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Experimental Evaluation and Validation of Random Pulse Position Pulse Width Modulation for Industrial Drives

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ABSTRACT

In industrial drives, random pulse width modulation (RPWM) is triumph for transferring of harmonic power from the detached spectrum of the output voltage to the unremitting spectrum, and offers the merits viz. The operation is free from an unpleasant acoustic noise and a mechanical vibration. The main objective of this paper is providing a comprehensive investigation of performance of random pulse position pulse width modulation (RPPPWM) for a three-phase voltage source inverter (VSI) fed induction motor drives. RPPWM scheme randomly varies the pulse position in every switching cycle, where the idea is inducing the random characteristics in the PWM pulses at fixed switching frequency. The competence in spreading the harmonic power of sinusoidal PWM (SPWM), random carrier PWM (RCPWM) and the RPPWM are compared using simulation. The results are corroborated through the prototype VSI designed. The developed RPPPWM based on a SPARTAN-6 FPGA (XC6SLX45) device, disperses the acoustic switching noise spectra of an induction motor drive

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1. INTRODUCTION

The importance and the exploitation of voltage source inverters (VSIs) are growing unprecedentedly in industrial applications. The theory involved in the pulse width modulation (PWM) technique, which is employed to obtain the required output voltage in the line side of the inverter, decides the quality of the output. Sinusoidal Pulse Width Modulation (SPWM) technique has become the most popular and important PWM techniques for VSI based drive systems. PWM-VSIs are dominantly employed in the power conversion system in industry today [1]. Ahead of the SPWM, a large number of PWM switching pattern generators have been developed over the last four decades to meet the application dictated output waveforms. The ingenious PWM concepts not only guarantee quality output waveforms and enhance the overall system performance [2]-[3]. Many VSI drives employ the SPWM and its variations due to their fixed switching frequency, low ripple current, and well-defined/determined harmonic spectrum characteristics. These carrier-based PWM methods ascertain a “per carrier cycle average output voltage” equal to the reference voltage. The generation of PWM patterns through modulation is just amplitude to width transformation and their harmonic profile is deterministic, are called as deterministic PWM methods.

Apart from requirements like reduced distortion, enhanced fundamental, easy filtering etc. the industrial drives added few more constraints over the VSI drives, which are reduced the emitted acoustic noise and the mechanical vibration. The output voltage spectrum of any deterministic PWM method has a large number of harmonic components around the switching frequency and its multiples. Thus acoustic noise, radio interference, and undesirable harmonic heating are generated in the ac motor drive systems. The acoustic noises and the vibrations can only be suppressed if the distinct harmonic clusters present in the deterministic PWM methods are spread over entire range of frequency instead of being clustered. That is, rather than having few numbers of dominant harmonics, having more number of harmonics with insignificant magnitude. If the pulse position or the switching frequency is randomly varied, the harmonics content will spread over wide range and the specific harmonic parts can be significantly reduced. This is the essential operation principle of random pulse width modulation (RPWM) techniques, which have received much attention in the recent years [4].

Constraining discrete dominant harmonics in the voltage harmonics spectrum for reducing the acoustic noise in the industrial drives has been instigated [5]. The application of RPWM concepts are well established for voltage source inverters and dc-dc converters. Hamid Khan et.al have proposed a discontinuous and randomized-modulation technique based on space vector calculation, intended for electric-drive oriented hybrid electric vehicle[6]. A fixed-carrier-frequency RPWM method based on a modified carrier wave has been proposed for modulation. Based on simulations and experimental measurements, it is shown that the spread effect of the discrete components from the motor current spectra and acoustic spectra is very effective and is independent from the modulation index. The flat motor current spectrum generates an acoustical noise close to the white noise, which improves the acoustical performance of the drive [7]. A dual randomized PWM technique has been devised as a hybrid of Randomized Pulse Position Modulation (RPPM) and Randomized Carrier Frequency Modulation [8]. With the modulating principle, a mathematical model of Power Spectral Density (PSD) of the output voltage has also been developed. PSD analysis shows that the proposed scheme is more effective on spreading PSD.

Thorough investigation on the performance of random pulse position pulse width modulation (RPPPWM) in a three-phase voltage source inverter (VSI) fed induction motor drive through simulation and laboratory testing is presented in this paper. The competence in spreading the harmonic power of sinusoidal PWM (SPWM), random carrier PWM (RCPWM) and the RPPWM are compared. The results are corroborated through the prototype VSI designed. The proposed Random Carrier PWM architecture has been designed using the VHDL language. The functional simulation of the architecture has been carried out using the tool Modelsim 6.3. The Register Transfer Level (RTL) level verification and implementation are done using the synthesize tool Xilinx ISE 13.2. Then the designed architecture has been configured to the SPARTAN-6 FPGA (XC6SLX45) device.

2. RANDOM PULSE POSITION SCHEME

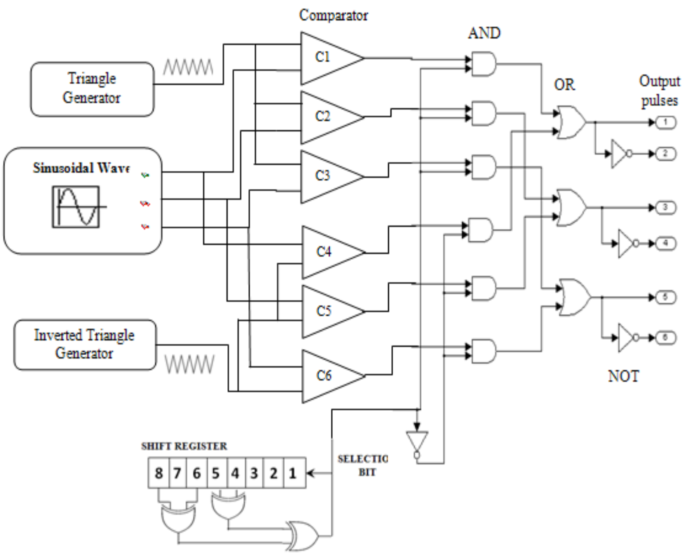

Figure 1. Fixed switching frequency with random pulse position scheme

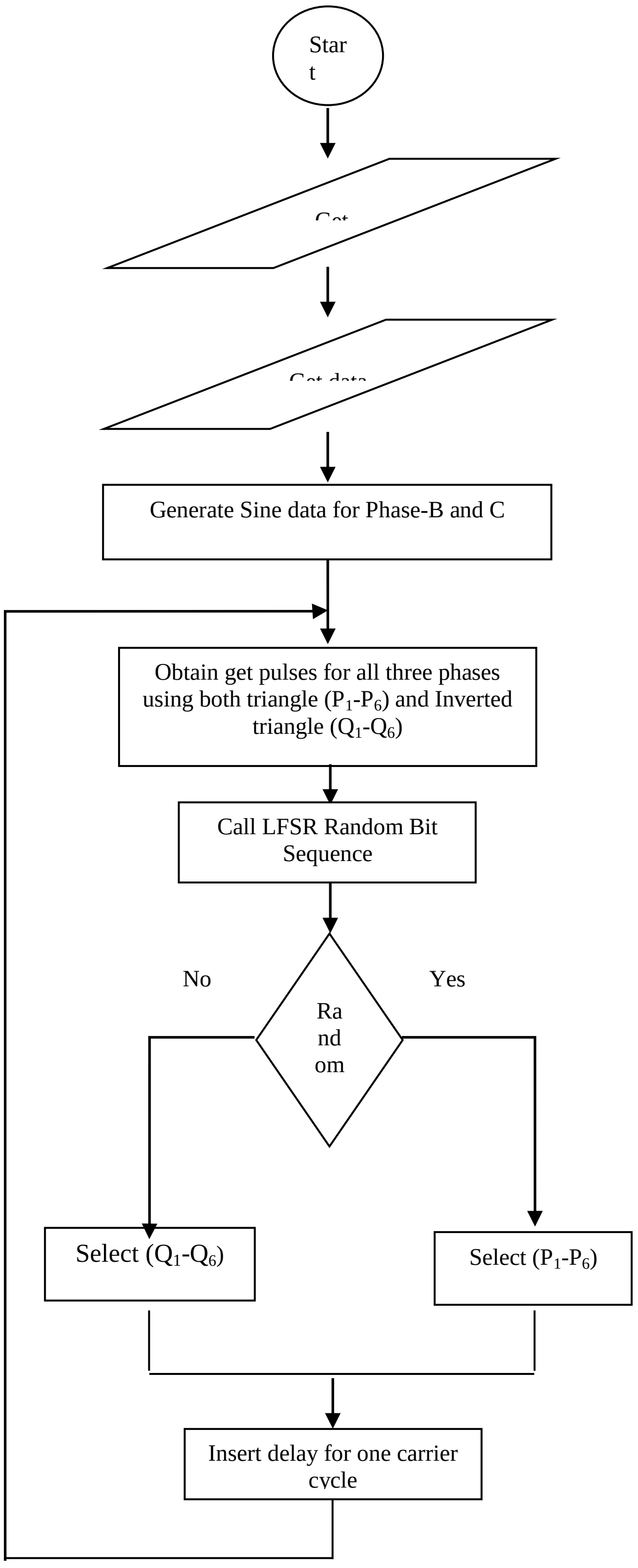

Figure 2. Step involved in RPPPWM

RPPPWM spreads voltage and current harmonics over a wide frequency range by incorporating randomness in the switching pulse positions. Fig.1 illustrates the fixed switching frequency RPPPWM scheme, which consists of logical circuits and random bits generator. Here the fixed frequency triangular carrier and its inverted form (180 degree shifted) are considered. The gating pulses are generated separately for both the types of carrier and hence pulses of two groups are available (P1-P3) and (Q1 to Q3). The selection among these two groups is done using a select signal, pseudorandom binary sequence (PRBS) bits. If the PRBS bit is 1, pulses (P1-P3) are selected else (Q1 to Q3). Once the group is selected then lingering pulses (either (P4-P6) or (Q4 to Q6)) are generated by inverting (P1-P3)/(Q1 to Q3). The complete steps involved with the RPPPWM are presented in Fig.2.

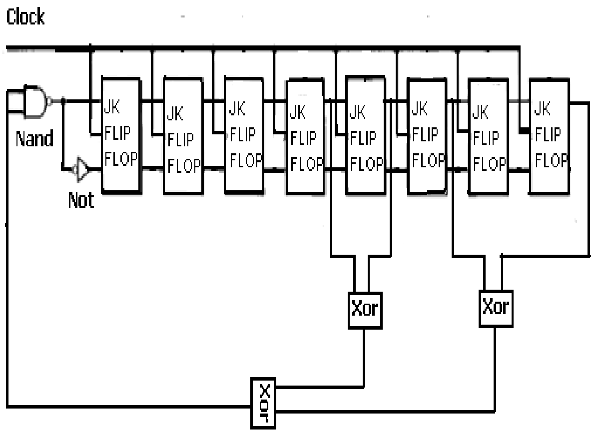

Figure 3. Feedback shift register

3. SIMULATION STUDY

A simulation study is carried out using MATLAB 7.10a software for a VSI with input dc voltage, Vdc=415V at entire range of modulation index (Ma).

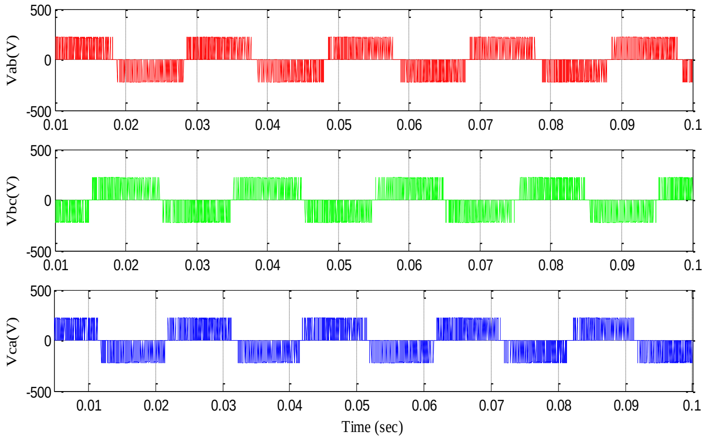

Figure 4. Simulated line-line voltage waveform for Ma=0.8

The carrier frequency (fc) is taken as 3 kHz. The load is a three-phase squirrel cage induction motor load (0.75kW and 2.5A) and ODE Solver ode23tb is used. Figures 4 and 5 show the simulation results of the line-line voltage and phase current waveform of the motor respectively. Archetypal harmonic spectrum and power density spectrum (PDS) are presented for Ma=0.8 and 1.2 from Figure 6 to Figure 9

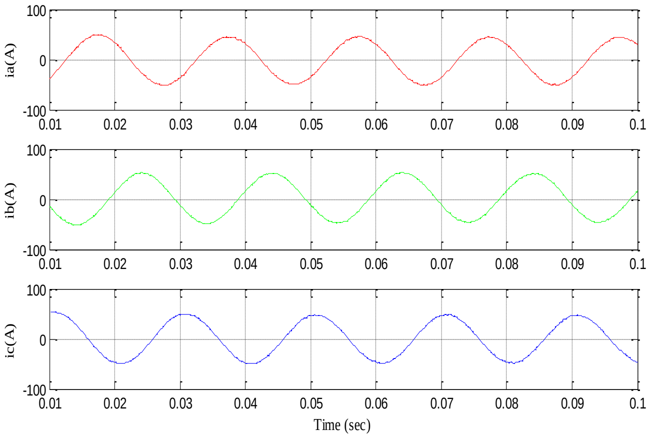

Figure 5. Simulated line current waveform for Ma=0.8

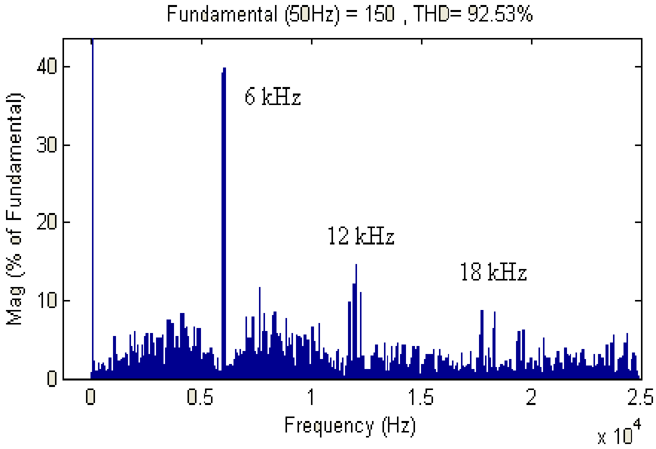

Figure 6. Spectrum of output voltage (Ma=0.8)

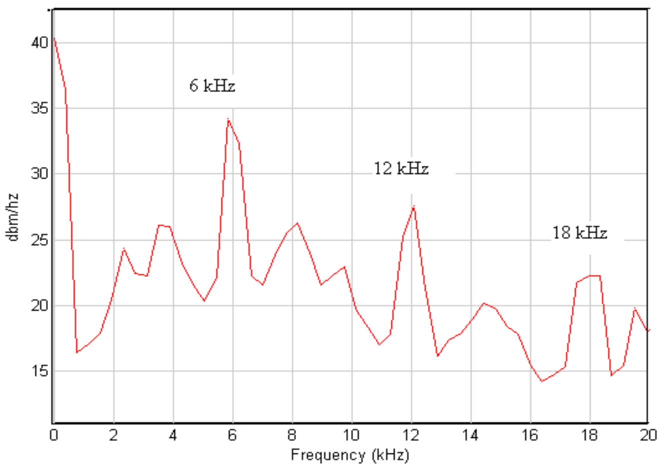

Figure 7. Power spectral density (PSD) for Ma= 0.8

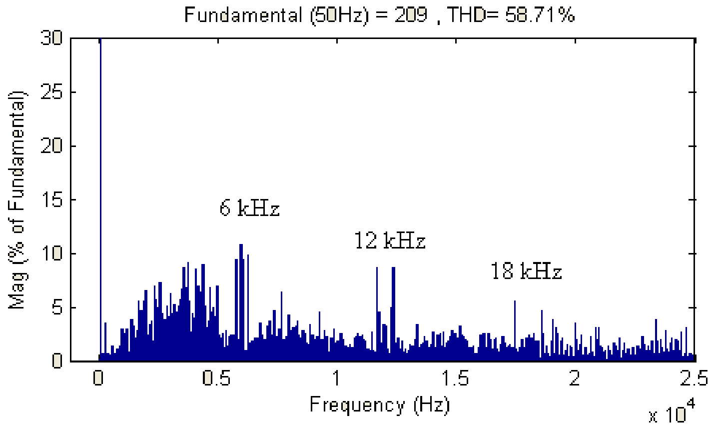

Figure 8. Spectrum of output voltage (Ma=1.2)

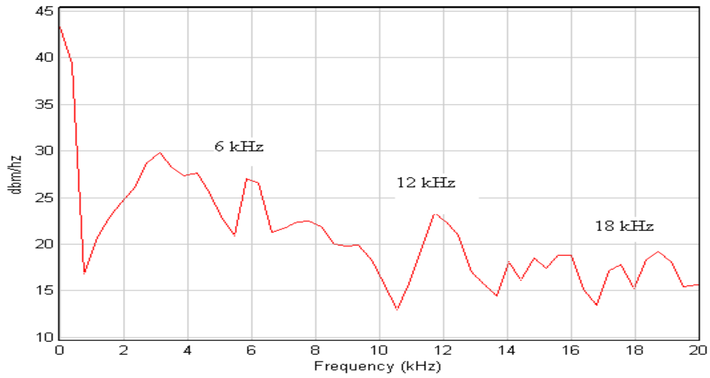

Figure 9. Power spectral density (PSD) for Ma= 1.2

Table 1.Comparison of SPWM, RCPWM and RPPPWM

M_a	V_1(V)			THD %			HSF		
	Sine	RC	RPP	Sine	RC	RPP	Sine	RC	RPP
0.2	49	75	76	258	241	241	8.3	4.9	4.8
0.4	76	137	140	164	168	166	6.1	4.7	4.4
0.6	114	211	213	121	122	121	5.9	4.6	4.3
0.8	153	294	294	91	89	89	5.6	4.1	4.0
1.0	170	367	368	81	66	66	5.2	3.7	3.6
1.2	190	395	400	68	58	56	5.0	3.5	3.2

Table 1 compares sinusoidal, random carrier (RC) and random position PWM methods in terms of output fundamental voltage (V1), THD and harmonic spread factor (HSF) [9]. From the results, it is understood that both RC and RPP PWM methods offer higher output voltage, lesser THD and minimum HSF than the conventional SPWM. Output voltage of the RPPPWM is little higher than RCPWM while HSF of them are almost equal.

4. HARDWARE IMPLEMENTATION

The proposed Random Carrier PWM architecture has been designed using the VHDL language. The functional simulation of the architecture has been carried out using the tool Modelsim 6.3. The Register Transfer Level (RTL) level verification and implementation are done using the synthesize tool Xilinx ISE 13.2.

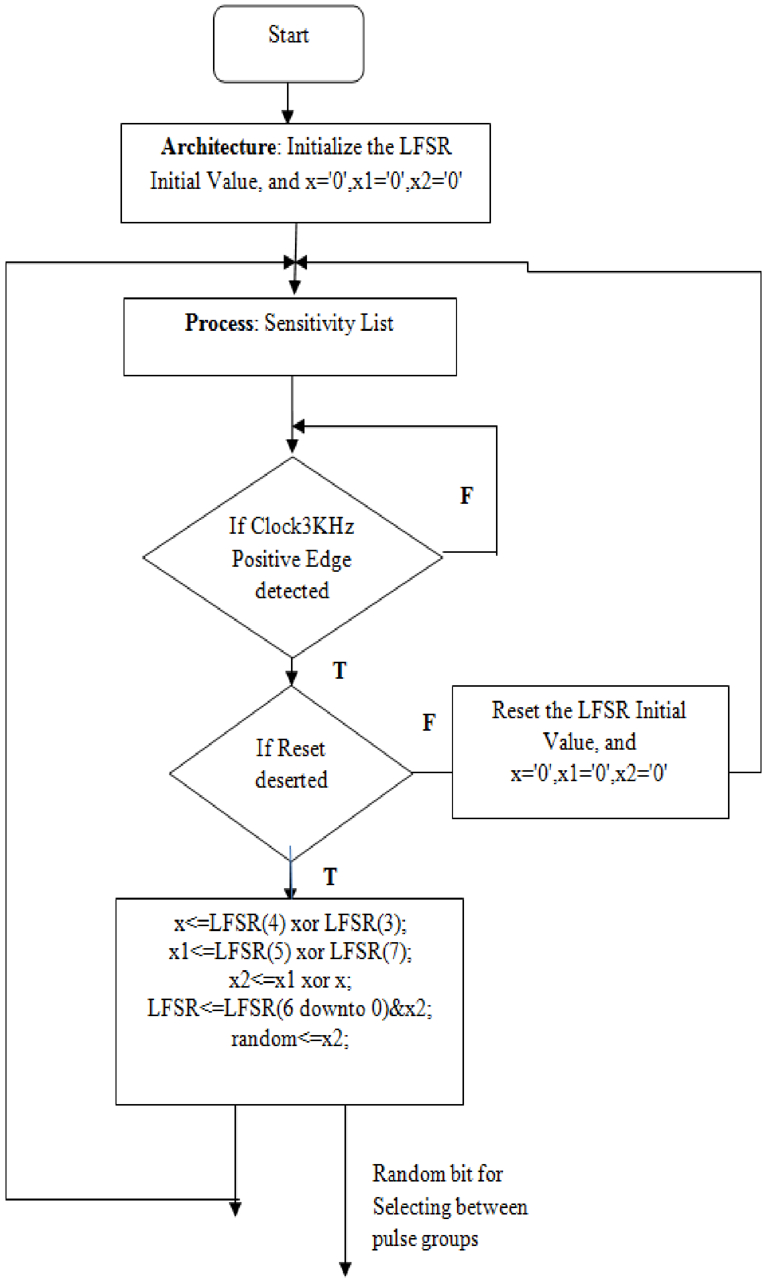

Figure 10. Generating PRBS

Then the designed architecture has been configured to the SPARTAN-6 FPGA (XC6SLX45) device. The functionality of each block in the architecture is simulated thoroughly using the Modelsim software.

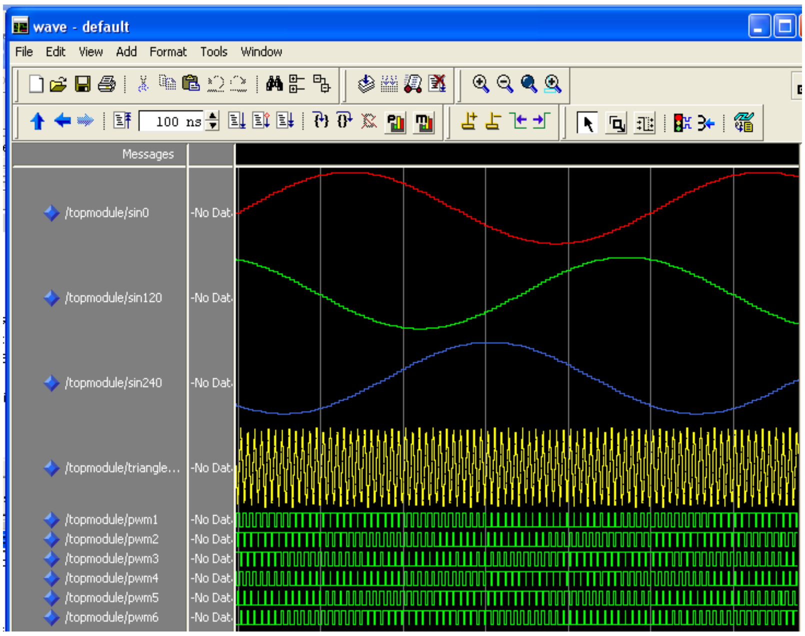

Figure 11. Modelsim output pulses

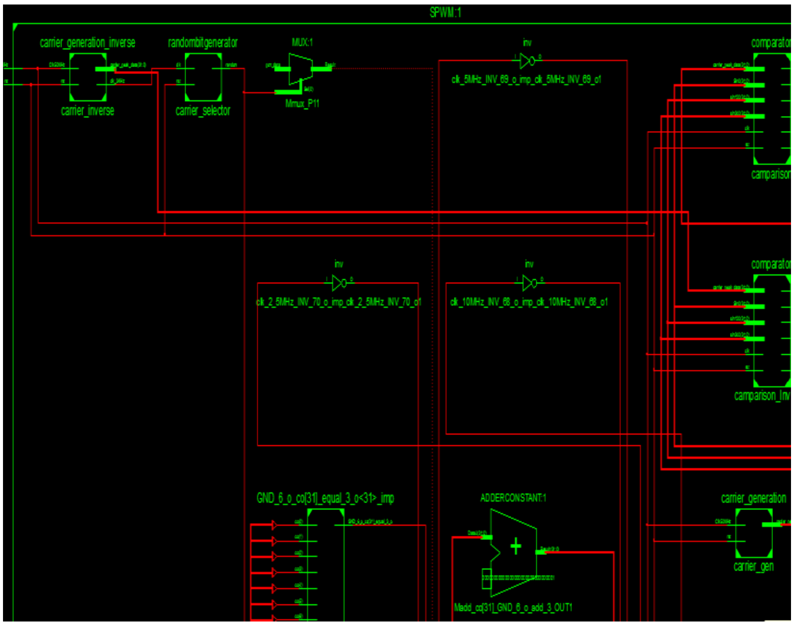

Figure 12. RTL Diagram for implemented RPPPWM architecture design

The triangular data is initialized first and inverse triangular data is derived from it. From the fed sine reference data of 'A' phase, data from 'B' and 'C' phases are derived. The pulses for the upper devices are generated by comparing triangular and three sinusoidal references. Similarly, another group of pulses are obtained from inverted triangular carrier.

Now the LSFR sequence select is used to choose between the pulse groups. Fig.10 details the algorithm employed for generating LFSR sequence in field programmable gate array (FPGA). The gating pulses generated by the VHDL design for the positive and negative group switching devices of inverter are analyzed in the Modelsim software.

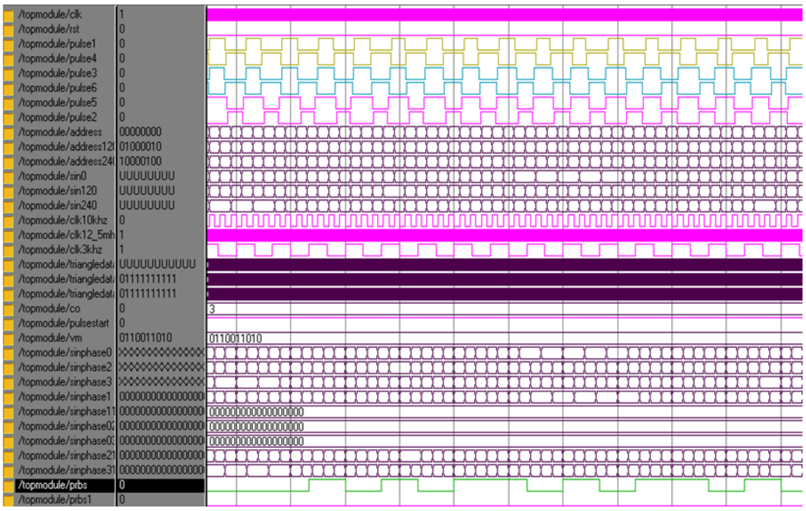

Figure 13. Complete timing analysis

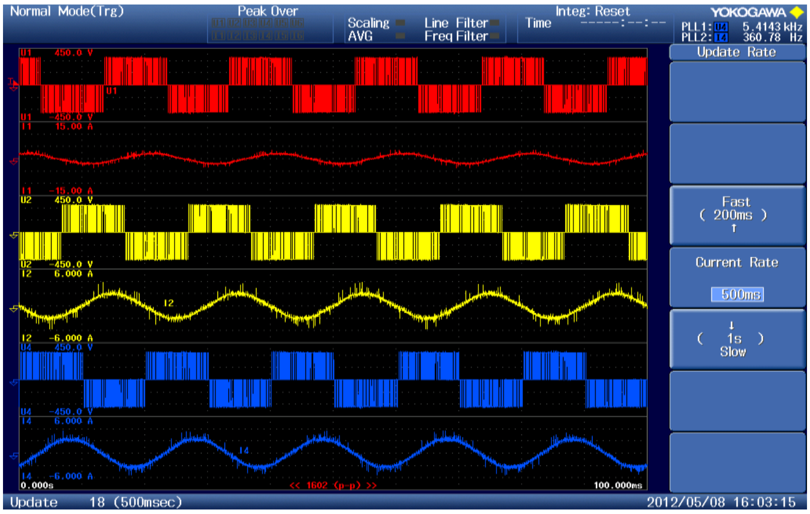

Figure 14. Experimental voltage and current waveforms

The gating pulses generated for the modulation index 0.8 is presented in Fig.11. Fig.12 shows the RTL diagram and the complete timing analysis is presented in Fig.13. Experimental voltage and current waveforms are depicted in Fig.14. Representative harmonic spectrum for Ma=1.2 is given in Fig.15.

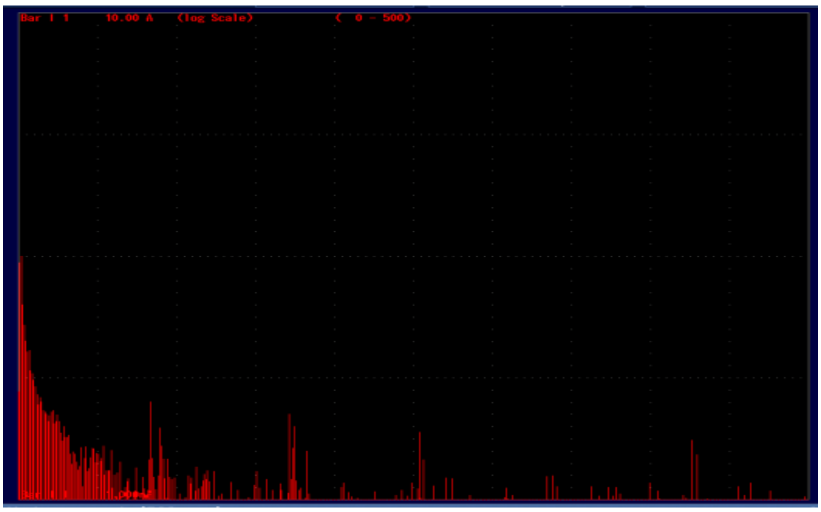
Figure 15. Representative Spectrum for Ma=1.2

5. CONCLUSION

RPWM has become a viable remedy to the acoustic noise and vibration in industrial drives, and replaces deterministic PWM. Indeed, by spreading the power spectrum as a continuous noise, this clause of techniques complies better with Electro-Magnetic Compatibility (EMC) standards for conducted Electro-Magnetic Interferences (EMI) and allows reducing the emitted acoustic noise in Variable Speed Drives (VSDs). The presence of discrete dominant harmonics mainly contributes to high vibration and noise under conventional SPWM.

A random pulse position PWM technique for a three-phase VSI-PWM inverter system for an induction motor control to reduce the annoying tonal noise and resonant vibration from ac machine drive is described. The idea of the developed RPPPWM is randomly varying the instantaneous pulse position from one carrier cycle to the next; the frequency distribution of harmonics is spread in a wide frequency range. The major advantage for using such a strategy is non-repetitive output spectral characteristics, which results in reduction of torque pulsations in motor drive systems. Experimental results show the reduced HSF and the well-distributed power density spectrum, which is not usually present with conventional sinusoidal modulation. Random PWM scheme is implemented by a logical pseudo random number generator with the aid of a high-performance FPGA SPARTAN-6 XC6SLX45 that serves as modulator and controller for the three-phase voltage source inverter.

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