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Investigation of FPGA Based PWM Control Technique for AC Motors

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ABSTRACT

This paper proposes a Random Frequency PWM synchronized for a three phase inverter implemented with use of FPGA and applied to a 1-hp induction motor drive system for the reduction of harmonics and improvement of fundamental peak voltage. For providing alternating output voltage with a specific magnitude and frequency to industrial applications, three-phase inverter is preferred. The gating signals to the inverter are produced by means of Random Frequency PWM to significantly reduce harmonics in comparison to currently used PWMs. FPGA is used to produce gating signals to the switches in a three-phase bridge inverter since a faster speed of operation is needed. The simulation is carried on VHSIC Hardware Description Language (VHDL) using ModelSim. Then, this VHDL model is imported into Matlab environment and co-simulated using HDL Cosimulation toolbox. The simulation and experimental results are presented with a view to determine whether Random Frequency PWM performs better in terms of fundamental voltage and Total Harmonic Distortion.

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1. INTRODUCTION

Solid state power devices have reached a state where PWM inverters have become more popular in many industrial applications [1]. According to the literature and present research outcomes, PWM inverters make it possible to control the frequency as well as the magnitude of the voltage applied to an induction motor. The main aim of pulse width modulation (PWM) technique in an inverter is to shape the output voltage/output current spectra in a way to eliminate lower order harmonics. If the controller part is analog based then the implementation needs complete substitution [2], [3]. Hence the need for fast prototyping and reprogrammable configuration is now growing up in control of power converters. FPGA incorporates the architecture of gate arrays and the programmability of programmable logic devices (PLD's). The fundamental component and total harmonic distortion (THD) can be controlled by Random Frequency carrier PWM. Each of the above methods possesses different patterns of pulse width modulation, and harmonic components [4], [5]. Though sinusoidal pulse width modulation renders many advantages, its foremost disadvantage is the fundamental magnitude restriction which can be overcome through overmodulation by increasing duty cycle [6]. But when this method is operated beyond a particular modulator voltage it introduces lower order harmonics. In order to minimise unwanted harmonic content, i.e., a THD, a number of pwm techniques have been developed to reduce THD and switching losses [7]. Since a three-phase bridge inverter provides adjustable frequency power than any other type of inverters it is preferred for industrial applications. In power electronics, various pulse width modulation (PWM) techniques are widely employed to control the output of inverters. The gating signals to the inverter are produced by means of Random Frequency carrier PWM technique. The Field Programmable Gate Array is used to produce the gating signals.

With successively improving reliability and performance of microprocessors, digital control techniques have predominated over their analog counterparts in the past decade [8]. Microprocessor based control schemes have the advantages of flexibility, higher reliability and lower cost. However, the demanding requirements of modern power conditioning systems have imposed tremendous computation load on the microprocessors. Therefore, the designers turn to the technology of field programmable gate array (FPGA) and hope that the high-speed hard-wired logic can enhance the computation capability of the digital controllers. The FPGA-based digital controller has the advantage of a well-designed hardware, which has higher computation speed, and short period of time for prototyping [9].

The organization of the paper is as follows. Section II recalls the random frequency PWM technique and the highlighting features. Section III depicts the Generation of RFPWM signals by modelsim. In Section IV simulation and experimental results are illustrated to indicate the efficiency of the developed application. At the end, conclusions are given in Section V.

The aim of this paper is to develop a control scheme which offers an improved performance when compared to the other PWM schemes in terms of fundamental voltage and THD, especially at higher modulation index. Finally, experimental results on a 1-hp induction motor drive system using the Hybrid RF-THI PWM control scheme are presented.

2. Random Frequency PWM Scheme

In power electronic systems, pulse width modulation techniques operate at a fixed switching carrier frequency which produces unwanted effects as well as harmonic spikes [10, 11]. The significant importance of a power electronic system employing RFPWM is that its output harmonics are dispersed and distributed. This popular scheme can be achieved by many ways such as varying the switching number in a cycle, the carrier frequency or the slope of the triangular wave [12].

In the proposed method, a randomly chosen carrier frequency signal with the help of random generator is used instead of a fixed carrier frequency as in the case of SPWM to perform the PWM switching scheme. It is preferred for high switching frequencies, owing to its simple architecture. However if the modulation index is low then the performance of the power electronic system will greatly degrade.

3. Generation of RFPWM Signals by Modelsim

The first and foremost aspect in generating sine PWM is to generate voltage-controlled oscillations. As the entire process is in digital format, it is not possible to generate the conventional analog sine wave [13. 14]. Further, this sine wave serves as a reference signal for comparison. Hence, if we know the values of the voltage controlled oscillations at any instant, then the purpose could be served. In this scheme, the controlled sinusoidal oscillations are generated in the form of a look up table and the amplitude control block controls the voltage magnitude. The regular sampling has certain advantages when implemented using digital techniques [15, 16]. Let the clock frequency be 50MHz which is the set frequency that the sine wave generator receives. It's quite a common thing to generate sine wave of set frequency using the governing equation given by, $V(t) = Vm \sin 2\pi ft$. But in digital logic, the problem arises in describing the limits for t, the time for which the wave has to be generated and the period of oscillations. Hence, the methodology we have adopted for creating the lookup table is that the instantaneous values of sinusoidal oscillations are fragmented to 200 values at equal intervals. These values are stored as an integer array named as memory.

Further instead of the factor $2\pi ft$ it is multiplied with an offset value and an integer which would in turn point to the value stored in the sine wave array.

The sine array is incremented in steps of one so that to represent a half cycle of the oscillation corresponding to 360°, it is essential to make 199 increments of the counter. Since we are in need of three phase sine wave, we need to have three sine wave generators, whose outputs are displaced by 120° each. That means, the output of the second generator must start from the initial value of zero when the first generator has swept an angle of 120 degrees. Similarly the third and second generators should follow the same fashion.

This is achieved by correlating the relation between the angular displacement and the sine array. Initially the output of first sine wave generator alone is activated and the remaining two are maintained at zero output condition. We have 360 degrees of the sine wave corresponds to 199 increments of the counter. Hence, 120 degrees of the wave would correspond to 66 increments of the counter.

Therefore, at the 66^{th} increment of the sine array of first generator, the output of second generator is activated. Similarly, at the 66^{th} increment of the sine counter of the second generator, the output of third one is activated. Once they are activated in this manner, then throughout the process, they are all displaced by 120° or 66 counts.

The high frequency carrier chosen for comparison is of ramp in nature. This is also digitally generated. The frequency of the ramp is randomly chosen as 6 kHz and 9 kHz or any value greater than this can be chosen. Unlike the sine wave, the frequency of the ramp is not maintained constant for a RFPWM. The triangular wave and the sine wave are compared and whenever the magnitude of the sine wave is greater than that of the ramp, output will be high otherwise it is low.

This pulse width modulation technique is described by VHDL and simulated using modelsim 6.3f. Since this method is flexible, an important advantage of VHDL is that it is technology independent [17].The pulses which are obtained as output is fed to the three phase bridge inverter using HDL co -simulation block.

The output of the three phase inverter is controlled by Random Frequency Pulse Width Modulation. The simulation model of the control circuit is shown in figure 1. Subsystem1 block generates pulses for the inverter as shown in figure 2. Powergui block given in the circuit measures the fundamental voltage and THD for various values of modulation index ranging from 0.2 to 1.2.

4. Simulation and Experimental Results

The fundamental voltage and Total harmonic Distortion were tested on an experimental test bench on RFPWM technique and the performance is evaluated by connecting a three phase inverter to a 1hp-1500 rpm squirrel cage induction motor.

Figure 3 shows the FFT analysis obtained by using the PowerGui block during the matlab-modelsim cosimulation and figure 4 shows the modelsim output for the proposed RF-THIPWM. The control of fundamental voltage determines the difficulty of the implementation of a given PWM strategy. In the given RFPWM, a linear relationship exists between fundamental voltage and modulation index and therefore the implementation is simplified. Here the fundamental voltage is varied as a function of modulation index ranging from 0.2 to 1.2. The impact is much significant in the higher values of modulation index. The important sources of distortion in power electronic systems are: the type of modulation technique employed and the nonlinearities in the output voltage. Total Harmonic Distortion (THD) is a standard measure used to characterize the distortion in the output [18], [19].

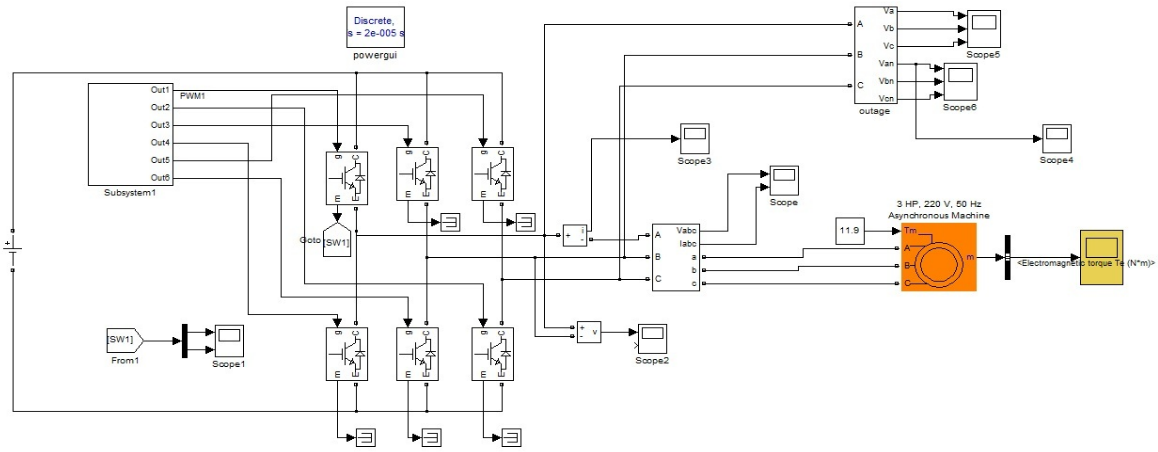

Figure 1. Simulation Circuit for a three phase inverter using Matlab

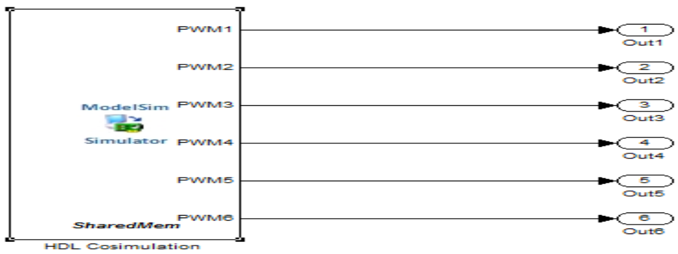

Figure 2. Co-Simulation Block for linking Matlab with Modelsim

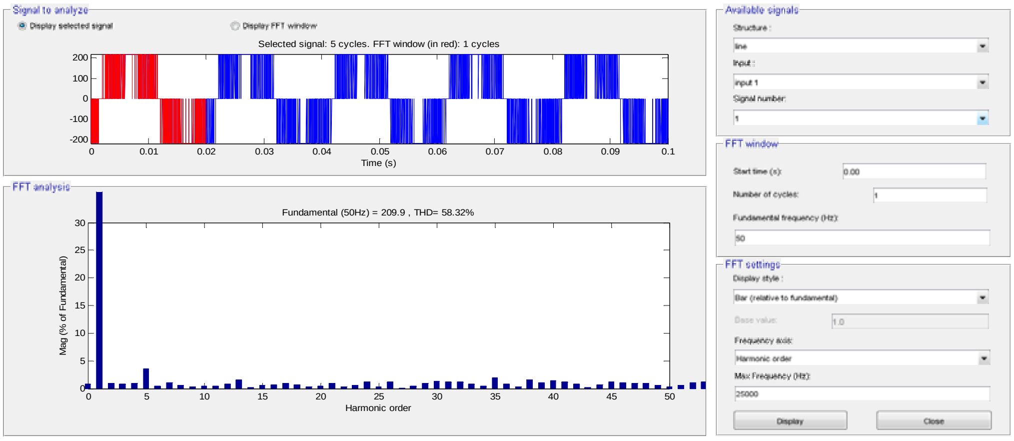

Figure 3. FFT Analysis for M.I=1.2 by RFPWM

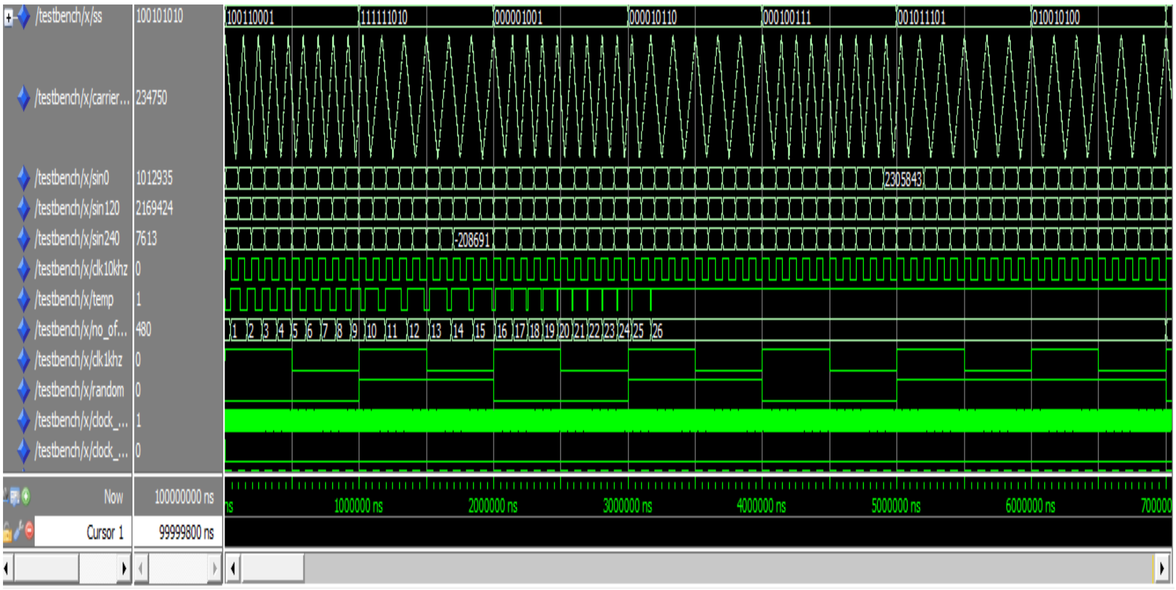

Figure 4. Modelsim output for RF-THIPWM

Figure 5 and Figure 6 shows the proposed scheme's advantage in the variation in the fundamental and THD. Along with this linearity is retained during both simulation and implementation between the fundamental voltage and modulation index.

From Table I, it is understood that fundamental voltage is linearly increasing and it is found to be highest value when the modulation index is equal to 1.2.

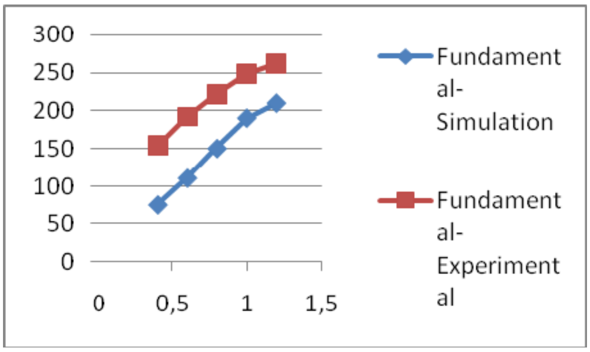

Figure 5. Modulation Index vs Fundamental Voltage

Table I. Simulation VS Experimental results for Fundamental Voltage

Modulation Index	Simulated Value	Experimental Value
0.4	75.87	153.39
0.6	111	191.88
0.8	150.4	221.47
1.0	190.2	247.99
1.2	209.8	261.93

Table II. Simulation VS Experimental results for Total Harmonic Distortion

Modulation Index	Simulated Value	Experimental Value
0.4	163.22	93.588
0.6	123.49	58.215
0.8	92.5	29.161
1.0	68.43	21.689
1.2	58.04	17.924

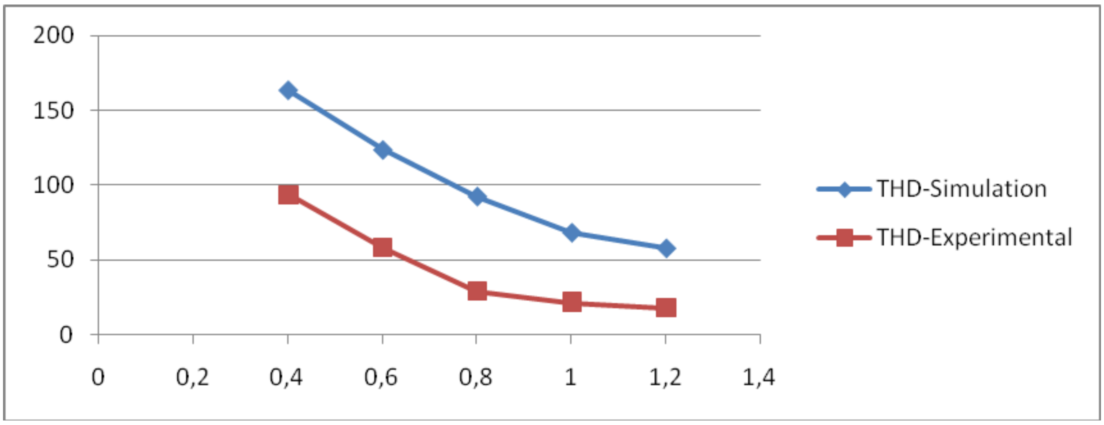

Figure 6. THD of the output voltage using RFPWM

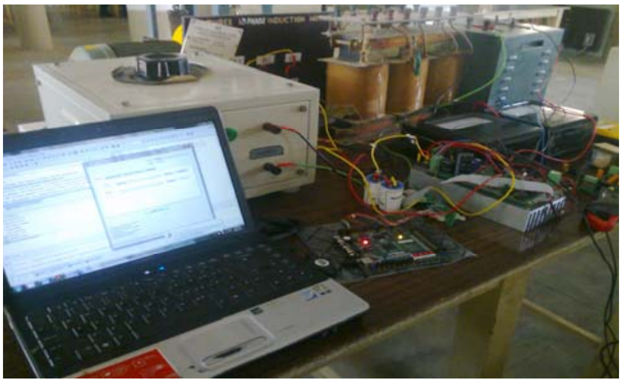

Figure 7. Experimental Implementation of RFPWM

Finally to demonstrate the improvements in THD using the experimental setup as shown in figure 7, Table II compares the variation in THD using experimental values with that obtained from the simulated values and Table III shows the variation in speed during implementation.

5. CONCLUSION

In this paper the proposed RFPWM is modeled in Matlab-Modelsim environment and evaluated for a 1-hp motor. The advantage of this pwm strategy is that it adopts a consistent approach for the entire range of modulation index and also eliminates lower order harmonics for any value of modulation index. There is significant improvement in THD and the fundamental voltage in the higher range of modulation index in a three phase inverter. Obviously the experimental waveforms validate the improved performance of RFPWM and the emergence of field programmable gate array (FPGA) has drawn much attention due to its shorter design cycle, lower cost, and higher density.

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