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SIMULATION OF HYBRID ELECTRICAL VEHICLE FOR TWO DIFFERENT DRIVING MODES

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Original scientific paper
This paper shows an example of computer simulation of hybrid vehicle in two different driving modes. This example shows multiple areas of operation of a simulated hybrid electric vehicle. The hybrid electric vehicle is of combined type, similar to Toyota Prius cars. This hybrid electric vehicle has two types of driving power: the electric motor and the internal combustion (IC) engine, to increase the level of efficiency of driving assembly and to reduce air pollution. A hybrid electric vehicle combines the advantages of electric motor drive (no pollution and high available power at low speeds) and the advantages of IC engine (high dynamic performances and little pollution at high speeds). In the simulation of a hybrid electric vehicle SimPowerSystems™ and SimDriveline™ (MATLAB) were used.

Keywords: *computer simulation; hybrid electric vehicle; modelling*

Simulacija hibridnog električnog vozila za dva različita režima vožnje

Izvorni znanstveni članak
U ovom radu je prikazan primjer računalne simulacije hibridnog električnog vozila u dva različita režima vožnje. Ovaj primjer pokazuje mnogostruko područje rada simuliranog hibridnog električnog vozila. Hibridno električno vozilo je kombiniranog tipa, slično kao u automobilima Toyota Prius. Vozilo ima dvije vrste pogonske snage: elektromotor i motor SUI, u svrhu povećanja stupnja djelovanja pogonskog sklopa i smanjenja zagađenja zraka. Hibridno električno vozilo udružuje prednosti elektromotornog pogona (nema zagađenja i velika raspoloživa snaga pri malim brzinama) i prednosti motora SUI (visoke dinamičke performance i malo zagađenje pri velikim brzinama). Pri simulaciji hibridnog električnog vozila korišten je SimPowerSystems ™ i SimDriveline ™ (Matlab 11).

Ključne riječi: *hibridno električno vozilo; modeliranje; računalna simulacija*

1 Introduction

Hybrid system is a drive which joins two or more heterogeneous engines that operate together (usually internal combustion engine and electric motor are combined) [15]. An example of a hybrid electric vehicle (HEV) is Toyota Prius (Fig. 1) [4], so the technical characteristics of this vehicle were used in the simulation of a combined HEV in this paper. Complete driving system of HEV [5] consists of:
- internal combustion (IC) engine,
- electric motor,
- generator,
- energy converter (inverter),
- gearbox (transmission) and
- battery.

The reason for existence of HEV lies in the fact that these vehicles do not have problems with range, as they use fossil fuel to drive IC engine and they are more environmentally friendly at the same time (they belong to a group of vehicles with low emission of harmful gases, LEV–Low Emission Vehicles) and they are more efficient when compared to conventional vehicles because they use the benefits of electric drive system [6, 20].

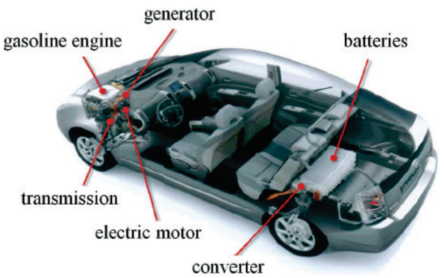

Figure 1 Toyota Prius

HEV considerably exceeds the requirements of Euro IV standards for exhaust emissions. According to Toyota's data, their Prius reduces carbon dioxide emissions by approximately one ton annually, compared to a conventional car of the same class. Also, the content of hydrocarbons is by 80 % less and of nitrogen oxides by 87,5 % less than the value required by the Euro IV for gasoline engines [14].

HEV can be divided into:
- mild HEV, that cannot move without the operation of IC engine and
- full HEV, that can move without the operation of internal combustion engine.

HEV performances are significantly influenced by its configuration. There are three HEV configurations [9]: series, parallel and combined (Fig. 2).

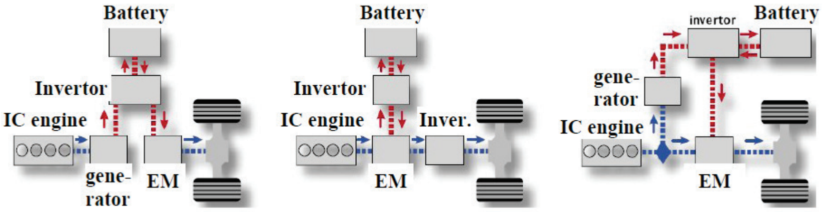

Figure 2 HEV configurations

2 Modeling of HEV

Fig. 3 shows a flow chart of a combined HEV. For more realistic layout, the model of a combined HEV is divided into the following sub-systems: electric, internal combustion engine, energy control, planetary gear and vehicle dynamics.

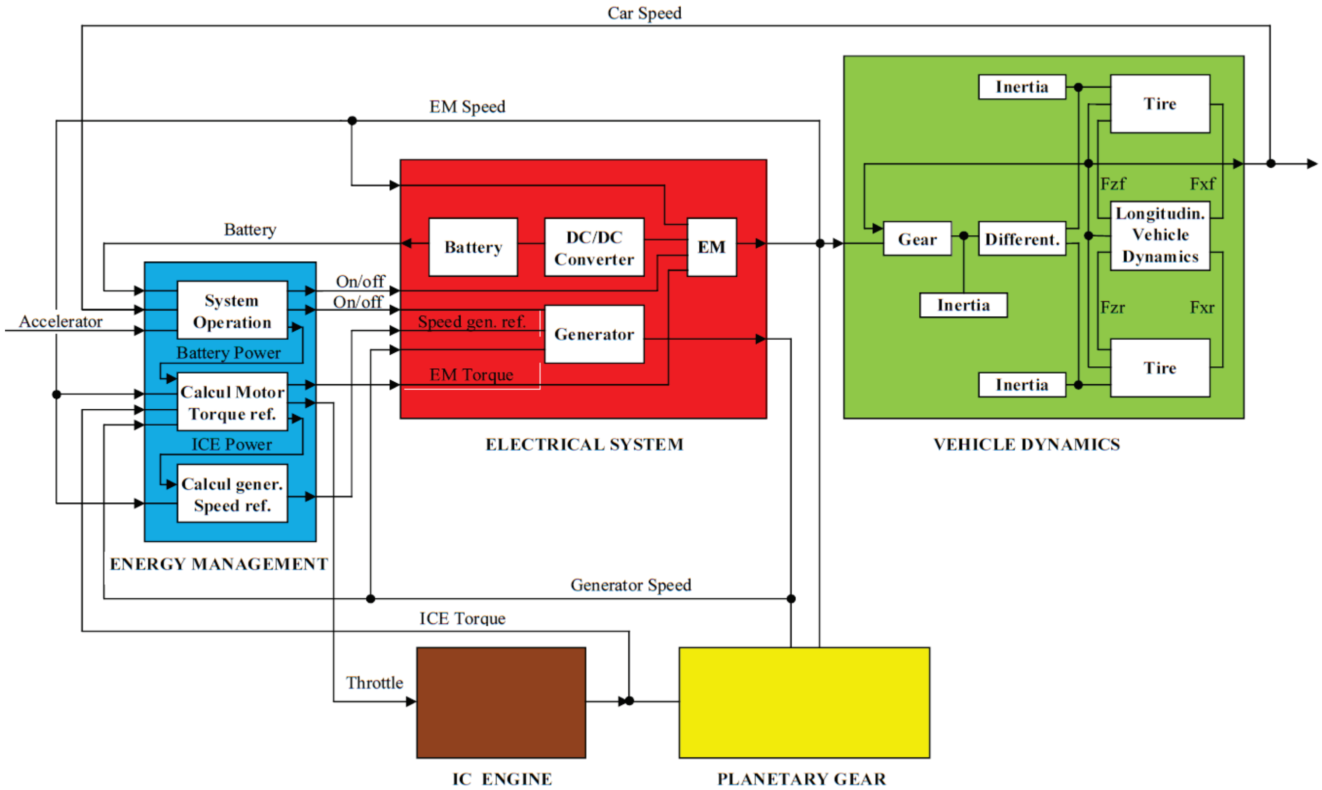

Figure 3 Flow chart of a combined HEV

3 Simulation of HEV

Based on the scheme of a combined HEV, simulation model was made in MATLAB Simulink for combined HEV, similar to cars Toyota Prius (Fig. 4) [1÷3, 7, 8, 10÷13, 16, 18, 19].

The input in this simulation scheme that can be changed is accelerator pedal and the speed of simulated HEV depends on it. Various inclines and declines of the road can be simulated with variable road angle in sub-system Vehicle Dynamics for the complete course of simulation, as well.

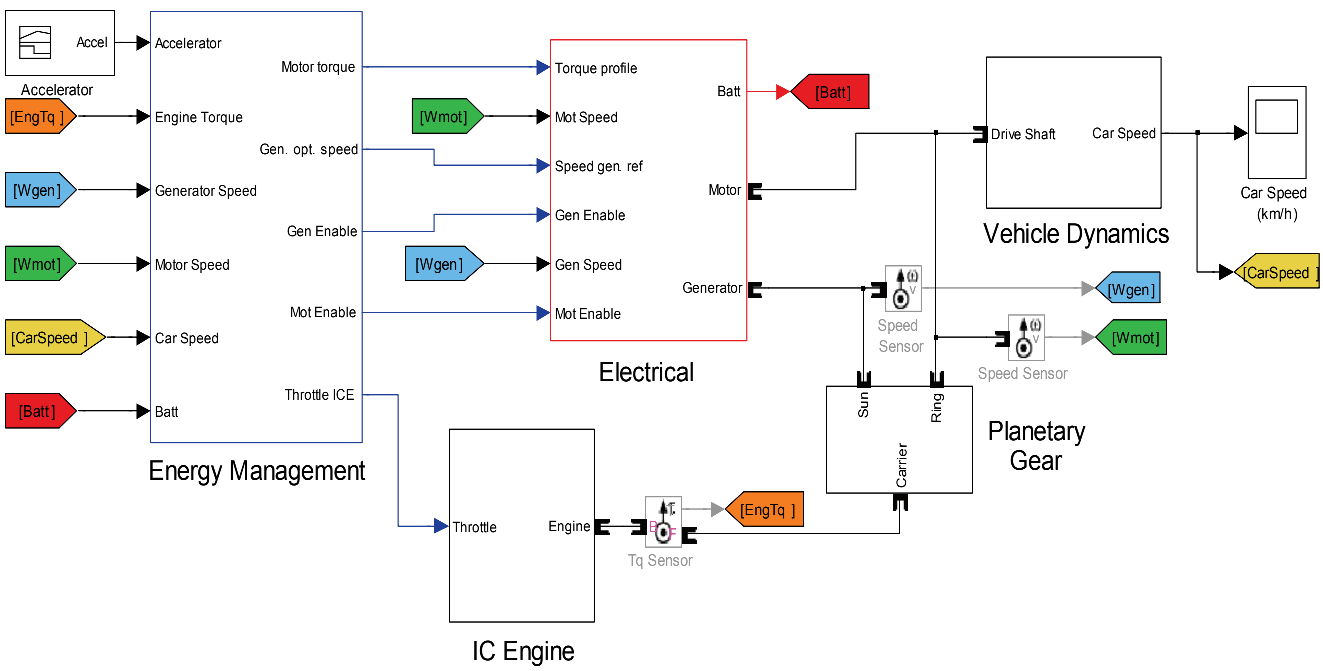

Figure 4 Simulation scheme of a combined HEV

The validation of simulated HEV was done for the value of accelerator pedal 1 (maximum acceleration) during the complete course of the simulation and the speed of the simulated HEV was obtained (Fig 5). As we could not measure the acceleration (speed) of vehicle Toyota Prius when the accelerator pedal is pressed to the maximum, the results from paper [17] were used for comparison.

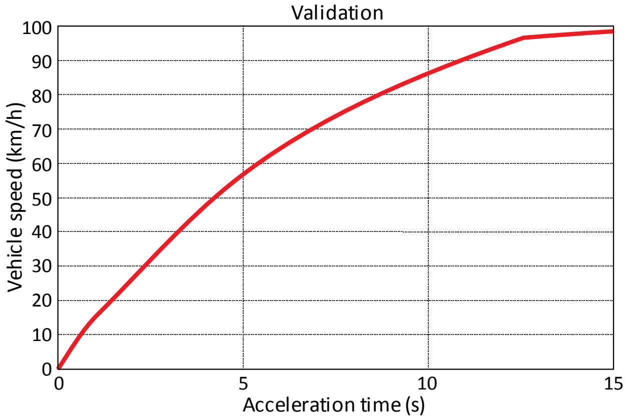

Figure 5 Graph of speed of simulated HEV for accelerator pedal 1

Experimental results of the acceleration of vehicle Toyota Prius from reference [17] compared with simulated results of HEV acceleration taken from Fig. 5 are given in Tab. 1.

Table 1 Comparative display of acceleration time of Toyota Prius

Acceleration	Acceleration time (s)	
	Experimental [17]	Simulated (Fig. 5)
0 ÷ 48 km/h	4,5	4,2
0 ÷ 97 km/h	13,1	13,1
48 ÷ 89 km/h	7,0	6,6

Tab. 1 shows that there are slight deviations (within allowed limits) between experimental and simulated values of acceleration time of vehicle Toyota Prius, so we conclude that simulated HEV depicts vehicle Toyota Prius rather truthfully.

The paper presents results of HEV simulations for two driving modes:
- driving in a city and
- driving on an open road.

3.1 Simulation of combined HEV in driving in a city

Simulation of a combined HEV during driving in the city was done for accelerator pedal as shown in Fig. 6. With thus specified accelerator pedal, maximum HEV speed of 45 km/h is obtained as the result of simulation (Fig. 8), which is satisfactory, because according to the Law on Traffic Safety, the speed of a vehicle in an urban area is limited to 50 km/h.

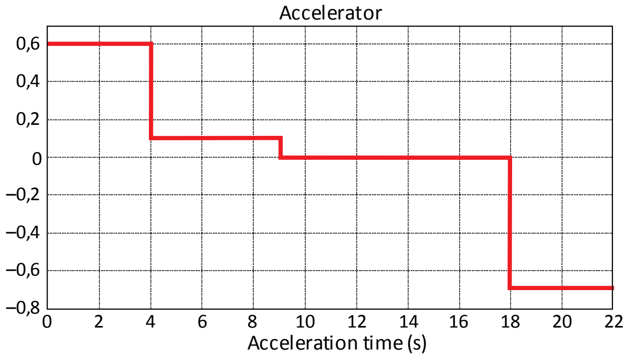

Figure 6 Diagram of accelerator

All specified and obtained diagrams depend on simulation time. The duration of this simulation is 22 seconds and the road was considered to be level.

Fig. 7 shows HEV modes of operation for this simulated model.

Fig. 7 shows that transitional modes of this simulation in times are: t_1 = 1,07 s; t_2 = 4 s and t_3 = 18 s.

In t_0 = 0 s, HEV is in start mode and it is moved by pushing the accelerator pedal 60 %. As long as the required power of HEV is less than 15 kW and speed less than 20 km/h, HEV is moved by the electric motor powered by battery.

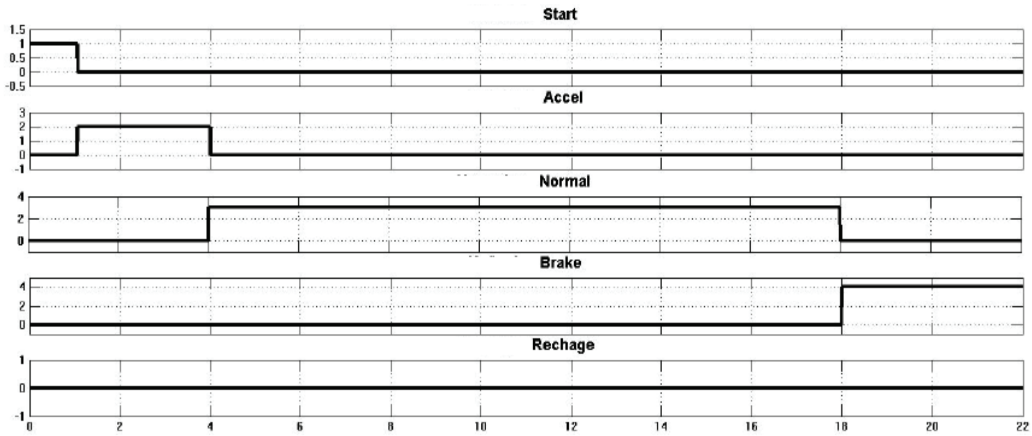

Figure 7 Diagram of complete cycle (mode) of HEV

In t_1 = 1,07 s, required power of HEV becomes higher than 15 kW, which requires hybrid mode of operation (HEV power comes from the IC engine and electric motor that is powered from the battery). HEV is in acceleration mode.

In t_2 = 4 s, after the HEV speed of approximately 40 km/h was achieved, the pressure on the accelerator pedal is reduced to 10 % in the following five seconds, and then the accelerator pedal is completely released until t_3 = 18 s (HEV operates in normal mode).

Then the power of HEV comes from the IC engine and electric motor, same as in acceleration mode, but now the electric motor is powered from the generator and not from the battery (there is no battery discharge).

In t_3 = 18 s, until the end of the simulation, HEV works in braking mode (in this simulation, braking is specified by a negative value of the accelerator pedal of −70 %). Then the IC engine and generator are turned off, only the electric motor is operating (whose power is negative, as it operates as a generator), which charges the battery with the electric energy created by braking.

The result of HEV simulation during driving in a city (HEV speed) is given in Fig. 8.

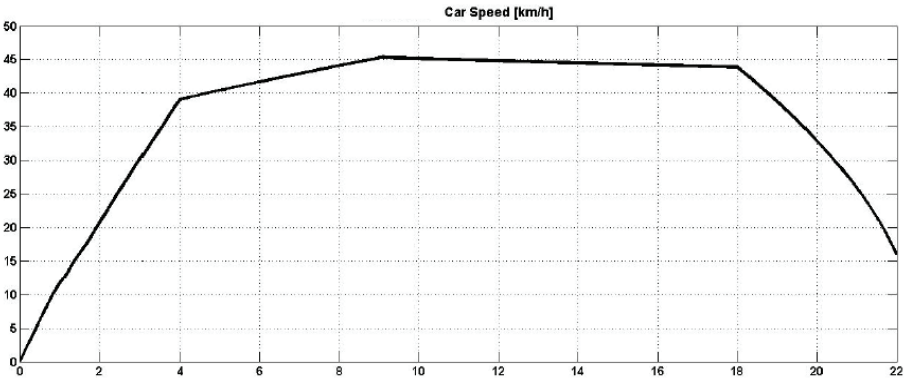

Figure 8 HEV speed diagram

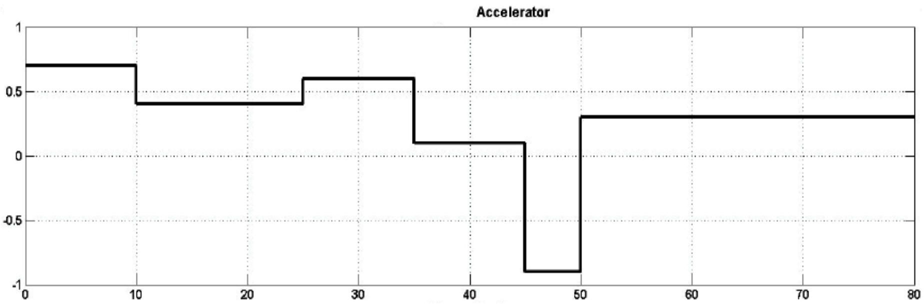

Figure 9 Diagram of accelerator

3.2 Simulation of combined HEV in driving on an open road

Simulation of combined HEV in driving on an open road was done for accelerator pedal as in Fig. 9 and for road angle given in Fig. 10. With thus specified input, maximum HEV speed is 120 km/h (Fig. 12), which corresponds to driving on a highway. All specified and obtained diagrams depend on simulation time, and the duration of this simulation is 80 seconds.

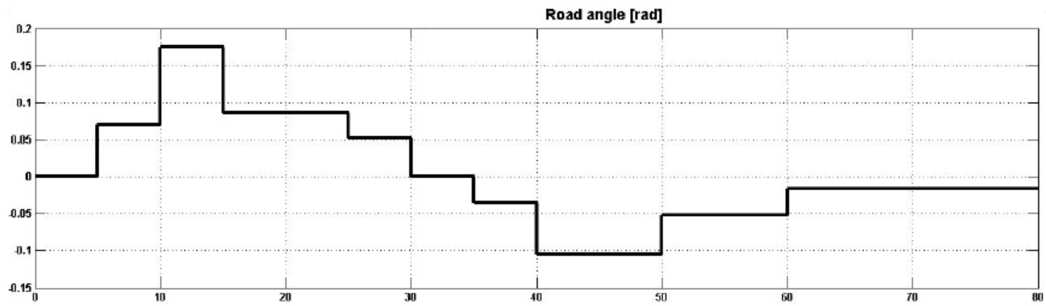

Figure 10 Diagram of road angle given

Fig. 11 shows HEV modes of operation in driving on an open road. Fig. 11 shows that transitional modes of this simulation in times are: t_1 = 0,77 s; t_2 = 8 s, t_3 = 45 s and t_4 = 50 s.

In t_0 = 0 s, HEV is moved by pushing the accelerator pedal 70 % (first 10 seconds). As long as the required power of HEV is less than 15 kW and speed less than 20 km / h, HEV is moved by the electric motor powered by battery. Then the generator and IC engine are turned off (they do not give power to HEV). HEV is in start mode then.

In t_1 = 0,77 s, the required power of HEV becomes higher than 15 kW, which requires hybrid mode of operation (HEV power comes from the IC engine and electric motor that is powered from the battery). HEV is in acceleration mode. The power of the generator is negative then, which means that the generator is operating as a motor and it provides power required to start the IC engine. Road angle for the first five seconds is 0 rad.

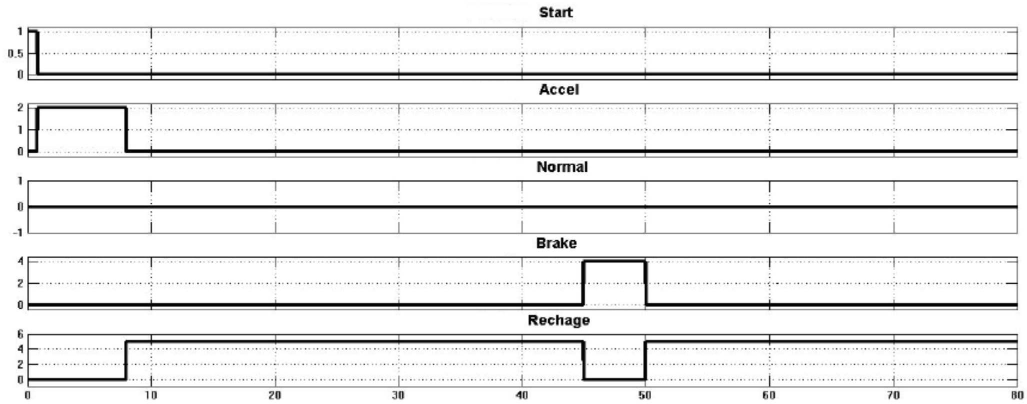

Figure 11 Diagram of complete cycle (mode) of HEV

In $t_2 = 8$ s, the state of battery charge – SOC becomes lower than 40 % (at the beginning of the simulation it was 42,52 %), so the battery needs to be charged and HEV operates in charging mode. The electric motor is not working then, and the power of IC engine is divided between differential (that moves the wheels) and generator (that charges the battery). In this mode, the power of the battery is negative, which means that the battery receives certain amount of power from the IC engine, through the generator, and it is being charged as the HEV moves. From the fifth to the thirtieth second, HEV movement was simulated on the incline with different road angle, so due to this, pressure on accelerator pedal is reduced to 40 % (because the gear is thus reduced, as well), so that HEV could overcome the given incline.

In $t_3 = 45$ s, regenerative braking is simulated, HEV operates in braking mode (in this simulation, braking is specified by negative value of acceleration pedal of -90 %). As from 35th second until the end of simulation the movement of HEV on the decline with different angle road was simulated, braking that lasts five seconds does not reduce the HEV speed, but it only prevents its rapid increase (the speed was increased by approximately 5 km/h). The IC engine and the generator are turned off, only the electric motor is operating (whose power is negative, as it works as a generator), which charges the battery by the energy created by braking (that is why the battery power is negative).

In $t_4 = 50$ s, the battery is charged with electricity from the generator until the end of the simulation, because currently the battery is 57 % charged (less than 80 % of full charge), so HEV operates in charging mode. The electric motor does not operate then and the power of the IC engine is divided between the differential (that moves the wheels) and generator (that charges the battery). Until the end of the simulation, the accelerator pedal is constantly kept at 30 % and the speed of 120 km/h is achieved, which is constant from the 60th second to the end of the simulation.

The result of the HEV simulation in driving on an open road (HEV speed) is given in Fig. 12.

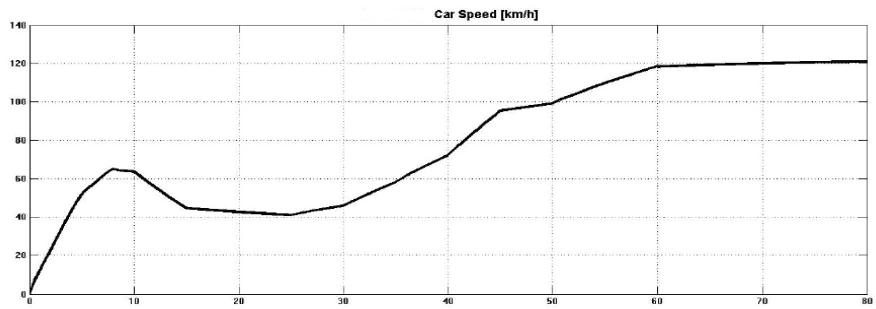

Figure 12 HEV speed diagram

4 Conclusion

In this paper, results of the simulation of a model of combined HEV faithfully describe vehicle Toyota Prius in driving in a city and driving on the open road. Also, HEV simulation provides the ability to monitor the output parameters of HEV (speed, acceleration, power, number of revolutions, state of battery charge etc.) depending on the changes of the input parameters (the accelerator pedal and the road angle). This possibility of simulation can produce significant financial savings in the automotive industry, as it reduces the need for laboratory testing of hybrid electric vehicle in its development stage and gives the possibility to simulate different vehicle versions until the best one is chosen.

Acknowledgements

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