Multi Carrier Based New Random Pulse Width Modulation For Three Phase Inverters

G. Jegadeeswari, B. Kirubadurai, D. Lakshmi, I. Shivasankkar

Abstract: PWM strategies are key options for extracting the quality controllable outputs from the VSI. The objectives involved in the different PWM strategies are improving the primary indices namely, enhancing the fundamental components, reducing the total harmonic distortion, minimizing the switching loss, specific removal of harmonic components etc… while the secondary Issues like suppressing the electromagnetic interference, spreading the harmonic power etc., are also to be considered in contemporary applications. This paper is disquiet about an enhancing the harmonic power dispersal of PWM strategies. The RPWM strategies cover non-predictable harmonic pattern and called as non-deterministic PWM strategies. The inverter is working under RPWM which generate the output harmonic spectra isolated and constantly distributes across frequencies and acoustic noise is also reduced. The paper has proposed a host of carrier based RPWM schemes to enhance the performance of the VSI and implemented them in FPGA involved digital platform. Power dissipation and Speed are presented in detail in term of resource use in FPGA. The RPWM technique is simulated by using time efficient co-simulation (Mat lab-Simulink) methodology.

Keywords: PWM techniques; Harmonics; switching loss; Random PWM; FPGA; VSI; acoustic noise; MATLAB/Simulink, Hardware Implementation.

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1. INTRODUCTION

The demand of higher rating power electronics like drives has increasingly grown in the recent years. In an adjustable speed ac drive, it has become very essential to control the ac voltage and frequency with specified distortion level. The line current becomes a twisted waveform when an induction motor is fed from such a motion. Harmonics therefore power the MMF and improve the harmonics with the same air gap permeance. Because of the radial magnetic forces produced by the harmonics, strong vibrations occur in the rotor and core system. [3] Consequently, vibration, acoustic noise, alternating torque and losses due to the current harmonics have been increased.Using a high switching frequency is a common method of reducing noise so that the produced sound is ultrasonic. But this can cause extreme losses in the switching devices and extreme stress. Therefore, the tricky task is to find a proposed PWM (RPWM) scheme that eliminates acoustic noise by suppressing the VSI output's leading harmonics. The main objective of these RPWM systems is to disperse the harmonic power throughout the spectrum instead of collecting at multiple frequencies of the carrier. The software specifications are higher than the performance of the current RPWM methods. [6] In an induction motor drive fed VSI application, the existing RPWM schemes need to be improved in the performance for enhanced distribution of harmonic power.

The major objectives of this proposed work is to:

1. Study the randomization levels of different RPWM in terms of harmonic spread factor and harmonic magnitudes etc.
2. Develop and design the new digital PWM pulses of RPWM techniques by VHDL Language.
3. Verify the functionality by using ModelSimSE 6.3f digital simulator
4. Verify the performance of FPGA by using the navigator tool Xilinx Project.
5. Prove the inverter functionality by combining MATLAB and Modelsim simulation. Create comparative study of PWM performance in terms of THD, HSF and fundamental component values of output voltage.
6. Corroborate the simulation results of existing and proposed RPWM schemes in the designed experimental set up (three phase VSI).
7. As a whole, this project aims at improving the performance of RPWM schemes applicable to VSI drive and calculating a formulaic, prudent, digital implementation of such schemes.

2. VOLTAGE SOURCE INVERTERS

Nowadays, inverter plays a vital role in every power converter as well as industrial applications. It is broadly divided into two types such as CSI and VSI. Out of which, VSI is more popular used power electronics converter broadly utilized power rating from various kilowatt to megawatt range. Inverter is a power electronics converter used to converts a fixed DC voltage to the variable three phase AC voltage with convenient frequency and magnitude. PWM based VSIs are usually used to control the shaft torque/ speed /position of AC motor drive applications and it have surge with stand potential in the inverter drives. [8] High power and medium voltage drives have established the wide applications in the industries. Mainly PWM-VSIs are used in Uninterruptible Power Supplies applications, regenerative drive applications (Umanand 2009), etc… and some other applications include static VAR compensators.

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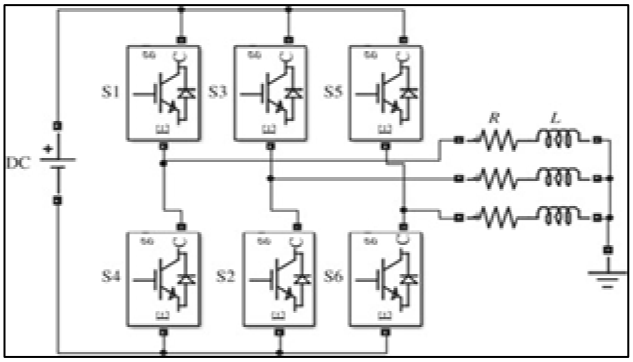


Fig 1: *Three Phase Voltage Source Inverter*

3. INFLUENCE OF PWM TECHNIQUES

The pleasant quality of diversified power converters, solid-state power semiconductor devices, specification-oriented pulse width modulation (PWM) theories and shade digital controllers have driven the migration of conventional power controllers to solid state arena. In further, drives are imperative component in the motion control, where not only the required mechanical characteristics are obtained from the motor and also the quality of the electrical power involvement have made conducive. In midst of the different drives, the application of voltage source inverters (VSIs) is plenary. An inverter's main objective is to produce a sinusoidal AC voltage with frequency and varying amplitude from a DC source. PWM strategies are the key options for extracting the quality controllable outputs from the VSI and have received a dominant position in the last few decades (Mahesh et al. 2009; Seung-Wook et al. 2016). [5] Many PWM schemes have been developed and implemented successfully for different applications. Even though in due course, there are different scales of classification in PWM techniques (Jagadish et al. 2012), [7] therefore, the certainty in arriving the harmonic profile at particular input and control structures spur a variant categorization. The PWM schemes mentioned hitherto offer a well-defined, predictable harmonic profile and it is called as deterministic PWM schemes

3.1 SINUSOIDAL PULSE WIDTH MODULATION

SPWM is one of the main proven and trouble-free methods used in drives for motor control and power inverter from all PWM schemes. [10] Its major features can be summarizing as sinusoidal-triangle wave relationship. Figure illustrates that a sinusoidal wave is just separated by a triangle wave, and if the instantaneous value of the triangle wave is much lower than that of the sinusoidal waveform, but the PWM output signal will be high, then it will show ' 1 ' otherwise it will be low, showing ' 0. '[14] Whenever the sine wave meets the triangle wave, the switch is created. Therefore the different positions which consequence the changeable output waveform with the duty cycle.

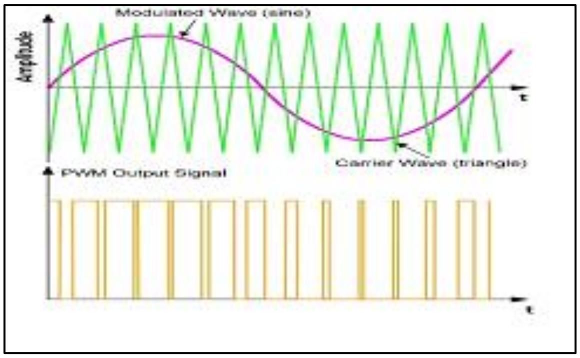


Fig 2. *SPWM waveform generation*

3.2 RANDOM PULSE WIDTH MODULATION

By adding two triangular carriers we can achieve random carrier, each one is similar to other fixed frequency, however of opposed phase. [3] Determination of random set of two carriers is achieved by "0" or "1" which states that pseudo random binary sequence which is listed in Table 1.1.

Table 1.1 *Truth of the Multiplexer*

PRBS Status	*MUX Output*
0	*C*
1	*C BAR*

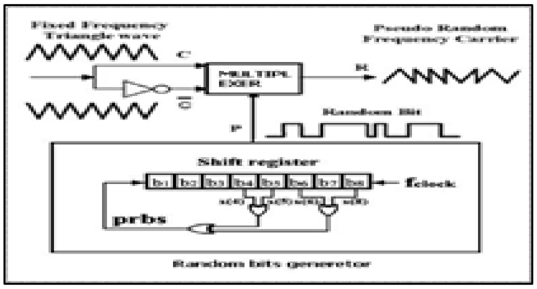


Fig 3. *Random bit generation*

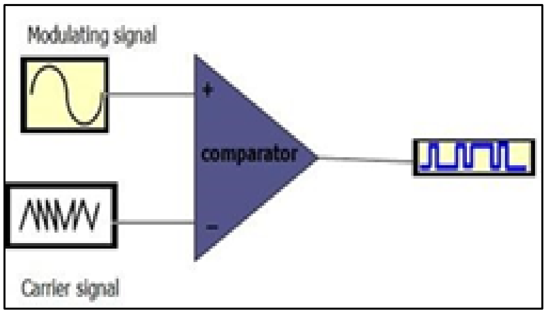


Fig 4. *Analog RPWM scheme*
RPWM digital Simulation output

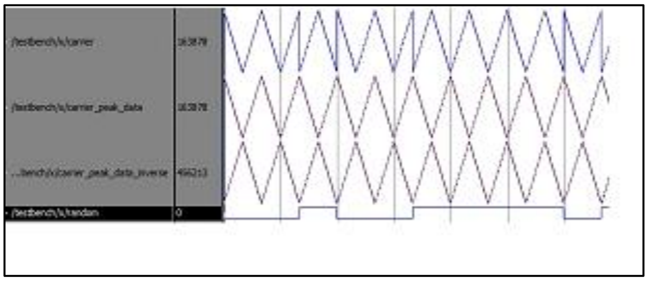


Fig 5. *Carrier Generation with Random bit*

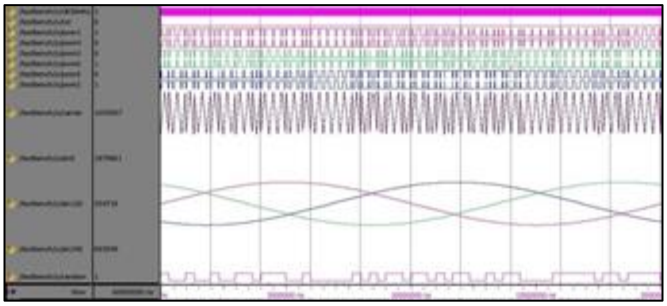


Fig 6. *Pulse Generation of RPWM with Random bit*

Figure 5 shows the output produced by the random carrier (fc=3 kHz). Figure 6 displays all the generation of switching pulses with the correct carrier and reference wave. In addition, the Random bit produced every 3 kHz, as shown in Figures 3 and 4.

3.3 INTRODUCTION TO FPGA

FPGAs allow designers to change their designs in the proposed process extremely delayed – they have been developed and implemented in the field even behind the end formation. [4] Xilinx FPGAs, on the other hand, require the removal of field updates, the elimination of costs related to manual upgrading or the re-design of electronic systems. FPGAs have evolved far away from the basic capabilities which are accessible in their predecessors, and include hard blocks of usually worn functionality such as DSP, clock management, and RAM. [11] The following are the essential mechanism in an FPGA: 1. complete clock management 2. Interconnect 3. Select IO (IOBs) 4. Memory Configurable logic blocks and 5. Configurable logic blocks as shown in Figure 2.

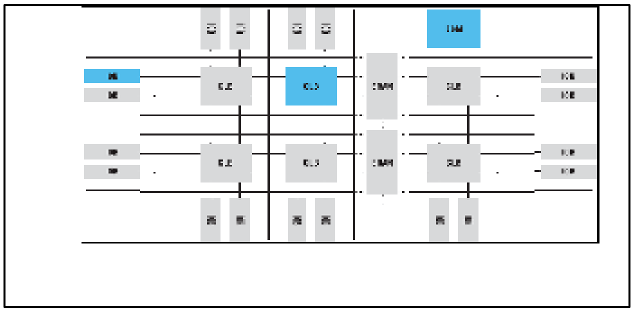


Fig 7. *FPGA Block Structure*

4. SIMULATION RESULTS

The three-phase voltage source inverter is intended in MATLAB 7.10 exclusive of using any filter in the inverter output as shown in Figure 8. The SPWM and RPWM pulses received from modelsim digital environment by using Cosimulation methodology.

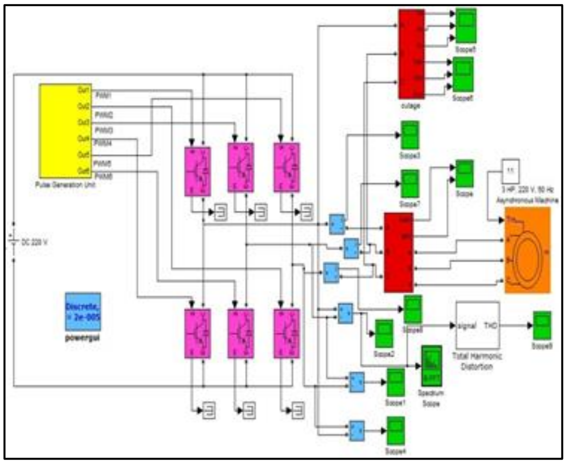


Fig 8: *SIMULINK Model of Three Phase Inverter*

Harmonic Spectrum Results

The Harmonics can be verified by using FFT window. 50 Hz line to line voltage cycle has been worn to calculate harmonics and their effects. The simulation outcomes are illustrated for a mixture of modulation indexes (ma) from 0.1 to 1.2. The harmonic spectrum of SPWM has shown in figure 9.1 to 9.12

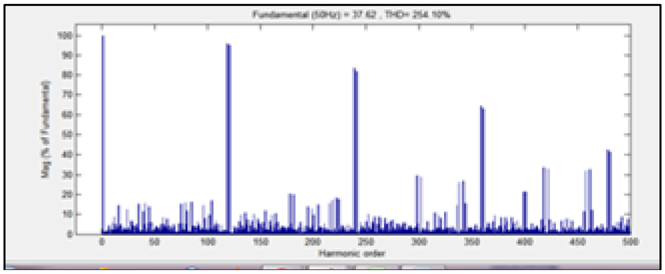


Fig 9.1 *Harmonic Spectrum-SPWM, ma=0.1 and mf=50*

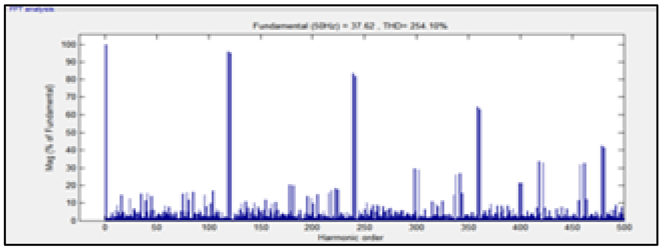


Fig 9.2 *Harmonic Spectrum-SPWM, ma=0.2 and mf=50*

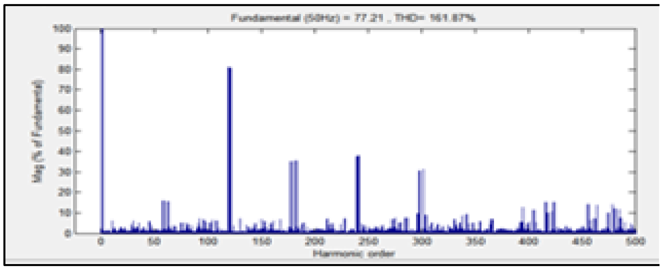


Fig 9.3 *Harmonic Spectrum-SPWM, ma=0.3 and mf=50*

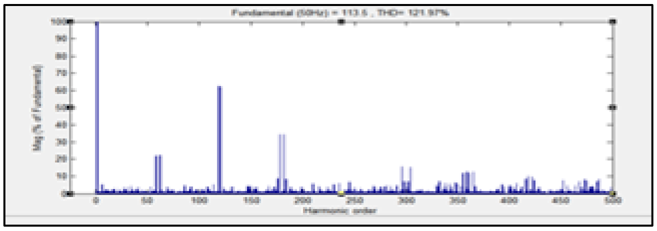


Fig 9.4 *Harmonic Spectrum-SPWM, ma=0.4 and mf=50*

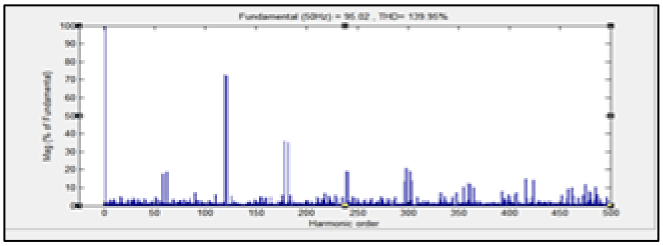


Fig 9.5 *Harmonic Spectrum-SPWM, ma=0.5 and mf=50*

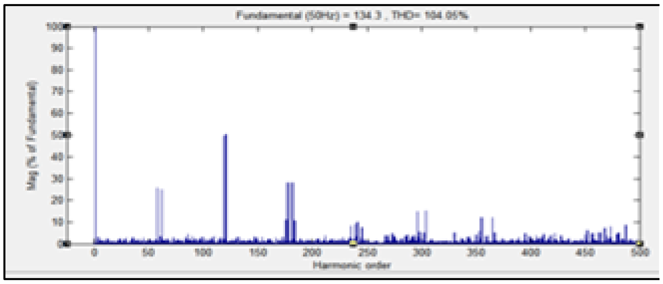


Fig 9.6 *Harmonic Spectrum-SPWM, ma=0.6 and mf=50*

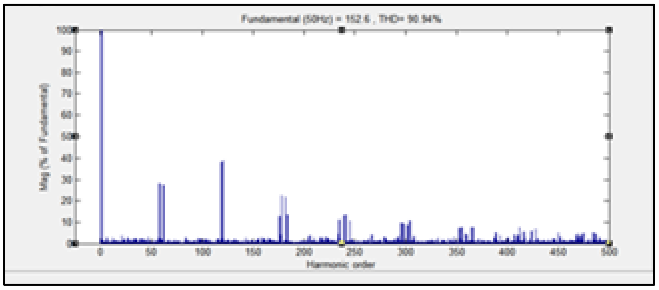


Fig 9.7 *Harmonic Spectrum-SPWM, ma=0.7 and mf=50*

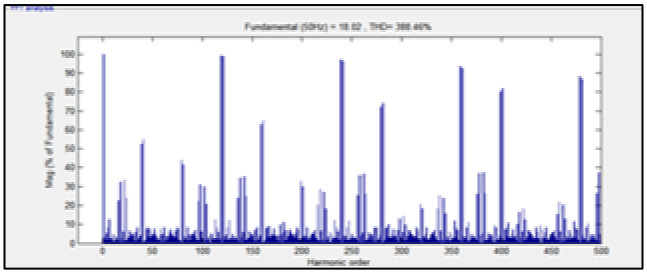


Fig 9.8 *Harmonic Spectrum-SPWM, ma=0.8 and mf=50*

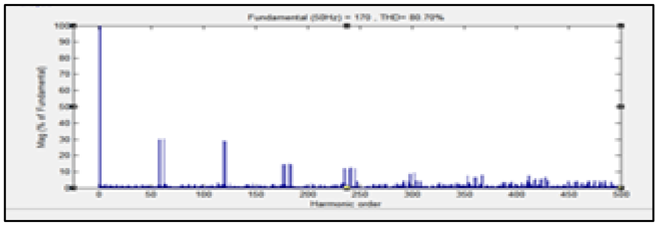


Fig 9.9 *Harmonic Spectrum-SPWM, ma=0.9 and mf=50*

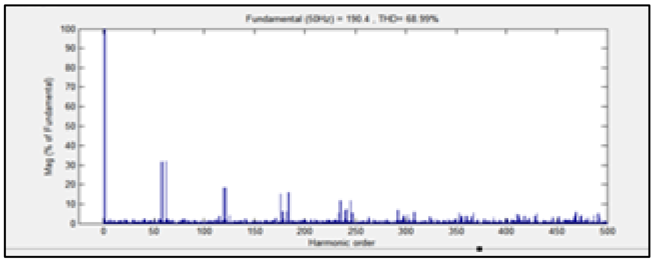


Fig 9.10 *Harmonic Spectrums-SPWM, ma=1.0 and mf=50*

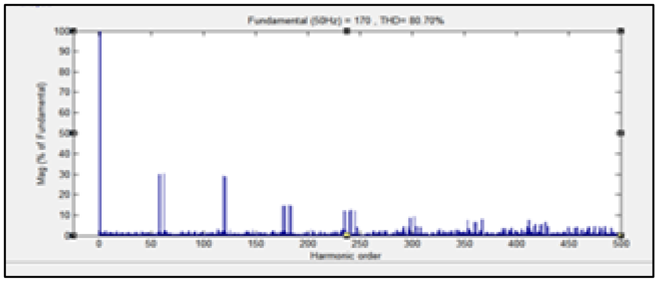


Fig 9.11 *Harmonic Spectrum-SPWM, ma=1.1 and mf=50*

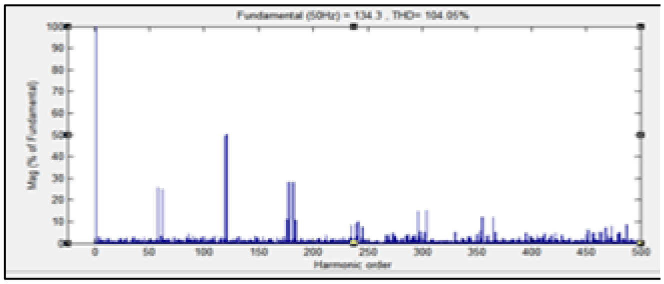


Fig 9.12 *Harmonic Spectrum-SPWM, ma=1.2 and mf=50*

Table 1.2 *Performance Comparisons*

ma	PWM Techniques Performance Parameters	SPWM	RPWM
0.1	Fundamental	18.02	18.11
	% THD	388.4	393.0
	HSF	15.33	14.01
	Dominating voltage Harmonics	58,62	119,121
0.2	Fundamental	37.62	39.9
	% THD	254.1	250.0
	HSF	10.8	9.22
	Dominating Voltage Harmonics	58,62,119, 121, 239,240	119,121, 239,360
0.3	Fundamental	58.19	60.13
	% THD	194.29	197.8
	HSF	7.80	7.18
	Dominating voltage Harmonics	58,62,119, 121	119,121,239
0.4	Fundamental	77.21	79.4
	% THD	161.8	164.3
	HSF	6.57	5.19
	Dominating voltage Harmonics	58,62,119, 121 ,178, 239	119,121, 239,120
0.5	Fundamental	95.02	100.4
	% THD	139.9	138.2
	HSF	5.67	4.9
	Dominating voltage Harmonics	58,62,119, 121,177	119,120,239
0.6	Fundamental	113.5	116.6
	% THD	121.9	125.0
	HSF	4.93	4.36
	Dominating voltage Harmonics	58,62,119, 121,177, 181	119,1, 120,359
0.7	Fundamental	134.3	137.8
	% THD	104.0	106.6
	HSF	4.19	3.6
	Dominating voltage Harmonics	58,62,119, 121	
0.8	Fundamental	152.6	157
	% THD	90.9	92.12
	HSF	3.63	3.0
	Dominating voltage Harmonics	58,62, 119,121	119,121, 239,120
0.9	Fundamental	170	175.1
	% THD	80.7	83.09
	HSF	3.18	2.56
	Dominating voltage Harmonics	58,62,119,121,	119,121,239
1.0	Fundamental	190.4	196
	% THD	68.9	71.23
	HSF	2.95	2.13
	Dominating voltage Harmonics	58,62, 119,121	119,121, 77,235
1.1	Fundamental	202.1	209.2
	% THD	62.2	63.9
	HSF	2.71	1.87
	Dominating voltage Harmonics	58,62,199,121	119,121,277
1.2	Fundamental	210.3	217.5
	% THD	58.2	60.1
	HSF	2.33	1.80
	Dominating voltage Harmonics	58,62,119,121	119,121,239,120

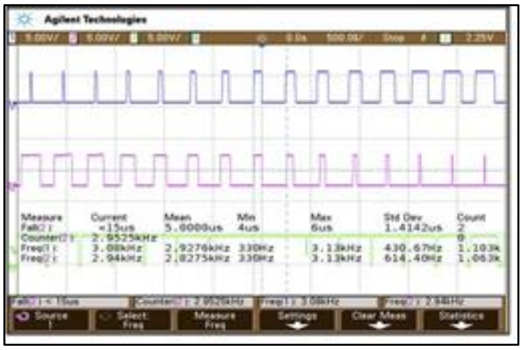
5. HARDWARE IMPLEMENTATION

Fig 10. *Experimental Setup*

The methods were checked with the planned configuration consisting of a PWM inverter circuit based on FPGA. This requires an FPGA panel, a driver circuit inverter module, an autotransformer, and a motor drive induction. Yokogawa Digital Storage oscilloscope will be used for all the inverter output measurements. The experimental setup for control of an induction motor is shown in Figure 6.1 and the parameters required for the setup is listed in the Table 1.2. Using an autotransformer and a rectifier, the inverter is supplied with a 220 V DC voltage. FPGA has developed the traditional and proposed methods of PWM signals. Between the switches of the same inverter aid, a dead time of 2.9μ seconds is introduced to ensure a smooth transition in the switching states of the inverter shown in figure 11. The basic frequency of the inverter voltage was set at 50 Hz in accordance with the traditional and proposed schemes study. The modulation index ranges the 0.2 to 1.0, all hardware tests are evaluated. In the following section, software and hardware results of the specific methods are compared.

5.1 SINUSOIDAL PULSE WIDTH MODULATION

Fixed switching frequency SPWM scheme is simulated in Simulink model and implemented by using FPGA based three phase inverter. The switching frequency of the fixed switching triangular frequency is 3 kHz. The harmonic spectral analysis of voltage waveform, output line voltage waveform, and output phase current waveforms and measurement window are revealed below from Figure 11 to 16



Measure	Current	Mean	Min	Max	Std Dev	Count
Fall(2):	<15us	5.0000us	4us	6us	1.4142us	2
Counter(2):	2.9525kHz					0
Freq(1):	3.08kHz	2.9276kHz	330Hz	3.13kHz	430.67Hz	1.103k
Freq(2):	2.94kHz	2.8275kHz	330Hz	3.13kHz	614.40Hz	1.063k

Fig 11. Simulation result of line to line voltage

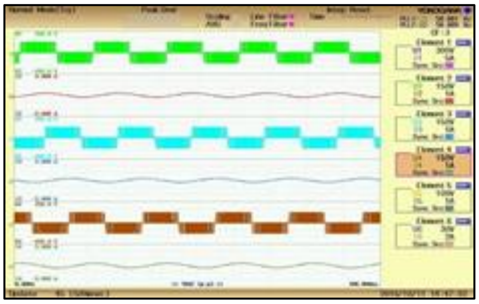


Fig 12 *Experimental result of line to line voltage with current*

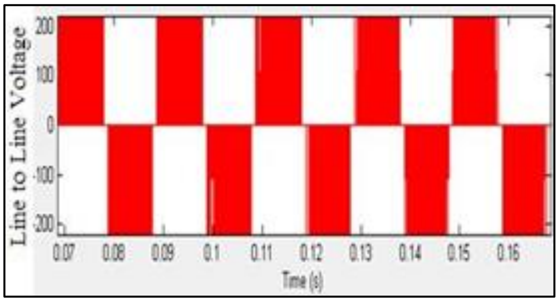


Fig 13 *Performance measurements, ma=0.8*

Fig 14 *PWM pulses with dead time, ma=0.8*

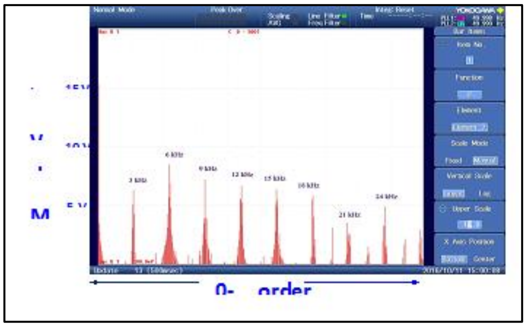


Fig 15. *Simulation Harmonic Spectrum for line to line voltage, ma=0.8*

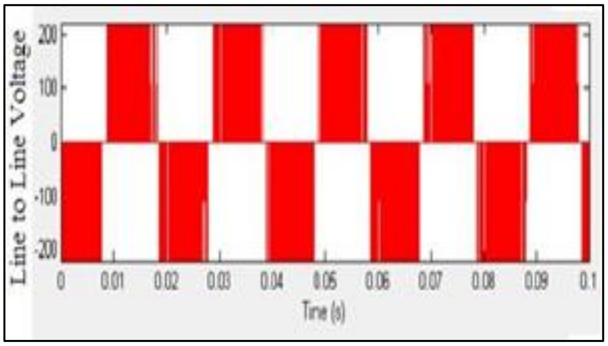


Fig 16. *Experimental Harmonic Spectrum for line to line voltage, ma=0.8*

Table 1.3 *Simulation and Experimental Result comparison*

Technique	SPWM					
	Simulation Results		Hardware results			
ma	Output Voltage	THD %	HSF	Output Voltage	THD %	HSF
0.1	18.02	388.4	15.33	17.54	69.34	2.895
0.2	37.62	254.1	10.86	36.5	60.67	3.545
0.3	58.19	194.29	7.80	57.21	53.68	4.155
0.4	77.21	161.84	6.57	74.6	45.81	4.765
0.5	95.02	139.95	5.67	94.10	36.89	5.045
0.6	113.5	121.97	4.93	112.5	30.21	5.355
0.7	134.3	104.05	4.19	133.4	27.53	5.415
0.8	152.6	90.94	3.63	151.2	24.01	5.465
0.9	170	80.70	3.18	168.2	21.43	5.186
1.0	190.4	68.99	2.95	186.6	18.66	4.465
1.1	202.1	62.28	2.71	200.9	16.96	4.274
1.2	210.3	58.24	2.33	208.2	15.76	4.056

5.2 RANDOM PULSE WIDTH MODULATION

MATLAB Simulink model simulates the two triangular Random PWM structures. The pseudo-random triangle frequency system's switching frequency is 3 kHz. The triangular carrier is randomized in ±3 kHz range. The harmonic spectral analysis for voltage waveform, output line voltage waveform, measurement window and RPWM pulses are shown below from Figure 6.10 to 6.15.

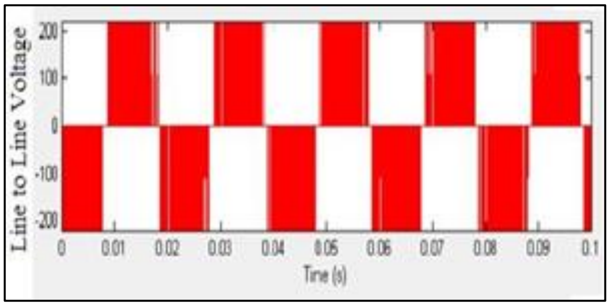


Fig 17 *Simulation result of line to line voltage*

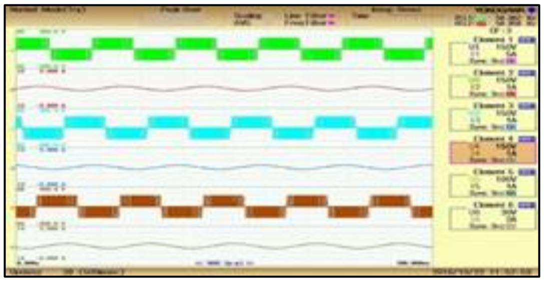


Fig 18. *Experimental result of line to line voltage with current*

Fig 19. *Experimental measurements*

Fig 20. *Experimental RPWM Pulses*

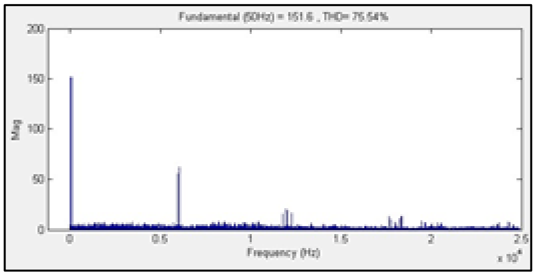


Fig 21 *Simulation Harmonic Spectrum for line to line voltage, ma=0.8*

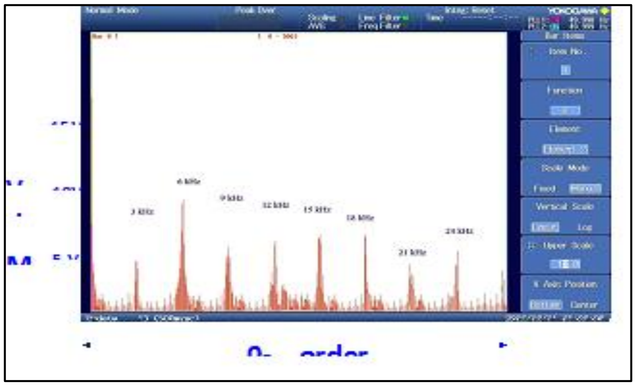


Fig 22 *Experimental results of Harmonic spectrum*

Table 1.4 *Simulation and Experimental Result comparison*

Technique	*RPWM*					
	Simulation Results			*Hardware results*		
M38.21	*Outut Voltage*	*THD %*	*HSF*	*Output Voltage*	*THD %*	*HSF*
0.1125.06	*18.11*	*393.07*	*14.01*	*25.43*	*71*	*3.843*
0.2106.67	*39.99*	*250.56*	*9.22*	*40.2*	*61*	*3.275*
0.3	*60.13*	*197.86*	*7.18*	*67.65*	*56*	*3.945*
0.4	*79.46*	*164.39*	*5.91*	*78.3*	*47*	*4.435*
0.5	*100.46*	*138.21*	*4.99*	*99.2*	*41*	*4.534*
0.6	*116.6*	*125.06*	*4.36*	*120.5*	*32*	*4.755*
0.7	*137.8*	*106.67*	*3.62*	*142.3*	*28.3*	*4.643*
0.8	*157*	*92.12*	*3.00*	*163.04*	*22*	*4.535*
0.9	*175.1*	*83.09*	*2.56*	*141.8*	*19.7*	*4.10*
1.0	*196.8*	*71.23*	*2.13*	*185*	*17.2*	*3.805*
1.1	*209.2*	*63.97*	*1.87*	*200.4*	*16.3*	*3.691*
1.2	*217.5*	*60.10*	*1.80*	*221.7*	*15.5*	*3.421*

6. CONCLUSION

Both sinusoidal PWM and two triangular random pulse width modulations are defined in the digital implementation of FPGA. There is talk of the comprehensive SPWM and FPGA's two triangle RPWM generation. In the MATLAB environment, the spectral analysis of the above methods is carefully investigated. Experimentation will examine the validity of the simulated spectral analysis. Comparisons demonstrated an outstanding equivalence between simulation and spectra that was actually measured. Two triangle random pulse width modulations outperform at the end of this study. But there is some scope to increase the fundamental by RPWM method if sine reference is replaced by space vector wave. The randomization also can be increased if the numbers of random carriers are increased.

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