6TH INTERNATIONAL CONFERENCE ON ELECTROMECHANICAL AND POWER SYSTEMS
October 4-6, 2007 - Chişinău, Rep.Moldova

ASPECTS REGARDING THE DRIVE LINE DESIGN OF THE PARALLEL HYBRIDE ELECTRIC VEHICLES

Gheorghe LIVINT, Gabriel CHIRIAC, Vasile HORGA

Technical University Gh. Asachi Iasi, Faculty of Electrical Engineering, Romania
glivint@tuiasi.ro, gabich_ro@yahoo.com, horga@tuiasi.ro

Abstract. This paper presents aspects regarding the design of the parallel hybrid electric vehicles. The design of the drive line starts from the estimation of the necessary power developed by the propulsion units. The necessary power is divided in two because the power can be generated by the engine and by the electric motor. It is calculated the power of the engine, of the electric motor and of the energy storage system (the batteries). There is presented the power variation of the engine for a hybrid electric vehicle for different slopes of the road. In the final paper it will be presented a series of simulation of the vehicle for different drive cycle (urban and extra urban drive cycle) using the Advisor program (Advanced Vehicle Simulation).

Keywords. *Parallel hybrid electric vehicle, drive line design, simulation.*

1. INTRODUCTION

The evolution of the technologies and transport systems increased the number of the vehicles over a half of a billion and for next 20-30 years it is estimate a doubling of their number. In this situation there are some serious problems about the necessary fuel and about the pollution of the medium. The hybrid electric vehicles are a viable solution for these problems. At this moment the hybrid electric vehicles past over the experimental phase and they present a more and more interest.

Concerned with the pollution and the energy crises many governs, research laboratories and cars constructors initiated researches to study and develop the vehicles with low emission or even with zero emission. The last years brings a significant evolution in the development of the hybrid electric vehicles because of the interest of the big cars companies, the quality of the new prototypes, the development of the batteries, super capacities and other possibilities to storage the energy on the vehicles.

Dynamic, energetically and economical performances of the vehicles depend both on the propulsion system and on the traffic conditions. Technical specifications of the propulsion system design can be divided in two categories: a) specifications based on the client's options (maximum acceleration and speed, fuel consumption, etc); b) ecological specifications depending on the engine emissions. First type of specifications gives the "hardware" dimension of the vehicle (the engine, the electric motor, the drive line) and the second gives, basically, the structure of the control system – the "software" dimension.

The design methodology regards or a global view for the definition of the performances' specifications of the vehicle or a selective view. In the selective design, the hardware components are projected such as the vehicle has an efficient drive for a specific type of a driving pattern. The control strategy is adjusted to some desirable's performances.

For the driving patterns are used the standard driving cycles. In the case of the design using the global specifications, the hardware and software components are sized and structured such as the performances are acceptable for different driving cycles. This approach doesn't assure optimal performances for any particular driving cycle. From the point of view of the mass production this approach is the cheaper solution because of the standardization of the hardware components.

2. THE STRUCTURE OF THE PARALLEL HYBRID ELECTRIC VEHICLES

In the parallel configuration of the hybrid electric vehicles, the engine is connected to the wheels as at the conventional vehicles and also is connected the electric motor. The engine assure generally the force of propulsion, while, the electric motor support the supplementary torque during the transient regimes (accelerations or decelerations) which assure a lower consumption and a lower pollution of the medium.

The electric batteries are necessary to supply the electric motor. When the electric machines works like generator (at the regenerative braking) the energy will be recovered into the battery. Because the electric motor only assists the engine in some working regimes, it is not necessary to it to give the main traction force and thus, the battery has a lower mass and volume, comparing to other type of the hybrid vehicles.

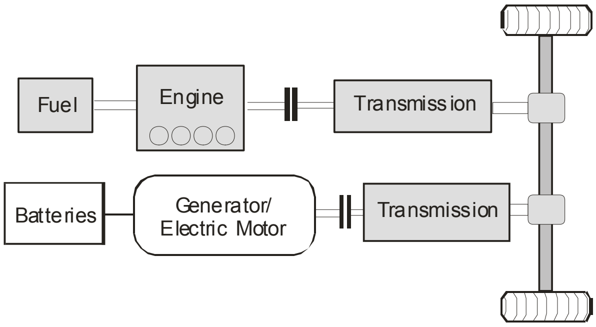

Figure1: Parallel structure with separated couplet motors to the wheels.

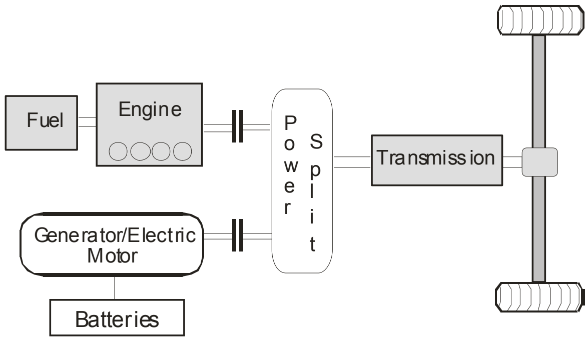

Figure 2: Power Split parallel structure of a hybrid electric vehicle.

Figure 1 present a schema for a parallel hybrid electric vehicle with the engine and the electric motor separated coupled to the wheels. Figure 2 present a structure of a parallel hybrid vehicle with a special transmission, called Power Split. In first case the structure is simple but there is the disadvantage that the engine can't be connected to the generator and it can't recharge the battery.

The battery can be recharge only during the recuperative braking of the vehicle. In the second case, more complex, the Power Split system offer the possibility to connect the two motors in a separate way and also simultaneous to the wheels. Thus, the vehicle can be drive only by the engine, or all electric, or in the mixed way (with both engine and electric motor connected to the wheels). The battery can be recharge during the braking, but also, it can be recharge from the engine, when the state of charge of the battery is below a fixed value.

The control strategy imposes for the engine to work in the area of the steady states, at higher and constant speeds and a high efficiency. In transient states, the electric motor cover a part from the necessary torque, while the engine is at a constant load. At the lower load, the engine is not connected to the wheels and it is shut down or it is used to recharge the state of charge of the battery.

All of this impose some specific demands for the electric motors used on the hybrid vehicles:

- a big instant power and a higher power density;
- A big torque at small speeds (for starting and to climb on slope) and big power at the high speeds (for long distance road);
- High efficiency for the regenerative braking;
- Safety and reliability for different conditions of drive;
- A good price;
- A quick response regarding the developed torque.

3. THE DESIGN OF THE DRIVE LINE FOR A PARALLEL HYBRID ELECTRIC VEHICLE

At the parallel hybrid electric vehicle both motors, the engine and the electric motor are used to develop torque at the wheels. The design of the drive line starts from the estimation of the necessary power developed by the propulsion unit, calculated with the relation [5]:

$$P = \frac{v \cdot \left(f_r m_v g + \frac{1}{2} \rho \cdot C_D \cdot A_F \cdot v^2 + m_v g \sin a + m_v \frac{dv}{dt} \right)}{\eta_t} + P_{aux} \quad [\text{W}] \qquad (1)$$

where:

- f_r is the friction coefficient between the wheels and the road,
- m_v is the mass of the vehicle,
- g - is the gravitational acceleration,
- ρ – is the air density, [kg/m^3],
- C_D – is the aerodynamic coefficient,
- A_F – is the frontal surface of the vehicle [m^2],
- α - is the angle of the road related to the horizontal,
- P_{aux} - the power necessary for the auxiliary consumers.

The equation (1) is divided in two (equation 2 and 3) because the power can be generated by the engine and by the electric motor:

$$P_{MT} = \frac{v \cdot \left(f_r m_v g + \frac{1}{2} \rho \cdot C_D \cdot A_F \cdot v^2 + m_v g \sin a \right)}{\eta_t} + P_{aux} \qquad (2)$$

$$P_{ME} = \frac{v \cdot m_v \frac{dv}{dt}}{\eta_t} \qquad (3)$$

where P_{MT} is the power generated by the engine and P_{ME} is the power generated by the electric motor, [W].

For the start, it can be considered some simplified hypothesis for the design: is neglected the resistance forces due to the slopes and is considered that the mass and the dimensions of the vehicle are fixed and so, all the parameters from the above equations, except the vehicle speed *v*, are constant.

In this way, the power of the engine is depending on the vehicle speed and the power of the electric motor is in proportion with the product between speed and the acceleration ($v\frac{dv}{dt}$).

With the relation (3), considering that the vehicle is accelerated only by the electric motor from zero to a speed of 50 [km/h] (13.88 [m/s]), it results a power of about 27.3 [kW]. Over 50 [km/h], usually it starts also the engine.

The electric power can be also estimated with the relationship:

$$P_{ME} = \frac{m_v}{2t_d}\left(v_{nm}^2 + v_n^2\right) \quad (4)$$

where v_{nm} is the vehicle speed corresponding to the rated speed of the motor

$$v_{nm} = \frac{\pi \cdot n_{nm} \cdot r}{30 \cdot i_t} \quad (5)$$

Considering the parameters: the rated speed of the motor n_{nm}= 1450 [rpm], the radius of the wheels r = 0.2794 [m], the gear ratio i_t= 3.22, it results v_{nm}=13.85 [m/s].

For a rated vehicle speed v_n of 27.77 [m/s] (100 [km/h]) and an acceleration time of t_d=12 [s] it results (relation 6) for the electric motor a power of about 58,18 [kW], and for t_d = 22 [s] it result a power of 31.74 [kW].

Considering also the gear efficiency it results for the second case a power of 34.5 [kW]. This is the peak power necessary from the electric motor, but its rated power can be smaller. Thus, for the parallel hybrid electric vehicle we can use an electric motor of about 20 [kW].

$$P_{ME} = \frac{m_v}{2t_d}\left(v_{nm}^2 + v_n^2\right) \quad (6)$$

Figure 3 presents the traction force characteristic of an electric motor which drive a hybrid electric vehicle.

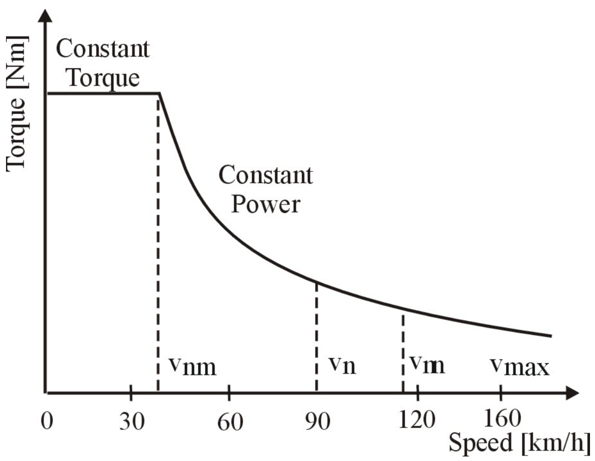

Figure 3: Traction force – speed characteristic for the electric motor

In the characteristic there are presented:

- v_n – nominal speed of the vehicle;
- v_{max} – maximum speed;
- v_{nm} – the vehicle speed corresponding to the nominal speed of the electric motor;
- v_{nn} – the speed to which the electric motor is in its natural function mode. The figure 4 presents the variation of the necessary power from the engine (estimated with the relation (2)).

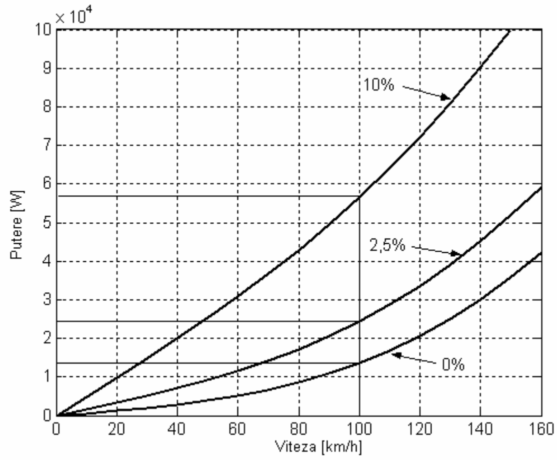

Figure 4: The power variation of the engine for a hybrid electric vehicle

From the figure it results that for a speed of 160 [km/h], for a tangent and level track movement, is necessary an engine with a power of about 45 [kW]. At the speed of 100 [km/h] the power from the engine is about 12 [kW]. To reduce the battery consumption it is considered that the auxiliary power (about 3-5 kW) is taken from the engine. Thus, the engine power necessary is about 50 [kW].

If it is known the power of the electric motor, P_{ME}, it can be estimated the battery power P_{bp}:

$$P_b = \frac{P_{ME}}{\eta_b \cdot \eta_{ME}} \quad (7)$$

where η_b is the battery efficiency (about 0.8) and η_{ME} is the efficiency of the electric motor, which depends on the motor type and its power. We consider a value of 0.92. For the utilization of NiMH battery for P_{ME} = 20 [kW] it results a total battery power of about 27.2 [kW], which correspond to a mass of about 45.3 [kg] and 3.48 battery. It can be used four NiMH battery with a voltage of 12 [V] and a capacity of 65 [Ah].

4. CHECK UP OF THE PERFORMANCES FOR THE DESIGNED DRIVE LINE

To analyze the performances of the parallel hybrid electric vehicle with the above determined characteristics there were made some simulations using the Advisor program. The aim is to verify the components calculated above on the base of the hybrid vehicle models from the Advisor. The simulations are made on a Honda Insight structure (which has a lower mass) with the next components characteristics:

- The engine power, 50 [kW];
- The electric motor is considered an induction motor with a power of 20[kW];
- Storage of the electric energy is on a NiMH battery ESS_NiMH_Ovonic, 28 [kW];
- The load is 180 [kg];
- For the control strategy it was adopted the powertrain control PTC_PAR_CD that corresponds with the parallel structure;

There were realize some simulation using a interurban traffic cycle, characterized by a maximum speed of 120 [km/h] and for a distance of 6.9 [km].

Figure 5 presents, on the first line, the characteristics of the prescript speed and the speed resulted on the simulations for 5 trafic cycle CYC_EUDC.

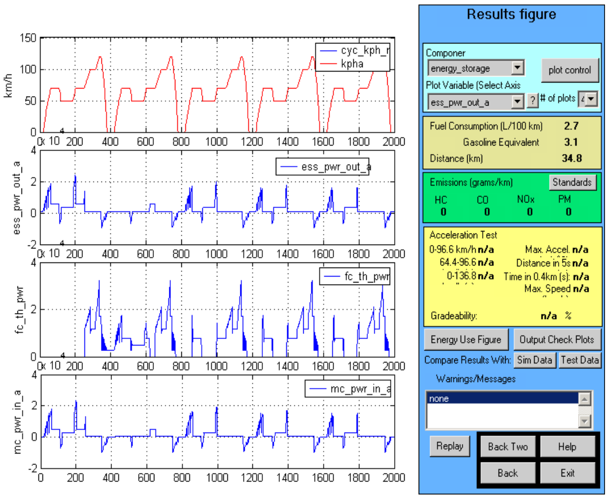

Figure 5: Battery power, engine power and electric motor power variation on 5 CYC_EUDC cycles

In figure 5, on the lines 2 to 4, there are presented the variation for the power of the battery, the power of the engine and the power of the electric motor. The characteristics shows that the simulated speeds correspond with the prescript speeds from the traffic cycle.

In the line 2 to 4 the are distinguished the area were the two motors are on and off, at the high speed working the engine and at the small speed is working, generally the electric motor. There are also distinguished the area of the regenerative braking, when the battery power is negative.

5. CONCLUSIONS

The design methodology presented offers the possibility to estimate the power of the two drive motors of the parallel hybrid electric vehicle and the power of the electric battery.

The power of the engine was determined considering that it operates at high and constant speeds, which assure a lower fuel consumption and lower pollution. The power of the electric motor is determined so it can be assure the acceleration and the movement with small speeds, specific to the urban area.

The dynamic simulation confirm the accuracy of the calculus and offers a base for the future researches in the area of the parallel hybrid electric vehicles.

References

[1] Chassis Trends, *Automotive Engineering International*, August 2002

[2] Cahn C.C. *The State of the Art of Electric and Hybrid Vehicles,* Proceedings of the IEEE, vol. 90. No.2, February 2002, pp. 247-275

[3] Gao. Y., Ehsani M. *Hybrid Electric Vehicle: Overview and State of the Art*, IEEE ISIE 2005, June 20-23, 2005, Dubrovnik, Croatia

[4] Husain I. *Electric and Hybrid Vehicles. Design Fundamentals*, CRC Press, 2003.

[5] Livinț Gheorghe, Radu Gaiginschi, Vasile Horga, Radu Drosescu, Gabriel Chiriac, Mihai Albu, Marcel Rățoi, Ion Damian, Marian Petrescu, *Vehicule Electrice Hibride,* Editura Venus, 2006.

[6] Zeraoulia M. Benbouzid M.E.H., Dialo, D. *Electric Motor Drive Selection Isssues for HEV Propulsion Systems: a Comparative Study*, IEEE 2005, 0-7803-9280-9/05, pp. 280-287.

[7] www.toyota.com