Simulation and V/f Control of Three Phase Squirrel Cage Induction Motor with SVPWM

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Abstract- The control of three-phase squirrel cage induction motors is crucial in a wide range of industrial applications due to their efficiency and robustness. This abstract provides an overview of the control methodology involving Space Vector Pulse Width Modulation (SVPWM) for the precise and efficient operation of these motors. Three-phase squirrel cage induction motors are the workhorses of various industrial processes, including manufacturing, transportation, and energy generation. To harness their full potential and achieve precise control, advanced modulation techniques like SVPWM are employed. SVPWM is a sophisticated modulation technique that allows for the precise control of voltage and frequency applied to the motor windings. It optimizes the motor's performance by generating a set of switching signals that produce a nearly sinusoidal current in the motor, reducing harmonics and minimizing losses. In this research, SimPower in the MATLAB/SIMULINK system is used to analyze the simulation model of SVPWM. This article compares, analyzes and reviews three phase induction motors using three different types of SVPWM. The simulation results are plotted and discussed showing the performance of the SVPWM system these findings show the difference in speeds of squirrel-cage induction motors under heavy industrial machine loads.

Keywords- Squirrel cage induction motor, Space vector PWM, V/f control, Harmonics.

1. INTRODUCTION

Three-phase squirrel cage induction motors play a pivotal role in a myriad of industrial and commercial applications, serving as the driving force behind machinery and processes that propel our modern world. These motors are renowned for their durability, simplicity, and reliability. However, achieving precise control over their operation has been a longstanding challenge, especially when it comes to fine-tuning parameters like speed, torque, and efficiency. In the pursuit of efficient and precise motor control, engineers and researchers have turned to advanced techniques, with Space Vector Pulse Width Modulation (SVPWM) emerging as a leading methodology. This introduction provides a foundational overview of the control of three-phase squirrel cage induction motors using SVPWM. It sets the stage for understanding the complexities and innovations associated with this control technique [1]-[2].

Three-phase squirrel cage induction motors have been the cornerstone of industrial and commercial power systems for over a century. Their inherent robustness, minimal maintenance requirements, and ability to operate in harsh environments have made them indispensable in applications ranging from manufacturing and transportation to utilities and renewable energy.While these motors excel in reliability, they have traditionally lacked the precise control capabilities essential for modern industrial processes. To optimize their performance, it is crucial to control parameters such as motor speed, torque, and power factor. Moreover, the demand for energy-efficient operation in an era of sustainability has driven the quest for advanced control techniques [3].

Space Vector Pulse Width Modulation, or SVPWM, is a sophisticated control technique that has revolutionized the way we manipulate three-phase squirrel cage induction motors. By precisely modulating the voltage and frequency applied to the motor windings, SVPWM allows for unprecedented control over these motors' behavior. The primary objectives of employing SVPWM in the control of three-phase squirrel cage induction motors include: Efficiency Enhancement, Precise Speed and Torque Control, Reduced Harmonics, and Dynamic Performance [4].

AC motors are considered fixed speed drives when they operate at a steady voltage and recurrence.Within the final two or three a long time we have seen broad investigate and advancement of variable speed AC motor drive systems, because the electric motor consists of armature winding and the commutator has been designed extensively without rotation and brush issues. This makes the machine work. in dirty and wet places. Because of these features, AC drives have replaced DC drives and are widely used in commercial and home applications. The speed control of the AC motor is important in the operation of the manual, there are many ways to control it, an ultra-modern andpopular backbone is a constant value (V / f), different stability and three power frequencies in the system, for this, inverter with PWM method is used [5]-[6].

In this article, the SVPWM inverter type is examined and simulated. The results obtained from simulation determines the performance of SVPWM.
The paper is classified into following sections. Section I covers the introduction of V/F Control of Three Phase Squirrel Cage Induction Motor With SVPWM.

2. The Main Components

In a variable recurrence drive, the three-phase AC voltage of the control supply is corrected to DC, an LC channel is utilized to decrease the swell, and the DC voltage is sifted by the inverter [5-6]. It is nourished to control converters such as (GTO, BJT, IGBT and control MOSFET) for the PWM flag. Variable recurrence yield offbeat engine is the most point of thisframework. The block diagram of this project is shown in Fig (1).

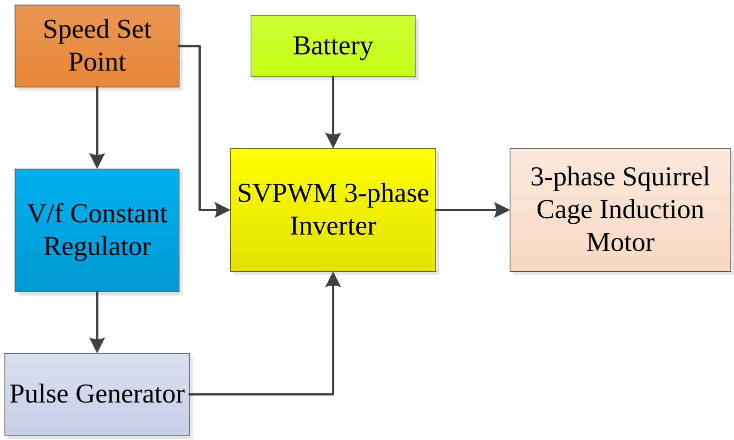


Fig: 1. Block Diagram of Model

2.1 Inverter

It represents the first part of the VFD, the core of the inverter is the power converter, for example (MOSFET or IGBT), and the differential gate transistor (IGBT) is a very fast electric power converter. They can be switched using a small positive of the gate and ground and the device will turn on and continue to operate at high frequency (2 kHz to 15 kHz). The three-phase inverter topology is sometimes called a VFD inverter [6]. B. Regulator This regulator concept adjusts the rate (V/Hz) using Pulse Width Modulation (PWM) techniques to produce different pulse widths; it means that the difference between the output voltages of the inverter is different [7]. Carrier frequency is indicated by the speed of the switch (ON and OFF), it is important to remember that increasing the carrier causes tilting more sinusoidal in the inverter output waveform. The inverter intelligently converts the fixed DC voltage to three-phase variable voltage. Synchronous speed (r.pm) N_s, f: fundamental frequency (Hz), P: number of poles. The difference between synchronousspeed and rotor speed is called slip-

$$s = \frac{N_s - N_r}{N_s} \qquad (1)$$

Also, can be written as

$$N_r = \frac{120 f (1-s)}{P} \qquad (2)$$

Here, N_r Rotor speed (rpm.), s is slip and P is no. of poles.

To maintain the (V/f) ratio is constant, so as lead to stator magnetic flux remains constant, if varying only the frequency and same voltage is applied to the AC machine that caused an increase in stator magnetic flux till to the saturation magnetic core, this lead to low performance of the motor.

$$V_{ph} = 4.44 kfN\phi_m \qquad (3)$$

$$\frac{V_{ph}}{f} = 4.44kN\phi_m \quad (4)$$

$$T = kN\phi_m I_2 \quad (5)$$

Where magnetic flux (Wb) (ϕ_m), number of phases (N). Stator phase voltage (V_{ph}).Constant depending on machine design (k), Shaft torque (N-m) (T), Rotor current with load (A) (I_2).

To avoid stator core saturation, to keep the ratio (V/f) constant, the flux must be kept constant using equation 5 to keep the motor torque constant at all speeds below the rated speed, which will maintain (V/f). There are 4 basic types of control for AC drives:

1) Volts per Hertz is a scalar control that gives the difference in speed keeping the ratio (V/f) constant. This type of control is used in applications such as fansand pumps, where it provides constant torque at high speeds and is low cost.
2) Sensor less vectoring is a control system that increases take-off torque and speed.
3) Flux vector control, a control method that uses a feedback loop to provide speed and power.
4) Field Oriented Control, this method shows more control of AC motors such as speed and power and makes the performance of AC motors equal to DC motors [8]-[9].

2.2 Pulse Generator

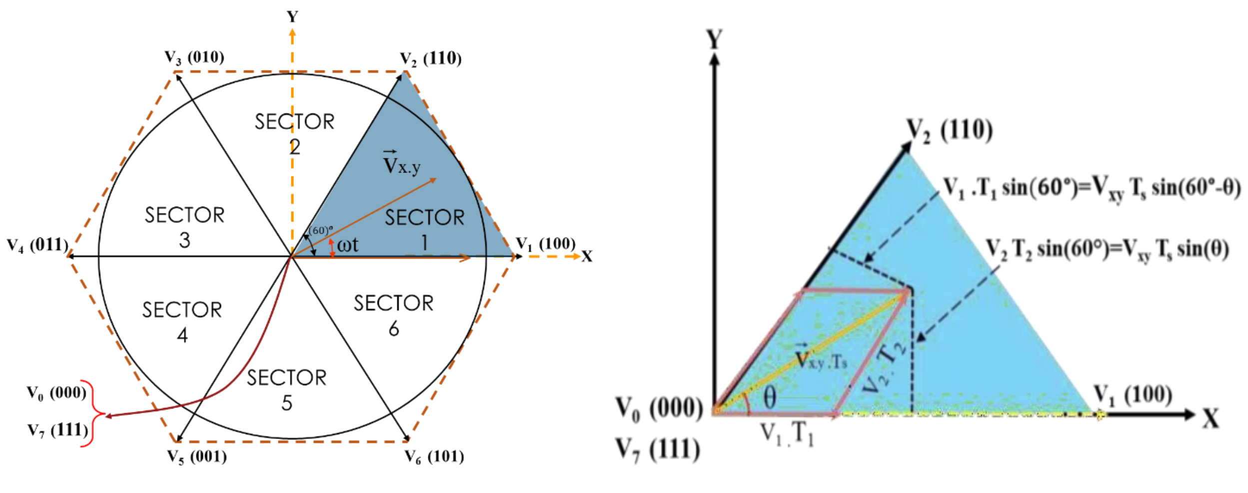
The Pulse Generator is an electronicdevice that generates periodic electrical pulses. These pulses can be used for many purposes, such as controlling the timing of other circuits or generating clock signals for digital systems. The purpose of the pulse generator is to provideaccurate and reliable electrical pulses for electrical circuits. These pulses can be used to synchronize the operation of multiple circuits, measure time differences, or create waveforms with specific characteristics.

2.3 Squirrel Cage Induction Motor

Squirrel cage induction motor is an electric motor that works on the principle of electromagnetic induction. The rotor has a rotor with shorter wires than the rings at the end, and the stator has a series of lines that generate a magnetic field. This is how induction motors work and are widely used in many industrial and commercialapplications due to their simplicity, reliability and ease of maintenance. The speed of the motor can be controlled by adjusting the frequency of the electric motor or by using a variable speed motor.

2.4 Source Vector Pulse Width Modulation Technique of VSI

The driving voltage VSI must have a voltage at which the Thevenin impedance must be zero. If the voltage source is not tight, this can be represented as a large capacitor connected to the input, proving the VSI's effectiveness as a ground source. Source (battery or diode ground from C or L-C ground). Always replace VSI as it is toxic and DC forced voltage is good so it is designed for inverters like forward control or asymmetric blocking bias (GTO, BJT and IGBT). There are sixtypes of programs. It can be seen that each functionhas (π/3) or (V/f) derived from the driver phase and generates each phase waveform independently as shown in Fig. 2 and Fig. 3. Medium-load machines are usually isolated, but SVPWM defines the inverter as a unit with mechanicaldevices that cause phase interference [10]-[11]. Before PWM, this interaction was not taken into account. The harmonics of the three-phase isolated neutral load are optimized using the space vector PWM method, utilizing the effect of the phases.



(a) **(b)**

Fig 2. (a) Sector Division, (b) Sector Angle

In the SVPWM process, the three coordination levels (A, B, C) are transformedinto two coordination organizations (X, Y), i.e., the whole process, (X axis) represents thereal axis and (Y axis) to represent. real axis.Strategic axis. Among them, "Vxy" represents the voltage vector rotating at a fixed angular frequency (ω), n SVPWM, andthe vector "V_1, V_2, V_3, V_4, V_5, V_6" has 6 planes, each section (π/3) Represent. or 60°, as shown in the picture. The voltage "Vxy" has two zero vectors (V0 and V7) andtwo zero vectors (V_1 to V_6). It is close to a sine wave when the step width is small and the frequency variation is large.

3. IMPLEMENTATION OF(SVPWM)

There are two ways to use SVPWM in control of three phase induction motor. The first is modulation based on sector selection and the second is carrier frequency based on SVPWM. This article uses the following types:

A. SVPWM is based on sector selection.

B. SVPWM based on carrier frequency.

C. SVPWM is based on reduced frequency carrier rotation [12]-[13] using SVPWM Sector Selection.

The steps of the process can be done as follows: -

Step 1: Cut (Vx, Vy, Vxy)

Step 2: Set Length (T1, T2, T0)

Step 3: Determine the switching time of each power transistor (S1 to S6).

Step 4: Determine (Vx, Vy, Vxy) and angle (θ): To understand SVPWM theory, the concept of rotation vector space and axis transform is very important. These three quantities can be represented by biaxial coordinates (Vx, Vy) [14]. Can be easily changed using the formula (6):

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos(0) & \cos(120°) & \cos(-120°) \\ \sin(0) & \sin(120°) & \sin(-120°) \end{bmatrix} \tag{6}$$

Or

$$\begin{bmatrix} V_x \\ V_y \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$T_s V_{xy} = T_1 V_1 + T_2 V_2 + T_0 (V_0 or V_7) \tag{7}$$

Where: (V_0or V_7) = 0V at the output of the inverter.

$$Vxy = \frac{T_1}{T_s}V_1 + \frac{T_2}{T_s}V_2 + (V_0\ or\ V_7)\frac{T_0}{Ts}$$

Where: (T_s), is the sampling time period of the switching frequency (f_s), and (V_{DC}) DC link voltage. The modulation index is:

Step 5: Determine the time (T_1 , T_2, T_0): spatial voltage "Vxy" moves from state 1 to state 2 with time sharing PWM of (V_1 & V_2) [3], compare for example in figure 5, if vector " Vxy" PWM between V_1 (100) and V_2 (110) in sector 1 with duty cycle of each (T_1 &T_2) with zero vector (V_0 (000) & V_7 (111)) duty cycle (T_o) is fixed. Volt-second duration of Sector 1. The time interval (T_1 and T_2), satisfies the reference voltage, but (T_0), fill up the remaining gap in (T_s), as shown in Fig. 3, Fig. 4, and Fig. 5.

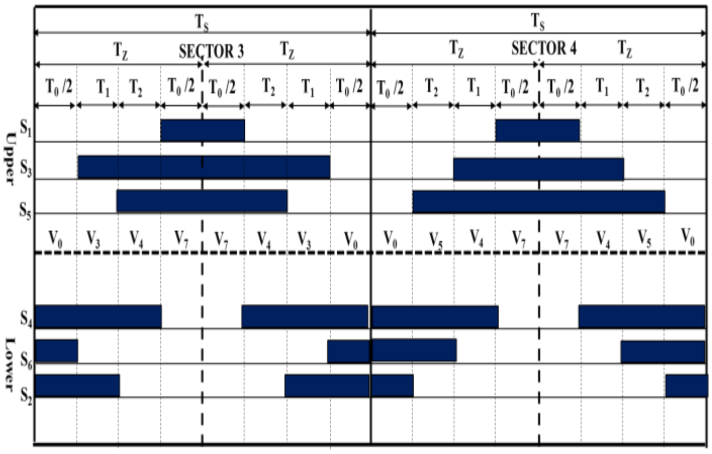


Fig. 3. Switching time of (S1 to S6) at Sector (3, 4)

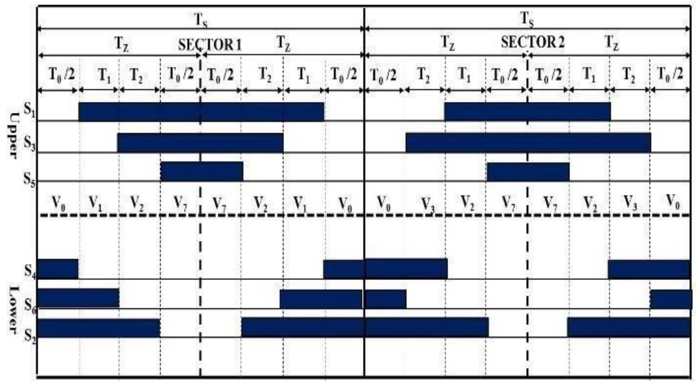


Fig. 4. Switching time of (S1 to S6) at Sector (1, 2)

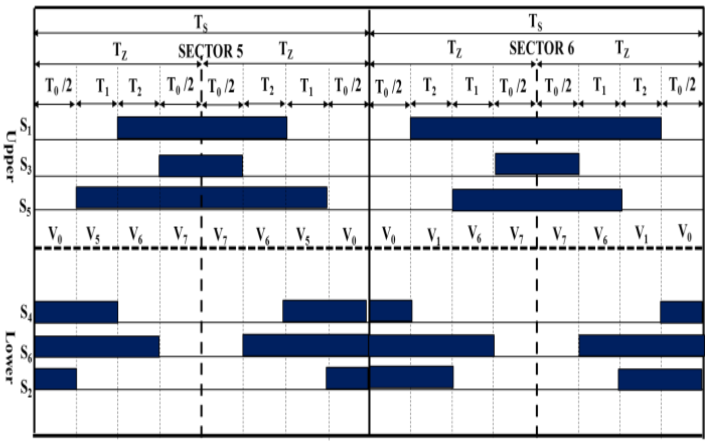


Fig. 5. Switching time of (S1 to S6) at Sector (5, 6).

Using SVPWM-based carriers is efficient, fast and easy. The method is based on comparing the function of pulses with a triangular loop with a user-adjustable frequency (f) configured as a sinusoidal pulse width modulation. SVPWM as a reduced switched carrier since the output rate can be reduced to 33%, it is betterto use SVPWM as a reduced switched carrier, which lowers the temperature of the switch. Table 1 shows the switching characteristics used in SVPWM [14]-[19].

Table 1. Switching of Sector 1 to 6

Sector	Upper Switching (S1 ,S2, S3)	Lower Switching(S2, S4,S6)
1	$S_1 = T_1 + T_2 + \frac{T_0}{2}$ $S_3 = T_2 + \frac{T_0}{2}$ $S_5 = \frac{T_0}{2}$	$S_1 = T_1 + T_2 + \frac{T_0}{2}$ $S_3 = T_2 + \frac{T_0}{2}$ $S_5 = \frac{T_0}{2}$
2	$S_1 = T_1 + \frac{T_0}{2}$ $S_3 = T_1 + T_2 + \frac{T_0}{2}$ $S_5 = \frac{T_0}{2}$	$S_4 = T_2 + \frac{T_0}{2}$ $S_3 = T_1 + T_2 + \frac{T_0}{2}$ $S_5 = \frac{T_0}{2}$
3	$S_1 = \frac{T_0}{2}$ $S_3 = T_1 + \frac{T_0}{2}$ $S_5 = T_1 + T_2 + \frac{T_0}{2}$	$S_4 = T_1 + T_2 + \frac{T_0}{2}$ $S_6 = \frac{T_0}{2}$ $S_2 = T_1 + \frac{T_0}{2}$
4	$S_1 = \frac{T_0}{2}$ $S_3 = T_1 + T_2 \frac{T_0}{2}$ $S_5 = T_2 + \frac{T_0}{2}$	$S_4 = T_1 + T_2 + \frac{T_0}{2}$ $S_6 = T_2 + \frac{T_0}{2}$ $S_2 = \frac{T_0}{2}$
5	$S_{1=} T_2 + \frac{T_0}{2}$ $S_3 = \frac{T_0}{2}$ $S_5 = T_1 + T_2 + \frac{T_0}{2}$	$S_4 = T_1 + \frac{T_0}{2}$ $S_6 = T_1 + T_2 + \frac{T_0}{2}$ $S_2 = \frac{T_0}{2}$
6	$S_1 = T_1 + T_2 + \frac{T_0}{2}$ $S_3 = \frac{T_0}{2}$ $S_5 = T_1 + \frac{T_0}{2}$	$S_4 = \frac{T_0}{2}$ $S_6 = T_1 + T_2 + \frac{T_0}{2}$ $S_2 = T_2 + \frac{T_0}{2}$

4. RESULT ANALYSIS

Asynchronous motor powered SVPWM inverterscan control multiple speeds of the motor. The speed of the 3 HP, 2 shaft, 50 Hz motor can be well controlled by the V/f control method. By changing the frequency of the inverter, the speedcan be changed from 1702 rpm to 188 rpm.

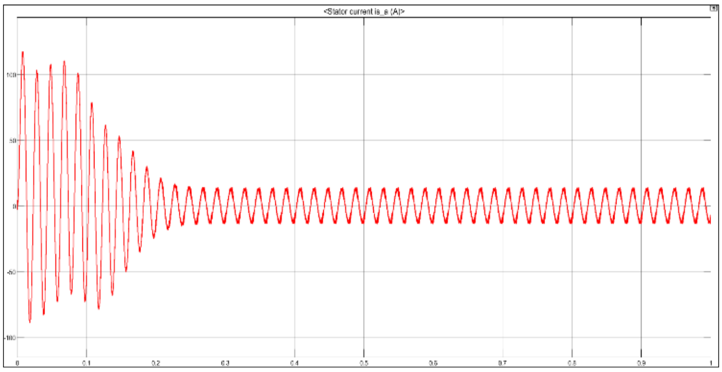


Fig. 6. Stator Current

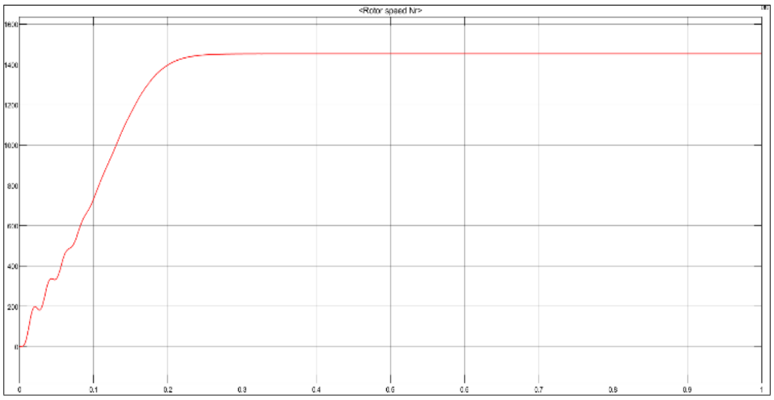


Fig 7. Rotor Speed (rpm)

4.1 Torque Calculation

The parameters are set for a 3 HP, 50Hz machine with two pairs of poles. Its nominal speed is therefore slightly lower than the synchronous speed of 3000 rpm, or ws = 314 rad/sec. The wide range of rotor speed is varied by the inverter frequency. It has been observed from the above waveforms that when the motor frequency is 20 Hz and60 Hz.

$$T = k \times w_s^2$$

The nominal torque of the motor is

$$T = \frac{3 \times 764}{314} = 7.13\ Nm$$

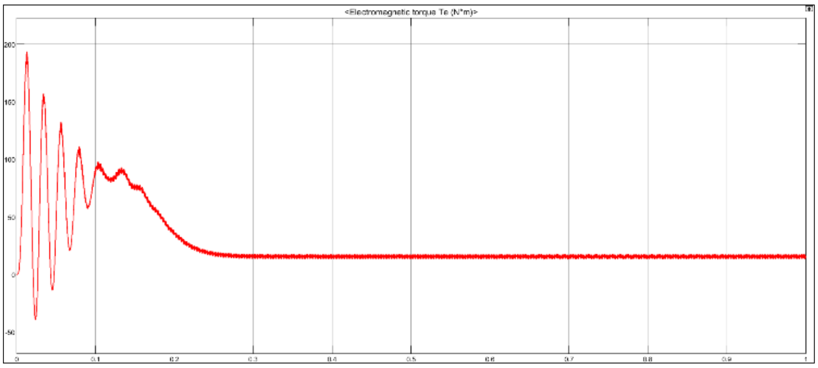


Fig. 8 Electromagnetic Torque

Table 2: Motor output at different frequencies

S. No.	Inverter Frequency (Hz)	Stator Current (A)	Rotor Speed (RPM)	Electromagnetic Torque (N-m)
1.	60	106.75	1702.5	137.067
2.	50	117.38	1452.8	193.499
3.	40	129.84	1181.3	271.815
4.	30	143.94	953.8	346.576
5.	20	154.55	820.1	332.513
6.	10	150.31	458.7	204.574
7.	5	186.74	188.6	100.395

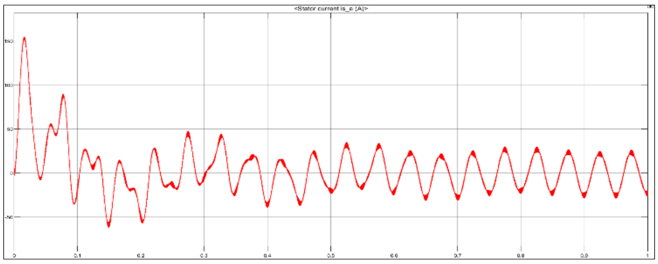


Fig 9. Stator current for f = 20 Hz

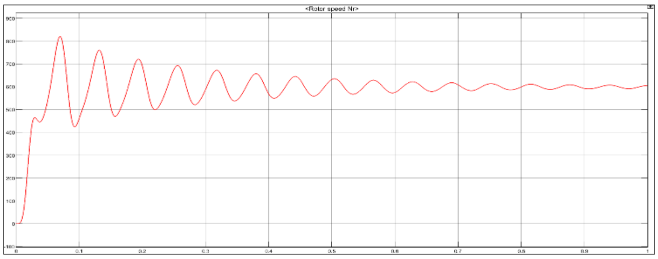


Fig 10. Rotor Speed for f =20 Hz

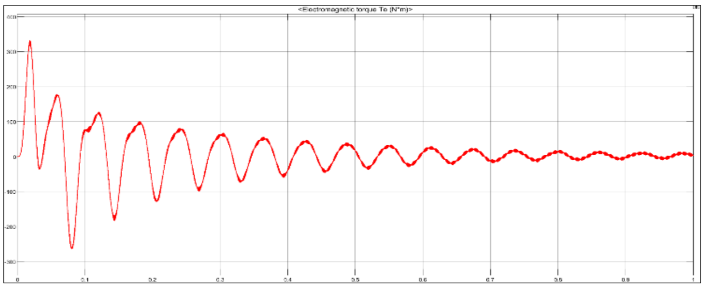


Fig 11. Electromagnetic torque for f = 20 Hz

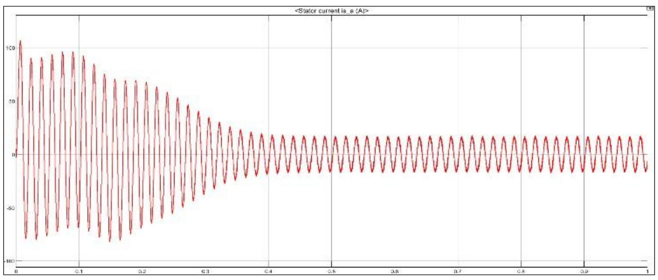


Fig 12. Stator current for f = 60 Hz

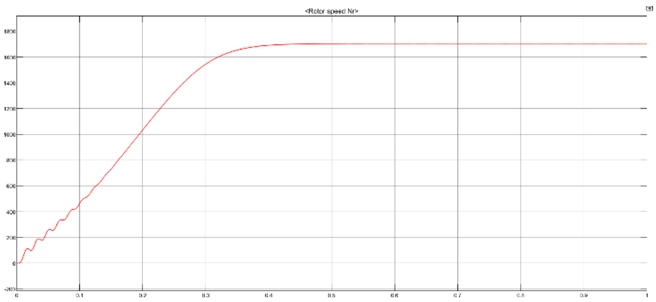


Fig 13. Rotor Speed for f = 60 Hz

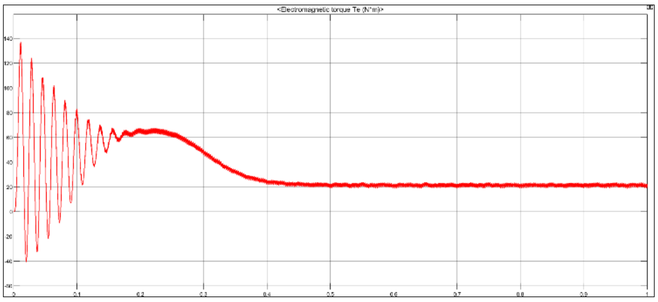


Fig 14. Electromagnetic torque for f = 60 Hz

4. Harmonic Analysis

The harmonic analysis has been done for output stator current and input line-to-line voltage. The THD in stator current when maximum frequencyis 5 KHz is shown in Fig. 15. The THD in input voltage when maximum frequency is 5 KHz is shown in figure 17.

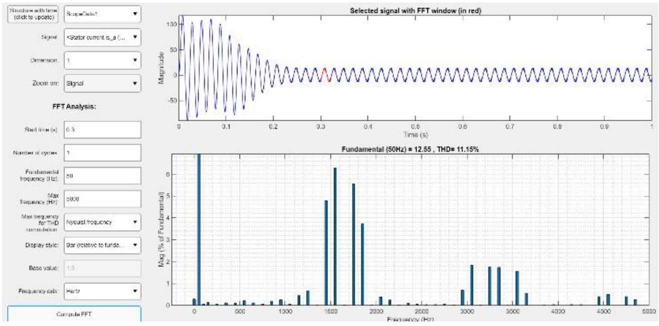


Fig. 15. THD in stator current when max. Frequency is 5 kHz

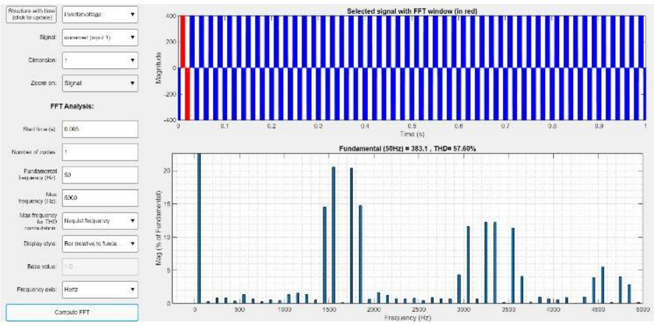


Fig. 16. THD in input voltage when max. Frequency is 5 kHz

5. Conclusions

In this study, a closed loop asynchronous motor fed PWM inverter model is proposed and developed in the latest version of Matlab/ Simulink. Behavioral changesin the motor system are examined. From the results obtained with the closed model, it was seen that the torque control method and the closed-loop model gave better results in reducing harmonics. The field control method is not only used to control induction motors as it has some of the disadvantages described earlier. Extensive simulation of a 3HP, 4-pole, and 50 Hz induction motor has been carried out and the simulation results provide the ultimate solution for speed control with reduced harmonics. Despite the rapid developments in electric motors and motor drivers; High speed asynchronous motors can be used as variable speed asynchronous drive using static electricity. For variable speed asynchronous motors, the motor must be driven by a static generator rather than being directly connected to a sinusoidal generator.Therefore, various speeds can be effectively controlledusing the V/f speed control method. The variable behavior of the motor is observed and the maximum speed can be fully controlled by the variable frequencyinverter. This model will be used for many future applications. Different motors from this model can be tested using different digital signal (DSP) techniques. Using a squirrel cage induction motor with an electric generator has significant cost and energy efficiencycompared to commercial solutions that require different speeds. However, PWM inverters can affect motor operation and cause major power lines to be interrupted. Therefore, it is necessary to understand the whole power system and the interaction of its parts (such as power lines - frequency inverter - asynchronous motor - load).

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