Modeling and Design of Hybrid PEM Fuel Cell Systems for Lift Trucks

Reducing CO₂ emissions is getting more attention because of global warming. The transport sector which is responsible for a significant amount of emissions must reduce them due to new and upcoming regulations. Using fuel cells may be one way to help to reduce the emissions from this sector. Battery driven lift trucks are being used more and more in different companies to reduce their emissions. However, battery driven lift trucks need a long time to recharge and thus may be out of work for a long time. Fuel cell driven lift trucks diminish this problem and are therefore getting more attention. The most common type of fuel cell used for automotive applications is the PEM fuel cell. They are known for their high efficiency, low emissions and high reliability. However, the biggest obstacles to introducing fuel cell vehicles are the lack of a hydrogen infrastructure, cost and durability of the stack. The overall aim of this research is to study different fuel cell systems and find out which system has the highest efficiency and least complexity. This will be achieved by modelling and optimizing the fuel cell system followed by some experimental tests. Efficiency of the stack is about 50%. But efficiency of the whole system is less than this value, because some part of the electricity produced by the stack would run the auxiliary components. This work deals with the development of a steady state model of necessary components in the fuel cell system (humidifier, fuel cell stack and ejector), studying different system configurations and optimizing the operating conditions in order to achieve the maximum system efficiency.

A zero-dimensional component model of a PEMFC has been developed based on polynomial equations which have been derived from stack data. The component model has been implemented at a system level to study four system configurations (single and serial stack design, with/without anode recirculation loop). System design evaluations reveal that the single stack with a recirculation loop has the best performance in terms of electrical efficiency and simplicity. To further develop the selected system configuration, the experimental PEMFC model is replaced by a zero-dimensional model based on electrochemical reactions. The model is calibrated against available stack data and gives the possibility of running the system under the operating conditions for which experimental data is not available. This model can be used as a guideline for optimal PEMFC operation with respect to electrical efficiency and net power production. In addition to the optimal operation, investigation of different coolants and operating conditions provides some recommendations for water and thermal management of the system.

After theoretically analyzing the system, there more attempts to improve the anode recirculation loop, basically by using an ejector instead of a recirculation pump. The CFD technique has been used to design and analyze a 2-D model of an ejector for the anode recirculation of the PEMFC system applied in a fork-lift truck. In order for the ejector to operate in the largest possible range of load, different approaches (with fixed nozzle and variable nozzle ejectors) have been investigated. Different geometries have been studied in order to optimize the ejector. The optimization is carried out not only by considering the best performance of the ejector at maximum load with prioritizing operation in the larger range, but also by catching the design point at maximum load even though it does not have the best efficiency at such point. Finally, a hybrid drive train simulation tool called LFM is applied to optimize a virtual fork-lift system. This investigation examines important performance metrics, such as hydrogen consumption and battery SOC as a function of the fuel cell and battery size, control strategy, drive cycle, and load variation for a fork-lift truck system. This study can be used as a benchmark for choosing the combination of battery and fuel cell.

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