DESIGN AND IMPLEMENTATION OF NEW DC MOTOR DRIVE CIRCUIT FOR ELECTRIC WHEELCHAIR USING PEM FUEL CELL

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Abstract

This paper introduces two types of newly designed DC chopper circuits that can drive two DC motors at the same time, which is applied to an electric wheelchair system. This system also has a Proton Exchange Membrane Fuel Cell stack as a power supply and an Electric Double Layer Capacitor bank as an energy buffer.

Feature of the first designed DC chopper is reducing the number of switching devices, but it has an elemental disadvantage which means decrease of chopper output voltage. Then the electric wheelchair cannot move at the inherent maximum speed. Therefore, this paper demonstrates an improved DC chopper which has voltage boost function to keep chopper output voltage to the maximum value. It is able to maintain DC bus voltage when the voltage of the PEM fuel cell varies. Besides, even in the case of the improved DC chopper, the number of switching devices does not increase. Operations of this chopper circuit is examined by experiments. As a result, it is cleared that the improved DC chopper has essential performance for driving two DC motors simultaneously.

Keywords: electric wheelchair, PEM fuel cell, EDLC, DC motor, DC chopper, boost function

1. INTRODUCTION

Recently, discussions on fuel cells have been increased significantly. Regarding problems of the global environment and exhaustion of natural resources, the study of an application of fuel cells is noteworthy (Hoogers, 2003), (Larminie, 2003). Besides, several types of electric vehicles using fuel cells have been developed by car manufacturers and institutes (Iizuka, 2006). Therefore, a combination of fuel cells and electric vehicles or wheelchairs is meaningful topic (Yamaguchi and Ikemoto, 2007).

For problem of air pollution, especially in Bangkok, Thailand, to study on application of fuel cells is meaningful. Because, fuel cells are clean energy power sources and have high efficiencies of power conversion. Also, there is an increasing problem of the aging society in Japan. From this viewpoint, the study of wheelchairs is important.

This paper introduces an electric wheelchair system which uses a Proton Exchange Membrane (PEM) fuel cell as a power supply. The system also has an Electric Double Layer Capacitor (EDLC) bank as an energy buffer, and a four-quadrant DC chopper which drives two DC motors. The motors are mounted on both of the back wheels, and speed detectors for experiments are installed on both of the back tires (Anyapo et al., 2006), (Saito et al., 2006), (Kamjitjam et al., 2007), (Saito et al., 2008).

Basic performances of two types of newly designed DC choppers are introduced in this paper. The additional point of this study is to examine a three-leg full-bridge DC chopper with boost function, which improves essential operation of DC choppers (Anyapo et al., 2008, 2009).

2. STRUCTURE OF ELECTRIC 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).

Fig. 1. Electric wheelchair.

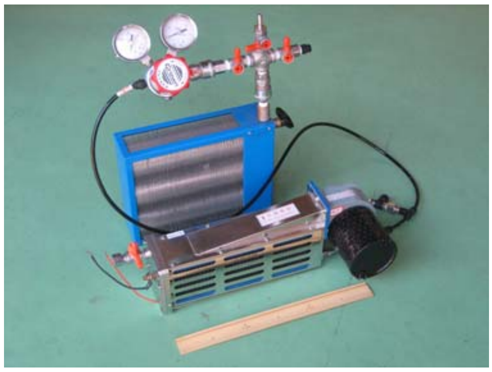


Fig. 2. PEM fuel cell and hydrogen storage alloys.

The two DC motors are driven by the newly designed four-quadrant DC chopper, and the EDLC bank is employed as an energy buffer managing energy flow of the system. Their major specifications are as follows;
(**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).
A user of the wheelchair handles only a joy-stick which can select a drive mode (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 of the back wheels are driven by the DC chopper for commanded drive mode.
Management of energy flow and the motor drive circuit of the wheelchair system are illustrated in Fig. 3. 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 the drive conditions of the wheelchair system. For example, the EDLC supplies energy to the two DC motors when the output power of the fuel cell lacks for motor drive. When regeneration of the motors occurs, normally the EDLC is charged.

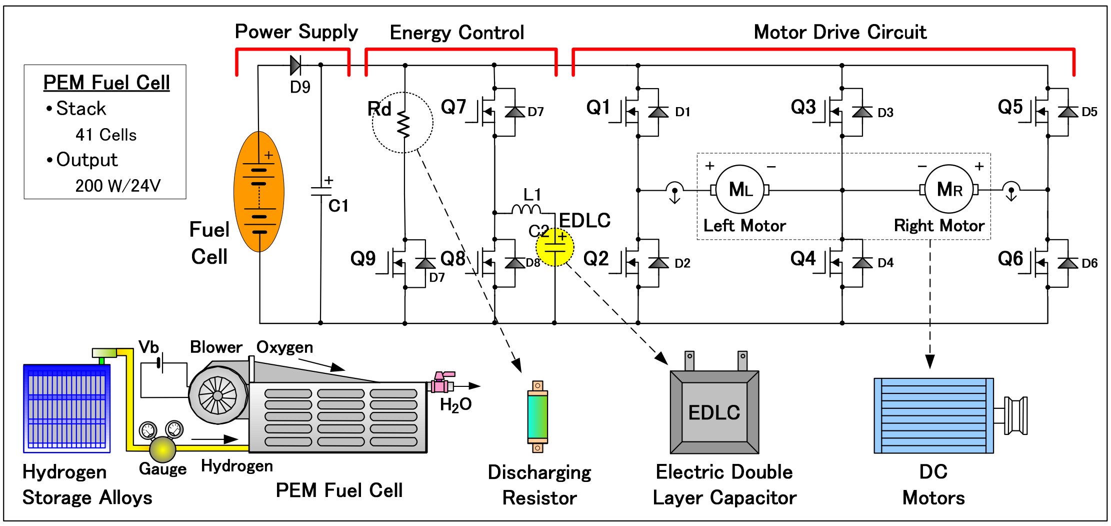


Fig. 3. Management of energy flow and the motor drive circuit.

3. CHARACTERISTICS OF PEM FUEL CELL

Several types of fuel cells have been developed and applied in many 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 are connected with the PEM fuel cell, as illustrated Fig. 3. This figure shows the flow of hydrogen and oxygen by the use of arrows. By the electrochemical reactions, only water vapor is exhausted.

Figure 4 demonstrates the characteristics of the PEM fuel cell obtained by experiments. As load (output current) increases, output voltage gradually drops. Meanwhile the maximum output power reaches around 200W.

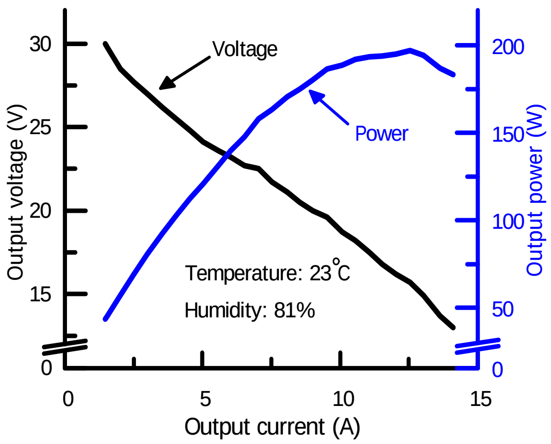


Fig. 4. Characteristics of the PEM fuel cell.

4. FOUR-QUADRANT DC CHOPPER

The motors mounted on both of the back wheels are driven by the four-quadrant DC chopper which is designed to simplify the motor drive system. The DC chopper which drives the two DC motors has a combined structure of two full-bridge choppers. Therefore, the number of switching devices can be reduced from eight to six, as illustrated in Figs. 3 and 5.

Figure 5 illustrates the operating condition of the DC chopper in the forward drive mode. Thick arrows indicate the current path of the two DC motors and the switching devices (MOSFETs). In the case of this mode, Q_1 & Q_5 and also Q_4 have PWM switching conditions. The PWM switching frequency of Q_1, Q_2, Q_5, Q_6 is 10kHz, and that of Q_3, Q_4 is 1kHz with 50-% duty cycle. When Q_4 is ON condition and Q_1 & Q_5 are in switching operations, the two DC motors rotate in a forward direction at once.

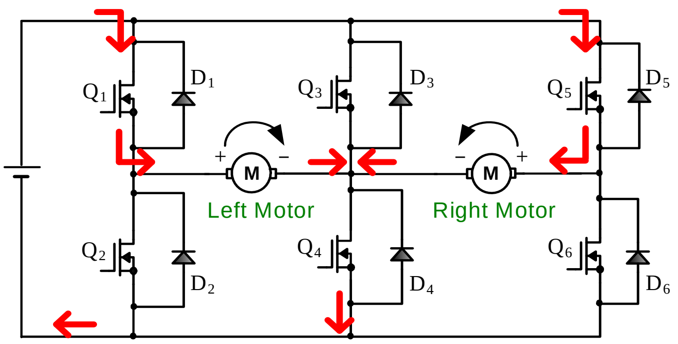


Fig. 5. Operation of the four-quadrant DC chopper (forward drive mode).

5. IMPROVEMENT OF DC CHOPPER

The DC chopper shown in Fig. 5 has an essential disadvantage, i.e., the 50-% duty cycle switching operation of Q_3 and Q_4 limits the chopper output voltages to half of the power source. Assuming that a 200-W, 24-V PEM fuel cell is a power supply, the maximum voltages across the two DC motors are limited to 12V, which implies that the maximum speed of the motors is reduced to half of the inherent rated value. Inserting a boost circuit between the power source and the three-leg full-bridge chopper may solve this problem, resulting in increase of the switching device counts and complexity of the circuit configuration.

A novel approach to solve the above drawback is presented in Fig. 6. The two DC motors are driven by the three-leg full-bridge chopper, which is composed with superimposed two full-bridge choppers at the center leg. The switching frequencies of MOSFETs are the same with the four-quadrant DC chopper shown in Fig. 5.

The most significant point of this configuration is a voltage boost function of the center common leg, where the power source is connected to the mid nod. The voltage boost ratio must be determined by the duty cycle of Q_3 and Q_4 to maintain the DC bus voltage at a constant value even though the power source voltage varies. Therefore, the duty cycles of Q_1, Q_2, Q_5 and Q_6 are also adjusted in accordance with the voltage boost ratio of the center leg.

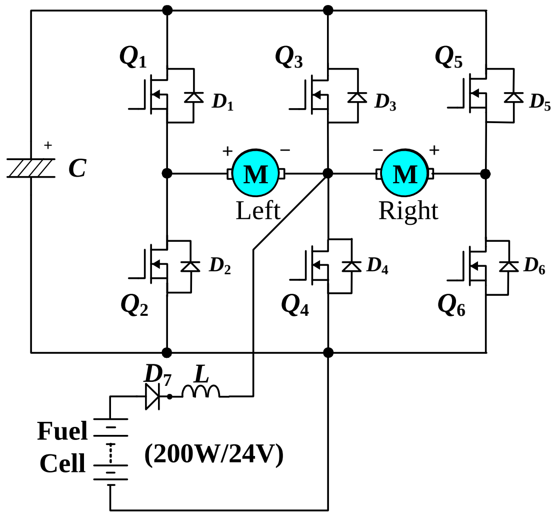


Fig. 6. Improved three-leg full-bridge DC chopper with boost function.

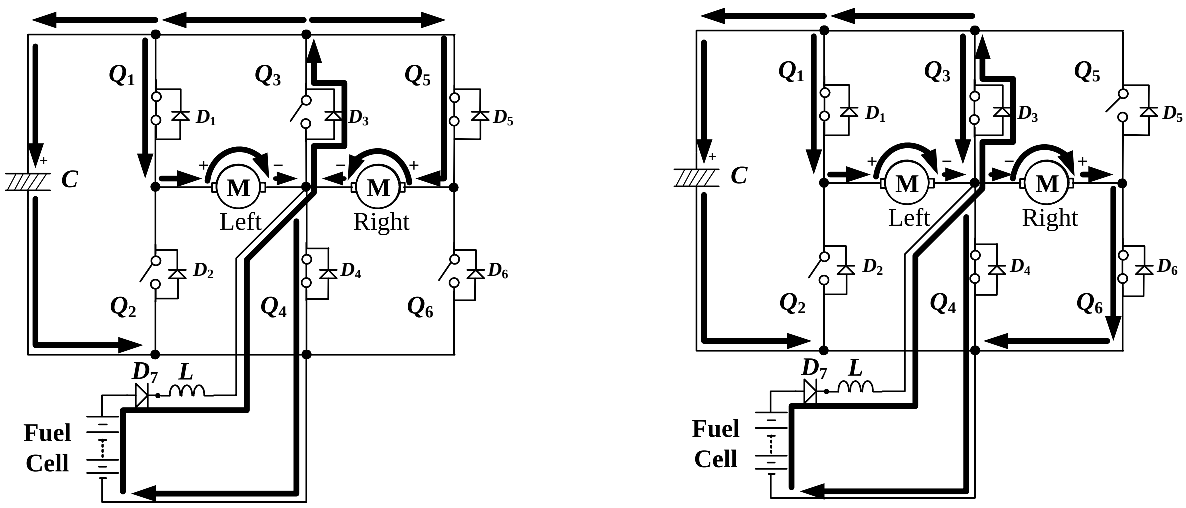
Fig. 7 shows the operation of improved DC chopper incorporated voltage boost function. Fig. 7 (a) illustrates the case of the forward drive mode where both of the two DC motors are operated in the same direction to move the wheelchair forward. On the other hand, Fig. 7 (b) illustrates the case of the right-turn pivot mode where the two DC motors are operated in the opposite directions with each other to turn the wheelchair to the right. The figures also indicate current paths in the DC chopper.

As shown in Fig. 7 (a), the forward mode makes Q_1, Q_4 and Q_5 turn on, and makes Q_2, Q_3 and Q_6 turn off. The switching operation of Q_4 allows voltage boost action and provides current flows through the two DC motors at the same time. For backward mode, Q_2, Q_3 and Q_6 are turned on, while Q_1, Q_4 and Q_5 are turned off.

Fig. 7 (b) shows the current paths when the right-turn pivot mode is carried out. In this mode, turning on Q_3 and Q_6 allows the right DC motor rotating in the reverse direction, while turning on Q_1 and Q_4 makes it possible to rotate the left DC motor in the forward direction and to boost the power source voltage at the same time.

In the case of regeneration from both of the two DC motors, a diode D_7 blocks the power flow back into the power source, i. e., the PEM fuel cell. The regenerated power of the motors is stored only in a DC bus capacitor *C*.

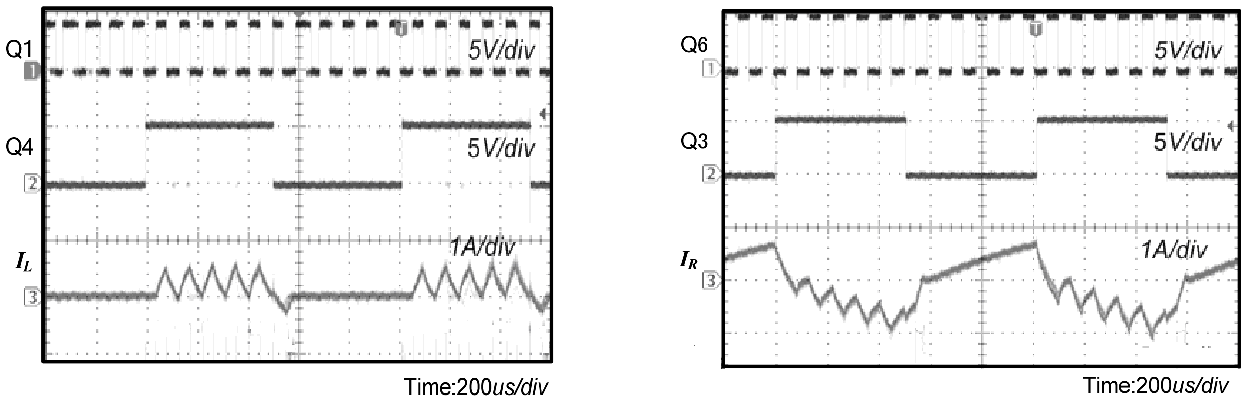
Fig. 8 shows experimental results; (a) is the case of the forward drive mode, and (b) is the case of the backward drive mode. The former shows the gate signals of Q_1, Q_4 and current waveform of the left motor I_L, and the latter shows the gate signals of Q_6, Q_3 and current waveform of the right motor I_R. Both of the actual drive operations are confirmed by experiments.



(a) Forward drive mode.

(b) Right-turn pivot mode.

Fig. 7. Basic operations of the improved three-leg full-bridge DC chopper.



(a) Forward drive mode.

(b) Backward drive mode.

Fig. 8. Experimental data of the improved three-leg full-bridge DC chopper.

6. CONCLUSIONS

In this paper, the prototype electric wheelchair using the PEM fuel cell is discussed. The points of the wheelchair system are also utilizing the EDLC bank as the energy buffer and the newly designed four-quadrant DC chopper which drives the two DC motors. Considering the essential characteristics of the PEM fuel cell, basic drive performance of the wheelchair has been examined.

Furthermore, this paper introduces the improved three-leg full-bridge DC chopper with voltage boost function, which can remove a disadvantage of the first designed four-quadrant DC chopper.

As a result, it is shown that the PEM fuel cell can be adapted to the electric wheelchair system, and fundamental operations of the improved DC chopper has been achieved.

The next stage of this subject is to examine the management of energy flow among the PEM fuel cell, the EDLC bank, and the two DC motors.

The authors hope that the ideas and technologies which have been investigated in this study will contribute to not only electric wheelchairs but also future electric vehicles and transportation.

ACKNOWLEDGEMENTS

We would like to thank Power Systems Co., Ltd. for providing the EDLCs, and QM Soft Co., Ltd. for informing us about the PEM fuel cell and the hydrogen storage alloys. Special thanks are due to Mr. Pitak Kamjitjam for carrying out some experiments and discussions.

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