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An Isolated Zeta Converter Topology for Switched Reluctance Motor Drive with Power Factor Correction

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Abstract

Objective: This paper presents an isolated zeta converter fed switched reluctance motor(SRM) drive with power factor correction for low power applications. **Methods:** A single phase AC supply is given to the diode bridge rectifier followed by a isolated Zeta converter then frontend converter with Switched Reluctance Motor (SRM) drive. **Findings:** To design the Power Factor Correction (PFC) isolated Zeta converter operated in Discontinuous Conduction Mode (DCM) for low power applications. For better current regulation, the input voltage is boosted without using any voltage are current sensors, we get both current and voltage wave forms are in phase. **Improvement:** For many variable speeds drives applications, the presented topology makes it a better choice due to power factor correction.

Keywords: Discontinuous Conduction Mode (DCM), Front End Converter, Isolated ZETA Converter, Power Factor Correction (PFC), Power Quality, Switched Reluctance Motor (SRM) Drive

1. Introduction

A plenty of unipolar excitation circuits are proposed in the literature for switched reluctance motor(SRM) drive[1,2]. There are so many front end converters are available for the SR motor drive. There are (q+1) switches, q switches per phase, and 2q switches per phase are available for the SR motor drive as front end converter. Each and every converter has its own advantages and disadvantages. In that two control switches per phase topology offers the maximum control flexibility over the remaining topology presented in the literature and it will be shown in Figure 1.

From the consumption side, required the operation of application, it will be necessary to improve the equipment to gratify the standards of harmonics. Which limits the current harmonics magnitude and it will be injected into supply. Conventional AC/DC converters having a diode bridge rectifier with a bulk dc link capacitor does not satisfies with these standards. Due to the large size, weight and cost normal power factor correction circuits are impractical 50-60hz single phase lines[3]. At the same time active PFC methods are more popular due to low cost switches. It consists of simple DBR followed by a dc-dc converter then DC link capacitor. By using this type of topology, we shaped the supply current to track the supply voltage. And also the advantage of this type of converter is complexity and extra charge of PFC stage was unnecessary for the maximum power factor for small power levels. By adding the additional PFC stage, the drive efficiency will be increased[4].

Similarly, the SR motor drive power factor improvement will be discussed in few papers. To make use of high feature rectifier for unity power factor was discussed in[5]. A new model c-dump converter was proposed to improve the power factor in[6]. A new buck-boost converter topology with a front end converter to get high power factor is[7]. A new converter topology, which consists of a two phase converter with dynamic supply current shaping for SR motor drive was discussed in[8]. A sepic converter fed SR motor drive was discussed in[9]. A power quality improvement of SR motor with zeta converter is discussed in[10].

The DCM uses only one voltage sensor to sense dc link capacitor voltage to get unity power factor at

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ac supply and stress up on the converter switches is comparatively high[11]. PFC converters are mostly used for the improving of power quality in supply. Plenty of non – isolated and isolated power factor correction converters are presented in literature review[12-15]. PFC converters are operated in two different modes of operations. One is CCM and another one is DCM of operations. The cost of DCM is comparatively low as CCM due to the sensing requirements. In CCM the stress on the switches is low but it uses different sensors for supply voltage, supply current and dc link capacitor voltage. So, for low power applications it will be preferred.

This paper explains the different properties of the PFC isolated zeta converter for unity power factor at ac supply. The converter is intended to work in DCM for small power levels. The supply current is always follows the sinusoidal profile of the supply voltage.

The following paper is structured as follows. The simple operation of proposed topology is discussed in section 2. Isolated zeta converter Operation and design are discussed in section 3 and section 4 respectively. Control techniques for proposed topology are explained in section 5, followed by Simulation results in section 6 and Section 7 concludes the paper.

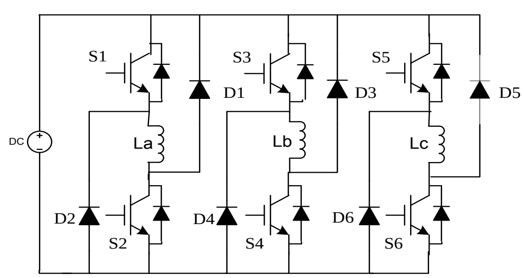

Figure 1. Asymmetric bridge converter.

2. Proposed PFC Based Isolated Zeta Converter Fed SR Motor Drive

Figure 2 shows the proposed converter topology for the switched reluctance motor drive. A single phase AC supply is given to the diode bridge rectifier followed by a LC filter to reduce the switching ripples in supply system. That rippleless output will be given to the PFC based isolated Zeta converter followed by a DC link capacitor. The isolated zeta converter output will be given to the SR motor through front end converter. A unipolar polar converter that is asymmetric bridge converter is used as the front end converter for SR motor. The voltage through the dc link capacitor is controlled by changing the duty ratio zeta converter. A single position sensor will be used to find rotor position of SR Motor and control the unipolar converter. The projected system is intended and simulated in matlab software and its performance is validated for improve the power factor of supply system for a different speed range.

3. Isolated Zeta Converter Operation

An PFC isolated Zeta converter can be divided into three different modes of operation. They are switch turn ON, switch turn OFF and Discontinuous conduction mode. Figure 3(a)-(c) and 4 represents the modes of operation and corresponding wave forms of isolated zeta converter respectively. These modes of operation are explained below:

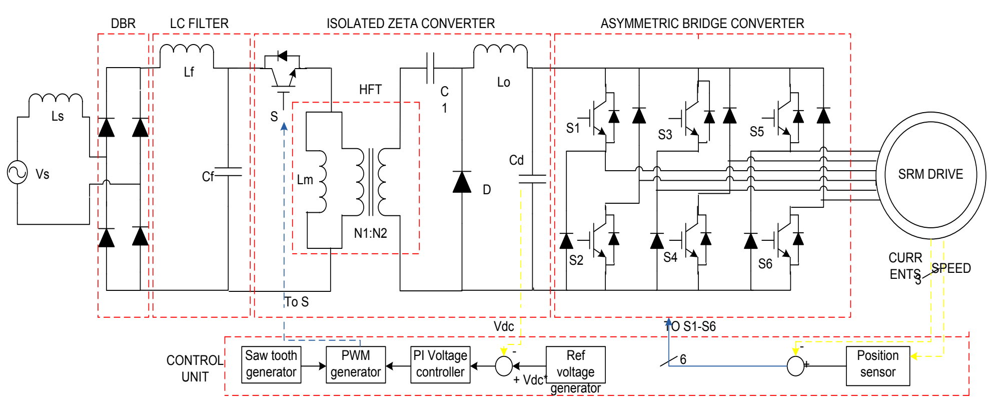

Figure 2. Proposed PFC isolated zeta converter fed switched reluctance motor.

Mode 1: Whenever turned ON the switch(s), the magnetizing inductance current (I_{lm}) and output inductor current ($I_{lo)}$ are gradually increases as shown in Figure 3(a). The intermediate capacitor voltage (V_{ci}) source for output inductor (L_o) and dc link capacitor (C_d). So, the output inductor current ((I_{lo}) and voltage of dc link capacitor are increases linearly and the voltage across intermediate capacitor (Cd) decreases gradually as shown in Figure 4.

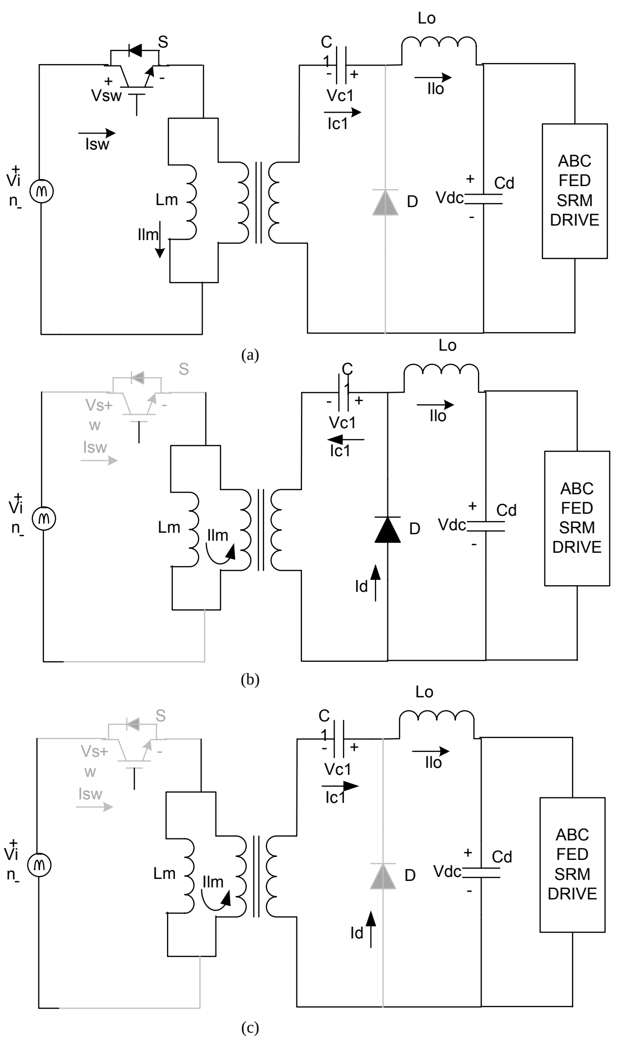

Figure 3. Modes of operation of high frequency isolated zeta converter.

Mode 2: Whenever turned OFF the switch(s), the magnetizing inductance current (I_{lm}) and output inductor current are decrease gradually and intermediate capacitor voltage (Vc1) increase linearly as shown in Figure 3(b). The energy for intermediate capacitor (C1) is supplied by the drawing inductance of high frequency transformer. In this mode of operation Diode (D) is conducts up to the energy in HFT is fully discharged as shown in Figure 4.

Mode 3: This mode is of purely DCM. The energy stored in HFT is decreases and output inductor (Lo) is charged linearly will be in Figure 3(c).The intermediate and dc link capacitor (Cd) source the energy for output inductor (Lo). Therefore, the intermediate and dc link capacitor voltage are reduced gradually and along this output inductor increases linearly will be shown in the Figure 4.

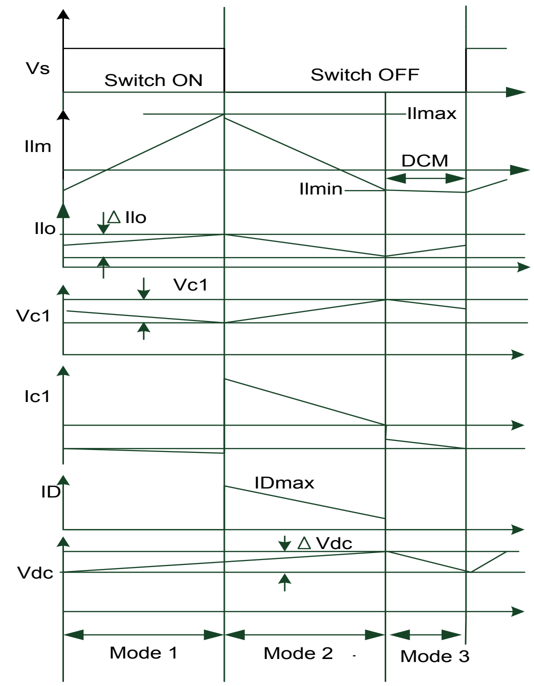

Figure 4. Waveforms for different modes.

4. Design of PFC Based Isolated Zeta Converter

For this operation, the zeta converter is operated in discontineous conduction mode. The design process of PFC isolated Zeta converter consists the design of different elements. That will be discussed in below:

Duty ratio value for a Isolated zeta converter operated in DCM is defined as:

$$D = \frac{V_{dc}}{\left(\frac{N_2}{N_1}\right) V_{in} + V_{dc}}$$

Where, V_{in} is input supply voltage, V_{dc} is dc link voltage, N2/N1 is transformer turns ratio and D is duty cycle. We choose the duty ratio as 0.4

The magnetizing inductance value is calculated by using the below expression:

$$L_m = \left(\frac{V_{dc}^2}{P_i}\right)\frac{\{1-D\}^2}{2Df_s(N_2/N_1)^2}$$

Where, P_i is rated power and f_s is switching frequency of PFC converter. We choose Lm value as 1mh.

The output inductor value is calculated by using the below expression

$$L_o = \frac{V_{dc}\{1-D\}}{f_s k I_o}$$

Where, k is the output inductor current ripple percentage and Io is current in output inductor. We choose the Lo value as 4.188mh.

The expression for intermediate capacitor is:

$$\frac{V_{dc}D}{\{\sqrt{\ } V_s \quad V_{dc}\}}\left(\frac{P_i}{\quad_{dc}}\right)$$

Where, μ is permitted ripple voltage across the intermediate capacitor? The C1 value is taken as 0.44 μf.

The expression for the dc link capacitor is:

$$C_d = \frac{1}{2\omega(\rho V_{dc})}\left(\frac{P_i}{V_{dc}}\right)$$

Where, ω is fraction of ripple in capacitor voltage? For this work the value C_d is taken as 2200f.

The expression for maximum value of filter capacitor is:

$$C_f = \frac{(P_i\sqrt{2}/V_s)}{\omega_l\sqrt{2}/V}\tan(\theta)$$

Where, θ is angle between the supply current and voltage? The C_f value is 320nf.

$$L_f = \frac{1}{4\pi^2 f_c^2 C_f} - 0.03\left(\frac{V_s^2}{P_o}\right)\frac{1}{\omega_l}$$

Where, f_c is cut-off frequency. The value of Ls is taken as 3.77mh.

5. Control Technique for Proposed Topology

The control technique for the proposed topology is categorized into two parts. They are DC link capacitor voltage control at isolated zeta converter and front end converter control for the SR motor.

5.1 Control of Zeta Converter

Voltage follower approach is used for the discontineous conduction mode of operation. Because, it is simple in operation and it uses only one sensor at dc link capacitor to sense the DC link voltage. It consists of a voltage feedback loop and no need of current control loop.

By using the feedback loop, we get the better voltage regulation, where the dc link capacitor voltage is compared by reference voltage for amplifying the produced error, we use a PI controller. Then that will be comparing with the saw tooth wave that produces pulses for the PFC converter switch. This control technique produce output voltage regulation with regular current shaping. The dc link voltage is controlled by adjusting the duty cycle.

5.2 Control SR Motor Drive

Asymmetric bridge converter is used as a frontend converter for Switched Reluctance Motor. It uses two switches per phase and there is charging elements are present. So, this converter is simple in construction as well as operation. The operation of asymmetric bridge converter uses a simple control technique which uses single position sensor.

The Switched Reluctance Motor drive rotor position is obtained by sense the speed of motor. That will be compared with the reference position angles and then compared with the phase current of Switched Reluctance Motor to produce pulses for asymmetric bridge converter.

6. Simulation Results and Discussions

The main purpose of modeling and simulation of PFC based isolated zeta converter fed Switched Reluctance Motor is to get the unity pf at ac mains and also low supply current harmonics. We use the 230v single phase ac supply and maintain the DC link capacitor voltage is constant, i.e 160V.

The supply current follows the supply voltage waveform is presented in Figure 5. Figure 6 displays dc link capacitor voltage and the motor three phase currents in Figure 7 and 8 shows the harmonic content present in the input current and Figure 9 shows the input current harmonic comparison between conventional and proposed converter.

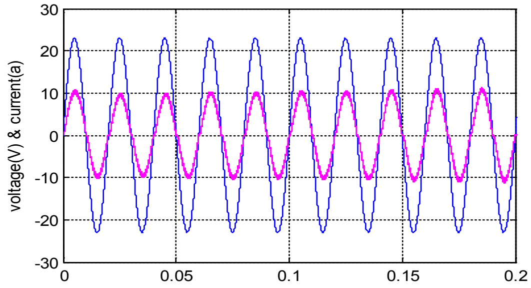

Figure 5. Input voltage and current.

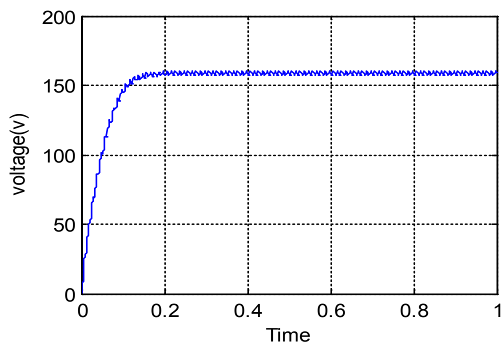

Figure 6. DC link voltage.

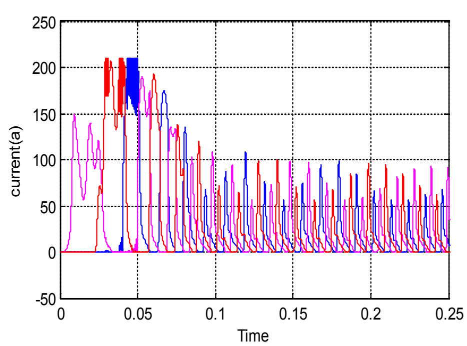

Figure 7. Phase currents.

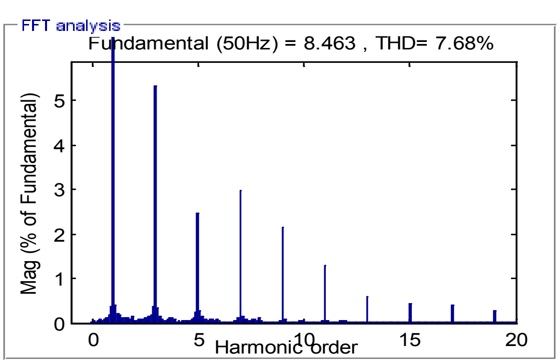

Figure 8. Input current harmonics.

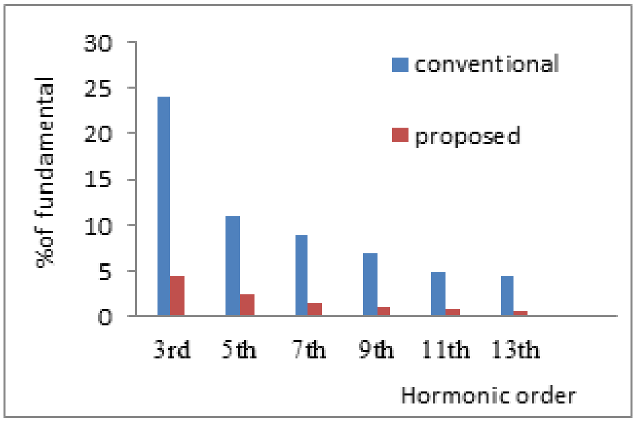

Figure 9. Input current harmonics comparison.

7. Conclusion

- A fresh topology consists of an isolated PFC zeta converter operated in Discontinuous conduction mode is used to drive the SR motor is developed and simulated for 60KW, 6/4pole.
- The designed isolated PFC zeta converter is working in DCM is shown an improved performance with power factor correction at supply side.
- The DC link capacitor voltage is kept constant for stable operation of an SR Motor.
- The proposed converter is applicable for small power application with ac supply and power factor correction at supply mains.

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