# INFLUENCE OF PWM TECHNIQUES ON AN INDUCTION MOTOR POWERED BY THREE-PHASE VOLTAGE INVERTER

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***Abstract:***

*This paper presents a study on the influence of different PWM control techniques for a voltage inverter on an induction motor. In the first step, we implemented the PWM techniques using the Xilinx System Generator tool, which allows implementation on the FPGA board. Then, we compared the different PWM techniques and their effects on the operation of the induction motor. The results obtained showed that the motor reached the nominal speed, with the best results for starting current and torque achieved by the Triplen Injection PWM (THIPWM) technique compared to the other two techniques, enabling good motor performance.*

## 1 Introduction

The induction motor coupled with a frequency converter is by far the most widely used type of motor for applications where it is necessary to control the speed and movement of a load. Among the main issues with induction motors are torque ripples and starting current. The amount of torque ripples produced by a motor depends on two main factors: the motor's construction and its control method. In many cases, these torque ripples can disrupt the proper operation of the machine. The starting current is approximately 6 to 7 times the rated current. It is imperative to provide current-limiting systems during startup (star/delta, frequency converter, etc.). Controlling the motor with a frequency and voltage converter offers several advantages, primarily: limiting the starting current and relatively minimizing torque regardless of the motor's speed. In this work, we study Pulse Width Modulation (PWM) control techniques for the voltage inverter and their impact on the torque and starting current of the induction motor using the Xilinx System Generator tool, which allows real-time implementation using FPGA in the LOOP. PWM modulation strategies implemented using complex analog circuits can now be realized more effectively using a lookup table accessed by a microprocessor or digital hardware. In an AC motor drive, the most appropriate modulation strategy for a particular speed range is easily selected.

Therefore, it is of interest to compare the different available PWM modulation techniques regarding additional harmonic losses in the motor and the pulsating torques developed. Our approach is based on the implementation of the sinusoidal PWM technique [1] [2] for the inverter, followed by the use of the random PWM technique [3] [4], and concludes with the introduction of the triplen harmonic injection PWM technique [5] [6], along with a comparison of the implementation and synthesis results and their influence on the operation of the induction motor.

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## 2 Influence of different PWM control techniques on the induction motor

### *2.1 Sinusoïdal PWM technique SPWM*

#### *2.1.1. Principle of the SPWM technique*

In the SPWM technique, the principle involves comparing a high-frequency triangular carrier signal with a sinusoidal modulation signal at the fundamental frequency (50Hz) to generate the control signal for the inverter switches. Figure 1 illustrates the principle of the SPWM control technique and equation 1 shows us the three sinusoidal voltages of references .

$$\begin{aligned} V_{a\text{ ref}} &= 1.15\, sin(\omega t) + 1/6 \sin(3\omega t) \\ V_{b\text{ ref}} &= 1.15\, sin(\omega t - 2\pi/3) + 1/6\, sin(3(\omega t - 2\pi/3)) \\ V_{c\text{ ref}} &= 1.15\, sin(\omega t + 2\pi/3) + 1/6\, sin(3(\omega t + 2\pi/3)) \end{aligned} \tag{1}$$

When the modulation signal is greater than the triangular signal, the output signal is high (1); otherwise, it is low (0). The ratio of the peak value of the sinusoidal modulation signal to the peak value of the carrier wave defines the amplitude modulation index (ma).

$$m_a = \frac{Vref}{Vc} \tag{2}$$

For 0 < ma ≤ 1, the output voltage of the inverter increases linearly with the modulation index ma. This region of PWM is called the linear modulation region.
When ma > 1, over-modulation occurs. In this region, the inverter's output voltage increases non-linearly with ma [7].

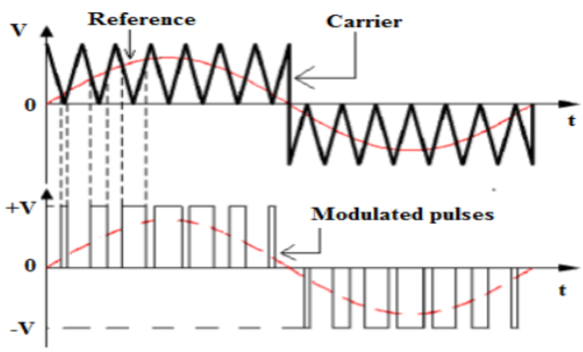



*Figure 1. Principle of the SPWM technique [8].*

#### *2.1.2. Implementation of the SPWM technique using Xilinx System Generator*

*a) Xilinx System Generator tool*

Several software design companies have shown interest in programming FPGA circuits. Numerous partnerships have been formed between these companies and FPGA market leaders like Xilinx and Altera. One of these companies is MathWorks, with its new tools HDL Coder and Xilinx System Generator. In collaboration with Xilinx, MathWorks engineers have developed a new library called "Xilinx" within Matlab-Simulink, which provides a rich set of pre-implemented blocks and models in HDL. Users of this library can leverage the simulation tools available in Matlab-Simulink while automatically converting the high-level model (based on Xilinx blocks described in HDL) into synthesizable HDL code. The Xilinx System Generator tool is a good example of IP reuse principle. Matlab-Simulink allows the simulation of Simulink blocks and Xilinx blocks (co-simulation), automatic conversion of Xilinx blocks into synthesizable code, and estimation of resource consumption on an FPGA target. XSG even simplifies configuration and physical implementation on FPGA platforms.

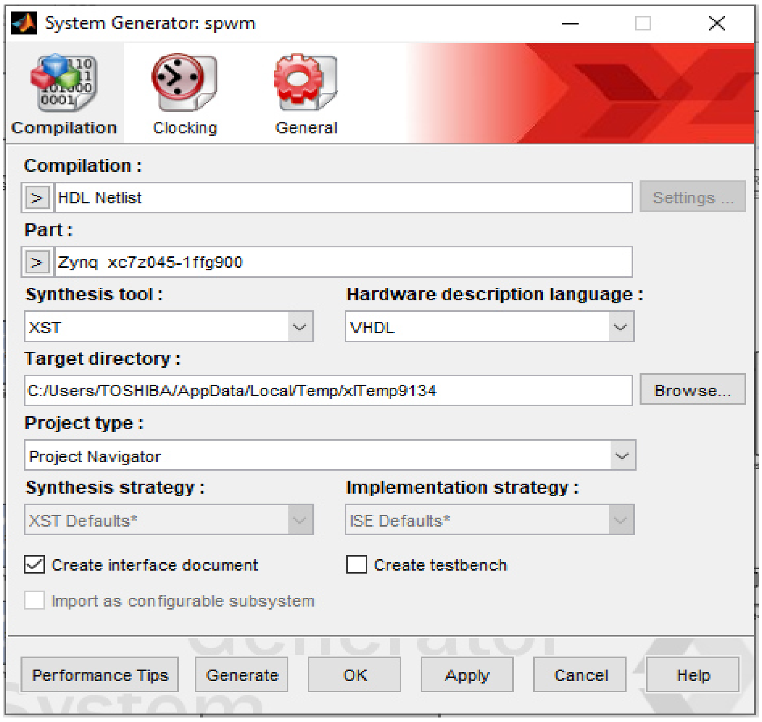



*Figure 2. Main block of Xilinx System Generator [9].*

*b) Generation of the SPWM control signal*

Applying the principle of the SPWM technique, we use Xilinx System Generator blocks to generate three sinusoidal signals that can be compared with a triangular carrier signal. To obtain the triangular carrier signal, we used a counter multiplied by a gain (Cmult). For the three sinusoidal signals, we used a counter combined with a CORDIC SINCOS block and MCODE function to ensure a pure sinusoidal signal with a 120° phase shift between the three sinusoids, as depicted in Figure 3. Figure 4 illustrates the comparison between the triangular carrier and the sinusoidal modulation, along with their SPWM results.

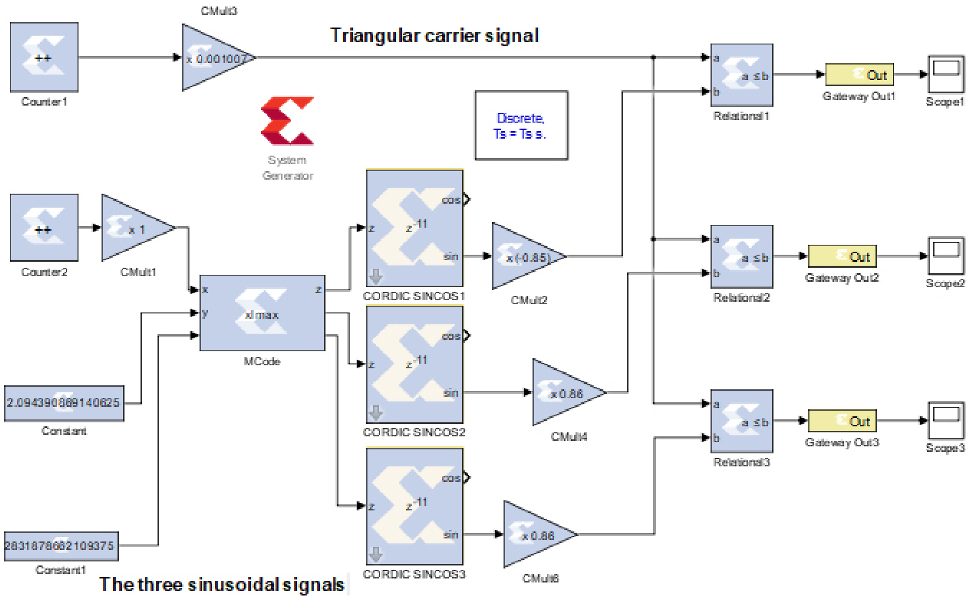
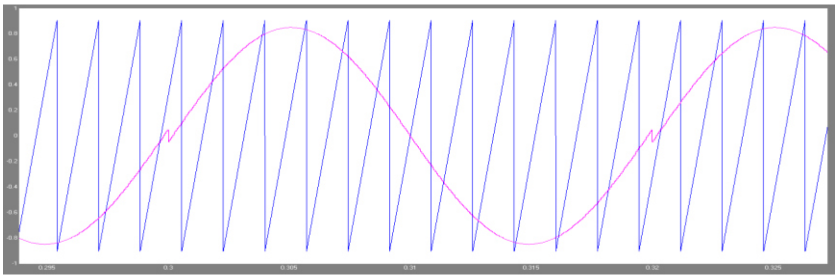
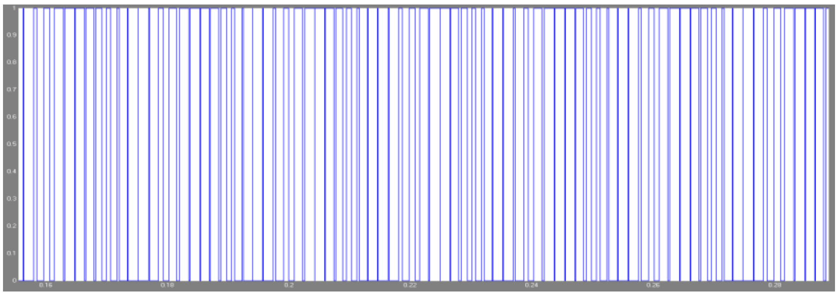



*Figure 3. Generation of the SPWM control signal using Xilinx System Generator.*



a) Sinusoidal triangular comparison



b) control signal SPWM

*Figure 4. Sinusoidal triangular comparison and the control signal SPWM.*

### 2.2 Random PWM technique RPWM

#### 2.2.1. Principle of the RPWM technique

Considered as an optimization of the PWM technique, the principle of the RPWM control technique is similar to the SPWM technique, except that in this case, the carrier signal is random. Figure 5 illustrates the principle of the RPWM technique [10].

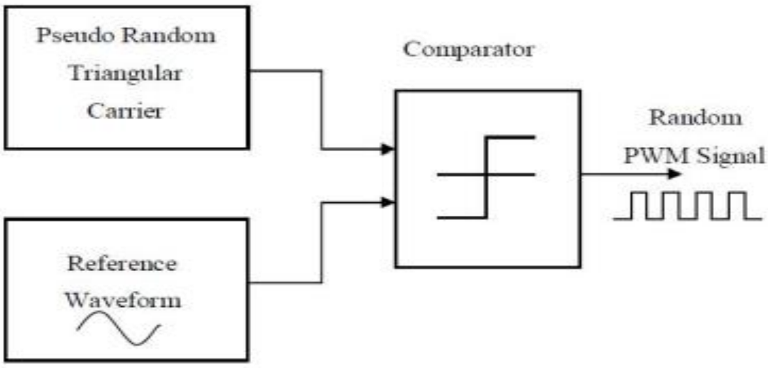



*Figure 5. Principle of the RPWM control technique [11].*

#### 2.2.2. Implementation of the RPWM technique using Xilinx System Generator

The generation of a random carrier signal using Xilinx System Generator blocks is based on the multiplication of two triangular carrier signals, one of which is inverted by the NOT block, and then multiplied by a gain (Cmult), as shown in Figure 6. Figure 7 illustrates the comparison between the random carrier and the sinusoidal modulation signal, along with the resulting RPWM control signal.

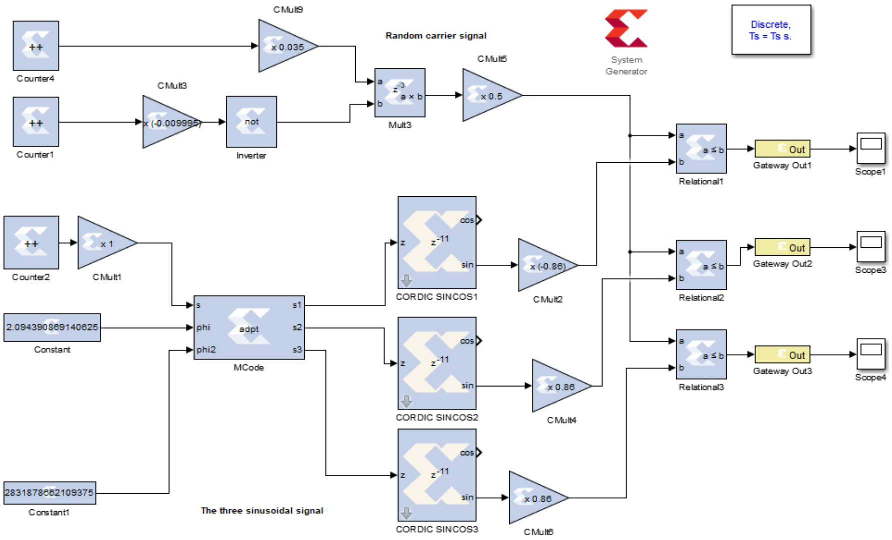
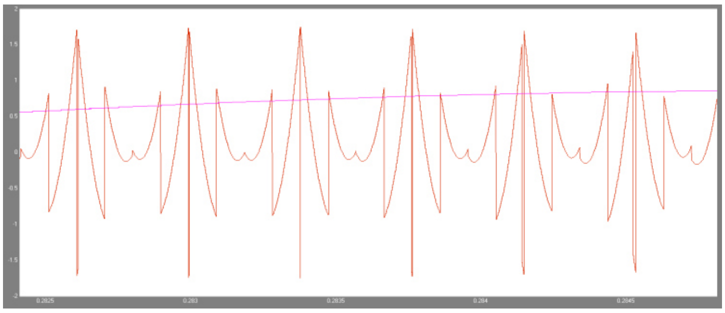
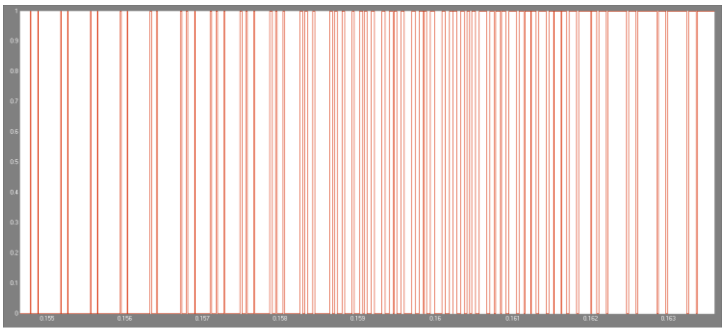



*Figure 6. Generation of the RPWM control signal using Xilinx System Generator.*



*a) Sinusoidal random comparison*



*b) RPWM signal control*

*Figure 7. Sinusoidal random comparison and the RPWM signal control.*

### *2.3. Triplen injection PWM THIPWM*

#### *2.3.1. Principle of the THIPWM technique*

Among the optimizations of the PWM technique, the Triplen Harmonic Injection PWM (THIPWM) technique is one of the earliest PWM techniques used in inverters. King had produced flat phase waveforms that improved the efficiency of a class B transistor inverter [12]. This is achieved by adding various amounts of third, ninth, fifteenth, etc., harmonics to the fundamental sinusoidal reference. This method succeeded in improving the performance of all PWM inverters. The Triplen Harmonic Injection PWM employs a triangular carrier waveform. It can be observed that the fundamental is increased by 15% compared to SPWM (Figure 8). The analytical expression for the reference waveform can be derived by adding other triplen harmonics, as indicated by equation 3.

$$y = 1.15 \sin \omega t + 0.27 \sin \omega t - 0.29 \sin \omega t \tag{3}$$

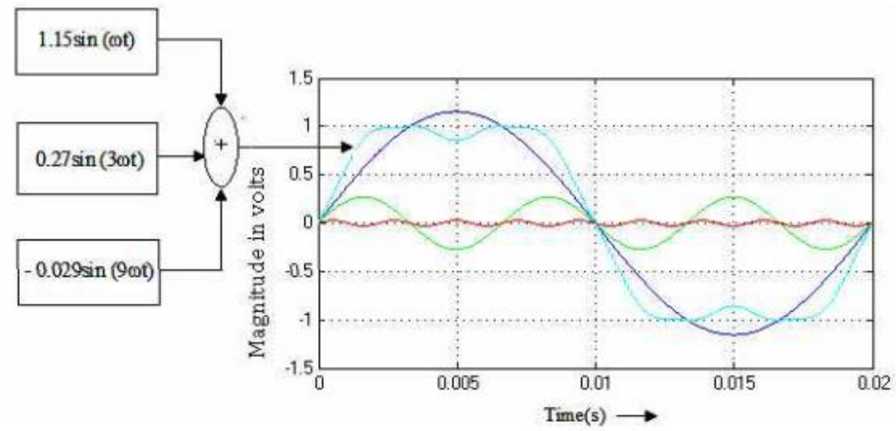



*Figure 8. Principle of the THIPWM technique* [13].

*2.3.2. Implementation of the THIPWM technique using Xilinx System Generator*

By applying the principle of the THIPWM technique and formula 3, we utilize the constants and ADD SUBB blocks from Xilinx System Generator to implement the technique, as shown in Figure 9. Figure 10 illustrates the comparison between the triangular carrier and the three triplen harmonic sinusoids injected.

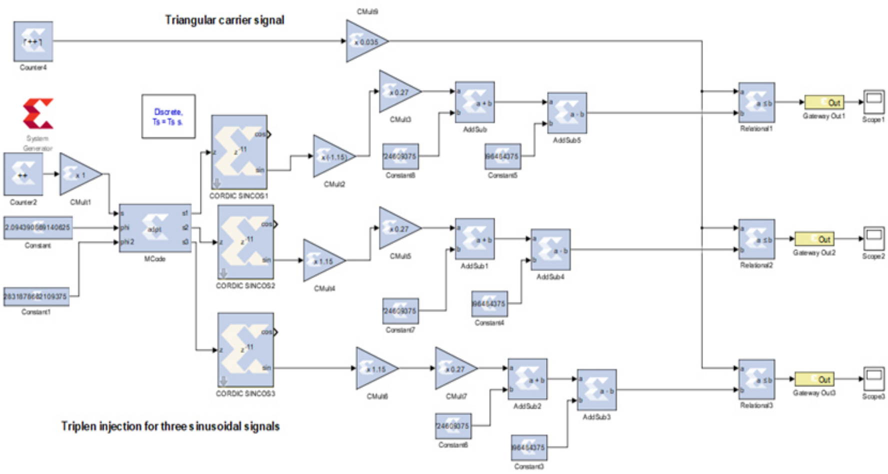
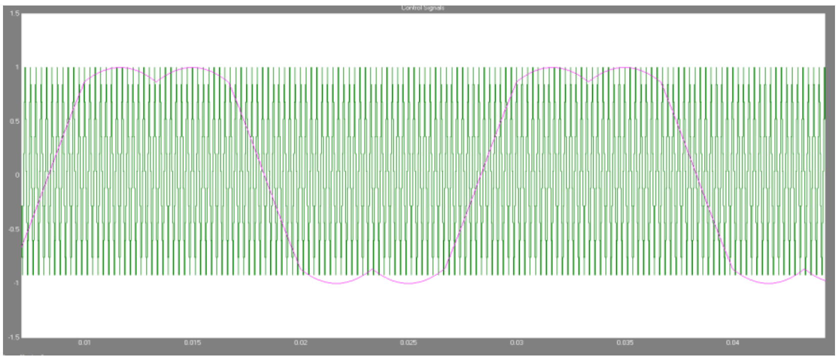
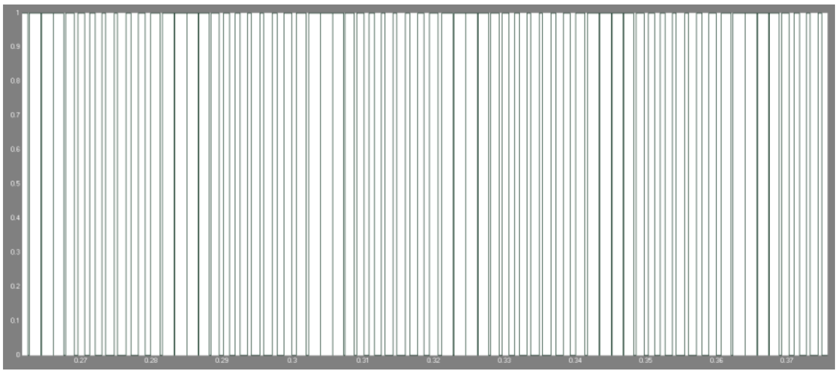



*Figure 9. Generation of the THIPWM control signal using Xilinx System Generator.*



*a) Triangular comparison with Triplen harmonic injection.*



b) THIPWM control signal.

*Figure 10. Triangular comparison with Triplen harmonic injection and THIPWM control signal.*

*2.4. Global installations of the induction motor*

In this phase of the work, we combine the controlled inverter with the three PWM techniques used with the induction motor to analyze the effect of these techniques on the motor's operation. Figure 11 illustrates the implementation diagram of motor control with the various PWM techniques used with the help of Xilinx System Generator.

*Table 1. Implementation parameters.*

| | |
|---|---|
| *inverter DC voltage* | *400V* |
| *Torque load* | *5NM* |
| *motor Power* | *4 KW* |
| *rotation speed of the motor* | *1430 RPM* |
| *Frequency* | *50 HZ* |
| *Step* | *Fixed* |

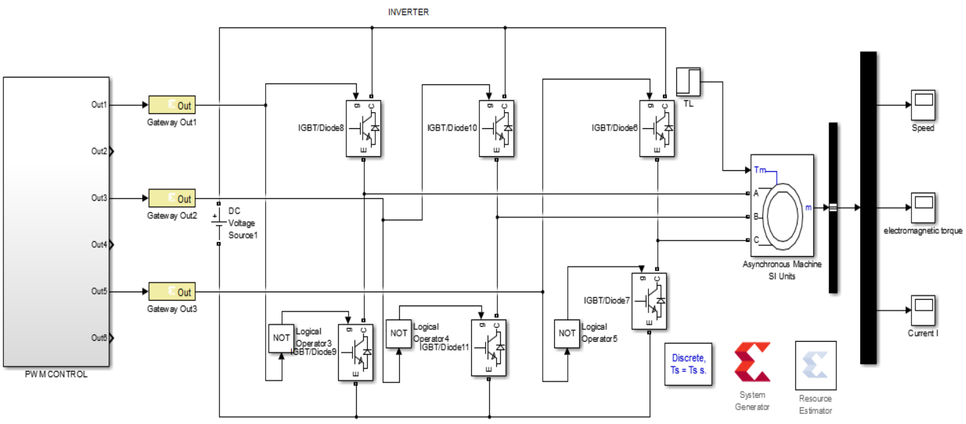
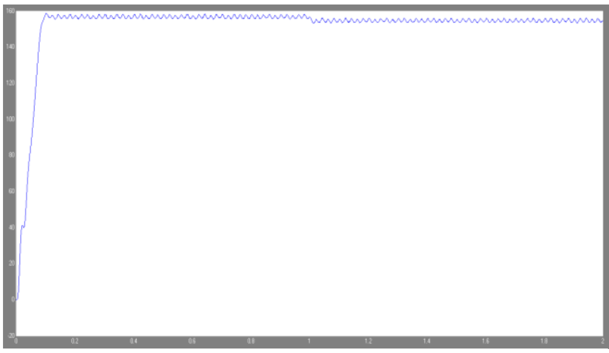



*Figure 11. Overall implementation diagram of the PWM techniques for the induction motor using Xilinx System Generator.*

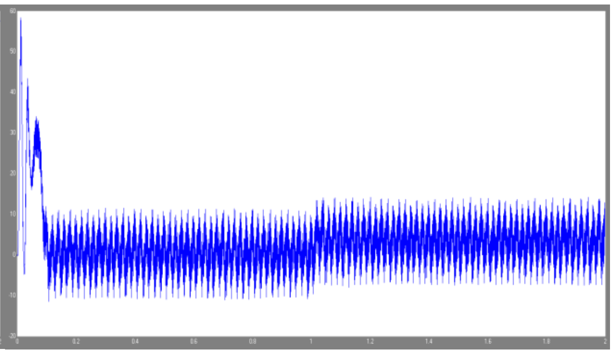
## 3 Results and discussion

### *3.1. Results*

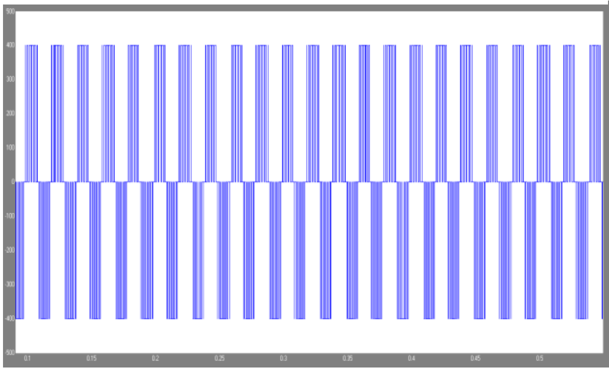
We took the following results for analysis: motor rotational speed and electromagnetic torque, as well as supply voltage and phase current along with their THD. Figures 12.1, 12.2, and 12.3 show the implementation results for each PWM technique used. Table 1 presents the THD values for each technique, and Table 2 illustrates the synthesis results obtained using the Resource Estimator block in Xilinx System Generator to estimate FPGA resource consumption.



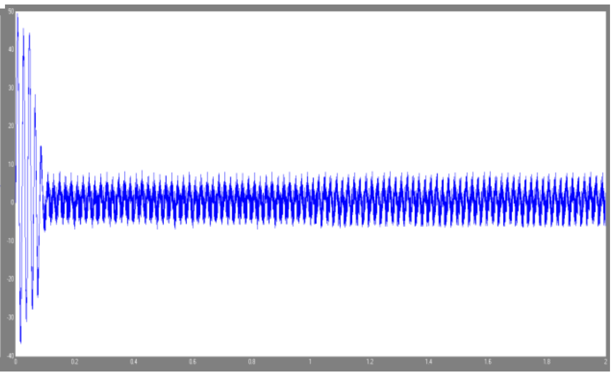
*a) Rotation speed of induction motor*



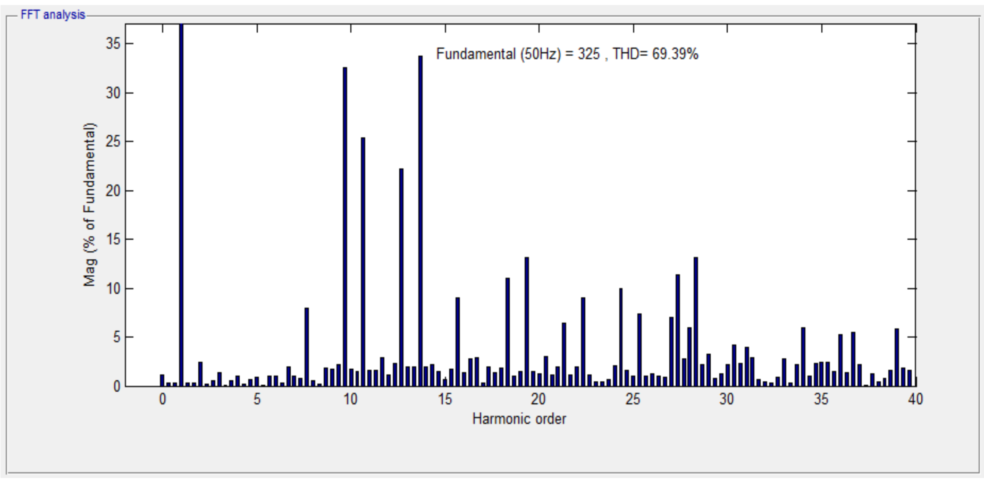
*b) Electromagnetic torque*



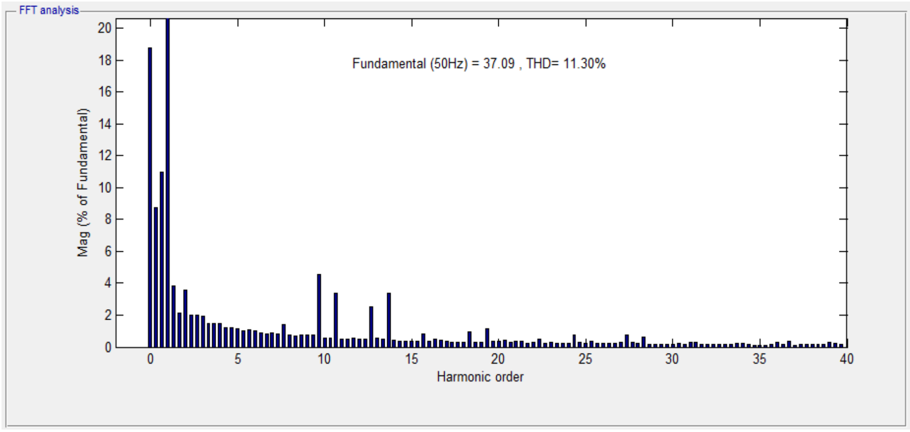
*c) Inverter output voltage*



*d) Phase Current*

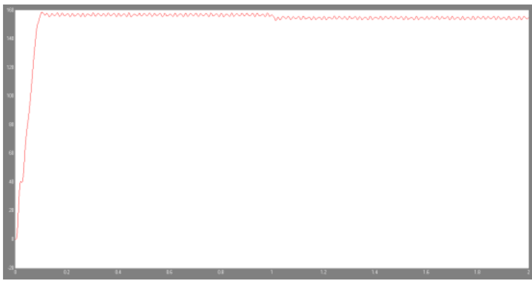



*e) Inverter output voltage THD*

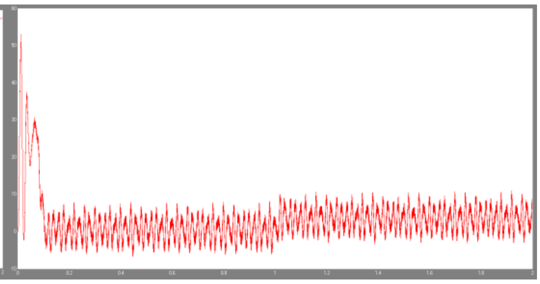



*f) Phase Current THD*

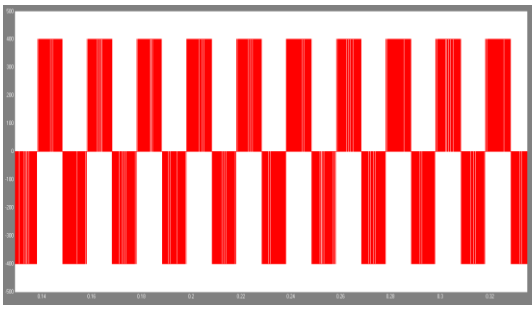
*1) Implementation Results of the SPWM technique*



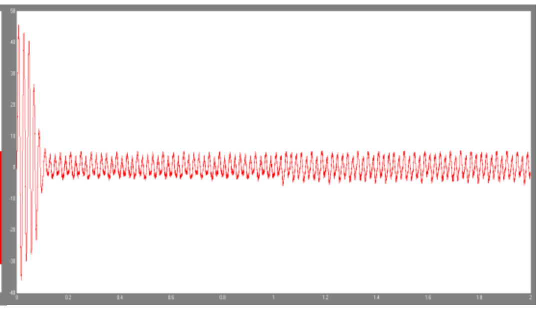
*a) Rotation speed of induction motor*



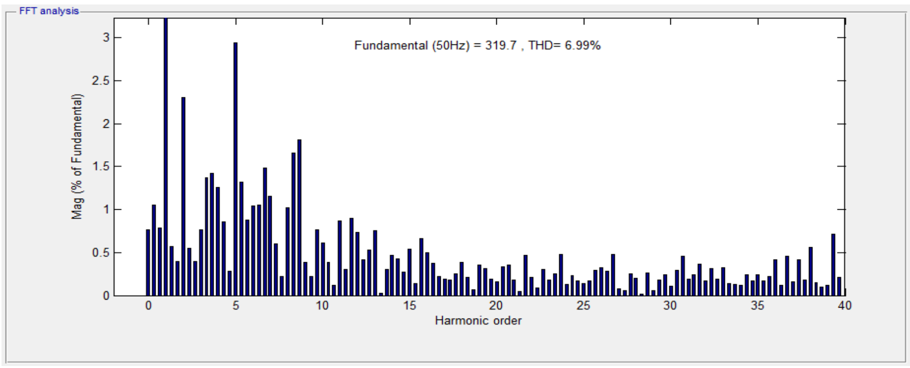
*b) Electromagnetic torque*



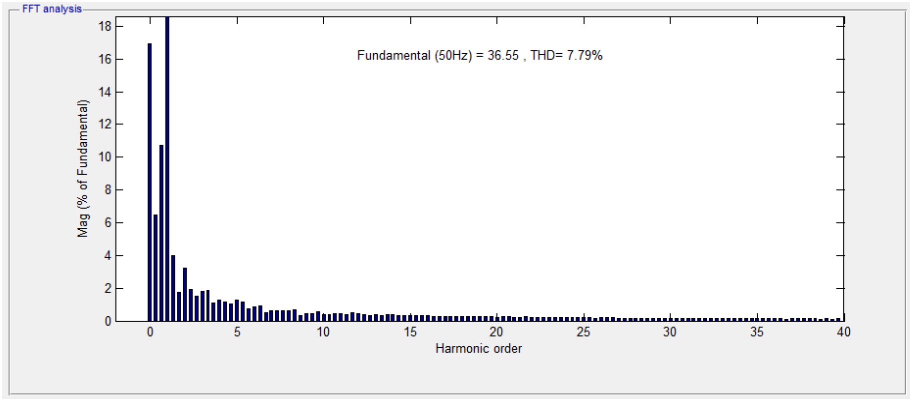
*c) Inverter output voltage*



*d) Phase Current*

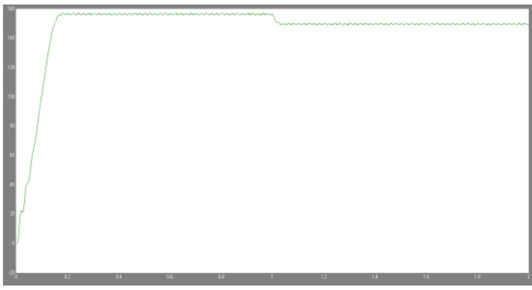



*e) Inverter output voltage THD*

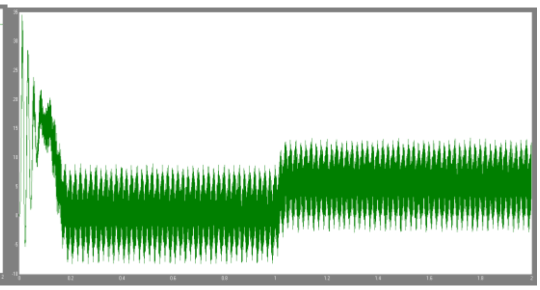



*f) Phase Current THD*

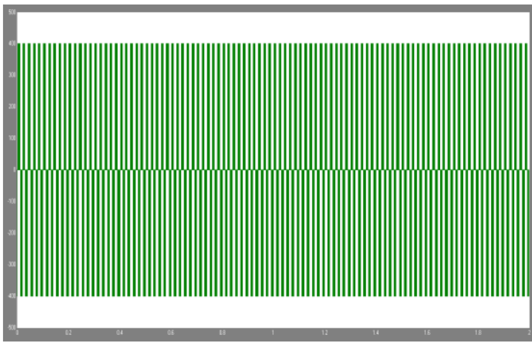
*2) Implementation Results of the RPWM technique*



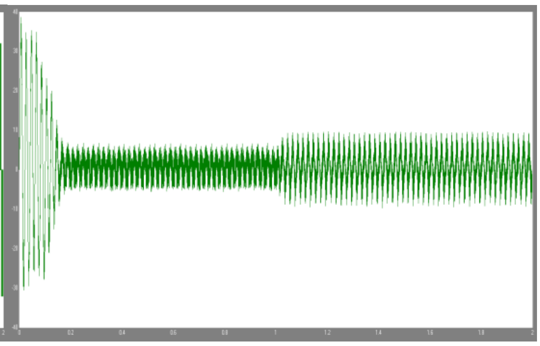
*a) Rotation speed of induction motor*



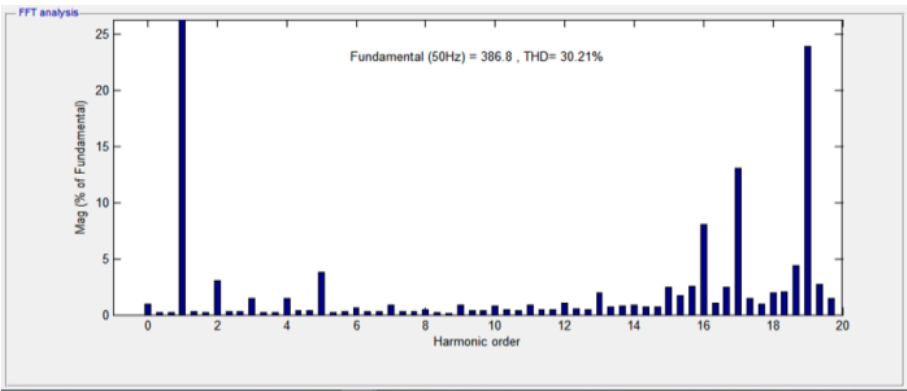
*b) Electromagnetic torque*



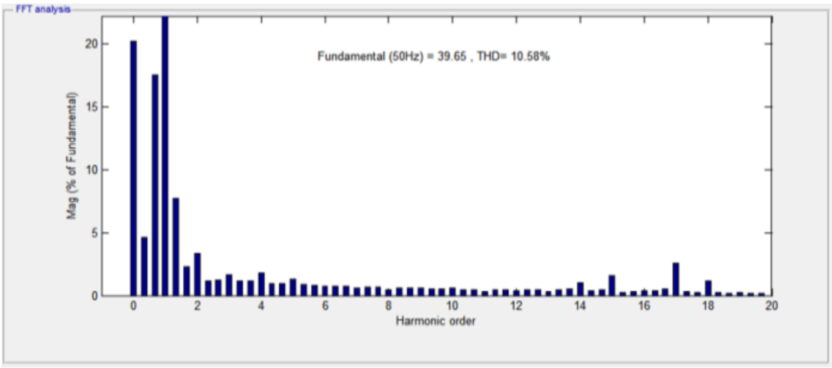
*c) Inverter output voltage*



*d) Phase Current*




*e) Inverter output voltage THD*




*f) Phase Current THD*

*3. Implementation Results of the THIPWM technique*

*Figure 12. Implementation results of the PWM Techniques for the induction motor using Xilinx System Generator.*

*Table 2. THD results for PWM techniques.*

| Techniques | THD % line voltage | THD % phase current |
|---|---|---|
| SPWM | 69.33 | 11.30 |
| RPWM | 6.99 | 7.79 |
| THIPWM | 30.21 | 10.58 |

*Table 3. Synthesis results.*

| Resources | SPWM | RPWM | THIPWM |
|---|---|---|---|
| Slices | 945 | 945 | 1098 |
| FFs | 270 | 270 | 270 |
| LUTs | 1761 | 1761 | 2052 |
| MULTs/DSP48s | 0 | 0 | 0 |

### *3.2. Discussion*

The speed curve shows that the motor reached nominal speed for all three techniques. The RPWM technique minimizes torque ripple and starting current, as indicated in the electromagnetic torque and phase current curves. The results for the THIPWM technique show the lowest starting current and torque compared to the other two techniques, allowing for good motor performance. Regarding the THD of voltage and current, we observe that the random technique has a lower THD compared to the other two techniques, as illustrated in Table 1. By analyzing Table 2, we can see that the synthesis allows us to implement the PWM techniques in real-time for the induction motor on FPGA using the FPGA IN THE LOOP technique.

## 4 Conclusion

In this paper, we studied the influence of different PWM control techniques on the operation of an induction motor using the Xilinx System Generator tool for FPGA implementation. We started by implementing the PWM control laws using Xilinx System Generator blocks to obtain the control signals for the inverter. In the second step, we conducted the motor-inverter association to analyze the influence of the PWM techniques on motor operation. The results obtained showed an improvement in motor performance, particularly the random technique, which minimized torque ripple and starting current with a lower THD for line voltage (6.99%). Additionally, the triplen harmonic injection PWM technique exhibited the lowest starting current and torque with the best fundamental line voltage (386.8 Volt). The synthesis results subsequently allow us to implement real-time control laws on the FPGA board using the IN THE LOOP technique.

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