Closed Loop Control of Three-Phase Induction Motor using Xilinx

Manoj Hirani,
M.Tech, Electrical Drives branch of Electrical Engineering,
Maulana Azad National Institute of Technology,
Bhopal, Madhya Pradesh, India

Dr. Sushma Gupta,
Department of Electrical Engineering,
Maulana Azad National Institute of Technology,
Bhopal, Madhya Pradesh, India

Dr. D. M. Deshpande
Department of Electrical Engineering,
Maulana Azad National Institute of Technology,
Bhopal, Madhya Pradesh, India

Abstract- **In this paper three-phase induction motor is controlled in closed loop by variable voltage variable frequency method. The control strategy is made by using Xilinx. Here Induction Motor (IM) is fed by Sine Pulse Width Modulated (SPWM) inverter using six switches. The control is obtained by keeping the ratio Voltage/Frequency constant. Performance characteristic of two levels inverter fed induction motor drive is presented. Steady state behaviour of speed, current and torque in induction motor are also analyzed. Models are developed for SPWM fed induction motor using MATLAB/ Xilinx.**

Keywords- Induction Motor (IM), Sine pulse width modulation (SPWM), Field Programmable Gate Array (FPGA), Xilinx

I.INTRODUCTION

Induction Motor is being widely used in industrial and domestic purposes. Due to easy maintenance and robustness, three-phase induction motor is now being used in vehicles also. Three-phase induction motor is an AC machine which runs at variable speed. To produce good speed response and less torque ripple these motors require good quality AC input [1].

The performance characteristic of three-phase induction motor depends on the quality of input line current. Different types of converters have their different quality of input line current [4-6]. The choice of particular converter depends on THD of input line current which must be as low as possible. Here speed of Three-phase induction motor is controlled in closed loop using only six switches. The controlling scheme is made using Xilinx.

In this paper Induction Motor is controlled using Xilinx block set because its hardware implementation can be possible [3]. Performance of induction motor is observed using SPWM inverter. Here in the pulse width modulation, motor is controlled using six switches in open loop system [2].

The controlling waveform is generated by comparing sinusoidal and triangular waveform using Xilinx block set. By using suitable value of (Frequency modulation index) m_f and (Amplitude modulation index) m_a switching losses and conduction losses can be limited.

Here speed is changed in steps by keeping ratio of voltage and frequency constant. The error signal is generated by comparing fundamental component of input line to line voltage of motor with reference voltage. According to that error, the value of m_a and m_f is changed. Also it has shown significant result on steady state torque and speed response. According to results and observations are made out and conclusion has been made accordingly.

II.CONVENTIONAL SPWM INVERTER TOPOLOGY

Here unipolar sine PWM technique is used, in which the voltage across the switch is equal to dc link voltage and maximum order harmonic is $m_f \pm 2$, $2m_f \pm 1$. So filter requirement is reduced which is the main advantage of PWM. Also for low values of m_f, to avoid non integer harmonic, synchronized PWM should be used and m_f should be an odd integer. To cancel out most dominant harmonic in the line to line voltage, m_f should be multiple of 3. From the lower switching losses point of view, used value of m_f is 27, and for under modulation, m_a is 0.8 and value of m_a is changed as frequency is changed but value of m_f will not changed.

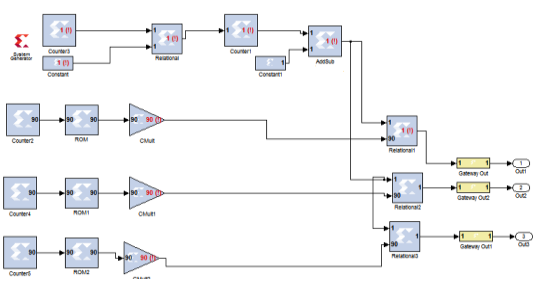

Fig.1 Generation of switching waveform for PWM using Xilinx

Figure 1 shows the control strategy and figure 2 shows the generation of PWM signals by comparing sine wave with triangular wave. Figure 3 shows complete block diagram of SPWM fed induction motor employing second order low pass filter with following parameters.

(Damping factor) $\xi = .707$
(Cutoff frequency) $\omega = 2\pi * 300$ radian/sec

Here in the PWM generation by XILINX, we use basic formulae;

Time period of wave = Explicit period * Count to value

Followings are the values taken in Xilinx block sets for PWM generation.
FPGA clock period = 10 nsec
System simulink period =1/622080
Explicit period for triangular wave = 1/622080
Explicit period for sine wave of 60 Hz = 1/7680
Explicit period for sine wave of 30 Hz = 1/3840

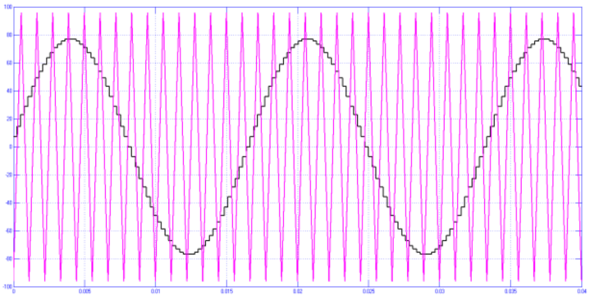

Fig. 2 Comparison of sinusoidal and triangular waveform using Xilinx

III. STRATEGY FOR CLOSED LOOP CONTROL

As the most important advantage of v/f control of three-phase induction motor is that, at every speed less than the rated speed maximum torque capability of motor is same. Also we can get higher value of torque at low speed and low current by this method.

The complete control strategy is shown in figure 4 using Xilinx block set. The subsystem for this control strategy is shown in circuit diagram using matlab as shown in figure 3. Here fundamental component of line to line voltage input to motor is subtracted from reference voltage to get the error voltage as shown in figure 3. This error voltage is then fed to PI controller through matlab block 'P' as shown in figure 4. Based on the value of output of PI controller, the value of m_a and m_f is changed.

The output of PI controller is compared with a constant block of Xilinx whose value is 70 using rational operator as shown in figure 4. The inputs to rational operator are output of constant block and output the of PI controller. The output of rational operator is fed to multiplexer (MUX) of both types, one belonging to generation of sine wave (shown by black ring) and other belonging to generation of triangular wave (shown by red ring). Considering the black ring, if the value of output of PI controller is greater than 70, then counter with 60 Hz sine wave is selected and if it is less than 70, then counter with 30 Hz sine wave is selected.

Similarly considering red ring, if the output of PI controller is greater than 70, then triangular wave with frequency 1620 Hz is selected and if it is less than 70, then triangular wave with frequency 810 Hz is selected, So that in both the cases, the value of (Frequency modulation index) m_f is 27. The output of PI controller is directly used for changing the amplitude of sine wave. The amplitude of triangular wave is not changed on changing frequency. The green ring shows the PI controller, which is fed by the error voltage 'P'.

The proposed scheme is used for getting only two speeds. One is 1726 rpm, with v/f ratio of 220V/60f and other is 860 rpm with v/f ratio of 110V/30f. By adding more counters inside the black ring we can obtain various speeds.

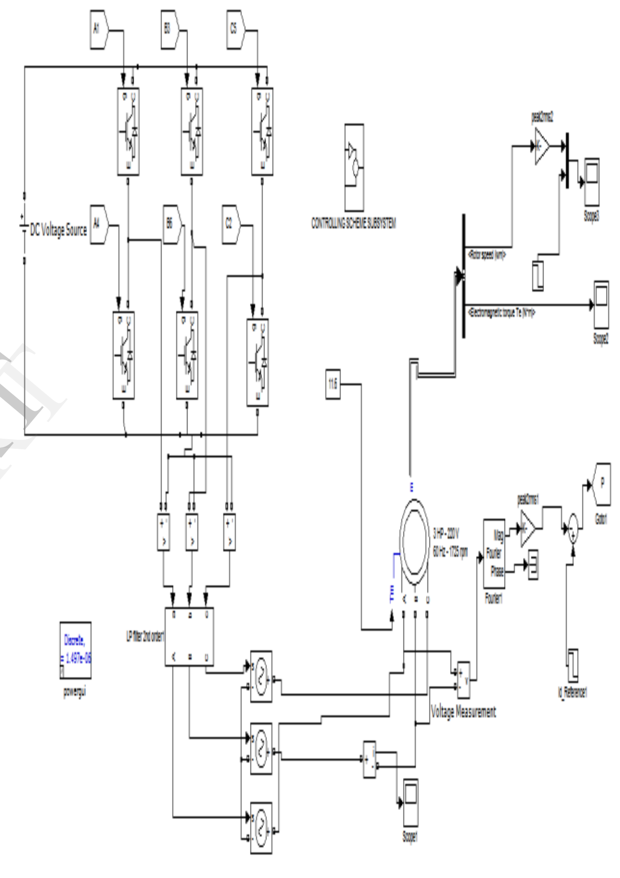

Fig. 3 Circuit diagram for V/f control of SPWM fed Three phase induction motor

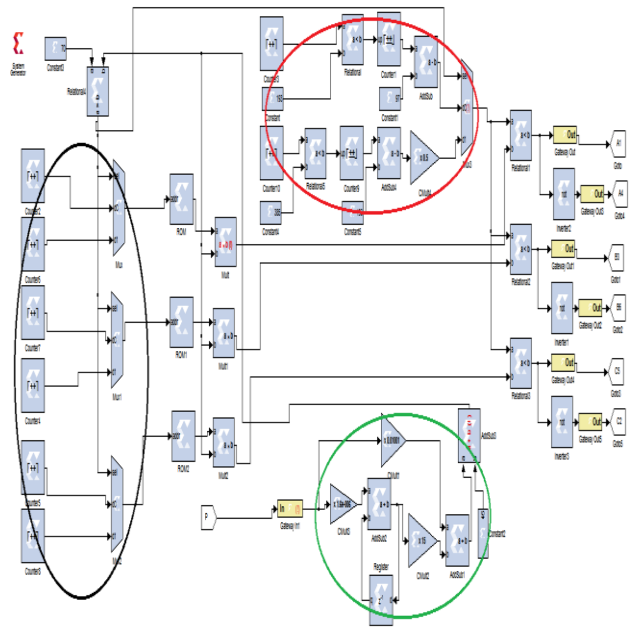

Fig. 4 controlling scheme for V/f control of SPWM fed three-phase induction motor using Xilinx block sets

IV. SIMULATION AND RESULTS

Simulation for the closed loop control of induction motor is performed using Xilinx. The parameters of three-phase induction motor used in the proposed control scheme are shown in Table I. Simulation results are obtained and are analyzed as follows. Figure 5 to Figure 9 shows the performance characteristics of induction motor. Each characteristic is plotted with respect to time. Also fundamental component of output voltage for PWM fed induction motor is 220.9 volts all the characteristics are obtained for following parameters of filter.

(Damping factor) $\xi = .707$

(Cutoff frequency) $\omega = 2\pi * 300$ radian/sec

As shown in figure 5, speed reaches steady state at about t = 0.85 second and when there is change in voltage & frequency occurs at t = 0.9 seconds from 220 volts/60 Hz to 110 volts/30 Hz, then the transient period is 0.08 seconds. After the change in v/f ratio, speed is changed from 1725 rpm to 860 rpm and ripple in steady state speed is negligible as shown in figure 5.

Table II is used to select the value of dc link voltage which is 220/.49 = 450 volts. For low THD point of view, used value of m_f is 27. For under modulation, m_a is 0.8, and value of ' m_a ' will be changed, as we change the reference voltage. For obtaining better THD, second order filter is used having values described earlier.

TABLE I: Specifications of motor

Parameters	Value
Power Rating	3 Hp
Line to line voltage	220 volts
Rotor type	Squirrel cage
Frequency	60 Hz
Rated Speed	1725 rpm
Stator resistance and Inductance [Rs(ohm) Ls(H)]:	[0.435, 2*2.0e-3]
Rotor resistance and inductance [R_r'(ohm) L_r'(H)]:	[0.816, 2.0e-3]
Mutual inductance Lm (H):	69.31e-3
Inertia, friction factor, pole pairs [J(kg.m^2) F(N.m.s) p( )]	[0.089, 0, 2]

TABLE II: Selection of DC link voltage

h \ m_a	0.2	0.4	0.6	0.8	1.0
1	0.122	0.245	0.367	0.490	0.612
$m_f \pm 2$	0.010	0.037	0.080	0.135	0.195
$m_f \pm 4$				0.005	0.011
$2m_f \pm 1$	0.116	0.200	0.227	0.192	0.111
$2m_f \pm 5$				0.008	0.020
$3m_f \pm 2$	0.027	0.085	0.124	0.108	0.038
$3m_f \pm 4$		0.007	0.029	0.064	0.096
$4m_f \pm 1$	0.100	0.096	0.005	0.064	0.042
$4m_f \pm 5$			0.021	0.051	0.073
$4m_f \pm 7$				0.010	0.030

Note: $(V_{LL})_h/V_d$ are tabulated as a function of m_a where $(V_{LL})_h$ are the rms values of the harmonic voltages.

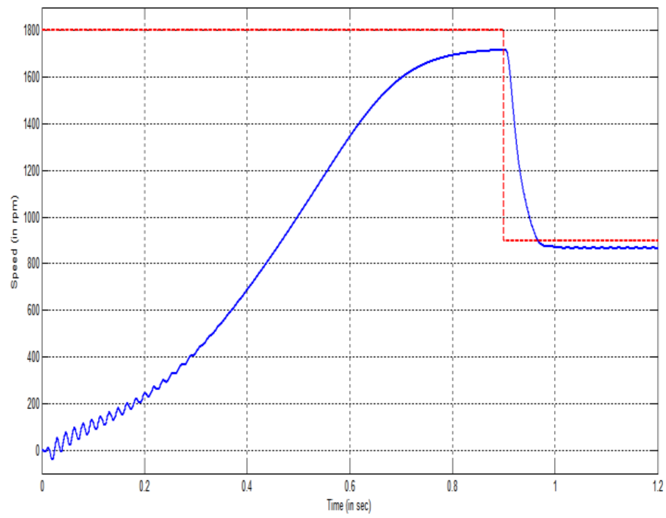

Fig.5 Complete speed characteristic of PWM fed induction motor having a change of frequency and voltage at 0.9 seconds

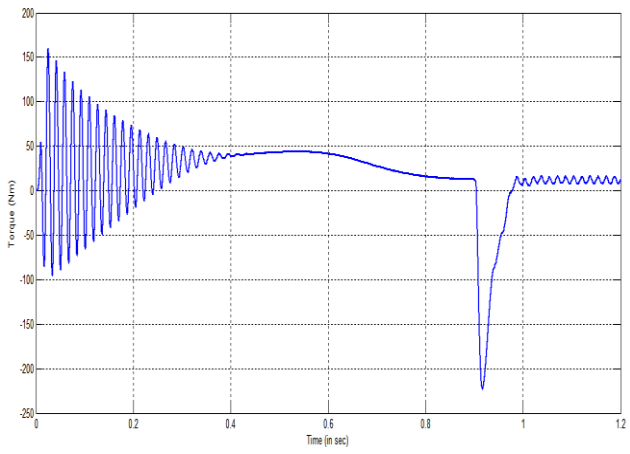

Fig. 6 Torque vs. time characteristics of SPWM fed induction motor having a change of frequency and voltage at t = 0.9 seconds

For load torque of 11.6 Nm, before the change in v/f torque ripple is very less, but after the change, torque developed by the motor is same as according to theoretical concept but torque ripple is significant as shown in figure 6. This is the only disadvantage of this method. The transient torque is also very high at t = 0.9 sec, and the value of this torque is about 200 Nm. Figure 7 shows the complete characteristic of line current input to induction motor, having the change in frequency at t=0.9 second. Here the maximum value of transient current is about 100 amperes. The frequency of current is changed from 60 Hz to 30 Hz. As shown in figure 8 and 9, the line current THD before and after change in frequency is 0.9% and 4.98%, so it is also observed that at low frequency THD of line current is more, also magnitude of line current at low frequency is increased.

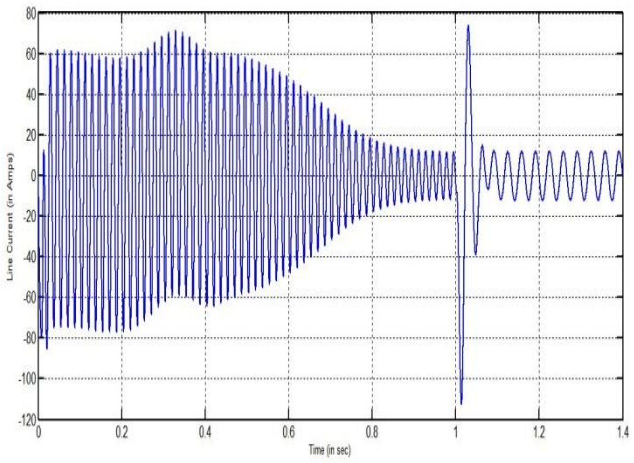

Fig. 7 Line Current vs. time characteristics of SPWM fed induction motor having a change of frequency at t=0 .9 second

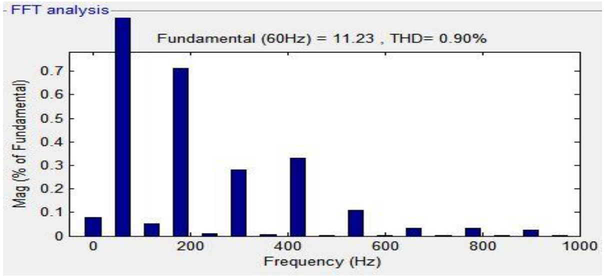

Fig. 8 FFT analysis of line current before change in frequency

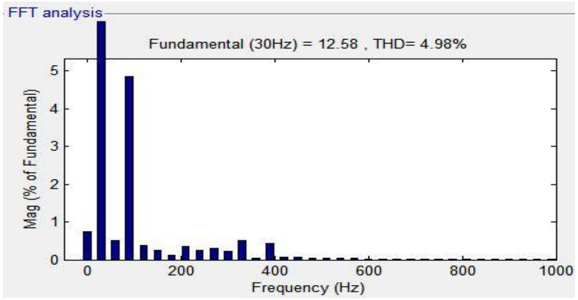

Fig.9 FFT analysis of line current after change in frequency

V. CONCLUSION

In this paper firstly Three-phase induction motor is simulated in closed loop control on MATLAB/Xilinx by SPWM inverter, then characteristics of various parameters are observed. It is observed that in PWM, only six switches are used and all the switches must be of higher rated frequency. Speed can only be varied in steps by using v/f control. Higher value of torque can be obtained at low value of current by v/f control. Hardware implementation can be possible using Xilinx. The main advantage of Xilinx is that it can produce only synchronized SPWM which improves motor performance. The only disadvantage with the proposed scheme is that torque pulsation is significant with low frequency. The line current THD is also very less before the change in voltage and frequency, although after the change it will be 4.98 %, but still satisfactory. With this method, due to use of Xilinx, if we have to increase the number of frequency steps, then additional blocks are required for the generation of both triangular wave and sine wave.

VI.REFRENCES

[1] Reddy M.H.V. and Jegathesan V.,"Open loop v/f control of induction motor based on hybrid PWM with reduced torque and current ripple," International Conference on Emerging Trends in Electrical and Computer Technology, pp.331-336, March 2011.

[2] Arulmozhiyal R., Baskaran, K, Devarajan N and Kanagaraj J, "Space Vector Pulse Width Modulation Based Induction Motor Speed Control Using FPGA," *International Conference on Emerging Trends in Engineering and Technology*,pp.742-747,Dec2009

[3] Nekoei F, Kavian, Y.S and Mahani A, "Three-phase induction motor drive by FPGA," *Iranian Conference on Electrical Engineering*, pp.1-6, May2011.

[4] Jianye Rao and Yongdong Li, "Sensor-less Drive of Induction Motor Based on A New Hybrid Cascaded Multilevel Inverter," IEEE Applied Power Electronics Conference and Exposition, 2009, pp.1819-1823, Feb. 2009

[5] Elena Villanueva, Pablo Correa and MarioPacas, "Control of a Single-Phase Cascaded H-Bridge Multilevel Inverter for Grid-Connected Photovoltaic Systems," *IEEE Transactions on Industrial Electronics,* Vol. 56, No. 11, NOVEMBER 2009

[6] Khoucha F, Lagoun M.S, Kheloui A and El Hachemi Benbouzid M, "A Comparison of Symmetrical and Asymmetrical Three-Phase H-Bridge Multilevel Inverter for DTC Induction Motor Drives," *IEEE Transactions on Energy Conversion*, vol.26, no.1, pp.64-72, March 2011

[7] Verma V and Kumar A, "Power balanced cascaded multilevel inverter fed scalar controlled induction motor pump sourced from photovoltaic source," *IEEE International Conference on Power Electronics, Drives and Energy Systems, 2012*, pp.1-6, Dec. 2012

Manoj Hirani was born in Vidisha, India, in 1989. He received B.E. degree from Samrat Ashok Technological Institute, Vidisha, India, in Electrical Engineering. He is currently M.Tech scholar at Maulana Azad National Institute of Technology, Bhopal, India. His research of interest is in power electronics, electrical machines, drives and its applications.