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Introduction of Power Module for Brushed and Brushless Exciter System of Electrically Excited Synchronous Motor

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Abstract

This paper introduces the APM (Automotive Power Module) series for the Brushless Exciter of EESM (Electrically Excited Synchronous Motor) 1200V motor driver application. EESM is a new EV (electric vehicle) motor solution with higher efficiency compared to the Asynchronous Motor (ASM) due to field-weakening operation. Additionally, EESM does not require permanent magnets (which are made of rare earth materials), making it more environmentally friendly and cost-effective compared to permanent magnet synchronous motors (PMSM). In this paper, the operation of brushed and brushless exciter systems will be explained and compare the power loss of the two exciter systems through simulation. Additionally, it will introduce the solution developed by ONSEMI, which can be applied to both exciter systems.

1 Introduction

According to market surveys, permanent magnet synchronous motors account for more than 80% of the automotive motor market. However, the production of permanent magnets requires mining of rare earth elements such as neodymium and dysprosium. To meet the increasing demand for environmental protection and reduce reliance on the development of rare earth elements, research and development of motors that can replace permanent magnets are currently in progress.

The Electrically Excited Synchronous Motor (EESM) [1][2], as shown in Figure 1, is an emerging alternative for EV motor design, Exciter circuit enclosed within the red dotted line. The three-phase circuit supplies three-phase alternating current to the motor. The stator coils carry currents that change direction, resulting in changing magnetic fields. As the rotor coil intersects with these changing magnetic field lines, it promotes the rotation of the electric rotor. When the Exciter circuit reaches the steady-state, the inductive load generates DC power and reduces the flux levels when the motor operates at high speed, allowing energy to be stored in the high-voltage battery.

However, the EESM it is a type of brushed Motor, that the brushes not only wear out over time and will need to be replaced. And their contact with copper commutator results in the creation of very fine dust. The dust is not only conductive, so it could create a dangerous connection, but it is also considered a health hazard if inhaled. Other parts are also prone to wear in this type of motor, such as the slip rings, which are a hugely important part of the unit that transfers power between the rotor and the stator.

Therefore, many brushless exciters have been extensively researched and applied in the fields of generators and aircraft. However, in terms of automotive applications, many automotive manufacturers are still in the process of research and development [3]-[5]. In this paper, the operation of brushed and brushless exciters will be introduced. However, the emphasis here is on the electrical characteristics and circuit operation of the excitation system, rather than the structure and principles of the motor and mechanics. Additionally, the power performance between these two types

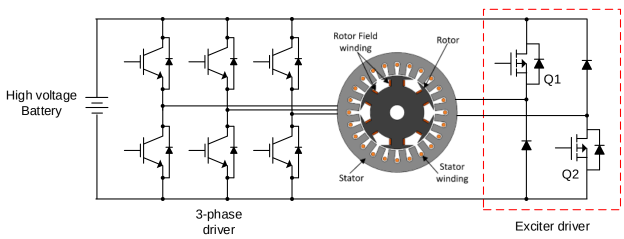

Fig. 1 Electrically Excited Synchronous Motor.

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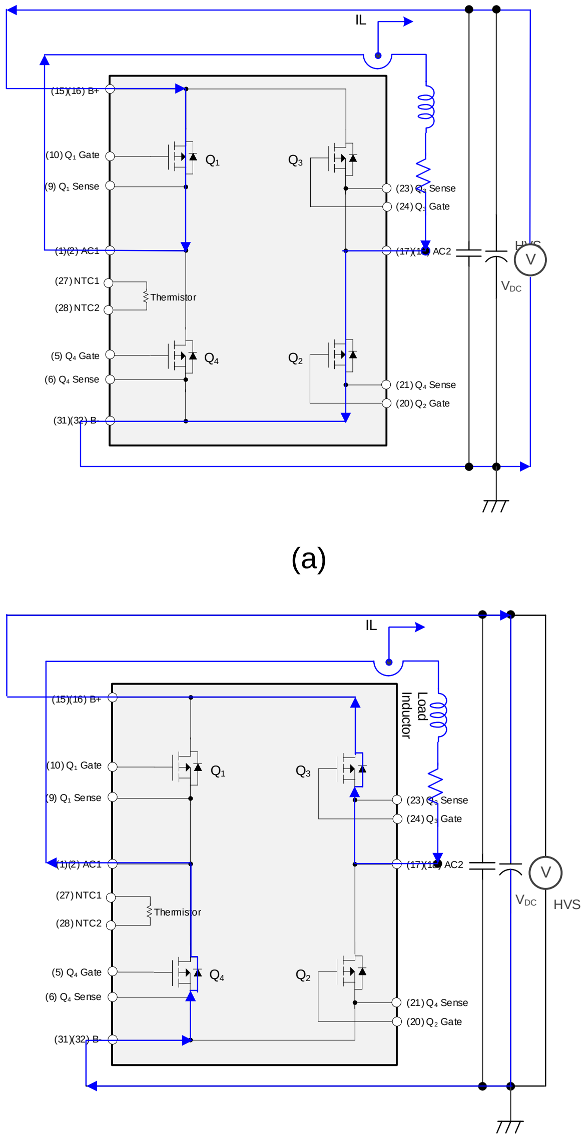
of exciter systems will be compared through simulation.

2 Operation of Exciter Systems

2.1 Brushed Exciter Operation

The brushed exciter charges and discharges the inductive load to generate a magnetic field with a constant direction, thereby replacing the permanent magnet. The current path of the brushed exciter is shown in Figure 2. When Q1 and Q2 are turn-on simultaneously, the high-voltage battery charges the inductive load (motor) of the Exciter, the current path as shown in Figure 2(a). Conversely, when Q1 Q2 are turn-off at the same time, the energy stored in the inductive load charges the high-voltage battery, thereby reducing flux levels during high-speed operation. And current will flow through the freewheeling diode when Q1, Q2 in off-state, as shown in Figure 2(b). This application is to obtain the required load current based on the duty control of Q1 and Q2. The duty of Q1 and Q2 should work between 0.5 and 1, 0.5 < duty < 1. Otherwise, the current of the inductive load could be not reaching the steady state to obtain the required load current.



(a)

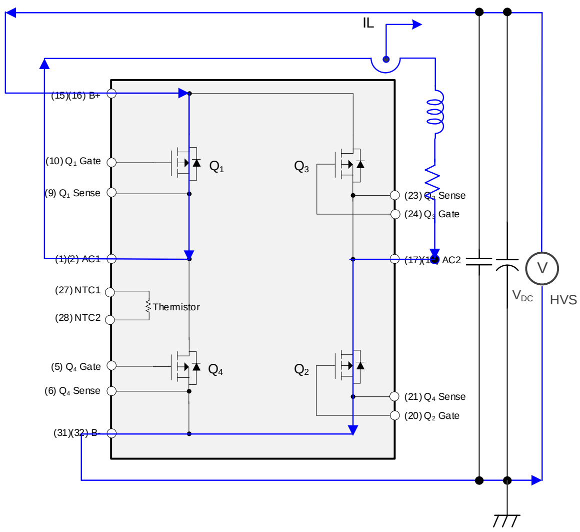
(b)

Fig. 2 Operation of brushed exciter application.

2.2 Brushless Exciter Operation

The operation principle of the brushless exciter is equivalent to that of an H-bridge circuit, which outputs AC current to the inductive load. The inductive load in this context is the primary side of the rotary transformer, which rectifies the current on the secondary side and supplies it to the rotor (inductive load). The H-bridge uses ONSEMI's product APM32. This paper will simulate the APM32 to predict power loss and provide the optimal solution.

The brushless exciter can operate in the signal mode of Sinusoidal Pulse Width Modulation (SPWM) or Space Vector Pulse Width Modulation (SVPWM). The simulation in this paper uses SPWM mode, and the current path is shown in Figure 3.



(a)

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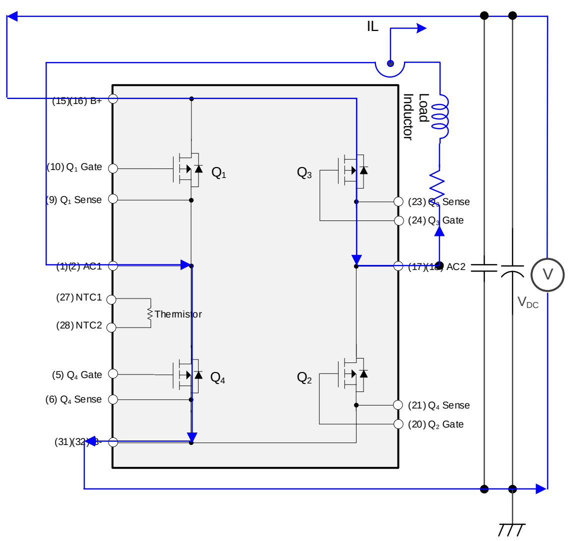

(b)

Fig. 3 Operation of brushless exciter application.

3 Simulation Result

As mentioned before, the Brushed Exciter system operation is when Q1 and Q2 are turned on at the same time to charge the inductive load, the duty of Q1 and Q2 should work between 0.5 and 1. When Q1 and Q2 are turned off at the same time, current will flow through the freewheeling diode when Q1 Q2 in off-state. So, the main power loss in Brushed Exciter system is switching loss and conduction loss of SiC MOSFET, and the reverse recovery loss and conduction loss of the freewheeling diode, here is body diode of MOSFET.

Condition: VGS=+18/-3V, Tf=65deg			External RG [ohm]		
			5	10	30
Total Power Loss [W]	Brushed Exciter	Q1, Q2	19.47	20.31	23.72
		Q3, Q4	35.25	34.96	34.66
	Brushless Ex-	Q1~Q4	44.02	46.20	60.80

Table 1 Total power loss of 2 kinds of Exciters.

The simulation condition for brushed exciter system is, VDC=826V, V_{GE}=+18/-3V, F_{sw}=20kHz, load current=20A, Tf=65℃, duty cycle=60%. The total power losses in simulation when the brushed exciter circuit reaches the steady state are presented in Table 1, and the values shown are per switch.

As for brushless exciter, operation under SPWM model, and the simulation condition is, VDC=900V, V_{GE}=+18/-3V, F_{sw}=70kHz, load current=20A_{rms}, Tf=65℃.

According to equation (1), the junction temperature can be calculated when the fluid temperature is fixed at 65 degrees. The calculation results are shown in Table 2. The thermal resistance values used in the calculations in Table 2 are Rthjf (SiC) = 1.433°C/W for SiC MOSFET. The maximum junction shown here is per switch.

$$T_j = T_f + R_{thjf} \cdot P_w \quad (1)$$

Condition: VGS=+18/-3V, Tf=65deg			External RG [ohm]		
			5	10	30
Max Tj [deg]	Brushed Exciter	Q1, Q2	92. 9	94.1	99.0
		Q3, Q4	115.5	115.1	114.7
	Brushless Excit-	Q1, Q2	128.1	131.2	159.0

Table 2 Estimation of the maximum junction temperature of 2 kinds of Exciters.

Due to the body diode of the MOSFET exhibits high V_F value at V_{GS} = 0V, the V_F value decreases when the MOSFET is turned on. It is evident that if the MOSFET is turned on during freewheeling instead of conducting directly through the body diode, the conduction loss during this period will be significantly reduced. Although turning on the MOSFET that should be turned off will increase the complexity of the circuit design because gate loops need to be designed for the other two MOSFETs of brushed exciter, this will reduce the system's losses.

Therefore, Table 3 presents the total power loss and maximum junction temperature of the Exciter system when Q1 and Q2 are turned off and Q3 and Q4 are turned on with V_{GS} = 18/-3V. It can be

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observed from the results in Table 3 that this application can also achieve better thermal performance results.

Condition: VGE=+18/-3V, Fsw=20kHz, 20A, Tf=65deg, duty cycle=60%		External RG [ohm]		
		5	10	30
Total Power Loss [W]	Q1, Q2	20.18	21.04	24.58
	Q3, Q4	7.58	7.58	7.60
Max Tj [deg]	Q1, Q2	93.92	95.14	100.21
	Q3, Q4	75.86	75.87	75.89

Table 3 Total power loss and maximum junction temperature estimation of Brushed Exciter for turning on the Q3, Q4 when Q1, Q2 off.

Figure 4 depicts the circuit diagram of the Excited Synchronous Motor Automotive Power Module proposed by ONSEMI. And outline overview showed in Figure 5. The product will ultimately be implemented using this package both for brushed and brushless exciter. We anticipate good thermal performance based on simulation results.

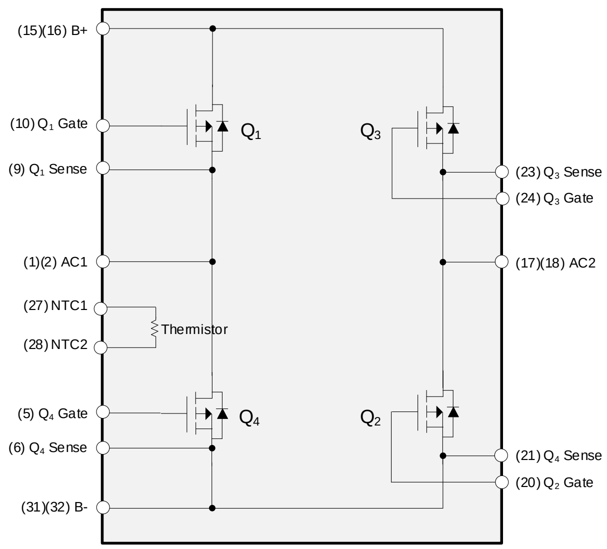

Fig. 4 Circuit diagram of Excited Synchronous Motor Automotive Power Module.

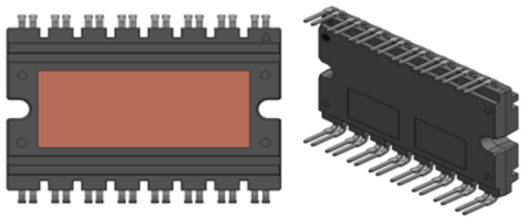

Fig. 5 Outline overview for APM32.

4 Conclusion

In this paper, we utilize PSIM for all simulation results to establish a reference basis for product design through simulation outcomes. The simulations in this article are conducted using discrete methods. During the product design stage, ONSEMI will provide relevant spice models for the simulations. This paper was simulated using the M3 series of SiC products, and the relevant spice models can be found on the ONSEMI official website. In further work, the simulations will transition to a modular approach, and after sample assembly, evaluations will be conducted to verify and compare the simulation results.

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