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Silent operating range of military electric hybrid vehicle using electric power splitter and different electric energy storage

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Abstract

Paper deals with operating range of hybrid car using electric power splitter and battery or super capacitor under special military condition. Special attention is paid to military vehicles having a duty to move in defined territory without using the combustion engine. Reason of this demand is to move without doing noise. It is reasonable to use under this condition only the electric drive and energy stored in the battery or super capacitor. The paper simulates in the given terrain and on basis of the given driving cycle that is velocity against time the ability of different storage systems to fulfil these demands. Mass of the vehicle is 2000kg. Mass of the battery respectively mass of the super capacitor is the same 70kg. The energy density in the battery is 150Wh/kg and the energy density in the super capacitor is 25Wh/kg. That means that energy stored in the battery is 10.5kWh at chosen rated voltage 240V. Energy stored in the super capacitor is 1.75kWh at maximum rated voltage also 240V. The 80% energy from battery or 75% energy from the super capacitor can be used for traction. The power of internal combustion engine (ICE) is controlled by a special program taking in account good efficiency of the engine, instantaneous acceleration, instantaneous power flow from the energy sources to vehicle wheels taking in account losses and instantaneous energy stored in battery or super-capacitor. The ICE is controlled in modus "stop and go". In "dangerous" region it is stopped totally. The traction power is taken partially from the ICE and partially from the battery or super capacitor. Sharing of these two power sources is controlled by the program. The lowest energy level in the battery may be 2,1 kWh and in super capacitor 0,55kWh.

Keywords: HEV (HEV (Electric hybrid vehicle), BEV (Battery electric vehicle), load management, power steering

1 Introduction

The main purpose of a hybrid electric car drive is to achieve a high efficiency in energy transmission from fuel tank to traction wheels of the vehicle. The hybrid electric drive has besides this also a feature to go without doing too much noise and heat emissions for possibility to be detected. The vehicle using this kind of drive can be used on a limited distance as purely electric driven vehicle. The combustion engine is the noisiest part of the car powertrain. It can be stopped when the silent movement of the vehicle whatever reasons may be is needed. The distance which can be covered in this operational mode depends on the design of electric vehicle, on energy storing system [1], [2], [11], on the powertrain system [3], on energy stored, on the driving cycle [6], on mass of the vehicle and on the terrain.

2 Experimental basis for vehicle design

An experimental working stand has been set up at the Department of Electric Drives and Traction at the Faculty for Electrical Engineering CTU Prague. There are two main innovative features of this hybrid drive. The first is the use of the super-capacitor (SC) as energy storage and the second is the use of the electric power splitter (EPS) constructed as a double rotor synchronous permanent magnet generator.

2.1 Electric power splitting drive description

Physical model of the hybrid electric vehicle powertrain with the electric power splitter [7] was built in the experimental laboratory in the Centre of Automobile Technology at the Czech Technical University in Prague and is depicted in Fig. 1.

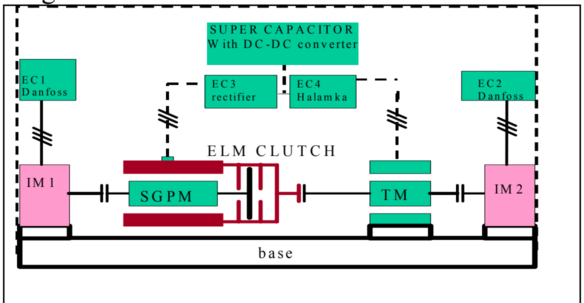

Figure 1: Physical scheme of the experimental laboratory model of the electric power splitting drive

The induction motor (IM1) simulates the internal combustion motor and drives electric power splitter SGPM constructed as synchronous generator with two rotors. On the first rotor are permanent magnets arranged. On the second rotor is electric winding in slots located. Both rotors of the electric power splitter SGPM rotate separately. The induction machine IM2 simulates the car wheels. Traction induction motor TM is added. The traction induction motor TM is supplied from the second rotor of the electric power splitter where electric winding induced from permanent magnets of the first rotor is arranged. Parameters of electric power for the traction motor TM are transformed in power electronic converters EC3 and EC4. The IM1 output power is divided into two parts. The first part is proportional to the difference between the IM1 and IM2 speeds and flows on the way EC3, EC4 to TM. The second part is carried directly by means of electromagnetic torque in the air gap of generator SGPM to the TM shaft. The scheme is completed with a super capacitor.

2.2 Performed measurements

The efficiencies of all powertrain components were measured and published in [3]. In this paper there are used in the control and calculation program.

2.3 Program structure for control and calculation of vehicle working regimes during special military service.

Different methods of simulation can be used. [4]. In this case simulation in Matlab programming interface has been used. The main aim in this simulation is to determine the power and energy fluctuations in the hybrid drive during moving on the prescribed way with the prescribed driving schedule. ICE is working in start stop regime. It is started when starting conditions are fulfilled. Starting conditions are calculated from instantaneous vehicle speed, battery or super capacitor voltage, instantaneous needed traction power, actual total losses and instantaneous acceleration demands. For this purpose, the function and behaviour of each component of the system is determined and taken into account, e.g. the power of the ICE is optimized. Further more the aerodynamic resistance, rolling resistance between tires and road and the efficiency of the electric power converters etcetera are taken into account. The kinetic model has been mathematically created for the predetermined car specifications, e.g., car weight, number of energy accumulative units and their combination. The program calculates (between others) for each tasks in the terrain the power from the combustion engine and energy taken from the energy storage to fulfil the task. Then the acceptability of the storage system can be judged.

2.3.1 Input data, parameters and constants for the simulation program

2.3.1.1 Case when battery is used:

Pmax=40 kW (Maximum power of the ICE)
Pmin=15 kW (Minimal power of the ICE)
m = 2800 kg (Mass of the vehicle)
g = 9.81 m/s^2 (Local acceleration of gravity)
f = 0.03 (Coefficient of rolling resistance between the tires and the road surface)
ρo = 1.3 kg/m^3 (Density of the ambient air)
AP = 3.5 m^2 (Cross-sectional area of the vehicle)
Cx = 0.9 (Coefficient of drag (wind resistance) in the direction of travel)
mbt = 70 kg (Mass of the battery)
Edbt = 150 Wh/kg (Energy density of the battery)
Wmax_kWh = mbt*Edbt/1000 kWh (Maximal allowed energy of battery in kWh)
Wmax = Wmax_kWh*1000*3600 J (Maximal allowed energy of battery in J)
Umax = 240 V (maximal voltage of the battery)

2.3.1.2 Case when super capacitor is used:

Pmax=40 kW (Maximum power of the ICE)
Pmin=25 kW (Minimal power of the ICE)
m = 2800 kg (Mass of the vehicle)
g = 9.81 m/s^2 (Local acceleration of gravity)
f = 0.03 (Coefficient of rolling resistance between the tires and the road surface)
ρo = 1.3 kg/m^3 (Density of the ambient air)
AP = 3.5 m^2 (Cross-sectional area of the vehicle)
Cx = 0.9; (Coefficient of drag (wind resistance) of the vehicle in the direction of travel
msc = 70 kg (Mass of the SC)
Edsc = 25 Wh/kg (Energy density of the SC)
Wmax_kWh = msc*Edsc/1000 kWh (Maximal allowed energy of SC in kWh)
Wmax = Wmax_kWh*1000*3600 J (Maximal allowed energy of SC in J)
csk = 1 (Number of super-capacitors)
Umax = 240*csk V (maximal voltage of the super-capacitors)
C = 2*Wmax/$Umax^2$ F (Total capacity of the super-capacitors)
Csc1 = C*csk F (Capacity of one super-capacitor)
Wmin = Wmax*0.25 J (Minimal allowed energy of SC)
wsk = 99 % (Starting voltage of SC in %)
U_0 = Umax*wsk/100 V (Starting voltage of SC in volts)
W0 = C*U_0^2/2 J (Starting energy of SC)

3 Prescribed vehicle velocity on the road and prescribed road height profile used for comparison

Comparisons between two military vehicles were performed. The same prescribed vehicle velocity on the road, the same prescribed road height profile and the same silent operation region were used. Vehicle velocity on the road is depicted in Fig.2.

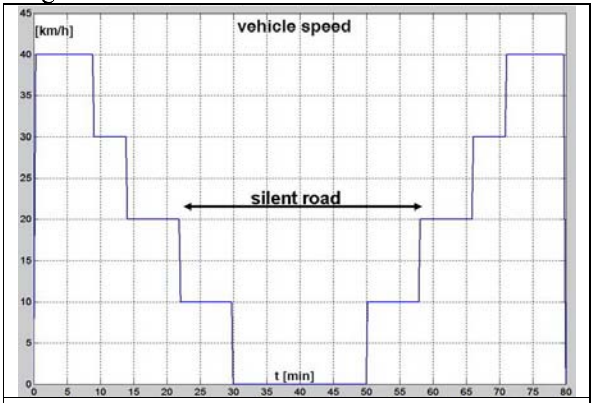

Figure. 2. Vehicle velocity on the road

Road height profile is depicted in Fig.3.

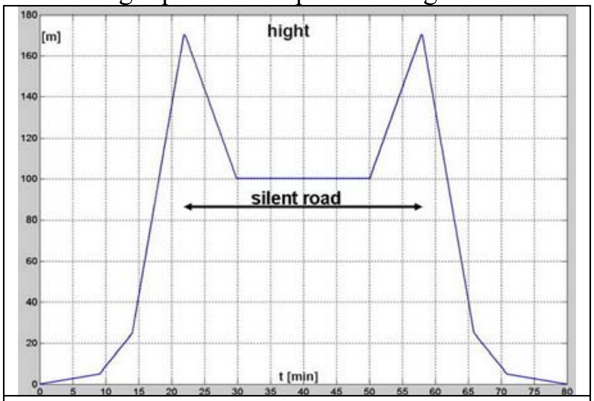

Figure. 3. Road height profile

The region in which the vehicle should go as silent as possible is given in both figures. The ICE is stopped during movement in "dangerous" region and the vehicle continues being driven only from electric energy storage. The task of the calculation

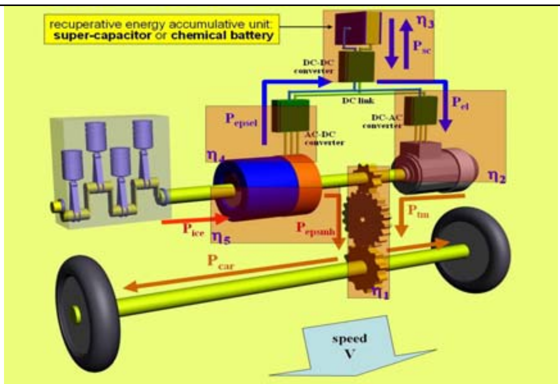

Figure 4 Hybrid drive assembly with power flow lines and its efficiency

is to get information how to project the energy storage for different duty tasks.

Both vehicles should have the same mass. Mass of the vehicle is 2000kg. Mass of the battery resp. mass of the super capacitor is the same 70kg. The energy density of the battery is 150 Wh/kg.and the energy density of the super capacitor is 25Wh/kg. That means that energy stored in the battery is 10.5kWh at chosen rated voltage 240V. Energy stored in the super capacitor is 1.75kWh at maximum rated voltage also 240V. The 80% energy from battery and 75% energy from the super capacitor can be used for traction.

4 Results of the comparison

Different sophisticated control of power sharing between the ICE and energy storage is possible. In the case of this paper the energy stored in the battery or super capacitor is maintained in chosen margins. The vehicle is driven by the electric drive as a matter of priority. When the energy in the battery or super capacitor is lower than wanted then the ICE is started. When the energy in the battery or super capacitor is higher the ICE is stopped. In this way the ICE is controlled to work with its highest efficiency.

The power of ICE is controlled by a special program taking in account the power that is needed for traction, good efficiency of the engine and instantaneous energy stored in battery or super-capacitor and others. The ICE is controlled in modus "stop and go". In "dangerous" region where the silent regime is needed it is stopped totally.

Results of the simulation can be obtained in many different graphs. We can get from the program parameters for example mechanical and electrical power in different power devices of the power train. See Fig. 4. We can monitor instantaneous efficiencies, charging and discharging battery or super capacitor currents, instantaneous energy stored in the battery or super capacitor and many others. Three kinds of graphs were chosen to depict the working regimes in the vehicle powertrain which is depicted in Fig. 4.

They are:

Time dependence of power demand for traction on wheels.

Time dependence of ICE power

Time dependence of energy which is stored in the battery or super capacitor during driving cycle.

4.1 Case when battery is used

In Fig.5 time dependence of power demand for traction on wheels together with time dependence of ICE power is depicted.

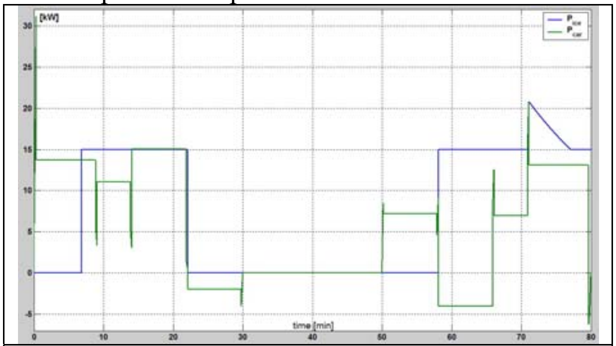

Figure 5. Time dependence of vehicle power demands during driving cycle. Blue line – ICE power, green line- power on driving wheels needed for vehicle movement

In Fig. 6 time dependence of energy which is stored in the battery during driving cycle is seen.

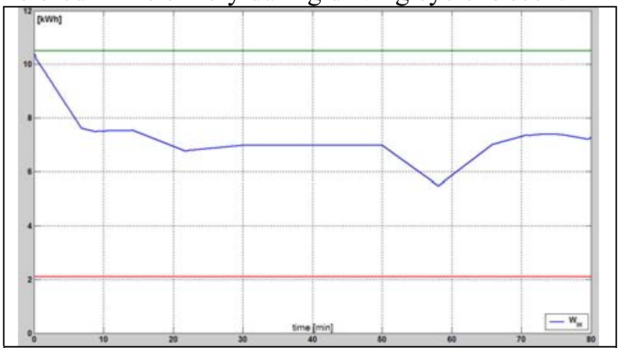

Figure 6. Time dependence of the energy stored in the battery during driving cycle. Upper and lower lines represent energy limits of the battery.

From Figures 5 and 6 we can see how the special program controls the ICE. ICE power in Fig.5 at the end of driving cycle is caused by high acceleration and by the effort to minimize sharp transients on the ICE.

From Fig. 6 we can see that the energy stored in the battery never falls down under the chosen limit 20% of the full energy which can be stored in the battery. That means that the vehicle is able to fulfil the given task with a good safety.

4.2 Case when super capacitor is used

For comparison the same time dependences as in previous case are used. In Fig.7 is time dependence of power demand for traction on wheels together with time dependence of ICE power depicted.

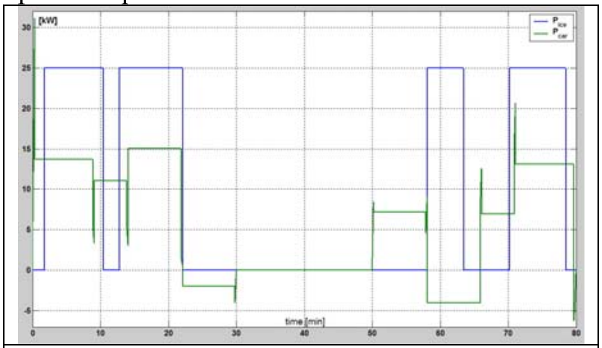

Figure 7 Time dependence of vehicle power demands during driving cycle. Blue line – ICE operation regime, green line- power on driving wheels needed for vehicle movement

In Fig. 8 time dependence of energy which is stored in the battery during driving cycle is seen.

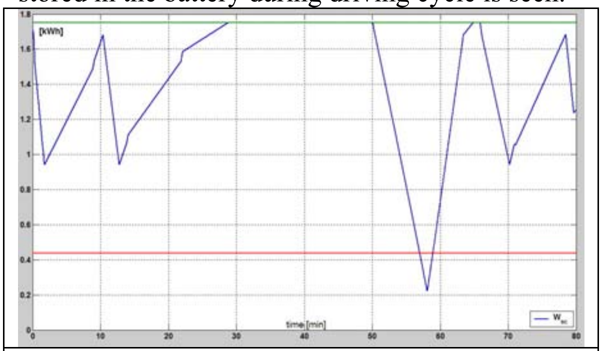

Figure 8. Time dependence of energy stored in the super capacitor during driving cycle. Upper (green) and lower (red) lines represent energy limits in the super capacitor.

It is seen that under given driving cycle it is not possible to carry out the desirable driving cycle in silent interval. As it is seen from the graph, 75% of the SC energy is not sufficient for desirable driving regime. It is necessary to start ICE at 57th minute of driving cycle.

From Figures 7 and 8 we can see how the special program controls the ICE.

From Fig. 8 we can see that using the described special ICE control program the instantaneous energy stored in the super capacitor falls down bellow the chosen minimal limit 25% of the full energy which can be stored in the super capacitor. That means that the vehicle is not able to fulfil the given task with a good safety.

5 Conclusion

The hybrid electric drive has a feature to go without doing too much noise. The vehicle using this kind of drive can be used on a limited distance as purely electric driven vehicle. The combustion engine is the noisiest part of the car powertrain. It can be stopped when the silent movement of the vehicle whatever reasons may be is needed. The electric power train must be very carefully designed. The distance which can be covered in this operational mode depends mainly from the energy storing device. The energy density of the modern battery enables to solve this problem on longer road distances then the super capacitor. Described simulation program allows to make the design with a more exact approach.

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Zdeněk Čeřovský started his carrier with CKD factory as DC/AC machine designer. Projected drives of trams, locos and ship generators. Changed for Czechoslovak Academy of Sciences, worked in power electronics. Projected the first tram with induction motors in ČSR together with CKD. Changed for Technical University in Prague as Professor. Is member of the Research Center JB of Automotive Technology

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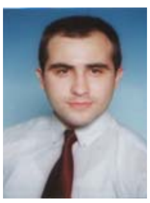

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