HIGH SPEED SRM USING VECTOR CONTROL FOR ELECTRIC VEHICLE

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ABSTRACT—

Motor reduction is particularly useful in conjunction with the high-speed motor utilized in electric vehicles (EV). The rotors in switched reluctance motors have the added benefits of being both simple and long-lasting, making them ideal for use in high-speed drives (SRM). A lot of noise and activity, however, is not desirable. Because of the intricacy of unipolar current excitation, developing a torque controller is challenging. The problems with SRM have been said to be solved by using vector control. Nonetheless, vector control did not apply to the SRM at the high speed area. Examining the connection between switching frequency and bus voltage can help establish driving conditions for vector control of the SRM in the high-speed zone. In the high-speed zone, the experimental findings show that the suggested SRM can provide a high output power with little vibration when operated by vector control.

Index Terms—Switched reluctance motor, high speed drive, Vector control

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1. INTRODUCTION

We need to drastically reduce gas emissions because of the damage they inflict to the ozone layer. This is due to increased pressure from environmentalists as well as mandates from the government [1]. Internal Combustion Engines (ICE) are used in most current transportation systems (vehicles), however their combustion of gas and fuel produces hydrocarbon oxides, which are harmful to the environment. Hybrid electric vehicles (HEVs) employ both internal combustion engines and electric motors to propel their wheels, and they have been made better and more efficient as well [2-4], despite the fact that most research has been focused on renewable energy sources. Since then, people have also been able to purchase and drive fully electric vehicles (EVs) [5]. These vehicles are propelled by electric motors. Researchers are currently exploring the feasibility of using clean energy sources including the sun, wind, and tidal waves to power environmentally friendly modes of transportation [7-10].

The energy supply system, the auxiliary system, and the electronic propulsion system are the three core subsystems of an electric vehicle [3,11,12]. This electronic propulsion subsystem includes the electronic controller, power converter, mechanical transmission, and electric motor. You may learn about the various types of electric vehicle motors available on this page (Fig. 1).

Electromagnetic induction was a concept developed by Faraday in the 18th century. For this reason, electrical motors were created. Invention of electric motors, including both ac and dc varieties, may be traced back to Faraday's law on the interaction of electric and magnetic fields.

Common components of an electric motor include a rotor, a stator, windings, an air gap, and commutators or converters. Various electric motor types are constructed by combining these components in various ways [15]. Electric motors with permanent magnets and no brushes are known as brushless motors. Groups of motors can also be created by examining the construction of their backs (Back-EMF). They can take the form of a trapezoid, a sine wave, or something else entirely. Permanent Magnet AC Synchronous Motors (PMSM) and Brushless DC Motors (BLDC) are two types of electric motors that differ in construction and energy transfer [17].

Electric motors must be compact, powerful, and reasonably priced if they are to be employed as the drive in electric cars. Drives for electric vehicle motors have unique requirements, such as frequent starting and stopping, rapid acceleration and deceleration, high torque at low speeds, low torque at high speeds, and a broad speed range. However, the intended function of the motor determines its precise design. The systems used in homes, regular vehicles, and light-duty vehicles all fall under this category. Motor performance is also affected by the vehicle's duty cycle, temperature factors, and cooling system [11]. You can see the classification of traction motors in this image. What follows is a brief summary of what has been learned about EV/HEV traction motors in the scientific literature. After discussing the characteristics of AC and DC motors, this study provides a literature overview of both types of motors.

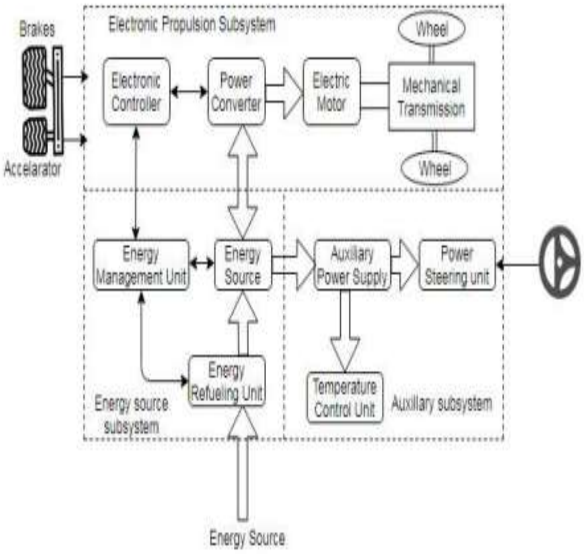


Fig. 1. Block diagram of an electric vehicle [13]

2. RELATED WORK

Switching reluctance motors are more rapid than stepper motors yet not requiring the use of pricey permanent magnets. Blending the advantages of a direct current (DC) motor, a brushless motor, and an alternating current (AC) induction motor. When more torque and higher speeds are required, the SRM is a more economical option than conventional synchronous and induction machines (Li et al. 2019). For a long time now, air pollution has been a major environmental issue. Vehicle fuel consumption is the leading contributor to air pollution. To reduce pollution, electric vehicles are preferable (Suresh et al. 2020; Karthik et al. 2020; Subasri et al. 2020; Sheela et al. 2020). Most modern electric vehicles employ a type of motor called a switching reluctance motor (SRM). SRMs are utilized in EVs due to their special properties (Aiso, Takahashi, and Akatsu 2019).

This is all true of conventional SRMs, however these devices also suffer from issues like torque ripples, noise, and magnetic saturation (Qianfan, Shumei, and Xinjia 2007). All of these factors diminish the quality of their service. Despite these obstacles, researchers continue to construct topologies with novel and diverse characteristics in an effort to improve performance.

A article describes an alternate strategy for boosting torque. It contains improvements to the design and discussions of the obstacles that prevent its widespread adoption. In an effort to maximize efficiency, Qianfan, Shumei, and Xinjie (2007) proposed a twin-rotor design. The dual-mode SRM is a hybrid device that operates in both synchronous and non-synchronous modes (Miller 1989). Adding more poles to the rotor, as suggested by Sun et al. (2019), is also a good strategy for increasing torque. Yet this results in a more cumbersome and costly equipment.

By switching the rotor poles of the SRM, Li, Ravi, and Aliprantis were able to decrease magnetic saturation and boost torque in 2016. To enhance the torque profile and decrease the quantity of material utilized, a novel topology is created, and the stator poles of the conventional SRM are modified. As part of the suggested architecture, a slotted stator tooth requires cutting out of the stator's core at a specific depth. The proposed SRM motor has winding that is analogous to standard motors.

This will accomplish rerouting the magnetic flux lines through the core, reducing the core material to make it cheaper and lighter, and reducing the core material. After optimizing the new topology, the torque and flux linkage was analyzed using the finite element method (FEM). This paper compares the attributes of the new model to those of the previous model and demonstrates that the new model is superior (Yang 2015; Kiyota et al. 2019; Desai et al. 2010; Zhu et al. 2017).

SRM Vector Control Controllability

A. Vector control theory and controller

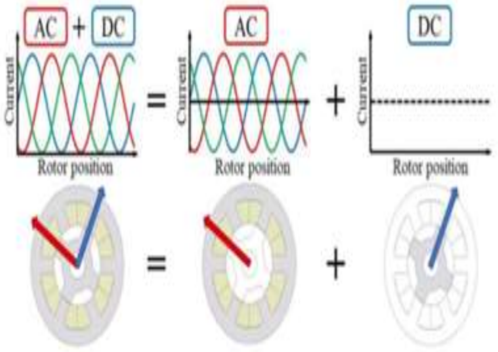


Fig. Vector Control of SRM

This schematic depicts the SRM's vector control mechanism. A sinusoidal, direct current (DC) offset current is applied in three phases to the patient, rousing them from sleep. As the current flows through the stator, it creates a magnetic field that spins. The location of the rotor determines the orientation of the direct current component that, together with the other components, forms the magnetic flux vector. In this case, the rotor field's vector represents the direction of the magnetic current that permeates the rotor. Making torque requires the rotor's magnetic flux to interact with the stator's revolving magnetic field.

The SRM uses a mathematical method called vector control to generate torque. [9] [10]. The d-q axis in the voltage equation of the analogous SRM represents the zero-phase volume. In this equation, we can see that the self-inductance of a wire coil is a function of the zero-phase voltage, the DC component of the voltage along the d-axis, the zero-phase volume, and the zero-phase voltage component.

After subtracting the DC component from the total current, the zero-phase excitation current is obtained (3). When calculating the second term (2) of the inductance matrix, this formula is employed.

The inertia of the digital rotor is represented by the innermost letter I of the symbol. Time-varying virtual rotor flows caused by zero-phase current are depicted in the figure. You may calculate the SRM torque by using the following formula:

To put it another way, you can take one of two distinct stances on this issue. (5) There are now twice as many folks who don't need clarification. In terms of magnitude and frequency, zero-phase currents remind me of rotating torque and flux currents.

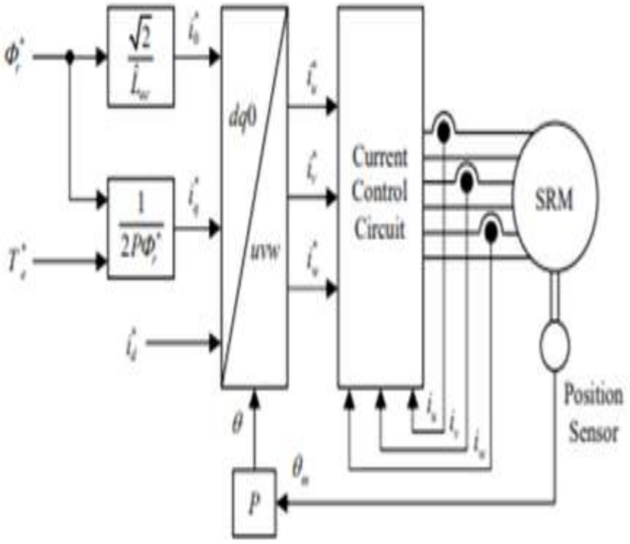


Fig. Vector Control System for SRM Drive

The present controller is investigated in detail in [13]. Current vector control controllers are depicted in this image. Here we see examples of the feed-forward controller, the disconnecting controller, and the PI controller in use at the present time. With these regulators, a carrier-based PWM inverter can be instructed in the direction of voltage flow. An important function of the PI controller is to regulate the current in each phase and axis of the circuit. Formatting a function transfer looks like this:

Its speed of one hundredth of a second every second is incredible. In this way, the RL circuits of the rotating reference framework can be viewed as the controlled SRM, which is a result of decoupling and forward control. In order to achieve the optimal first-order current response of the controlled machine, c should be set equal to Ldc/R, as depicted in the figure. The Kc gain of a system can be calculated by measuring how quickly it reacts to inputs at the moment. The purpose of this research is, in part, to replicate and assess an existing controller.

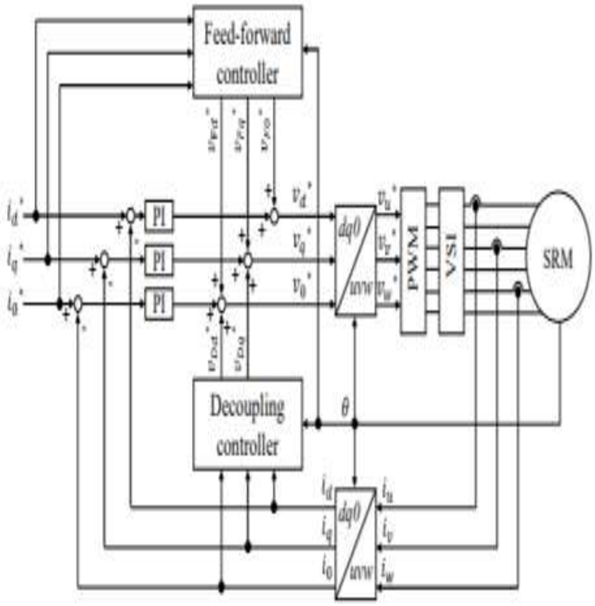


Fig. Current Controller for Vector Control

B. Controllability of high speed drive

In turn, these factors define the 20000 rpm rotating speed, bus voltage, required power, and switching frequency. The simulation analyzes the current and torque waveforms at 20,000 rpm and a reference torque of 16.2 Nm. You can see the effects of varying the switching frequency on the waveforms of the current and torque in the graph. The frequency with which the switch is flipped on and off has an effect on the harmonic distortion and the current wave ratio. Common measures of harmonic distortion include the current ripple ratio (CRR) and the effective value of the harmonic current order (I1).

The current amplitudes at their maximum (imax), minimum (imin), and average (iave) values are represented by the variables maximum (imax), minimum (imin), and average (iave). Table II displays, for the switching frequency presented in Figure, the q-axis, zero-phase THD, and current rippling ratios. The graph and table indicate that THD and the rate of current ripple decrease with increasing switching frequency. Harmonic fluxes in high-speed motors increase the iron loss, hence THD must be kept to a minimum.

3. PROPOSED SYSTEM AND SIMULATION RESULTS

PROPOSED SRM

The specifications for the two SRMs shown in Figure, one with a 12-pin configuration and eight poles and the other with a 30-pin layout and twenty poles, are presented in Table I. This smaller SRM has eight fewer poles and 12 less pins. It was crucial to keep in mind that the 20-pole, 30-slot SRM would have the same electric angular frequency and electrical qualities as the 8-pole, 12-slot SRM in order to prove that it could be controlled at high speeds.

$$f_m = N_m \times \frac{P}{60}$$

An electric motor can spin at a maximum frequency of 60 P f N (1). Here, P is the number of poles, fm is the highest possible electric frequency, and Nm is the highest possible rotational frequency. According to the Model A's specifications, its maximum electrical frequency is 6.67 kHz (1). In addition to the standard ten-pole Model A, a twenty-pole variant exists that can reach speeds of up to 20,000 revolutions per minute. Every aspect of these two SRMs is identical: large outer diameter, short inner diameter, short stack length, and long air gap. In addition, the standard deviation of their auto-inductance distributions is quite close to that of the distributions in Figure. The SRM torque can be calculated using the following formula:

$$T = \frac{P}{2}\frac{\partial L}{\partial \theta} i^2$$

P for torque output, L for inductance, E for electric angle, and I for current are the variables in the equation P L T I. (2). A linear increase in torque can be observed with increasing pole count (2). When compared to the Model A, the Model B produces 2.5 times as much torque. Model B requires 0.63 times more current to provide the same torque output as Model A. The depiction accurately depicts the current state of affairs. For "torque," see "torque" as an abbreviation. Model B torque is 2.5 times that of Model A torque when the same current is applied and no magnetic saturation area is present (see Fig).

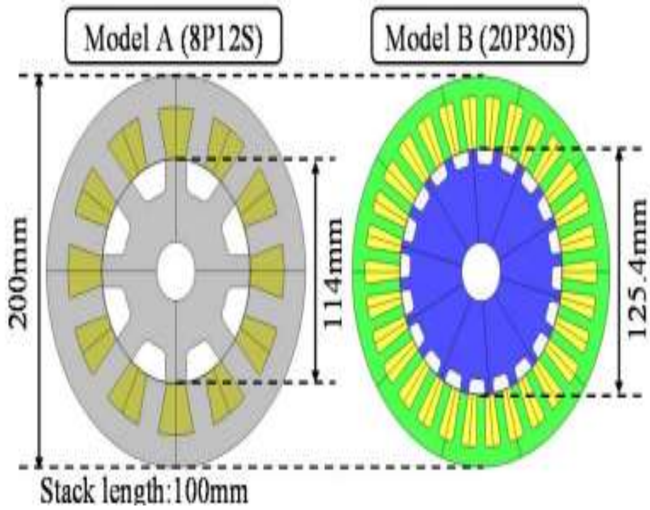


Fig. Motor structure of the proposed SRMs.

TABLE I

SPECIFICATION OF PROPOSED SRM

	Model A	Model B
Pole / Slot	8 / 12	20 / 30
Output power [kW]	85	34
Maximum speed [rpm]	50000	20000
Air gap length [mm]	0.5	0.5
Number of turns [turn/teeth]	5	5
Diameter of coil [mm]	6.0	4.0
Resistance [Ω/phase]	0.003	0.018
Core material	-	20H1200

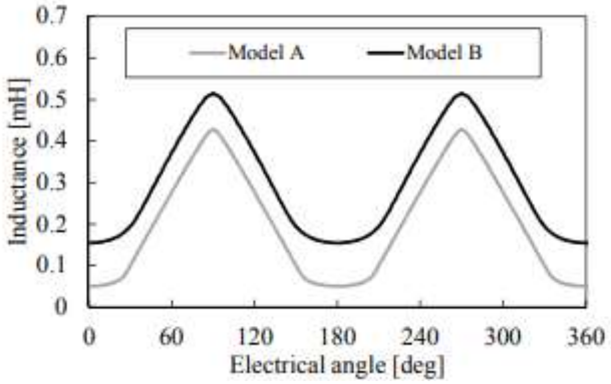


Fig. Self-inductance waveforms of the proposed SRMs.

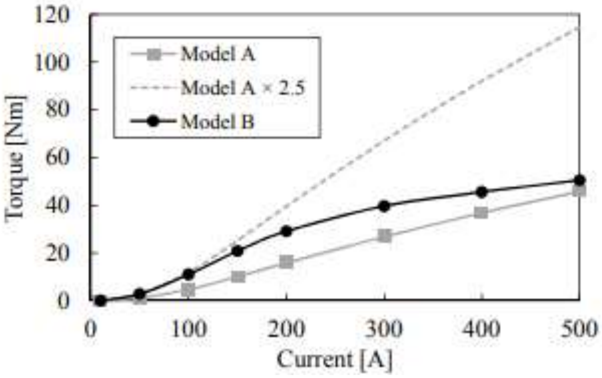
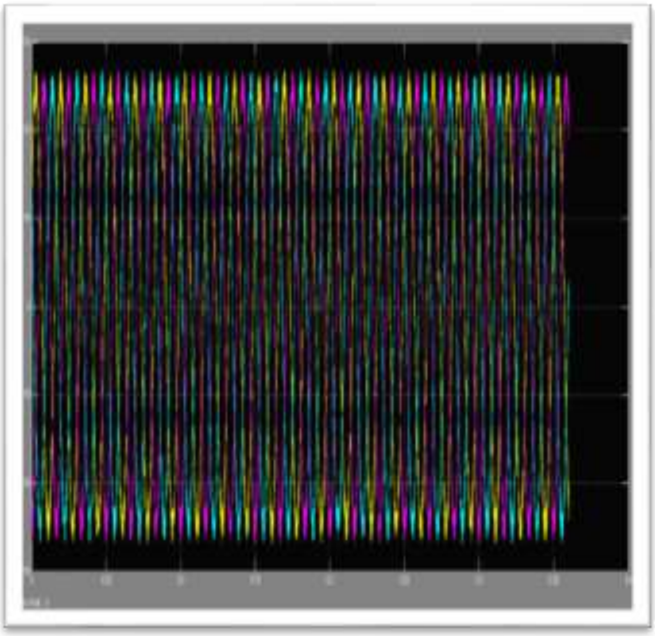
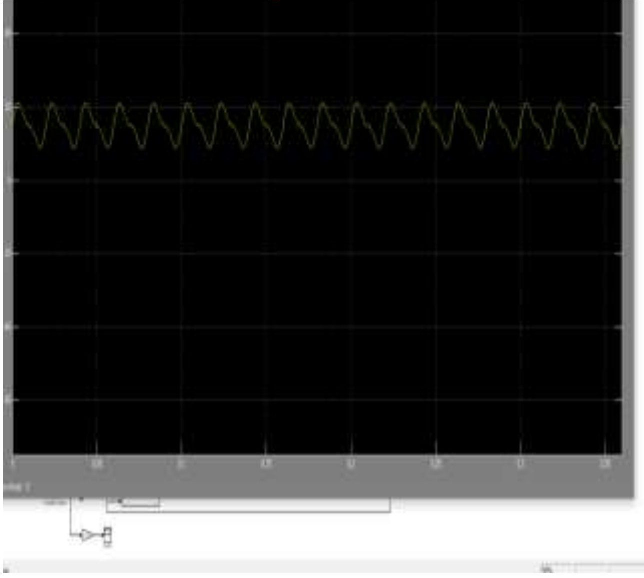
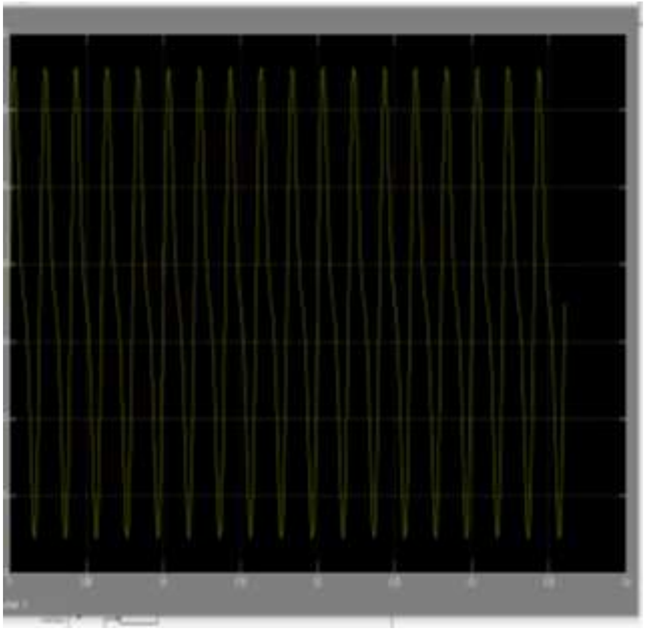


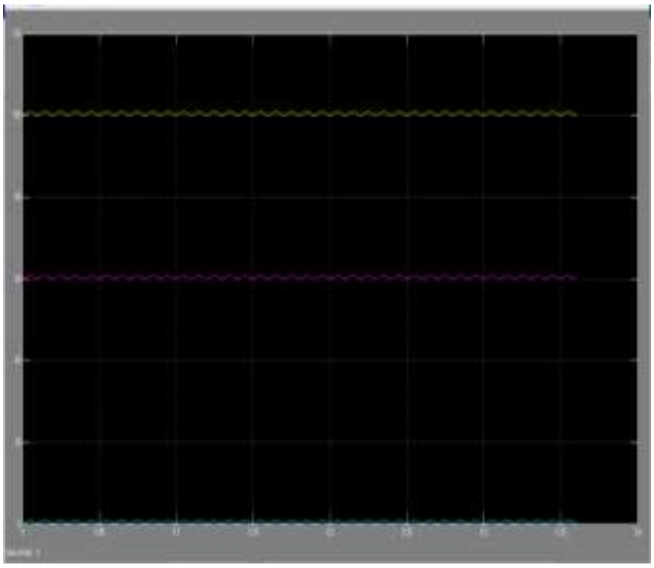
Fig. Current-Torque characteristic.

SIMULATION RESULTS









4. CONCLUSION

For this study, a 20-pole 30-slot SRM was constructed and tested, and it was shown to have the same electrical angular frequency as a 12-slot SRM driven at 50,000 rpm by the same amount of electrical current. The SRM in the high-speed drive was modified in this way so that vector control could be implemented. Both the vector control system's torque and output power requirements might be satisfied by the proposed motor. This was achieved by employing a SiC inverter with a 200kHz switching frequency. The experiment validated that the desired SRM rotational speed of 20,000 rpm is achievable with vector control. Simply said, the vector control can spin an eight-pole, twelve-slot SRM at 50,000 rpm. Finally, it was demonstrated that SRM vibration at high speeds can be reduced by using vector control rather of the conventional single pulse driving.

REFERENCES

[1] M. Besharati, J. Widmer, G. Atkinson, V. Pickert, Jamie Washington : “Super-high-speed switched reluctance motor for automotive traction”, IEEE Energy Conversion Congress and Exposition (ECCE), pp.5241-5248, September 2015.

[2] Earl W. Fairall, Berker Bilgin, Ali Emadi : “State-of-the-Art High-speed Switched Reluctance Machines”, IEEE International Electric Machines and Drives Conference (IEMDC), pp.1621-1627, May 2015.

[3] M. N. Answar and Iqbal Husain, “Radial Force Calculation and Acoustic Noise Prediction in Switched Reluctance Machines” IEEE Transaction on Industry Application, Vol.36, No.6, pp.1589-1597, 2000.

[4] Chenjie Lin and Babak Fahimi,“Prediction of Radial Vibration in Switched Reluctance Machines”, IEEE Transaction on Energy Conversion, pp.250-258, Vol.29, No.1, 2014

[5] H. Makino, T. Kosaka, Nobuyuki Matsui, “Digital PWMControl-Based Active Vibration Cancellation for Switched Reluctance Motors”,

IEEE Transaction on Industry Application, Vol.51, No.6, pp.4521-4530, Nov 2015.

[6] A. Tanabe, K. Akatsu, “Vibration reduction method in SRM with a smoothing voltage commutation by PWM”, 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia), June 2015.

[7] K. M. Rahman, B. Fahimi, G. Suresh, A. V. Rajarathnam, and M. Ehsani, "Advantages of Switched Reluctance Motor Applications to EV and HEV: Design and Control Issues," IEEE Transactions on Industry Applications, vol. 36, No. 1, pp. 111-121, January/February 2000.

[8] I. Husain and S. A. Hossain, "Modeling, Simulation, and Control of Switched Reluctance Motor Drives," IEEE Transactions on Industrial Electronics, vol. 52, No. 6, pp. 1625-1634, December 2005.

[9] N. Nakao, K. Akatsu, “Vector control specialized for switched reluctance motor drives”, International Conference on Electrical Machines (ICEM), pp.943-949, September 2014.

[10] N. Nakao, K. Akatsu, “Vector control for switched reluctance motor drives using an improved current controller”, IEEE Energy Conversion Congress and Exposition (ECCE), pp.1379-1386, Sept 2014.