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The optimization of the driving power distribution between power units of the HEV powertrain based on the velocity profile

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One of the main advantages of a Hybrid Electric Vehicle (HEV) is the possibility to control flow of the power distribution between vehicle power units especially in case of recuperation energy mode. In general, the power distribution can be controlled independently on the vehicle velocity and current state of the other vehicle power units, but with respect to physical limits and other boundaries. The HEV is designed from two main power circuits – driving power circuit and the thermal power circuit [1]. Both of mentioned circuits can be in general independent from energy flow point of view and the same from the control point of view, but the specific and most important advantage of HEV is also connecting driving power circuit and thermal power circuit on both points of view. By the energy connecting of both circuits is possible to recuperate the waste thermal energy especially from ICE cooling circuit to the cabin heating. The cabin heating requirement or vehicle engine and battery preheating requirement can be also powered directly from recuperation electric energy. The presented heating and preheating requirements open the new way for smart control all type of energy flow between each energy units, especially if it is vehicle velocity profile known in advance.

The presented control process can be provided by ordinary type of controller for example by PID controller in feedback control, it can be provided by the higher level of controller, for example by the predictive control strategy with chosen value of predictive horizon and in the highest level, it can be provided by the previous optimization of the energy flows for all considered route. The task defined by this idea can be one part of the whole optimization problem focused on the optimization the total energy consumption on the primary energy sources (vehicle battery and fuel tank). The presented whole optimization problem may be designed for example in two steps. In the first step is optimized the vehicle velocity profile and subsequently in the second step will be optimize the internal energy flows. The value of total energy consumption is calculated in the objective function for lower optimization level with respect to define velocity profile obtained from higher optimization level. The contribution presented on the next lines is focused on the concept for optimization energy flow between vehicle power unit with respect to given vehicle velocity profile.

The basis for optimization task is define the possibilities how to control energy flows between each power units based on individual concept of the vehicle powertrain and in the second line the possible energy inputs and its distribution control. The first presented category is directly fixed on the vehicle powertrain concept. For example for the parallel hybrid powertrain concept is possible to considered energy flow into the motors controlled independently. The vehicle energy inputs also directly depends on vehicle powertrain design, for example for plug-in hybrid powertrain (PHEV) is possible to considered two external inputs – electric energy and gasoline and the additional source can be considered recuperation possibilities depends on specific route properties. The vehicle battery is possible charged from external and internal sources, whereas for basic type hybrid powertrain (HEV) without external charging connection is possible battery charging only from internal sources. This introduced properties is most important for energy flow control, because the battery state of charge have to be kept on requires level in both cases, but in the case of PHEV is possible to powered the vehicle only on ICE without forced charging and in second one it is not possible [2]. If it will be considered the case of PHEV powertrain, the most important energy flow for optimization is power dividing between each vehicle motors. The power ratio between each motors can be define by parameter *U* based on the power requirement on the vehicle wheels. The *U*-parameter is given by following power equilibrium equation

$$
\begin{aligned}
P_{source}\left(U_{(t)}, t\right) &= P_w + P_{HVAC\ ICE} + P_{loss\ EM} + P_{HVAC\ el} + P_{aux} \\
&= \frac{1}{\eta_{gear}} \cdot [(1-U) \cdot P_W + U \cdot P_W] + \frac{1}{\eta_{ICE}} \cdot (1-U) \cdot P_W + \frac{1}{\eta_{EM}} \cdot U \cdot P_W \\
&+ P_{HVAC\ el} + P_{aux}
\end{aligned}
$$

where P_W represents driving power on the vehicle wheels, $P_{HVAC\ ICE}$ represents the loss power from ICE, $P_{loss\ EM}$ represents loss power from electric motor, $P_{HVAC\ el}$ represents the electric power input to the cabin heating, if it is considered and P_{aux} represents the power of auxiliary units, like vehicle lights etc.

The other energy flows is controlled with respect to introduced parameter *U* by the conventional controllers with respects to following preferences.

a) The temperature of ICE have to be achieved in the shortest time (the cabin heating is possible only by electric heating unit)
b) The cabin is primarily heating by energy losses from ICE to the cooling system

The presented method have been used for optimization the *U*-parameter at the testing route and chosen velocity profile and the result of this test is shown in following Fig. 1.

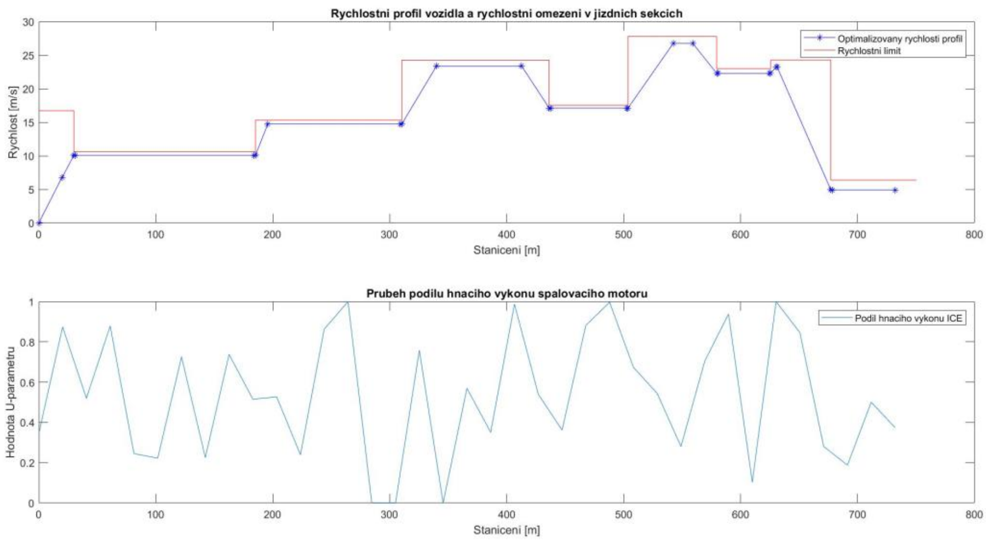

Fig. 1. Optimal velocity profile (above) and *U* parameter result (below)

The cabin heating has been controlled by basic PID controller that the controller constants have been settings by MATLAB control settings tool.

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References

[1] Denk, P., Šika, Z., Steinbauer, P., Macek, J., Morkus, J., Mathematical model of the Hybrid Electric Vehicle for driving consumption optimization, Proceedings of the 33rd conference Computational Mechanics, Špičák, 2017.

[2] Denk, P., Šika, Z., Steinbauer, P., Macek, J., Morkus, J., The study of possibilities towards to extending the Hybrid Electric Vehicle mathematical, Proceedings of the 34th conference Computational Mechanics, Srní, 2018.