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MATLAB Simulation of Closed-Loop Speed Control of Three-Phase Induction Motor using Slip-Control Method and Space Vector PWM Technique

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***Abstract:-* MATLAB simulations to find out which is the better method to control the speed of a Three-Phase Induction Motor using a Three-Phase Inverter between SPWM (Sine Pulse Width Modulation) and SVPWM had been carried out. For this project, a Three-Phase Inverter, with three different methods was simulated. Study on Space Vector Pulse Width Modulation was carried out and then its simulation for Open-Loop and Closed-Loop Control was performed. The aim of the project as mention above is to control the speed of a Three-Phase Induction motor with the help of a Three-Phase Inverter. It was noted that Sine Pulse Width Modulation was better than the normal pulse generator as it gave us lower Total Harmonic Distortion of load current and by using Space Vector Pulse Width Modulation we get an even lower Total Harmonic Distortion of load current.**

I. INTRODUCTION

An inverter is a power electronic device or circuitry that changes direct current to alternating current. The resulting AC (Alternating Current) frequency obtained depends on the device employed. The input voltage, output voltage and frequency, and overall power handling depend on the design of the specific device or circuitry. The inverter does not produce any power; it is provided by the DC (Direct Current) source. Power inverters are primarily used in electrical power applications where high currents and voltages are present; circuits that perform the same function for electronic signals. For this project, MATLAB simulations for controlling the speed of the Three-Phase Induction Motor using a Three-Phase Inverter were observed. It will be observed that simulations of the Three-Phase Inverter with different methods. i) Open-Loop and ii) Closed-Loop for an inverter operated by Space Vector Pulse Width Modulation (SVPWM). It was observed that SVPWM gives us less Total Harmonic Distortion (THD) value than previously observed Sine Pulse Width Modulation which is desirable and that Closed-Loop Control is better because the parameters can be changed in real-time and it changes the working of the motor without having to stop the simulation repeatedly.

II. DESIGN OF SPACE VECTOR PULSE WIDTH MODULATION

An inverter is an electronic device that converts Direct Current to Alternating Current. For it, semiconductor switches are used for switching purpose. Control of output of the inverter is done by giving a different type of pulse to switch for switching action. [1, 2]

Depending on the number of phases available at the output, there are two types of the inverter. They are single-phase and three-phase inverter.

For the control of the inverter different type of pulse is used and some of the pulse control methods are as follows

- Single-Pulse Control
- Multi-Pulse Control
- Sine Pulse Width Modulation
- Space Vector Pulse Width Modulation

Here a model is designed for a system for the Speed Control of the Three-Phase Induction Motor through a Three-Phase Inverter. For this, we will use Space Vector Pulse Width Modulation for controlling the output of the inverter.

A) Quality of Inverter

The output of the inverter is not a pure sine wave but it contains harmonics in addition to the fundamental components. The presence of harmonics in the output leads to the deficient performance of the inverter as well as reduced system efficiency. Therefore the quality of the inverter depends on the harmonics. These harmonics can be reduced by different type of modulation techniques as well as by designing a filter to filter out the harmonics of higher frequencies. To improve the quality of the inverter we are using the Space Vector Pulse Width Modulation technique. [1, 2]

B) Types of Pulse Width Modulations

The technique of PWM in an inverter comprises of two signals. One signal is for the reference and the other will be

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the carrier. The pulse required for switching the mode of the inverter can be generated by the comparing those two signals.

- Single Pulse Width Modulation

For every half cycle, there is only one pulse available to control the technique. The square wave signal will be for reference and a triangular wave will be the carrier. The gate pulse generated will be the result of the comparison of the carrier and the reference signals. Higher harmonics is the major drawback of this technique.

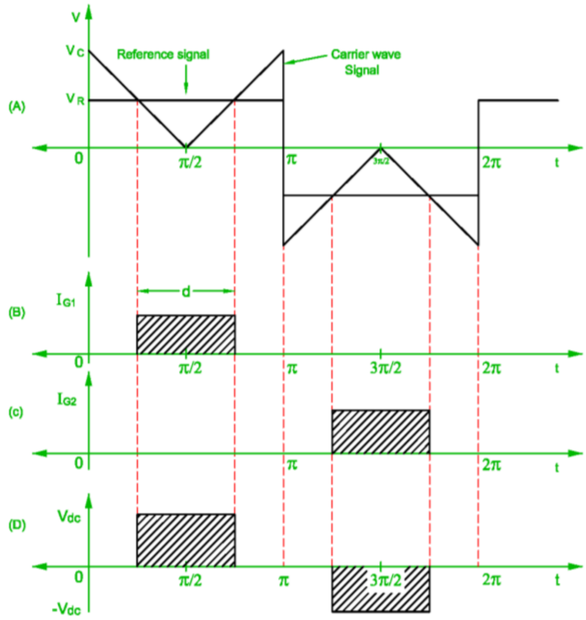

Fig. 1 Waveform of Single Pulse Width Modulation [3]

- Multiple Pulse Width Modulation

MPWM technique is used to overcome the drawback of single pulse width modulation. Instead of a single pulse, multiple pulses are used for every half cycle of the voltage at the output. The frequency at the output is controlled by controlling the frequency of the carrier.

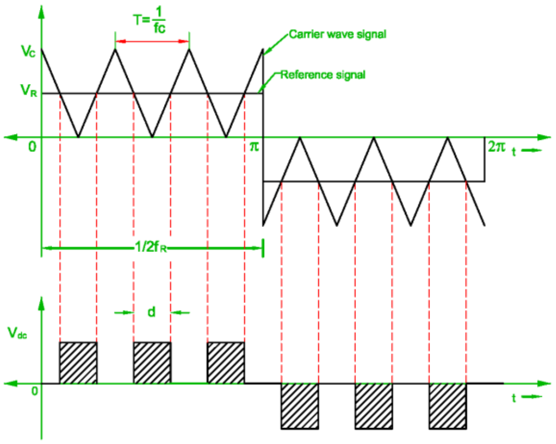

Fig. 2 Waveform of Multi Pulse Width Modulation [3]

- Sinusoidal Pulse Width Modulation

In this type of PWM technique, instead of a square wave, a sine wave is used as a reference and the carrier will be a triangular wave. The sine wave will be the output and its Root Mean Square (RMS) value of voltage is controlled by the modulation index.

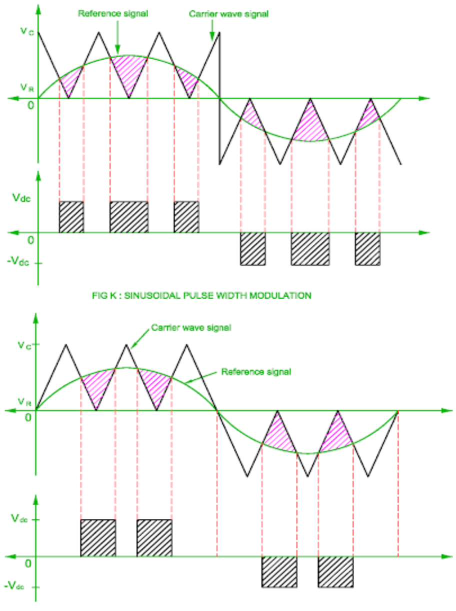

Fig. 3 Waveform of Sinusoidal Pulse Width Modulation [3]

C) Space Vector Pulse Width Modulation

Space Vector Pulse Width modulation (SVPWM) is an algorithm for the control of pulse width modulation for the control of the output of the inverter. This method is based on the theory of rotating MMF of machines that is resultant MMF of Three-phase system is rotating MMF with constant magnitude and direction at every instant of time. Here the variable of Three-Phase is represented by a single vector.

Resultant vector of load phase voltage and current are

$$V_r(t)=\frac{2}{3}\left[V_{an}(t)+V_{bn}(t)e^{\frac{j2\pi}{3}}+V_{cn}(t)e^{\frac{j4\pi}{3}}\right]$$

(1)

$$I_r(t)=\frac{2}{3}\left[I_a(t)+I_b(t)e^{\frac{j2\pi}{3}}+I_c(t)e^{\frac{j4\pi}{3}}\right]$$

(2)

The phase voltages for the eight switching pattern combinations may be determined and then converted into the stator two phase reference frames. Six non-zero voltage vectors and two zero voltage vectors come from this change. The non-zero vectors are used to make the axis of a hexagon with six sectors (V1). Any adjacent two non-zero vectors form a 60 electrical degree angle.

The zero vectors are at the origin, and the motor receives a zero voltage vector. The maximum output voltage is located at the envelope of the hexagon created by the non-zero vectors. Controlling the stator currents represented by a vector is what SVPWM is all about. This control is based on projections, which convert a three-phase time and speed dependent system into a two-coordinate time invariant system (d and q co-ordinates).

There are 2^3=8 combinations for switches

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State	S1	S3	S5	Phase Voltage			V
				V_{an}	V_{bn}	V_{cn}	
0	0	0	0	0	0	0	0
1	0	0	1	$\frac{2V_{dc}}{3}$	$-\frac{V_{dc}}{3}$	$-\frac{V_{dc}}{3}$	$\frac{2}{3}V_{dc}\angle 0$
2	0	1	1	$\frac{V_{dc}}{3}$	$\frac{V_{dc}}{3}$	$-\frac{2V_{dc}}{3}$	$\frac{2}{3}V_{dc}\angle 60$
3	0	1	0	$-\frac{V_{dc}}{3}$	$\frac{2V_{dc}}{3}$	$-\frac{V_{dc}}{3}$	$\frac{2}{3}V_{dc}\angle 120$
4	1	1	0	$-\frac{2V_{dc}}{3}$	$\frac{V_{dc}}{3}$	$\frac{V_{dc}}{3}$	$\frac{2}{3}V_{dc}\angle 180$
5	1	0	0	$-\frac{V_{dc}}{3}$	$-\frac{V_{dc}}{3}$	$\frac{2V_{dc}}{3}$	$\frac{2}{3}V_{dc}\angle 240$
6	1	0	1	$\frac{V_{dc}}{3}$	$-\frac{2V_{dc}}{3}$	$\frac{V_{dc}}{3}$	$\frac{2}{3}V_{dc}\angle 300$
7	1	1	1	0	0	0	0

Fig. 4 Switching Sequence in Binary Digits and their corresponding Phase Voltages [6]

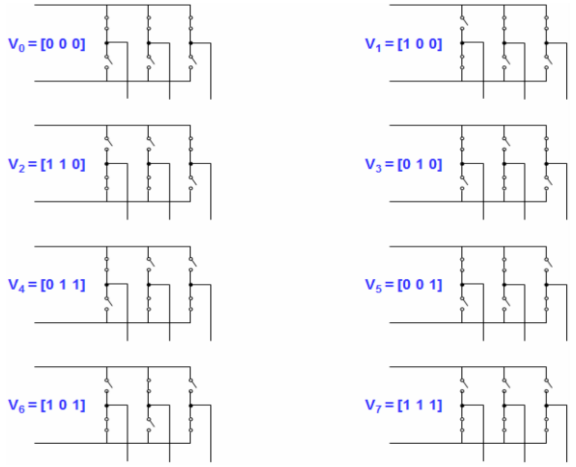

Fig. 5 Switching pattern according to the Binary Digits [4]

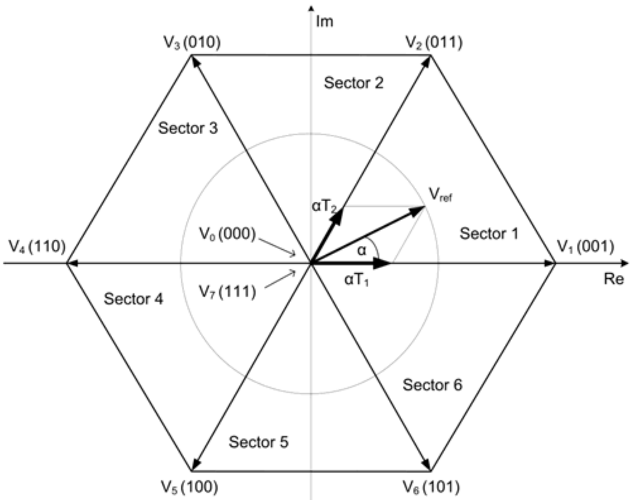

Fig.6 Locus of Space Vector and its Sectors [6]

It is seen that in 8 vectors there are two inactive vectors (000 & 111) because the output is not available in this state and 6 active vectors when output is available. It can also be seen that V_{ref}, which is the resultant vector, is rotating with constant magnitude.

D) DETERMINATION OF REFERENCE ANGLE α

$$V_d = V_{an} * V_{bn} * \cos 60 * V_{cn} * \cos 60 \quad (3)$$

$$V_d = V_{an} - \left(\frac{1}{2} * V_{bn}\right) - \left(\frac{1}{2} * V_{cn}\right) \quad (4)$$

Similarly,

$$V_q = V_{an} + \left(\frac{\sqrt{3}}{2} * V_{bn}\right) - \left(\frac{\sqrt{3}}{2} * V_{cn}\right) \quad (5)$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (6)$$

$$\alpha = \tan^{-1}\left(\frac{V_d}{V_q}\right) \quad (7)$$

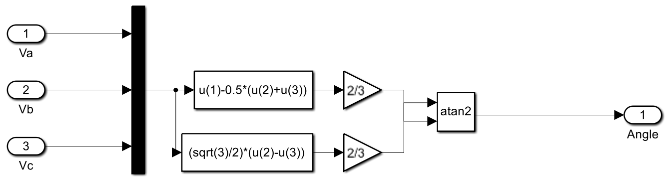

Fig. 7 MATLAB circuit to determine the reference angle α

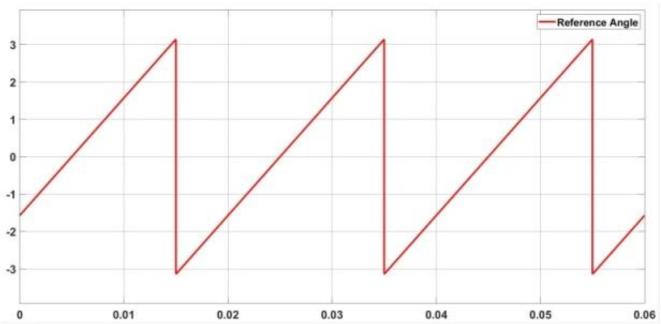

Fig. 8 Waveform of reference angle α

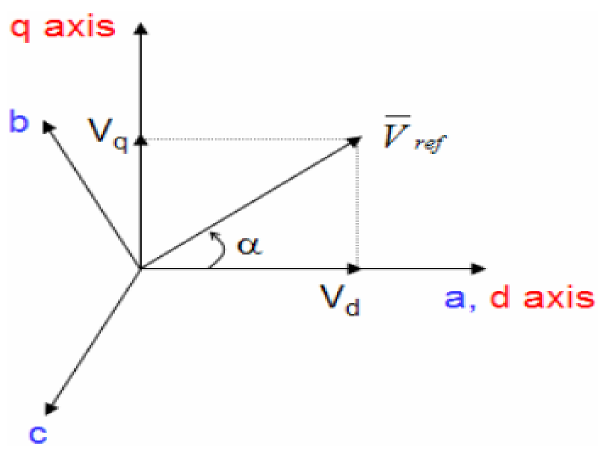

Fig. 9 Vector Diagram of Reference Vector with d and q axiss [7]

E) DETERMINATION OF SECTOR

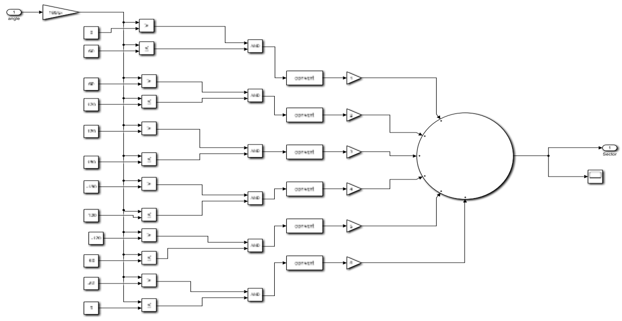

Fig. 10 MATLAB circuit to determine the sectors

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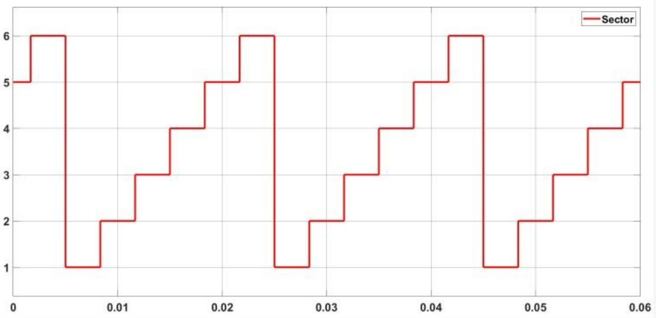

Fig.11 Waveform of determining the sectors

F) DETERMINATION OF TIME OF SWITCHING (T_1, T_2, T_0)

$$T_Z \cdot V_{ref} = (T_1 \cdot \overline{V}_1 + T_2 \cdot \overline{V}_2) \quad (8)$$

$$T_1 = T_Z * a * \frac{\left(\sin\left(\frac{\pi}{3} - \alpha\right)\right)}{\sin\left(\frac{\pi}{3}\right)} \quad (9)$$

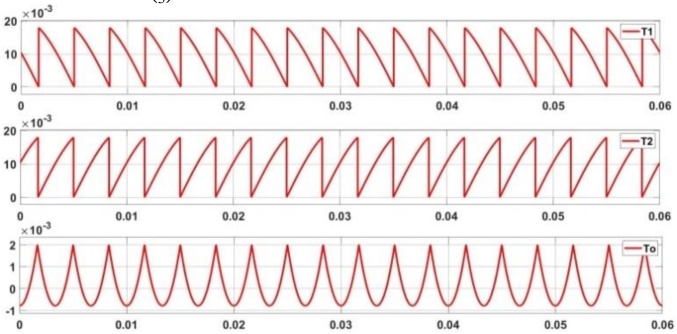

Fig. 13 Waveforms of switching time (T_1, T_2, and T_0)

G) SWITCHING TIME OF EACH SEMICONDUCTOR SWITCH ($S_1 – S_6$)

Sector	Upper Switches (S_1, S_3, S_5)	Lower Switches (S_4, S_6, S_2)
1	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_0/2$ $S_6 = T_1 + T_0/2$ $S_2 = T_1+T_2+T_0/2$
2	$S_1 = T_1 + T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_0/2$	$S_4 = T_2 + T_0/2$ $S_6 = T_0/2$ $S_2 = T_1+T_2+T_0/2$
3	$S_1 = T_0/2$ $S_3 = T_1 + T_2 + T_0/2$ $S_5 = T_2 + T_0/2$	$S_4 = T_1+T_2+T_0/2$ $S_6 = T_0/2$ $S_2 = T_1 + T_0/2$
4	$S_1 = T_0/2$ $S_3 = T_1 + T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1+T_2+T_0/2$ $S_6 = T_2 + T_0/2$ $S_2 = T_0/2$
5	$S_1 = T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_2 + T_0/2$	$S_4 = T_1 + T_0/2$ $S_6 = T_1+T_2+T_0/2$ $S_2 = T_0/2$
6	$S_1 = T_1 + T_2 + T_0/2$ $S_3 = T_0/2$ $S_5 = T_1 + T_0/2$	$S_4 = T_0/2$ $S_6 = T_1+T_2+T_0/2$ $S_2 = T_2 + T_0/2$

Fig.14 Switching time according to the Sectors [5]

The output of the SVPWM inverter depends on the modulation index. The modulation index can be defined as the largest radius of the inscribed circle in the space vectors

$$T_2 = T_Z * a * \frac{\sin \alpha}{\sin\frac{\pi}{3}} \quad (10)$$

$$T_0 = T_Z - (T_1 + T_2) \quad (11)$$

Where T_1 and T_2 are time of adjacent vector in sectors and T_0 is time taken by zero vectors. T_Z is the total time of all vectors.

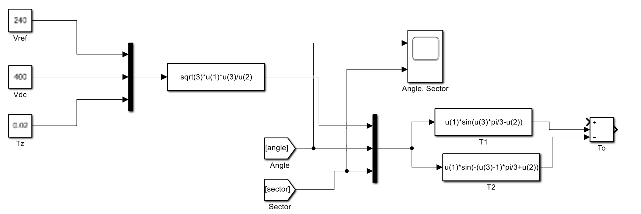

Fig. 12 MATLAB circuit diagram to determine switching time (T_1, T_2, T_0)

hexagon. The modulation index range from 0 - 1. The reference vector is sampled at regular intervals of time. During a sampling interval T_Z, V_{ref} and α are held constant. The reciprocal of T_Z is called the sampling frequency. The ratio f_Z/f, where f is the inverter output frequency, is called the frequency modulation index and decides the inverter output voltage harmonic spectrum as well as the device switching frequency.

H) GENERATION OF MW WAVEFORM

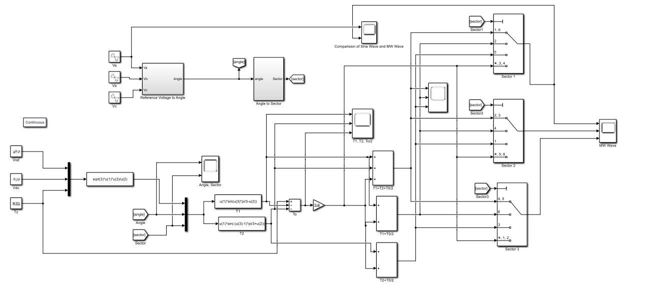
Fig.15 MATLAB circuit to generate MW Pulses

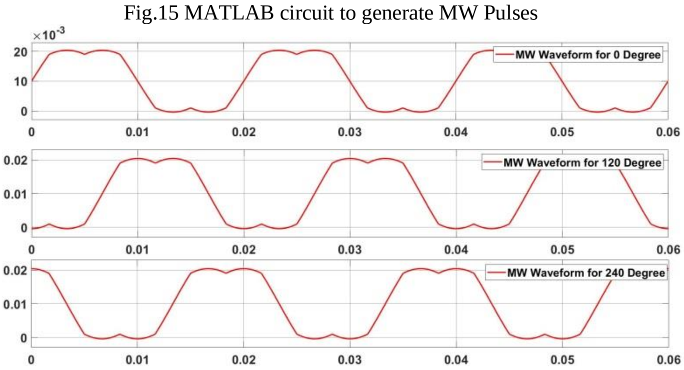

Fig.16 Waveforms of MW Pulses

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I) SVPWM INVERTER

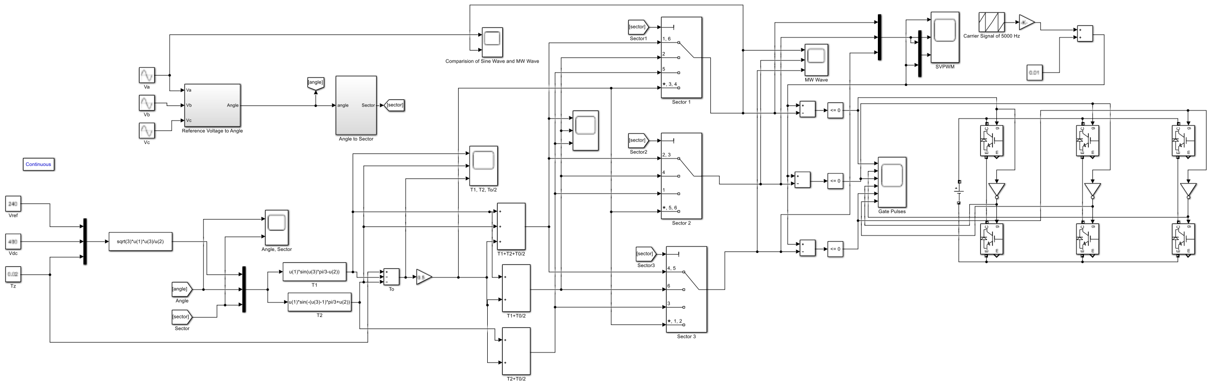

Fig. 17 MATLAB circuit of Three-Phase Inverter using SVPWM

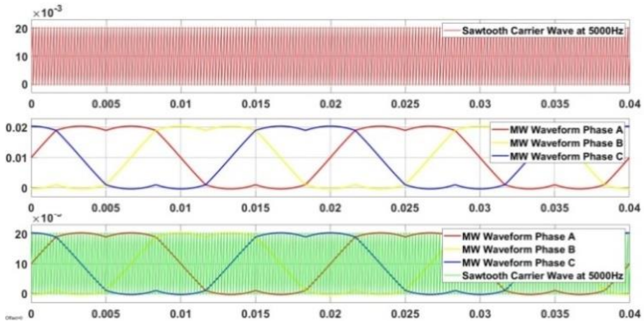

Fig. 18 Waveforms of carrier wave of 10k Hz compared with Three-Phase MW Waves of 50 Hz

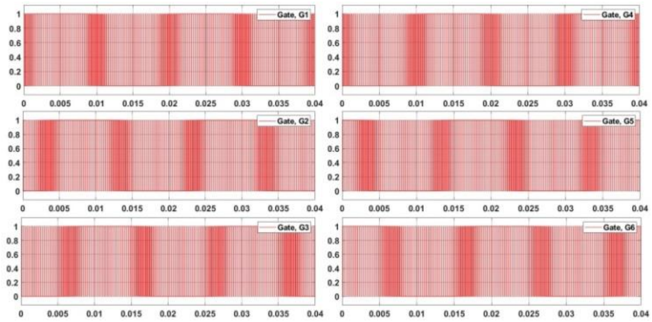

Fig. 19 Gate Pulses using SVPWM

J) OPEN-LOOP SPEED CONTROL OF THREE-PHASE INDUCTION MOTOR USING SVPWM

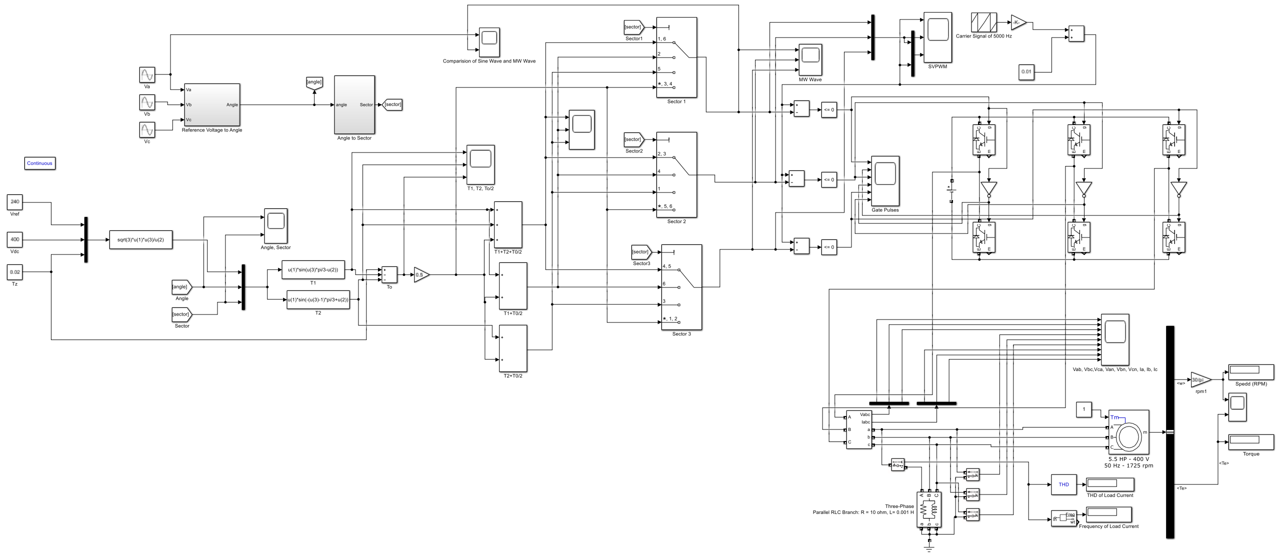

Fig. 20 MATLAB circuit of Open-Loop Speed Control of Three-Phase Induction Motor using SVPWM

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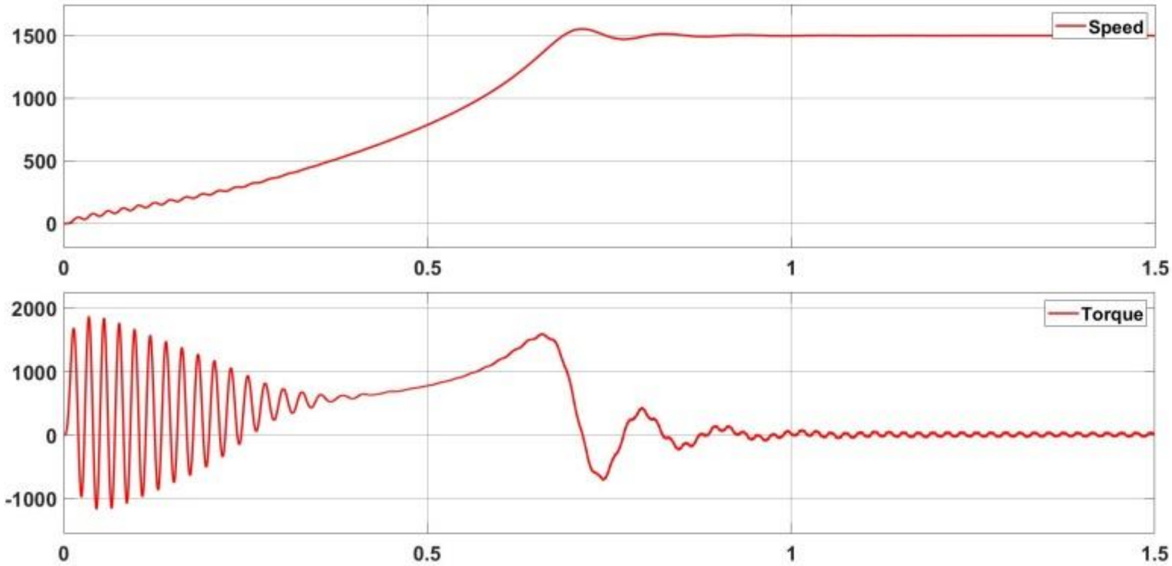

Fig. 21 Waveforms of Speed and Torque of Open-Loop Speed Control of Three-Phase Induction Motor using SVPWM

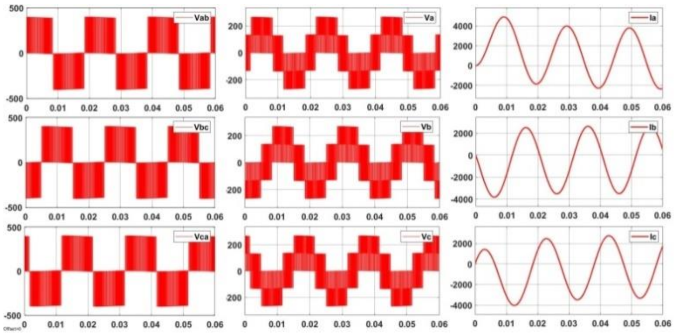

Fig. 22 Waveforms of Line Voltage, Phase Voltage, and Line current of Open-Loop Speed Control of Three-Phase Induction Motor using SVPWM

K) CLOSED-LOOP SPEED CONTROL OF THREE-PHASE INDUCTION MOTOR USING SVPWM

The output of the inverter back to the input so that the system can compare it with the reference input and adjusts itself accordingly. Here we are using the speed of the machine in RPM to feedback into the machine.

- Proportionality constant, K_p = 0.0001
- Integral constant, K_i = 0.1

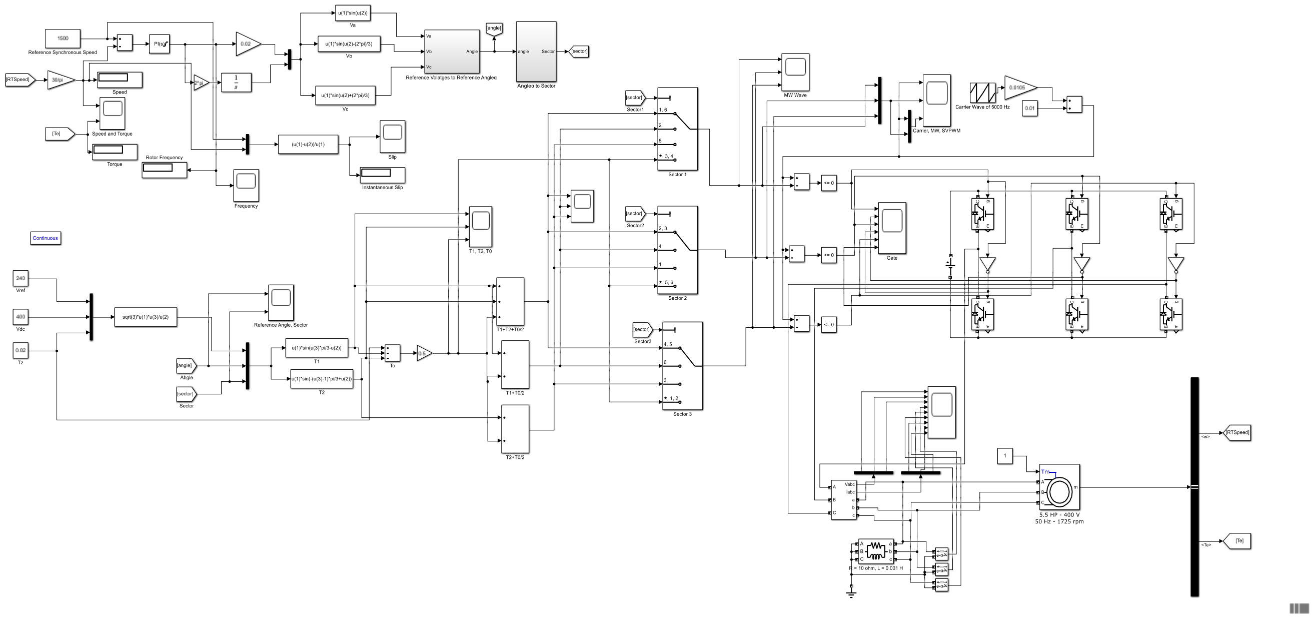

Fig. 23 MATLAB circuit of Closed-Loop Speed Control of Three-Phase Induction Motor using SVPWM

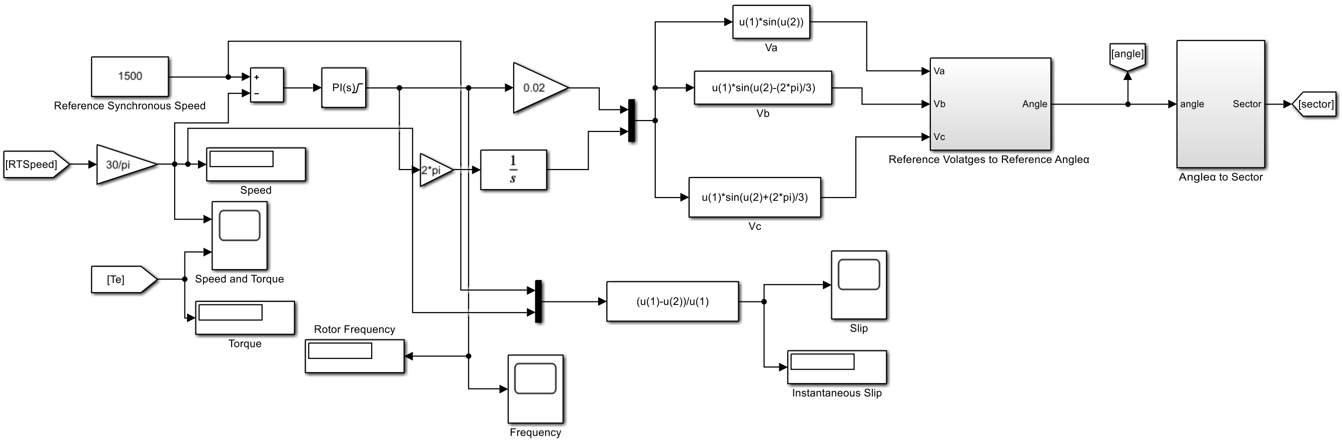

Fig. 24 Feedback of Real Time Rotor Speed given to the PI Controller after comparing it with of Reference Synchronous Speed which in turn controls the Frequency of the Inverter.

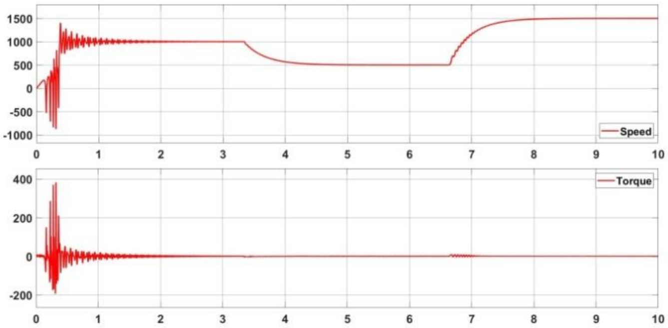

Fig.25 Waveforms of Speed and Torque of Closed-Loop Speed Control of Three-Phase Induction Motor at N_{Sref} = 1000, 500, 1500 RPM

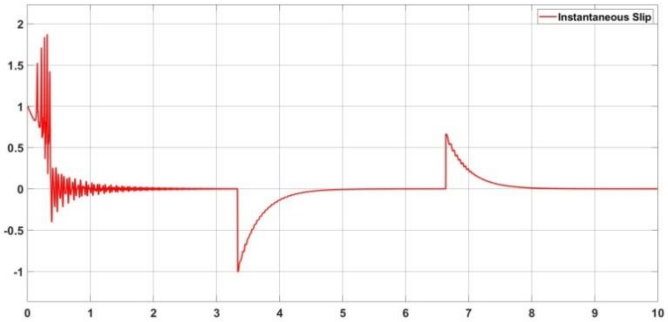

Fig.26 Waveform of Instantaneous Slip at N_{Sref}=1000, 500, 1500 RPM

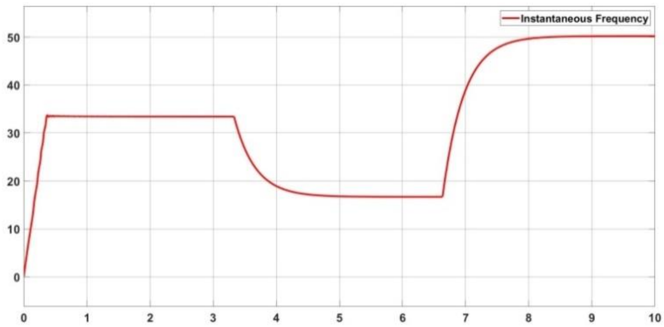

Fig.27 Waveform of Instantaneous Frequency N_{Sref}=1000, 500, 1500 RPM

L) COMPARISION OF TOTAL HARMONIC DISTORTION OF LOAD CURRENT

Table 1
Comparison of Total Harmonic Distortion of Phase A Load Current

Pulse Width Modulation	Total Harmonic Distortion
Square	28.97%
Sinusoidal	16.62%
Space Vector	1.9%

M) ADVANTAGES OF SPACE VECTOR PULSE WIDTH MODULATION

- The space vector modulation technique has the advantage of an optimal output and decreases the harmonic content of the output voltage/current.
- 90.7% of the fundamental component of the square wave is available in SVPWM as compared to 78.5% of sine PWM. Thus, the fundamental component is increased in this method so it can be said that harmonics are decreased by using this method [8].
- In comparison to other PWM approaches, SVPWM can be efficiently done in a few microseconds and achieve similar outcomes.
- SVPWM (space vector PWM) allows for simple digital implementation and greater dc bus efficiency.

N) DISADVANTAGES OF SPACE VECTOR PULSE WIDTH MODULATION

- Switching losses are more in this method
- Complex Switching connections
- Generation of MW wave is tedious

III. FUTURE SCOPE

- Finding other methods to improve the THD and in turn improving the speed control of an Induction motor
- Implementing these in the real life by making working devices
- Make changes to the current model and try to make it better
- Removing selected harmonics.

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IV. SUMMARY

This project is aimed to control the speed of a Three-Phase Induction Motor using a Three-Phase Inverter. This is a common arrangement in the field of power electronics. After performing this experiment, we learn that SVPWM has a low value of THD. On comparison with SPWM, the value of THD is noted to be lower in case of SVPWM. This gives us a direction conclusion i.e. Closed-Loop, SVPWM method is the most suitable method to control the speed as Closed-Loop allows us to change the parameters in real time without having to stop the process repeatedly.

V. CONCLUSION

The main objective was to find a better technique to control the speed of a Three-Phase Induction Motor. From the results of this experiment it is evident that a Closed-Loop SVPWM system is one of the best methods to control the speed of a Three-Phase Induction Motor using a Three-Phase Inverter.

ACKNOWLEDGEMENT

We are overwhelmed in all humbleness and gratefulness to acknowledge our depth to all those who have helped us to put these ideas, well above the level of simplicity and into something concrete.

We would like to express our special thanks of gratitude to our guide Mr Ketan Bhavsar, Assistant Professor, Electrical Engineering Department, and our Head of the Department, Dr Prakruti Shah who gave us the excellent opportunity to do this wonderful project on the topic Speed Control of a Three-Phase Inverter, we came to know about so many new things we are thankful to him. Any attempt at any level cannot be satisfactorily completed without the support and guidance of our parents and friends.

REFERENCE

[1] Rashid, M. H. (2014). Power electronics handbook: Devices, circuits, and applications (Fourth ed.). Noida, Uttar Pradesh: Pearson.

[2] Umanand, L. (2009). Power electronics: Essentials and applications. New Delhi, New Delhi: Wiley India Pvt.

[3] Revolution, E. (n.d.). Pulse Width Modulation (PWM). https://www.myelectrical2015.com/2017/07/pulse-width-modulation-of-inverter.html

[4] N. R. Govinthasamy, R. Arungopal, S. Haridharan, K. Prabakaran and T. Rajashekar, "Space vector PWM based inverter," 2017 International Conference on Innovations in Green Energy and Healthcare Technologies (IGEHT), 2017, pp. 1-5, Doi: 10.1109/IGEHT.2017.8094087.

[5] How to determine time needed to stay in a Voltage vector state in Space Vector PWM for 3 PHASE INVERTER? (1968, April 01). Retrieved May09,2021,fromhttps://electronics.stackexchange.com/questions/448661/how-to-determine-time-needed-to-stay-in-a-voltage-vector-state-in-space-vector-pRahman, T., Motakabber, S., & Ibrahimy, M. (2016). Design of a Switching Mode Three Phase Inverter. 2016 International Conference on Computer and Communication Engineering (ICCCE). doi:10.1109/iccce.2016.43

[6] Space vector modulation theory. pscad online help system. (n.d.). https://www.pscad.com/webhelp/ol-help.htm#Master_Library_Models/HVDC_and_FACTS/Space_Vector_Modulation/SVM_Theory.htm.

[7] Thummala, S., Swarnalatha, E., Suramanjhari, B. U., & Kumar, N. S. (2014). Microcontroller Based Efficient Multilevel Inverter Using SVPWM Technique. IOSR Journal of Electronics and Communication Engineering, 9(3), 127–133. https://doi.org/10.9790/2834-0934127133

[8] Avinash Mishra, R. sen, S. save (2021). Space Vector Pulse Width Modulation. Ijser.org. Retrieved 24 April 2021, from https://www.ijser.org/paper/Space-Vector-Pulse-Width-Modulation.html.