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A model-based approach to battery selection for truck onboard fuel cell-based APU in an anti-idling application

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HIGHLIGHTS

- Model based approach for APU performance evaluation is presented.
- Simplified purpose-oriented model of a diesel powered fuel-cell APU was built.
- Truck night-stay energy consumption profile was identified.
- Three batteries were evaluated for use with the FC-based APU.

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ABSTRACT

The paper presents a model-based approach to supporting battery selection for a fuel cell (FC)-based auxiliary power unit (APU). It is introduced to a case study of electrical power production and consumption management in a truck anti-idling application of a diesel-powered FC-based APU, a system under development in FCGEN, a FCH JU European project of the FP7 program. With fuel cell and related technologies increasingly competing with others in the market, they need to form complete systems with matching and well-balanced components to enable using the technology to its best. Within the whole system, the battery, serving as an energy buffer, represents a medium-cost element, but it affects the operating parameters importantly. Within the scope of this study, a purpose-oriented model of the diesel powered FC-based system is developed together with a realistic load scenario for the comparison of three batteries. The battery size and type are investigated and discussed in the light of the simulation results.

1. Introduction

Fuel cells with a membrane made from a polymer material, known as *Polymer Electrolyte Membrane fuel cells* (PEM FC), are a clean and efficient source of electrical energy [1–4]. Other advantages are their low operating temperatures, high power density, and silent operation [5,6]. Nowadays, as fuel cell (FC) technologies are getting closer to everyday use, they are increasingly competing with other technologies on the market for both stationary [7], mobile [8] and portable [9] applications. This requires several aspects of such systems to be optimized; namely, their economics, reliability, and sustainability [2,6]. Therefore, the system integrator must choose the supporting components correctly, tune the control accordingly, and possibly implement additional diagnostic methods [10,11] to exploit each component optimally and allow optimal operation of such a power unit as a whole. Still, FC systems are mainly produced in a small series and, as a result, the supporting subsystems are rarely properly matched to the FC stack and reformer-rated power. The consequences of inappropriate dimensioning of system parts (e.g., pumps, blowers, fans, batteries, etc.) may result in higher prices, lower efficiency, and shorter lifetimes of the overall systems.

Recently the niche market for FC-based onboard auxiliary power generation units (APU) has been making big steps towards acquiring a presence in the wider market [12,13], with APUs often also including the fuel processor (FP) [14,15]. There is an interest in such products in the vehicle market for trucks, caravans, and busses, and in the nautical field for small to mid-sized yachts and sailboats, providing that a decent price, reliability, and a sufficient lifetime are offered. Among the above, there is a field of truck anti-idling APU applications, where recent interest and a development push has come about due to the negative effects of idling [16] and a tightened regulative environment [17,18]. The fuel cell-based onboard APUs [19,20] run at higher efficiency and have

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much lower emissions. Market analyses [21], as well as possible use and impact investigations [22], have been done already and several research projects (e.g., FCGEN [23], DESTA [24]), etc. have been financed to overcome further obstacles to commercialization and to demonstrate their use.

One important performance and price-influencing APU component is the battery. Due to thermo-chemical processes, the FC systems and the fuel reformers even more so belong to slowly responsive energy sources and such APUs therefore predominantly require an energy buffer to cover the load transients [7,8]. Yet, an energy storage element places limitations on the energy and power capacities, which dictates its price. Therefore, the selection of an appropriate battery for such a system is a delicate task, requiring experience and insight that can be obtained through experimentation; it is an expensive and time-demanding task, and sometimes it is also difficult to carry out due to operational restrictions. On the other hand, a simulation approach is a good alternative that overcomes most of these issues [8,25] and enables observation of close to real system behaviour to take place in a faster, more convenient, and less expensive way.

In this work we present a model-based approach to supporting decisions about battery selection for an APU system. The concept comprises (i) the efficiency and power models of the main APU components, (ii) the battery models, (iii) the power consumption model, and (iv) the control system. This approach is used to evaluate the three batteries considered within the FCGEN project: the lead-acid starter and traction batteries, and the lithium battery. There the task to select an appropriate battery was a part of the APU process design phase – before the components were built and real process data was available to verify the model precisely. Therefore the results are not expected to yield precise numbers but to give insight and better background for well informed decision on battery to be used.

To enable a sensible evaluation to take place, typical loads were identified and their usage profiles for an anti-idling truck onboard application were specified. The resulting overall load profile was confirmed by the truck-producing company. Additionally, an advanced control algorithm from previous work [26] was upgraded to comply with the components' limitations and to further optimize the overall APU performance. The simulations are used to generate data on the basis of which the advantages and disadvantages of each APU-battery assembly are discussed.

The paper first presents the relevant model of the APU, consisting of the lumped component models of a reformer, a stack, a DC/DC converter, and parasitic loads and batteries in three variants. Following the description of the advanced-level control system structure and functions, the related loads and the profiles of the truck's onboard application are presented. The batteries are evaluated in the simulation using the described model and load profile. The findings of the comparison are summarized and there is a discussion relating to overall efficiency, battery price, and aspects of practical use.

2. The APU model

The diesel-powered FC-based APU with 3 kW net electrical output power, developed within the FCGEN project, is a complex system consisting of several reactors, where various chemical reactions take place. Reactor masses impose spatial temperature distributions and high order responses. Furthermore, the reformate chain connecting all the reactors means that each phenomena propagates through downstream reactors, which imposes tight control constraints. Thus the challenges are also in succeeding to manage and control the operation of the complete system reliably and efficiently. The APU process scheme is shown in Fig. 1. Due to complex and slow dynamics, imposed predominantly by fuel processor, the battery is required to compensate the APU power excess/shortage in relation to load demand.

However, the focus of the analysis presented here is on the APU power, battery and load-related phenomena and has a macroscopic nature. It was required to help decide the most suitable battery to use with the APU in advance – during the APU design phase. This has two implications. First, due to macroscopic nature of the study the use of detailed dynamic process models of APU components does not bring significant benefit, but complicates the modelling and increases the model complexity over the desired level. Therefore, lumped models are used, which include only the most dominant time dynamics of some components and their characteristics. Second, the model is based on preliminary component characteristics provided by component producers/developers.

The component degradation is not taken into account in this work. The degrading phenomena are prevented to the highest possible degree by the means of operation-optimized control strategy and set-points selected in the safe area of operation. E.g. the starvation possibility is reduced by the stack blower controlled to the appropriate lambda and by means of stack current rate constraints, implemented through the DCDC converter control that allow the FP to follow with preparation of the requested reformate flow. During these transients the battery takes the load until the stack current gradually reaches an adequate level.

The model comprises the following:

- Fuel processor (FP).
- Fuel cell stack (FC).
- Power converter (DCDC).
- Battery.

To run the model correctly the following load parameters also have to be defined:

- Daily load profile.
- Power consumption characteristics of the balance of plant (BoP) components.
- Duration and power consumption of APU startup and shutdown procedures.

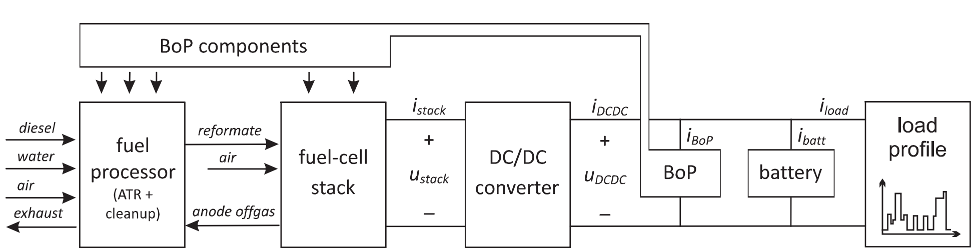

Fig. 1. The APU process scheme.