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Active load current sharing in fuel cell and battery fed DC motor drive for electric vehicle application

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ABSTRACT

In order to reduce the stress on fuel cell based hybrid source fed electric drive system the controller design is made through active current sharing (ACS) technique. The effectiveness of the proposed ACS technique is tested on a dc drive system fed from fuel cell and battery energy sources which enables both load current sharing and source power management. High efficiency and reliability of the hybrid system can be achieved by proper energy conversion and management of power to meet the load demand in terms of required voltage and current. To overcome the slow dynamics feature of FC, a battery bank of adequate power capacity has to be incorporated as FC voltage drops heavily during fast load demand. The controller allows fuel cell to operate in normal load region and draw the excess power from battery. In order to demonstrate the performance of the drive using ACS control strategy different modes of operation of the hybrid source with the static and dynamic behavior of the control system is verified through simulation and experimental results. This control scheme is implemented digitally in LabVIEW with PCI 6251 DAQ I/O interface card. The efficacy of the controller performance is demonstrated in system changing condition supplemented by experimental validation.

1. Introduction

Environmental concern is now motivating the use of renewable and clean energy. Global climate change due to vast use of fossil fuels is now a biggest threat to our life along with tapering of fuel reserves leads to the development of clean alternative energy source for different electric drives used in vehicle applications [1–5]. The beneficial qualities of fuel cells such as high efficiency, low environmental pollution, fuel diversity, reusability of exhaust heat and modularity leads to power generation for various applications [2]. The major draw backs of fuel cell include limited operating voltage range and load handling capability during transients [2,3]. These draw backs can be overcome by combining a battery bank of sufficient power. This combination can provide a good dynamics and can provide peak loads increasing the lifespan of fuel cell and keeping the battery State of charge (SOC) within safe limit [1–3]. Hence electrical power generation from fuel cell can easily be achieved with zero emission, higher efficiency and all most at low noise from hydrogen gas and air [4]. Conversely due to draw backs like high cost, long start up period and slow dynamic response impose hurdles against wide application of fuel cell [6,7]. By virtue of fuel cell potential, it has been widely used in different application as primary energy source along with battery/supercapacitor as auxiliary energy source with multiple input converter topologies [8,9]. Due to the characteristics of batteries in terms of high energy density, compact size and reliability, these are widely been adopted in hybrid vehicles [10–12].

For controlling the power flow from such hybrid power system many control strategies have been proposed by many researchers in the past. In such hybrid power system the control of energy flow is based on operation scenarios are explained in many literatures [9,11–25]. The concept of the predictive controller is also found in the literature for hybrid fuel cell vehicles which focus more on a prediction of load power and an optimal system control [23]. A two layer energy management system is discussed for fuel cell hybrid vehicle. The first layer deals with vehicle energy consumption where as the second layer deals with power splitting between fuel cell and battery [22]. A component level predictive current controller for fuel cell boost converter, a battery boost converter, an ultracapacitor (UC) bidirectional converter and a brush less dc motor drive for light electric vehicle which claims better dynamic response than a conventional PI controller based system is presented. Predictive controllers are designed separately for FC boost converter, UC bidirectional converter, for brush less dc motor

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(BLDC) drive [24]. However in these work source components are controlled independently without any interaction between the sources, eventually reduces flexibility in source power management.

Adaptive control based on eight states as presented in literature [25] is also in order to decide the operating point for each component of hybrid system. It generates the reference power for FC and battery and the power to be dissipated in the braking resistor. Furthermore, this control tries to avoid the continuous changes in the FC reference power, since the FC dynamic response is slow.

A simple systematic approach for design and digitally control FC/battery hybrid power system which guarantees a flexible FC operation over a wide range for drive application is presented in this paper. Although the application of ACS was implemented using DSP controller has been tested with grid connected hybrid power system [12], its performance in electric drive system is substantially better which has been focused in this paper. The current sharing mechanism introduces additional complexity in the closed loop control of electric drive and also to the parallel converter system dynamics. Without a proper design of control loops for parallel converters with current sharing mechanism, the performance of the drive system can degrade. This paper explores the possibility of using LabVIEW platform for implementing the proposed active current sharing control algorithm in such hybrid electric drives.

Digital control of electric drives in LabVIEW platform greatly reduces the system complexity [16,17]. Accurate control and measurement of various parameters of dc drive system require an efficient interface. The data acquisition (DAQ) systems Peripheral Component Interconnect (PCI) 6251 can be directly interfaced with the low-power analog electronic circuits and control systems [10,11]. The overall system complexity can be greatly reduced when the electric drive system is directly interfaced with DAQ system. This paper describes the detail implementation of closed loop control of dc drive system with analog electronic circuits in combination with digital control. To study the dynamic behavior of dc motor drive fed from hybrid source with active current sharing control makes the system more complex and such system can easily be controlled using DAQ devices. The work described in this paper provides a real world experience with control and measurement objectives which can be implemented practically in drive applications. The real time computational capabilities of the controller allow complex control algorithms to be implemented. As the controller lend itself to software paving the way to flexible manufacturing system with high degree of automation.

A 0.5 HP DC motor drive system is developed in the laboratory to study the feasibility of the proposed active current sharing strategy which composed of (i) fuel cell system as primary energy source, (ii) battery as auxiliary source, (iii) a bidirectional dc–dc converter and a unidirectional dc–dc converter system for controlling the power flow, (iv) a common dc bus, and (v) motor–generator set. The simulation study of the drive system has been carried out with a 5 HP DC motor. The control system is implemented in LabVIEW. The hardware consists of PCI 6251 DAQ input/output interface card.

2. Hybrid electric drive system

Fig. 1 shows the basic topology for fuel cell/battery based dc drive system. Different power converter system configurations have been proposed in conjunction with hybrid power sources for UPS system, portable electronics and grid connected power systems [9,12]. Among them the converter system structure presented in [12] has more advantages and most suitable for FC/bat

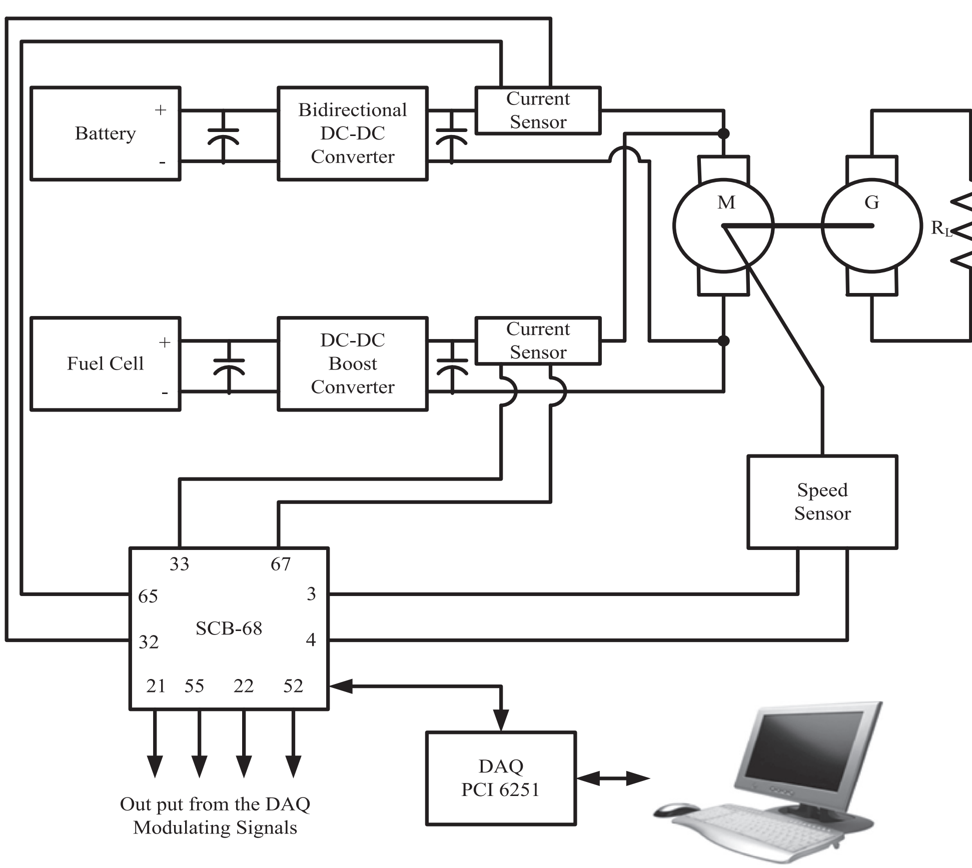

Fig. 1. Proposed topological arrangement of a hybrid electric drive system.