

Decision process to manage useful life of multi-stacks fuel cell systems under service constraint



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ABSTRACT

A management of multi-stacks fuel cell systems is proposed to extend systems useful life in a Prognostics and Health Management (PHM) framework. The problem consists in selecting at each time which fuel cell stacks have to run and which output power has to be chosen for each of them to satisfy a load demand as long as possible. Multi-stacks fuel cell system useful life depends not only on each stack useful life, but also on both the schedule and the operating conditions settings that define the contribution of each stack over time. As the impact of variable operating conditions on fuel cell lifetime is not well-known, a simplified representation of fuel cell behavior under wear and tear is used to estimate the available outputs over time and their associated Remaining Useful Lives (RUL). This health state prognostics model is configured to suit to Proton-Exchange Membrane Fuel Cells (PEMFC) specific characteristics. The proposed scheduling process makes use of an optimal approach based on a Mixed Integer Linear Program (MILP). Efficiency of the associated commitment strategy is assessed by comparison with basic intuitive strategies, considering constant and piecewise constant load demand profiles.

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1. Introduction and related work

Fuel cells appear to be of growing interest for power conversion [1]. This technology offers indeed a potential alternative to conventional power systems and is involved in many applications. Fuel cells are for instance increasingly being used as backup systems in hybrid power supply systems composed of renewable energy sources [2], such as solar and wind generator. In fact, renewable energy sources being intermittent by nature, they need to be combined with other systems which can generate power on demand. In this context, fuel cells are only used occasionally, during periods when the energy produced by renewable sources is not enough to meet the load demand. Azcarate et al. [3] developed for instance a simulation model for a wind-H₂ energy system and proposed dynamic management policies based on the

conversion of electricity into hydrogen and the use of the stored hydrogen to produce electricity during demand peaks using a hydrogen fuel cell. Bigdeli [4] proposed different optimal techniques for the management of a hybrid electric power generation system that consists of a photovoltaic array as primary energy source and of a fuel cell and a battery as backup units. Load sharing among the available resources to achieve optimal performance is addressed using several optimization approaches (imperialist competitive algorithm, particle swarm optimization, quantum behaved swarm optimization, ant colony optimization and Cuckoo optimization algorithm). Studies proposed in the literature considering fuel cells technology in such power supply systems mainly focused on the evaluation of their performance on life cycle cost, optimal sizing and hybridization, rather than optimal control [2]. For this latter purpose, Sichilalu et al. [2] developed an optimal control strategy model for an integrated grid system considering renewable energy sources (wind and

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photovoltaic) and fuel cells. The proposed control strategy avoids using the fuel cells at all times: they are used only during peak periods or when the main power generation system is completely unavailable.

Combined with batteries, fuel cells are also being used in stand-alone applications, in which they mainly serve as indirect storage of energy and as stable power sources. Lopez et al. [5] developed for instance two genetic algorithms to find an optimal configuration of the components involved in a stand-alone renewable energy hybrid system with hydrogen storage (power conversion being performed by a fuel cell). First proposed genetic algorithm searches for possible component configurations, whereas second one optimizes the strategy for each of the configurations. Abadlia et al. [6] considered the power management of a renewable energy source associated to an energy storage system composed of a proton exchange membrane fuel cell (PEMFC) and batteries in a photovoltaic system used in stand-alone. They proposed a fuzzy logic power management strategy to ensure a good management of the power flow, which maximizes the production of hydrogen and controls the charge/discharge mode operation of the battery. In these stand-alone applications, as well as in the hybrid power supply systems introduced previously, the main challenge is to properly control the load power sharing among the main and the secondary power sources in order to comply with the availability of the different energy sources considered and with the variability of the load demand.

Fuel cells are also used as primary sources and coupled with batteries to provide the necessary power for transportation applications. For such applications, fuel cell systems are considered as the best energy sources that reduce fuel consumption and CO₂ emissions [7]. Some studies have considered the use of fuel cells for electric vehicles. Aouzellag et al. [8] proposed a control strategy to manage the power distribution among two energy sources (PEM fuel cell and battery) for fuel cell hybrid electric vehicles. Neffati et al. [9] tackled also the power management for a hybrid full electric vehicle with a fuel cell system as main energy source and a super-capacitor as storage element. The considered objective was to minimize the overall cost of hydrogen consumption for a given power demand. This was performed by optimizing the power distribution on the two sources considering availability, performance and state of charge constraints. An off-line optimization strategy for the energy management has been proposed, in which dynamic programming has been used to provide a benchmark regarding the maximum potential fuel savings. An on-line strategy based on fuzzy switching of fuzzy rules has also been proposed for a real-time energy management taking into account the evolution over time of the state of charge of the storage element.

Contrary to a vast majority of contributions in the literature addressing the use of fuel cell systems, such as those previously introduced, fuel cells are considered in this article as the unique power source. All the auxiliary functions necessary to guaranty a good functioning of fuel cells are moreover not considered in this study and are supposed to be well managed by auxiliaries, independently from the addressed decision process. For instance, the storage of hydrogen or the management of the chemical reactions that lead to power conversion are out of the scope of the proposed contribution, in which fuel cells associated to their auxiliaries are seen as black boxes that deliver a certain power output. In order to reach suitable power outputs, systems composed of several fuel cell stacks are considered. Each stack is supposed to be independent but the multi-stacks system has to

globally deliver a given power output based on a need of energy. At each time, this global output is determined by the sum of each output of the stacks that are currently running. The scheduling of such systems is addressed, with the maximization of their global useful life as objective. In fact, the increase of fuel cells lifetime and reliability has been highlighted by Borup et al. [10] to be an important challenge. Durability of fuel cells is indeed not consistent with most applications. Then, we propose to contribute to this challenge by defining an original management of a set of fuel cells stacks. Our purpose is not to improve each fuel cell lifetime, but to propose a way to use several fuel cells in parallel in an appropriate manner so as to globally increase the whole system durability.

Considering a global needed power output, the multi-stacks system useful life depends not only on each stack useful life, but also on both the schedule and the operating condition settings that define the contribution of each stack over time. Indeed, operating conditions have been shown by Borup et al. [10] to have an impact on each fuel cell output and on their durability. The same statement applies to batteries. The maximization of a battery charge used while constraining the probability of a shut off in flight has been studied by Saha et al. [11] for electric unmanned aerial vehicles. Prognostics is used to predict remaining battery life. Advantage is taken of this information to optimize mission plans without exceeding the available battery charge. In a same way, fuel cell available outputs and their associated lifetime can be determined at each time by a Prognostics and Health Management (PHM) process based on both the past and the future operating conditions [1]. Steps involved in a PHM process are depicted in Fig. 1. It has been pointed out by Jouin et al. [1] that researches in PHM dealing with fuel cells have been mainly focused on data acquisition and data processing. Less attention has been paid to condition assessment and diagnostics and few works addressed prognostics. Papers taking into account decision making are even scarcer. In those papers, the decision part deals furthermore only with corrective actions (see Refs. [12,13]), which tend to master fuel cell operating conditions through the control of physical parameters. This real-time control operates at timescales from nanoseconds to seconds. In the decision process involved in this paper, larger timescales (hours

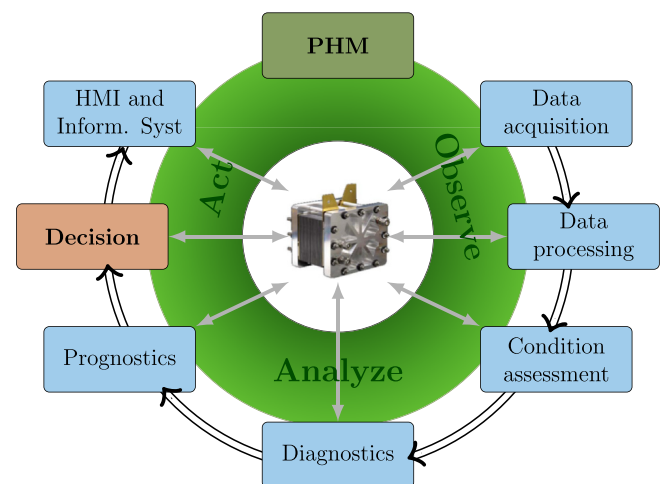


Fig. 1. PHM process.

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