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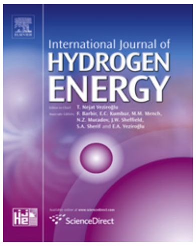

Time delay control for fuel cells with bidirectional DC/DC converter and battery

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ABSTRACT

Transient behavior is a key property in the vehicular application of proton exchange membrane (PEM) fuel cells. A better control technology is constructed to increase the transient performance of PEM fuel cells. A steady-state isothermal analytical fuel cell model is constructed to analyze mass transfer and water transport in the membrane. To prevent the starvation of air in the PEM fuel cell, time delay control is used to regulate the optimum stoichiometric amount of oxygen, although dynamic fluctuations exist in the PEM fuel cell power. A bidirectional DC/DC converter connects the battery to the DC link to manage the power distribution between the fuel cell and the battery. Dynamic evolution control (DEC) allows for adequate pulse-width modulation (PWM) control of the bidirectional DC/DC converter with fast response. Matlab/Simulink/Simpower simulation is performed to validate the proposed methodology, increase the transient performance of the PEM fuel cell system and satisfy the requirement of energy management.

1. Introduction

Fuel cells provide an environmentally friendly, highly efficient power source without Carnot's limitation of efficiency. The proton exchange membrane fuel cell (PEMFC) is considered one of the most promising technologies for application in hybrid vehicles due to its high-power density, zero pollution, low operating temperature, a certain level of rather quick startup capability, and long life time.

Three major subsystems exist in a typical pure hydrogen fuel cell system: air supply with thermal management, fuel supply, and recirculation. In the air supply subsystem, reasonable flow rate and pressure are regulated to avoid oxygen starvation, water flooding of the membrane, and excessive auxiliary power consumption. Anode recirculation is used to reduce hydrogen waste, maintain the pressure difference between anode and cathode to a minimum, and run the fuel in the anode in order to obtain better water management. A fuel cell system with dynamic response is important for vehicular applications because fluctuations in power demand. A fuel cell and its subsystems usually do not operate at the optimal steady-states designed by the manufacturer. Therefore, it is important to construct a precise PEM fuel cell dynamic model and adopt a robust control technique to satisfy the aforementioned power fluctuation requirements.

Numerous fuel cell models have been built to predict polarization [1–5]. However, these contributions are not suitable for the control study, although they provide a good understanding of the fundamentals of fuel cells. Unlike studies on the steady-state, only a few dynamic models of fuel cell systems have been published [6–11]. Pukrushpan developed a system level model that includes a compressor, supply and return manifolds, a humidifier, and anode and cathode

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channels [12]. This model was used for air system control without anode recirculation. The LQR optimal control theory was used for air to increase the transient performance. However, the control required an observer and a lengthy linearization process. Moreover, the linear model used is insufficient for a non-linear PEM fuel cell model. In addition to the linear analysis, an increasing number of adaptive and intelligent controllers have been designed for fuel cell application. Schumacher [13] presented a fuzzy logic controller for a miniature PEM fuel cell. Hasikos [14] applied a neural network in the robust control of hydrogen utilization with oxygen stoichiometry regulation. Shen [15] designed an adaptive fuzzy controller for MCFC stack temperature control. Model-predictive control was also used for the power tracking of a fuel cell [16].

If the fuel cell is not a stand-alone component and is instead connected to another power generation device, such as a battery, thorough control of the power supply becomes necessary. For this purpose, a bidirectional DC/DC converter is usually placed between the battery and the DC link. DC/DC converters are used in applications where an average output voltage is required, to be higher or lower than the input voltage. This is achieved by governing the period in which the main switch of the converter conducts electricity, which usually occurs at constant frequency (PWM). A converter system that connects the battery as the secondary energy storage to a fuel cell electrical vehicle system is presented in this paper (Fig. 1). The battery is connected to the DC link of the fuel cell electric vehicle system through a bidirectional DC–DC converter. The bidirectional converter discharges current from the battery upon an increase in the load current (boost mode), and then charges it back when the fuel cell has surplus power relative to the required load power (buck mode). An accurate duty cycle control is required for the bidirectional DC/DC converter as a means to charge or discharge the battery with fast response, and to avoid drift in output voltage. To address these objectives, a PID controller with a small signal model and a sliding mode controller for converter PWM calculations have been studied in the field of electrical engineering [17–20]. Recently, several researchers have applied the unidirectional or bidirectional DC/DC converters to fuel cell hybrid vehicles. Zumoffen used adaptive predictive control for to improve fuel cell transient dynamics using unidirectional DC/DC converters. A simple fuel cell model was used, but details of the DC/DC converter control method, was not mentioned [21]. Choe used PID control for a unidirectional DC/DC boost converter with a fuel cell dynamic model but did not include a secondary energy storage device [22]. Andujar used a small signal model with a linearized PEMFCl model to control the DC/DC converter [23]. In addition, Andujar used linearized fuel cells and DC/DC converter models, given that the control parameters should be changed if the operating condition varies. Dalvi used an optimization method to determine the point of maximum fuel cell efficiency by using an ultra capacitor as a secondary energy device. However, no mention was made on the DC/DC converter duty cycle control [24]. Camara presented an excellent DC/DC converter duty cycle control method with a polynomial controller, but did not include fuel cell dynamic model, which included pressure distribution and oxygen stoichiometry [25]. Marsala introduced a PEMFC emulator based on a buck converter, but the fuel cell emulator model was not real because only cathode dynamics was considered [26].

In this paper, a PEM fuel cell dynamic model, which excludes a startup or shut-down process, is introduced. The model includes a study of the air and hydrogen flow and a robust control technique. Time delay control (TDC) is used to enhance transient fuel cell performance, (i.e., to prevent oxygen starvation.) Dynamic evolution control (DEC) is used to regulate bidirectional converter duty cycle [27]. DEC has been proven to be capable of providing constant boost voltage to the DC link with a quick response improving the dynamic response of the fuel cell. A simple power management strategy for the fuel cell and battery is considered in order to verify if the proposed method can work well in distributing power between the fuel cell and the battery.

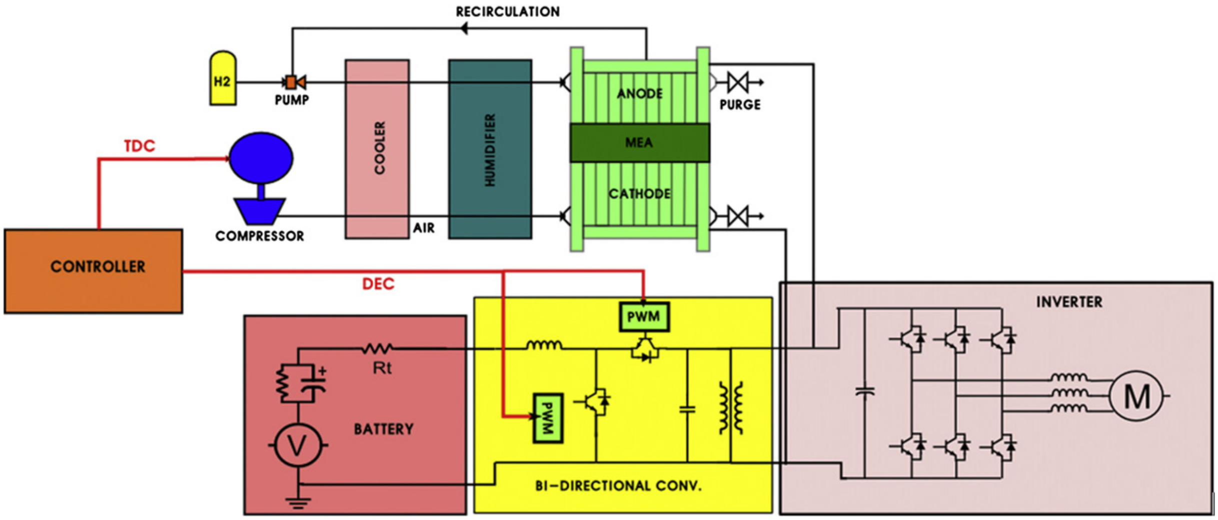

Fig. 1 – Configuration of fuel cell system.