Mode definition and operation strategies for secondary battery assisted hybrid-type DMFC systems

SangCheol Lee, JangSook Chang, S. M. Lee and Ju H. Park

Abstract—In relatively small allowable volume fuel cells are unable to provide the average power and essentially high peak power demanded by specific electric load. Hybrid-type direct methanol fuel cell (DMFC) systems composed of fuel cells and secondary batteries could combine the high power density of clean fuel cells and the high energy density of convenient batteries which exist already within the original system. This paper presents a study on operational strategies for passive power sharing in such a hybrid fuel cell/battery power source and external adaptor. We define the eight operational modes and specify the condition on which the mode transitions occur. Also, emergency mode is defined and activated at each abnormal condition. To implementation purpose four electric switches are appended at specific power paths, i.e. fuel cell stack output, secondary battery output, electric load input, and charger input.

I. INTRODUCTION

Many applications, such as portable electronic devices (notebook PC, PMP etc.) and communication equipment, have a common characteristic in their load profiles. That is, they have a high ratio of peak power to average power. Fuel cells (e.g. direct methanol fuel cell-DMFC) are considered to be the most promising alternatives among next generation energy devices due to their high energy density and clean energy [1,2].

However, limited by their inherent characteristics, fuel cells have a long start-up time and poor response to instantaneous power demands. Compared with fuel cells, lithium rechargeable batteries have a rapid transient response without any warm up or start up time, and their specific power capability is also much higher than that of fuel cells.

Combining fuel cells with batteries yields hybrid power sources that make the best use of the advantages of each individual device and may meet the requirements for the above mentioned applications regarding both high power and high energy densities [3,4]. In such a hybrid fuel cell/battery power source, the fuel cell is controlled to satisfy load average power requirements over a long term; the battery, on the other hand, is used to serve high pulse power requirements in short intervals. Clearly, the load time-averaged power should be less than or equal to the fuel cell rated power capability, otherwise the battery will eventually become exhausted.

In addition, a fuel cell/battery hybrid system could have a number of advantages over either stand-alone component. Providing that the temperature was not too low, the battery would enable instant cold-start operation since it would provide the majority of the load requirement whilst the fuel cell was warming up. It would condition the power output from the fuel cell to provide a voltage range that would be acceptable to the equipment since most devices are already designed to withstand the load characteristics of a battery [5].

A hybrid system would allow both components to be of smaller dimensions and operate with higher efficiency since neither would have to provide full load and capacity. The fuel cell would provide enhanced capacity and recharge capability.

In the following section 2, the overall system configuration setup is detailed. Section 3 then defines the mode and power flow diagrams to describe power supplying from the battery, fuel cell, and external adapter. And, in section 4, mode transition is specified depending on conditions such as voltage, power, and temperature. Finally, the conclusions are given in Section 5.

II. SYSTEM CONFIGURATION

The overall system as shown in Fig. 1 consists of fuel cell stack and smart battery pack which supplies electric power for a notebook PC (Q30 model made in Samsung Electronics Inc.). Also, the notebook PC is connected with an adaptor for the purpose of external power supply through utility line. The data communication channel is established through a SM-bus and a serial port for the purpose of fuel gauging and program debugging, respectively.

The fuel cell pack consists of a fuel cell stack and four balance-of-plants (BOPs) -fuel pump, feed pump, air compressor, and heat exchange fan, which are controlled by PWM for the purpose of variable voltage supply. And, the smart battery pack consists of Li-ion batteries managed by smart battery circuit (BMS). Also, the fuel cell circuit which manages the fuel cell stack and BOPs is placed in the battery pack not the fuel cell stack to minimize the fuel cell stack volume.

Fig. 2 shows the printed circuit boards (PCBs) which are inter-connected among the fuel cell pack with BOPs, the smart battery pack including fuel cell circuit, and a notebook.
PC with external adaptor attached through connectors. The notebook PC is a commercial one including its internal circuits to manage charging through external adaptor.

III. MODE DEFINITION AND CLASSIFICATION

The operational scheme should be proposed to coordinate three power sources such as the fuel cell, smart battery, and additional adaptor. In general the power path switching should be determined in hybrid power supply system. There are four FET switches (SW_{STACK}, SW_{BOP}, SW_{BATTERY}, SW_{CHARGER}) and one manual switch (SW_{MSP430}). In the initial mode, battery supplies the smart battery circuit only as shown in Fig. 3 to withstand the long time keeping without system turn-on and it is called by OFF state.

If the manual switch is ON, then only the circuit is powered from battery as shown in Fig. 4, which is called by idling mode (I mode). I mode means stand-by mode to power the circuit only and to make mode transition to any modes.

Several modes can be classified depending on the switching ON/OFF state. The mode label A is denoted by adaptor, B as battery, C as charger, and O as bop, respectively. For example, SBO means Stack-Battery-Bop operated mode and SCO means a Stack-Charger-Bop operated mode as shown in Fig. 7(a) and (b).

In normal operation, there exists 8 status only with each switch ON and OFF condition as shown in Fig. 5-7, based on the operation of adaptor attached (four A modes), battery supplied (two B modes), and fuel cell stack activated (two C modes). The power flow is highlighted with the bold lines and arrow indicates power flow direction.

In Fig. 5(a) denoted by B mode, only the internal battery is utilized to supply notebook PC power, which is same as the conventional notebook PC power supplying configuration. However, the BOPs are powered by battery in BO mode as shown in Fig. 5(b).

If the external adaptor is attached at notebook PC port, notebook PC can operate without fuel cell stack or battery power utilization as shown in Fig. 6. Especially in AC and ACO modes, external adaptor can be utilized to charge the...
battery pack without detaching the internal battery pack from fuel cell stack.

Fig. 7(a) shows power flow diagram with fuel cell stack to supply power into notebook PC and Fig. 7(b) to charge the battery pack without external power source, which is very convenient in the case of no external utility line to supply notebook PC. The SBO mode is normal operation mode, where three switches are ON state to supply power at the notebook PC with power sharing between fuel cell and smart battery.

IV. MODE TRANSITION STRATEGY

In real system operation, mode transition should be occurred among each defined mode in the previous section. With specific conditions which is described in mode transition arrow, mode transition occurs as shown in Fig. 8.

$V_b$ and $V_f$ denote the battery voltage and fuel cell voltage, respectively. $P_f$ and $P_n$ denote fuel cell output power and notebook PC power, respectively. If hard switch is ON, I mode can be the initial mode. Depending on the monitored condition, mode change occurs automatically. Any mode changing can be accomplished with some intermediate mode transitions. However, it is recognized as emergency to make mode change into I mode as shown in Fig. 9. And it is called an abnormal condition.

Fig. 10 shows the typical mode transition in the start-up sequence. If we compare the proposed mode definition and transition strategy with the conventional flow chart diagram,
Fig. 7. Power flow diagram at each mode with fuel cell stack supplied:
(a) SBO mode and (b) SCO mode

Fig. 8. Mode transition in normal operation condition

the proposed method is simple and easy to understand. It is from the difficulty to treat the current state and the next state to be changed depending on the individual conditions.

V. CONCLUSIONS

Current battery technology by itself is insufficient to provide the mandatory long-term power these systems require. Fuel cells are also unable to provide the essentially high peak power demanded by these systems. The proposed hybrid systems composed of fuel cells and secondary batteries could combine the high power density of clean fuel cells and the high energy density of convenient batteries.

Fig. 9. Mode transition when abnormal condition occurs

Fig. 10. Typical start-up sequence with mode change
This paper presents a system operation on mode definition and transition strategies for passive power sharing in such a hybrid fuel cell/battery power source. The proposed algorithm is simple and easy to implement on the existing DSP control circuit.

VI. ACKNOWLEDGMENTS

This work was supported in part by the Daegu Gyeongbuk Institute of Science and Technology (DGIST) research program of the Ministry of Education, Science and Technology (MEST) and the Daegu-Gyeong Leading Industry Promotion Program funded by the Ministry of Knowledge Economy (MKE) in Republic of Korea.

REFERENCES


