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ANALYSIS OF DYNAMIC PERFORMANCE COMPARISON OF DIFFERENT PWM TECHNIQUES INVERTER FED INDUCTION MOTOR DRIVES

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ABSTRACT

PWM Inverter fed induction motor drive plays a major role in industrial application such as drilling mills, crane, hoist etc. The major problem in Pulse Width Modulation(PWM) inverter is torque ripple, fluctuation in stator current and transient response of the speed. This paper deals with the modelling and simulation of dynamic performance of various PWM inverter fed induction motor drives in stationary frame. The Induction motor is modeled and stimulated in Stationary frame theory. The steady state and transient response of drive under dynamic load condition is studied and compared with different types of PWM techniques. Space vector modulation fed induction motor drive is compared with various PWM fed inverter drive and the performance is analyzed in MATLAB/Simulink.

Keywords: *Pulse width Modulation, Torque, Induction motor, MATLAB/ Simulink.*

1. INTRODUCTION

In recent days induction motor drives are commonly used in automation, engineering and household applications. It works on the principle of mutual induction. As the available supply i.e. in generation, transmission and distribution is alternating current (AC), induction motors are used in industrial drives. The induction motors out ruled the dc motor because of the following advantages i.e. simple and robust construction, able to operate in any type of environment and less maintenance cost because of the absence of commutators and brushes[1]. Based on construction the induction motors are broadly classified in to squirrel cage induction motor and slip ring induction motor but squirrel cage induction motor is mostly used in industrial drives applications. The Variable Frequency Drives (VFD) plays a major role in industrial and home applications.

For the drives control applications, induction motors are fed from pulse width modulated inverter i.e. by controlling the stator voltage of the induction motor we can able to control the speed of the drives[2].

Pulse Width Modulated inverter fed drives are progressively applied in industrial applications.

There are numerical PWM techniques which can be used to obtain variable frequency and variable voltage. No single PWM technique is best suited for all applications[3].

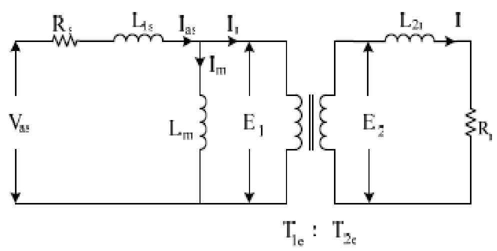

Figure 1: Equivalent Circuit of Induction motor

Induction motor can be modeled in three reference frames i.e. stationary reference frame, rotor reference frame and synchronous reference frame. The selection of reference frame depends on the type of application[4]. Main limitations and

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requirements of inverter fed induction motor drives are harmonics , switching frequency, better dc bus utilization factor and the torque ripples. In this paper modelling and simulation of various PWM inverter fed induction motor drive and two-level diode clamped space vector modulation inverter in stationary theory is compared and its dynamic performance is observed using MATLAB/Simulink. Comparison of dynamic simulation of torque response, stator currents and settling time response of space vector modulation fed induction motor drive and various PWM techniques are presented.

2. MODELLING OF INDUCTIONMOTOR

Induction motor can be modelled using three reference frames theory. Depending upon our applications we can choose appropriate reference frame theory. The major advantages of reference frame transformation is number of voltage equation is reduced and then the time varying voltage equations is changed in to time invariant one[4]. The first step in the modelling of induction motor is to determine the equivalent circuit parameters.

The equivalent circuit elements of the induction motors are obtained from No-load test, DC test, Blocked Rotor test. These tests are carried out to determine the elements of the equivalent circuit – R_{sr}, R_{rr}, X_{sr}, X_{rr} and X_{ml}[5].

Where R_{sr}, R_{rr} are resistances in stator and rotor side similarly X_{sr}, X_{rr},X_{ml} are stator , rotor and mutual inductances respectively.

In the stationary reference frame the angle theta is zero. In rotor frame the d-q axes rotate at rotor speed. In the synchronous frame the d-q axes rotate at synchronous speed. The general stator and rotor voltage equations of three phase induction motor in arbitary frame are[2]

$$V_{qsr} = R_{sr} i_{qsr} + p\lambda_{qs} r + \Omega\lambda_{dsr} \quad (1)$$

$$V_{dsr} = R_{sr} i_{dsr} + p\lambda_{dsr} - \Omega\lambda_{qsr} \quad (2)$$

$$V_{qrr} = R_{rr} i_{qrr} + (\Omega - \Omega_{rr})\lambda_{drr} r + p\lambda_{qrr} \quad (3)$$

$$V_{drr} = R_{rr} i_{drr} - (\Omega - \Omega_r)\lambda_{qrr} + p\lambda_{drr} \quad (4)$$

where V_{qsr} is the stator q axes voltage, V_{dsr} is the stator d axes voltage .

3. SPACE VECTOR MODULATION

The main advantage of using the space vector modulation is the increased use of dc bus utilization , less harmonics and easier digital realization. In a three phase two level space vector modulation inverter there is twenty possible combinations($6c_3 = 20$). Out of these twenty combinations there is four illegal combinations for each leg, so for three leg there will be twelve illegal combinations. So (20-12) we will get eight combinations. The eight different possible combinations of space vectors are(000,001,010,011,100,101,110,111).

"1" represents that the upper switch of leg is turned on and "0" corresponds to the lower switch of the leg[6]. The SVPWM generates lesser harmonics in three phase AC voltage which is supplied to the AC motors. It also allows 15.5% increased utilization of the DC bus compared to other techniques. SVPWM can be realized using the following steps

Step 1 :
Convert three phase voltage quantities in to two phase quantities using the alpha-beta transformation. Then determine the voltage in alpha axes, beta axes and the reference voltage.

Step 2 :
The second step is to determine time duration of voltage vectors i.e. T1for vector V1, T2 for vector V2, T0 for null vector.

Step 3 :
The third step is to determine the switching time for each devices.

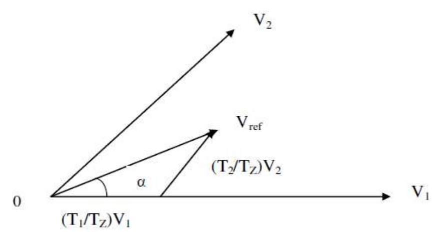

Figure 2. Reference vector with respect to sector1

3.1 In the alpha axis:

V1T1+V2T2cos60=Vrefcos θ TS (5)

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$$VdcT1+VdcT2\cos 60=Vref\cos\theta TS \quad (6)$$

amplitude ratio, $a=\dfrac{V_{ref}}{V_{dc}}$

$$V1=V2=V3=V4=V5=V6=Vdc \quad (i)$$

substituting (i) in equation(5)

$$T1+T2\cos 60=a\cos\theta TS \quad (7)$$

$$T1=\frac{aT_s\sin(60-\theta)}{\sin 60} \quad (8)$$

3.2 In the Beta axis:

substituting (i) in beta axis,

$$Ts\sin 60=a\sin\theta Ts \quad (9)$$

$$T2=\frac{aT_s\sin\theta}{\sin 60} \quad (10)$$

Then

T0=Ts -(T1+T2)

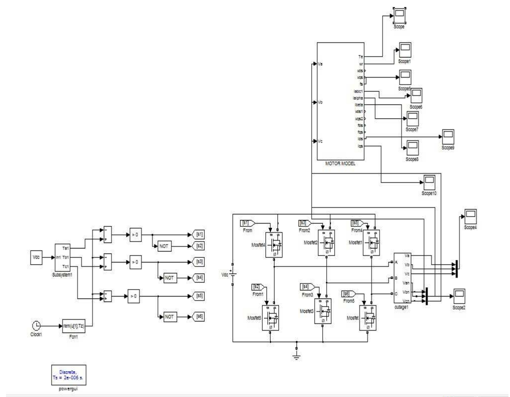

Figure 3: Space Vector Pulse Width Modulation Fed Induction Motor Drive

4. SINUSOIDAL PULSE WIDTH MODULATION INVERTER

Sinusoidal PWM (SPWM) technique is the well know Pulse width Modulation techniques which is extensively used in the industrial applications.. For the implementation of the SPWM, the frequency of the carrier wave must be greater than the reference sine wave frequency. The intersection of the carrier wave V_c and the reference sine wave V_r determines the switching instants and commutation of the modulated pulse In the SPWM inverter the utilization of the DC bus voltage is 78.8%[3].

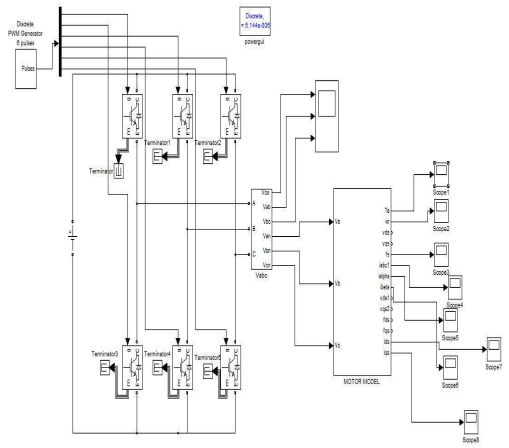

Figure 4: SPWM Fed Induction Motor Drive

5. TRIPLEN HARMONICS INVERTER

Induction motor drive fed by Triplen Harmonics PWM inverter is similar to the space vector modulation, but the implementation scheme is different. Triplen harmonic modulation technique increases the DC bus utilization factor to 90.1% which is higher than the SPWM technique.

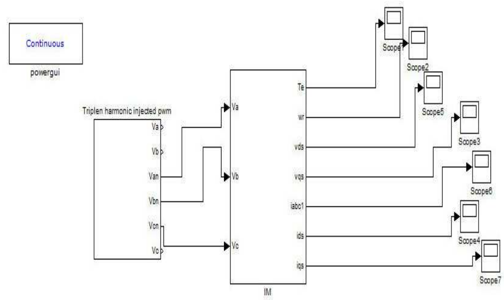

Figure 5: Triplen Harmonic PWM Fed Induction Motor Drive

6. MULTILEVEL INVERTER

Multilevel inverter plays a predominant role in high power applications. Multilevel inverter has several advantages compared to other PWM techniques such as less voltage stress and less harmonics due to the exact sinusoidal resemblance of output waveform. As the number of levels is increased the harmonics will be low but the number of power semiconductor devices is more and the cost is higher. In this paper induction motor in stationary frame is fed by eleven level cascaded H bridge inverter. Cascaded H Bridge inverter consists of number of H Bridge cells which are connected in cascaded manner[7]. Each cell is supplied by

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separate dc source which may be a capacitor.

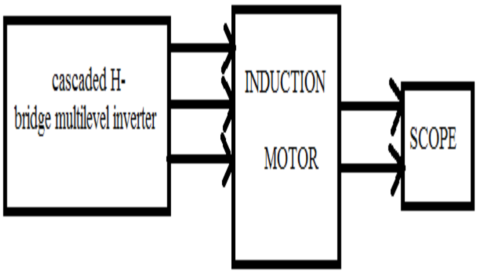

Figure 6: Multilevel inverter Fed Induction Motor Drive

7. SIMULATION RESULTS

7.1 Dynamic Conditions:

Torque applied to the motor is zero during 0 to 0.7 ms, i.e. the motor is running in no-load condition.

The torque applied to the motor is increased from 0 to 30 N-m at 0.7 ms.

During 0.9 ms the torque applied to the motor is reduced from 30 to -30 N-m as a result the torque becomes zero after 0.9 ms.

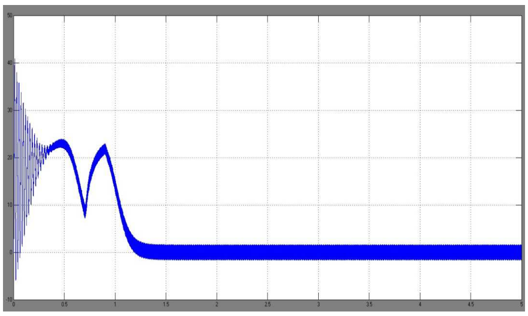

Figure 7: Torque Waveform Of Space Vector Modulation Fed Induction Motor

Figure 7: shows the simulation of torque response waveform of SVPWM fed induction motor in stationary reference frame with dynamic load conditions. It is observed that during 0 to 0.7 ms the motor is operated in noload condition as a result the torque reaches to steady state . During the time of 0.7 ms the torque applied to the motor is 30 N-m therefore the torque increases. At 0.9 ms the torque is decreased to zero as a result the motor runs in no load condition.

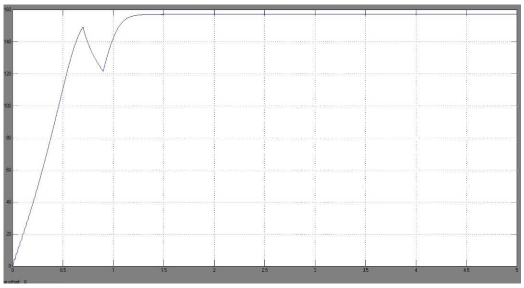

Figure 8: Speed Response Waveform OF Induction Motor Fed By Space Vector Modulation

Fig 8: shows the simulation of speed waveform of induction motor in stationary frame with dynamic load conditions. It is noted that at 0 to 0.7 ms the motor is operated in noload condition therefore the speed reaches its rated speed. At 0.7 ms load torque of 30 N-m therefore the torque increases and the speed decreases. At 0.9 ms the load torque is decreased to zero as a results the motor runs in no load condition and the speed increases and reaches the rated speed.

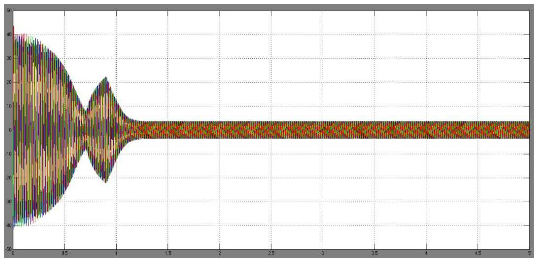

Figure 9: Stator Currents Of Space Vector Modulation Fed Induction Motor

Fig 9: shows the simulation waveform of stator currents induction motor drive in stationary reference frame fed by SVPWM with dynamic load conditions. It is noted that during 0 to 0.7 ms the motor is operated in noload condition therefore the stator current reaches its rated value. At 0.7 ms load torque of 30 N-m therefore the torque increases, speed decreases and the stator current increases. At 0.9 ms the load torque is decreased to zero as a results the motor runs in no load condition and the speed increases to rated value and the stator current decreases to rated value.

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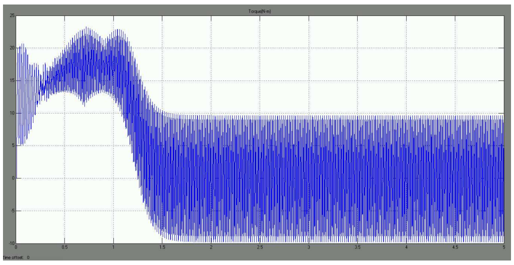

Figure 10: Torque Response Waveform Of Induction Motor Fed By Cascaded H-Bridge Eleven Level Inverter

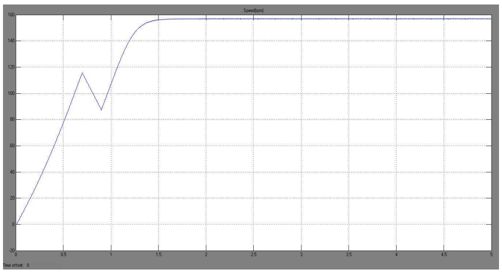

Figure 11: Speed Waveform Of Induction Motor Drive Fed by Cascaded H-Bridge Eleven Level Inverter

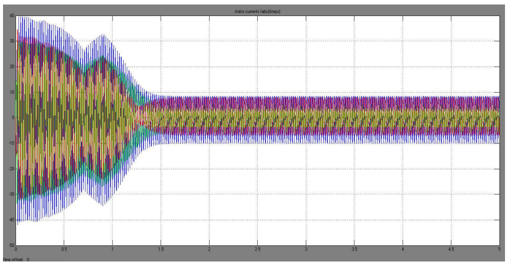

Figure 12: Stator Currents Of Induction Motor fed By Cascaded H- bridge Eleven Level Inverter

Fig.10 shows the simulation results of torque response waveform of induction motor in stationary frame fed by cascaded H-Bridge eleven level multilevel inverter in dynamic load conditions. Fig.11 shows the simulation results of speed response waveform of induction motor fed by multilevel inverter in dynamic conditions.

Fig.12 shows the simulation of stator current waveform induction motor in stationary frame fed by eleven level inverter fed with dynamic load conditions. It is observed that at 0 to 0.7 ms the motor is operated in noload condition as a result the torque reaches to steady state, the speed reaches to rated value and the stator current also reaches to ite nominal value . At 0.7 ms load torque of 30 N-m therefore the torque increases, speed decreases and the stator current increases. At 0.9 ms the load torque is decreased to zero as a result the motor runs in no load condition, speed increases and the stator current decreases to rated value.

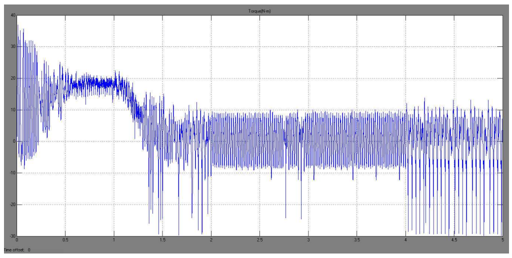

Figure 13: Torque Waveform Of Triplen Harmonic Inverter Fed Induction Motor

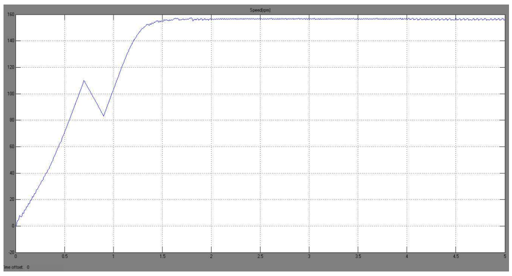

Figure 14: Speed Waveform Of Triplen Harmonic Fed Induction Motor

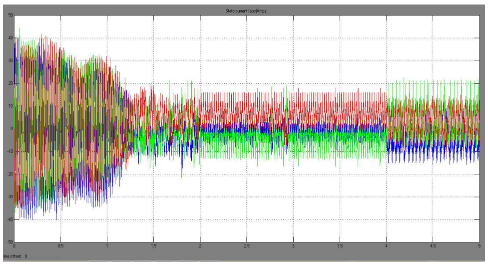

Figure 15: Stator Currents Of Triplen Harmonic Inverter Fed Induction Motor

Fig.13 shows the simulation of torque response waveform of induction motor drive in stationary frame fed by Triplen harmonic PWM inverter in dynamic conditions. Fig.14 shows the simulation of speed response waveform of induction motor fed by Triplen harmonic injected PWM inverter in dynamic conditions.

Fig.15 shows the simulation of stator currents waveform of induction motor drive in stationary reference fame fed by Triplen harmonic PWM inverter in dynamic conditions. It is noted that at 0 to 0.7 ms the motor is operated in noload condition as a result the torque reaches to steady state value, the speed reaches to rated value and the stator current also reaches to ite nominal value .

At 0.7 ms load torque of 30 N-m therefore the torque increases, speed decreases and the stator current increases. At 0.9 ms the load torque is

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decreased to zero as a result the motor runs in no load condition, speed increases and the stator current decreases to rated value.

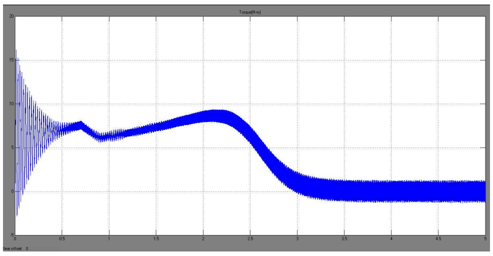

Figure 16: Torque Waveform Of SPWM Fed Induction Motor

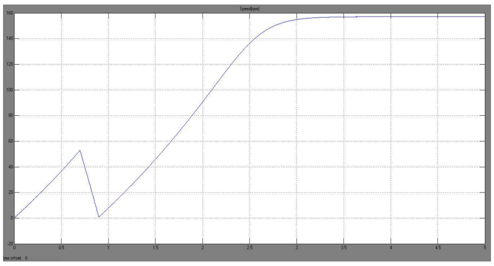

Figure 17: Speed Waveform Of SPWM Fed Induction Motor

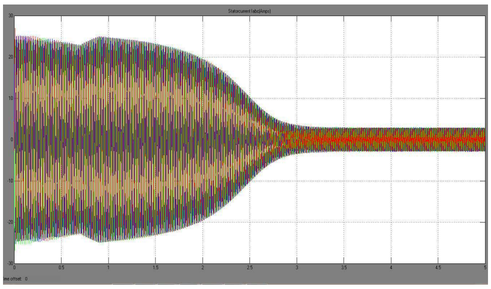

Figure 18: Stator Currents Waveform Of SPWM Fed Induction Motor

Fig.16 shows the simulation of torque waveform of SPWM fed induction motor drive in dynamic conditions. Fig.17 shows the simulation of speed waveform of induction motor in stationary frame fed by SPWM inverter with dynamic load conditions.

Fig.18 shows the simulation of stator currents waveform of SPWM fed induction motor drive with dynamic load conditions. It is noted that at 0 to 0.7 ms the motor is operated in noload condition as a result the torque reaches to steady state, the speed reaches to rated value and the stator current also reaches to ite nominal value .

At 0.7 ms load torque of 30 N-m therefore the torque increases, speed decreases and the stator current increases. At 0.9 ms the load torque is decreased to zero as a result the motor runs in no load condition, speed increases and the stator current decreases to rated value.

7.2 Induction motor Specifications:

Table 2: Induction Motor Specifications

Symbol	Name	Values Of Input
P	Pole Number	4
N	Speed	1500rpm
f	Supply Frequency	50Hz
Rs	Resistance Of Stator	1.89
Rr	Resistance Of Rotor	1.36
L_{ls}	Leakage Inductance Of Stator	4.9e-3
L_{lr}	Leakage Inductance of Rotor	4.9e-3

8. COMPARISON RESULTS

Table 3: Torque Ripples In Different PWM Technique

PWM Technique	Torque Ripples
Sinusoidal Pulse Width Modulation	2.1 %
Multilevel Inverter	18 %
Triplen Harmonic Injected PWM	16 %
Space Vector Modulation	1.3 %

Table.3 shows the torque ripples of induction motor in dynamic conditions with different PWM schemes.

It is observed that space vector modulation fed induction motor shows low ripples of about 1.3 N-m.

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Table 4: Settling Time Of Torque And Speed Response In Different PWM Technique

PWM Technique	Torque Response	Speed Response
Sinusoidal Pulse Width Modulation	2.1ms	2.1ms
Multilevel Inverter	0.6ms	0.6ms
Triplen Harmonic Injected PWM	0.7ms	0.7ms
Space Vector Modulation	0.3ms	0.3ms

Table.4 shows the settling time of speed and torque response of different PWM inverter fed induction motor operated in dynamic conditions. It is observed that the space vector modulation fed induction motor shows faster settling time than other PWM techniques.

9. CONCLUSION

The dynamic performance comparison of different PWM fed induction motor drive shows that the space vector modulation fed induction motor drive produces less torque ripples compared to other PWM technique also the setting time of torque and speed response space vector modulation is much faster when compared to other techniques. The above discussion shows that the Space vector modulation technique is best suited for drives applications in open loop and closed loop system. In Space Vector Pulse Width Modulation the DC bus utilization is also higher when compared to other PWM techniques. The digital realization of the SVPWM is also easier which make it best suitable for drives control applications.

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