Using a Traction Battery as Thermal Storage

The driving range of electrical vehicles decreases significantly at low outside temperatures. In order to reduce the dependency of the driving range on the ambient conditions, the partners Denso, Fraunhofer LBF, ika of RWTH Aachen University and the Virtual Vehicle Research Center work on a solution in the Optemus project consisting of a battery system and a compact compact refrigeration unit, capable of using thermal energy stored in the battery as a heat source.

DRIVING RANGE PROBLEMS OF ELECTRICAL VEHICLES

Current EVs have the problem of a strongly varying driving range depending on the ambient conditions. At winter conditions and the use of resistance heating the driving range can drop by 50 %. The use of the refrigerant cycle as heat pump is a promising solution for this issue.

In the EU-funded research project Optemus the partners Denso, Fraunhofer LBF, ika of RWTH Aachen University and the Virtual Vehicle Research Center as project coordinator are developing a solution with a compact refrigeration unit, which enables the use of different heat sources. Because of its high mass the traction battery has also a high thermal capacity. Thus, a concept for the usage of the lithium-ion battery as thermal storage was developed in the project. In combination with a predictive preconditioning functionality, which considers for instance the departure time as well as the expected weather conditions, the battery can be tempered adequately. The stored heat can then be used by the heat pump system for the heating of the cabin, which is much more efficient than resistance heating and thus increases the driving range.

COMPACT REFRIGERATION UNIT

The Compact Refrigeration Unit (CRU) from Denso, Figure 1, is a water-to-water system that consists of a compressor, two heat exchangers and an Expansion Valve (EXV) in the same housing, [1]. On the evaporator (chiller) side, heat is withdrawn from the coolant circuit and transferred to the coolant that flows through the condenser. The two emerging temperature levels can be used for the thermal management in the vehicle, that means the cold and hot coolant can be redirected by means of valves in the vehicle in order to combine heat sources and heat sinks in an energy efficient way.
This system enables heat pump operation mode, where electric components as well as the battery are cooled and this heat is used for heating up the passenger cabin. If there is the demand to heat the battery and the cabin, the ambient air can be used as heat source. Also for cooling mode this system enables the appropriate combination of heat sources and heat sinks in the vehicle.

**BATTERY WITH PCM AND THERMALLY INSULATED HOUSING**

The performance of state-of-the-art lithium-ion traction batteries is significantly lower at low as well as high temperatures. A battery temperature of 0 °C results in a 20 % decrease of battery efficiency compared to a battery temperature of 20 °C [2]. The battery concept developed at ika, transfers heat over the system boundary via a water-glycol cycle, which enables for heating and cooling of the battery. To improve the thermal stability of the battery and to enhance the thermal capacity of the battery, a special Phase-change Material (PCM) is used inside the battery modules. **FIGURE 2** shows a schematic layout of such a battery module.

The Optemus battery module consists of 144 lithium-ion cells of the type 18650. The resulting empty spaces between the cells are filled with PCM. To ensure an equal temperature distribution, all cells stand upright on a common cooling plate, which was flow optimized using 3-D simulation.

Between 35 to 15 °C battery temperature, 1.7 kWh of heat can be transferred into the water-glycol cycle with a maximum heat transfer rate of 1.9 kW. The maximum heat transfer rate is limited by the thermal conductivity of the PCM, which is increased by 400 %, due to the addition of boron nitride particles, while maintaining the same level of electrical insulation [3]. In addition, the thermal contact of the PCM could significantly be improved, due to the installation of copper pins. **FIGURE 3** shows the temperature distribution inside the battery module at the end of a 15-min charge at maximum charging rate, which results in a heat generation of 0.83 W/cell. The initial temperature of the battery was 25 °C, during the entire charge the cooling plate temperature was maintained at a constant 15 °C.

Due to the improved thermal contact of the PCM the maximum axial temperature difference of the cells as well as the average cell temperature inside the battery module is significantly lower. In further simulations, ika proved that even without cooling the Optemus battery is capable of absorbing the total amount of heat, dissipated during a fast charge at room temperature, without reaching critical temperatures or temperature gradients.

**FIGURE 1** Compact refrigeration unit from Denso in the vehicle (© Virtual Vehicle)
In order to optimally use the thermal storage capabilities of the module for preconditioning, a thermally insulated housing was developed, FIGURE 4. It is based on an integral polymer foam serving essentially as thermal insulation. The foam is enhanced with high strength facesheets made of continuous fiber reinforced thermoplastics (TP-FRP) resulting in a sandwich structure. The latter is manufactured using a novel hybrid process based on foam injection moulding technology.

An experimental test series was conducted in order to analyze the thermal insulation of the novel housing. Therefore an aluminum housing as reference as well as a TP-FRP sandwich housing have been manufactured. Battery sub-modules have been built-up with both housings including 40 round cells of the 18650 type, two of which have been equipped with temperature sensors. It could be shown that at an ambient temperature of -10 °C the cooling rate of preconditioned cells from 23 to 2 °C was reduced by 250 % by using TP-FRP sandwich housings instead of aluminum housings thus significantly increasing thermal insulation.

**PRECONDITIONING**

The preconditioning of an electric vehicle offers two essential advantages: Firstly, the comfort is improved because the passengers do not enter into a cold or hot cabin; secondly, the drop of electric range is reduced by lowering of the compressor power when entering or driving of a non-conditioned vehicle. The preconditioning can also be applied to the battery to achieve an optimal battery temperature when driving away, especially in cold winter conditions, which improves the electric range and...
the battery life. In addition, the heat stored in the battery can also be used for heating the vehicle cabin, as already mentioned.

To enable an efficient thermal preconditioning of the cabin of electric vehicles, Denso has developed an innovative solution that offers maximum comfort to the user with low energy consumption and increases the range of the vehicle [1]. The challenge is to find the optimum time to start the vehicle’s preconditioning (heating or cooling of the cabin room) without significantly reducing the range of the vehicle (if the vehicle is not connected to a charging station). For this purpose, both a user-triggered (by means of an app) and a predictive algorithm have been developed, which foresees the driver behavior (approach to the vehicle) to ensure the timely preconditioning of the cabin room upon arrival of the driver.

As shown in Figure 5, the user can control the preconditioning functionality with an app that communicates with the vehicle’s human machine interface (HMI) through a cloud server. The HMI sends the required information to the thermal management ECU (TMECU) through the CAN bus gateway (GW). After this, the high-level controller starts the optimized preconditioning process to reach the desired target temperature in the cabin room upon arrival of the driver.

**SIMULATION RESULTS**

To quantify the impact of the described technologies on the energy need and the driving range, four different scenarios of passenger cabin heating at -10 °C ambient temperature are compared by means of simulation: In case 1 a PTC heater heats up the passenger cabin from -10 °C, in case 2 the passenger cabin is preconditioned to 20 °C during battery charging. In case 3, the preconditioned passenger cabin is heated by the compact refrigeration unit, using the ambient air as heat source (average COP = 1.1) and in case 4 the battery is used as heat source (average COP = 2.1). Figure 6 shows that during the 30 min of the Aachen Driving Cycle at either starting temperature, the cabin heating initially operates at full load, due to its control strategy. For the preconditioned cabin, the heating control reduces power significantly earlier, which reduces the energy consumption from 2.06 kWh to 1.18 kWh. The use of the CRU enables for additional energy savings: using the ambient air as heat source reduces the energy consumption to 1.07 kWh, using the battery as heat source further reduces the energy consumption significantly to 0.56 kWh, Figure 6 (top right). For the simulated A-segment vehicle this leads to an increased driving range from 103 km (case 1) to 108 km for case 2 (+5 %), to 111 km for case 3 (+7 %), to 117 km (+13 %) in case 4, when all technologies are applied.
CONCLUSIONS AND OUTLOOK

The use of the compact refrigeration unit in combination with a battery with integrated PCM as heat storage enables together with preconditioning of the battery and the cabin a significant reduction of the energy consumption during driving. Simulation results for a 30-min drive in heating mode at low outside temperatures (-10 °C) show a reduction of 1.5 kWh, which leads to an extension of the driving range by 14 km (+13 %) for an A-class vehicle. The next steps are a further optimization of the battery cooling loops as well as a reduction of the coolant volume (for example with the help of dry battery modules with a common cooling plate).

REFERENCES

[1] Caldevilla, A.; Özbek, M.; Hünemöder, W.; Györög, T.; Hougard, E.; Pintea, M.: Efficient cloud-based cabin preconditioning for EVs with a compact heat pump system. EVS30 Symposium, Stuttgart, October 2017
[2] Kontinuierliches Design und Funktions-Benchmarking von Elektrofahrzeugen. Online: https://benchmarking.fka.de, access: February 28, 2017
[3] Mimberg, G.; Massonet, C.: Battery concept to minimize the climate-related reduction of electric vehicles driving range. 12th International Conference on Ecological Vehicles and Renewable Energies (Ever), Monaco, April 2017

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