Supervisory Energy Management of an Integrated Fuel Cell / Battery System for Vehicular Applications

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This work presents an energy management strategy (EMS) for an integrated fuel cell and battery system for vehicular applications. A challenging issue when integrating fuel cells to such applications is the handling of the dynamics that arise by their use. Additionally when a fuel cell is combined with a battery then various decisions should be made in order for the integrated system to operate in an optimum way, while fulfilling the frequently and rapidly changing load demand (Rodatz et al., 2005). In that context the resulting hybrid system should be complemented by a control system that will be able to handle the complex dynamics and the discrete decisions of the overall system (Arce et al., 2009). At the core of the considered control system an EMS is developed that dictates the appropriate decisions for each subsystem at various operating conditions. The goal of this work is to explore the behavior of the hybrid system under a realistic operation scenario which will be controlled by an EMS that relies on a Hybrid Timed Automaton (HTA) (Hahn et al., 2013). Besides the fulfillment of the load demand, the objectives of the EMS include the optimal use of the available hydrogen, the protection of the battery's lifetime and the preservation of the fuel cell's durability.

The design and development of an efficient and modular EMS is motivated by a system that considers a lithium-ion battery stack, a Polymer Electrolyte Membrane (PEM) fuel cell system and a programmable electronic DC load that simulates the behavior of an actual load. Based on the chosen topology, the main energy providers are the battery and the fuel cell. For each subsystem a dynamic mathematical model is developed and a set of operation scenarios will be performed in order to produce the appropriate amount of data. Subsequently a formal parameter estimation technique that involves mainly the battery and the fuel cell subsystem will be applied. A sensitivity analysis will be performed for the determination of the major variables and parameters that influence the behavior and response of the integrated system (e.g. State of Charge (SOC) of the battery, excess ratio levels of hydrogen and air of the fuel cell etc). By this analysis a set of variables/parameters will be determined that will guide the levels of operation of each subsystem.

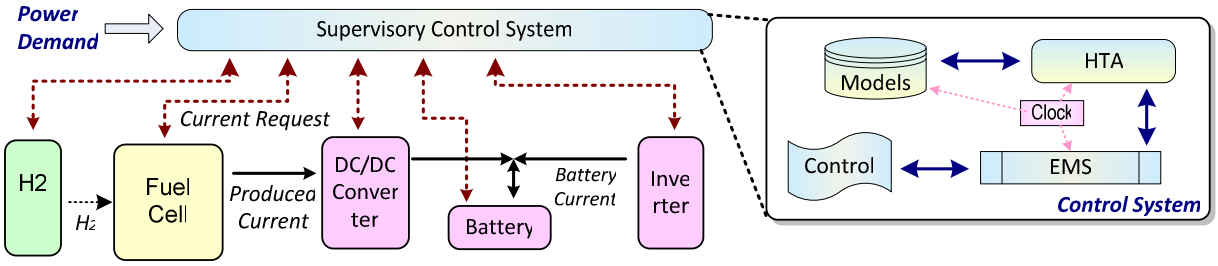


Figure 1: Integrated subsystems and components of the control system

In order to supervise the operation of the subsystems an EMS is necessary. The purpose of the EMS is twofold, to supervise the status of each subsystem and to be able to adjust to system operational modes (Ziogou et al., 2013). In this work the proposed EMS will take into account the main requirements and constraints which are posed by the vehicle's operation. One of the most challenging tasks for an effective EMS is to consider the interactions among the electronic and the electrochemical subsystems. Therefore, an approach that can handle this challenge is a hybrid timed automaton (HTA) that switches between the system's operational modes and sets the set-points for the lower-level control loops. More specifically an HTA is a dynamic approach that describes the evolution in time of a set of discrete and continuous state variables. The interaction between discrete and continuous operating states motivates the use of the hybrid approach and thus the hybrid automaton appears as a

formulation that includes the semantics for the realization of a generic EMS. In this context a modular strategy is proposed which uses the automaton based structure while the system requirements are translated into a propositional based logic representing a set of operating rules. It consists of a series of switching actions in order to drive the system from any initial condition to an operating mode appropriate for every subsystem, taking into consideration the specifications and the constraints.

After the development of the EMS a deterministic optimization problem is formulated in order to examine a set of operation scenarios and to determine the values for the variables that will result from the sensitivity analysis The scope of the optimization framework it to enhance the performance of the system and most importantly to enable a smooth operation of the subsystems in terms of reliability. The utilization pattern of the battery and of the fuel cell determines the frequency of equipment replacement and maintenance and therefore the operating costs, over the lifespan of the overall system. Thus, the optimization problem focuses on these operation parameters, which are considered as decision variables. The optimization framework is evaluated on a case study regarding the optimal operation of the system. The optimal values of the operating parameters are identified and their effect to the overall system operation is discussed. Finally the effectiveness of the EMS we be evaluated using a set of predefined driving profiles described by a time-varying curve of power demand. The results of the case study will focus on the coupling of the fuel cell and the battery subsystems towards the production of the desired power demand. The results will reveal the potential of the proposed EMS, explore the synergy among the various subsystems and demonstrate the response of the integrated system.

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