Four-Quadrant Operation of Two DC Motors with Three-Leg Full-Bridge Chopper Incorporated Voltage Boost Function

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1. Introduction

This paper proposes a novel chopper circuit and its operation capable to drive two DC motors at the same time, which is mainly applied to an electric wheelchair drive. The key feature of the proposed circuit is reduced counts of the switching devices without sacrificing a perfectly independent four-quadrant operation and a voltage boost operation of a power source. Several experimental results are presented to confirm proper operations of the proposed circuit.

2. Three-Leg Full-Bridge Chopper to Drive Two DC Motors

Figure 1 shows a three-leg structure based full-bridge chopper to drive independent two DC motors simultaneously, which was proposed by the authors in the past work (1), (2). In the circuit, a center leg composed with Q_3 and Q_4 is operated at a relatively low-frequency, e. g., 1 kHz, while the other two legs composed with Q_1, Q_2, Q_5 and Q_6 are operated at a frequency approximately ten times of the center leg. The switching operation of Q_3 and Q_4 is complementary with a 50-% duty cycle; hence the proposed chopper allows independent drive of the two DC motors in four-quadrant operation modes.

However, 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 12 V, 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. 2. 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 total number of the switching devices is reduced to six. The switching frequency of Q_1, Q_2, Q_5 and Q_6 is 10 kHz, while that of Q_3 and Q_4 is set at 1 kHz.

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 node. 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.

3. Operations of Proposed Chopper Incorporated Voltage Boost Function

In this section, two basic operations are discussed. One is the case of a forward motion where both of the two DC motors are operated in the same direction to move the wheelchair forward. The other is a right-turn pivot motion where the two DC motors are operated in the opposite directions with each other to turn the wheelchair to the right.

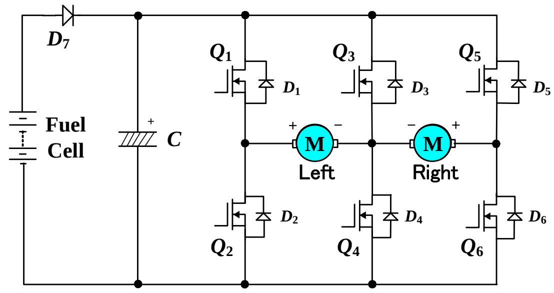


Fig. 1. Three-leg full-bridge chopper for pair of DC motors.

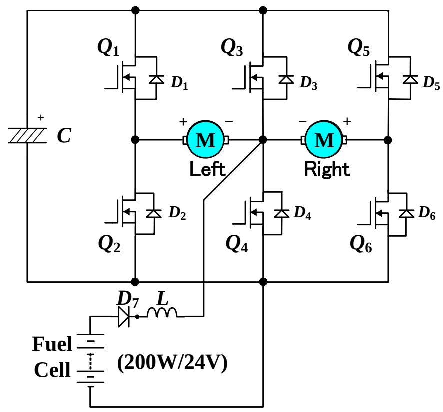
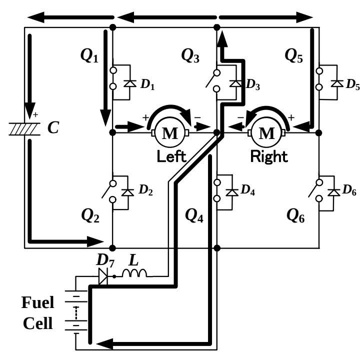
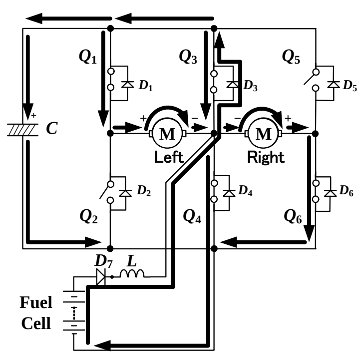


Fig. 2. Three-leg full-bridge chopper with boost function.



(a) Forward motion.



(b) Right-turn pivot motion.

Fig. 3. Basic operations of proposed circuit.

Figure 3 (a) and Figure 3 (b) illustrate current paths in the three-leg full-bridge chopper with voltage boost operation. As shown in Fig. 3 (a), the forward motion 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 motion of the wheelchair, Q_2, Q_3, and Q_6 are turned on, while Q_1, Q_4 and Q_5 are turned off.

Figure 3 (b) shows the current paths when the right-turn pivot motion is carried out. In this motion, 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 .

4. Experimental System and Results

A prototype of the proposed circuit was designed and set up, of which principal electrical parameters are listed in Table 1. Using the prototype, some basic operations were examined through the experimental tests. Figure 4 and Figure 5 show the gate signal waveforms of the switching devices in the prototype circuit. Figure 4 (a) corresponds to the forward motion of the wheelchair, and Fig. 4 (b) represents the waveforms in backward motion.

As described in the previous section, the forward motion makes Q_1 and Q_5 operate at 10 kHz and Q_4 at 1 kHz with 50-% duty cycle. As shown in Fig. 4 (b), Q_2 and Q_6 repeats their switching action at 10 kHz according to the motor voltage command, and Q_3 and Q_4 keep on operation of 1 kHz with 50-% duty cycle.

Figure 5 shows the gate signals when the right-turn pivot motion is performed. Even in this case, Q_3 and Q_4 maintain 1 kHz, 50-% duty cycle operation, which makes it possible to boost up the power source voltage.

5. Conclusion

A novel technique to drive independent two DC motors at the same time was proposed in this paper. The proposed power circuit consists of three-leg full-bridge chopper, which has advantage over conventional circuit configuration in the reduced counts of the switching devices. In addition, the proposed three-leg configuration incorporates the voltage boost function of the power source. This function compensates for the reduced voltages applied to the motors. This circuit configuration can be applied to not only electric wheelchairs but also other traction systems that require multiple pairs of DC motors.

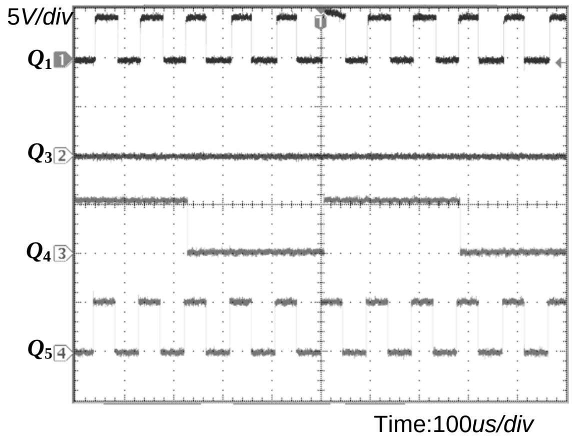
References

(1) C. Anyapo, K. Saito, T. Noguchi, “Development of Electric Wheelchair Using Fuel Cell”, Proceedings of Niigata Branch of IEEJ, IV-6, p. 56, 2006.

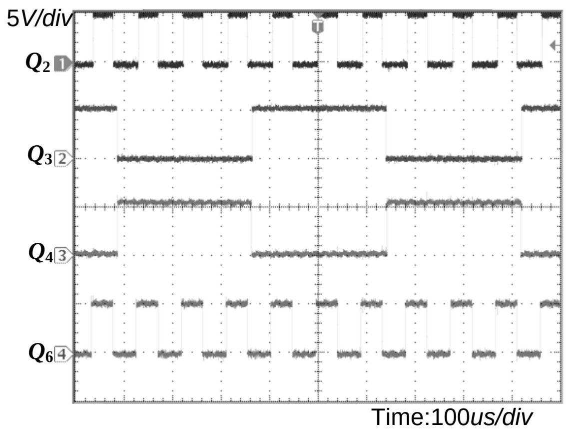
(2) C. Anyapo, K. Saito, T. Noguchi, “Full-Bridge Chopper for Driving Two DC Motors with Reduced Counts of Switching Devices”, Proceedings of Niigata Branch of IEEJ, IEEE-13, p. 143, 2008.

Table 1. Electrical parameters of prototype.

Voltage of power supply	24 V
Switching frequency (Q_1, Q_2 , Q_5, Q_6)	10 kHz
Switching frequency (Q_3, Q_4)	1 kHz
Capacitor C	3600uF, 350 V
Rated power of DC motors	110 W
Rated voltage of DC motors	72 V



(a) Forward motion.



(b) Backward motion.

Fig. 4. Gate signals in forward and backward direction.

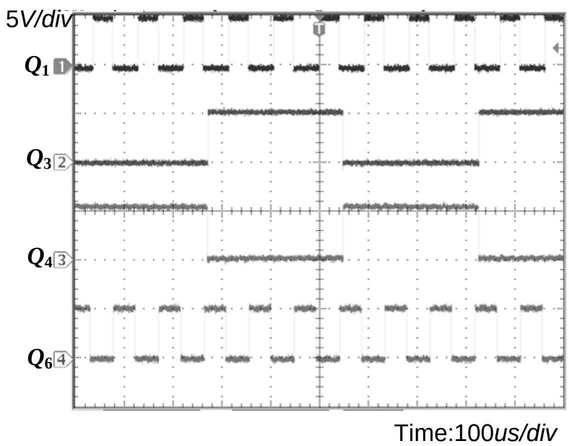


Fig. 5. Gate signals in right-turn pivot motion.

