Design of a PM Brushless Motor Drive for Hybrid Electrical Vehicle Application

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Abstract[*]

Visual Computing Systems (VCS) and Oak Ridge National Laboratory are partnered in a research effort to design and build a power inverter for use with an automotive traction permanent magnet (PM) motor provided by VCS. The inverter is designed to fit within the volume of the housing, which is integrated with the motor. Moreover, a modular design for both the inverter and motor is employed to reduce the development cost by stacking modular units to meet the requirement of higher power ratings. The motor is operated in brushless DC mode. The effect of different commutation and current-sensing strategies on current control is analyzed. Torque and regeneration control algorithms are implemented with a digital signal processor. A traction motor drive system is constructed by using two modular inverters and a PM motor with two sets of stator coils. Each inverter separately drives a set of stator coils. The drive system will be used to repower a hybrid vehicle converted from a Chevrolet Suburban and will increase its fuel economy substantially. Design, analytical, and experimental results are included in the paper.

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Digest

1. INTRODUCTION

Permanent magnet (PM) motors have higher efficiency due to the elimination of magnetizing current and copper loss in the rotor. It is also easier to achieve high-performance torque control with PM motors, in particular, brushless direct current (BLDC) motors. Owing to these advantages, PM motors have been widely used in a variety of applications in industrial automation and consumer electric appliances. Recent advancements in permanent magnetic materials have made the PM motor a great candidate for traction motors in electrical vehicle applications.

Visual Computing Systems (VCS) and Oak Ridge National Laboratory (ORNL) are partnered in a research effort to design and build a power inverter for use with an automotive traction PM motor provided by VCS. To reduce the cost and space requirement of the drive system, emphasis is placed on the layout design of the inverter so that it can fit within the volume of the housing, which is integrated with the motor. Moreover, a modular design for both inverter and motor is used to reduce the development cost by stacking modular units to meet the required higher power ratings. The motor is operated in BLDC mode. The effect of different commutation and current-sensing strategies on current control is analyzed. Torque and regeneration control algorithms are implemented with a digital signal processor. Design, analytical, and experimental results are included in the paper.

2. SYSTEM CONFIGURATION

Fig. 1 shows the traction drive system configuration, in which two modular inverters are employed to drive a PM motor with two sets of stator coils; each inverter separately powers one set of stator coils. Each inverter module is rated for 15 kW continuous power with a peak power of 45 kW for a short duration. The axial gap motor has a maximum speed of 4000 rpm and is operated in BLDC mode. Torque and regeneration control

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algorithms are implemented with a digital signal processor. The drive system will be used to repower a hybrid vehicle converted from a Chevrolet Suburban to substantially increase its fuel economy.

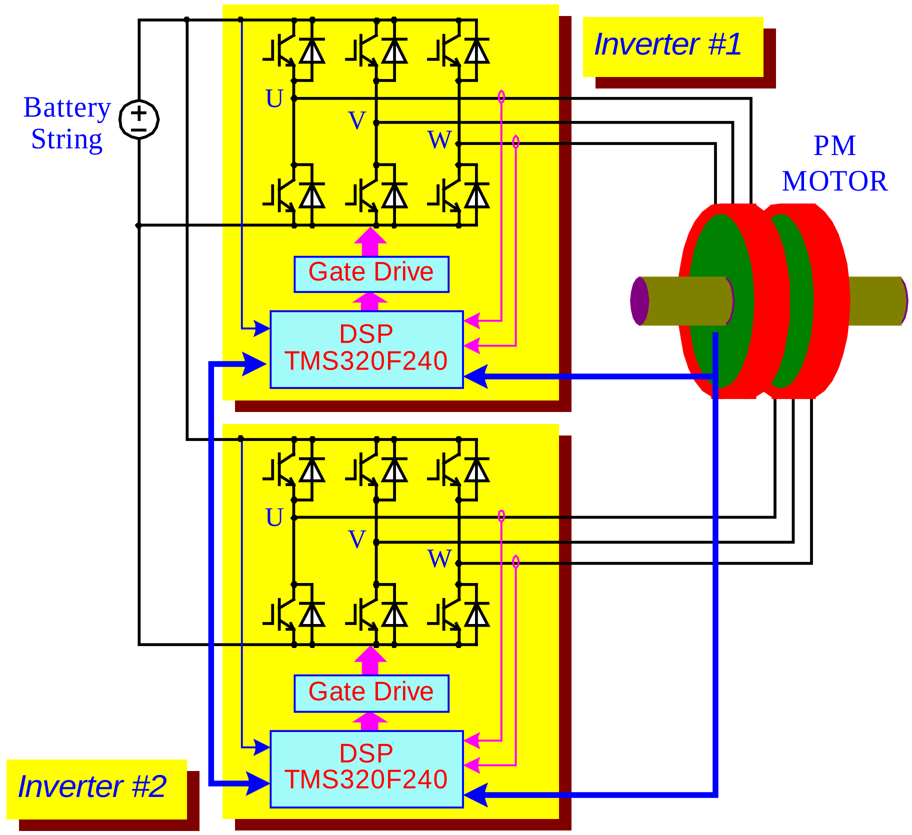


Fig. 1. Traction drive system configuration.

3. Design and Analysis

The effect of different commutation and current-sensing strategies on current control is analyzed. Fig. 2 shows the two pulse-width-modulation (PWM) strategies for current control in motoring mode. In PWM strategy #1, only the upper three switches of the inverter perform pulse-width-modulation, while the bottom switch of a phase leg keeps conducting for 120 electrical degrees at the appropriate time. In strategy #2, PWM operation is rotated among the six switches. Each switch begins PWM for 60 electrical degrees and then keeps conducting for another 60 electrical degrees. Compared to PWM strategy #2, PWM strategy #1 is easy to implement but has an adverse effect on the motor current waveform, as will be shown in the simulation results. Other possible PWM strategies, including those for regeneration, will be discussed in the paper.

Two phase currents are sensed to control the motor torque in the motoring mode or to control the regeneration current for charging the battery. It is important to properly construct a current feedback signal from the two detected phase currents. Detailed discussion of modulation strategies and synthesis of the current feedback signals along with will other design issues be given in the paper.

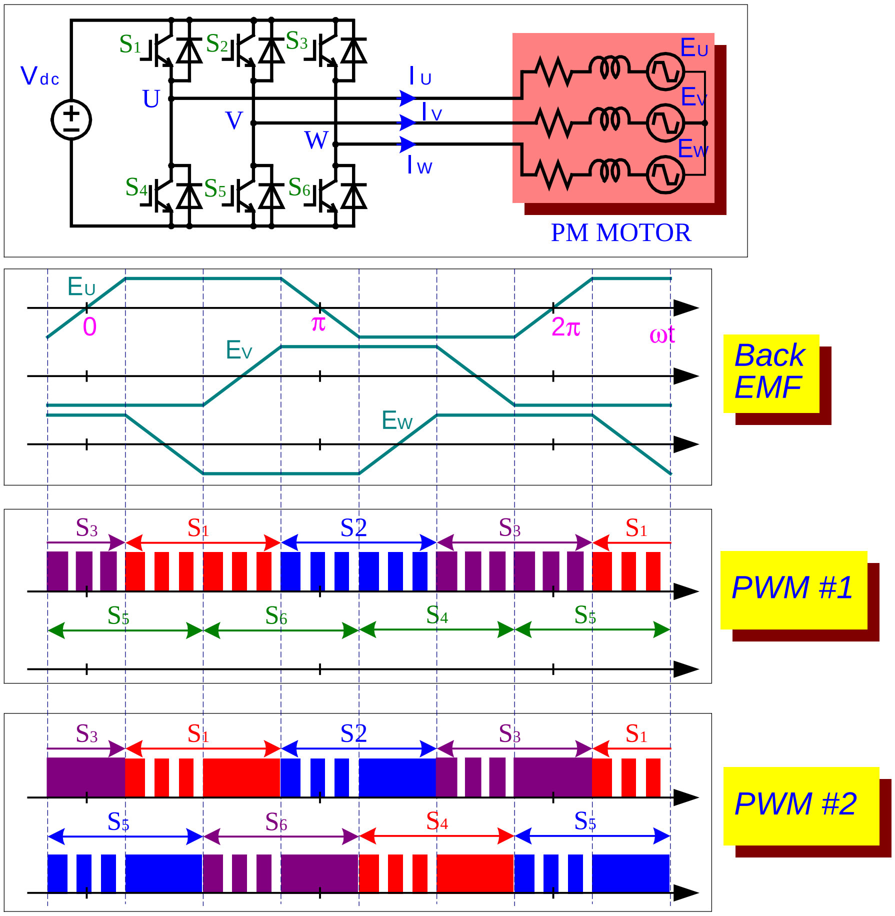
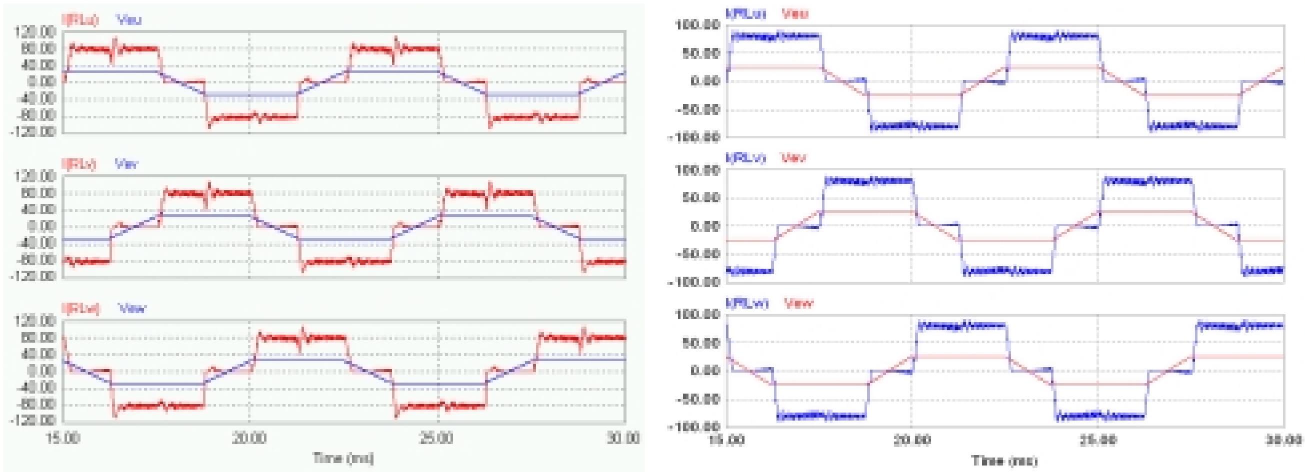


Fig. 2 PWM strategies for current control in motoring mode.

Fig. 3 shows typical simulation waveforms genergated by the two PWM strategies, where (a) is for PWM #1 and (b) is for PWM #2. It can be seen that strategy #1 produces an oscillation at the middle of the positive half cycles of current waveform, but it does not appear for the modulation strategy #2.

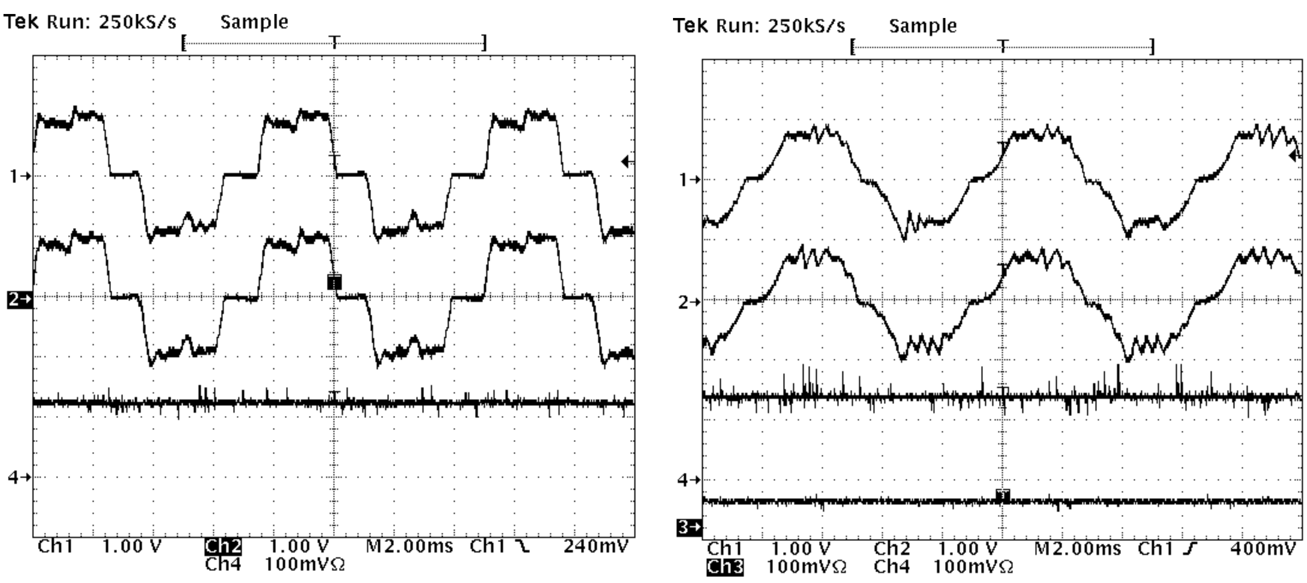


(a) for PWM #1. (b) for PWM #2.

Fig. 3 Simulation waveforms with different PWM modulation strategies.

4. Experimental Results

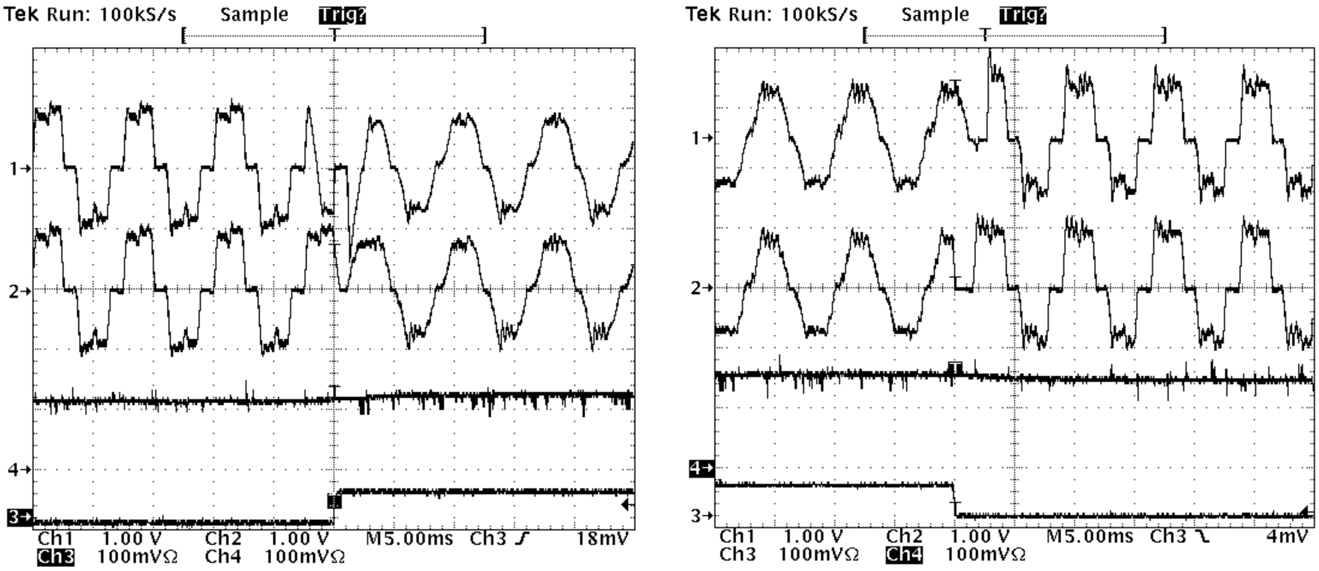
Fig. 4 shows typical current and DC bus voltage waveforms of both inverters in steady states, where (a) is in the motoring mode and (b) is in the regeneration mode. It clearly indicates that the two inverters are operating in a perfectly synchronized manner.



(a) Motoring (b) Regeneration

Fig. 4 Steady state waveforms at 1000 rpm. 1: Phase W current of inverter #1, 100 A/div, 2: Phase W current of inverter #2, 100 A/div, 4: DC bus voltage, 200 V/div, 2 ms/div.

Fig. 5 shows typical current and DC bus voltage waveforms of both inverters in transient states, where (a) shows a transition from motoring to regeneration and (b) a transition from regeneration back to motoring. Successful operation of transition from motoring to regeneration and then back to motoring can be observed.



(a) Transition from motoring to regeneration (b) Transition from regeneration to motoring

Fig. 5 Transient state waveforms at 1000 rpm. 1: Phase W current of inverter #1, 100 A/div, 2: Phase W current of inverter #2, 100 A/div, 4: DC bus voltage, 200 V/div, 5 ms/div.

5. CONCLUSIONS

A modular design for both an inverter and a PM motor is described for a hybrid electrical vehicle traction drive application. The modular approach can significantly reduce the development time and cost by stacking modular units to meet the required power ratings for different applications. The effect of various commutation and current-sensing strategies on current control is analyzed. A comprehensive discussion on the drive design issues will be included in the final paper. Experimental results have demonstrated successful operation of a PM BLDC drive employing the modular design for hybrid vehicle application.

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