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Design of Integrated Power Module for Electric Scooter

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Abstract

This paper concerns the design of a general purpose integrated power module (IPM) for electric scooters. The basic design concepts of the IPM are to integrate the protection circuit into the gate driving circuit and dispose an anti-reverse connection device between an input end of the electric power and the motor controller. With that, the damage problem of the power board can be efficiently improved. Furthermore, the complexity of implementation of the control board is also reduced. Finally, the validity of proposed IPM is experimentally tested on a 2kW electric motor.

Keywords: integrated power module, protection circuit, electric scooter.

1 Introduction

In many countries in Asia, scooters are regarded as the primary vehicle used for transportation. Due to air pollution and other issues, electric scooters are regarded as an alternative to substitute the scooters with gasoline-powered internal-combustion engines [1-5]. The most important technology of electric scooters is electrical propulsion system (EPS). Generally speaking, an EPS is consisted of traction motor, motor control unit (MCU) and vehicle control unit (VCU). Today's solutions for EPS require more flexibility and a higher level of integration that could be achieved only through specialized devices. According to the present market estimate for electric scooters in Taiwan, a scheme consisting of 2kW EPS and 48 Volt batteries is regarded as one of main developments for the future [5]. The benefit of this scheme has to be seen in a lower system cost due to the reduction of battery volume and high integration of power module. However, high integration poses a number of practical challenges to the designers. Therefore, it motivates us to develop a general purpose integrated power module (IPM) for electric scooters. The remainder of this paper is organized as follows. In Section 2, a brief schematic diagram for IPM is provided. The design objectives of this paper are formally stated. In Section 3 we have developed several specialized module to form the proposed IPM. Among them, we also introduce an anti-reverse connection device to avoid the occurrence of the damage problem of the power board. The simulation results are presented in Section 4. Conclusions are provided in Section 5.

2 Background

A three-phase motor is connected to the IPM, as illustrated in Fig. 1.

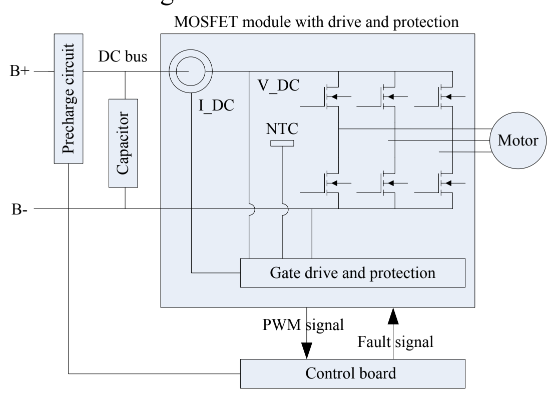

Figure1: Schematic diagram for IPM

Table1: Electrical characteristics of a general purpose IPM

Electrical parameters	**Values**	**Unit**
Max. voltage	80	V
Max. input rated current $_{(rms)}$	100	A
Input rated voltage	48	V
Over voltage (OV) protection	60 (adjustable)	V
Under voltage (UV) protection	36 (adjustable)	V
Over current (OC) protection	100 (adjustable)	A
Over temperature (OT) protection	125 (adjustable)	℃
Dimension	127(L)x96(W)x33(H)	mm
Cooling (Ta=25)	Natural cooling	
Input	Six individual PWM signal to drive the MOSFET power devices Reset inputs +15V GND	
Output	DC current DC bus voltage Power devices fault signals Digital error signals(OC/OV/UV/OT)	

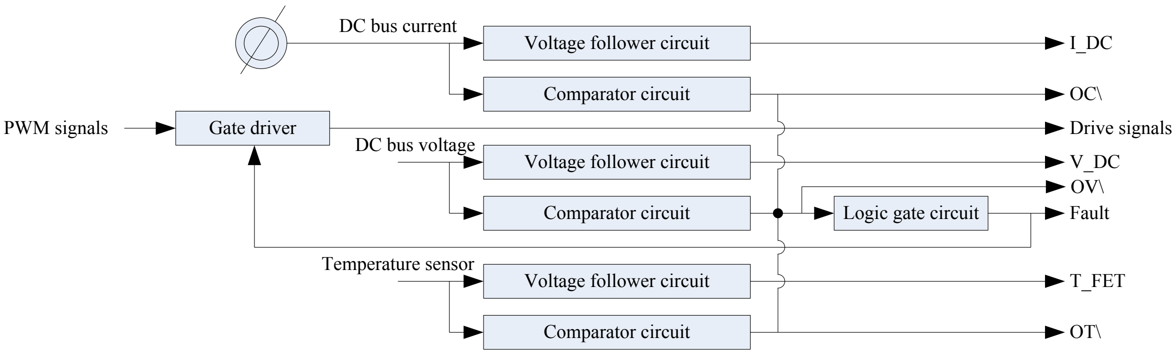

Figure2: Schematic diagram for gate driving circuit

The protection circuit of the proposed IPM can deal with the most important types of those failures, which are the over current (OC), the over/under voltage (OV/UV) and over temperature (OT). The relevant discussions can be found in [6-8].

If any fault is detected during operation of the motor, a warning message appears on the digital signal processor (DSP) of the control board and then the operation of the motor is changed. Briefly speaking, the goal of this paper is to form a protection mechanism preventing the damage of power board. Table 1 lists all characteristics of the proposed IPM.

3 Main Results

In order to form the proposed IPM, the design concepts of the gate driver and power stage are presented in order. Then an anti-reverse connection device is investigated for solving the damage problem of the power board

3.1 Gate Driver

Through the measuring data from DC bus, the sub-circuits of the gate driving circuit produce the corresponding signals. Meanwhile, by inputting the signals to a logic gate circuit, the gate driver gives the relevant drive signals. Of course, if any signal is over its pre-defined level, a disable signal is produced. Due to this, the power components can be protected and the control board can directly enable the relevant protection circuits. A schematic diagram for gate driving circuit is shown in Fig. 2.

3.2 Power Stage

For achieving low switching loss and low cost, the power stage is constructed by three half-bridge modules with three MOSFETs in parallel (per arm of the bridge). Therefore, it should be known that there is 18 MOSFETs used in the power stage and each MOSFET is with about 33% phase current. Besides, in order to achieve the functions of over temperature protection (OTP) and detection, a detection circuit is built by the divided voltage of the NTC resistances.

For practical issues, although the maximum values of operating voltage and continuous current are 100V and 100A, respectively, it is necessary to consider the possible transient responses of the whole circuit (e.g. voltage overshoot and voltage spike). Therefore, for safety purpose, the power components are chosen to satisfy the requirement of 150% transient response in voltage.

3.3 Anti-reverse connection device

In Fig. 3, an anti-reverse connection device for motor controller is provided which includes a pre-charging unit, a protection unit, a power conversion unit, and a control unit. When a high-voltage source is connected reversely, the power conversion unit will not convert the power signal outputted by the protection unit into a work voltage to the control unit. In other words, the pre-charging unit does not produce a pre-charge power signal to the power conversion unit; therefore, the reverse-bias voltage source will not affect the back-end circuit. Consequently, an anti-reverse connection mechanism is formed.

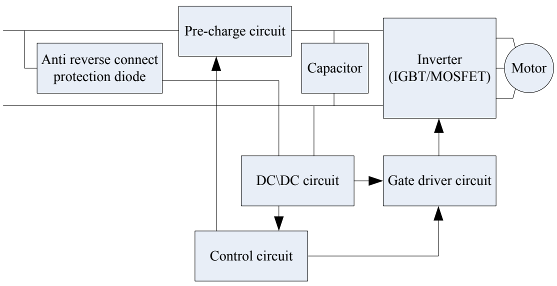

Figure3: Schematic diagram of the anti-reverse connection device

4 Experiments

The performance of the developed IPM is evaluated on a testing platform, where a 2kW permanent-magnet synchronous motor (PMSM) is used. Fig. 4 shows the testing platform for the IPM controller and Fig. 5 shows the experimental test for an electric scooter with IPM controller. By giving a range of values for torque, the performance of the system and the IPM are shown in Fig. 6 and Fig. 7, respectively. At first, it can be shown that the highest system efficiency is 89.4% when the torque of the PMSM is 3.04 Nm and its speed is 4,299 rpm. Furthermore, the efficiency of the IPM is 96.6%. Next, in Fig. 8, the maximum power of the IPM is about 2.4kW when the PMSM is running at the speed of 2,898 rpm. Meanwhile, the output power of the PMSM achieves 2.1kW.

From the experimental results, we conclude that the proposed IPM can be used to drive a 2kW PMSM achieving expected performance.

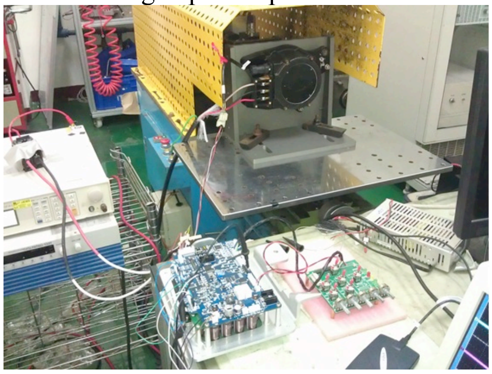

Figure4: Testing platform for IPM controller

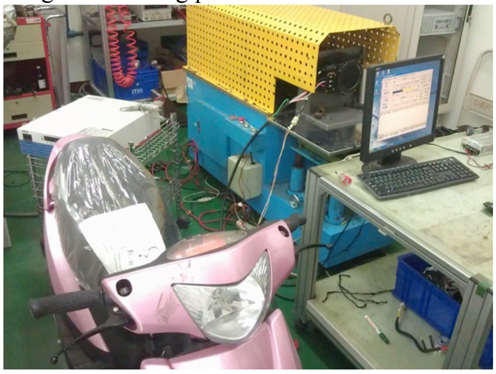

Figure5: Testing platform for Electric scooter

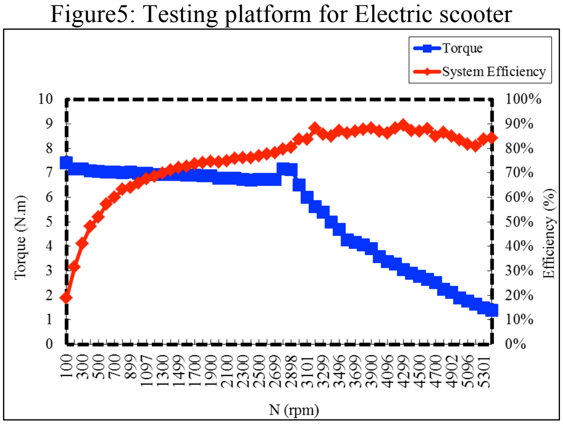

Figure6: Torque vs. system performance

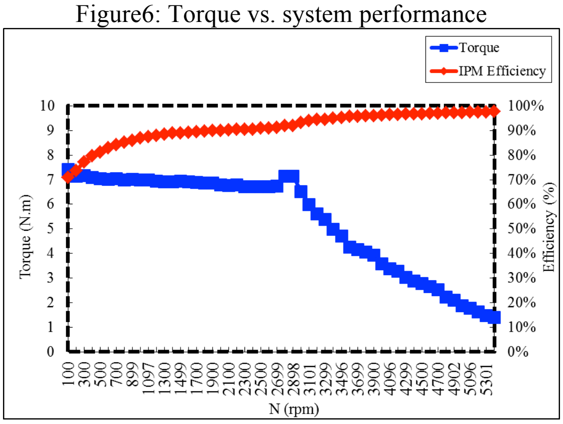

Figure7: Torque vs. IPM performance

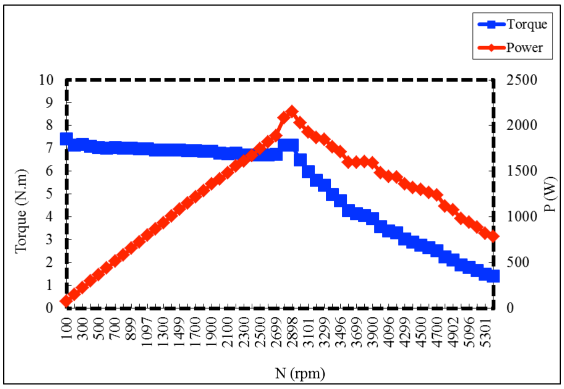

Figure8: Torque vs. controller performance

5 Conclusions

In this paper, a protection mechanism for power module is investigated. A three-phase motor is connected to the protection circuit through the measuring components, as illustrated in Fig. 1. The proposed DSP-controlled protective mechanism deals with the most important types of failures, which are summarized as the over current, the over/under voltage and over temperature. The efficiency of the proposed protection mechanism is verified on a 2 kW electrical motor.

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