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전압형 인버터가 연결된 새로운 방식의 SRM 컨버터

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New SRM converter connected to the voltage source inverter

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ABSTRACT

In this paper the novel converter topology for the switched reluctance motor drives is proposed, which is composed of the minimum switch per phase and is connected to the single-phase voltage inverter for ac voltage source. The proposed converter topology is divided into two types according to the voltage source inverter of half bridge type and full bridge type. Proposed converters of two types are proposed, analyzed and compared with each other. The SRM using proposed converter maintain the high efficiency though the power switches are reduced.

I. Introduction

The cost and performance of the switched reluctance motor(SRM) drive have been determined by many converter topologies invented, and unlike the conventional inverters-fed induction machines, the SRM drives are highly dependent on the converter topology used to drive the SRM. Ever since the promising features of the SRM drives have been realized, developments in the converter topologies have proceeded in parallel with the machine design. Since that time, there has been standardized as yet. In addition, the optimum converter concept for SRM drives appears to be much more application[1].

Numerous converter topologies invented up to date have become popular and used in a variety of applications. The most flexible and the most versatile SRM converter is the asymmetric bridge converter of them shown in Fig.1, which requires two switches and two diodes per phase. The main advantage of this converter is high efficiency because the energy returns from the motor to the source after turn-off of phase switches. Also, this converter can control each phase independently when the

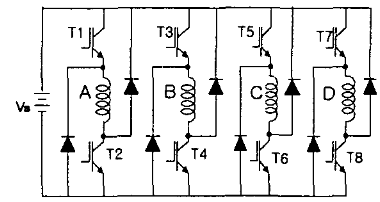


Fig.1 Asymmetric bridge converter topology.

overlapping conduction is desired. However, the number of switches required is twice to the number of phases and the upper level switches need the floating drivers. This converter is suitable for high voltage, high power drives [1,2].

In this paper new converter topology for the switched reluctance motor drives is proposed, which is composed of the minimum switch per phase, and is connected to the single-phase voltage inverter for ac pulse voltage source while all the SRM drives are supplied by dc voltage source. Two SRM converter topologies are proposed according to the inverter type in this paper, and several operating modes and characteristics are explained and compared each other when the half bridgeor full bridge inverter is connected to the proposed converter.

II. Proposed converter topology

In the paper the new converter topology is proposed as shown in Fig.2. The proposed converter uses the ac pulse voltage source. It consists of one switch per phase. Particularly, ac pulse voltage source is involved in the converter, while the fixed dc voltage source in conventional converter. Polarity of next phase switch and next phase winding becomes reverse.

When one switch is turned off, the phase current tail decreases quickly by negative voltage, that is, the energy returns to the source from the motor. Though the off-going switch is turned on, the phase current starts flowing because polarity of two switches is different each other. This characteristic is same

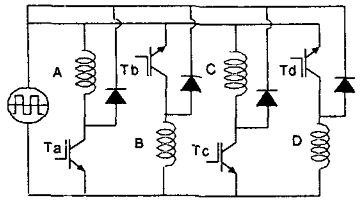


Fig.2 Proposed converter for four phase SRM drives.

to asymmetric bridge converter of Fig.1. Accordingly, it is predictedthat the SRM with the proposed ac pulse source converter has high efficiency. The single-phase inverter, which is divided into the half bridge type and the full bridge type, is used to supply the ac pulse source to drive.

III. Proposed converter connected to single-phase half bridge inverter

Fig.3 shows the proposed Converter connected to the single-phase Half Bridge Inverter(CHBI). The single-phase Half Bridge Inverter(HBI) is composed of two switches, two diodes, and a center-tapped dc voltage source. It is suitable for low speed control because the maximum voltage utilization rate in half bridge inverter is 50%. The PWM voltage to phase winding is controlled by the inverter part, and the turn on/off angle is controlled by the converter part.

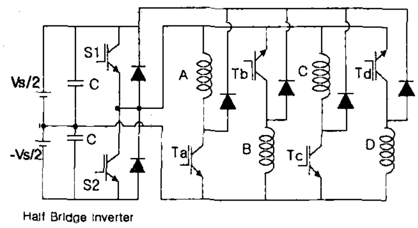


Fig. 3 Proposed SRM converter connected to the HBI (n=4).

A. Operation of Mode

Winding voltage, current and power of SRM converter are changed according to the type of topology, speed, load, the turn-on/off of the phase switches and so on. The operation is divided three modes per cycle and transient mode, as shown in Fig.4.

Mode [I] (Magnetizing period): When the phase switch Ta and inverter switch S1 is turned on and S2 is turned off, the input voltage $v()=Vdc/2$ is applied to the phase A winding, as shown in Fig.4(a).

Mode [II](First regenerating period): When the phase switch Ta is turned on and also the inverter switch S1 and S2 are turned off, the energy returns to dc half link voltage $-Vdc/2$ from SRM, as shown in Fig.4(b).

Mode [III] (Second regenerating period):When the phase switch Ta, and also the inverter switch S1and S2is turned are turned off, the energy returns to dc link voltage $-Vdc$ from SRM, as shown in Fig.4(c).

Mode [IV] (Transient period):Mode IV exists during the transient period when the ON period is changed from the phase A to the phase B. When the phase switch Tb and inverter switch S2 is turned on and S1 is turned off, the reverse dc link voltage is applied to the phase A winding, and the dc link voltage is applied to the phase B winding, as shown in Fig.4(d).

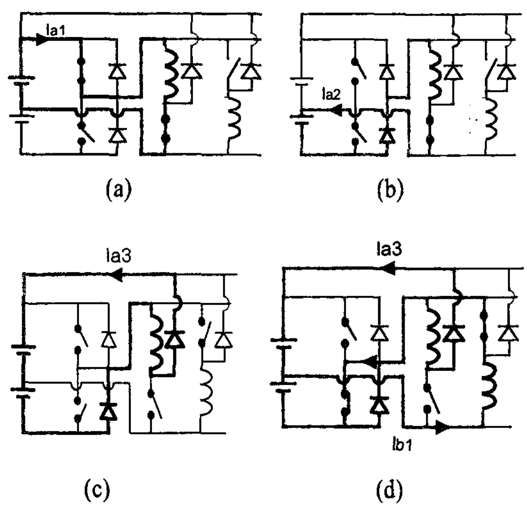


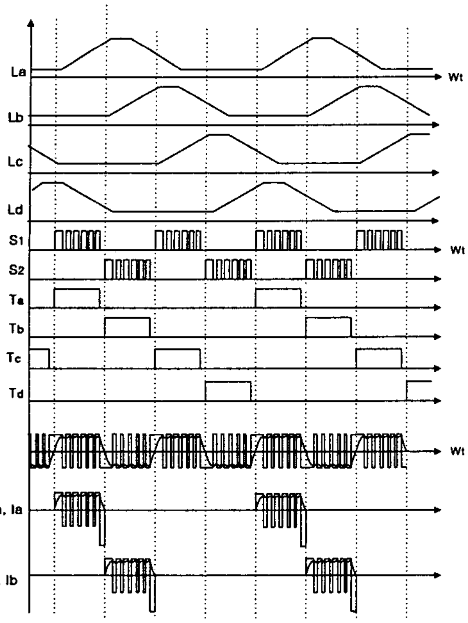
Fig.4 Four modes of operation in the CHBI. (a) Mode I (b) Mode II (c) Mode III (d) Mode IV

B. Waveforms

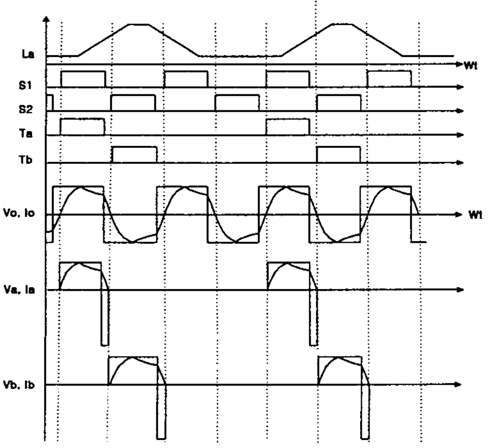
Input voltage of proposed converter has the PWM or pulse waveform, which is different to the conventional converter with the fixed dc link voltage. Input voltage waveform is controlled by the inverter part, and phase voltage waveform is controlled by the converter part in proposed converter.

Fig.5 shows the waveforms for the inductance profile, switch signal, output voltage and current of each phase, output voltage and current of inverter when the CHBI is operated by two control methods. When the chopping control method is applied to the proposed SRM converter at low speed as shown in Fig.5(a), the speed of SRM is controlled by adjusting the current in an inverter. The output voltage at inverter has the shape of PWM waveform, and its current is also similar to ac pulse waveform. When the single-pulse control method is applied to the proposed converter at high speed as shown in Fig.5(b), the speed of SRM is controlled by adjusting the turn-on/off angle.

IV. Proposed converter connected to single-phase full bridge inverter



(a)



(b)

Fig.5 Waveforms for inductance profile, output voltage, current of inverter and the switch signal, output voltage and current of each phase in the CHBI. (a) Chopping control method. (b) Single-pulse control method.

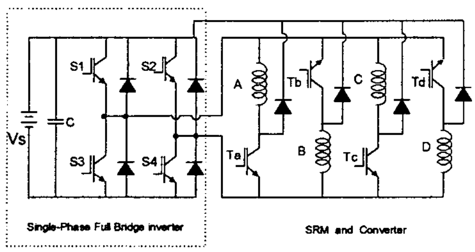


Fig. 6 Proposed SRM converter connected to the FBI (n=4).

Fig.6 shows the proposed Converter connected to the single-phase Full Bridge Inverter(CFBI). The CFBI has advantage that the multitude of input voltage is same to the output voltage, and has three-level output voltage (Vdc, 0. Vdc). The maximum voltage utilization rate of CFBI is 100 %, which is twice to the CHBI. It is useful to apply for SRM with more phases because total switches become smaller relatively comparing to another converter as the number of phases increase.

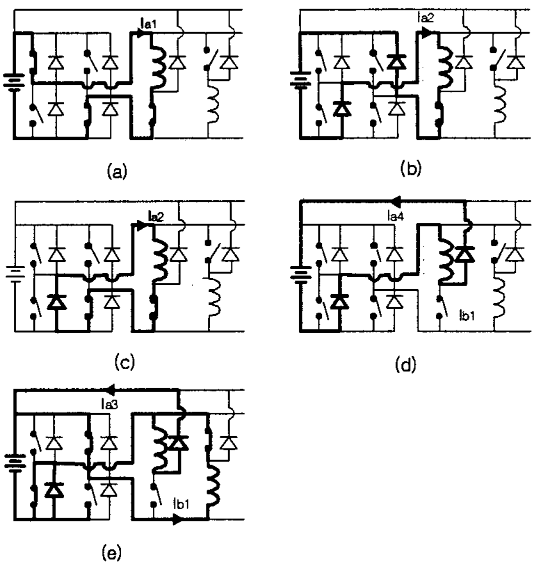


Fig.7 Four modes of operation in the CFBI. (a) Mode I (b) Mode II (c) Mode III (d) Mode IV

A. Operation of Mode.

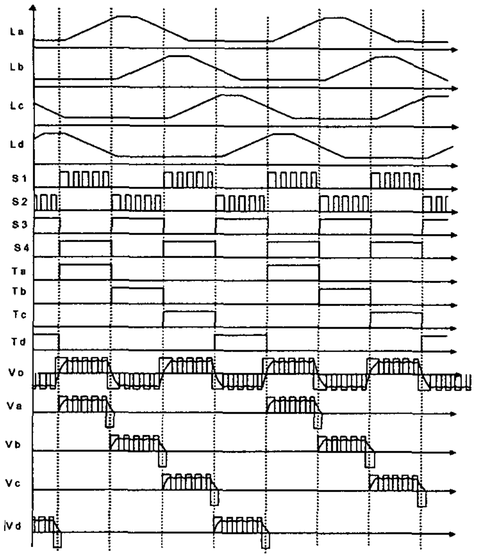
The operation of the CFBI is similar to the CHBI. There are four modes and transient mode per half cycle, as shown in Fig.7. The phase equation during operation is given by eq.(1) and eq.(2).

Mode [I] (Magnetizing period): When the phase switch Ta and inverter switch S1, S4 is turned on and S2, S3 is turned off, the input voltage *v*()=*Vdc* is applied to the phase A winding, as shown in Fig.7(a).

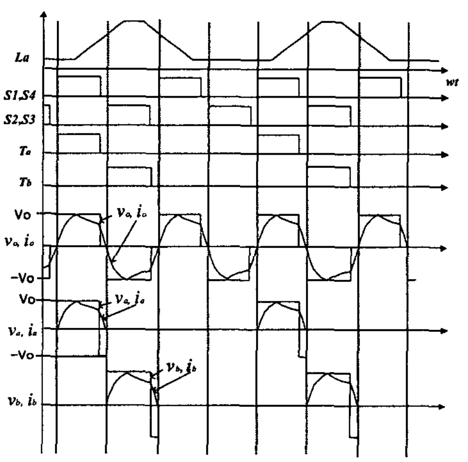
Mode [II](First regenerating period): When the phase switch Ta is turned on and also the inverter switch S1, S2, S3 and S4 are turned off, the energy returns to the dc link voltage -*Vdc* from SRM, as shown in Fig.7(b).

Mode [III] (Freewheeling period): When the phase switch Ta the inverter switch S14 are turned on and S1, S2, S3 are turned on, the energy in phase A is freewheeled through the diode in the inverter, as shown in Fig.7(c).

Mode [IV] (Second regenerating period): When the phase switch Ta is turned off and also the inverter switch S1, S2, S3 and S4 are turned off, the energy returns to dc link voltage -*Vdc* from SRM, as shown in Fig.7(d). The operation circuit by this mode is similar to that of Mode II.



(a)



(b)

Fig. 8 Waveforms for inductance profile, output voltage, current of inverter and the switch signal, output voltage and current of each phase in the CHBI. (a) Chopping controlmethod. (b) Single-pulse control method.

Mode [V] (Transient period): Mode V exists during the transient period when the ON period is changed from the phase A to the phase B. When the phase switch Tb and inverter switch S2, S3 are turned on and S1,S4 are turned off, the reverse dc link voltage is applied to the phase A winding, and the dc link voltage is applied to the phase B winding, as shown in Fig.7(e).

B. Waveforms

Fig.8 shows the waveforms for the inductance profile, switch signal, output voltage and current of each phase, output voltage and current of inverter when the CFBI is operated. Fig.8(a) shows the waveforms and signals at low speed when the chopping control method is applied to the CFBI. It is observed that several waveforms to maintain constant phase current at low speed. Two PWM signals to the upper inverter switches S1, S2 make the output current constant by hysteresis controller. Two signals to the lower inverter switches S3,S4 and the signals to the phase switches are single pulse wave, which must be synchronized each other. The chopping is operated in the inverter, and the turn on/off angle and the speed of SRM are controlled by adjusting the current in the inverter.

Fig.8(b) shows the waveforms and signals at high speed when the single-pulse control method is applied to the CFBI. The speed of the SRM to the CFBI can be controlled by the turn-on/off angle of inverter switches and phase switches. After the turn-off, the full dc voltage is applied to suppress the winding current quickly. From the figure, it is shown that the full bridge inverter has three-level output voltage (Vdc, 0. Vdc) according to the turn-on/off angle. Also, the turn-on/off signals to phase switches at inverter have to synchronize with those at converter regardless of control method.

V. Experiments

A test circuit for the proposed was builtand evaluated with 8/6, 1.5 hp SRM. Inverter part in the drive is designed for a maximum dc voltage of 120V. The IGBT module is used in a inverter part and IGBT switches of three legs type are used in a converter part.

A. Proposed Convert Connected to Half Bridge Inverter

Fig.9 shows the oscillographs for two gating signals of inverter switches S1,S2 and two gating signals of phase switches Ta, Tb when the SRM operates at low speed under constant load by the chopping method. It is observed that the gating signal for inverter switch S1 is synchronized with that for Ta, and the signal for S2 is synchronized with that for Tb. Fig.10 shows the load current of inverter and the current of phase winding built by two gating signals of inverter switches and the gating signal of phase switch. It is observed that the load current and the phase current are similar to the trapezoid waveform. Also, the load current is synchronized with the phase current. Fig.11 shows the oscillographs for the waveforms of two currents by the gating signals. Upper wave means current flown in upper voltage source, down wave means current flown in down voltage source. It is observed that upper and down current at inverter part are also influenced by the regenerating current.

B. Proposed Convert Connected to Full Bridge Inverter

Fig.12 shows the oscillographs for the output current of inverter and the current of phase winding by chopping. It is

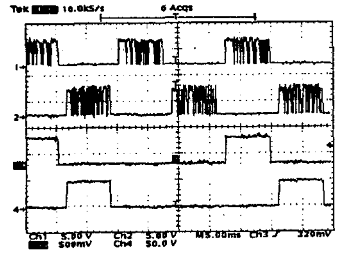


Fig.9 Experimental gating signals to phase switches at chopping in CHBI.

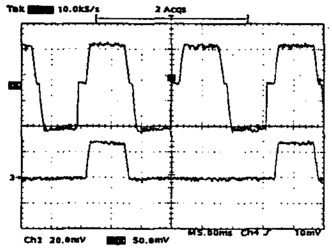


Fig.10 Experimental load current of inverter and phase current of SRM at chopping in CHBI.

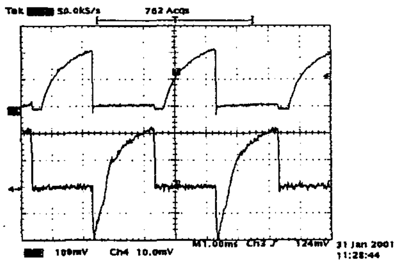


Fig.11 Experimental currents of inverter by single pulse method in CHBI

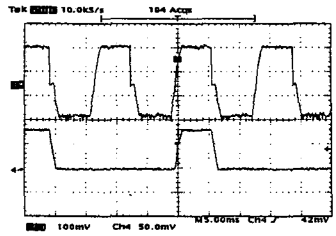


Fig.12 Experimental load current of inverter and phase current of SRM at chopping in CFBI.

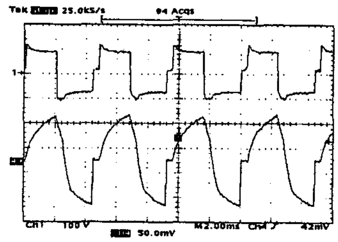


Fig.13 Experimental output voltage and current of inverter at angle control in CF

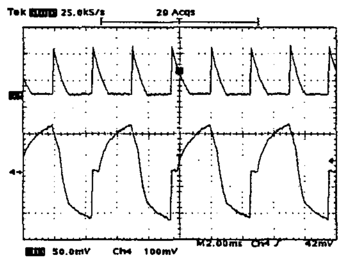


Fig.14 Experimental regenerating current and output current at angle control in CFB

observed that the two currents in CFBI are similar to those of CHBI in Fig.9. Fig.11 shows the oscillographs for the input current of converter and the output current of inverter when the SRM is operated by the single-pulse method at high speed. It is observed that the current is not symmetrical because of regenerating current. Fig.13shows the oscil-lographs for regenerating current and output current of inverter by the single-pulse method. From the figure, the output current of inverter are certainly influenced by the regenerating current.

V. Results

Proposed converter has ability that the energy is returned to the dc link. Particularly, performance of proposed converter connected to the half bridge inverter is similar to the split source converter. However, this type can chop the phase voltages by inverter at low speed, while the split source converter is difficult forchopping. Though the converter has minimum switches, total switches are not of small number because the full inverter has four switches. Accordingly, it is also useful to apply for SRM with more phases because total switches become smaller relatively comparing to another topology as the number of phases increase. Power circuit can be also more simplified if the IGBT module or the IPM in inverter is used.

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