# Modeling and Simulation of Frequency Converter Used In Speed Control of Asynchronous Motor

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*Abstract*- Controlling the speed of the Induction Motor is very essential in today's industry. Conventionally Gear box is used for speed control which consumes more energy. This Paper presents the Modeling and Simulation of frequency converter used for speed control of asynchronous motor through digital approach which has high reliability and energy conservation by using MATLAB/ SimulinkTM. The Frequency Converter is mainly used as variable frequency source to adjust the speed of asynchronous motors. The Frequency Converter circuit consists of three-phase Rectifier, IGBT module, DC link and the three phase inverter. The Transistor three-phase inverter converts the DC voltage into variable voltage and variable frequency (VVVF) power source. The commonly used Capacitors bank is replaced by the LC filter. The Inductor and the capacitor are used to reduce switching stresses so that during power up the voltage source inverter is protected by the inrush currents. The circuit is simulated and output results are obtained.

*Index Terms*- Asynchronous Motor, Pulse Width Modulation (PWM), MATLAB/SimulinkTM, variable voltage and variable frequency (VVVF) power source

## I. INTRODUCTION

The three phase asynchronous motors are the primary movers in all the industrial applications in each stage of processing and manufacturing. Generally these asynchronous motors are implemented due to low cost and reliability. This converter transforms fixed frequency of power line into constant DC voltage via diode three-phase rectifier. Then the inverter converts fixed frequency of power line into variable voltage and variable frequency (VVVF) power source. A VVVF AC drive is a power electronic controller used to control the speed of 3hp AC motors (synchronous or induction) by varying the frequency and the voltage applied to the motor terminals.

Moreover this converter can keep high power factor and it greatly reduces the interference of variable frequency supply to the network power line. The project is simulated using MATLAB/ SimulinkTM by using different components such as three-phase rectifier, DC link and the IGBT module which constitute the inverter operation. The inverter has to produce a motor current within acceptable level of current ripple, which should be lower than 5%for most of the applications. A MOSFET can be employed for low power (up to a bound of few KW's) and work efficiently up to 50 KHz. This handles low inductance up to few hundred μH. In order to sustain high power levels such as tens of kW's, IGBT modules are used as switching devices and can switch up to 20 kHz. These are available in two- or six-pack modules. The modulation technique used here is the Pulse Width Modulation (PWM).

## II. PROTOTYPE MODELLING

The prototype mainly constitutes of Three-phase Rectifier, Inverter DC link, Three-phase Inverter and asynchronous motor. The design aspect consists of:

### A. Three Phase Rectifier

Rectifiers are often found serving as components of DC power supply and high-voltage direct current power transmission system. The input three phase voltage (1)-(3) are given below:

$$Vsp = Vs\,sin(\omega t) \tag{1}$$
$$Vsq = Vs\,sin\left(\omega t - \frac{2\pi}{3}\right) \tag{2}$$
$$Vsr = Vs\,sin\left(\omega t + \frac{2\pi}{3}\right) \tag{3}$$

Where the Vsp, Vsq, Vsr are the input voltages to the three phase rectifier with magnitude Vs and angular frequency ω and the above equations can be approximated to

$$Vpn \approx Vpn1 = Vpeak\ sin(\omega t - \emptyset) \tag{4}$$
$$Vqn \approx Vqn1 = Vpeak\ sin(\omega t - \emptyset - \frac{2\pi}{3}) \tag{5}$$
$$Vrn \approx Vrn1 = Vpeak\ sin(\omega t - \emptyset + \frac{2\pi}{3}) \tag{6}$$

Where Vpeak = (4)/ (π) (Vo/2+ Vd) and Vo is the constant-voltage output of the rectifier and φ is the phase angle between each voltage source (Vsp; Vsq; Vsr) and their line-to-neutral voltages are Vpn, Vqn, Vrn for each phase. From the above given (4)-(6) equations the current equations can be as (7)-(9) as shown below and the phase currents will have the form

$$Ia \approx Ip1 = Is1\ sin(\omega t - \emptyset) \tag{7}$$
$$Ib \approx Iq1 = Is1\ sin(\omega t - \emptyset - \frac{2\pi}{3}) \tag{8}$$
$$Ic \approx Ir1 = Is1\ sin(\omega t - \emptyset + \frac{2\pi}{3}) \tag{9}$$

The line-to-neutral voltages Vpn1, Vqn1, Vrn1 are in phase with their respective line currents ia1, ib1, and ic1.The phasor of the line current in phase 'a' is given by:

$$Ia = \frac{Vs}{\sqrt{(R)^2+(\omega Ls)^2}}e^{-j\tan-1(\omega\,Ls/R)} = Is1\ e^{-j\phi}$$

$$(10)$$

The average and root-mean-square output voltages of an ideal single-phase full-wave rectifier are:

$$Vdc = Vav = \frac{2Vpeak}{\pi}$$

$$Vrms = \frac{Vpeak}{\sqrt{2}}$$

For a three-phase full-wave rectifier the average output voltage is

$$Vdc = Vav = \frac{(3\sqrt{3})Vpeak}{\pi}\cos\alpha$$

Where:

$\alpha$ = firing angle of the thyristor (0 if diodes are used to perform rectification)

The rectifier is modeled with the following parameters:

Table 1: rectifier parameters

| No of Bridges | 3 |
|---|---|
| Snubber Resistance | 100Ω |
| Snubber Capacitance | 0.1e-6 F |
| Device used | Diodes |
| Forward Voltage | 0.8V |
| Ron | 1e-3 Ω |

### B. DC Link

An AC-AC converter with approximately sinusoidal input currents and bidirectional power flow can be realized by coupling a rectifier and a PWM inverter to the DC-link. The DC-link quantity is then impressed by an energy storage element that is common to both stages, which is a capacitor C for the voltage DC-link or an inductor L for the current DC-link.

Due to the DC-link storage element, there is the advantage that both converter stages are to a large extent decoupled for control purposes. Furthermore, a constant, AC line independent input quantity exists for the PWM inverter stage, which results in high utilization of the converter's power capability. On the other hand, the DC-link energy storage element has a relatively large physical volume, and when electrolytic capacitors are used, in the case of a voltage DC-link, there is potentially a reduced system lifetime. The large electrolytic capacitors can be replaced by the LC Filter. During the switching of the inverter the higher order harmonics are removed by the LC Filter.

The LC Filter costs up to one sixth of the electrolytic capacitor bank and also occupies less space. Another advantage of the LC Filter circuit is that it shields the Voltage source inverter from current inrush during power up. When the DC link current is continuous and if U is the RMS value of line-to-line voltage of mains then the DC link voltage will be the solution of equation (11):

$$Udc = \frac{3\sqrt{2}}{\pi}U = 1.35U$$

$$(11)$$

The DC link is modeled with the following parameters:

Table2: DC link parameter

| Inductance | 200e-6 H |
|---|---|
| Capacitance | 4700e-6 F |

### C. Three-Phase Inverter

After the signal is rectified the energy is stored in the DC link inductors for the current source inverter and the DC link capacitor for the voltage source inverter. The IGBT of the inverter bridge takes the energy in the form of the DC mode and has to deliver the sinusoidal wave to the induction motor. The speed of the motor is controlled by the fundamental components frequency of this AC waveform.

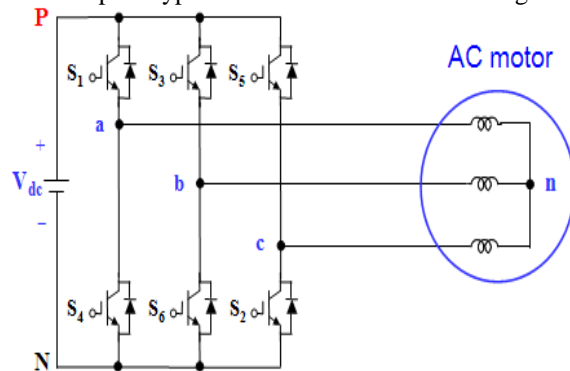The prototype of the inverter is shown in Figure1 below:



Figure1: Inverter Block Diagram

The line-to-line voltage of the output of the inverter can be expressed as:

$$Vl = \sqrt{\left[\int_0^{\frac{2\pi}{3}}(Vs)^2 d(\omega t)\right]}$$

$$Vl = \sqrt{\frac{2}{3}}Vs = 0.8165Vs$$

$$(12)$$

The Three-phase Inverter is modeled with the following parameters:

Table3: Three phase inverter parameter

| Bridges | 3 |
|---|---|
| Snubber Resistance | 1e5 Ω |

| Snubber Capacitance | ∞ |
|---|---|
| Device used | IGBT/Diodes |
| Ron | 0.2e-3 |
| Tf(s), Tt(s) | 1e-6,2e-6 |

## III. OPERATING PRINCIPLE

The inverter is fed by a dc voltage and has three phase-legs each consisting of two transistors and two diodes. With PWM control, the switches of the inverter are controlled based on a comparison of a sinusoidal control signal and a triangular switching signal. The sinusoidal control waveform establishes the desired fundamental frequency of the inverter output, while the triangular waveform establishes the switching frequency of the inverter. The ratio between the frequencies of the triangle wave and the sinusoid is referred to as the modulation frequency ratio. The switches of the phase legs are controlled based on the following comparison is shown in Figure2:

$$v_{control(phase-a)} > v_{triangle}, T_{a+} \text{ is on}$$

$$v_{control(phase-a)} < v_{triangle}, T_{a-} \text{ is on}$$

$$v_{control(phase-b)} > v_{triangle}, T_{b+} \text{ is on}$$

$$v_{control(phase-b)} < v_{triangle}, T_{b-} \text{ is on}$$

$$v_{control(phase-c)} > v_{triangle}, T_{c+} \text{ is on}$$

$$v_{control(phase-c)} < v_{triangle}, T_{c-} \text{ is on}$$

Figure 2: Switching of Transistors in inverter

In most instances the magnitude of the triangle wave is held fixed. The amplitude of the inverter output voltages is therefore controlled by adjusting the amplitude of the sinusoidal control voltages.

The ratio of the amplitude of the sinusoidal waveforms relative to the amplitude of the triangle wave is the amplitude modulation ratio. The diodes provide paths for current when a transistor is gated on but cannot conduct the polarity of the load current. For example, if the load current is negative at the instant the the upper transistor is gated on, the diode in parallel with the upper transistor will conduct until the load current becomes positive at which time the upper transistor will begin to conduct.

By controlling the switches in this manner, the line-line inverter output voltages are ac, with a fundamental frequency corresponding to the frequency of the sinusoidal control voltage. In most instances the magnitude of the triangle wave is

held fixed. The amplitude of the inverter output voltages is therefore controlled by adjusting the amplitude of the sinusoidal control voltages. The output waveforms are shown below in figure.3:
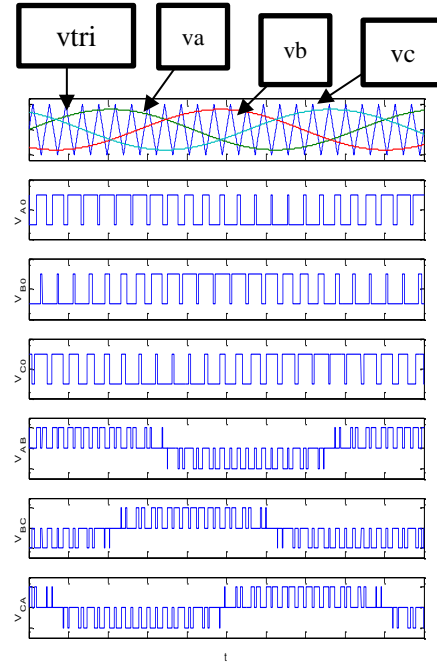


Figure 3: Waveforms of three-phase sine PWM inverter

When $v_{control} > v_{tri}$, $V_{A0} = V_{dc}/2$

When $v_{control} < v_{tri}$, $V_{A0} = -V_{dc}/2$

Where   $V_{AB} = V_{A0} - V_{B0}$

$V_{BC} = V_{B0} - V_{C0}$

$V_{CA} = V_{C0} - V_{A0}$

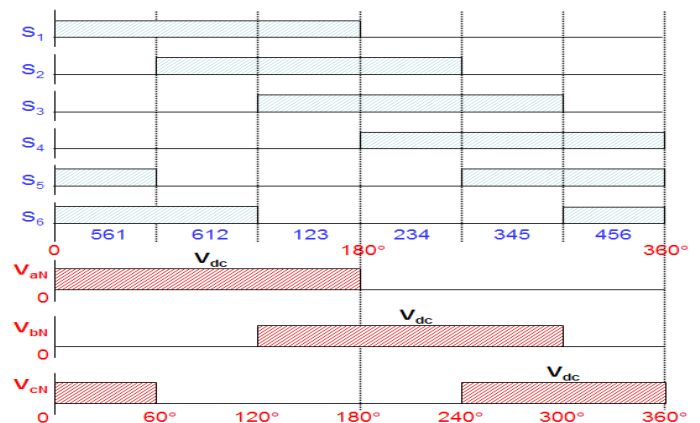The gating sequence is shown below in Figure4:

Figure.4: Waveforms of gating signals, switching sequence, line to negative voltages

The switching sequence is shown in Figure5:

$V_1 = [1\ 0\ 1]$

$V_2 = [1\ 0\ 0]$

$V_3 = [1\ 1\ 0]$

$V_4 = [0\ 1\ 0]$
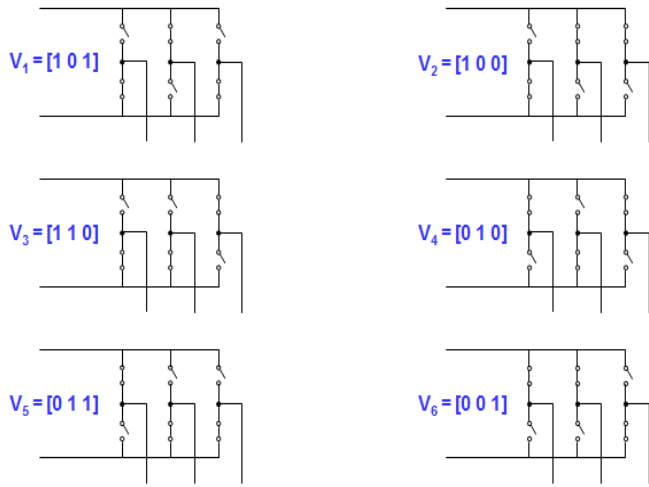
$V_5 = [0\ 1\ 1]$

$V_6 = [0\ 0\ 1]$

Figure 5: Six inverter voltage vectors

The output of the inverter is the PWM signal in the form of the square wave. This square wave constitutes voltages Vab, Vbc, Vac which are given by the equations (13) and (14).

$$Vab = \frac{Ao}{2} + \sum_{n=1}^{\infty} (An \cos(n\omega t) + Bn \sin(n\omega t))$$

$$Bn = \frac{1}{\pi}\left[ \int_{-\frac{5\pi}{6}}^{\frac{5\pi}{6}} -Vsd(\omega t) + \int_{\frac{\pi}{6}}^{\frac{5\pi}{6}} -Vsd(\omega t) \right]$$

$$Bn = \frac{4\pi}{n\pi} \sin(\frac{n\pi}{2}) \sin(\frac{n\pi}{3})$$

$$Vab = \sum_{n=1,3,5\ldots}^{\infty} \frac{4Vs}{n\pi} \sin(\frac{n\pi}{3}) \sin n(\omega t + \frac{\pi}{6})$$

(13)

$$Vbc = \sum_{n=1,3,5\ldots}^{\infty} \frac{4\pi}{n\pi} \sin\frac{n\pi}{3} \sin n(\omega t - \frac{\pi}{2})$$

(14)

The voltage between the output terminals 'a' and 'c' is given by:

$$Vca = \sum_{n=1,3,5,\ldots}^{\infty} \frac{4Vs}{n\pi} \sin\frac{n\pi}{3} \sin n(\omega t - \frac{7\pi}{6})$$

(15)

## IV.   SIMULATION RESULTS

The circuit consists of rectifier, DC link, three phase inverter and an asynchronous motor connected to the output of the three phase inverter which is used to drive the motor. The whole circuit is simulated using MATLAB/Simulink and the respective circuit diagram and the waveforms are visualized in the below figures.
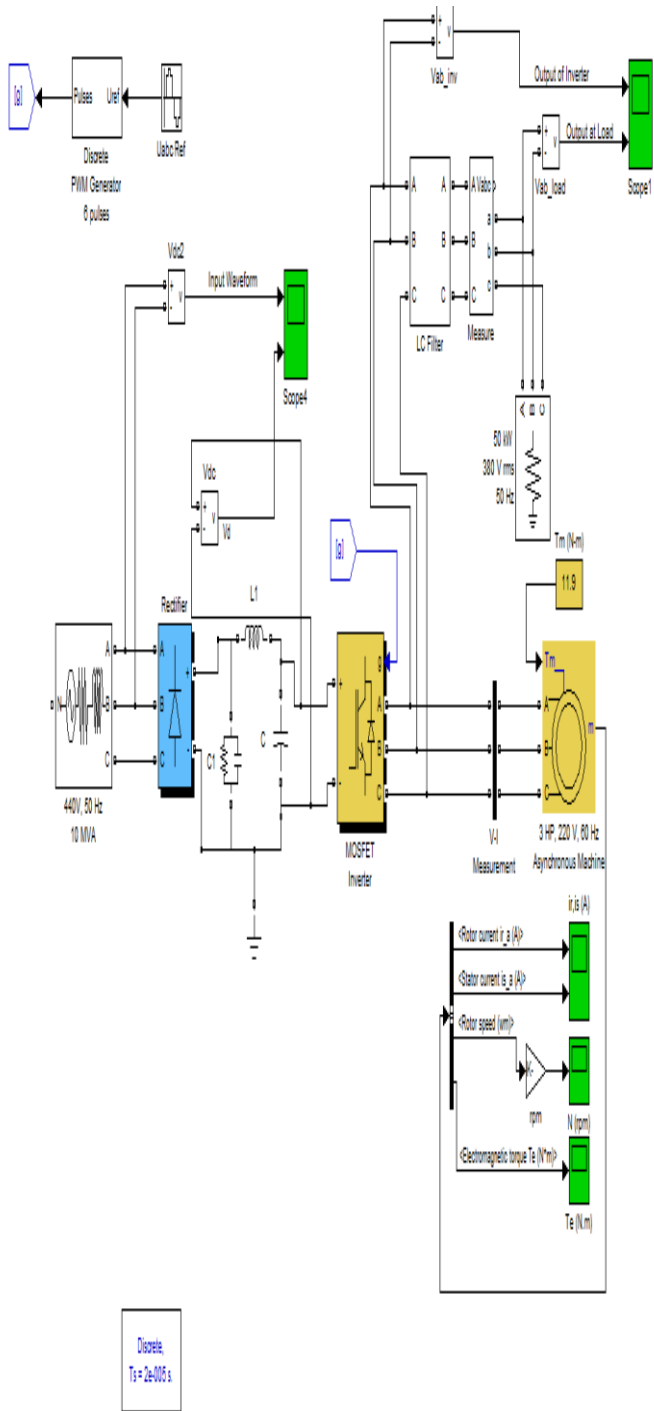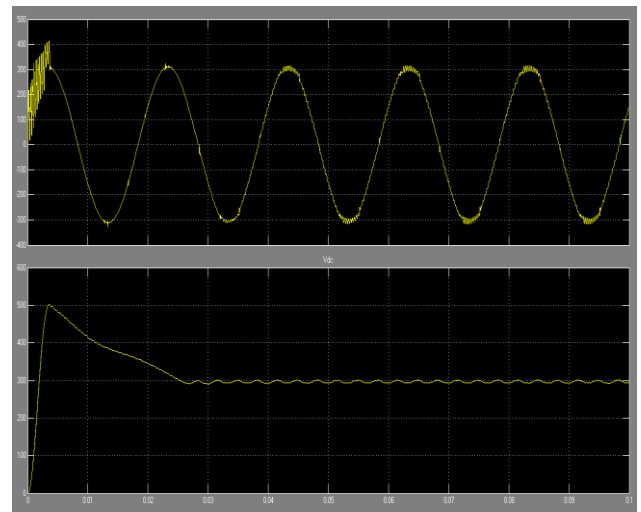
Figure 6: Proposed Circuit diagram



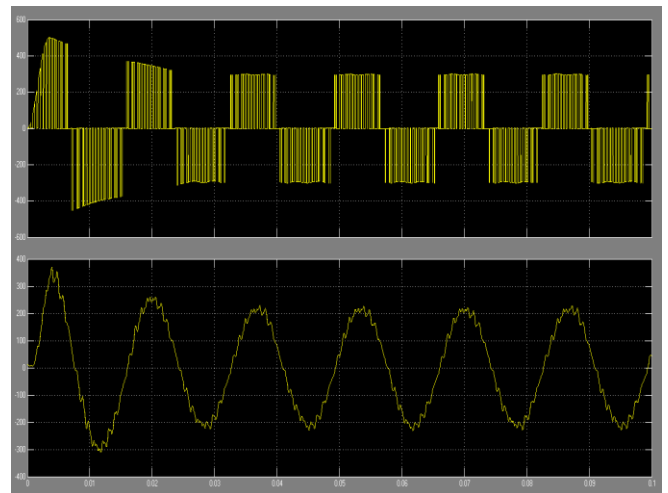Figure 7 :a) one Input waveform of three-phase
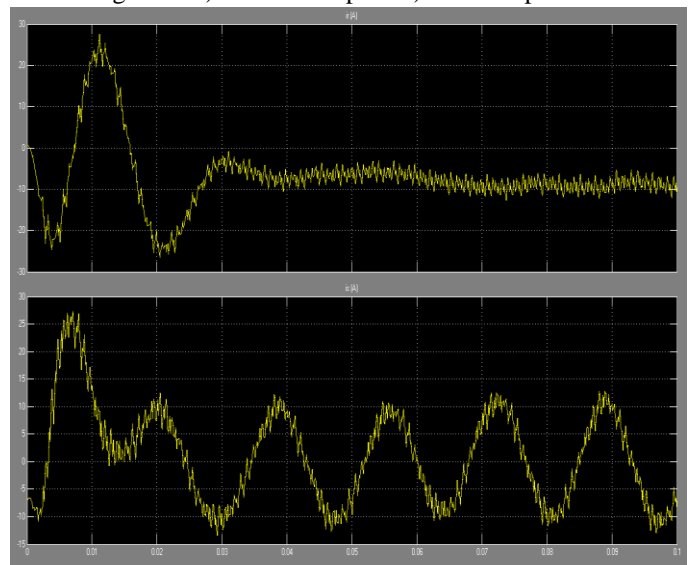b) DC link output



Figure 8: a) Inverter output   b) Load output
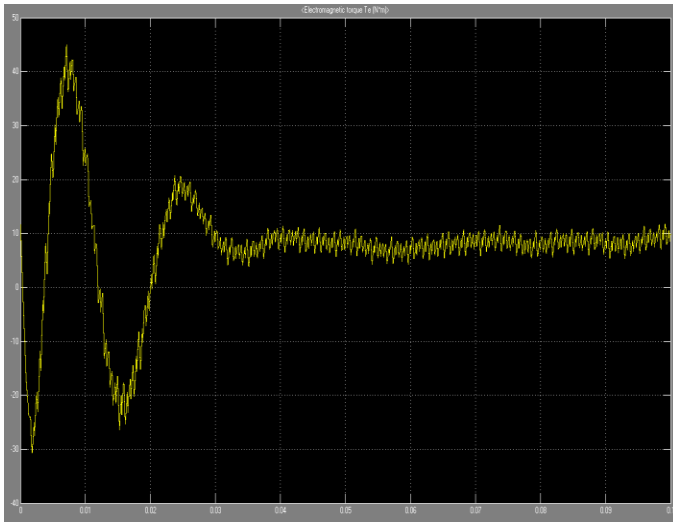


Figure 9: a) Rotor Current   b) Stator Current

Figure 10: Electromechanical Torque (N.M)

## V.    CONCLUSION

This paper presents the modeling of the circuit which can be used in Frequency Converters. The circuit described above has been simulated using MATLAB/Simulink and the output graphs such as voltage at the inverter, voltage at the load, Rotor current, Stator current and the Torque waveform are obtained and which are in sync with the desired output. This circuit eliminates the use of large electrolytic capacitors by using LC filter for lower input and output distorted currents. This circuit uses IGBT which have better input and output characteristics than BJT. This circuit can be used in Frequency converters which are generally used in different Industrial applications to cater operations such as Grinding.

## ACKNOWLEDGMENT

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