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A Plug-in Hybrid Diesel-Electric Vehicle

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Abstract

The paper presents the GRAND HAMSTER ELECTRICWAY 4WD hybrid concept car, developed within the *Automotive Engineering* Research Centre of the University of Pitesti during 2011, in order to create a green version of Dacia 4WD. The car was built on the mechanical platform of the DACIA DUSTER crossover car, 4x2 versions, by implementing an electric propulsion system in the rear axle. The EcoMatic Hybrid System (Energy conversion with autoMatic Hybrid System) is a diesel-electric version, parallel with two shafts, and plug-in type, organized in a motorized solution E-4WD (Electricway-4WD). The name of the vehicle designates the hybridization obtained with the diesel engine 1.5 litre dCi FAP, 79 kW (107 bhp), placed in the front of the vehicle and the asynchronous electric motor offering a maximum power output of 31kW/42 bhp located at the rear of the vehicle. The traction battery, Lithium Iron Phosphate (LiFePO₄) technology, 205V, 12 kWh is rechargeable by the on board single faze charger. The recharging 12V auxiliary battery is realised by a DC/DC converter 205V/12V and is completed by an assembly of the photovoltaic panel placed on the car's roof .

Keywords: Passenger car, PHEV (Plug in Hybrid Electric Vehicle), Parallel HEV

1 Introduction

To promote in the academic environment the ways for reducing global warming produced by the transport, the *Automotive Engineering* Research Centre of the University of Pitesti deployed the *ECOlogic* Program. The last experimental environmentally-friendly vehicle developed during 2011 in this program is GRAND HAMSTER- ELECTRICWAY 4WD, a

Plug-in Hybrid Electric Vehicle (figure 1). This PHEV combines the advantages of an electric vehicle with those of a hybrid vehicle. This concept car was officially presented for the first time in November 2011 at CAR 2011 Congress [1].

This study is an academic attempt and has no connection with the projects or future car models of Dacia-Group Renault.

2 Development Objectives

The following development objectives were established for this project in order to obtain a low cost ecologic crossover car:

- Development of the concept GRAND HAMSTER on the mechanical platform of the DACIA DUSTER vehicle. This low cost crossover car is made by the Automobile Dacia-Group Renault, at their plant near the city of Pitesti;
- Reduction of pollutant emission under 115 g CO₂/km using a Plug-in Hybrid Electric Propulsion system, Diesel-Electric type, with a preheating engine system;
- Automatic transmission behaviour at low and mild speed when the vehicle runs in the electric mode, with speed under 75 km/h;
- Running 4 wheel drives part time using the PHEV architecture organised in motorized solution E-4WD;
- Cockpit ventilation & auxiliary battery (12V) recharging by the Photovoltaic Panel placed on the roof.

3 Vehicle design and mode of operation

Figure 1 shows the GRAND HAMSTER car developed on the crossover DACIA DUSTER.



Figure 1: The GRAND HAMSTER ELECTRICWAY 4WD concept car developed by University of Pitesti and based on the Dacia Duster

3.1 Powertrain architecture

Similarly to the HAMSTER ELECTRICWAY 4WD CAR [2], the architecture of the hybrid powertrain *EcoMatic Hybrid System (Energy conversion with autoMatic Hybrid System)* is a parallel system type, with torque addition and with two shafts. The organization of this hybrid

propulsion equipment *Plug-in* type is done by dividing it in two parts, (motorized solution E-4WD): the diesel powertrain in the front side and the electric powertrain in the rear side.

The advantages of this design layout are:

- Minimum changes upon the base vehicle DACIA DUSTER 4W2, which give us both the cost reduction of the functional model and the possibility of using it in the traffic, in order to perform the road tests;
- The reduction of the electric equipment's geometric restrictions (electric motor, electronic control unit, traction battery) regarding type, mass and global dimensions;
- Flexibility in choosing the electric motor through the possibility of tuning its characteristics with vehicle's demand using a reduction unit with constant transmission ratio;
- Capitalizing the all wheels drive (E-4WD, part time);
- Shocks reduction when changing the functioning mode (from the electric mode to the thermic mode and vice-versa), due to the "elastic" link between the front and the rear wheels.

3.2 Mode of operation

In accordance to the preliminary specifications, the GRAND HAMSTER vehicle will have the following operational main modes (figure 2):

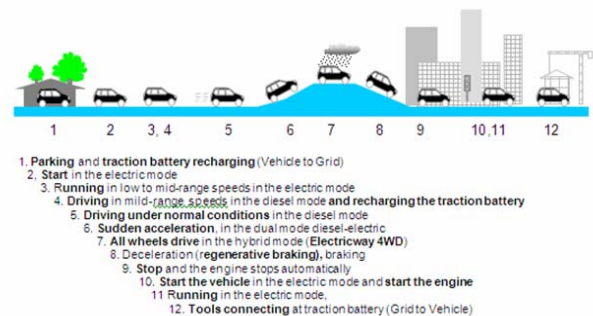


Figure 2: Modes of operation of the GRAND HAMSTER ELECTRICWAY 4WD in the final stage

Parking (1) and **traction battery recharging** (plug-in) by coupling the Vehicle to Grid (figure 6). The estimated charging time is 6 – 8 hours.

Starting (2, 10) and **running** (3, 11), with low to mild-range speed in the *electric mode*, when the electric motor takes its energy from the traction battery. This operation mode is a non-pollutant traction and occurs on short distances in urban driving conditions. The estimated autonomy in the electric mode is 50 km.

The maximum speed is set by the Traction Inverter Motor (TIM) at 75 km/h. The pure electric mode is controlled by pushing the EV/HEV button (figure 2).

In this mode only the rear wheels will be actuated, the motor control (TIM) being realised through the electrical acceleration pedal featuring a potentiometer sensor; the master-vacuum is assisted by an auxiliary vacuum electropump and the electrohydraulic steering is also actived.

Driving on normal conditions (4), in the *thermal mode*, which ensures performances (acceleration, autonomy, etc) close to those of the standard car. Moreover, when driving at low loads (5) by recharging the battery, the engine specific load is increased, thus improving the engine efficiency. This is made by the electric motor operating as a generator.

Sudden acceleration (6), in the hybrid mode providing increased dynamic performances by simultaneous operation of the diesel engine and the motor. The speed range in the hybrid mode depends upon the motor power, the operational rotation speed range and the rear transmission ratio. In the first stage, this specific hybrid mode is not operational.

All wheels drive (7), in the *hybrid mode E 4WD*, obtaining increased driveability on the slippery roads. In the first stage, this specific hybrid mode is not operational.

Regenerative braking (8), when decelerating by replacing the classical engine brake with a process of transforming the vehicle's kinetic energy in electric energy, reusable afterwards in the acceleration process. This is made by the electric motor operating as a generator. In order to do this, the brake pedal was modified.

Stop and the engine stops automatically (9), cutting the fuel consumption and pollutant emissions.

Tools connecting at traction battery and the eng&gen (12), an operation mode allowing supplementary functions absent to other hybrid vehicles. In the first stage, this specific hybrid mode is not operational.

4 Hybrid Powertrain System

4.1. Diesel Powertrain System

The diesel powertrain system of the GRAND HAMSTER E- 4WD include the standard diesel engine Renault 1,5 dCi FAP - K9K THP 896, 1461 cmc, direct common rail with turbo compressor and intercooler. The performances

are: 79 kW (107 hp)@4000 rpm, 240 Nm @ 1750 rpm.

The driveline includes a friction clutch and the 6 manual gearbox. To increase the process of recuperating the energy in decelerating periods, after driving in thermal mode, a hydraulically system (in construction) decouples automatically the clutch.

In the engine compartment (figure 3) was mounted an additional facility used for brake vacuum in the electric mode. It includes an electric pump fuelled at 12V, 650 mm Hg and very low noise level assisted by a vacuum tank 1,5 litre and a switch sensor.



Figure 3: The engine compartment with the auxiliary new components: the electric vacuum pump and the electric motor throttle box.

The throttle signal is provided by the throttle box resistive type (0-5Kohm) potentiometer placed also in the engine compartment and actuated by the throttle pedal by cable.

In order to enhance the reduction of the pollutants under 115g/km CO₂ by avoiding as much as possible the cold starting of the diesel engine, it was redesigned the ThermoSTART preheating system similar to the Hamster concept system [2]. This system has a thermal isolated chamber of 5 liters volume, which contains the engine cooling liquid, resulted from the previous operation of the engine. It features a recirculation pump and an electromagnetic valves system, controlling the liquid flow to the engine and to the passenger compartment (if it is necessary). Moreover, one electrical heating resistance, fuelled with 240V AC electricity from the network, runs during parking periods (when the vehicle is plugged-in to charge the traction battery) or fuelled when necessary by the traction battery. A dedicated computer (in construction) controls the preheating of the liquid and the liquid flow to the engine or to the HVAC system of the passenger compartment, depending on the situation.

4.2. Electric powertrain System

Figure 4 shows the general scheme and the main component of the electric powertrain system of the GRAND HAMSTER ELECTRICWAY 4WD: the electric drive system, the traction battery system, the recharging batteries system, the high voltage wiring circuit and the low voltage wiring circuit.

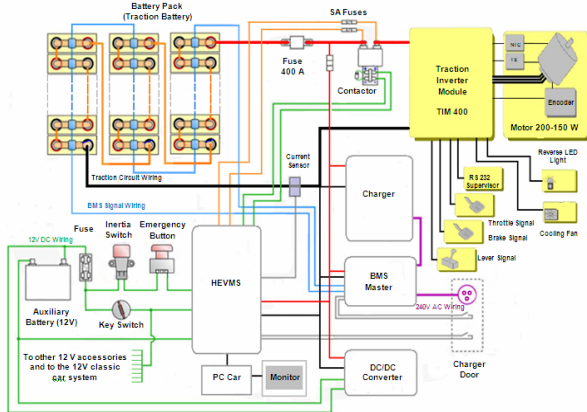


Figure 4: The Electric Powertrain System of the GRAND HAMSTER E 4WD

4.2.1. Electric drive system

The electric drive system developed on the rear side of the vehicle (figure 5) is coupled on the original axle developed for this E 4WD vehicle.



Figure 5: The rear axle and the electric drive mounted on the frame in the rear side of the GRAND HAMSTER E 4WD

The electric drive system includes an AC Induction motor (asynchronous motor type), a mechanical transmission and a Traction Inverter Module.

The electric motor, 200-150W liquid cooled, made by MES SA - Swiss, provides a constant 18 kW (24.5 bhp), and has a peak output of 31 kW (42 bhp). It generates a constant torque of 90 Nm @ 2850 rpm, or a peak of 160 Nm @ 1400 rpm [4]. Figure 6 shows the main characteristics of this equipment.

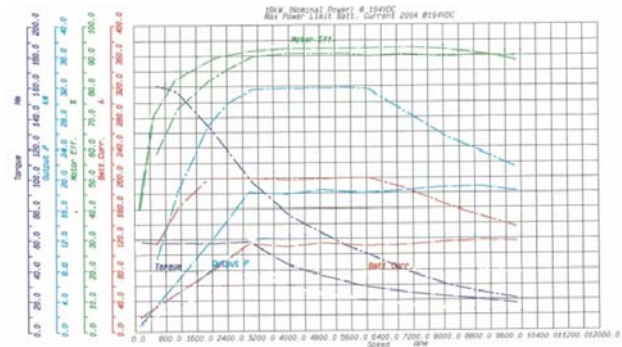


Figure 6: The main characteristics of the 200-150W AC Induction motor by MES SA

The mechanical transmission includes the reduction & differential gearbox unit and two new shafts with homocinetic joints.



Figure 7: The Electric Drive System calibration with MES Software on the electric motor test bench (top) and on the vehicle roller test bench (down)

The electric motor control is TIM (Traction Inverter Module) 400 type, an AC motor drive control designed by MES-SA - Swiss for electric and hybrid vehicles. The electric system was calibrated using the MES SA software, first on the experimental electric motor test bench and then on the vehicle roller test bench (figure 7).

4.2.2. Traction Battery System

The Traction Battery System includes the battery pack, the Battery Management System and the Battery Monitor System.

The battery pack is Lithium Iron Phosphate (LiFePO₄) technology 205V, 12 kWh. It has 64 modules FLP 60 AHA from Thunder Sky China, coupled in series. These cells are mechanical coupled with a special frame placed on the floor of the rear side of vehicle (figure 8).



Figure 8. The traction battery (front) the Traction Inverter Module (back) and the on-board charger (left) placed in the rear side

The Battery Management System includes 64 BMC (Battery Management Cells) and a Management Control Unit MCU-EV2, provided by EV Power Australia.

The Battery Management Cell is an analogue cell module suitable for Thunder Sky LFP60AHA. Connecting the signal output from the serial cell module and the master unit, we realised the protection to overcharge and over-discharge. The battery pack Master Unit monitors the signal of the cell modules and acts to prevent charging or discharging if the heartbeat signal is broken.

The Battery Monitor System includes the battery monitor (figure 9), a gauge, a 500A shunt resistor and a 10:1 pre-scaler.

The battery monitor is an “e-xpert pro-hv” from TBS Electronics Holland. (figure 9). This e-xpert pro selectively displays the battery voltage, the charge and discharge current, the consumption in Ah, the remaining battery capacity and the time remaining.



Figure 9: The traction battery monitor (205V) and the auxiliary battery (12V) monitor (down) and the VBox instruments (up).

This instrument monitors also the 12V auxiliary battery of the car.

4.2.3. Recharging batteries system

The recharging batteries system includes the charging traction battery circuit 240VAC/205VDC and the recharging auxiliary battery circuit 205VDC/12VDC.

The recharging traction battery circuit includes the on-board battery charger, the inlet charge and the charging cable (figure 10).

The on-board battery charger adopted is ZIVAN NG3 type, single phase, from Italy.

This charger is an isolated, high frequency switch mode charger suitable for lithium battery pack. It is fully automatic and microprocessor controlled, with internal protection against overload, short circuit, incorrect connection and voltage transients. The characteristics are: input - 240V 15A single phase AC, nominal pack voltage - 205V, charge rate - 8A, efficiency - 85-90%, operating temperature range: - 20°C to 50°C.



Figure 10: The traction battery recharging by coupling the GRAND HAMSTER E4WD to the Grid (220V AC/16A)

To recharge the 12V auxiliary battery we use a DC/DC converter 205V/12V in the electric mode, to supply the low voltage electric network that fuelled among others the “gourmand” auxiliary vacuum electro-pump and the electro-hydraulic steering group.

The recharging system of 12V auxiliary battery is completed by an assembly of photovoltaic cells placed on the car's roof (figure 11).



Figure 11: The photovoltaic module in construction (top) and the solar panel on the roof of the hybrid concept GRAND HAMSTER (down)

This photovoltaic panel includes 4 photovoltaic modules special designed for the dimensions and the curvature of the car's roof. They are coupled in series in pairs (front and rear), and then the two subsets in parallel. Table 1 presents the main parameters of the photovoltaic panel.

Table 1: The main parameters of the solar panel

Reference irradiation	1000 W/m ²
Reference temperature	25 °C
Nominal Power at STC	185 Wp
Technology	Si-mono
Short-circuit current	10.58 A
Maximum power point current	9.84 A
Temperature coefficient	2.1 mA/°C or 0.02 %/ °C
Short-circuit voltage	21.58 V
Maximum power point voltage	17.79 V
Total no. of cells	72
No of modules	4
No. of cells/module	3x6=18
Total panel area	1.33m ²

The recharging of the auxiliary battery is controlled by a LS1024R, a light controller type protecting the battery from being over charged by the solar photovoltaic panel.

4.2.4. The electrical control systems

The control panel of the traction electrical equipment, situated in the bottom of the console, includes the *EV/HEV* switch, the *Emergency* red button in the centre and the *Reverse - Neutral-Drive* selector for the electric mode on right. A red LED confirms the "Traction Enable" state of the system.

5. The performances on board instrument

To monitor the parameters registered during tests with the VBox Raceologic, on the base of the windshield was mounted the monitor of the equipment (figure 9).

The VBox Mini is a low cost, self-contained GPS data logging and display system suitable for a large range of vehicle testing applications.

Using a high performance GPS engine, data such as velocity and position are accurately recorded at 10Hz.

Conclusions

The GRAND HAMSTER E- 4WD project, deployed within the *Automotive Engineering Research Centre, Alternative Propulsion System & Renewable Energies* laboratory, offered an experimental vehicle to study the ways of reducing the pollutant emissions of DACIA DUSTER car.

The vehicle was developed based on the experience acquired in the HAMSTER ELECTRICWAY 4WD project.

Considering its specific operating modes, this ecologic vehicle could be used as utility vehicle for special services in areas with environmental restrictions. In addition, its battery with high voltage (205 V) and high capacity (12 kWh) may allow supplying the specific equipment in remote areas requiring a motor-generator group. This function could facilitate the client's acceptance of additional costs.

The EcoMatic Hybrid System (Energy conversion with autoMatic Hybrid System), diesel-electric version, a parallel two shafts, plug-in type, organized in a motorized solution E- 4WD (Electricway- 4WD) mounted on this demonstrator in diesel-electric version is designed to be applied to all types of Dacia cars.

Our research on this subject will continue by the following stages:

- Performing road tests to determine the performances in real conditions, yet unrealized because of adverse weather conditions;
- The engine has Stop@Start system implemented;

- Adaptation of an improved HEVMS (Hybrid Electric Vehicle Management System) able to extend to all operating modes presented in figure 3. In the first stage, this specific hybrid mode is not operational.
- Implementing a system for automatic release of the clutch from the Thermal Powertrain, in order to improve the efficiency of the recuperative brake.

The *Alternative Propulsion System & Renewable Energies* research laboratory of *Automotive Engineering* Research Centre have equipments (dynamometric testing roller benchmark and DATRON CORREVIT road testing equipments) that will allow developing future projects regarding the ecological propulsion of the vehicles and extension of the cooperation with other interested team, having similar research objectives.

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