A Novel Random Carrier Frequency Modulation Technique for Drive Applications

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ABSTRACT

In high power usages, dc/dc converters have been extensively employed. Most of the converters are controlled by a constant switching frequency pulse width modulation (PWM) technique that results in significant harmonic intensity at the switching frequency. This will cause high EMI and will affect the nearby electronic devices. The traditional ways to overcome this problem include adding EMI filter or using EMI shielding. However, these methods will increase the component counts and cost. RPWM technique can well distribute the harmonic cluster to adjacent frequencies as compared with conventional PWM technique (diagonal PWM switching without random PWM). Like any other deterministic random PWM methods Diagonal switching PWM technique produces predictable harmonic components of objectionable magnitude. Harmonic causes switching losses, excessive stress on the switching devices and thus reduces the efficiency. The scheme has been investigated with the intention of distributing the harmonic power. Hence, an improved overall better performance is obtained.

Keywords: HSF, THD, PWM, RPWM, Novel ZVZCS, PRBS and RCFPWM Technique.

1. INTRODUCTION

Today power converters are the indispensable tool in any industry. Drives are playing major role in industries and hence their associated converter circuits and control strategies get importance. In power electronics wide range of converters are available. To name few, the basic single phase full wave phase controlled rectifiers, three phase rectifiers, Pulse Width Modulated (PWM) inverters, Vienne rectifiers, Multilevel inverters, Luo converters, Resonant converters etc. Researches are in full stream for further advancement of power converters. Harmonics play a major role in the performance of any power electronic converter. The presence of harmonic will degrade the performance of power converter and it will cause Acoustic noise, Mechanical vibration and EMI. So the necessity of harmonic dispersion becomes mandatory in power electronic convertors to reduce the Acoustic noise, Mechanical vibration and EMI.

2. RANDOM PWM TECHNIQUES

Random PWM techniques have been established for several years. These random PWM methods have the improvement of spreading the harmonic cluster to adjacent frequencies, and thereby sinking EMI filter size or removing it. However, random PWM techniques consequence in the rise of switching counts. This is particularly significant to an isolated full-bridge dc/dc converter since there are four power devices on the primary side and with the rise of switching counts the losses will increase significantly. Lim Y. C., et al. have presented a pseudorandom carrier modulation scheme and its harmonic spectra spread effect. The pseudo random carrier of the projected scheme are produced through the random synthesis of the two triangular carriers, each of the same fixed frequency, but of opposite phase [1]-[3].

Drissi et al. have survived on electric drives based discontinuous random space vector modulation for Inverter. Switching losses are attuned and life expectancy can be amplified using appropriate discontinuous modulation

procedure [4]. A novel hybrid random PWM scheme in which Random PWM pulses are fashioned complete by a logical evaluation of a pseudorandom binary sequence bits with the PWM pulses analogous to two random triangular carriers [5]-[6]. Random modulation techniques with constant switching frequency for three-phase power converters has familiarized by M. M. Bech. The techniques are based on adjusting the period of the zero-vectors or regulating the three PWM pulses in a switching period [7]. Y. S. Lai, has introduced novel PWM technique keeping the sampling frequency and the average inductor current constant Harmonics is decreased with constant average inductor current and constant sampling frequency, output voltage ripple is decreased requires additional compensating devices [8]. Random PWM techniques are proposed to drive at a low switching frequency to reduce the noise. The Random PWM techniques are operating at variable switching frequencies. However, the discrete part is considerably decreased. Hence, acoustic noise and mechanical vibration are reduced. The discrete harmonic spectrum present in the deterministic PWM technique is considerably suppressed by using random PWM technique [9]-[12].

3. OBJECTIVES

The main objectives of this paper is to understand and evaluate the harmonic spreading effects of diagonal switching pulse width modulation (DSPWM) and the random carrier PWM (RCPWM) in the full bridge dc-dc converter. To present a comprehensive comparison of DSPWM and PRBS bit based RCPWM. To verify its effectiveness by using MATLAB 7.1.0 (2007a)-SIMULINK software and hardware testing. To study the effect of insufficient filtering of dc link in harmonic spreading. To project the incapability of RPWMs of converter (working with constant dc) at fluctuating dc link. To perform a case study with four different dc link capacitors. To compare the performance of both conventional DSPWM and RCPWM in both converter working constant dc input and fluctuating dc input. As a whole, this work is aimed to evaluate the limitations of existing RPWM schemes in full bridge dc-dc converter working with constant dc and fluctuating dc and also provide effective alternative schemes for both the conditions.

4. NOVEL ZVZCS PWMFB CONVERTER

4.1. Current Reset Strategies

In order to make the primary current decay to zero in zero state, a blocking voltage source can be inserted in series with the primary winding. In zero state, if i_p flows in the positive direction, the blocking voltage source is positive and if i_p flows in the negative direction, the blocking voltage source is negative. The blocking voltage source can be simply realized by a capacitor c_b, named a blocking capacitor. When $Q_1 and Q_4$ conduct, i_p charges c_b. And when $Q_2, and Q_3$ conduct i_p discharges C_b. During zero state, the voltage of C_b keeps constant and resets i_p as shown in fig 3.2.
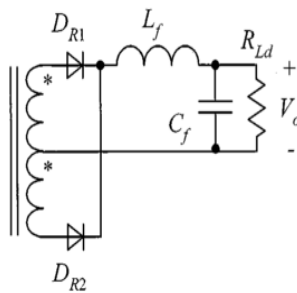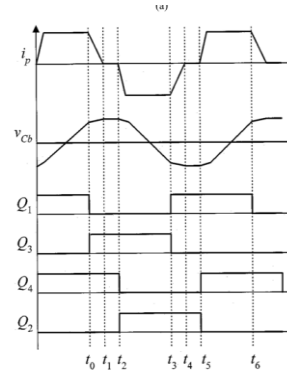
Fig. 1 ZVZCS Main Circuit

Fig. 2 ZVZCS Switching Waveforms

In zero state, the blocking capacitor has been fully discharged, so when the lagging leg turns on, the primary current has an excess high current spike due to charging of the blocking capacitor. The larger the blocking capacitor, the larger the current spike. When the leading leg turns off, the rectified voltage ramps down. As it becomes lower than the blocking capacitor voltage, the blocking capacitor will supply the rectified output filter inductor current.

4.2 Comparison of the ZVZCS PWMFB Converters:

The converter is very simple because only one saturable inductor is needed. However, the use of the saturable inductor results in two drawbacks. First, it causes a secondary duty cycle loss. In general, as the input voltage v_{in} has a certain variation range L_s should be designed according to $v_{in\ max}$ to prevent L_s from saturation during zero state; thus, the effective secondary duty cycle is reduced as v_{in} decreases. The lower the v_{in} the larger the secondary duty cycle loss. Second, the saturable inductor causes high core loss since it saturates in both directions. The blocking capacitor is shifted to the secondary side and an active switch is introduced, which cannot only reset the primary current, but also clamp the rectified voltage to depress the parasitic voltage oscillation. However, the converter requires an additional active switch and the associated control circuitry. The energy stored in the blocking capacitor is delivered to the load during zero state. The converter is better than the other two in terms of simplicity.

5. PROPOSED METHOD

5.1 Introduction of RCFM pwm technique

Random Carrier Frequency Modulation techniques dither the switching period with a small amplitude variation around the nominal value, so that the harmonic power is redistributed over the spectrum of concern. From Figure 4 where a PWM signal is generated from a continuous time input signal. Added random number is obtained by applying a uniformly generated random number to a suitable mapping function. If the saw-tooth peak value is constant, then slope is proportional to frequency, resulting in a Carrier Frequency Modulated PWM signal. In this approach duty cycle is preserved. This is critical in closed loop applications since loop dynamics such as gain and phase margin is a function of duty cycle.
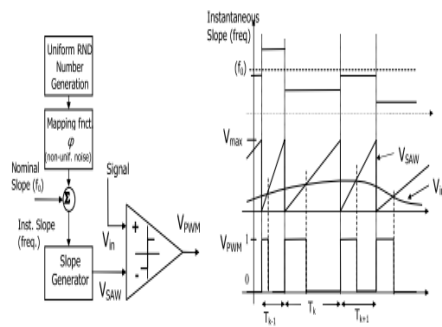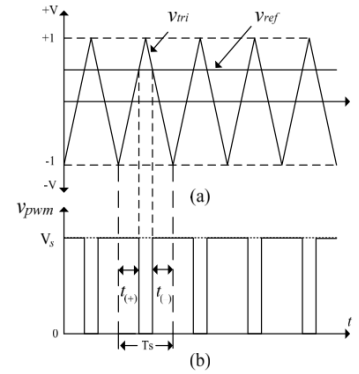
Fig: 3 Randomized PWM Generation Scheme

Fig: 4. CSFPWM
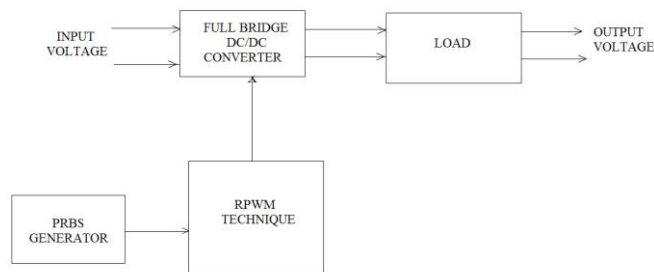
6. PROPOSED BLOCK DIAGRAM

Fig: 5. Proposed block diagram

The Zero-voltage switching (ZVS) phase shift modulated full bridge (PSM-FB) DC/DC converter with MOSFET switches has been proposed in fig 6. Low component count and zero full load switching losses enable this topology to achieve low cost, high power density, high efficiency, and low EMI, so for medium to high power DC/DC applications it is a good choice.
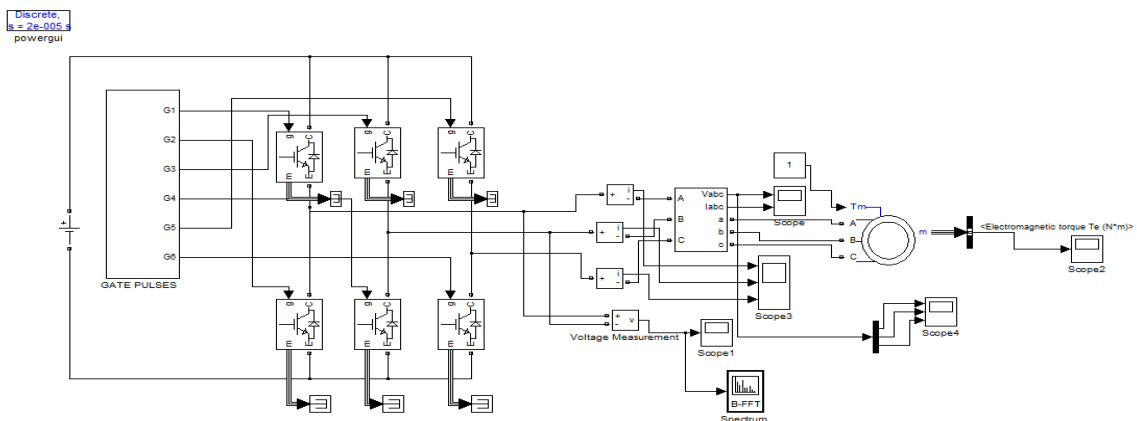
Fig: 6. Simulink schematic of RPWM drive in IM drive

6.1. *Full bridge dc-dc Converter*

Two switches turn ON and OFF at the same time; the primary leakage inductor current will freewheel through the body diodes to zero after the switches turn OFF, therefore no circulating current. Before the turn ON instant, because four switches are all OFF, the turn ON voltage is half the input voltage. For case 2, after energy transfer interval one of the switches Q1 or Q2 is still ON; primary side leakage inductor current will circulate through Q1 or

Q2 and the body diodes of Q3 or Q4, causing additional conduction losses. For case3, switchesQ3 and Q4 are complimentary turned ON and OFF; after the energy transfer interval, primary side leakage inductor current will first circulate through upper (Q1, Q3) switches and then circulate through lower (Q2, Q4) switches vice versa. This depends on the current direction and next period PRBSG value.

6.2. PRBS Generator

A binary sequence (BS) is a sequence $a_0, \cdots, a_{N-1}$ of N bits, i.e.

$$a_j \in \{0, 1\} \text{for } j = 0, 1, ..., N-1. \qquad \text{A BS consists of}$$
$$m = \sum a_j \text{ones and } N - m \text{ zeros.}$$

A BS is a pseudo-random binary sequence (PRBS) if its autocorrelation function:

$$C(v) = \sum_{j=0}^{N-1} a_j a_{j+v} \qquad \text{Have only two values:}$$

$$C(v) = \begin{cases} m, & \text{if } v \equiv 0 \pmod{N} \\ mc, & \text{otherwise} \end{cases} \qquad \text{Where}$$

$$c = \frac{m-1}{N-1}$$

Is called the *duty cycle* of the PRBS, similar to the duty cycle of a continuous time signal.

7. RESULTS AND DISCUSSION

The simulation study is performed in MATLAB/Simulink software. A full bridge dc-dc converter is considered. The complete specification of the full bridge dc-dc converter is given in Table 1. The input dc voltage (V_{in}) is 400V and the switching frequency (f_{sw})of DSPWM is 100kHz.

Table 1. Converter Specification, HSF values for DSPWM technique and Calculated HSF Value for RCFPWM Technique

Full bridge dc-dc converter Specification		HSF values for DSPWM technique		
Input Voltage(V_{in})	400 V	**PWM method**	**HSF**	**Peak Intensity of Harmonics**
Output Voltage (V_0)	12 V	Diagonal PWM switching without random PWM	2.298	0.84
Output Current (I_0)	44 A			
Output Power (P$_0$)	528 W			
Output Load (R$_L$)	0.273 Ω			
Transformer Turns Ratio($n_1 : n_2$)	45:4	Diagonal PWM with random PWM (one dimensional random)	2.225	0.6
Output Inductance (L$_1$,L_2)	33µH			
Output Capacitance(C_{out})	2000µF	New random PWM (70k, 85k, 115k, 130k)	2.051	0.16
Normal Switching Frequency(f_{sw})	100kHz			
FPGA Clock Rate(f)	200MHz			
Calculated HSF Value for RCFPWM Technique				

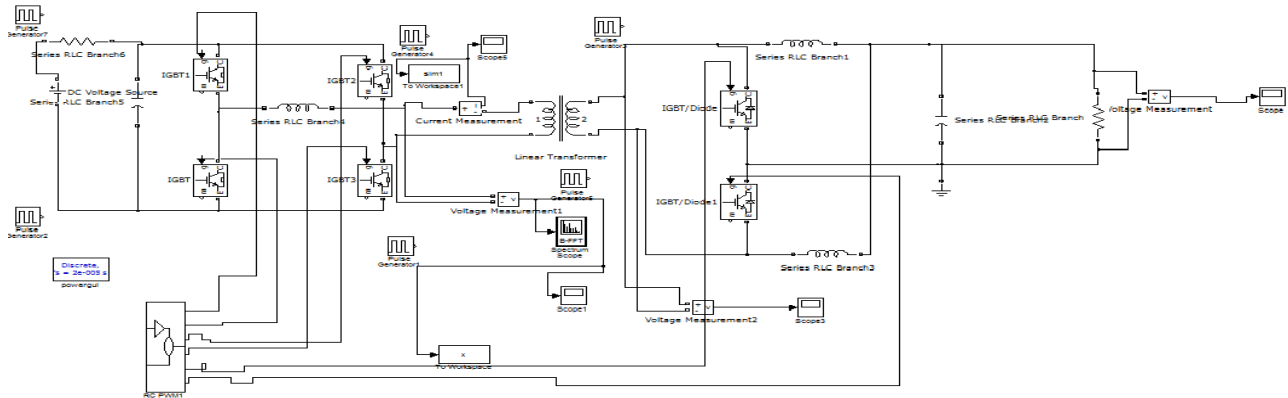| PWM Technique	HSF Value
Random Carrier Frequency Modulation Technique	0.1105

Fig: 6. MATLAB- Simulink Model of Full bridge dc-dc Converter

The measured harmonic spread factors for diagonal switching with and without random are shown in Table 1.
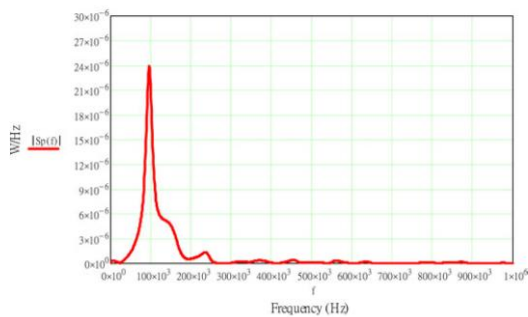

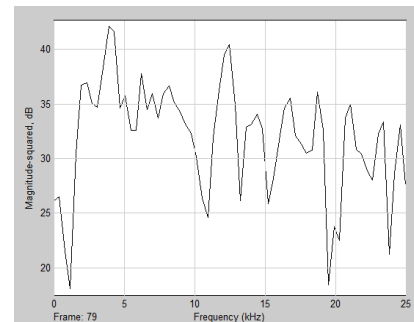Fig: 7. Calculated PSD for Diagonal PWM Technique with 80, 90kHz

Fig: 8. Calculated PSD for RCFM PWM Technique

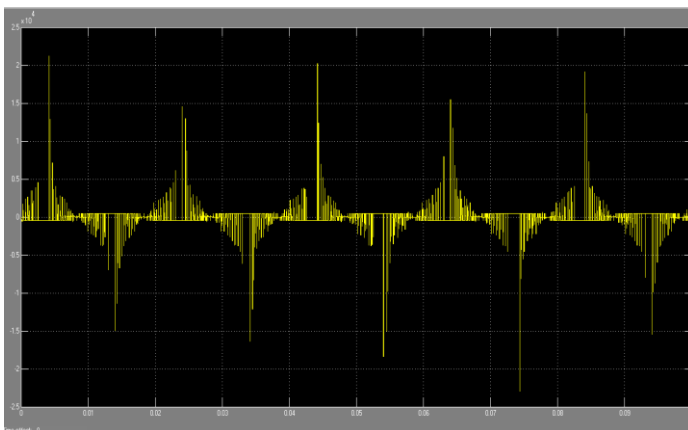Voltage across the point a and b can be shown in fig 9.and FFT analysis on figure 9
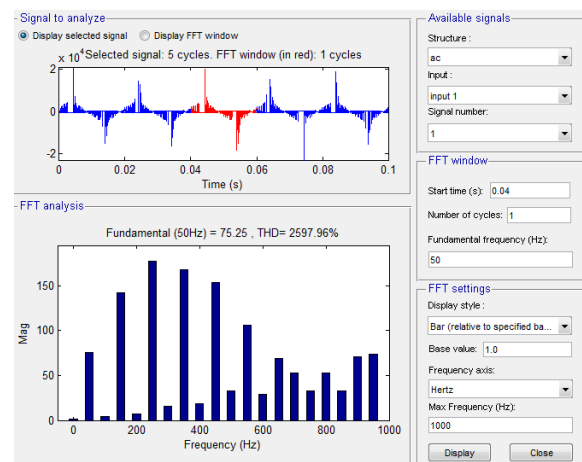

Fig: 9. Output Voltages

Fig: 10. FFT Analyses

8. CONCLUSION

The converters are controlled by a diagonal switching frequency pulse width modulation technique that results in significant harmonic intensity at the switching frequency. Random PWM is widely used to spread the harmonic power, and hence reduce the torque ripples and acoustic noises of the ASDs. A comprehensive comparison of DSPWM and Pseudo Random Binary Sequence (PRBS) bit based RPWM is presented in this chapter. The distribution of harmonic power in the output voltage of full bridge dc-dc converter when controlled using DSPWM is studied for three-phase star connected resistive load. A comparative analysis of SPWM and RPWM methods characteristics such as DC bus utilization and the harmonic spread factor is presented. The proposed architecture of RCPWM is the effective solution for the acoustic noise in the Adjustable Speed Drives. The results such as device utilization summary, power estimation and temperature dependency are very useful for the handling of digital device used for the control purpose. The harmonic power spreading ability of the RPWM is validated by the simulation study .The RCPWM offers higher output voltage, lesser THD and minimal HSF than the DSPWM for the entire working range.

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