Study on Electric Wheelchair System Using Fuel Cell

Chan Anyapo, Kazuo Saito, and Toshihiko Noguchi

Department of Electrical Engineering, Nagaoka University of Technology, Japan

Abstract *This paper shows an electric wheelchair system using a PEM fuel cell. The system also has an EDLC bank as an energy buffer, and a newly designed four-quadrant DC chopper which drives two DC motors mounted on the wheelchair. Essential characteristics of the PEM fuel cell and drive performance of the wheelchair are investigated by experiments. Consequently, it is cleared that the PEM fuel cell is adaptable to the electric wheelchair system, and the wheelchair is satisfied with required operations.*

Keywords: electric wheelchair, PEM fuel cell, DC motor, four-quadrant DC chopper, EDLC

1. Introduction

Recently, discussions on fuel cells have been increased amazingly [1], [2]. For problems of the global environment and exhaustion of harmful gases, to study on application of fuel cells is noteworthy. Besides, several types of electric vehicles using fuel cells have been developed by car manufactures and institutes [3]. Therefore, combination of fuel cells and electric vehicles or wheelchairs is notable subject [4].

Furthermore, there is a big problem of the aging society in Japan. From that viewpoint, development of new type wheelchair is meaningful topic [5].

This paper shows an electric wheelchair system using a PEM (Proton Exchange Membrane) fuel cell. The system also has an EDLC (Electric Double Layer Capacitor) bank as an energy buffer, and a four-quadrant DC chopper which drives two DC motors. The motors are mounted on both the wheels, and speed detectors are installed on both the tires. Characteristics of the fuel cell and drive performance of the electric wheelchair are investigated [6]-[10].

2. Structure of Wheelchair System

Figure 1 shows a photograph of the electric wheelchair which originally has the following specifications; the diameter of each wheel is 22 inches, the maximum speed is 6km/h, the output power of each DC motor is 90W, and the power supply is a Li-ion battery (25.9V/6Ah). The electric wheelchair has been improved on several points. In particular, the power supply is replaced by the PEM fuel cell stack with the hydrogen storage alloys, which are seen in Fig. 2 (front side: the PEM fuel cell stack).

The two DC motors are driven by the newly designed four-quadrant DC chopper, and the EDLC bank is employed as the energy buffer controlling energy flow of the system.

The major specifications of them are as follows;

Fig. 1 Electric wheelchair

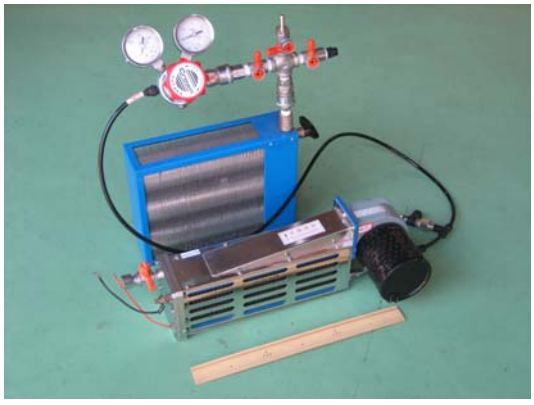


Fig. 2 PEM fuel cell and hydrogen storage alloys

(**1**) PEM fuel cell: 200W-24V (output),
(**2**) Hydrogen storage alloys: 500ℓ (capacity of H_2),
(**3**) DC motor: 90W (output power each),
(**4**) EDLC: 1350F-2.7V (capability/ 1 piece).

Figure 3 shows the relationship among the main devices of the electric wheelchair system. A user should only handle a joy-stick which can select any drive modes (forward, backward, right/left turn, and pivot). The energy control and motor drive circuit work depending on signals from the joy-stick. Then, the two DC motors mounted on both the wheels are driven by the chopper for commanded drive mode. Figure 3 also indicates that the PEM fuel cell is the power supply, EDLC is the energy buffer, and the two DC motors drive the wheels of the wheelchair.

Control of energy flow and the motor drive circuit of the system are illustrated in Fig. 4. In terms of the PEM fuel cell, hydrogen is supplied from the hydrogen storage alloys, and oxygen in the air is inhaled using a blower DC motor.

The EDLC bank is charged or discharged depending on drive conditions of the system. For example, the EDLC supplies energy to the two motors when the output power of the fuel cell lacks for motor drive. When regeneration of the motors occurs, normally the EDLC is charged. Figure 5 illustrates two kinds of examples of energy flow; (a) indicates the energy flows from the fuel cell to the motors, and a part of the energy can charge the EDLC. Figure 5 (b) shows the regeneration mode; the energy flows from the motors to the EDLC (condition 1), or a discharging resistor (R_d) works to dissipate the energy if the EDCL is fully charged (condition 2).

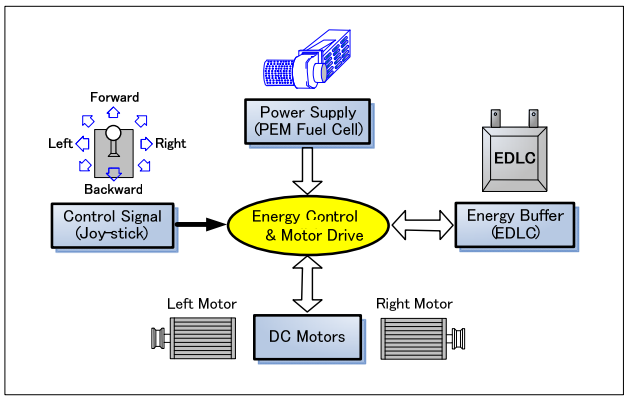


Fig. 3 Relationship among main devices

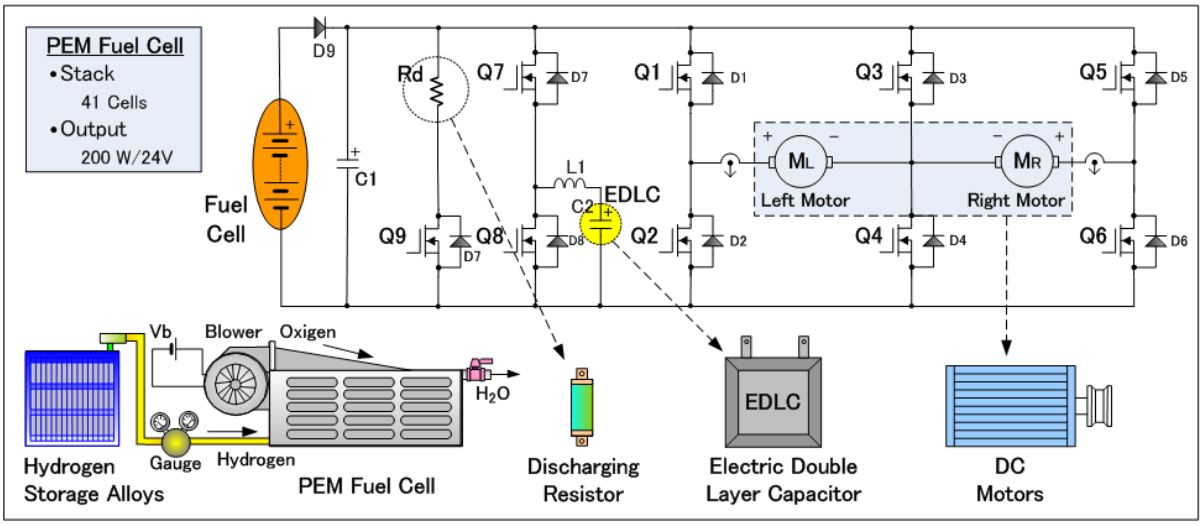
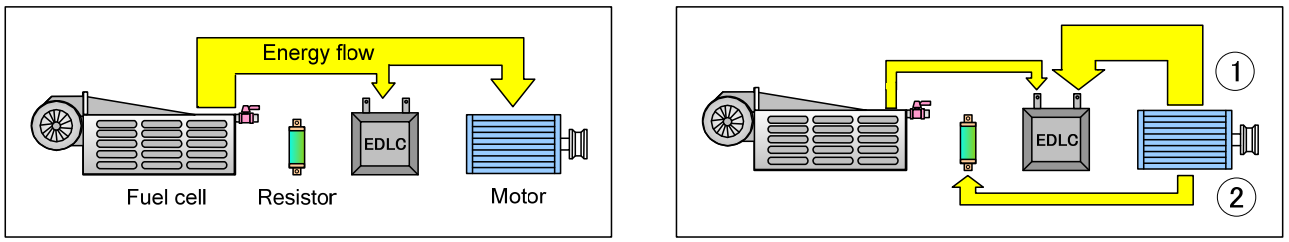


Fig. 4 Control of energy flow and motor drive circuit



(a) Motoring mode (b) Regeneration mode

Fig. 5 Examples of energy flow among main devices

3. Characteristics of Fuel Cell

Several types of fuel cells have been developed and applied on a lot of fields, above all things, PEM fuel cells are the most suitable for electric vehicles or electric wheelchairs, because PEM fuel cells can be used at room temperature and the sizes are small. The hydrogen storage alloys is connected with the PEM fuel cell as illustrated in Fig. 4. This figure also shows the flow of hydrogen and oxygen by the arrows. Effect of chemical reaction, only water vapor is exhausted.

Figure 6 demonstrates the characteristics of the PEM fuel cell obtained by experiments. As load (output current) increases, output voltage droops gradually. Meanwhile the maximum output power reaches around 200W.

Figures 7 and 8 show the experimental results for the output power of the PEM fuel cell, when the forward mode and the left turn mode are carried out. As shown in Fig. 7, the maximum output power reaches at 100W, and the steady state value of it is about 55W. For Fig. 8, the correspondent values are 105W and 45W, respectively. Besides, the output power is about 30W when the two motors don't work (indicated "Stop" in Figs. 7 and 8). The reason of it is operation of the blower, i. e., the PEM fuel cell is also used as the power supply of the blower motor which inhales oxygen from the air.

These data assures that the PEM fuel cell has enough capability for the electric wheelchair system.

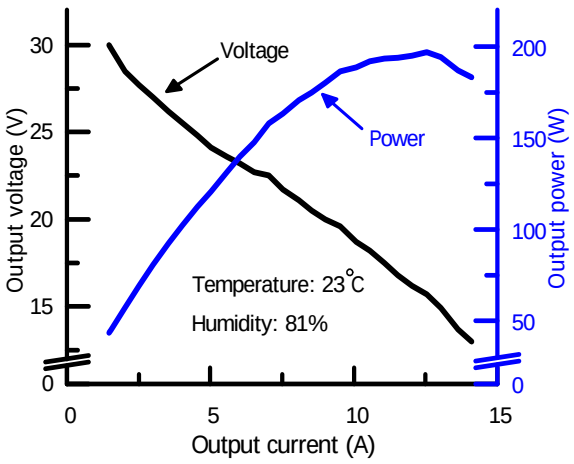


Fig. 6 Characteristics of PEM fuel cell

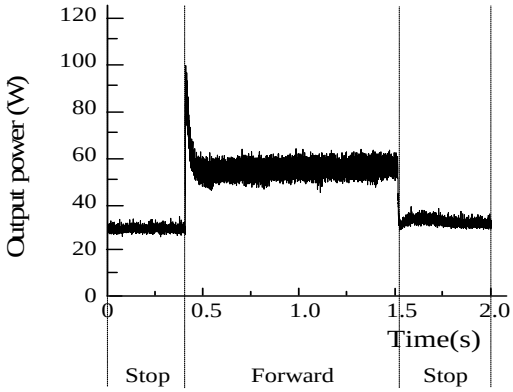


Fig. 7 Output power of PEM fuel cell (Forward)

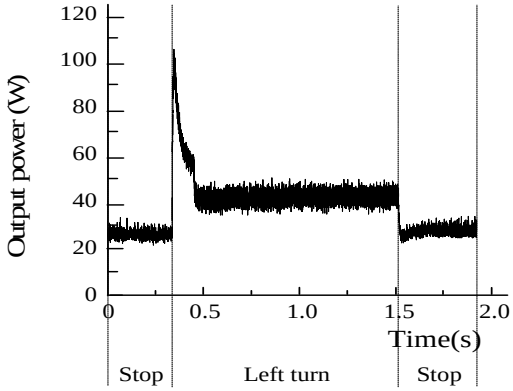


Fig. 8 Output power of PEM fuel cell (Left turn)

4. Drive Performance of Wheelchair

The electric wheelchair has several drive modes; forward, backward, right/left turn, and pivot mode. The motors mounted on both the wheels are driven by the four-quadrant DC chopper which is designed to simplify the motor drive circuit. While, to measure the velocities of the wheels, speed detectors are installed on both the tires.

4.1 Four-Quadrant DC Chopper

The four-quadrant DC chopper has a combined structure of two full-bridge choppers. Hence, the number of switching device can be reduced from eight to six, as illustrated in Figs. 4 and 9.

Figure 9 illustrates the operating condition of the DC chopper at the forward mode. Thick arrows indicate the current path of the two DC motors and the switching devices (MOSFETs). For the forward mode, Q_1 & Q_5 and also Q_4 have PWM switching condition.

Figure 10 shows the waveforms of the DC chopper at the forward mode. PWM switching frequency of Q_1, Q_2, Q_5, and Q_6 is 10kHz, on the other hand, that of Q_3 and Q_4 is 1kHz. When Q_4 is ON condition and Q_1 & Q_5 are in switching operation, the two DC motors rotate in forward direction at once.

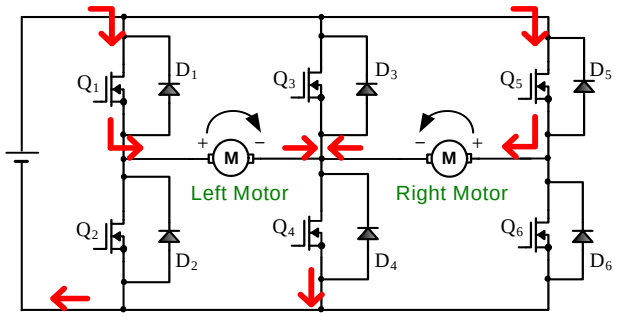


Fig. 9 Operation of DC chopper (Forward)

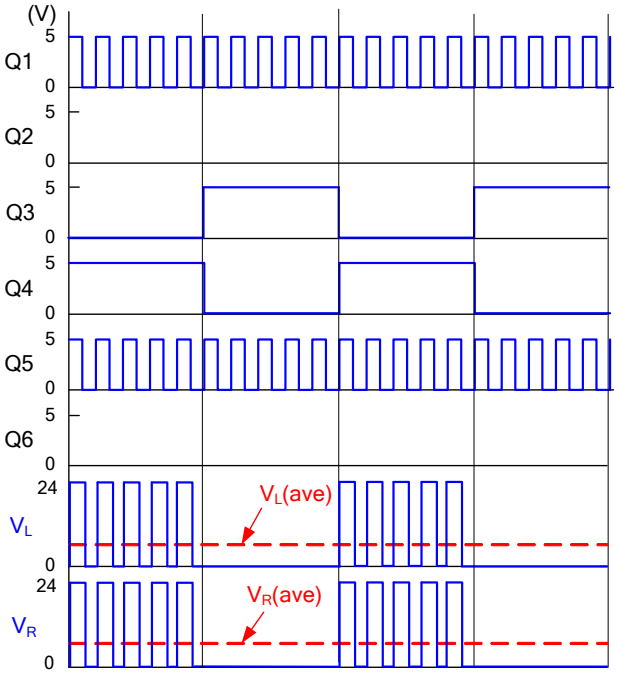


Fig. 10 Waveforms of DC chopper (Forward)

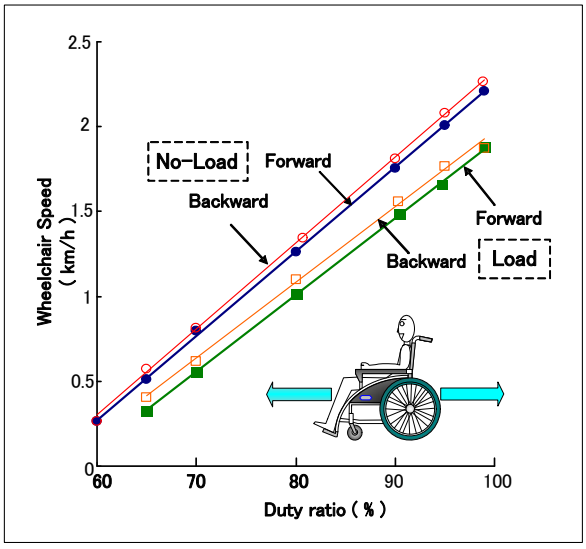


Fig. 11 Wheelchair speed to switching duty ratio

Figure 10 also describes the voltage waveforms of the left motor (V_L(ave)) and the right motor (V_R(ave)) of the wheels, when chopper operation is acting. Thus, the electric wheelchair moves forward.

4.2 Speed Characteristics of Wheelchair

Figure 11 shows the wheelchair speeds for the forward and the backward modes under both the conditions of load (a user who weighs 75kg) and no-load. From these data, it is known that the speeds increase linearly as the switching duty ratios of Q_1 & Q_5 (for the forward mode) or Q_2 & Q_6 (for the backward mode) get higher. According to these experimental results, basic speed characteristics of the electric wheelchair have been assured.

5. Conclusions

In this paper, the electric wheelchair system using the PEM fuel cell is discussed. The additional points of the system are utilizing the EDLC bank as the energy buffer, and the newly designed four-quadrant DC chopper which drives the two DC motors. Essential characteristics of the PEM fuel cell and drive performance of the wheelchair have been investigated by experiments.

As a result, it is proved that the PEM fuel cell is adaptable to the electric wheelchair system, and basic operations of the wheelchair have been achieved.

The authors expect the ideas and technologies which are examined by this study will contribute to not only electric wheelchairs but also future electric vehicles and transportation.

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References

[1] G. Hoogers, “Fuel Cell Technology Handbook”, CRC Press, USA, 2003.

[2] J. Larminie and A. Dicks, “Fuel Cell Systems Explained (2nd Edition)”, John Wiley & Sons Ltd., UK, 2003.

[3] S. Iizuka, “Possibility of Fuel Cell Cars and Electric Vehicles”, Grand Prix Publisher Co., Ltd.,

Japan, 2006.

[4] S. Yamaguchi and T. Ikemoto, “Electric Wheelchair Using Ni-MH Battery Aided by Fuel Cell”, Journal of Asian Electric Vehicles, Vol. 5, No. 2, pp. 1049-1053, 2007.

[5] R. A. Cooper, “Wheelchair Selection and Configuration”, Demos Medical Publishing, Inc., USA, 1998.

[6] C. Anyapo, K. Saito, and T. Noguchi, “Development of Electric Wheelchair Using Fuel Cell”, Niigata Branch of IEEJ, IV-6, p. 56, 2006.

[7] K. Saito, C. Anyapo, and T. Noguchi, “Development of Electric Wheelchair Using PEM Fuel Cell”, The International Workshop on Mechatronics, pp. 44-46, 2006.

[8] K. Saito, C. Anyapo, and T. Noguchi, “Basic Performance of an Electric Wheelchair Using Fuel Cell”, The Joint Seminar on Advances in Engineering between Thammasat Univ. and Nagaoka Univ. of Tech., pp. 38-40, 2006.

[9] K. Saito, P. Kamjitjam, C. Anyapo, T. Noguchi, ”Development of Electric Wheelchair Using Fuel Cell in Nagaoka Univ. of Tech.”, The Joint Symposium 2007 between Pathumwan Inst. of Tech. and Nagaoka Univ. of Tech. on Advanced Practical Engineering, pp. 63-68, 2007.

[10] C. Anyapo, K. Saito, and T. Noguchi, “Development of an Electric Wheelchair Using PEM Fuel Cell”, The 1st Thailand-Japan International Academic Conference, NS-E06, pp. 107-108, 2008.