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# "Bizzarrini P538 Eco Targa" Project

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**Abstract**

The "Bizzarrini P538 Targa Eco" project has been developed by the INFOCOM department - "Sapienza" Rome University. The project consisted in the design and construction of historic Italian car replica, upgraded to LPG fuel and today hybrid-type plug-in technologies assisted by start and stop system and Lithium-polymer battery storage system. The research aimed at undertaking practical experimentation on parallel hybrid vehicles, with a special focus on the problems related to the construction and optimization of hybrid propulsion systems. The prototype under construction has a space-frame chassis, with double wishbone - push rod suspension system.

The internal combustion engine is mounted at the rear axle. It is a direct injection petrol engine 2.2 JTS, having 185 Hp power and 225 Nm torque. The electric motor, together with its electronic control, is placed at the front axle, and both are produced by C.I.S. Srl. The electric motor is a 22 kW power rating brushless type featuring 45 kW peak power. It is 222 Vdc powered from a lithium polymer batteries storage system produced by Kokam, able to store 6.8 Kwh energy. The supervising CPU (central processing unit) is a PC/104-standard platform based on x86 microprocessor architecture that realizes also the acquisition of electrical and mechanical data, furthermore, there are a car PC and a LCD screen for viewing the prototype data. The hybrid parallel scheme configuration has been designed and analyzed through Advisors simulation code, running under Matlab/Simulink® environment, to achieve the specific proposals. The Matlab/Simulink® environment has been used for realizing the powertrain management software in particular the software structure has been developed in Simulink and the xPC Target toolbox has allowed to employ such a control scheme into the PC/104 hardware.

*Keyword: Parallel HEV, Lithium battery, Power management*

## 1 Introduction

In November 2008 through an agreement between the "Regione Lazio" and the "Sapienza" university, the Pomos was born (Sustainable Mobility Research Center), it is located in Cisterna di Latina, near Rome, with the aim to study the traction technology, improving the existing technology standards. In this center, the involved researchers organized a study group to develop, design and build a parallel hybrid electric vehicle in order to validate experimentally the potentialities of this kind of propulsion system. The research team is assisted by Eng. Giotto Bizzarrini, worldwide well known specialist in sport-cars, “father” of the 1962 Ferrari GTO. Therefore the project, called Bizzarrini P538 Eco Targa, is a partnership between Scuderia Bizzarrini in Livorno (Tuscany) and Pomos.

The car is conceived as a “moving test bench” to verify “on the road” simulation results of hybrid vehicles. Bizzarrini P538 Eco Targa is equipped with a central spark engine and a front electric motor. The basic idea is to combine the spark-engine performance with the innovation of the electric traction, operating either as power boost to the spark engine or unique zero-emission propulsion system. The goal to be reached is the realization of a low-consuming sports vehicle that exploits the advantages of both kinds of engine, having complementary characteristics.

The Bizzarrini P538 Eco Targa car prototype is still incompleted and it is currently under construction. Results of the design and the construction are presented and discussed in present document paying particular attention to the layout of the prototype, to the energy simulations and to the HEV-powertrain management software optimization.

## 2 Bizzarrini P538 Eco Targa layout

The mechanical layout of the Bizzarrini P538 Eco Targa prototype is shown in Fig. 1. It is a two-seat roadster, with a space frame rolling chassis and fiberglass body (see Fig. 2). For each subsystem composing the prototype, design and simulation activities were performed first, leading to the subsequent construction of the prototype itself. CAD 3D tools have been used for the prototype’s rolling-chassis design, while CAE tools have been employed to value the performance of the chassis structural (see Fig. 3) as for the suspension and steering systems cinematic simulation (see Fig. 4). A spark engine and an electric drive, acting respectively on the rear and front wheels, make up the propulsion system. The engine is placed in central position, mounted transversally behind the seats. It has mechanical gearbox and a final drive transmitting the traction power to the rear wheels. In parallel, an electric drive placed at the front axle, in longitudinal position, is connected to the final drive through a single-speed gearbox, which transmits torque to the front wheels. In central position, just behind the two seats, takes place the storage system (lithium polymer battery) and behind the driver seat is placed the supervising central processing unit that manages the entire system.

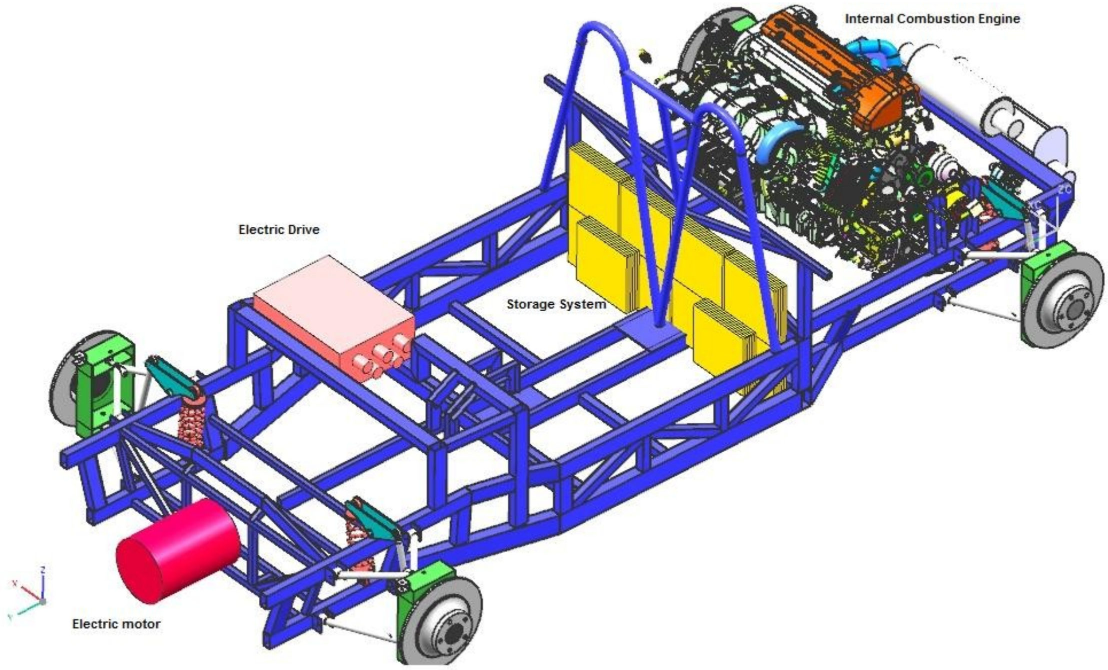


Fig.1. Bizzarrini P538 Eco Targa powertrain layout

Fig.2. Bizzarrini P538 EcoTarga with its fiberglass body

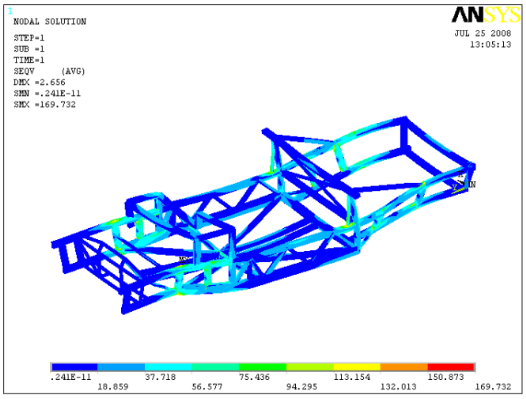


Fig.3. Bizzarrini P538 EcoTarga Test chassis, Ansys software

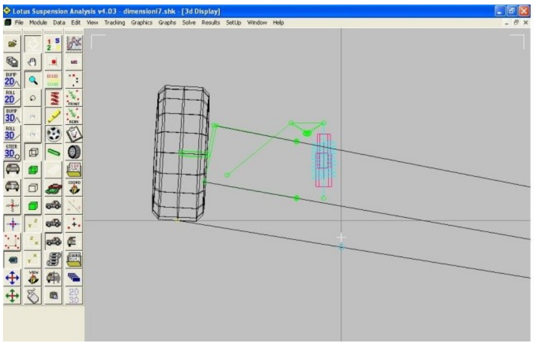

Fig.4. Bizzarrini P538 EcoTarga suspension design, Lotus Shark software

The internal combustion engine is spark ignition with direct injection; this is a "lean-burn" engine that allow reduction of fuel consumption, thanks to the compression ratio higher and exhaust gas recirculation. See Tab. 1 for internal combustion engine specifications.

Tab. 1. Internal Combustion Engine specifications

| | |
|---|---|
| Type | Spark Ignition Engine (lean-burn) |
| Cylinders | 4 |
| Displacement | 2.200 liters |
| Maximum Power | 137 kW @ 6800 rpm |
| Maximum Torque | 220 Nm @ 4600 rpm |
| Injection | Direct injection (Jet thrust Stoichiometric) |

The electric drive is a brushless synchronous three phase motor produced by C.I.S srl, provided with electronic inverter; both are liquid cooled. See Tab. 2 for drive specifications.

Tab. 2. Electric drive specifications

| | |
|---|---|
| Type | PM synchronous motor |
| Power (nominal/peak) | 22 / 45 kW |
| Max Speed | 4,000 rpm |
| Torque | 60 Nm |
| Peak Torque | 120 Nm |
| Size (LxW) | 356 x 217 mm |
| Weight | 55 kg |
| Transmission Ratio | 1:8.64 |
| Cooling System (flow rate) | Water + Glycol (8 l/min) |
| Inverter | |
| Type | IGBT |
| Max Continuous Current | 200 A |
| Modulation | PWM (switching freq. 4 kHz) |
| Max Frequency | 400 Hz |
| Control | Microprocessor (vector control) |
| Size (LxWxH) | 400x300x150 mm |
| Weight | 14 kg |
| Cooling System (flow rate) | Water + Glycol (8 l/min) |
| Voltage Range | 140 – 480 V |

The storage system contains 60 high power lithium-polymer elements connected in series, with 222 Vdc of nominal voltage and 6.68 Kwh of energy storage. The battery management system controls the voltage and the temperature of all cells and it allow to send any information about the battery pack to the car pc for control of the storage system.

Tab. 3. Single cell lithium polymer specifications

| | |
|---|---|
| Rated Capacitance | 31 Ah |
| Rated Voltage | 3.7 V |
| Specific Energy | 133 Wh/kg |
| Weight | 860 g |
| Thickness | 8.4 mm |
| Width | 215 mm |
| Heigth | 220 mm |

To reduce fuel consumption, especially in urban cycle, when the vehicle is stationary, it is necessary to turn off the internal combustion engine and then turn it back on later, when the electric motor is unable to provide the required torque and power. For this reason a “start & stop” prototype system has been installed, it comes from Delco Remy and is named BAS (Belt Drive Alternator Starter); specifications are given in tab. 4

Tab. 4. Bas specifications

| | |
|---|---|
| Motor torque<br>(crank 0/200 rpm) | 35 Nm |
| Generator<br>(1800/6000rpm) | 90/145 A |
| Voltage | 14 Vdc |
| Continuous generating<br>Power | 2 kW |
| Cooling Method | Air |
| Length<br>(shaft to cover) | 167 mm |
| Stator Diameter | 144 mm |

A Voom-2 (High-End) Offroad-CarPC (12/24V) is installed too. The main specification are:

- M2-ATX-HV 140Watt Automotive power supply (for 12V/24-car/truck-batteries)

- Jetway Extreme ITX Mainboard with Intel T2500 CoreDuo 2Ghz CPU

- Adapter (Slim-to-IDE)

- 2024MB DDR-II RAM

- 2.5” Automotive Harddrive 80GB SATA

- Sirf-3 USB GPS receiver

- DVD Slot-In drive

- Windows XP Home (pre-installed)

- 8.4" Display CTF840-SH (VGA/Video, Touchscreen, USB, Speakers, Sunlight-Readable PRO)

On-board diagnostic, named Gpx21, is installed too. See in Tab.5 Gpx21 specifications.

Tab. 5. GPX21 specifications

| Name | Value/Range |
|---|---|
| CPU model | ARM926 |
| CPU frequency | 266 MHz |
| Multimedia | accelerator Integrated with CPU |
| RAM | 64 MB |
| Serial ports | RS232, RS485 |
| Wireless connectivity | GSM, GPRS, UMTS |
| USB | 2.0 |
| Ethernet | 10 Mbps |
| CAN bus | 500 bps |
| Operating system | Linux 2.4 |
| Flash disk | 64 MB |
| Display | TFT 5.7” |
| VGA | Resolution 640 x 480 |
| Temperature range | -40, + 85 C |
| Supply voltage | 9, 30 V |
| Power consumption | 5 W |
| Size | 170 x 123 x 44 mm |
| Weight | 400 gr |

Finally the parallel hybrid power train is controlled by a CPU based on a PC/104 unit; it is a Diamond System Prometheus device equipped with 16 single-ended analog inputs, 16 single-ended analog outputs and several digital I/O. This unit acts also as onboard data acquisition device in combination with a laptop computer.

The management software resident in the PC/104 CPU has been realized with rapid-prototyping and real-time techniques thanks to Matlab/Simulink® and its xPC-Target-toolbox environment. In the next paragraph details on management philosophy will be given. The main input signals acquired in order to implement the control strategy are:

- Accelerator pedal position (measured with a rotating potentiometer);
- Engine speed;
- Vehicle speed (derived from electric drive speed);
- Lithium- polymer storage system voltage and current;
- Friction and braking pedals position (on/off).

The CPU evaluates the information acquired and generates a real time signal representing the load requested by each motor; this signal is sent to electric-drive inverter and engine management ECU (electronic control unit), i.e. the engine ECU doesn't get the signal directly from the accelerator potentiometer, as happens in a standard vehicle, but from the Prometheus CPU. This way it is possible to manage the engine output torque following an optimal control strategy evaluated by the supervising software. The same procedure is adopted to control the electric drive.

# 3 Bizzarrini P538 Eco Targa Simulation

The project target is the realization of a hybrid sport car. The prototype is asked to be high in speed performance such as cheao in fuel consumption, while the full electric autonomy is not so relevant.
For these reasons the drive cycle simulation is based on a series of UDDS cycles and on acceleration test. This simulation is used to valid the choice of various component and their sizes. The first step to realize a drive cycle simulation, using Advisor Matlab tool, is the creation of a model coming from the prototype layout. The model has several sub-models like fuel-converter, energy storage system, and motor. These sub-models have been defined from specific map, and they are based on Advisor's default models. For example about the fuel converter model, the 2.2 litres gasoline engine, the fuel use map is indexed by engine speed range and torque range (or better by the BMEP!), but actually, the engine CO, HC, NOx emissions by the use of LPG are not available, so the drive cycle simulation shows only consumption and dynamic data.
The same procedure is applied to realize the model for the motor (PM 22 kW), the energy storage system (Li-ion batteries), the transmission (six gear), the powertrain control and the vehicle specifications (mass, coefficient of aerodynamic drag, frontal area).
After the modelling, we proceed to evaluate the consumption of our prototype in 100 UDDS (Urban Dynamometer Driving Schedule) driving cycles. It is commonly called the "LA4", "FTP 72", "EPA II", or "the city test", it represents city driving conditions. This has been done to have a large simulation and a valid test.
Moreover, the model has been performed in three different acceleration tests: in hybrid configuration, using the internal combustion engine only (conventional configuration) and in full electric mode, to evaluate the increased performance in hybrid configuration.
The car is a parallel hybrid vehicle, so it can be used also in full electric configuration. The full electric drive tests have been done in a series of UDDS cycles to verify the zero-emission autonomy.
All the results are showed in Fig. 5, Fig. 6 and Tab. 6.

Tab.6. Result Advisor simulation

| Acceleration test | 0-100 km/h | 80-120 km/h | Max speed | Max acceleration |
|---|---|---|---|---|
| Hybrid configuration | 8.3 s | 3.6 s | 190.9 km/h | 3.8 m/s^2 |
| Conventional configuration | 8.6 s | 3.7 s | 192 km/h | 3.7 m/s^2 |
| Full electric | 26.6 s | 32.6 s | 132 km/h | 3.8 m/s^2 |

The full electric mode autonomy is 8 km in ECE cycles, while the SOC history is showed below.

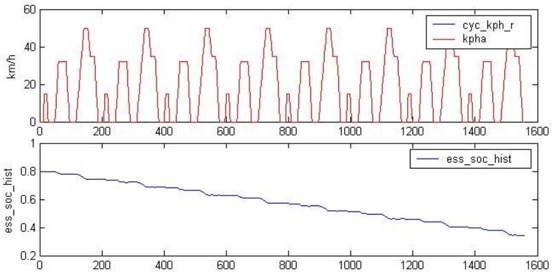

Fig. 5. ECE cycles and Soc rate, full electric simulation mode

After 100 UDDS cycles, in hybrid configuration, the consumption rate is 6.1 L/100km, while after the same number of cycles in conventional mode the consumption rate is 7.2 L/100km. These results match the expectations.
Below the cycle diagram and the SOC history are shown for only one driving cycle, to simplify the understanding. In the diagram the regeneration phases are clearly visible.

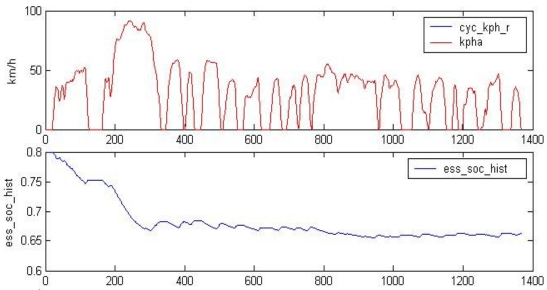

Fig. 6. UDDS cycle and Soc rate, hybrid simulation mode

# 4 Powertrain management system and data acquisistion equipment

The Matlab/Simulink® environment has been used for realizing the powertrain management software; in particular the software structure has been developed in Simulink and the xPC Target toolbox has allowed to employ such a control scheme into the PC/104 hardware. The PC/104 I/O boards have supported the communication with the physical system.
In Fig.7 the main model of P538 Eco Targa management software is shown. The ADC board "MM PC/104 Diamond Analog Input" allows the Prometheus CPU to read the input data, and the DAC board "Ruby-MM-1612 Diamond Analog Output" on the right side feeds the computed data to external devices connected to the board outputs - the engine injection ECU and the electronic inverter. The box called "Prometheus" contains the software management model that elaborates in real time the output signals as function of the acquired input data. The "Host Scope" box in lower right corner of Fig. 7 is the xPC Target/Simulink block that collects data acquired during testing: input data from external sensors and transducers (e.g. voltage and current of battery pack) but also data processed and elaborated by the management system (e.g. load requested to the electric drive). The PC/104 acquires the signals

- Reverse drive switch, labeled with "Retromarcia" in the model, from an on/off sensor mounted on gasoline engine mechanical gearbox;
- Braking pedal switch, labeled with "Freno" in the model, from an on/off sensor mounted on braking pedal;
- Clutch pedal switch, labeled with "Frizione" in the model, from an on/off sensor mounted on clutch pedal;
- Accelerator pedal position, labeled with "Acceleratore Pista 1" and "Acceleratore Pista 2" in the model, from a potentiometer mounted on the accelerator pedal; this is a two-track potentiometer for safe operation;
- Storage system voltage, labeled with "SOC" in the model, from a Hall-effect transducer
- Storage system current flow, labeled with "Shunt" in the model, from a shunt;
- Electric drive speed, labeled with "Encoder" in the model, from an encoder mounted on the electric drive shaft. As explained, the electric drive is connected to the front wheels with a fixed-transmission-ratio gear and its speed is thus proportional to the vehicle one.
- Electric drive speed, labeled with "Encoder" in the model, from an encoder mounted on the electric drive shaft. As explained, the electric drive is connected to the front wheels with a fixed-transmission-ratio gear and its speed is thus proportional to the vehicle one.

Currently the engine rotational speed information, read from the injection ECU, is sent to a dashboard display and to the Prometheus CPU for acquiring it; this information is not used in the hybrid powertrain software.
The management system generates the load values requested to electric drive and gasoline engine. In particular, the "Prometheus" Simulink (see Fig. 7)

block provides the managing of the following powertrain parameters:

1. Electric drive load through the analog output port labeled with “Acceleratore (Inverter)” in the model. It is connected to the inverter 0-5V input port;
2. Electric drive forward-reverse switch through “Marcia Indietro” and “Marcia avanti” analog output ports in the model;
3. Regenerative braking function of the electric drive through the analog output port labeled with “Freno” in the model, connected to the on/off switch of the electronic inverter. An analog proportional regenerative braking function will be implemented in the future by upgrading the software of the C.I.S. electronic inverter;
4. Internal combustion engine load through analog output ports labeled with “Acceleratore pista 1” and “Acceleratore pista 2” in the model, connected to the 0.78-3.88V and 0.39-1.94V input ports of the injection ECU. The second port is needed for vehicle management safety;

The last output port, labeled with “Al tachimetro”, is a digital port used for driving the tachometer mounted in the vehicle dashboard. Moreover, the main model calculates the energy stored in the battery pack and the time derivative of the accelerator pedal position; the last one is a useful parameter necessary for an upcoming release of this hybrid management software.
The Data acquisition section, called “Host Scope”, is designed for acquiring the parameter history of:

1. Electric drive requested load;
2. Internal combustion engine requested load;
3. Storage system voltage;
4. Vehicle speed, calculated from the electric drive speed;
5. Clutch and brake pedals position (on/off);
6. Time derivative of accelerator pedal position.

In Fig. 8 detail of “Prometheus” block is represented; it is the core part of the Simulink model, in which the elaboration of the powertrain management is executed. Several blocks make up the model, but the most important are the ones that determine the optimal values of electric drive and engine requested loads. The evaluation of these two parameters depends mainly on the storage system state of charge (i.e. the battery pack total voltage), the driver request (measured from the pedal potentiometer) and the vehicle speed. The control of regenerative braking is performed using brake and clutch pedals positions and accelerator pedal position (whenever it is released). In order to assure a safe and continuous operation to the inverter, the “Prometheus” block checks that the storage system voltage be always compatible with the inverter voltage range. Generating the signals regenerative braking (“Freno” output port), “Acceleratore (inverter)” and the forward-reverse switch, this result may be gained. In particular the following conditions have been considered:

- Regenerative braking function is avoided in any case if storage system voltage > 202V.
- The electric drive load request is disabled (forced to zero) if SOC is decreasing and reaches 100 V, independently from the accelerator pedal position; the drive torque is set to zero, and as soon as the accelerator pedal is released (coastdown or braking), the drive torque is regenerative.
- The electric drive can operate again if SOC is rising and is higher than 110 V;

In this way a simple control of the battery voltage is performed and the voltage range is compatible with the inverter operating window. Once the storage system voltage variation range is bounded, the electric drive load and the internal combustion engine load can be primarily evaluated as function of accelerator, brake and clutch pedal positions, and - as lower-weight function - of vehicle speed. Due to the low-energy content of the battery pack and the narrow window of the inverter operating-voltage, sometimes the electric drive peak torque cannot be generated. Considering the accelerator pedal position information and the torque that the drive each time step has to provide, the best solution is to limit the value of the electric drive load request; in this way we gain an uninterrupted support of the drive to the traction effort. Otherwise, if the storage system voltage reaches the inverter operating voltage thresholds, the “electrical” torque contribution is intermittent and the driving comfort obviously decreases. In other words, sometimes it is preferable to generate an electrical power contribution lower than the peak power the electric drive is able to produce (22 kW), but uninterruptedly.

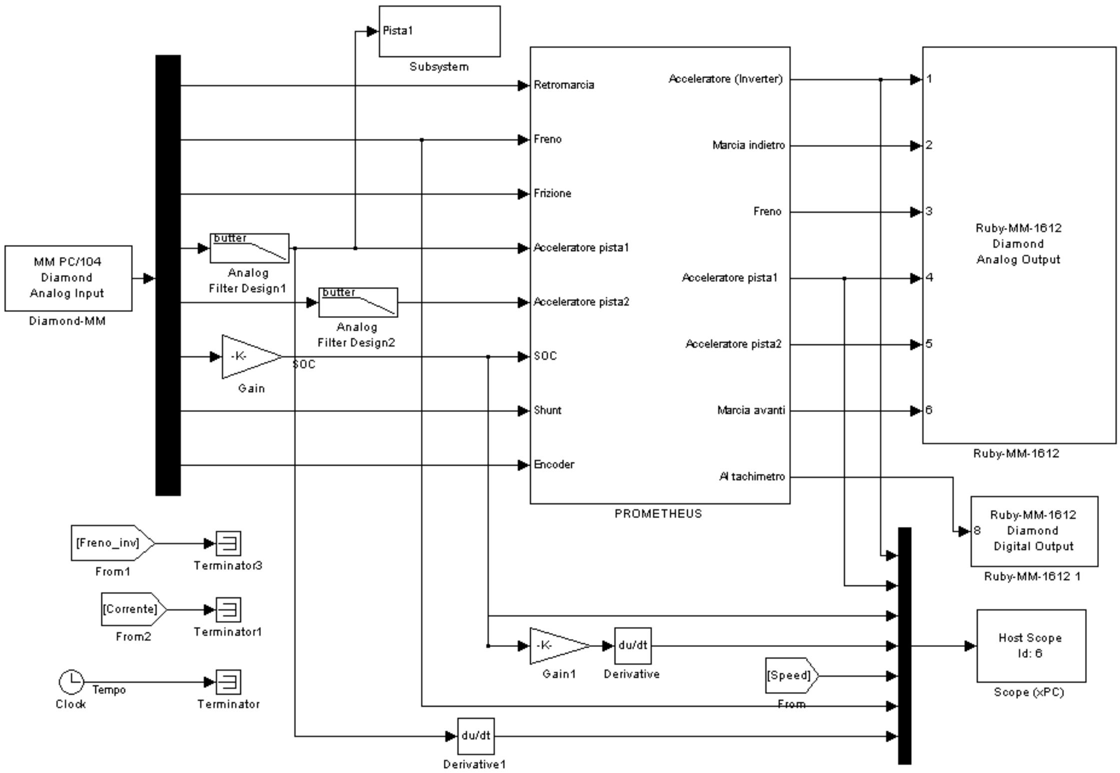


Fig.7. Simulink model of the management system

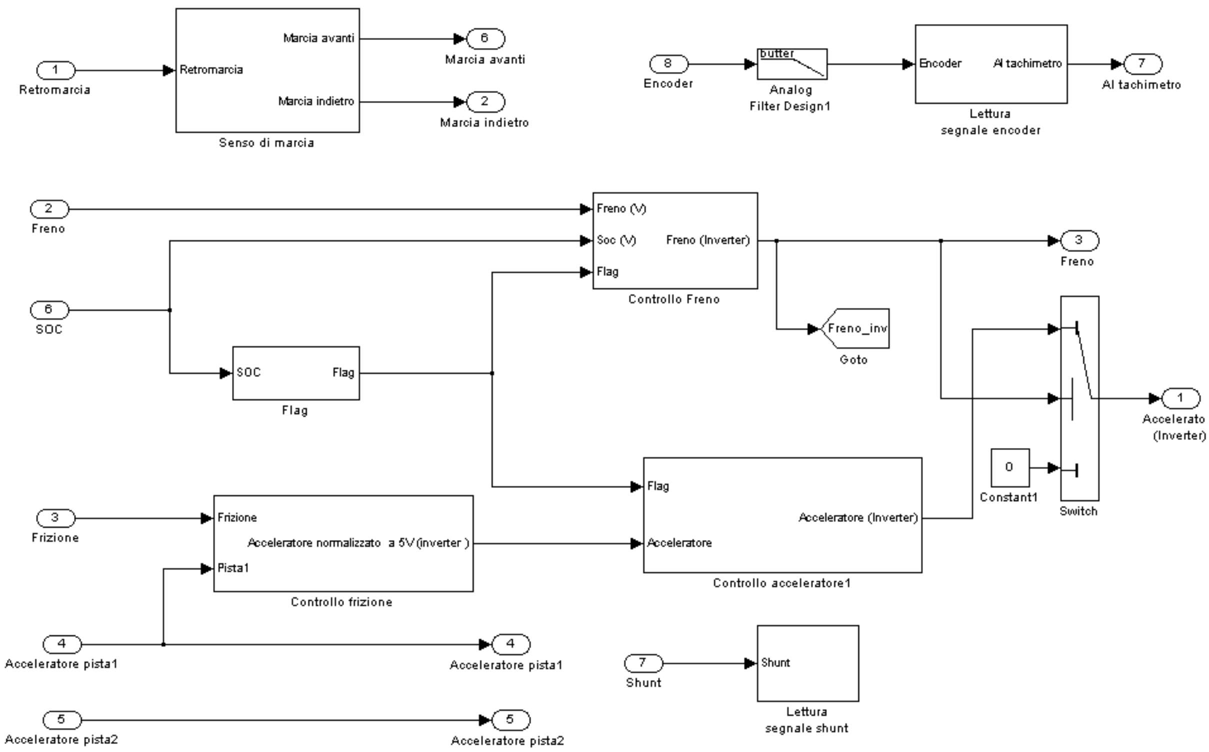


Fig.8. Simulink model of the “Prometheus” block

## 5 Conclusion

Bizzarrini P538 Eco Targa is a project developed by Sustainable Mobility Research Center, in collaboration with Eng. Giotto Bizzarrini.
The first prototype of the P538 project is a parallel sport car, currently under construction.
The most important purpose that we obtain with the prototype is the experimental testing on the best management techniques for a parallel hybrid powertrain with a storage system made up by Lithium battery and a LPG internal combustion engine. So the P538 will become the starting for research and testing on vehicles and fuels innovation. The first results of this experimentation are reported in this paper.

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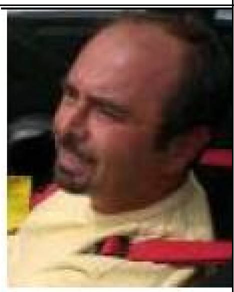
|  | Leone Martellucci, Dr. Ing., Sapienza University of Rome. leone.martellucci@uniroma1.it L. Martellucci received the M.S. in mechanical engineering in 1991 and the Ph.D. degree in 1996 from Sapienza University of Rome, Italy. He currently joins as researcher POMOS, a Sustainable Mobility Research Centre of Sapienza University of Rome. Martellucci is the chief of POMOS Prototypes Development Area. |

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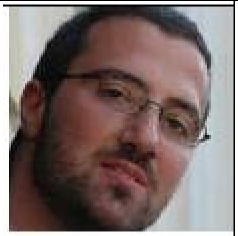
|  | Simone Sgreccia, Dr. Ing., Sapienza University of Rome. simone.sgreccia@gmail.com S. Sgreccia received the M.S. in mechanical engineering in 2008 from Sapienza University of Rome, Italy. He currently joins as researcher POMOS, a Sustainable Mobility Research Centre of Sapienza University of Rome. |
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