Adaptive Passivity-Based Control of PEM Fuel Cell/Battery Hybrid Power Source for Stand-Alone Applications

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[1]***Abstract*—In this paper, a DC hybrid power source composed of PEM fuel cell as main source, Li-ion battery storage as transient power source and their power electronic interfacing is modelled based on Euler-Lagrange framework. Subsequently, adaptive passivity-based controllers are synthesized using the energy shaping and damping injection technique. Local asymptotic stability is insured as well. In addition, the power management system is designed in order to manage power flow between components.**

Evaluation of the proposed system and simulation of the hybrid system are accomplished using MATLAB/Simulink. Afterwards, linear PI controllers are provided for the purpose of comparison with proposed controllers responses. The results show that the outputs of hybrid system based on adaptive passivity-based controllers have a good tracking response, low overshoot, short settling time and zero steady-state error. The comparison of results demonstrates the robustness of the proposed controllers for reference DC voltage and resistive load changes.

***Index Terms*—Adaptive Passivity-Based Control, Batteries, Fuel Cells, Hybrid power systems, Load management**

I. INTRODUCTION

Distributed Generation (DG) has the advantages of low investment, low pollution, high efficiency, and high reliability. Fuel cells (FCs) are mostly being used due to some merits compared to the other types of DG sources [1]. However, one main disadvantage of fuel cell is its slow dynamics [2]. Hence, hybrid power sources are introduced to make the best use of its advantages and elimination of the aforementioned disadvantage [3-5]. Batteries are a secondary source which can supply power under transient conditions [6].

Fuel cells act as converters which convert the chemical energy into electrical energy [7]. Proton Exchange Membrance (PEM) fuel cell is a prime candidate for hybrid systems, because it has higher power density and lower operating temperature than the other types of FC systems [8].

Power electronic converters have a significant role in the hybrid systems [9]. These are interface between the DG sources and the other parts of hybrid system [7, 10]. Recently, some of researchers have concerned on control of hybrid power sources [11-13]. The methods of controller design classifies into two categories: linear and nonlinear. The linear methods performed relying on locally linearized models. Hence, their performance will not remain the same under any changes on equilibrium points. The PI controller is a main linear controller which is being used in DG applications [14-17]. The dynamic equations of the power electronic converters have a nonlinear nature due to the multiplications of the state variables by the control inputs [18]. Therefore, the nonlinear methods such as robust [19], feedback linearization [20], sliding mode [21] and passivity-based control [22] are used for control of converters. In particular, a passivity-based control method has taken into consideration in various industrial applications.

The Passivity-Based Control (PBC) was introduced, by Ortega et al., as a controller design methodology which achieves stabilization by passivation [23]. Two theories for PBC were developed which are: Euler-Lagrange (EL)-PBC [24, 25] and Interconnection and Damping Assignment (IDA)-PBC [23]. These methods have been mostly used for control of induction motors [26], and switching power converters [27, 28].

Lee has used EL-PBC for control of three phase AC/DC voltage source converter [29]. Also, a single phase PWM current source inverter control with applying IDA-PBC has been implemented by Komurcugil [30]. The control of DG hybrid systems based on the IDA-PBC is achieved [31].
In the most of hybrid systems, the value of the resistive load is constant but unknown. Therefore, adaptive type of controllers has been used to handle this type of uncertainty. Sira-Ramirez et al., has developed adaptive input-output linearization controller [32], and adaptive passivity based controller [33] for DC/DC converters.

The study in this paper is concentrated on the lagrangian modeling of the fuel cell/battery DC hybrid power source, which the fuel cell is a main power source and battery storage is used as a transient power source. The control signals are achieved by Adaptive PBC (APBC). Power flow between hybrid system components is managed in the power management unit.

The paper is organized as follows. Section II introduces the hybrid DC power source and explains the suitable model of each component which is applied on hybrid system. Section III presents Euler-Lagrange model of DC hybrid power source. Adaptive Passivity-Based Controllers design is achieved in section IV Linear PI controllers are provided in section V for comparison with proposed system. Section VI describes power management system. Section VII validates the proposed model by simulation results and section VIII concludes the paper.

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