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단상 SRM용 컨버터 특성비교

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Comparison of Converter Topologies for Single Phase Switched Reluctance Motor

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Abstract - Comparison of three converter topologies for single phase switched reluctance motor is proposed in this paper. Due to the limitation of dc-link voltage, conventional asymmetric converter is difficult to build up enough phase current in the high speed operation. In order to solve this problem, boost converter is used to improve the performance. Two active boost converters are reviewed: one is series-connected type, another is parallel-connected. Otherwise, a novel active boost converter is proposed. The comparison of these converters is based on the voltage raring of capacitor, stability and converter topology. Because the converter selection depends on the motor design, the single phase 6/6 SRM is considered in this paper. Some simulations results are executed. And the results verified the analysis in this paper.

1. Introduction

Switched Reluctance Motors(SRM) is low cost and has a simple and robust structure with high power density, reliability, controllability and intense temperature variations. The single phase SR drive is low cost, and suitable for the high speed application[1].

However, the terminal voltage of motor windings also is limited by the voltage of source in conventional SR drive. Many boost converters have been proposed in past few years[2-11]. They can divide into two types: one is passive boost converter which has a simple structure and low cost, but the boost voltage is out of control[3-7]. Another is active boost converter, the major advantage is the boost voltage which can be controlled by additional power switch. The two types of active boost converter are proposed[11]. One is two capacitors in series-connected type another is two capacitors in parallel-connected type. The fast excitation and demagnetization mode can be obtained in these two converters. Due to the recovery energy change in difference case, the active power switch should be control to keep the stable voltage or avoid the over voltage of converter.

In this paper, comparison of three converter topologies for single phase switched reluctance motor is proposed. Two active boost converters are reviewed: one is series-connected type, another is parallel-connected. Otherwise, a novel active boost converter is proposed. The comparison of these converters is based on the voltage raring of capacitor, stability and converter topology. Because the converter selection depends on the motor design, the single phase 6/6 SRM is considered in this paper. Some simulations are executed. And the results verified the analysis in this paper.

2. Review Two Types of Single Phase SR Drive

2.1 Active Boost Converter of Single Phase SRM using Two Series-connected Capacitors

In order to break through the limitation of dc-link from the source, the boost converter is required. The four level converter for high speed SR drive was proposed as shown in Fig. 1. To this converter, the primary characteristic is that the boost capacitor and the dc-link capacitor are connected in series. The positive terminal of dc-link capacitor is directly connected to the negative terminal of boost capacitor. In order to avoid short circuit, the diode D_1 should be added. If the boost capacitor has some voltage, when the power switch Q_{Bo} is turned on, the diode D_1 will be turned off automatically.

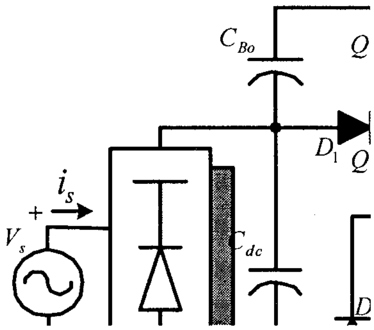

Fig.1 Boost converter using two series-connected capacitors

The operation modes of this converter are divided to 4 modes: fast excitation mode, normal excitation, freewheeling mode and fast demagnetization mode. The major advantage of this converter is that the two capacitors are connected in series, so the fast excitation mode and the fast demagnetization mode can support the superposition voltage of two capacitors to obtain quicken variational phase current. As a result, the excitation time and demagnetization time is reduced, and the power of motor is increased.

However, the additional components which are added increase the cost of converter. And the voltage rating of power component should be increased due to the boost voltage generated in four level converter. In order to avoid the overcharging of boost capacitor, the voltage controller or other voltage protector should be added. The voltage characteristic of boost capacitor is shown in Fig. 2. In this figure, the recovery energy is fixed, with the discharge time of boost capacitor decreased, the voltage of boost capacitor increases and reaches another balance point. Toward an ideal case, the max voltage can reach infinite. But considering the cost and motor performance, one time of dc-link voltage is useful in this converter.

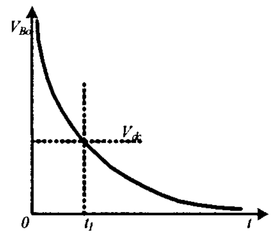

Fig. 2 Voltage characteristic of boost capacitor in two series-connected capacitors

2.2 Active Boost Converter of Single Phase SRM using Two Parallel-connected Capacitors

Different from the two series-connected capacitor type converter, the active boost converters using two parallel-connected capacitor is proposed[3]. The structure of this converter is shown in Fig. 3. The negative terminals of dc-link capacitor and boost capacitor are connected together. The active boost switch controls the discharge time of boost capacitor. So the each capacitor is as independent source to supply the energy. However, which capacitor works depend on the voltage of two capacitors.

The operation mode of this converter is divided into 5 modes: fast excitation mode, normal excitation, freewheeling mode, fast demagnetization mode and boost capacitor charge at start-up. In the fast excitation mode, the active switch is turned on, and the high voltage of boost capacitor makes the diode D_1 turn off. So the high voltage can inject to the phase winding and build the fast excitation current. In the fast demagnetization mode, the recovery energy only charge the boost capacitor, but the high voltage is in the boost capacitor, so the fast demagnetization is easy to achieve. In the boost capacitor charge at start-up, the precondition is that the boost capacitor is empty before. So the dc-link capacitor can charge the boost capacitor until the same voltage.

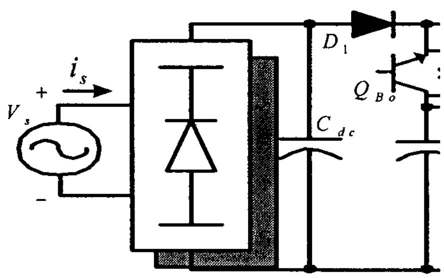

Fig. 3 Boost converter using two parallel-connected capacitors

Similar to four level converter, the parallel type of active boost converter also has same problems of cost, voltage rating of power components and voltage control. However, the voltage characteristic of boost converter is different to four level converter shown as Fig. 4. After the boost capacitor charge at start-up, the voltage of boost capacitor is more than or equal to the dc-link voltage. The voltage rating of boost capacitor is higher than 4-level converter's. So he cost of in parallel type converter is higher than in series one. the voltage characteristic of boost converter the voltage characteristic of boost converter.

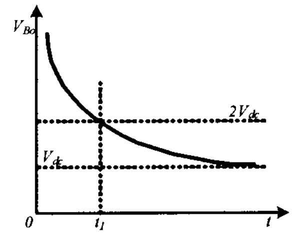

Fig. 4 Voltage characteristic of boost capacitor in two parallel-connected capacitors

3. Proposed Boost Converter of Single Phase SR Drive

In order to combine the advantage of series-connected capacitors and parallel-connected capacitors, a novel active boost power converter with hybrid-connected capacitors is shown in Fig. 5. Compared with the series-connected capacitors converter or the parallel-connected capacitors converter, the proposed converter only adds one diode.

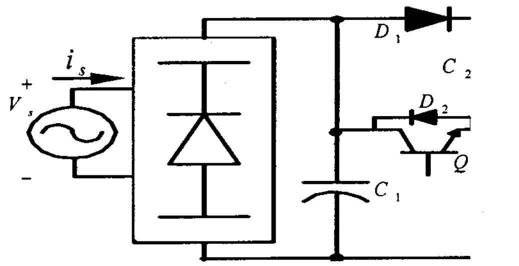

Fig. 5 Proposed active boost converter

To analyze the operation modes of the proposed converter in the single phase SR drive, they can be divided into six modes from different states of switches and diodes. i.e. boost capacitor excitation mode, dc-link capacitor excitation mode, two capacitors excitation mode, fast excitation mode, freewheeling mode and fast demagnetization mode, respectively, as shown in Fig. 6.

The voltage characteristic of proposed converter is shown in Fig. 7. The voltage curve is separated into two parts:

Region 1(0 ~ t_1): the voltage of boost capacitor keeps constant value which is same to dc-link voltage. Profit from the two capacitor in parallel-connected in proposed converter, the overcharge energy can be discharged automatically. Therefore, in this region, never consider overcharge or not, the discharging time can easy to set an appropriate value.

Region 2(t_1 ~ ∞): the voltage will drop under the dc-link voltage. So this region is similar to two capacitor series-connected converter. If the stable boost voltage is required, the boost voltage should be added.

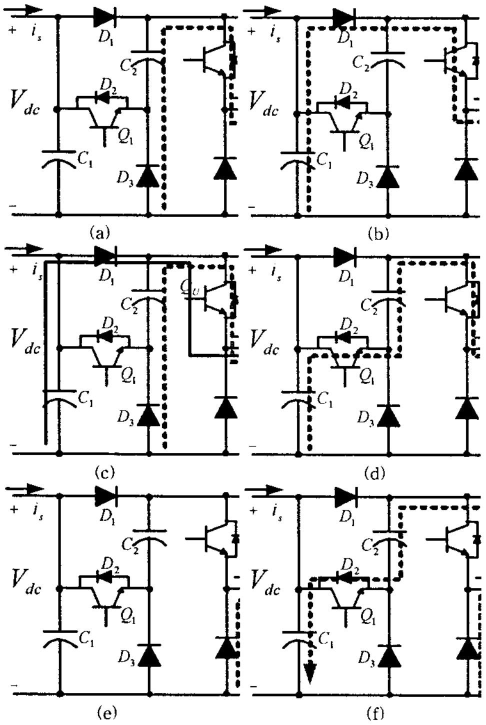

Fig. 6 Operation modes of proposed converter for single phase SRM
(a) Boost capacitor excitation mode
(b) Dc-link capacitor excitation mode
(c) Two capacitors excitation mode
(d) Fast excitation mode
(e) Freewheeling mode
(f) Fast demagnetization mode

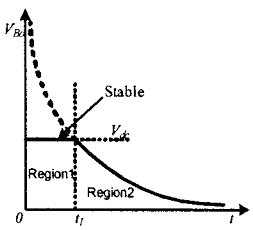

Fig. 7 Voltage characteristic of boost capacitor in two hybrid-connected capacitors

4. Simulation

In order to compare the performance of three typies converter, some simulations have been evaluated using Simulink. The contrastive simulation results of the three types active boost converter are shown in Fig. 8. The boost voltages of phase winding which are the same are shown in the figure. As discussed before, the voltage of boost capacitor is higher in the two capacitor parallel-connected converter. In this simulation, the boost voltage of series and parallel type boost converter is controlled by boost switch. So the boost voltage controller is needed. To proposed converter, based on the proposed topology, the boost voltage is automatically keep stable.

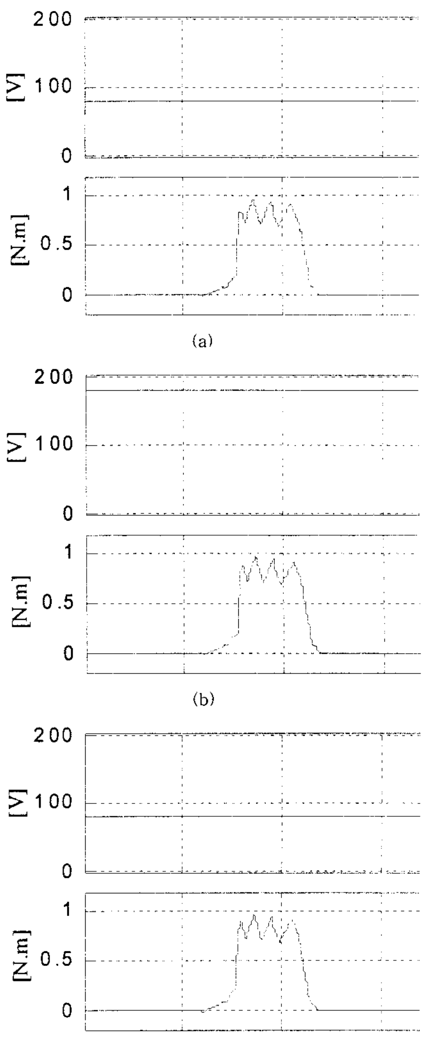

Fig. 8 Simulation results of three types active boost converter
(a) Two capacitors series-connected converter
(b) Two capacitors parallel-connected converter
(c) Two capacitors hybrid-connected converter

The simulation results of proposed converter in region 1 are shown in Fig. 9. In this region, the voltage of boost capacitor is same to the voltage of dc-link. The worse case of series-connected converter and parallel-converter is that the boost active switch is turned off due the other reason. In this case, the boost voltage will increase until broken converter. However, to the proposed converter, the turn-off state of boost active switch is useful to improve the current ripple in the current chopping control. Furthermore, it can improve reliability and controllability in the drive system.

Two capacitors series-connected converter, two capacitors parallel-connected converter and proposed converter are introduced in this paper. The comparison of 3 types power converter are shown in Tab. 1. Even though the series-connected type and parallel type can obtain higher boost voltage than proposed converter. However, the higher boost voltage is used, more cost should be increased in this case.

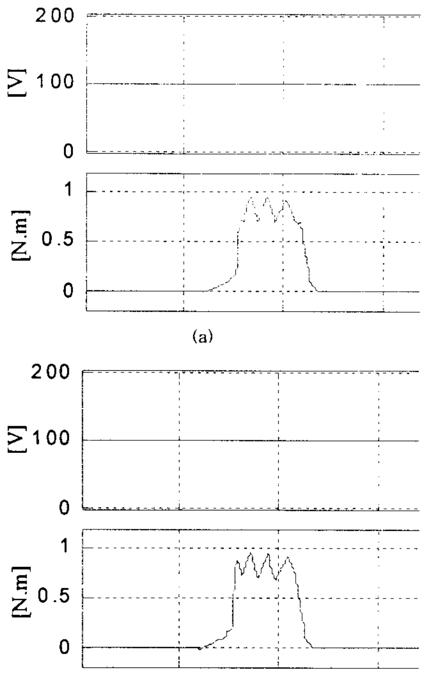

Fig. 9 Simulation results of proposed converter in region 1
(a) turn-off Q1 (0 degree) (a) turn-on Q1 (2 degree)

Since the proposed converter can limit the maximum voltage at two times of dc-link, the proposed converter is more stability and controllability. If the discharging time of boost capacitor is controlled in region 1, the voltage control of boost capacitor can be removed.

TABLE 1
The comparison of 3 types power converter

	series type	parallel type	Proposed
V_{max}	$\infty/^{\#}2V_{dc}$	$\infty/^{\#}2V_{dc}$	$2V_{dc}$
$V_{control}$	*Yes*	*Yes*	*optional*
V_{C1_rate}	V_{dc}	V_{dc}	V_{dc}
V_{C2_rate}	$\infty/^{\#}V_{dc}$	$\infty/^{\#}2V_{dc}$	V_{dc}
$S_{witches}$ *No.*	*3*	*3*	*3*
D_{iodes} *No.*	*3*	*3*	*4*
Stability	*Normal*	*Normal*	*Good*

Note: # is the case that the boost voltage controller is added.

5. Conclusion

In this paper, comparison of three converter topologies for single phase switched reluctance motor is proposed. Two active boost converters are reviewed, and characteristic of them are introduced. A novel active boost converter is proposed. The operation modes of proposed converter are analyzed. The comparison of three converters is based on the voltage raring of capacitor, stability and converter topology. Based on the single phase 6/6 SRM, some simulations are executed. And the results verified the analysis in this paper.

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