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Single-stage power-factor-corrected converter for switched reluctance motor drive

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Abstract

A new single-stage power-factor-corrected converter is proposed to improve input power factor for an efficient switched reluctance (SR) motor drive. The proposed converter uses the winding of SR motor as an input inductor for power-factor-correction. Converter switches play two important roles; one is to improve the input power factor and the other is to excite the motor phase. Consequently, ac-to-dc power converter and SR motor driver are incorporated into one power stage, so called a single-stage approach is realized; thus, it shows a simple structure. A laboratory prototype to drive a single-phase 6/6-pole SR motor is manufactured to evaluate the performance of the proposed drive system. Design example is given in detail, and the validity of the proposed converter is verified by experimental results.

Keywords: Converter; Power-factor-correction; Single-stage approach; SR motor

1. Introduction

The principal characteristics of switched reluctance motor (SRM) are simplicity, low-cost and robust structure suitable for variable-speed as well as servo-type applications. With relatively simple driver and control requirement, the SRM is gaining a great attention in the drive industry. Generally, the conventional SRM driver employs a diode rectifier with a filter capacitor to supply dc voltage source from ac utility line. Although this structure is simple, it draws a pulsating ac line current resulted in low power factor and high harmonic line current. With the increasing demand for better power quality, this approach is no longer suitable for high performance SRM drive. The best way to obtain a high power factor is the use of a power-factor-correction circuit with a SRM driver. In order to achieve sinusoidal input currents and to improve the low power factor in SRM drive system, several approaches have been introduced [1–11]. Among them, the approach in ref. [2] consists of the cascaded power stages of a boost and a buck eliminating pulse width modulation (PWM) control in the machine-side converter while delivering sinusoidal ac input current. This converter topology has high power factor and improved input current waveform; however, this approach is not recommendable choice in practical and low cost applications because of the complexity and high cost due to the cascaded power stages. The described SRM driver employing a half-wave zero-current switching (ZCS) quasi-resonant boost converter [3] obtained better performances and higher power densities using high quality rectifier with capacitive energy storage. Line current pollution generated by electric drives was reduced by addition of both passive input filters and active input current shapers; however, it consists of two-stage approach resulted in the increase of power conversion losses. In this paper, a single-stage power-factor-corrected SRM converter is presented to improve input power factor. The most outstanding figure of the proposed driver is a simple configuration compared with conventional counterparts employing a power-factor-correction circuitry. The switches for SRM drive are mutually used for power-factor-correction and phase magnetizing. An improved power factor with stable motor drive can be achieved with only one additional active switch. The validity and

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high-performance of the proposed SRM drive system is verified by experimental results.

2. Proposed power-factor-corrected SRM driver

Fig. 1 shows configurations of the classic converter and the proposed power-factor-corrected (PFC) SRM driver, respectively. Generally, the conventional converter illustrated in Fig. 1(a) employs a bulk capacitor in the end of the diode rectifier. Although it shows simple configuration, it draws a pulsating ac line current resulted in low power factor and high harmonic line current. In the viewpoint of energy saving, to improve the power factor is very important in practical applications. To solve the problems, power-factor-correction circuitry is often added in front of the conventional converter. However, the two-stage approach has several disadvantages such as complexity of the circuit composition, additional control loop, cost increase, etc. One of the important factors in the selection of a driver for the SRM may be the cost; thus, a single-stage power-factor-corrected converter is desirable for a practical and low cost SRM drive industry. Fig. 1(b) shows the proposed single-stage power-factor-corrected converter for SRM drive. The most remarkable characteristic of the proposed converter is that there is no bulk capacitor in the end of the diode rectifier. Therefore, it can control the input current covering all ranges of the input power. When the phase switch is turned off, capacitor C_f is necessary to recover the energy stored in the motor winding, which is used for an input inductor. It separately works with the input part.

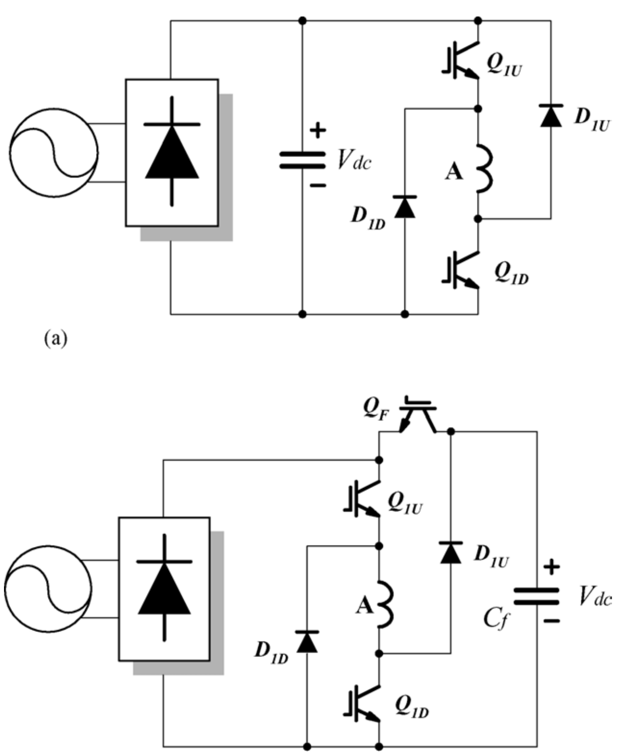

Fig. 1. Configuration of conventional and proposed converter for SRM drive: (a) asymmetric converter without power-factor-correction circuit and (b) proposed power-factor-corrected converter.

To simplify the operational analysis of the proposed converter, the following assumptions are made for analysis purposes. All of power switching devices and diodes are ideal, and voltage drop, the effect of stray components is negligible. The inductance $L=L(\theta,i)$ is assumed to be constant for the sake of simplification. Operational modes are divided into three modes: a phase excition by the external capacitor, a phase excition by the input voltage source and demagnetizing mode.

Mode 1: With turning on the phase switches Q_{1U} and Q_{1D}, a phase current begins to flow from the external capacitor. Because the amplitude of the input voltage is lower than that of the external capacitor voltage, there is no input current from the ac line. The higher voltage that is recovered and stored at Mode 3, is more efficient for the faster settling of a flat-topped phase current. The phase current flows through C_f, Q_F, Q_{1U} and Q_{1D}.

Mode 2: This mode starts when the amplitude of voltage across the external capacitor becomes equivalent to that of input voltage. The phase is continuously magnetized by input voltage source instead of the external capacitor. The phase current flows through Q_{1U} and Q_{1D}. During Mode 2, Q_F should be turned off to draw current from the input supply. The voltage across the capacitor C_f maintains a constant voltage level under a same motor speed. The voltage level is controlled by the duty ratio of the converter switches. To increase the motor speed, the capacitor voltage should be increased. To do so, the duty ratio of the switches should be increased. Internally, the relationship between the capacitor voltage and the duty ratio is very similar to that of the general boost converter.

Mode 3: When the phase switches are turned off, a reactive power of the phase winding is transferred to the external capacitor through freewheeling diodes, D_{1D} and D_{1U}.

The proposed SRM converter cannot obtain a perfect sinusoidal input current in itself because the input current operates on discontinuous current conduction mode. It requires an input LC filter to filter out high-order harmonic components from the input current. The main objective of Mode 1 is the faster settling of a flat-topped phase current. Mode 2 plays a role to draw input currents from the supply by means of so called semiautomatic current shaping theory. The peak value of the input current will follow the shape of the input voltage wave automatically. It is the matter of cause because the input current flows through the motor winding during on state of the Q_{1U} and Q_{1D}.

3. Design example

Specifications of the tested SRM are listed as

pole configuration: 6/6-pole (single-phase);
rated output: 400 W;
winding resistance of a phase: 1.1 Ω;
input voltage: 110 V_{rms};
rated voltage: 160 V_{dc};
rated speed: 1800 rpm;
efficiency: 80%.