4-레벨 컨버터 구동 방식에 의한 SRM DITC 제어

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DITC of SRM using 4-Level Converter

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Abstract - This paper proposes a DITC(Direct Instantaneous Torque Control) of SRM (Switched Reluctance Motor) using a novel 4-level converter for smooth torque control and high efficiency. DITC of SRM is very useful for smooth torque control, but the driving efficiency is low due to advanced current that does not produce torque. For the high efficiency control of SRM, fast excitation and demagnetization of phase current are required. A novel 4-level converter and a new control scheme are present to improve the driving efficiency. The proposed DITC of SRM using 4-level converter is verified by computer simulation.

1. INTRODUCTION

Switched reluctance motor (SRM) is a low cost, simple and has robust structure, high ratio of torque to rotor volume, reliability, controllability and high efficiency characteristic. However, the double saliency construction and the discrete nature of torque production by the independent phases lead to higher torque ripple compared with other machines. So the higher inherent torque ripple is big defect to SRM[1].

In order to overcome the above disadvantage, various control techniques have been proposed to reduce to high inherent torque ripple in recent years [2]-[4]. Compare to the previous control techniques, DITC (Direct Instantaneous Torque Control) enables torque to be generated during all region and instantaneous torque control to be possible. So it can get a stable and smooth output torque characteristic.

However, the driving efficiency of DITC is disadvantageous due to switching loss and motor loss in the advanced excitation current region, where it doesn't generate any torque production. So fast excitation and demagnetization current are required for the high efficiency control.

This paper presents DITC of SRM using a novel 4-level converter for smooth torque control with high driving efficiency. The 4-level converter has additional high voltage to build up fast excitation and demagnetization current. Therefore, it brings on high efficiency and high performance for DITC. For suitable DITC of SRM using the novel 4-level converter, a novel state scheme is described and analyzed. Finally, the proposed DITC of SRM drive system is verified by computer simulation.

2. DITC OF SRM USING ASYMMETRIC CONVERTER

2.1 SWITCH STATE OF ASYMMETRIC CONVERTER

The asymmetric converter and its operating modes shown in Fig.1(a). This converter has the independent control of each phase, which is particularly important when phase overlap is desired in DITC. The asymmetric converter has three modes, which are define as state 1, 0 and state -1, respectively. The state 1 is shown in Fig.1(b). Two switches turn on, the source voltage V_s is supplied to the phase winding, the state 0 is shown in Fig.1(c). One switch and one diode turn on, and the phase current is freewheeling. The state -1 is shown in Fig.1(d). Two switches turn off, and phase voltage is $-V_s$. the demagnetization current feedback the energy to capacitor.

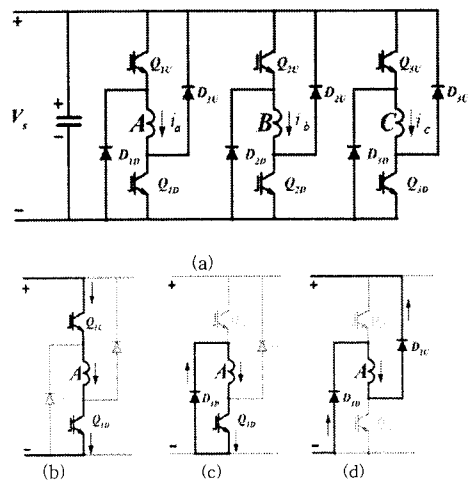


Fig. 1. Phase switching states of asymmetric converter
(a) asymmetric converter
(b) state 1 (c) state 0 (d) state -1

2.2 THE STATE SCHEME OF DITC

Diagram of DITC SRM drive system is shown in Fig.2. the torque estimation block and hysteresis controller block are very important in the DITC. The

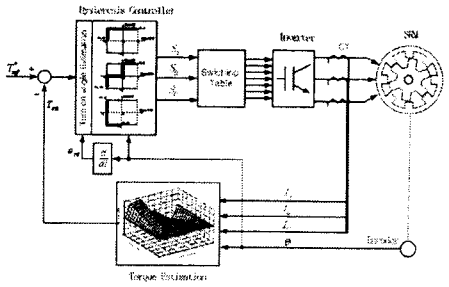


Fig.2 Block diagram of DITC SRM system

torque estimation block is generally implemented by looking up 3-D table using the phase currents and rotor position. And the digital torque hysteresis controller generates the switching signals for all activated machine phases according to torque error between the reference torque and estimated torque.

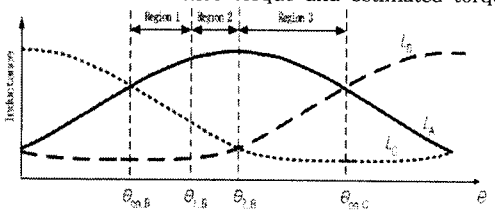
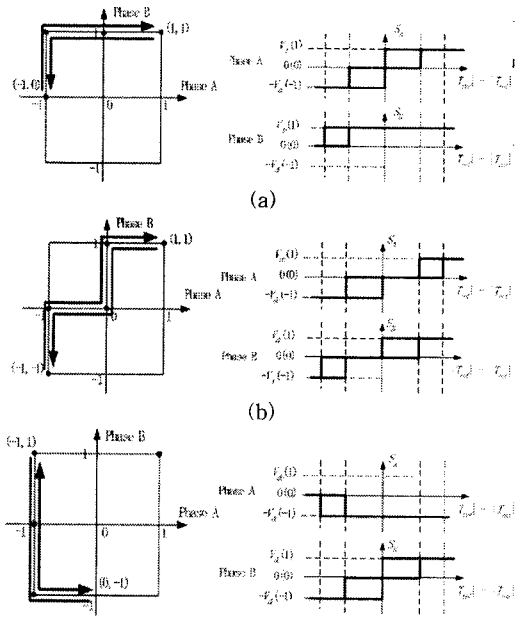


Fig.3 Phase inductance profile



(a)

(b)

(c)

Fig.4 Each region Switching schemes
a) region 1 (b) region 2 (c) region3

This scheme of DITC is different from other DITC. the phase inductance has been divided to 3 region as Fig.3. The reason of partition depends on the geometrical structure of SRM and condition case. The boundary of 3 region are $\theta_{onB}, \theta_{1\_B}, \theta_{2\_B}$ and θ_{onC}. θ_{onB} and θ_{onC} are advance angle which dependents load and operation speed, θ_{1_B} is rotor position which is the inflexion of phase B inductance. And θ_{2_B} is middle point of phase B inductance.

In region 1, output instantaneous torque is produced by phase A, the next excitation current should be built-up for the enough torque produced. Shown in Fig.4(a), the states of (1,1) and (0,1) must be included. In order to improve the dynamic performance of torque, the states of (-1,1) and (-1,0) are added.

In region 2. phase B current has been built up, and started to produce the instantaneous torque. Because the variation of inductance is decreased sharply, torque of phase A is reduced quickly. the detail state scheme is shown in Fig.4 (b). The desired torque is mainly produced in phase B, and lacking part produces by phase A. So the state(0,1) and (0,0) is desired. The state (1,1), (-1,0) and (-1,-1) improve the dynamic torque response.

In region 3, phase A produces negative torque. So the best state of phase A is -1, Phase B produces primarily torque. The state scheme is shown in Fig.4 (c). therefore, the (-1,0) and (-1,1) must be included in the scheme. The others improve the dynamic torque response, too.

3. DITC OF SRM USING 4-LEVEL CONVERTER

3.1 THE PROPOSED 4-LEVEL CONVERTER

The proposed 4-level converter for 3-phase SRM is shown in Fig.5. The 4-level converter has additional charge capacitor C_{CD}, power switch Q_{CD} and diode D_{CD} more than general asymmetric converter. The charge capacitor C_{CD} and C_{DC} store the demagnetization phase current during the switching turn-off, So the phase current is fast demagnetized due to the high negative bias. Then the charged high voltage is supplied through the power switch Q_{CD} to the next excitation phase winding for the fast phase current build-up.

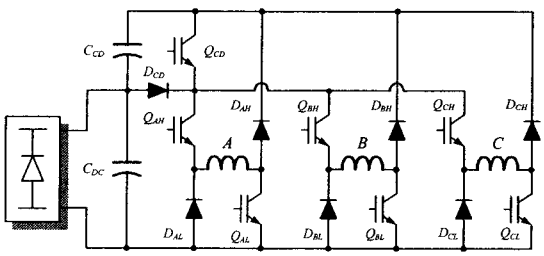
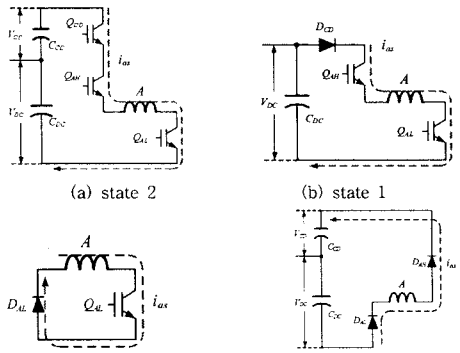


Fig.5 the proposed 4-level converter

In the state 2 of Fig. 6(a), DC link voltage V_{DC} and charged voltage V_{CD} are supplied in excited phase winding, then the excited phase current is fast established by the high charged voltage $V_{DC} + V_{CD}$. As similar, the demagnetized phase current during the state -2 is fast decreased by the high negative bias $-(V_{DC} + V_{CD})$. The state -2 is shown as Fig. 5(d). The state 1 (general excitation mode) and state 0 (

wheeling mode) of Fig. 6(b) and (c) are same in asymmetric converter of SRM with turn-off state of Q_{CD}.



(a) state 2 (b) state 1

(c) state 0 (d) state -2

Fig. 6 Operating state of the proposed 4-level converter

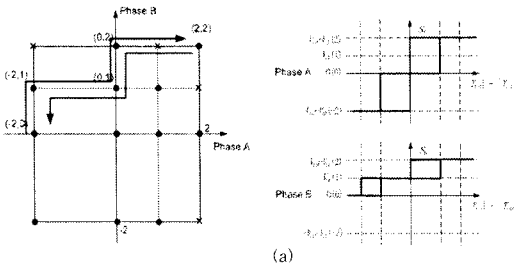
3.2 A NEW STATE SCHEME OF DITC USING 4-LEVEL CONVERTER

Since the 4-Level converter has 4 states(2,1,0,-2), the general control scheme of DITC using asymmetric converter is not suitable for 4-level converter. As a result of state 2 and state -2, fast excitation and demagnetization of phase current are obtained. the new state scheme is present in Fig.7. As similar as the state scheme of DITC using asymmetric converter, the new state scheme has 3 region too.

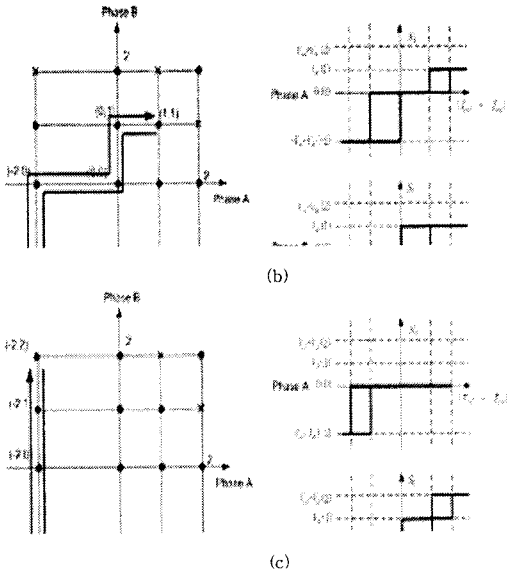
In region 1, state 2 is usable. The high voltage makes the fast excitation current in phase B, and improves the driving efficiency due to short time of excitation current. Phase A produce the primarily torque. The state scheme of region 1 is shown in Fig.7 (a). So (2,2) and (0,2) must be included, and the state (0,1), (-2,1)and (-2,0) are as the alternate in order to consider dynamic torque response.

In region 2, this state scheme is very similar to asymmetric one in same region. Except state -2 is instead of state -1. The negative high voltage makes the fast demagnetization current in two phase improve the dynamic performance of torque, the state scheme of region 2 is shown in Fig.7 (b). the state (0,1) and (0,0) is desired. the other states are in support for dynamic torque response.

In region 3, state -2 makes the fast demagnetization current in phase A, which can reduce negative torque for improving the driving efficiency. Phase B produces primarily torque. The state scheme of region 3 is shown in Fig.7 (c). the state (-2,0) and (-2,1) is needed in this scheme. (-2,2), (-2,-2) and(0,2) are in support for dynamic torque response, too.



(a)



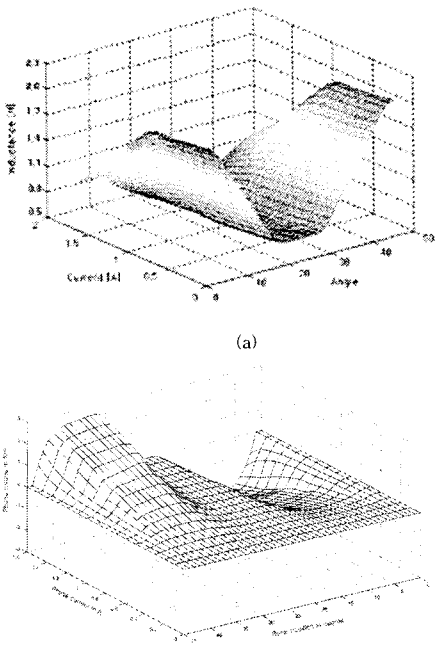
(b)

(c)

Fig.7 Each region new Switching schemes
a) region 1 (b) region 2 (c) region3

4. SIMULATION

In order to verify the proposed DITC of SRM drive system using 4-level converter, the proposed control scheme has been simulated using MATLAB. The pre-measured inductance and torque profile are used in SRM system simulation, which is shown in Fig.8. The simulation results of the DITC control of SRM using the general asymmetric converter and the proposed 4-level converter are compared in Fig.9 and Fig.10.



(a)

(b)

Fig.8 Inductance and torque profile of SRM
(a) Inductance profile (b) torque profile

In Fig.9 and Fig.10, advance angle of instantaneous torque control of asymmetric converter is longer than the proposed 4-level converter. The excitation current during advanced position does not produce output torque, so the driving efficiency is reduced in case of asymmetric converter. However, the fast excitation and demagnetization state of 4-level make fast build-up of excitation current and fast demagnetization current. The shorter advance angle is used shown as Fig. 10.

And the total torque of proposed drive system is more stable than the asymmetric one.

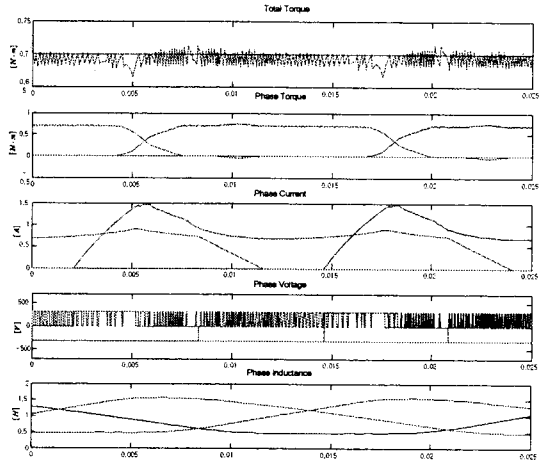


Fig.9 the DITC of SRM using asymmetric converter

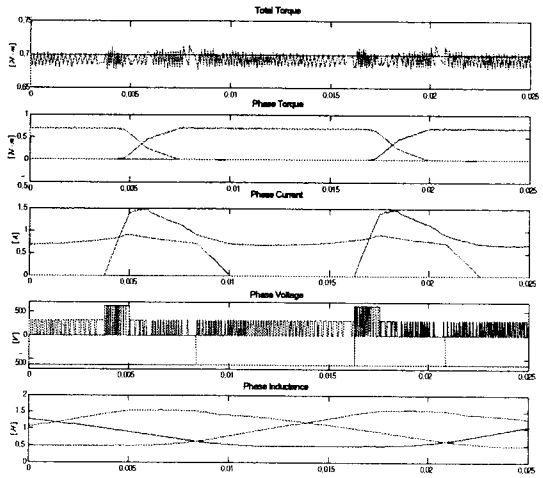
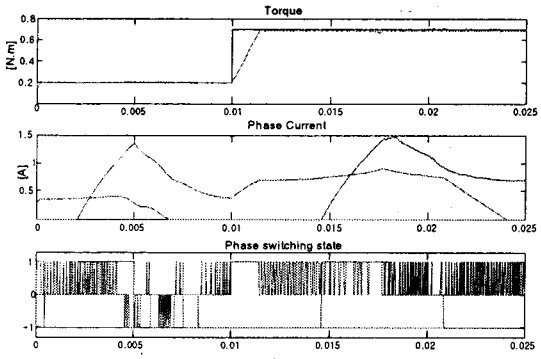


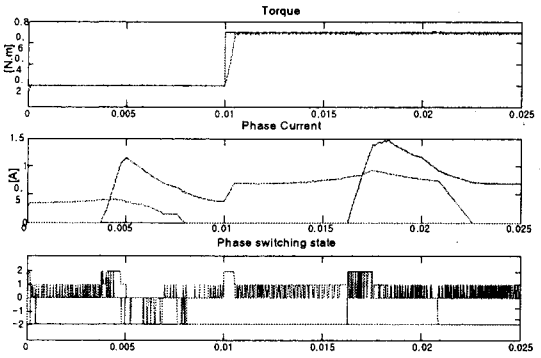
Fig. 10 the DITC of SRM using 4-level converter

Torque step response of DITC using two converter is shown in Fig. 11. Because of state 2 of 4-level converter, the response time of 4-level converter is shorter than asymmetric converter. So DITC of SRM using 4-level conveter has better dynamic response than asymmetric one.

Therefore, from the two simulation result, the proposed drive system can obtain higher efficiency and higher performance than conventional DITC drive system.



(a)



(b)

Fig.11 Torque step response of DITC using two converter (a) Asymmetric converter (b) 4-Level converter

5. CONCLUSION

In this paper, the DITC of SRM using 4-level converter was presented. Because of addition high charged voltage state of 4-level converter, the fast excitation and demagnetization current have been obtained and improved driving efficiency and performance. In addition, a new switching scheme was proposed for combining DITC and 4-Level converter. Finally, the proposed DITC control of SRM drive system is verified by computer simulation.

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