Institute for Design and Control of Mechatronical Systems

Power In Motion ROTAX BRP

Diploma Thesis

Simulation of Hybrid Electric Recreational Vehicles

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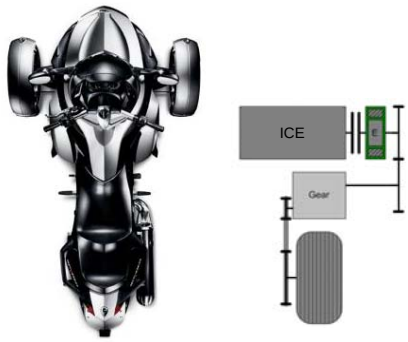
Abstract

In this thesis, the potential of a hybrid electric three-wheeler compared to three different combustion propelled models is studied. The thesis first explains the development of a vehicle simulation model of the existing vehicle with a conventional internal combustion engine (ICE) realized with Matlab® and Simulink®. After alignment with measured data this simulation model was adapted to two future ICE propelled models. Then the extension to the hybrid electric model is described. Studying the potential of a hybrid electric propulsion system requires a complex energy management to fully use the possible efficiency benefits. Hence, development and optimization of an operating strategy are an essential part of this thesis. Analysis of the simulation results leads to the comparison of technologies while the key points of interest are fuel consumption in world motorcycle test cycle (WMTC) and driving performances. Finally the simulation results show a high potential of the hybrid electric model as it consumes 19% less fuel than the reference model equipped with the identical internal combustion engine while it has better acceleration and top speed.

Introduction

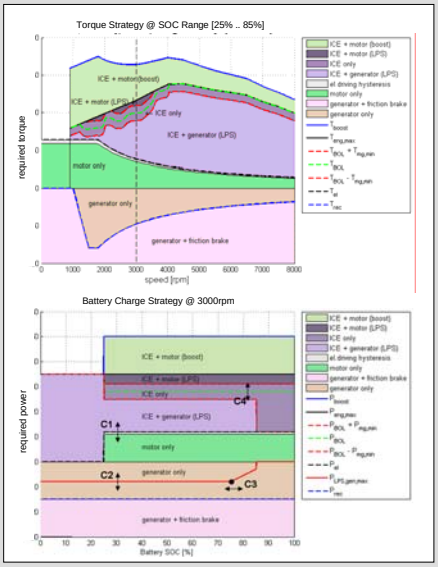


Configuration of the hybrid electric three-wheeler

Vehicle Specifications

- Vehicle: rear-wheel driven 3-wheeler, 398kg dry weight (HEV)
- Engine: 4-stroke gasoline engine
- Motor/Generator: permanent magnet synchronous machine (PSM)
- Battery: LiFePO4, 300V / 6.9Ah / 2.05kWh

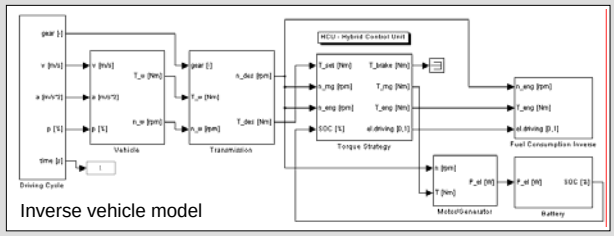
Operating Strategy and Optimization



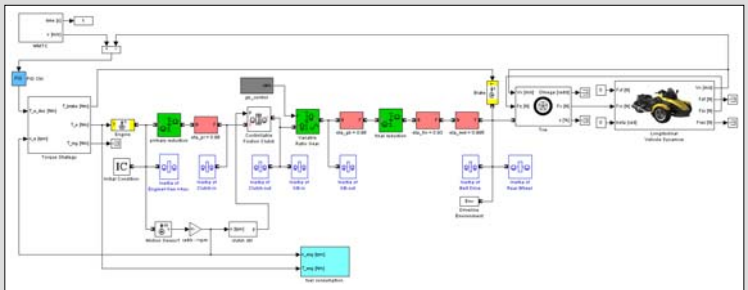
- Operating strategy adapted to power train characteristics
- Minimization of cost function *e* by variation of the parameters C1 – C4
- Cost function *e* considering (i.a.):
  - Low fuel consumption in WMTC
  - Balanced battery SOC
  - Limitations due to PSM
- Weight factors k1 – k6 to define the priority of the different components of *e*

$$
\begin{aligned}
e &= k_1 \cdot FuelCons \\
&+ k_2 \cdot (dSOC)^2 \\
&+ k_3 \cdot (I\_bat)^2 \\
&+ k_4 \cdot lowSOC \\
&+ k_5 \cdot EM\_lock \\
&+ k_6 \cdot EM\_hot
\end{aligned}
$$

Simulink Models



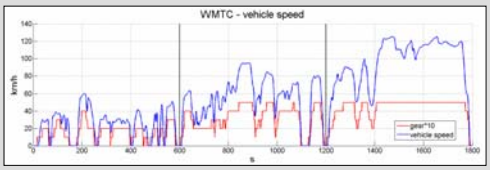
Inverse vehicle model

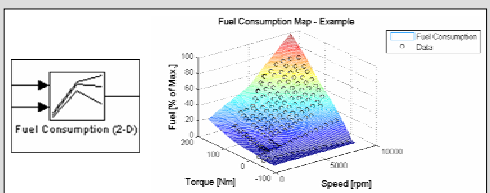


Closed-loop vehicle model using Simscape

Simulation of Fuel Consumption

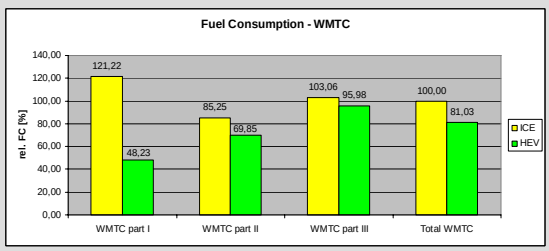
Based on the World Motorcycle Test Cycle (WMTC)



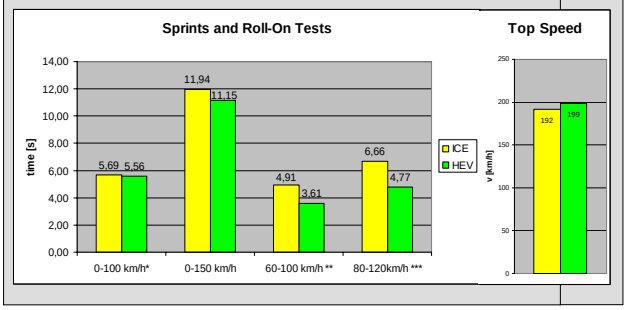


Determination of fuel consumption

Results – Fuel Consumption

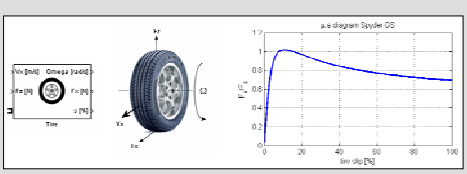


Results – Driving Performance



Simulation of Driving Performance

- Dynamic tire model
- Traction break during gear shifting
- Vehicle dynamics including dynamic weight distribution



Conclusions

In the proposed diploma thesis a hybrid electric Can-Am Spyder GS in parallel configuration is presented. The three-wheeler is equipped with an 4-stroke gasoline engine combined with a PSM and a 6-speed manual gearbox. Electric energy is stored in a 2kWh LiFePO4 battery which ensures an electric driving range of 20 kilometers. The vehicle is studied with two key points of interest: fuel consumption based on a defined driving cycle and driving performance which consists of acceleration and top speed. A conventionally driven vehicle with the same ICE is used as a benchmark in comparison of the simulation results.

Vehicle simulations performed with Matlab Simulink show some significant differences of the HEV compared to the reference model:

- Significantly decreased fuel consumption (-19% in the WMTC)
- Better driving performance:
  - Higher top speed
  - Faster at sprints tests
  - Significantly faster at roll-on tests

Besides those advantages one must not forget the disadvantages of the hybrid electric 3-wheeler:

- Increased weight (+ 50kg)
- Increased system complexity (additional degrees of freedom due to the electric propulsion unit)
- Highly increased costs, mainly due to expensive battery

Outlook

- Verification of the simulation results by building and testing a vehicle prototype
- Alternative power train configurations:
  - Power-split hybrid
  - Series hybrid
- Alternative transmission layout:
  - Automatic transmission
  - Continuous variable transmission (CVT)
- Thermal studies of the electric components
- Alternative vehicles to be used as a HEV:
  - Quad & ATV
  - Skidoo, Seadoo