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Journal of Power Sources 142 (2005) 253–263
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Real-time strategy for active power sharing in a fuel cell powered battery charger

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Received 30 September 2004; accepted 25 October 2004
Available online 19 December 2004

Abstract

This paper presents a real-time strategy for active power sharing in a fuel cell powered battery charging station. This control scheme can adjust the charging currents of the batteries being simultaneously charged in real-time according to the estimated state-of-charge (SOC) which is obtained by estimating the battery open-circuit voltage with current correction and linearly fitting between the open-circuit voltage and the state-of-charge. The charge controller that executes the real-time strategy is designed and implemented in Matlab/Simulink for both system simulation and experimental tests. Simulation results show that all batteries can become fully charged simultaneously with the real-time strategy and the estimation method for battery state-of-charge is effective for the active power sharing strategy. Experiment results validate the simulation and show that the battery state-of-charge estimation method is practical.

Keywords: Fuel cell; Battery charger; Active power sharing; Control strategy; Real-time; Power converter

1. Introduction

The limited usable time of rechargeable batteries, which are playing an increasingly significant role in the utilization of portable electronic devices such as portable computers, cellular phones and camcorders [1], makes it essential to develop some kind of portable battery charging system. The fuel cell, which is emerging as one of the most promising technologies for the future power sources [2,3], may provide a good solution for powering the portable charging station [4], which may be far away from the utility power. However, when charging advanced technology batteries such as lithium ion cells, it is hazardous to exceed certain current or voltage limits. The fuel cell has a limited power capacity, and large power demand may go beyond its power limit. Both the fuel cell and lithium ion battery are strongly nonlinear [5–8]. All of these present some difficulty for the control design.

In order to meet the simultaneous requirements of multiple users, power converters are connected in parallel, each for one battery pack. In the general case, the initial states of the batteries being inserted are considerably different. A battery with lower initial state-of-charge (SOC) may require a larger charging current or otherwise a longer charging time. Therefore, the power from the fuel cell should be distributed efficiently among the charging branches. Three basic static control schemes have been initially investigated in [4]. Among these three strategies, with equal rate charging strategy, the battery with the highest initial state-of-charge can become full fastest but the total charging time is the longest due to the most depleted battery. Proportional rate charging strategy and pulse current charging strategy change the situation and it is possible for all the batteries to become fully charged almost simultaneously. However, with these static strategies, the charging currents or the duty cycles of the pulse currents are set up at the very beginning according to the estimation of the initial states and do not change any more during the current regulation mode. The simultaneous termination of charging is not guaranteed. In order to reduce

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doi:10.1016/j.jpowsour.2004.10.025

Nomenclature

a, b, c constants used in Eq. (7)
C charge remaining in the battery (A h or C)
C_0 rated capacity of the battery (A h or C)
d duty cycle in the current time step
d_i duty cycle of the ith buck converter
d_{old} duty cycle in the previous time step
I sampled charging current of the battery (A)
I_{fc} current available from the fuel cell (A)
I_i charging current of the ith battery (A)
I_{lim} preset limit for the total charging current (A)
I_{ref} reference charging current of the battery (A)
$k_{\mathrm{i}i}$ integral gain for current regulation
$k_{\mathrm{i}v}$ integral gain for voltage regulation
$k_{\mathrm{p}i}$ proportional gain for current regulation
$k_{\mathrm{p}v}$ proportional gain for voltage regulation
P_{fc} power available from the fuel cell (W)
P_i power to the ith charging channel (W)
r equivalent series resistance (ESR) of the battery
SOC_i state-of-charge of the ith battery
SOC_0 initial state-of-charge
t_{end} total charging time (h)
V sampled charging voltage of the battery (V)
V_{ref} reference charging voltage of the battery (V)
v_1 up-limit voltage corresponding with the condition that the state-of-charge is approximately equal to 0.9 (V)
v_2 low-limit voltage corresponding with the condition that the state-of-charge is approximately equal to 0.1 (V)

the total charging time and the fuel use, the power sharing among the battery banks should be optimized in real-time and vary with the state-of-charge of each battery.

The state-of-charge is a defined variable that is used to represent the charge remaining in the battery and it is widely used in the electrochemical field. However, it cannot be measured directly and it also is difficult to estimate the state-of-charge. Many people have studied the approaches to the state-of-charge estimation. Liu et al. [9] presented two methods to estimate the state-of-charge, whereas the ampere–hours method requires the information of initial state-of-charge and the recursive method needs many offline experimental data to obtain the many parameters. In this application, a simple and practical approach may be desired to estimate the state-of-charge based on the measured charging current and voltage of the battery.

This paper presents a novel real-time control strategy (RTCS) for active power sharing in a fuel cell powered battery charging station. The remainder of this paper is organized as follows. The system design and the control issues involved are discussed in Section 2. Section 3 addresses the real-time control strategy that can adjust the charging currents according to the estimated state-of-charge which is obtained by estimating the battery open-circuit voltage with current correction and linearly fitting between the open-circuit voltage and state-of-charge. Section 4 presents the Simulink implementation of the charging controller. The simulation results are given in Section 5. Section 6 demonstrates the experiment results and validates the control strategy. Conclusions are made in Section 7.

2. System design and problem definition

In general, the battery charging station should allow multiple batteries to be charged simultaneously, and it should be possible to insert or retrieve any battery at any time. A typical case of three charging channels is studied in this paper, which can represent the general solution of many charging channels.

The block diagram of the fuel cell powered battery charging station is shown in Fig. 1, where the parameters are also shown. A fuel cell stack, which is the power generation system, is used to charge up to three lithium ion battery packs, each through a DC/DC step-down buck converter. Each battery contains four series-connected cells. The buck converters control the charging current and voltage supplied to each battery, and allocate the available power among the batteries. A controller is used to coordinate these power converters. The real-time control strategy for active power sharing in this fuel cell/battery system is implemented in this controller. The charging currents and battery voltages are monitored and fed to the controller. This controller can calculate the reference charging current for each channel and the corresponding

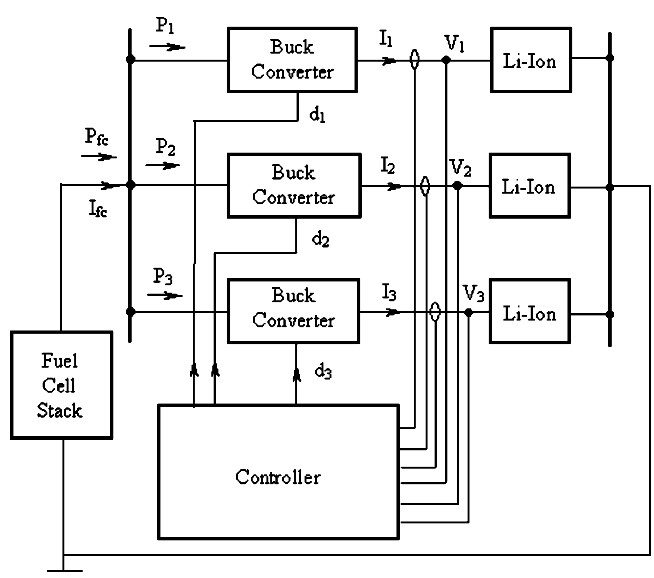

Fig. 1. Block diagram and parameter definition of the fuel-cell-powered battery-charging station.