Determining an energy-optimal thermal management strategy for electric driven vehicles

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Abstract

In electric, hybrid electric and fuel cell vehicles, thermal management may have a significant impact on vehicle range. Therefore, optimal thermal management strategies are required. In this paper a method for determining an energy-optimal control strategy for thermal power generation in electric driven vehicles is presented considering all controlled devices (pumps, valves, fans, and the like) as well as influences like ambient temperature, vehicle speed, motor and battery and cooling cycle temperatures. The method is designed to be generic to increase the thermal management development process speed and to achieve the maximal energy reduction for any electric driven vehicle (e.g., by waste heat utilization). Based on simulations of a prototype electric vehicle with an advanced cooling cycle structure, the potential of the method is shown.

Kurzfassung

In Elektro-, Hybrid- und Brennstoffzellenfahrzeugen kann das Thermomanagement zu einer deutlichen Verringerung der Fahrzeugreichweite führen, was optimale Thermomanagementstrategien erforderlich macht. In diesem Aufsatz wird eine Methode vorgestellt, die es ermöglicht, eine energieoptimale Strategie zur Erzeugung der benötigten thermischen Leistung zu bestimmen, wobei alle Komponenten (Pumpen, Ventile, Lüfter usw.) und Einflüsse, wie die Umgebungstemperatur, Fahrzeuggeschwindigkeit, Motor- und Batterietemperatur sowie die Kühlkreislauftemperaturen berücksichtigt werden. Die Methode ist allgemein formuliert, um den Entwicklungsprozess für beliebige elektrisch angetriebene Fahrzeuge zu beschleunigen und dabei eine maximale Energieeinsparung zu erreichen (z. B. durch Abwärmenutzung). Basierend auf Simulationen von einem Versuchsfahrzeug mit einem komplexen Kühl- und Heizsystem wird das Potenzial der Methode aufgezeigt.

1. Introduction

Modern batteries with high specific energy require a thermal management system to ensure safety, efficiency and lifetime requirements [1–3]. Especially lithium-ion batteries in high-power applications with wide operating temperature range and wide range of climate conditions, like in electric drive vehicles, can be destroyed or thermal runaway can occur if the temperature is not controlled within the operating limits. Additionally, optimal efficiency and lifetime can only be achieved if the battery temperature is held within a narrow range [1].

Electric vehicles may require an active thermal management system with liquid cooled

Figure 7: Traction system and charger cooling at different ambient temperatures.

The method was analyzed over a wide range of condition values. The results imply that the control strategy does not change within large regions of conditions. Therefore, it can be concluded that taking into account a single time step for thermal power generation leads to a near-optimal solution, because the following steps start with conditions leading to the same or very similar control strategy until a new region is reached.

5. Conclusion

In this paper, a method to determine the energy-optimal control strategy for vehicle thermal management has been described. By transforming the single-stage decision with a large amount of possible combinations into a multi-stage decision, the computation effort is reduced. The simulation results provide the different regions of possible control strategies at all conditions (ambient temperature, traction system temperature, . . .) to get the minimal energy consumption for given thermal power requests of the battery, the cab and the traction system. This automatically implies optimization approaches as waste heat utilization and the optimal choice between passive fan cooling and active refrigerant cycle cooling. Based on a prototype setup of an electric vehicle, the reliability of the method has been shown. In future work the method will be tested on a real prototype considering additional control values (e.g., recirculation air/outdoor air) and the heat losses of the cooling cycle pipes.

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