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O/p Loop Control of Induction Motor Using PWM Technique for Adjustable Speed Drive Applications

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ABSTRACT—The rapidly developments in power semiconductors technology, converter topologies and control techniques have provided many features in controlling of electrical machine. Induction Motors (IM) are considered work horse for industrial due to a high power/weight ratio, high reliability, robust structure and low cost. A three-phase voltage source inverter is used here to provide variable voltage and frequency supply required by AC drives. In this paper pulse width modulation technique (PWM) is used to obtain variable voltage output from inverter to control the speed of induction motorin order to obtain smooth operation and provides torque control. The PWM techniques make possible 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. Finally, 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” [1-4]. They have a lot of advantages to be used in different applications such as industries, transportation, household appliances, laboratories …etc. They cheaperthen 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 [5]. And other advantages which make them widely used in all the world. Thevoltage 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 [6]. 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 [7]. 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 [8]. An ideal inverter should give a sinusoidal output voltage waveform. But practical inverters produce non-sinusoidal waveforms which they contain harmonics [9]. 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)[7].In this report just will concentrate about the first type voltage sources inverter (VSI). In figure. 1 below show sa circuit diagram of a three-phase inverter. This 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 [9].

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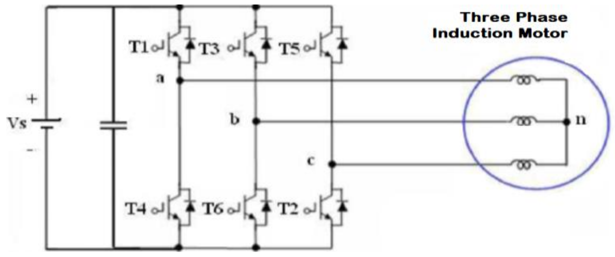

Fig .1. Three−phase Voltage Source Inverter

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 120° out-of-phase load voltages, are used three modulating signals that are 120° 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 M_f should be an odd multiple of 3. Therefore, all phase voltages (V_{AN}, V_{BN} ,V_{CN}) are identical but 120° out of phase without even harmonics [10].

The amplitude of a sinusoidal signal is A_s, and the amplitude of triangular carrier wave is A_c, 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 [4,11]. 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.

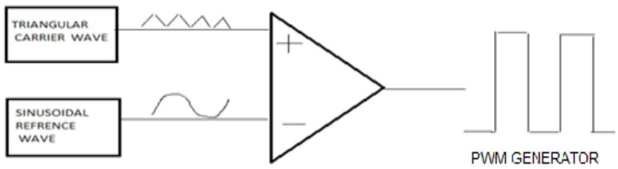

Fig. 2. Sinusoidal Pulse width modulation

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 [9].

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

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

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

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

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

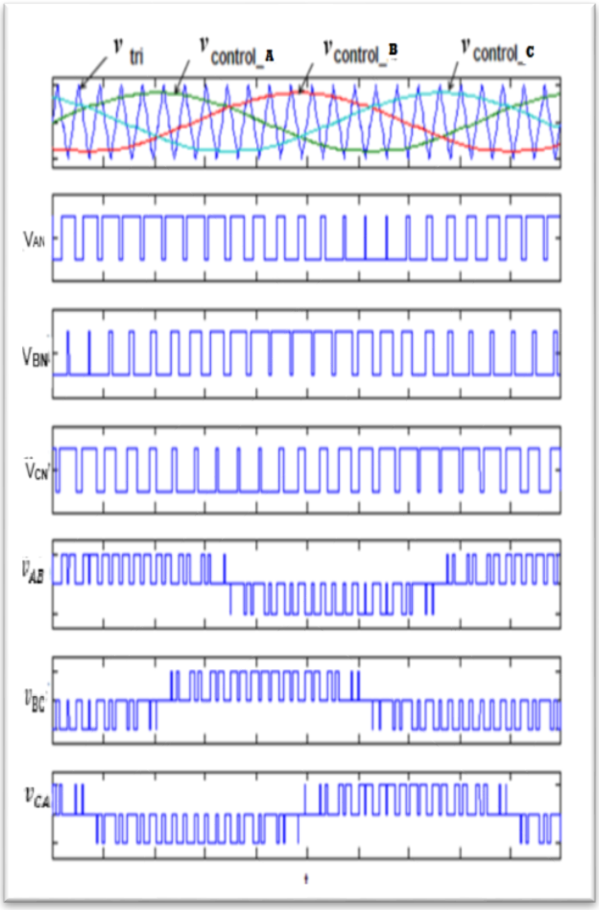

Fig.3. Waveforms of three−phase SPWM inverter

IV. THREE PHASE INDUCTION MOTORS

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

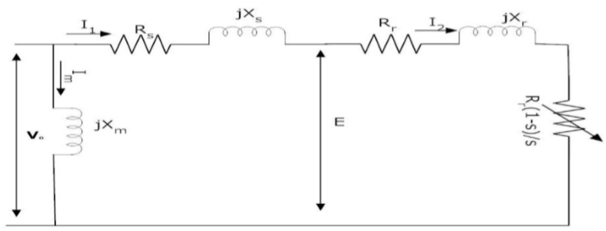

Fig. 4. Equivalent Circuit of an Induction Motor

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

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

$Where: -$

$Ns = \text{Synchronous speed}$

$Nr = \text{Rotor speed}$

The following expressions can be derived from the above circuit,

Rotor Current

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

Torque

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

The mechanical power developed P_m

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

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

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.5. 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-phaseIM. 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 whichconvertedback again to AC output power,but with variable voltage and frequency to feedIM. The switching frequency is set to 3 KHZ using PWM technique.

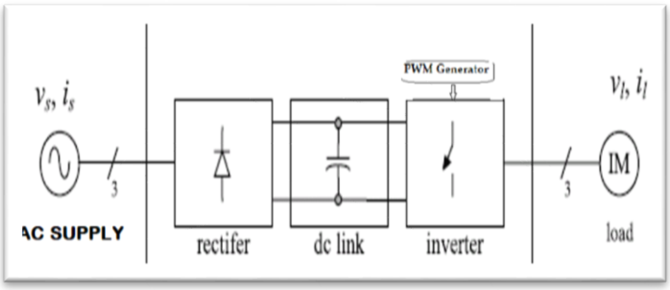

Fig. 5. Block diagram of the electrical power conversion topology

VI. SIMULATIONRESULTS AND ANALYSIS

Figure 6 showsthe 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: $V(rms) = 400volt$, $f = 50\ hz, Rs = 1.405\ ohm, Rr = 1.395\ ohm,\ Ls = Lr = 0.005839\ H,$ $Lm = 0.1722\ H, J = 0.0131\ Kg.m2,\ F$ =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 whichused in this model has been built using six IGBTsemiconductor devices.

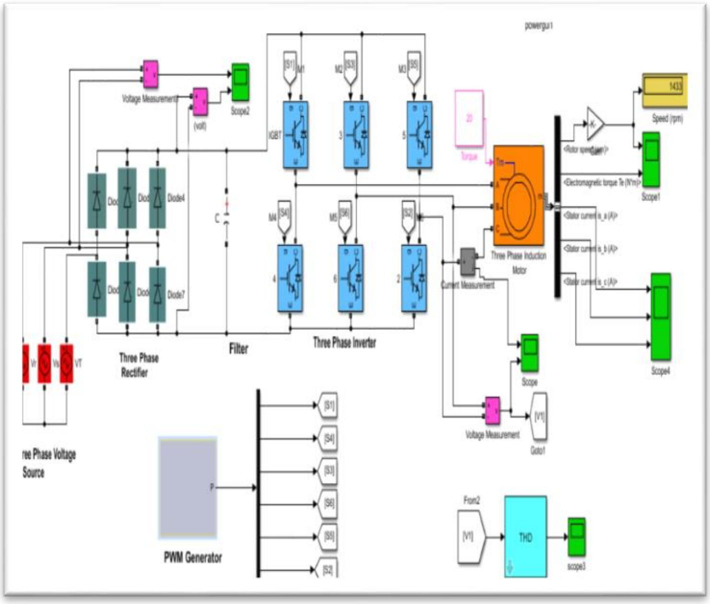

Fig.6. Simulink diagram of threephase inverter fed IM drive

From the figures below, it has been observed that the IM attains steady state at $t =$ 0.15 $s$approximately. Figure .7. shows the waveform of input phase voltage before rectified and output of rectifier waveform after filtered. In figure 8. the output phase current and output phase voltage of inverter are showed.While figure .9. is illustrated the three phases stator current of IM. Lastly the waveform in figure.10. 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 tableI. 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 tableII. But should keep the ratio of voltage/frequency constantto maintain torque load constant.

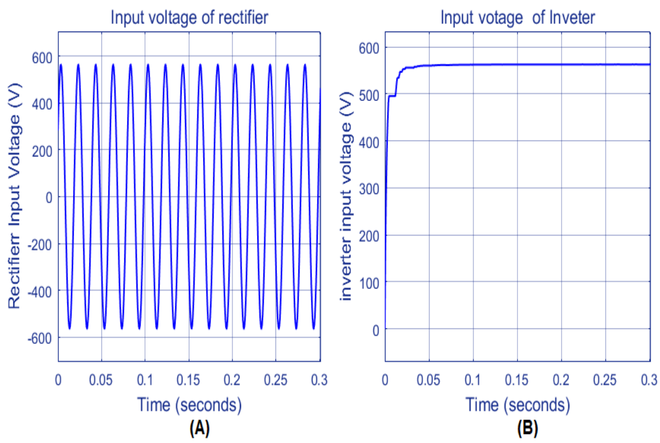

Fig.7. (A) Input phase voltage of rectifier, (B) Input DC voltage of inverter

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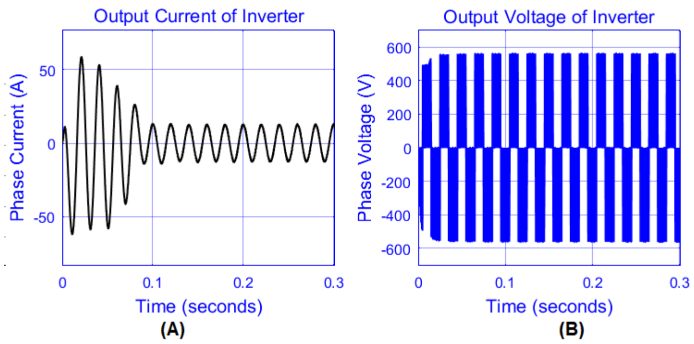

Fig.8. (A) Inverter output phase current (B) Inverter output phase voltage

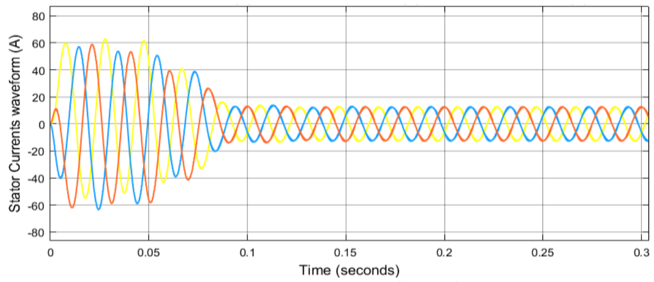

Fig.9. Stator currents waveform of IM

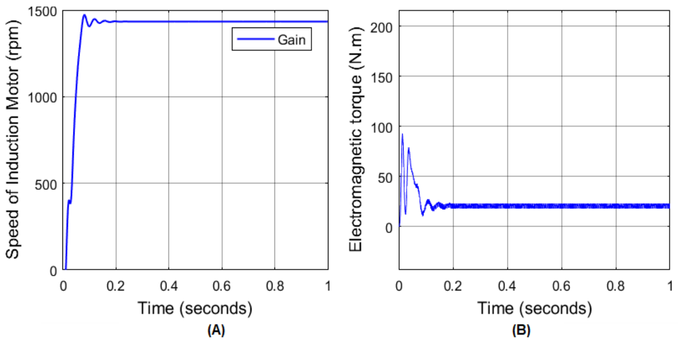

Fig.10. **(A)**Speed of IM in rpm**, (B)** Electromagnetic torque of IM

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 frequencyat modulation Index=1

Frequency of voltage supply IM (HZ)	Speed of IM drive (rpm)	Ratio of speed decrease (%)	THD OF Fundamental Voltage (%)
50	1433	-	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 ratioto maintain torque load constant. The speed change ratioof IMisnot fixed,in which increases moreat 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 the torque responserises to a maximum value and then settle down to steady state value, whereas the rotor speed reachedthe rated speed and remain constant. The motor was fully utilized, and successful speed control was accomplished.

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