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Contributions on optimizing the performance of a sport utility vehicle through hybridization of propulsion - gaster electricway 4wd project

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Abstract. The paper presents some of the results of the *GASTER Electricway 4WD* concept, developed within the *Automotive Engineering* Research Centre of the National University of Science and Technology POLITEHNICA Bucharest - Pitesti branch. The aim of the project was to build a Plug-in Hybrid Electric Vehicle (PHEV), by implementing a hybrid propulsion system with an electrified rear axle on the Dacia Duster model. The car has a hybrid parallel system with two shafts, organized in E4WD (Electricway 4WD) motorized solution. The thermal power train, placed in the front of the vehicle, consists in an 1.6-liter engine fueled with Compressed Natural Gas (CNG) and a CVT (Continuously Variable Transmission). The electric powertrain, located at the rear side of the vehicle, includes an electric motor coupled with a mechanical transmission, powered by a traction battery Lithium Ferro Phosphate (LFP) type.
Keywords: Plug-in Hybrid Electric Vehicle (PHEV), Compressed Natural Gas (CNG), Variable Transmission (CVT), Electric Powertrain (EP)

INTRODUCTION

Global warming, depletion of mineral resources and pollution in urban and peri-urban areas are problems that must be solved in the new century, while imposing new requirements through standards for automotive propulsion systems.
It is estimated that 94% of CO2 emissions from transport are attributed to the road sector [1].
The new environmental standard required that the average CO2 emissions level for all vehicles produced by a brand be 95g/km after 2020.
The average CO2 emissions of new cars registered in the EU will have to be 15% lower in 2025 and 35% lower in 2030, compared to the emission limits valid in 2021.
This evolution of the emission level requires rethinking the strategy for developing new propulsion systems that are based in particular on total electrification, in the case of battery electric vehicles (BEV) or fuel cell vehicles (FCV) or partial electrification, in the case of hybrid electric vehicles (HEV) or plug-in hybrid vehicles (PHEV).
In recent years, as a result of market demand in Europe, sport utility vehicles (SUVs) have experienced significant growth. As a result, this category of vehicles, known to be some of the most polluting, needs the highest degree of hybridization integration.
In addition to solving the requirements imposed on SUVs related to the reduction of emissions that contribute to global warming, through hybridization of the propulsion achieved by inserting one or more electric motors, it is also possible to improve the dynamic behavior of the vehicle through all-wheel drive.

In this context, within the above-mentioned project, the main objective was to develop a plug-in hybrid concept (PHEV). This concept, called GASTER ELECTRICWAY 4WD (E4WD), was realized in an original architecture, an architecture that is not found in series production and was built on a series Dacia-Renault Duster platform (Figure 1) [2], [3], [4], [5], [6].

Figure 1. The GASTER ELECTRICWAY 4WD vehicle concept

REALIZATION OF THE FUNCTIONAL MODEL

Following the study of hybrid vehicle architectures developed in recent years, in accordance with the project theme and the proposed objectives, the development of a parallel hybridization solution, connectable to the grid (PHEV), with electric all-wheel drive was carried out.
So, the basic architecture chosen for this vehicle is of the P4 type. The general organization solution of the vehicle is presented in Figure 2.
The components available for the rear-mounted electric powertrain for this hybrid system are:
- An asynchronous electric motor with a maximum power of 32 kW (11), coupled to the differential reducer (12);
- An innovative rear drive axle with a torsion beam developed for the first time at the Automotive Engineering research center [4].

The hybrid propulsion system concept called SEPIA (Electric Propulsion System for All-Wheel Drive Automobiles) has:
- A thermal powertrain with advanced depollution, with a spark ignition engine and automatic transmission;
- An electric powertrain mounted at the rear axle.

The components provided by Renault Technologie Roumanie and the possible combination for a front powertrain of the experimental hybrid system are organized according to the diagram in Figure 2:
- A Renault H4M 4-cylinder, 1.6-liter internal combustion engine (1), fueled with CNG through a sequential injection system (8, 9) with gas stored in the cylinder assembly (7);
- A continuously variable transmission CVT X-Tronic (3, 4, 5).

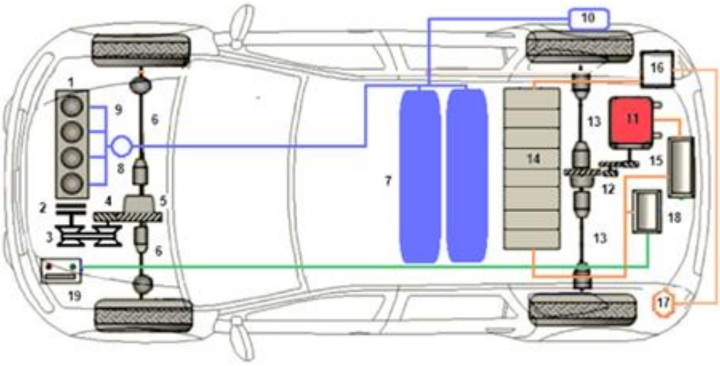

Figure 2. The architecture of the GASTER Electricway 4WD PHEV concept

The electric powertrain with the electric motor (11) added is mounted on the rear side. The CNG fuel tank with two cylinders (7) is under the rear seats. The refill sockets of CNG and gasoline (10) are placed on the rear right side. The traction battery (14) is installed above the rear axle. The Traction Inverter Module of the electric motor (15), the onboard battery charger (16), the auxiliary 12 V battery charger (18), and the refill socket of the traction battery (17) are mounted on the rear side. The auxiliary 12 V battery (19) is on the front side.

ELECTRIC EQUIPMENT OF THE *GASTER ELECTRICWAY 4WD PHEV* CONCEPT

Figure 3 shows the electrical diagram of the electric propulsion equipment.

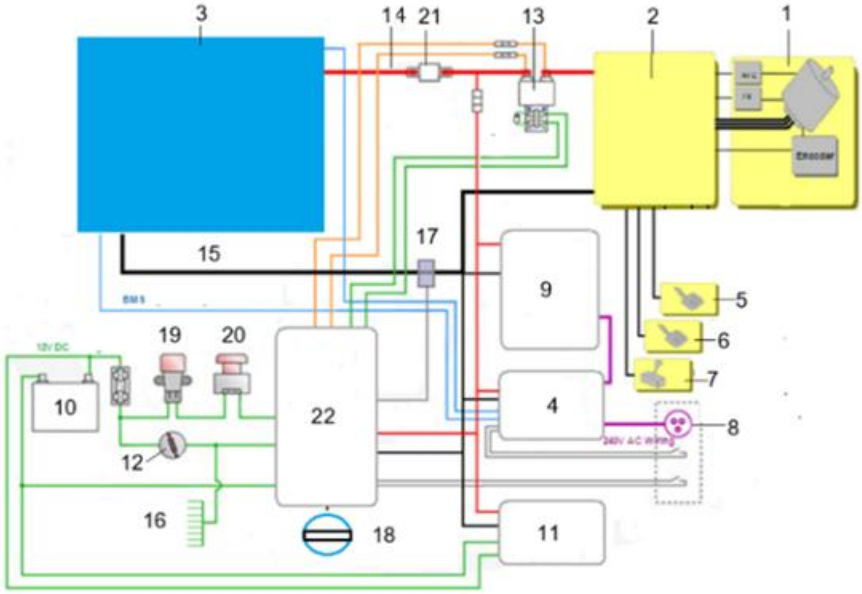

Figure 3. The diagram of the electrical propulsion equipment from the GASTER E4WD PHEV concept

The electric motor (1) is powered by the inverter (2) from the traction battery (3), equipped with the Battery Management System (BMS) (4). The main signals for controlling the inverter are from the accelerator pedal (5), the brake pedal (6), and the RND (Rear - Neutral - Drive) selector button (7). Charging the traction battery (3) from the socket (8) is carried out by the on-board charger (9). Charging the 12 V auxiliary battery (10) is carried out from the traction battery (3) via the DC/DC converter (11). When the ignition key (12) is actuated by the contactor (13), the inverter (2) of the electric motor (3) is fed through the high-voltage circuit (14) and (15) simultaneously with the accessories connected to the 12 V low-voltage circuit (16). The system does the monitoring of the operating parameters including a current sensor (17) and a monitor (18). To provide safety, the electrical system also includes an inertia switch (19), an emergency contactor (20), and the 400A fuse (21) on the high-voltage circuit. The electrical propulsion equipment is connected to the energy management system (22).

SIMULATION OF THE OPERATION OF THE HYBRID CONCEPT IN ELECTRIC MODE IN THE NEDC CYCLE

In the following there will be analyzed the performance of the hybrid vehicle when running the *NEDC cycle (New European Driving Cycle).* In order to highlight the self-propulsion capacity of the electric car, it was exclusively analyzed the urban regime. [7]
Figure 4 shows the section of the NEDC cycle used for the evaluation.

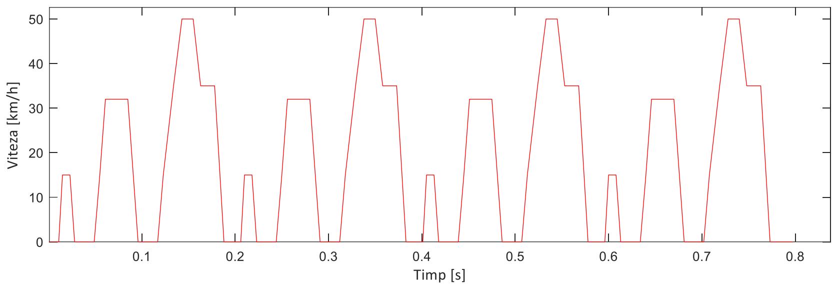

Figure 4. Urban NEDC cycle

The duration of the road trip $t = 800\ s$. The maximum speed $v = 50\ km/h$.
The average acceleration (a_v) for each road section can be determined as follows:

$$a_v = \frac{\Delta v}{3.6 \cdot \Delta t} \tag{1}$$

Figure 5 shows the graph of the average acceleration of the vehicle for each road section included in the NEDC test cycle.

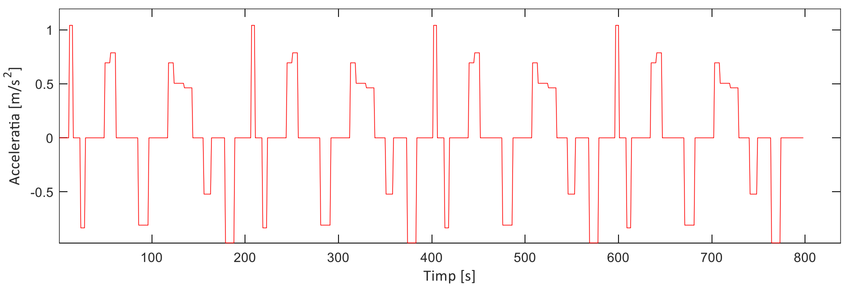

Figure 5. Urban NEDC cycle. Acceleration of the vehicle

The distance covered by the vehicle during the cycle is determined below:

$$s_i = s_{i-1} + v_{i-1,i} \cdot \Delta t + \frac{1}{2} \cdot a_{i-1,i} \cdot (\Delta t)^2 \tag{2}$$

The variation of the vehicle speed as a function of the distance covered is shown in Figure 6.

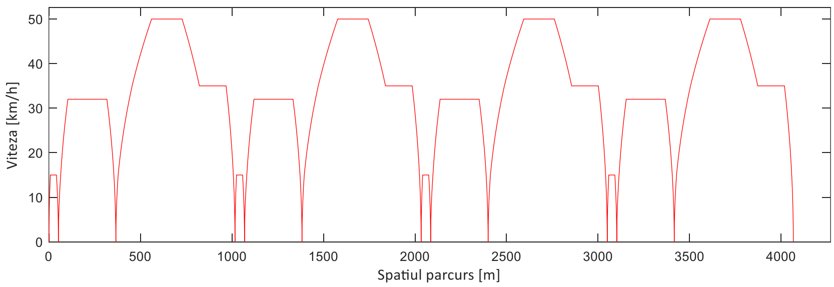

Figure 6. Urban NEDC cycle. Speed vs. distance covered

The general equation of motion becomes:

$$P_R = P_r + P_a + P_d \tag{3}$$

Where:

P_R - power required to propel the vehicle
Pr - power required to overcome rolling resistance
Pa - power required to overcome air resistance

Pd - power required to accelerate the vehicle

Figure 7 shows the power corresponding to overcoming the rolling resistance.

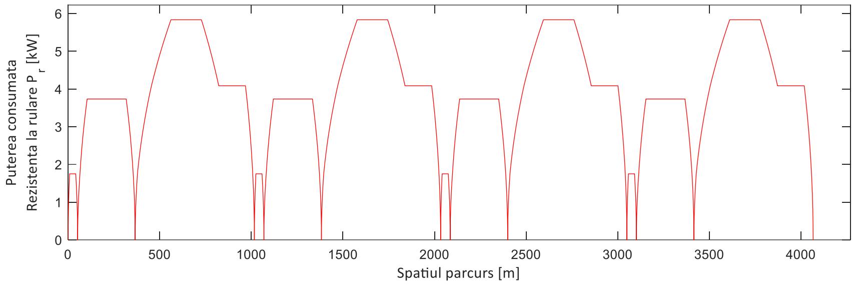

Figure 7. Urban NEDC cycle. The power required to overcome rolling resistance

Figure 8 shows the variation of the power required to overcome air resistance.

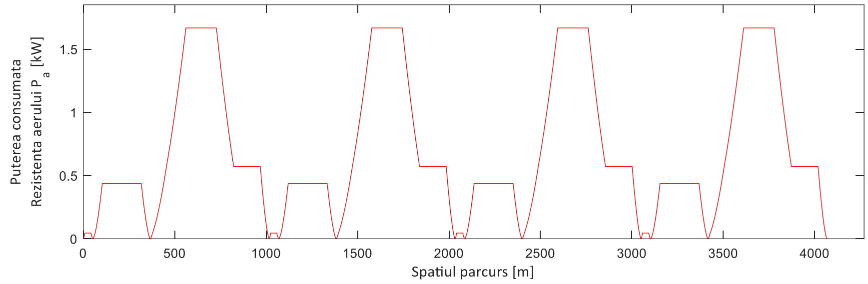

Figure 8. Urban NEDC cycle. Power required to overcome air resistance

Information on vehicle acceleration allows identification of the variation in starting resistance depending on the distance traveled.

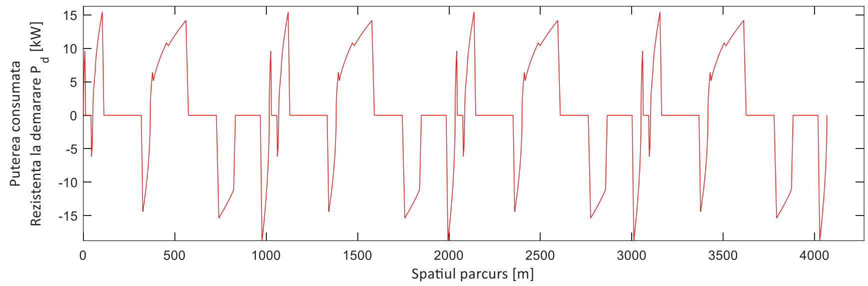

Figure 9. Urban NEDC cycle. Power required to accelerate the vehicle.

By evaluating the information presented in Figures 7 - 9, the variation of the wheel power can be determined.

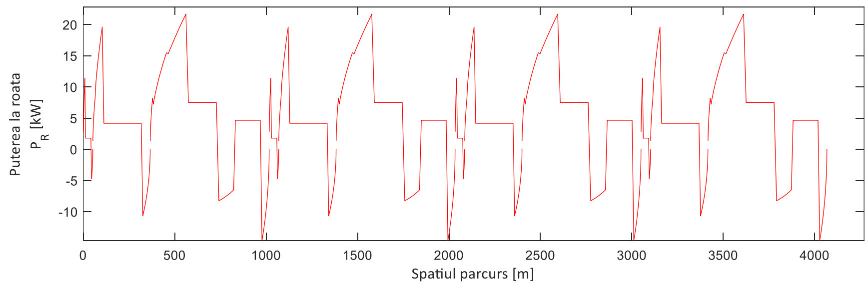

Figure 10. Urban NEDC cycle. Wheel power

The data presented in Figure 10 are processed accordingly to highlight the power required in traction mode.

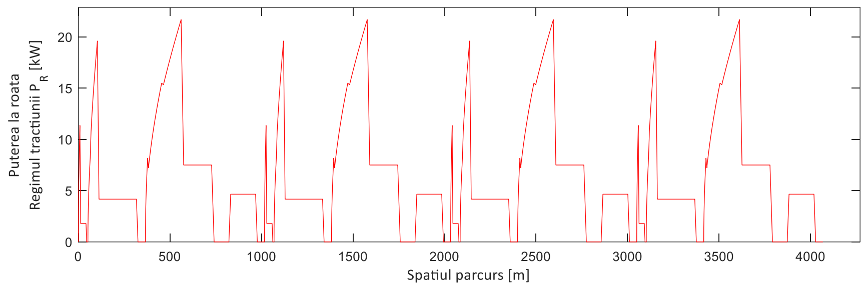

Figure 11. Urban NEDC cycle. Power required at the wheel in the traction mode

The data presented in Figure 10 are converted into electrical power from the batteries. The equaiton (4) defines the value of the electric current intensity required from the traction battery.
The current required during engine operation is defined as:

$$I_{out} = \frac{P_{me}}{V_{nom}} \tag{4}$$

Where:
P_{me} - the power of the traction motor
V_{nom} - nominal voltage of the electrical power system
The variation graph is shown in Figure 12.

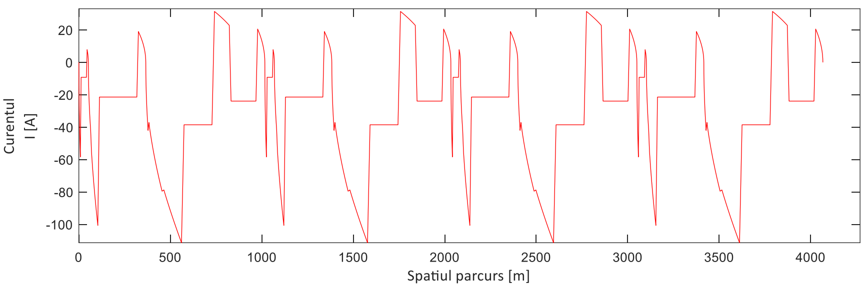

Figure 12. Urban NEDC cycle. Current intensity

Negative values are specific to the traction regime, and positive values indicate the current intensity for the regeneration and charging process of the traction battery. The state of charge of the battery can be determined to evaluate the distance that can be traveled under NEDC conditions (Figure 13).

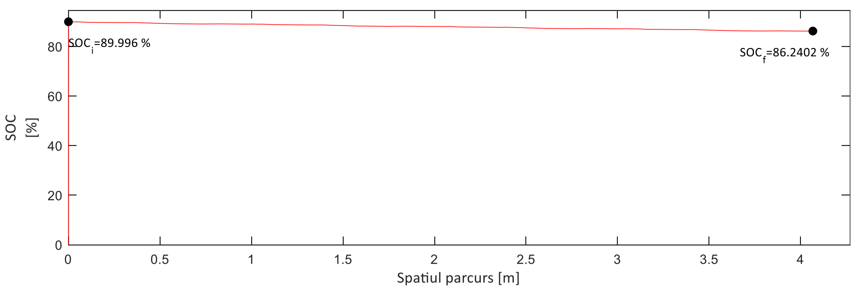

Figure 13. Urban NEDC cycle. Battery charge state

The results show that for the cycle it is consumed:

$$SoC_{NEDC} = 90 - 86.24 = 3.76\ \% \tag{5}$$

The maximum distance under NEDC conditions can be determined:

$$S = \frac{SoC_{max} - SoC_{min}}{SoC_{NEDC}} \cdot S_{NEDC} \approx 74.5\ km \tag{6}$$

The evaluation of the engine torque (M_{me}) and its integration into the operating characteristic is useful for defining the operating regime.
Figure 14 shows the torque variation diagram at the electric motor shaft.

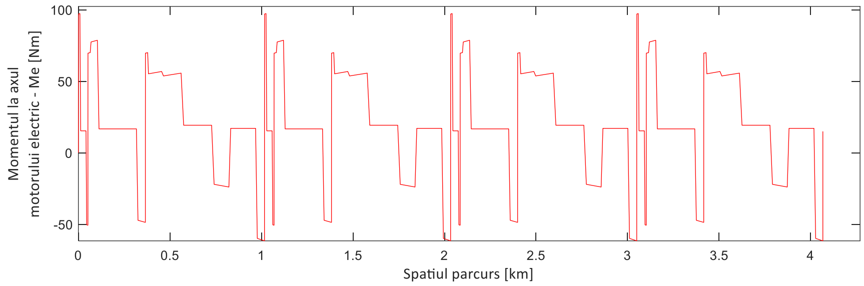

Figure 14. Electric motor operating regime

Figure 15 shows the torque variation diagram as a function of speed with the indication of the specific NEDC operating regimes.

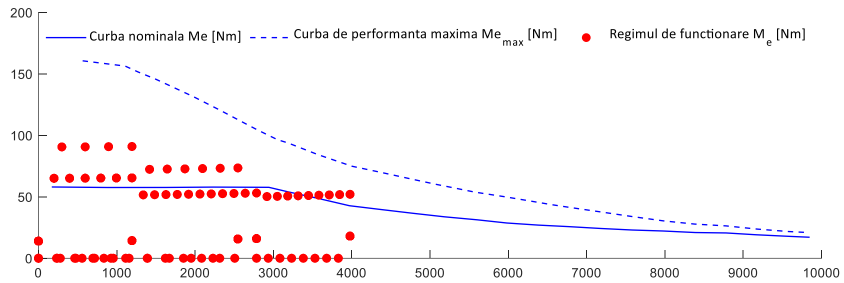

Figure 15. Electric motor operation

CONCLUSIONS

The *GASTER Electricway 4WD* is a Plug-in Hybrid Electric Vehicle Concept in development within the *Automotive Engineering* Research Center of the National University of Science and Technology *Politehnica* Bucharest – Pitesti branch in a partnership project between *Automotive Engineering* Research Center and *Renault Technologie Roumanie*.
It represents an experimental vehicle for studying ways of reducing the pollutant emissions of the DACIA DUSTER car to under 95g CO2/km, using a hybrid system with an engine fueled by Compressed Natural Gas (CNG) coupled by an intelligent transmission CVT and a part-time all-wheel drive by electrified rear axle.
In the current paper, the elements that were the basis for the simulation of the operation of the concept vehicle in electric propulsion mode were presented. The simulations were carried out using the NEDC cycle (New European Driving Cycle). Thus, it was demonstrated that the electric propulsion of the vehicle is possible, managing to overcome its forward resistance (rolling resistance, air resistance and acceleration resistance). Analyzing the performance of the electric propulsion system, it is found that during the NEDC cycle, a consumption of

3.76% of the traction battery capacity is expected, and the maximum distance that can be covered in electric propulsion mode according to the NEDC cycle is approximately 74.5 km. These results confirm the correctness of the choice of the constructive solution and give us confidence that the results that will be obtained during the road testing of the concept vehicle will be positive.

Acknowledgments

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