Modeling, Diagnosis, and Control of Fuel-Cell-Based Technologies and Their Integration in Smart Grids and Automotive Systems

SOCIETY is gradually becoming aware that the current energy system based on the use of fossil fuels is inefficient, highly polluting, and finite supply. Within the scientific community and industry stakeholders, there is a unified agreement that indicates that hydrogen (H_2), as an energy vector, combined with other sources of alternative energy, represents a safe and viable option to mitigate the problems associated with hydrocarbon combustion because the entire system can be developed as an efficient, clean, and sustainable energy source. In this context, the change from the current energy system to a new system with a stronger involvement of H_2 relentlessly involves the introduction of fuel cells as elements of efficient energy conversion.

Nowadays, it is public knowledge that the introduction of fuel cells as series products in the market of stationary and mobile applications has recently begun, being part of the major R&D investments in almost all the automotive companies and related original equipment manufacturers. However, despite current advances in fuel-cell-based technologies, high costs, moderate reliability, and reduced lifetime may remain as major limitations. For this reason, together with the continuous improvement of materials and components, the incorporation of advanced control and diagnosis systems embodies a major technological challenge to address, in order to achieve cost reduction, performance improvement, and efficiency optimization of these promising power generation systems. In this sense, the design of control systems must be understood in a global way, taking into account the interface power electronics, actuators, and local control schemes for each subsystem, supervisory strategies for optimal energy management at each operating condition, and reliable diagnosis systems for early fault detection and prognosis against irreversible damages.

Aiming to provide a diffusion platform to new technological breakthroughs in the field, the Guest Editors first proposed in 2014 this Special Section of the IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, broadcasting the Call for Papers to the entire scientific community related to fuel-cell-based systems. The aim was to merge all the discussions and important conclusions about the latest challenges in the field into high standard journal contributions.

In this context, the main objective of the current Special Section is to collect, formally present, and discuss the most recent and relevant advances in control-oriented modeling and validation, system diagnosis, and advanced control design of complex energy conversion systems based on fuel cells. Moreover, the Special Section is also focused on providing the researchers and engineers with the state-of-the-art research and guidelines in these important fields for the next years.

TABLE I
PAPER DISTRIBUTION ACCORDING TO THEIR RESEARCH FIELDS

Research Field	Manuscripts
Modelling & System Diagnosis	[1], [2], [3], [4]
Management & Control	[5], [6], [7], [8], [9], [10], [11], [12]
Monitoring & Observation	[13], [14], [15], [16], [17]
PEMFC-based Setups	[1], [2], [3], [4], [8], [10], [12], [13], [14], [15]
Other Configuration Setups	[7], [9], [11]

In total, the Special Session is composed by 17 contributions covering the research in theoretical aspects related to modeling, diagnosis, and control applied to energy management systems based on fuel cells or considering fuel cells as part of overall hybrid systems. Table I proposes a first classification of the main topics addressed and their corresponding papers. Note that some papers can be found in more than one row because the classification groups are nondisjoint sets. It is also important to highlight that most of the papers consider configurations based on low temperature *polymer electrolyte membrane* fuel cells (PEMFCs). Nevertheless, there are two manuscripts related to high-temperature PEMFCs and one that addresses the control of a solid oxide fuel cell.

Going to the selected contributions, the first set of papers deals with the broad and complex fields of modeling (mainly dynamical) and diagnosis approaches for fuel cells and hybrid systems. In regard to modeling, two novel approaches considering water-cooled PEM fuel-cell-based systems [1] and PEMFC stacks by using NARX and NOE neural networks [2] are here reported. Diagnosis approaches are proposed and then deeply discussed in two papers: The first methodology considers both data-driven diagnosis and detection of faults in PEMFC [3], and the second presents an online diagnosis of high-temperature PEMFC considering CO poisoning [4].

Innovative approaches in the field of control design based on sampled-data passivity [5], model predictive control (MPC) [6],

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interval-based sliding mode control (SMC) [7], dither-less extremum seeking [8], economic MPC [9], and high-order SMC [10] are reported and further discussed for different PEM fuel-cell-based systems as well as other configuration setups such as microgrids. Moreover, advanced topics on energy management also applied to hybrid systems are reported [11], while a new power electronics interface is presented in [12].

Regarding the area of monitoring and observation, five contributions address novel approaches on diverse and important topics such as lifetime and efficiency of the fuel cells. Hence, approaches treating degradation mechanisms [13], electronic short circuits [14], and temperature observation in extreme membrane conditions [15] collect the main discussions related to observation and estimation. Explicit monitoring contributions cope with the fuel cell condition via voltage monitor [16] and by using impedance spectroscopy [17].

In light of the presented contributions, the increasing interest among the scientific community in topics related to hybrid systems is particularly evident. This trend is strongly driven by the current industry demands, related to stationary and automotive applications, where fuel cells play a decisive role and need to compete with mature technologies such as gas turbines and diesel engines. However, given the high complexity of the involved subsystems, several aspects must be solved, and new approaches have to be developed. This is clear from several contributions of this Special Section, where specific efforts were put to give solutions in areas from modeling, estimation, monitoring, diagnosis, and nonlinear control.

The next step to be jointly covered by the industry and scientific community is necessarily related to perform consistent long-term developments, in order to put together the presented alternatives in common software and hardware platforms. This would allow a major breakthrough in fuel cell technologies, with countless options to optimize the involved subsystems and improve their reliability and lifetime.

The Guest Editors find themselves extremely pleased and privileged to have had the opportunity to edit this surely successful "Special Section on Modeling, Diagnosis, and Control of Fuel-Cell-Based Technologies and Their Integration in Smart Grids and Automotive Systems." We truly hope that future readers of this Special Section will find the papers comprehensive, interesting, and inspiring for their research and future developments.

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