# 4-레벨 컨버터 회로를 통한 SRM의 DITC 시스템의 성능향상

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# Improvement of DITC SRM with a Novel 4-level Converter

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**Abstract** - This paper presents a direct instantaneous torque control (DITC) of Switched Reluctance Motor (SRM) with a novel 4-level converter to obtain smooth torque and dynamic performance improvement. The DITC method can reduce the high inherent torque ripple of SRM drive system, but driving efficiency and dynamic performance are somewhat low due to the slow excitation current build-up. Since the 4-level converter can obtain a addition high voltage to get fast excitation current and demagnetization current, so, it can improve dynamic performance easily. As a high performance SRM drive system with low torque ripple and high dynamic performance can be implemented. The validity of proposed method is verified by some computer simulations and comparative experiments.

## 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 can generate smooth output torque during all region, and get a fast dynamic characteristic.

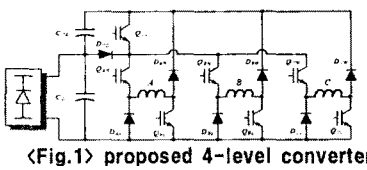
However, DITC used relatively long advanced angle due to get flat excitation current and slow dynamic response. Therefore, fast excitation and demagnetization current are required for the high dynamic performance of SRM drive.

This paper presents DITC SRM with a novel 4-level converter to obtain smooth torque and dynamic performance improvement. The 4-level converter has additional high voltage to build up fast excitation and demagnetization current. Therefore, it brings on high dynamic performance from DITC method of SRM drive. For suitable 4-level converter, a novel state scheme is described and analyzed. Finally, the proposed DITC method of SRM drive based on 4-level converter is verified by some computer simulations and comparative experiments.

## 2. DITC METHOD OF SRM DRIVE BASED ON 4-LEVEL CONVERTER

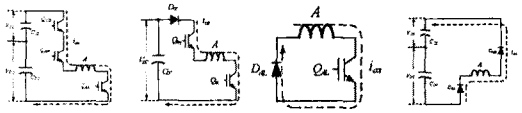
### 2.1 DITC State of 4-level Converter

The proposed 4-level converter for 3-phase SRM is shown in Fig.1. The 4-level converter has additional charge capacitor $C_{CD}$, power switch 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.1> proposed 4-level converter

Fig.2 shows the operating modes of proposed 4-level converter. In the state 2 of Fig. 2(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 $V_{DC} + V_{CD}$ . Similarly, the demagnetized phase current during the state -2 is fast decreased by the high negative bias $-(V_{DC} + V_{CD})$ shown as Fig. 2(d). The state 1 (general excitation mode) and state 0 ( wheeling mode) of Fig. 2(b) and (c) are same in asymmetric converter of SRM with turn-off state of $Q_{CD}$.

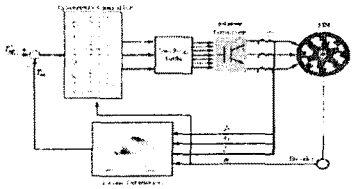


(a) state 2 (b) state 1 (c) state 0 (d) state -2

<Fig.2> Operating state of proposed 4-level converter

### 2.2 DITC SRM system

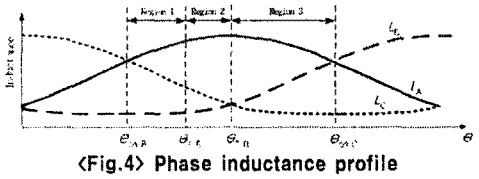
Fig.3 shows the control diagram of DITC SR drive system. The torque estimation block and hysteresis controller block are very important in the DITC. The torque estimation block is generally implemented by looking up 3-D table using the phase currents and rotor position. And the digital torque hysteresis controller generates the switching signals for all activated machine phases according to torque error between the reference torque and estimated torque.



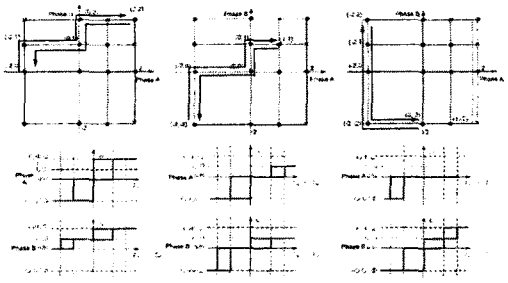
<Fig.3> Block diagram of DITC SR Drive system

### 2.3 DITC Method of 4-level Converter

The phase inductance has been divided to 3 region shown as Fig.4. The reason of partition depends on the geometrical structure of SRM. The boundaries of 3 region are $\theta_{onB}$, $\theta_{1\_B}$, $\theta_{2\_B}$ and $\theta_{onC}$. $\theta_{onB}$ and $\theta_{onC}$ are advanced angle which dependents load and operation speed, $\theta_{1\_B}$ is rotor position which is the inflexion of phase B inductance. And $\theta_{2\_B}$ is middle point of phase A inductance.



<Fig.4> Phase inductance profile



(a) region 1 (b) region 2 (c) region3

<Fig.5> Switching states of DITC

In region 1, output instantaneous torque is produced by phase A

primarily. The high voltage makes the fast excitation current in phase B, and it should be built-up for the enough torque produced for next region. The state scheme of region 1 is shown in Fig.5 (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.

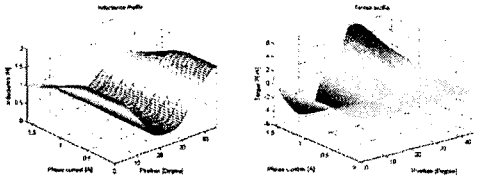
In region 2. phase B current has been built up, and started to produce the instantaneous torque. Because the variation of inductance is decreased sharply, and torque of phase A is reduced quickly. The desired torque is mainly produced in phase B, and lacking part produces by phase A. The negative high 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.5 (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.5 (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.

## 3. SIMULATIONS AND EXPERIMENTS

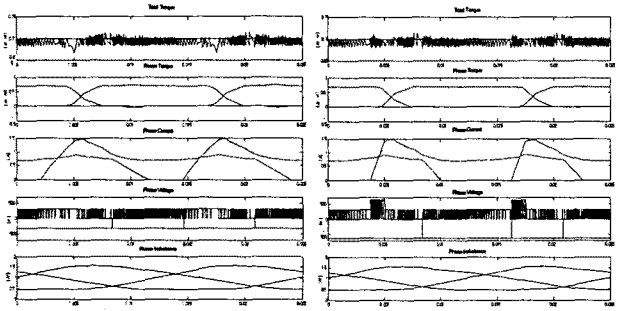
### 3.1 DITC Method of Two Converter

In order to verify the proposed DITC method of SRM drive based on 4-level converter, control scheme of the proposed method has been simulated using MATLAB. The inductance and torque profile are used in SRM drive system simulation, which is shown in Fig.6. The simulation results of the DITC method of SRM drive based on the general asymmetric converter and the proposed 4-level converter are compared in Fig.7.



(a) inductance profile (b) torque profile

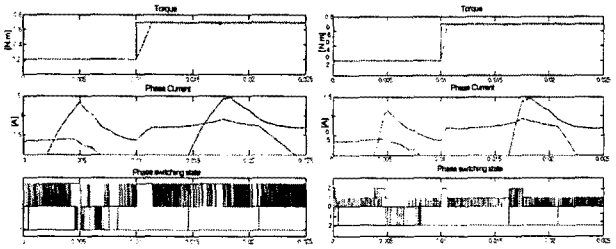
**<Fig.6> Inductance and torque profile**



(a) asymmetric converter (b) 4-level converter

**<Fig.7> DITC method according converter topologies**

In Fig.7, advance angle of DITC of asymmetric converter is longer than the proposed 4-level converter. The fast excitation and demagnetization state of 4-level make fast build-up of excitation current and demagnetization current. The shorter advance angle is used shown as Fig. 7(b). And the total torque ripple of proposed drive system is similar to the asymmetric one.



(a) asymmetric converter (b) 4-level converter

**<Fig.8> Torque step responses of DITC according to converters**

### 3.2 Torque Step Response of Two Converter

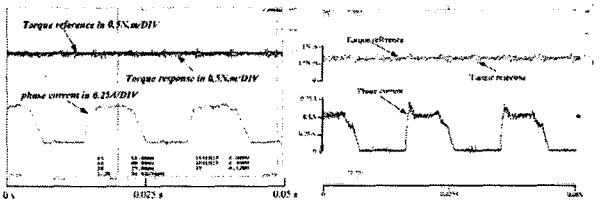
Torque step response of DITC based on two converter is shown in Fig. 8. Because of additional high charged voltage of 4-level converter, the response time of 4-level converter is shorter than asymmetric converter. So DITC method of SRM drive based on 4-level converter has better dynamic response than asymmetric one.

Therefore, from the two simulation result, the proposed drive system can obtain low torque ripple and higher performance than asymmetric DITC drive system.

### 3.3 Experimental Results

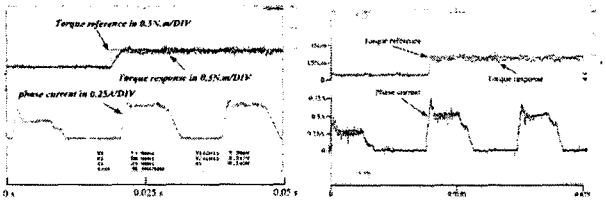
The experiment result of two converters is shown in Fig.9. In this experiment, the SRM operates at 400 [rpm], and output torque is 0.7 [N.m]. Compare with the asymmetric converter, the 4-level converter obtains fast excitation current and reduce the advance angle of motor operation.

The experiment result of torque step response is shown in Fig.10. The torque reference have a step from 0.2 to 0.7[N.m], and torque response follows torque reference quickly in these two systems. But the DITC system using 4-level shows faster dynamic response in the Fig.10.



(a) asymmetric converter (b) 4-level converter

**<Fig.9> Experimental results of two converters(0.7[N.m])**



(a) asymmetric converter (b) 4-level converter

**<Fig.10> Experimental results of torque step response (0.2 to 0.7[N.m])**

## 4. CONCLUSION

In this paper, DITC SRM with a novel 4-level converter was presented to obtain smooth torque and dynamic performance improvement. Because of additional high charged voltage of 4-level converter, the fast excitation and demagnetization current have been obtained smooth torque and improved dynamic performance. In addition, a new switching scheme was proposed for combining DITC and 4-level converter. Finally, the proposed DITC method of SRM drive is verified by computer simulations and comparative experiments.

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