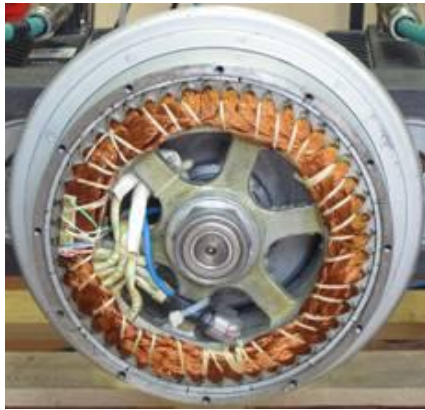


Fig. 2 Permanent magnet motor directly integrated in the two rear wheels of the three wheeler

Formula EHI **2008** was held at the Fiat Safety Center in Orbassano (Torino).

A variety of prototypes were presented and demonstrated:

- In the domain of **electric vehicles**, an improved version of the three wheeler, presented in the previous edition, was the winner of Class 2.
- A **solar car** was realized by Università del Salento, with flexible photovoltaic panels applied on the body.
- In the domain of **fuel cell**, a low drag vehicle, was presented by Politecnico di Torino (fig. 3)



Fig. 3 The fuel cell vehicle on the autocross circuit

In the domain of **hybrids**, a Class 1 “Plug-in” car was exhibited and demonstrated by ETH Zurich team. The parallel hybrid system was conceived with the principle of starting and power conditioning at lower speed only by a high

efficiency traction motor, with ample speed ratio in flux weakening, with clutch interface, without gear shifting (fig. 4).



Fig. 4 Hyb-alpha, of ETH Zurich, winner of 2008 Class 1, on the test track at Fiat Safety Center in Orbassano (Torino)

## 2.2 Hybrid systems development

The fifth edition of Formula EHI was hosted by ENEA, at the facilities and Proving Ground of Center “Casaccia” in Roma, in October 2009.

A remarkable fact of 2009 event was the important participation of the international Countries, with an increased number of teams registered in Class 1. The demonstration of the technology findings on a common structural frame, that is the formula style body, makes the comparative evaluation of the system easier. This was the address given to the teams for future developments.

### 2.2.1 Parallel architecture “Plug-in” Hybrids

In the field of plug-in hybrids, Politecnico di Torino and ETH Zurich participated with cars equipped with different power train:

- The first was using the approach of gear shifting (fig. 5)

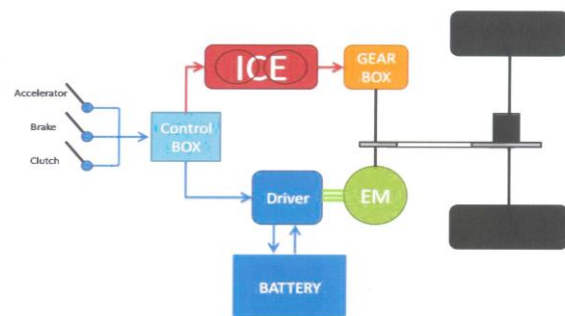


Fig. 5 Scheme of the Parallel Hybrid system with gear box



Fig. 6 Squadra Corse car, of Politecnico di Torino, winner of 2009 Class 1, on the test track at ENEA Casaccia circuit

Some consideration about the difference of the two previously presented plug-in hybrids Class 1:

- 1) Difference on the power and speed control: In the case of Squadra Corse the control is operated by mechanical gearbox and clutch; in the case of ETH car it is performed only through the control of electric motor, featuring a speed field 3000 – 11000 r.p.m. at full power, and clutch. In this case the electric drive covers the function of variable speed transmission and it is automatically actuated by the electronic control.

The choice of the system design concept involves a trade-off between weight/cost of the power train and the overall vehicle energy efficiency, furthermore consideration about the ergonomic aspect of driving versus the automatic control.

- 2) Difference on the sharing strategy between fuel and electricity as energy vector to involve during the mission fulfillment.

The externally chargeable procedure offers the opportunity to establish the most effective sharing between the use of the two energy vectors, through the appropriate management control.

At the level of system design, the energy use sharing brings into consideration the trade-off related to the size of the battery and the related weight, which is depending of the mission requirement, with the cost of the fuel and the electricity at the utilization level, and also the consideration of the impact of the use of the primary energies and on the environment.

### 2.2.2 Series architecture hybrids

Two hybrid vehicles with series architecture have been demonstrated, with supercapacitors as buffer

- Prototype, by Drexel University , with two rear electric motors (fig. 7)

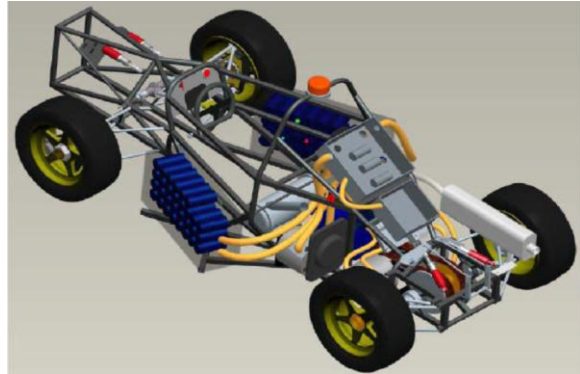


Fig. 7 Series hybrid, with two rear electric motors

- Prototype, by Roma La Sapienza - Roma TRE – ENEA (fig. 8)

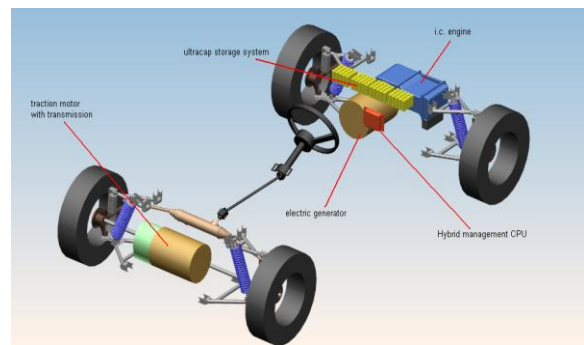


Fig. 8 Series hybrid with super-capacitor buffer

## 2.3 Introducing the pure electric Class 1

For the edition 2010, which was held at the Fiat Safety Center in Orbassano, two Class 1 cars were established for Electric (1E) and Hybrids (1H) and keeping the Class 2 and 3, as in the previous editions.

The Dynamic Events were established the same, with harmonized rules with those of other International Formula Student [2].

An important point for the evaluation of the vehicles is the energy. For this purpose, an innovative procedure has been introduced ,to measure directly the electric energy consumption on board (Tank to Wheel): an energy meter was developed to be applied on the power circuit, measuring, integrating and recording the energy



flow, direct and reverse, based on a Hall effect current sensor, and voltage.

For the externally rechargeable hybrids, the total energy is evaluated, as the sum, in Joule, of the electric energy and the consumed fuel.

The system gave good result in the EHI 2010 and was introduced in the rules for the following editions.

The 2010 event registered the participation of teams from six Countries.

Class 1E:

- Green Team, University of Stuttgart
- AMZ Team, from ETH Zurich
- Ecurie Aix Electric, RWTH Aachen
- Stuba Green Team, Slovak University

Class 1H

- Squadra Corse, Politecnico di Torino
- UPC ecoRacing, Universitat Catalunya
- Thapar University Formula Hybrid, India

Class 2

- Mecc-H2, Politecnico di Milano, with a fuel cell vehicle
- PicoFarad Racing Team, Politecnico di Torino, with an electric kart
- Hakhamanesh H.V., Sharif University of Technology, Iran, with an electric car

Class 3

- R2Hybrid, Università di Roma "Tor Vergata"
- BUS4M, Università di Padova
- UNIVAQ-ENEA, Università dell'Aquila

### 2.3.1 Electric drives applications

From the evaluation of findings of the Formula EHI editions, it is possible to draw the following considerations regarding the electric drives:

- The majority of the vehicles makes use of synchronous motors, mostly permanent magnet (e.g. ETH Zurich, hybrid and electric, Squadra Corse, hybrid, Green Team Stuttgart, electric), but also DC brushed (e.g. Drexel), or synchronous reluctance (e.g. PicoFarad, ECOSCOOTER)
- Numerous vehicles integrate double motors, individually driven by electronic control (e.g. Drexel, PicoFarad, Green Team Stuttgart, E-Snake of University of Padova, with hub motors [3]).

The application of two electric drives, electronically controlled looks as a trend toward the multiple motors approach.

Actually this approach, eventually extended to the four wheel drive, offers opportunities for

vehicle design, as a consequence of the release of the structure from the mechanical transmission constraints and for the vehicle stability, maneuvering and handling.

### 2.3.2 Energy storage and supply systems

**Electrically Rechargeable Storage System** applications, for plug-in hybrids and for pure electric vehicles, are oriented to Lithium-Ion batteries, even with different chemistry solutions. All the applications are equipped with the Battery Management System, as an indispensable means to keep the battery under control, assuring the necessary safety level, the appropriate thermal conditions and endurance.

The reliable demonstration given by the vehicles in the various editions can be considered a contribution to validation of this approach and an indication of a trend of application.

**Super-capacitors** use have been demonstrated for non-externally rechargeable hybrid systems application (e.g. Drexel, parallel hybrid; Roma TRE – ENEA, series hybrid)

**Plug-in system** practice has been shown as a viable solution for the real time operation and for the flexibility of energy management with sharing between electricity and fuel utilization in hybrid systems.

**Fuel cell systems** have been demonstrated in two low drag vehicles, showing good system reliability and management.

## 3 Conclusion

Formula Electric and Hybrid Italy is fundamentally addressing the formation of students and young engineers in the domain of technology for an environmentally sustainable mobility, as a complement of the education they receive in the academic courses.

The research outcomes, which are fruit of a yearly work in team can offer good hints to industries and research institutions for new concepts, ideas and validation of solutions, for possible further engineering developments.

The results achieved up to now, from the various editions since 2005 constitute a good assessment of the state of the art of the technology and an indication of trends for further researches.

## 4 References

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

## Author

### Ing. Giampiero Brusaglino

ATA – Associazione Tecnica dell'Automobile

Tel: +39 011 9083 085

Fax: +39 011 9080 400

Electrical and Aeronautical Engineer

He has been Vice Director at Centro Ricerche Fiat, responsible of development of electric vehicles.

He was President of A.V.E.R.E. in years '84 – '87.

He is chairman of the Technical Committee CEI-CIVES