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Open Loop V/F Control of Induction Motor based on PWM Technique

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ABSTRACT— The rapidly developments in power semiconductors technology, converter topologies and control techniques with increased reliability and reduced cost led to the production of AC induction drives. The need for variable speed of an AC motor with maintain torque constant is necessary in many industrial applications. So, the line voltage should also be varied directly with frequency to remains torque very nearly constant. In this paper a three-phase voltage source inverter is used here to provide variable voltage and frequency supply required by AC drives. The Pulse width modulation technique (PWM) techniques are used here to control frequency voltage-sourced inverters. The relationship between supply frequency and speed of induction motors is directly proportional, i.e., the increase in supply frequency of induction motor, corresponds to increasing in speed induction motor and vice versa. The total harmonics distortion (THD) are measured at varying modulation indexes. The simulation test-bed is described and simulated using MATLAB/SIMULINK. Lastly, results are discussed, and conclusions are provided.

Keywords— Induction Motor (IM), Speed Control, Frequency, PWM, Inverter, Rectifier, Filter, Total harmonic distortion (THD).

I. INTRODUCTION

Induction motors are widely used in industrial applications "Workhorse of the Industry" [1-5]. They have a lot of advantages like, low manufacturing cost, wide speed range, high efficiency, robustness…...etc [6]. Also, this kind of motors are used in different applications such as industries, transportation, household appliances, laboratories …etc. They cheaper then DC and Synchronous motors. Also, they have very high starting torque which makes useful in applications especially where the load is applied before starting the motor. In addition, induction motors are very reliable, and they have high efficiency of energy conversion [7]. And other advantages which make them widely used in all the world. The voltage source inverters (VSI's) are widely used to control the speed of three-phase Induction Motors (IM's) over a wide range by varying the stator frequency. Generally, the most modern variable frequency drives operate by converting an AC voltage source to DC voltage using rectifier. After the power flows out of the rectifiers it is stored on a dc bus. The dc bus has capacitors for accepting power from the rectifier, stores it, after that it delivers that power through the inverter. The inverter contains power electronics switches that deliver power to the motor [2]. There are various methods to control speed of an IM, such as pole changing variable, supply frequency control, variable supply voltage control, variable rotor resistance control, voltage / frequency (V/f) control vi. slip recovery and vector control. But the V/f control is the most popular method used to control the speed of an IM for many reasons, such as it provides good range of speed. Also, the transient performance and running of this type of IM is good. In addition to, the starting current is had low. Also, It has a wider stable operating region [8]. At base speed Voltage and frequencies reach rated values. So, Induction motors run at constant speed which its speed depends on frequency. By changing the frequency can be controlling and changing the range of speed. The ratio of the applied voltage / frequency of supply is directly proportional with torque that developed by the IM. By varying the frequency and voltage, but keeping their ratio constant, throughout the speed range the torque developed can be kept constant as shown in figure .1 [9]. Output voltage of an inverter can be controlled with in the inverter itself which it is called (internal control), or from outside either from the input of inverter (External control of dc input voltage) or from the output side of the inverter which it is called (External control of ac output voltage). Pulse width modulation is one of methods that controlling output of inverter from inside the inverter, which comes under internal control [10]. An ideal inverter should give a sinusoidal output voltage waveform. But practical inverters produce non-sinusoidal waveforms which they contain harmonics [11]. The one of the objectives of PWM techniques in this paper is to reduce these harmonics that content in Three Phase VSI's.

II. THREE PHASE INVERTERS

Static inverters may be classified into two types based on their operation: Voltage source inverter (VSI) and Current sources inverter (CSI) [9]. In this report just will concentrate about the first type voltage sources inverter (VSI). In figure. 1 below shows a circuit diagram of a three-phase inverter. This

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inverter consists three arms and six semiconductor devices which arranged in each arm has two semiconductor devices. It is fed from a rectifier circuit or any other dc supply sources. It works to convert the input dc supply into three phase ac output supply, where the amplitude, phase, and frequency of the voltages should always be controllable [11].

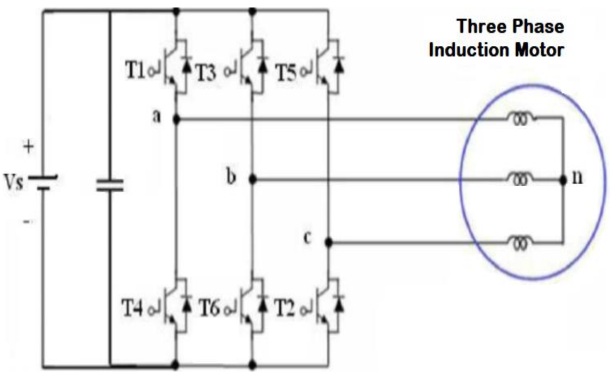

Fig. 1 Three−phase Voltage Source Inverter

III. SINUSOIDAL PULSE WITH MODULATION IN THREE-PHASE INVERTER

In sinusoidal pulse width modulation (SPWM) there are multiple pulses per half-cycle and the width of them pulses is varied with respect to the sine wave magnitude. To output 120o out-of-phase load voltages, are used three modulating signals that are 120o out of. Figure.2. shows the ideal waveforms of three−phase sinusoidal pulse width modulation. To maintain the features of the PWM technique and use a single carrier signal, the normalized carrier frequency Mf should be an odd multiple of 3. Therefore, all phase voltages (V_{AN} , V_{BN} , V_{CN}) are identical but 120o out of phase without even harmonics [12].

The amplitude of a sinusoidal signal is As, and the amplitude of triangular carrier wave is Ac, so the ratio m=As/Ac is known as the Modulation index. Figure 2. shows the general scheme to SPWM, a high frequency triangular carrier wave is compared with the sinusoidal reference wave determines the switching instant [5,13]. Generating controllable magnitude and frequency balanced for three phase sinusoidal wave forms is a little difficult task for an analog circuit, so a mixed analog and digital circuits is often preferred.

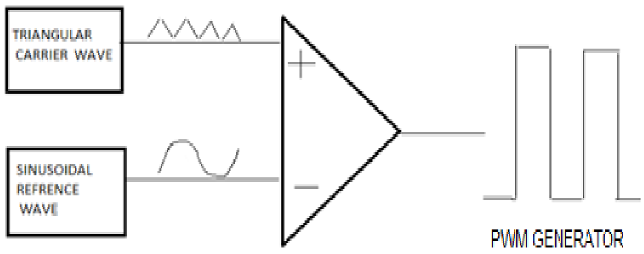

Fig. 2 Sinusoidal Pulse width modulation

The the three phase PWM signal is showed in Figure. 3. Which (V_{tri}) is waveforms of carrier wave signal and ($V_{Control}$) is control signal , inverter output line to neutral voltage (V_{AN} , V_{BN} , V_{CN}), inverter output line to line voltages (V_{AB}, V_{BC}, V_{CA}), respectively [11].

$$V_{AB} = V_{AN} - V_{BN}$$

$$V_{BC} = V_{BN} - V_{CN}$$

$$V_{CA} = V_{cN} - V_{AN}$$

$$Amplitude\ Modulation, M_a = \frac{A_S}{A_C}$$

$$Frequency\ Modulation, M_f = \frac{f_S}{f_C}$$

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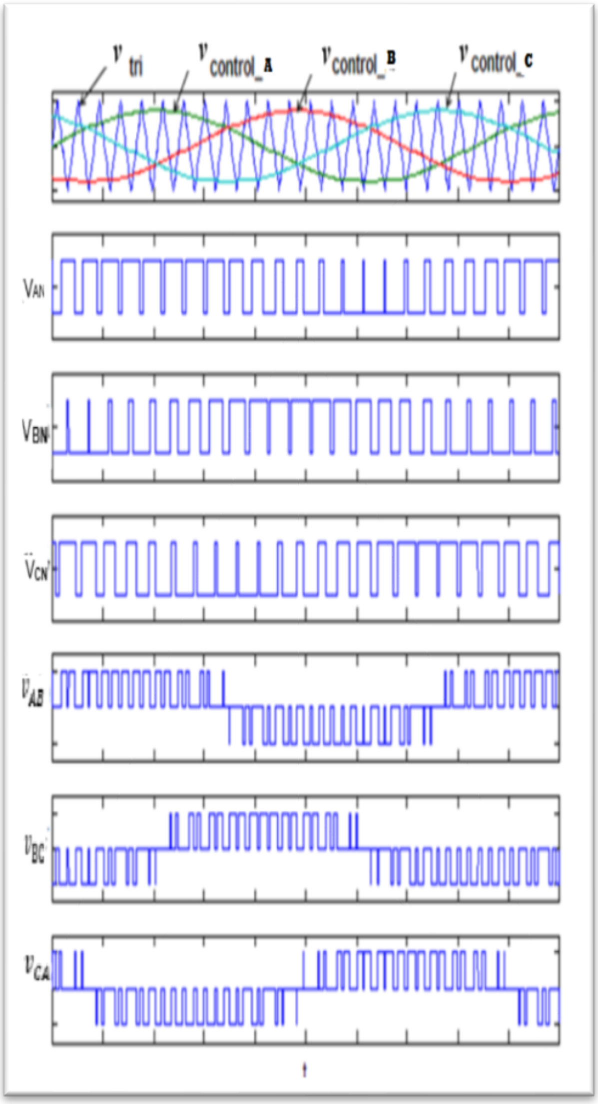

Fig. 3 Waveforms of three−phase SPWM inverter

Percentage of individual harmonics is calculated by the eqn.

where, n= nth harmonics.

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Percentage of total RMS of the output, when M_f is even

$$\%\frac{rms(n)}{V_{DC}} = 100\left(\frac{4}{n\pi\sqrt{2}}\sum_{p=1}^{M_f}(-1)^{i+1}\, cosn\alpha_i\right)$$

where, n= nth harmonics

Percentage of total RMS of the output, when Mf is even

$$\%\mathrm{Vn} = 100 \times \sqrt{\frac{2}{\pi}\sum_{p=1}^{\frac{Mf}{2}}(\alpha_{2p} - \alpha_{2p-1})}$$

When M_f is odd

$$\%V_n = 100 \times \sqrt{\left[\frac{2}{\pi}\sum_{p=1}^{\frac{M_f-1}{2}}(\propto_{2p} - \propto_{2p-1)}) + \frac{\pi}{2} - \alpha_{M_f}\right]}$$

Total harmonics distortion (THD) is given by,

$$THD = \frac{V_h}{V_1},$$

$Where:-$

$$V_h = \sqrt{\sum_{n=2,3,\dots}^{\infty} V_n^2} \quad or, V_h = \sqrt{V_{out}^2 - V_1^2}$$

IV. THREE PHASE INDUCTION MOTORS

A. Constriction

An induction motor is machine contains rotor part and stator part. The windings are three-phase which put in the slots of stationary part of the machine "stator". The stationary part of motor is composed of lamination of high-grade sheet steel. The rotating part of induction motor " rotor" also contains either a distributed three-phase winding or cage of interconnected copper bars that serve as rotor winding conductors. Not like dc machine, induction motors have a uniform air gap [14].

B. Working

The stator winding is energized by a three-phase supply, a rotating magnetic field in this machine is established which rotates around the stator at synchronous speed Ns. The stationary rotor is cut by this flux and in the rotor, windings induces an electromotive force. So, the current flows in the rotor windings because of short-circuited in them. Mechanical force will be exerted in the conductors that placed is stator by Lenz's law. Lenz's law said that the direction of rotor currents will be such that they will try to oppose the cause producing them. Hence, a torque is produced which tries to reduce the relative speed between the rotor and the magnetic field. Thus, the rotor and flux will rotate in the same direction. Thus, the relative speed between the magnetic field and the rotor will be drives the rotor. Hence the rotor speed Nr of this kind of motor remains less than the synchronous speed Ns. So, the Induction Motors are also called Asynchronous Motors [7].

C. Torque-Speed Analysis

The equivalent circuit of an Induction Motor can be depicted as shown in figure.4

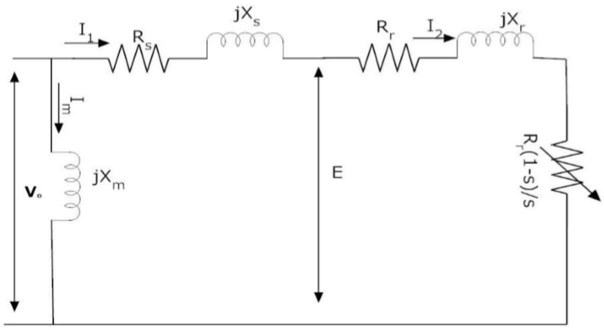

Fig. 4 Equivalent Circuit of an Induction Motor

$Where:$
$Xm = Magnetizing\ Reactance$
$Xs = Stator\ Reactance$
$Xr = Rotor\ Reactance$
$Rs = Stator\ Resistance$
$Rr = Rotor\ Resistance$
$S = slip$
$p = pole\ per\ phase$
$F = output\ frequency$

In an Induction Motor the slip is given as

$S = \frac{N_s - N_r}{N_s}$, $N_s = \frac{120F}{p}$

$Where:-$
$Ns = Synchronous\ speed$
$Nr = Rotor\ speed$

The following expressions can be derived from the above circuit,

Rotor Current

$$I2 = \frac{Vo}{\left(Rs + \frac{Rr}{s}\right) + j\,(Xs + Xr)}$$

Torque

$$T = \pm\frac{\left(\frac{3Vo^2 Rr}{s}\right)}{ws\left[\left(Rs + \frac{Rr}{s}\right)^2 + (Xs + Xr)^2\right]}$$

The mechanical power developed Pm

$p_m = T\frac{2\pi N}{60}$ $where\ \omega = \frac{2\pi N}{60}$ $so\ \ P_m = T\omega$

$\omega = output\ speed \quad rad/sec$

The following are the torque and speed characteristics for an Induction Motor for various frequencies as shown in figure .5.

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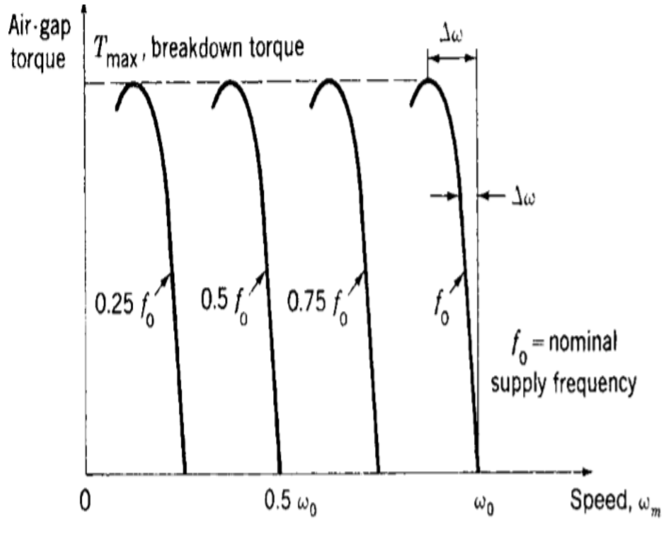

Fig. 5 Torque vs Speed Curves for V/f Controlled Induction Motor for various frequencies

V. MODELING OF INDUCTION MOTOR DRIVE FED BY PWM INVERTER.

The Block diagram of a voltage source inverter fed IM drive is showed in Figure.6. It consists mainly four blocks as it can be seen below, three-phase rectifier, filter circuit (DC link), three phase inverters and PWM generator. All those blocks are used to feed a three-phase IM. Firstly, the three-phase AC voltage are converted into DC using diode rectifier circuit. Then the output DC voltage of rectifier is filtered using capacitor C for reducing ripple voltage. After that the obtained DC voltage supplied to the three phase IGBT inverter in which converted back again to AC output power, but with variable voltage and frequency to feed IM. The switching frequency is set to 3 KHZ using PWM technique.

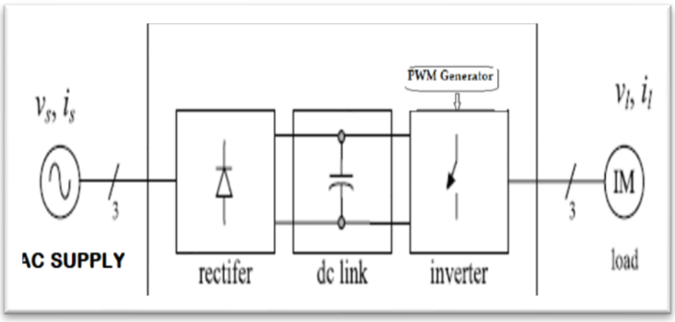

Fig. 6 Block diagram of the electrical power conversion topology

VI. SIMULATION RESULTS AND ANALYSIS

Figure 7 shows the Simulink model for three Phase inverter fed IM drive which has been designed and implemented by using MATLAB Simulink. The parameters of IM that used for simulation are as follows: 5.4 Hp, 2 $pole$, 1430 rpm, 3-phase with parameters: $V(rms) = 400 volt,\ f = 50\ hz, Rs = 1.405\ ohm, Rr = 1.395\ ohm,\ Ls = Lr = 0.005839\ H,$ $Lm = 0.1722\ H, J = 0.0131\ Kg.m2,\ F$ =0.002985 N.m./s . The dc link filter parameter is $C = 0.1$ μF. The load torque applied to the machine's shaft is constant = 20 $N.m$ .The inverter which used in this model has been built using six IGBT semiconductor devices.

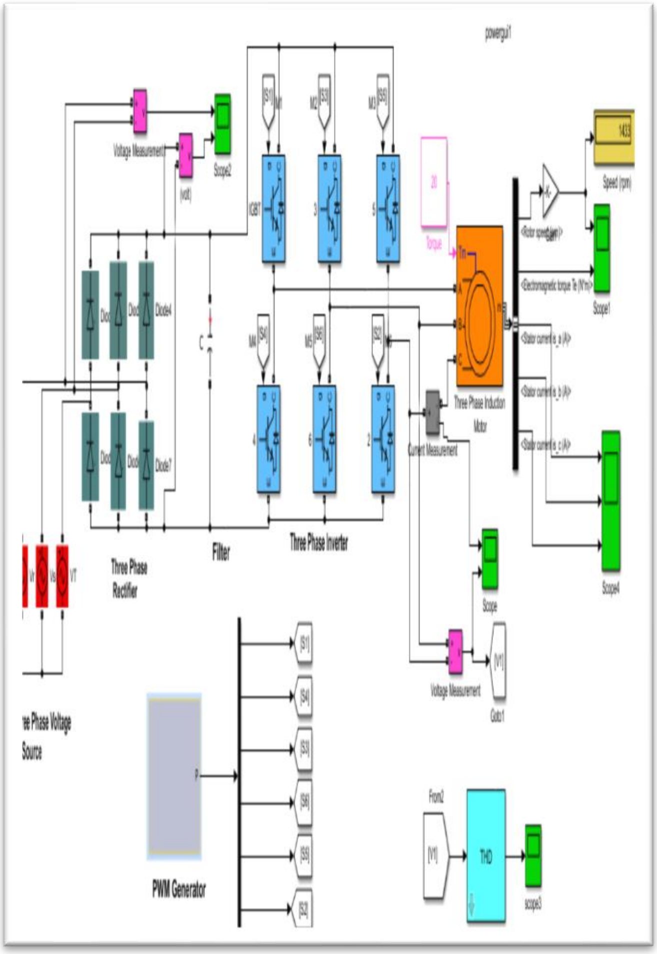

Fig. 7 Simulink diagram of three phase inverter fed IM drive

From the figures below, it has been observed that the IM attains steady state at $t = 0.15\ s$ approximately. Figure .8. shows the waveform of input phase voltage before rectified and output of rectifier waveform after filtered. In figure 9. the output phase current and output phase voltage of inverter are showed. While figure .10. is illustrated the three phases stator current of IM. Lastly the waveform in figure.11. shows the torque response, the torque is started at high value then it settles and remains a constant as the IM attains the speed. The output voltage harmonics are presented out as sidebands of the switching frequency and its multiples in a PWM inverter. The table I. below represents the changes in total harmonic distortion according to different modulation indexes. The speed of IM is controlled by varying in frequency as shown in table II. But should keep the ratio of voltage/frequency constant to maintain torque load constant.

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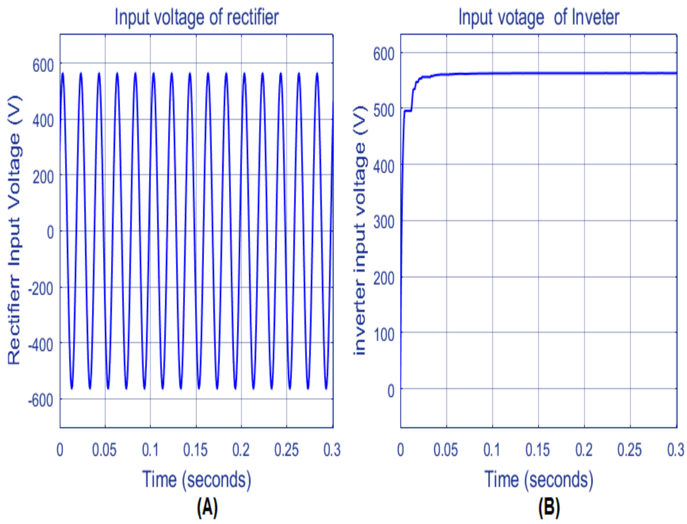

Fig. 8 (A) Input phase voltage of rectifier, (B) Input DC voltage of inverter

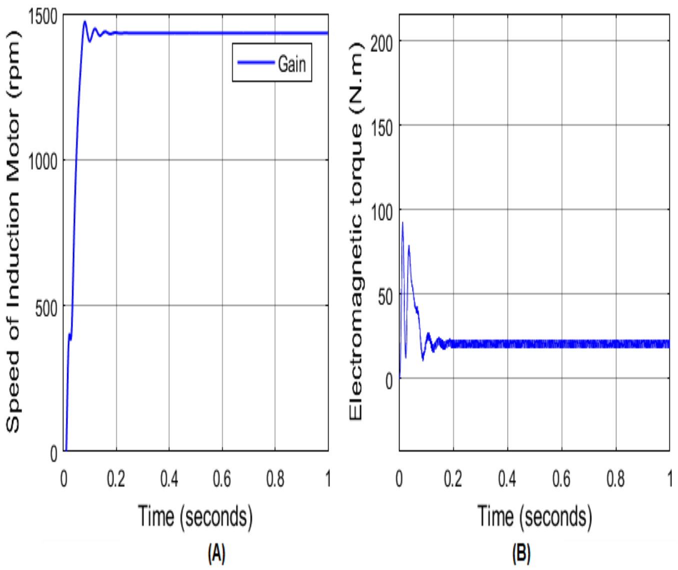

Fig. 9 (A) Inverter output phase current (B) Inverter output phase voltage

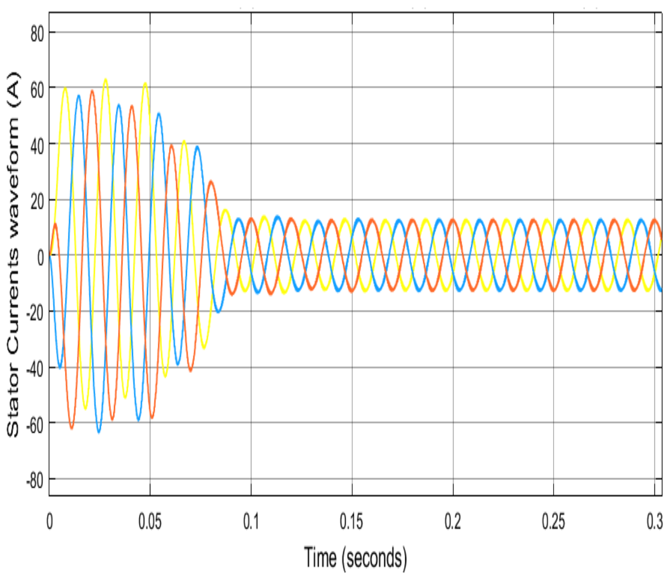

Fig. 10 Stator currents waveform of IM

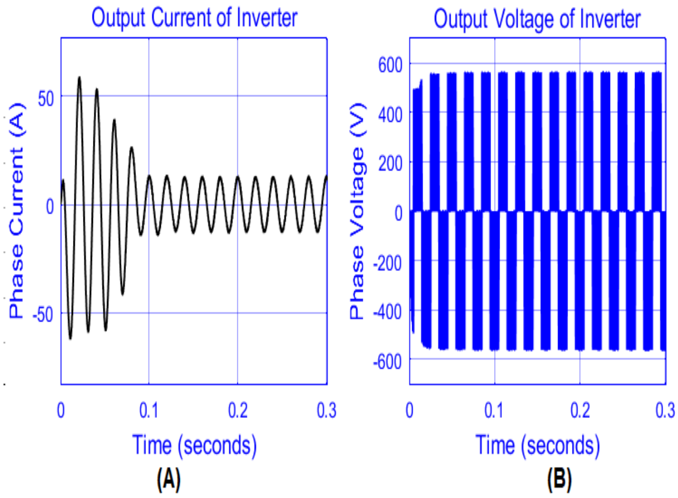

Fig. 11 **(A)**Speed of IM in rpm**, (B)** Electromagnetic torque of IM

TABLE I
THD FOR VARIOUS MODULATION INDEXES

Modulation Index	**THD OF Fundamental Voltage (%)**	**Speed of IM Drive(rpm)**
0.7	104.9	1341
0.8	91.54	1388
0.9	79.6	1416
1	68.58	1433

TABLE II
SPEED FOR VARIOUS FREQUENCY AT MODULATION INDEX=1

Frequency of voltage supply IM (HZ)	**Speed of IM drive (rpm)**	**Ratio of speed decrease (%)**	**THD OF Fundamental Voltage (%)**
50	1433	0	68.58
40	1132	21	78.17
30	829.4	26.73	90.77
20	523.5	36.88	122.2
10	179	65.81	311.9

VII. CONCLUSION

In this paper, a speed control of IM is presented. It can be concluded that as the modulation index increases total harmonic distortion (THD) decreases. Therefore, THD can be reduced by increasing modulation index. Also, the variations in modulation index affects the speed of IM drive. The speed of IM drive has been controlled by varying supply voltage and frequency with constant (Voltage/frequency) ratio. Hence, the motor runs at variable speed below rated speed by maintaining constant V/F ratio to maintain torque load constant. The speed change ratio of IM is not fixed, in which increases more at low frequencies. Also, the THD of voltage is high at low frequencies. Therefore, this method of controlling speed induction motor is useful more at high frequencies. Graph for

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the torque response rises to a maximum value and then settle down to steady state value, whereas the rotor speed reached the rated speed and remain constant. The motor was fully utilized, and successful speed control was accomplished.

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