Influences of different heating concepts for the energy demand of an airfield luggage tug

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I. Motivation

The advantages of battery electric vehicles (BEV) like good overall energy usage, no local emissions and reduced noise are well known. On the other side there are also disadvantages like a dramatic loss of range caused by thermal management of the driver cabin or long recharging times. In [1], the influence of different environmental conditions on the energy demand of a commercial electric car was disclosed. It was shown that the overall energy consumption was increased up to 50 % for winter conditions (heating), and 30 % for summer conditions (cooling). A combined range extender system based on a high temperature polymer electrolyte fuel cell was proposed in [2]. It allows both, to recharge the traction battery on board as well as optimized thermal management using waste heat for conditioning the driver cabin. Besides the raise of range, energy density and storage ability of hydrogen are decreasing the downtime of BEVs dramatically. Unfortunately, hydrogen filling stations are currently not widely available. The amount of 400 public refilling stations are planned up to 2023 in Germany. One way to hasten market penetration of fuel cell powered propulsion systems is to focus on local closed areas, e.g. airports. The advantages of being local emission free (e.g. driving in closed buildings, reducing air pollution, noise), the high amount of vehicles and a high operating time are predestined using fuel cell powered propulsion systems. In a project funded by the German government, DLR, Bosch and others are upgrading a BEV luggage tug (Figure 1) to a fuel cell vehicle (FCV) with a fuel cell based on board charging system.

Figure 1: airfield luggage tug Mulag Comet 3E – BEV

The electric airport luggage tug (BEV) weighs around 4000 kg and is powered by a 31 kW_{peak} electric engine. Energy is stored in a 48 kWh conventional lead acid battery working at 80 V. For cold environmental conditions and safety purposes, an electric 1.5 kW PTC-Heater is integrated in the luggage tug to heat the drivers cabin and avoid windshield fogging. In the upgrade, the BEV is rebuilt to a FCV with 8 kWh Li-Ion battery and 20 kW low temperature polymer electrolyte membrane fuel cell (PEM-FC). The aim is to study the energy saving potential of fuel cell thermal management using a virtual luggage tug model created in Dymola.

Table 1: Parameters of Comet3E– BEV

Weigh	$E_{Bat,BEV}$	$P_{mot,max}$	v_{max}	P_{PTC}
4000 kg	48 kWh	31 kW	30 km/h	1.5 kW

II. STRATEGY

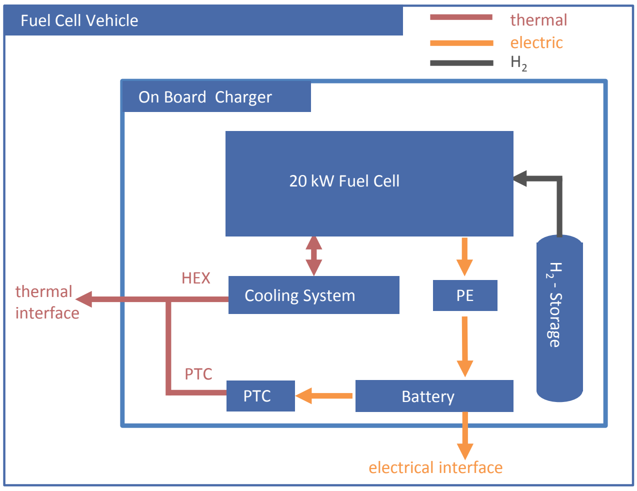

Figure 2: Heating Possibilities of Comet 3E–FCV

Beside the possibility using a PTC–Heater powered from the rechargeable Li-Ion battery, a PEM-FC as an on board charging device generates two alternative heating abilities (Figure 2). One possibility is the usage of waste heat generated by the fuel cell while battery charging via the power electronics (PE in Figure 2). The heat of the stack dissipates to the primary fuel cell cooling system and to the cathode air outlet. Integrating a cabin heat exchanger (HEX) in the primary cooling system leads to the possibility to heat the driver cabin. Another way is mixing the cold air temperature with hot, wet cathode air for preheating. The limiting aspect is the condensation of humid air on cold indoor surfaces. That leads to the possibility of three different heating strategies for the luggage tug which have to be calculated and compared using a suitable simulation model.

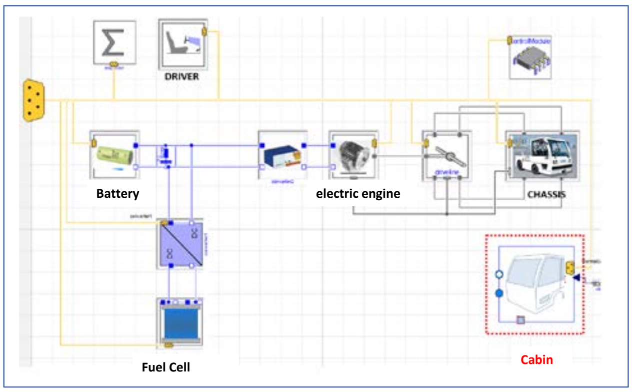

Figure 3: Simulation Model of Comet 3E–FCV based on Modelica - AlternativeVehicles Library [1]

A virtual model of the baggage tug is created using the Modelica Library "AlternativeVehicles" developed by the Institute of Vehicle Concepts at the German Aerospace Center. It contains predefined, parametrized models of the Li-Ion battery, powertrain, and a chassis representing the luggage tug shown in Figure 3 [1]. In order to map the thermal energy flows, a new, energetic representative model of the drivers cabin has to be created and validated based on different heating measurements according to DIN 1946-3 [2]. The widely used standard driving cycles New European Driving Cycle (NEDC), Artemis or WLTP are not suitable. A new benchmark cycle has been created tracking a baggage tug on the airfield in Stuttgart shown in Figure 4. In Table 2 are the main characteristics of this driving cycle.

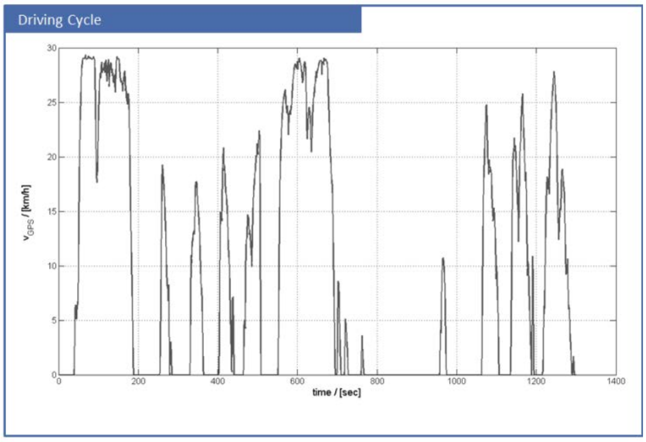

Figure 4: Created driving cycle for the baggage tug

Table 2: luggage tug driving cycle

time	length	v_{max}	v_{mean}	idletime
1300 s	3.2 km	30 km/h	17.8 km/h	50 %

III. RESULTS

To validate the simulation model, a heating test (Figure 5) of the luggage tug drivers cab was performed at minus 10 °C in the climate chamber of DLR Institute of Vehicle Concepts. The amount of 12 temperature sensors were mounted at the footwell (8 Sensors) and headrest (4 Sensors) to verify the simulation model. The difference was ascertained to -2 °C in the footwell and +2 °C in the headrest while having a good agreement on average temperature. More details will be presented in the final paper.

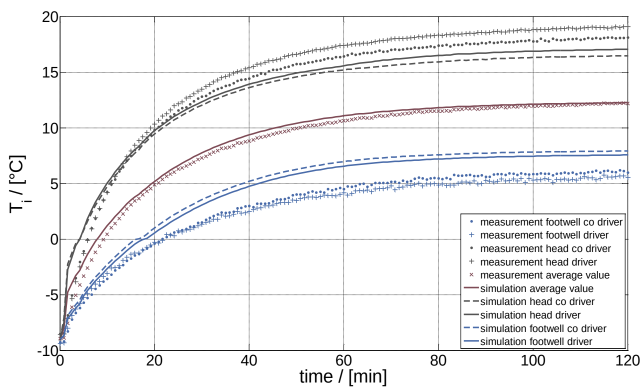

Figure 5: left: Model validation at Tamb = - 10 °C

Table 3: Boundary conditions

t_{Sim}	8 h
$T_{Ambient}$	-10 °C
$E_{Bat,FCV}$	8 kWh
P_{FC}	20 kW
m_{H2}	3 kg
SOC_{Start}	<0.3
SOC_{End}	>0.8
P_{PTC}	1.5 kW
kA_{HEX}	200 W/K
$V_{Storage}$	60 l

To compare the heating strategies mentioned in Figure 2, the boundary conditions in Table 3 were used. All simulations refer to the created driving cycle. For all calculations a working time of 8 hours was assumed at an ambient temperature of -10 °C. The 20 kW electric fuel cell was coupled to a 3 kg hydrogen storage. It starts to reload the 8 kWh Li-Ion battery while dropping State of Charge (SOC) under 0.3 and finishes after reaching SOC_{End} = 0.8. The maximum power of the PTC–Heater was set to 1.5 kW, the heat transfer coefficient of the cabin heat exchanger (HEX) was set to a value of 200 W/K. The evaluation of the cathode exhaust air was carried out over dew point in the vehicle cabin. It turned out that must occur at the latest after 6.5 minutes fuel cell operation window fogging. The concept is therefore unsuitable for cabin air conditioning. More details will be presented in the final paper. In a further case study, a 60 liter enthalpy storage system concept was additional integrated to the primary cooling system of the fuel cell (Figure 6).

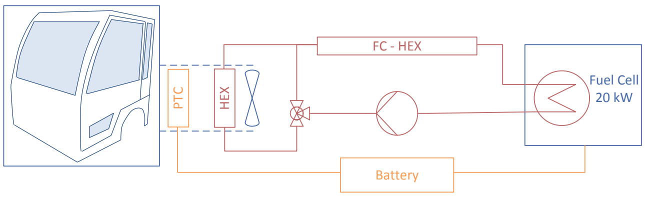

Figure 6: Proposed thermal management system including HEX, PTC and sensible heat storage

An energy demand of 11.9 kWh was calculated to drive the luggage tug on the driving cycle. Taking into consideration the PTC heating demand of BEV and FCV, additional 12 kWh of energy are needed to heat the driver cabin up to an average temperature of 6 °C. Using FCV with only a cabin heat exchanger (HEX), just 5 kWh of thermal energy can be used. That leads to an average cabin temperature of -2 °C. Using a PTC and HEX in the FCV, the total amount of 18.7 kWh thermal energy is available to heat the driver cabin up to an average temperature of 15 °C. The combination of PTC and HEX nearly doubles the amount of waste heat available from the fuel cell because of a higher average energy demand caused by the PTC what led to smaller recharge intervals of the Li-Ion battery. The integration of a 60 liter sensible enthalpy storage rises the available thermal heat dissipated from the fuel cell energy in the primary cooling system up to 16 kWh. Due to this the driver cabin can be heated up to an average of 21 °C. The energy demand of the PTC can be reduced to 5.6 kWh while just adding 1.2 % additional weight on the luggage tug. The electric energy saving potential for heating the cabin using an enthalpy heat storage system is approximately 50 %, compared to the BEV or FCV with PTC only.

Table 4: Simulation results at $T_{Ambient}$ = -10°C

	A: PTC	B: HWT	C: PTC+HWT	D: PTC+HWT+60l
$P_{PTC,mean}$	1.5 kW	--	1.1 kW	0.6 kW
$P_{HEX,mean}$	--	0.75 kW	0.8 kW	1.35 kW
E_{PTC}	12 kWh	--	8.8 kWh	4.8 kW
E_{HWT}	--	6 kWh	6.4 kWh	10.8 kWh
$T_{cab,mean}$	11 °C	1 °C	18 °C	19 °C

IV. References

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[3] T. Braig, H. Dittus, J. Weiss-Ungethüm, T. Engelhardt: "The Modelica Library "Alternative Vehicles" for Vehicle System Simulation", SNE Simulation Notes, 2012.

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