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Comparative study on performances of a continuously variable transmission used in two different powertrain architectures

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Abstract. Given the importance of reducing carbon emissions from road transport, price and security of oil supply, hybrid electric vehicle can provide a viable alternative solution to conventional vehicles, equipped with thermal engines, which use fossil fuels. Based on the growing trends of new vehicles sales, which include hybrid and electric vehicles closely associated with their use in terms of harmful emissions, strict regulations are established. In this paper were created models of thermal and hybrid electric powertrains groups, using computer simulation program AVL Cruise, making a comparative study using petroleum fuels for continuously variable transmission. The results obtained highlights both fuel consumption as well as pollutant emissions.

1. Introduction

According to ICCT (The International Council on Clean Transportation), in the past decade could be observed a trend that becomes dangerous: the gap between consumption and pollution in real life and those reported by manufacturers. It is estimated that, if in 2001 the difference between the theoretical and the real consumptions was 7-8%, 10 years after these difference are 3-4 times higher (figure 1).
Therefore, to eliminate these discrepancies, in 2017 the European Union intends to adopt a new cycle and a new test cycle called WLTC (Worldwide Harmonized Light Vehicles Test Cycle) [10].

Starting with 2020, all new vehicles will be tested only with WLTC and the CO2 emission targets should met by this procedure.
Based on the new requirements of the test cycle WLTC, in this paper are considering following directions:

- optimization of thermal and hybrid powertrains (HPG) groups including a continuously variable transmission (CVT) in order to reduce poluttant emissions;
- optimization of powertrain tuning with the vehicle in order to preserve the dynamic performances.

To accomplish these goals were created models of thermal and hybrid powertrain using computer simulation program AVL Cruise, making a comparative study using petroleum fuels or electricity for the new test cycle WLTC.

The results provide important insights about fuel consumption and electricity, pollutant emissions that will respond favorably to the new development strategy powerplants

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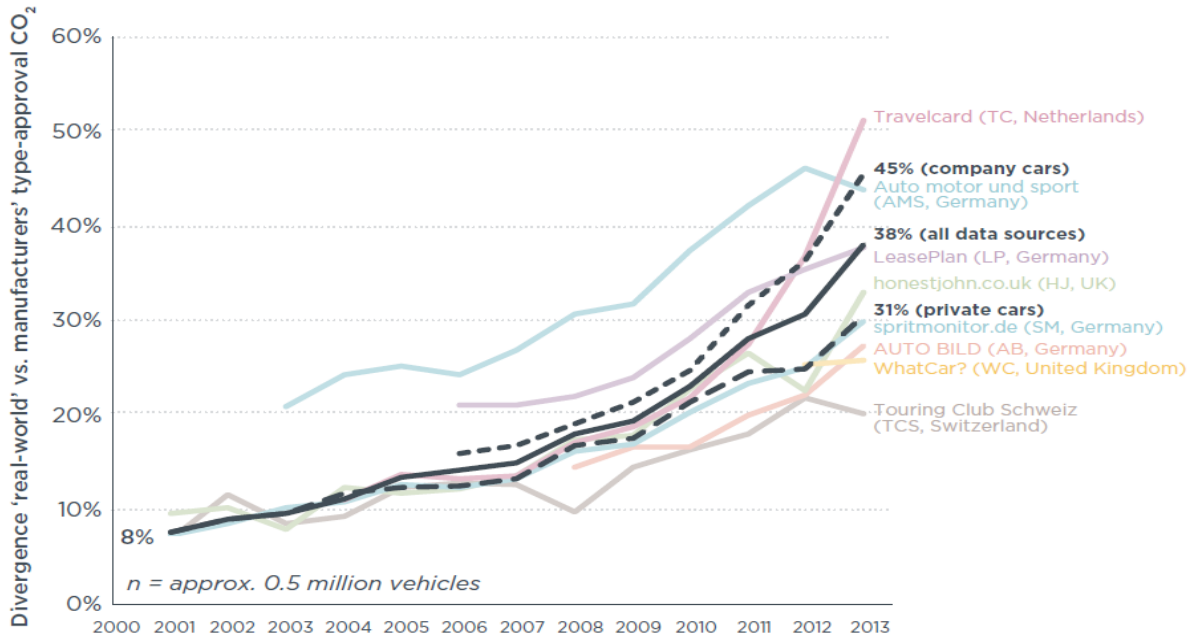


Figure 1. Discrepancy between the real CO_2 emissions and those reported by car manufacturers [14].

2. Classification of Hybrid Drive Systems

Hybrid drive systems can be classified in two categories: serial and parallel, which can themselves be combined in many subcategories according to the constructive architecture. The hybrid vehicles with a serial transmission of the energy flow or Serial Hybrid (Fig. 2) have no mechanical connection between the internal combustion engine and wheel drive shaft, and the propulsion is assured by the electric motor [6].

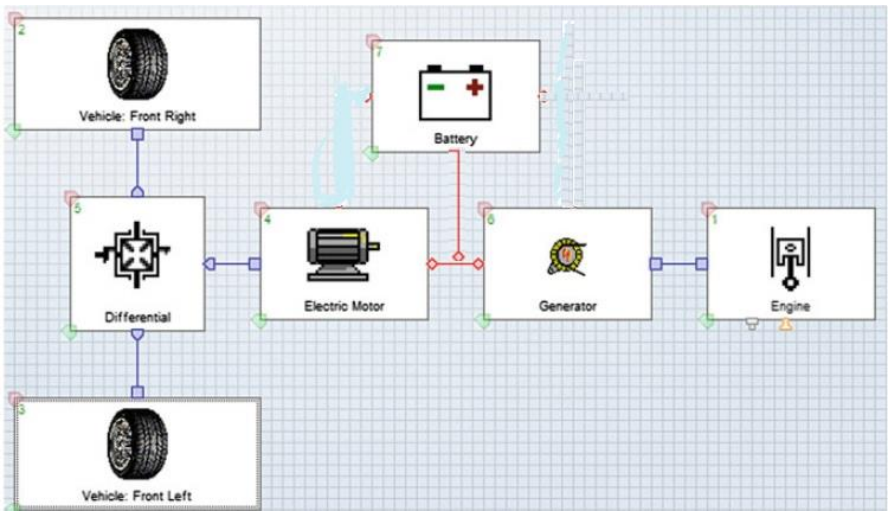


Figure 2. Serial hybrid architecture [6].

Hybrid vehicles with a parallel transmission of the energy flow or Parallel Hybrid (Fig. 3) have an internal combustion engine connected to the wheel drive shaft, but also a generator with the role of charging the batteries system. The system is called parallel because the power flow is transmitted towards the motor wheels in parallel [6].

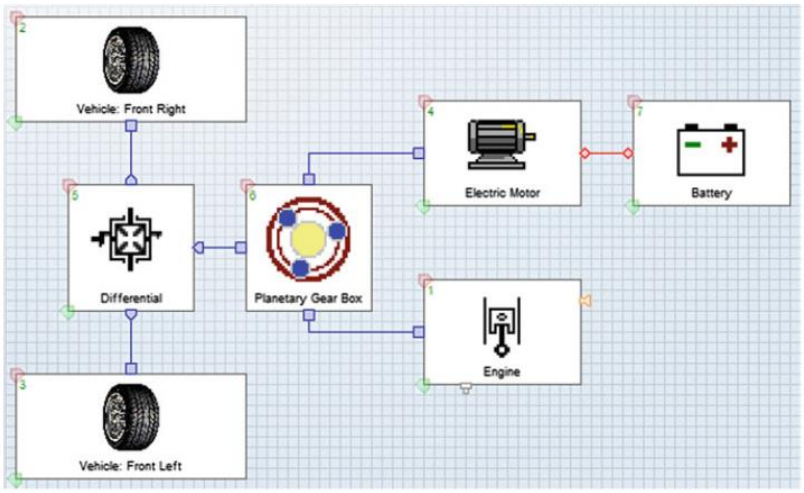


Figure 3. Parallel hybrid architecture [6].

3. Configuration of a hybrid electric vehicle simulated and the algorithm simulation process using the application AVL Cruise

AVL Cruise application is a suite of software tools for the simulation of a wide variety of car models, which can generate, develop and study the various categories of vehicle construction with various propulsive systems solutions (thermal, electric or hybrid).

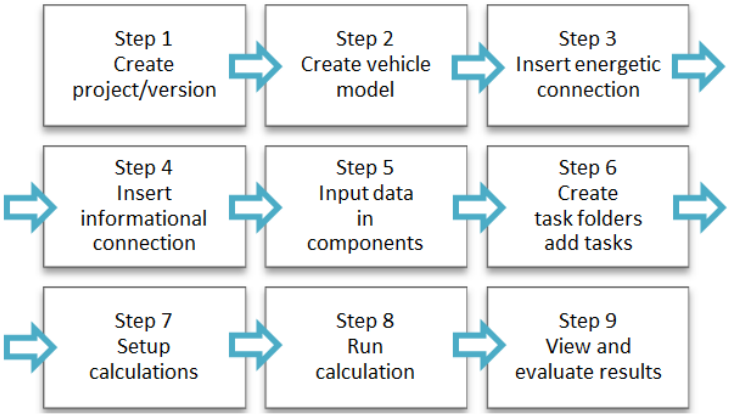


Figure 4. Process simulation algorithm [4].

The configuration of a hybrid electric vehicle simulated is a drive train in which the engine supplies its power mechanically to the wheels like in a conventional ICE-powered vehicle. It is assisted by an electric motor that is mechanically coupled to the transmission. The powers of the engine and electric motor are coupled together by mechanical coupling, as shown in Figure 5.

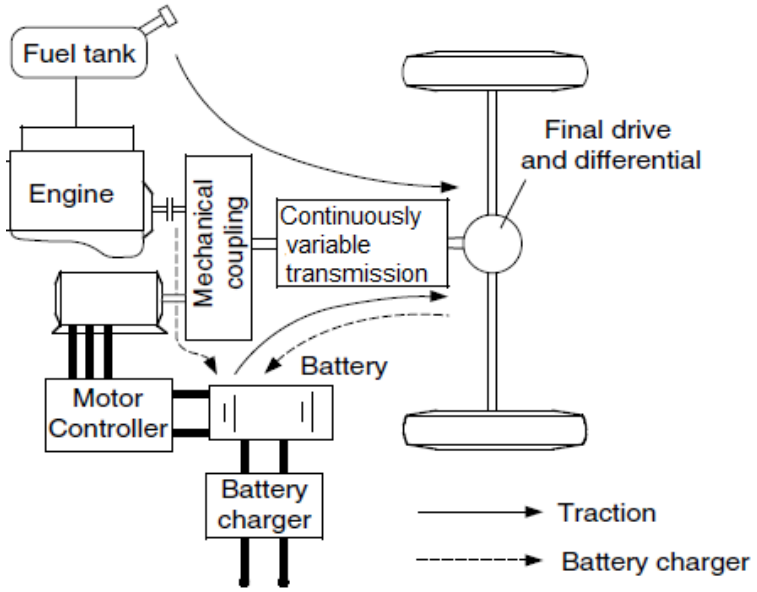


Figure 5. Configuration of a hybrid electric vehicle simulated.

4. Modeling of a thermal powertrains groups, hybrid and electric with continuously variable transmission

According to statistics, official data show that the national car park in Romania count at the end of 2015, about 6.6 million units, up 5.27 % from the same period last year, when count 6.27 million of copies. Used preferred brand in Romania continued to be Volkswagen (18.311 units, + 15.48 % relative T1 of 2015), followed by Opel (10 662 units, +15.50 %) and Audi (4,962 units, +35.24%).

As such, computerized simulation using AVL Cruise I chose as the most widely used standard car in Romania, Volkswagen brand with spark-ignition engine and a cylinder capacity of 1.4 l.

This car belongs to the category of light vehicles whose group powerplant will be equipped for the purpose of the simulation with a continuously variable transmission for the WLTC test cycle.

To simulate the operation of the car chosen by middle class was created and developed the model for computer simulation in AVL Cruise application version 2014.

Table 1. General data of car.

Model	**Volkswagen Golf 5**
Engine type	1.4 i 16V (75 Hp)
Transmission	CVT
Power	75 CP /5000 rot/min
Capacity	1390 cm3
Engine torque	126 Nm /3800 rot/min
Fuel type	Gasoline
Traction	Front-wheel drive
Unladen mass	1189 kg
Maximum authorised mass	1780 kg

Below it can be seen the graphic representation of the WLTC test cycle profile for thermal and hybrid electric powertrains groups after de simulation in AVL Cruise, characterized by speed zones that is more aggressive due to the operation in the transitional phases. This graphic is just for drawing

the profile test cycle that runs the vehicle in order to obtain the results of the simulation (section 4.1) for the two powertrains groups (figure 6).

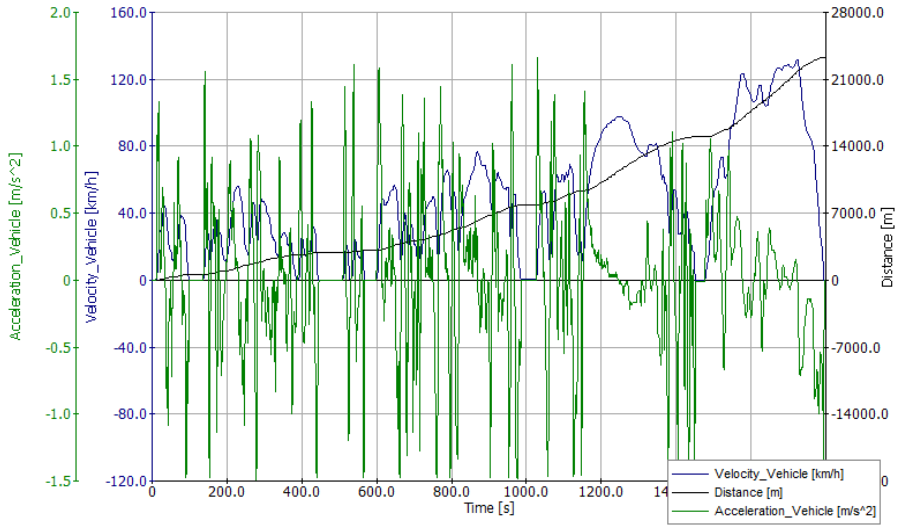


Figure 6. WLTC test cycle profile for the thermal and hybrid electric powertrains group.

In the cartogram of WLTC consumption test cycle for hybrid electric powertrain it could be seen that almost all of the operating points are used (figure 7), but in cartogram of WLTC consumption test cycle for thermal powertrain the operation points are restrained in the first part of cartogram (figure 8).

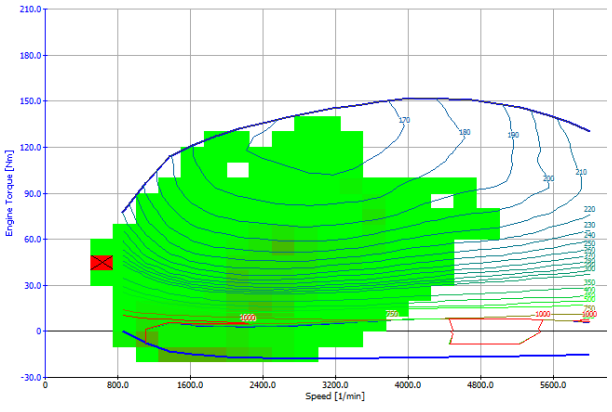


Figure 7. Map of consumption WLTC test cycle for hybrid electric powertrain .

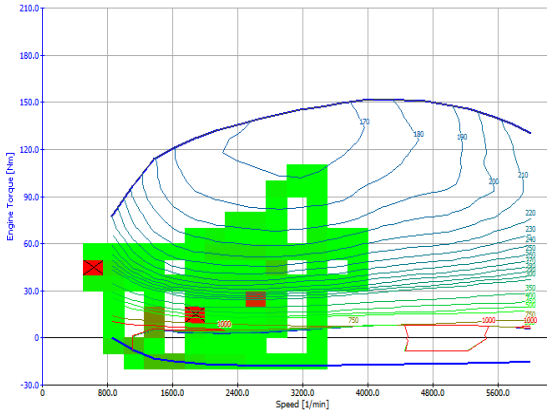


Figure 8. Map of consumption by WLTC test cycle for thermal powertrain.

4.1. Comparative interpretation of the results obtained

Below are the results obtained by computerized simulation using AVL Cruise for thermal powertrains groups, hybrid and electric with continuously variable transmission for the new WLTC test cycle:

Case 1

Table 2. Fuel consumption and CO2 emission for a vehicle with thermal powertrains group, tested by WLTC test cycles using CVT.

	WLTC
Fuel Consumption	6.1 [l/100km]
CO2	140.3 g CO2/km
CO	139 g CO/km
NOx	46 g NOx/km

Case 2

Table 3. Fuel consumption and CO2 emission for a hybrid electric vehicle, tested by WLTC test cycles using CVT.

	WLTC
Fuel Consumption	4.8 [l/100km]
CO2 emission	110.4 g CO2/km
CO	2.9 g CO/km
NOx	0.45 g NOx/km
Fuel Consumption of electrical motor	20 kWh /100 km

5. Conclusions

The data obtained as a result of computer simulation using AVL Cruise shows a noticeable decrease of fuel consumption and CO2 emission in the transition loads for a vehicle with thermal powertrains group vs. hybrid electric vehicle: fuel consumption decrease with 1.3 l /100 km (21.31%) and emission with 29,9 g CO2/km (21.31%).

After simulations conducted it was found that better behaviour in terms of fuel consumption for hybrid electric powertrain actually is due to hybridization, because are equipped with an internal combustion engine and an electric motor, thus using two different sources of energy. Each of these engines can transmit the torque to the wheels through a parallel hybrid architecture.

By modelling it is necessary to work at the same time to optimize the transmission and the engine calibration in order to obtain a powertrains groups to satisfy operating conditions on the transient stages of the WLTC testing cycle.

Even superior results can be achieved if the engine is calibrated so that it behaves more effective on the transient running stages.

In order to respond more favorably to the new WTLC test cycle, it appears that the tendency is to use hybrid electric vehicles with continuously variable transmission (CVT) and a more rigorous approach to engine calibration methods, together with a new strategy of development of the engines, because the WLTC test cycle is much tougher and is characterized by transient running stages.

The comparative results provides information on fuel consumption and polluting emissions powertrain variants studied and allows the specialists in the field to take the best decisions of the adoption the methods of propulsion for future car models.

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