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Analysis and Comparison of DTC Technique in 2 Levels & 3 Level Inverter Fed Induction Motor Drive

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***Abstract*- Two level inverter fed technique has dynamic performances but very large amount of torque ripple is appears. To reduce torque ripple higher level of inverter is used which has large number of voltage vector which is helps to reduce torque ripple. Three level diode clamped inverter is used. In order to develop high dynamic characteristics, direct torque control technique is applied. Squirrel cage induction motor is used as ac motor drive which is widely used in industrial applications. Multilevel inverter also used to reduce THD in current and common mode voltage can be minimized. The simulation results carried out by using MATLAB/ Simulink.**

***Index Terms*- 3L-NPC MLI, Induction motor, hysteresis band controller, torque ripple.**

INTRODUCTION

Due to its simplicity, ruggedness, less maintenance, low cost and also can be used in aggressive environment, an induction motor is being workhorse of the industrial applications. A motor which is used widely for adjustable speed drives.

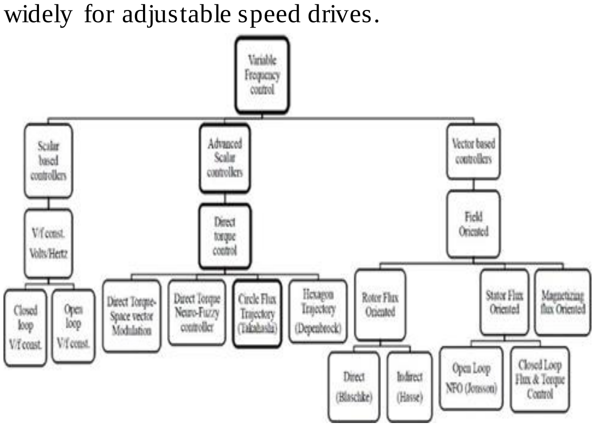


Figure 1: Types of speed control methods of an Induction motor

This is happened due to use of power electronics and digital data processor which allows easily implementations of sophisticated control techniques. To vary speed of IM, there are many speed control methods like scalar control, vector control and advance scalar control. All the Adjustable Speed Drive techniques further explained in Figure 1. Circular flux trajectory is developed by Ishao takahashi which is applied in this work.

Torque ripple appears a lot in conventional two level voltage source inverter. Minimization of torque ripple is possible with the help of different algorithms in constant switching frequency, use of the more number of phases in an induction motor and two level inverters, apply different type of controllers like fuzzy (nuero fuzzy), artificial intelligence, and also can use higher level of Inverter. Simplicity of the technique should be maintained.

Hence, three level neutral point clamped is used which is highly applied in industrial due to its advantages of smoother waveform, less switching frequency, lower costs, and less distortion.

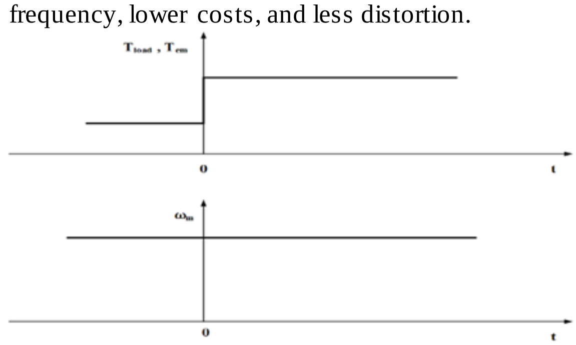


Figure 2: Need for controlling the torque

Controlling of the electromagnetic torque is mandatory, figure 2 shows the need for controlling the torque. When rotor speed is constant load torque has change and also step change required in electromagnetic torque. DTC is applicable especially where high torque per ampere required for high efficiency. [2]

PRICIPLE OF DIRECT ORQUE CONTROL

In direct torque control technique, electromagnetic torque and stator flux can be controlled independently and directly by selecting optimum switching voltage vectors.

Block diagram of two level inverter fed DTC is shown in Figure 3. Three phase induction motor is fed by two level voltage source inverter. Output voltage and current of inverter is converted two axis from three axis.

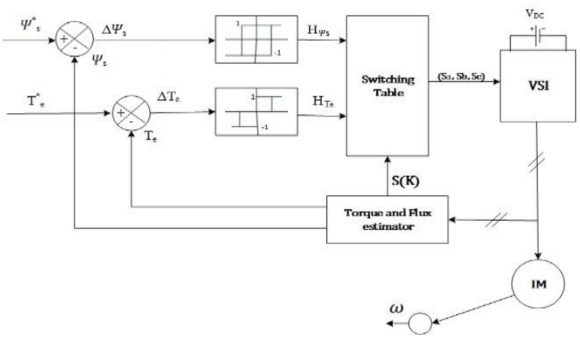


Figure 2: Block diagram of two level-VSI fed DTC

By using this two axis voltage and current, torque, flux and theta can be calculated. Which is referred estimated value which is deducted from reference value and gives error. Error is applied to hysteresis band, limit the certain value and outcome will be the digital form according the status of torque & flux. For two level inverter six sectors appears. Switching table incorporates with torque, flux and sector gives switching pulses for every switch used in inverter. Hence closed loop control mentioned.

$\widehat{T_e} = \frac{3}{2}\frac{P}{2}(\widehat{\Psi}_{ds}\hat{\imath}_{qs} - \widehat{\Psi}_{qs}\hat{\imath}_{ds})$ ……… (6)

$\widehat{\Psi_s} = \sqrt{\widehat{\Psi}_{qs}{}^2 + \widehat{\Psi}_{ds}{}^2}$ ……… (7)

The reference between desired value and actual value of torque and flux gives error which is given to torque and flux hysteresis controller. The output of hysteresis controller in the digital form

$H_{\Psi_s} = 1 \; if \;\; \Delta\Psi_s > +\mathrm{HB}_{\Psi s}$,

$H_{\Psi_s} = -1 \; if \;\; \Delta\Psi_s < -\mathrm{HB}_{\Psi s}$ ……… (8)

For torque control

$H_{T_e} = 1 \; if \;\; \Delta T_e > +\mathrm{HB}_{T_e}$,

$H_{T_e} = 0 \; if \; -\mathrm{HB}_{T_e} < \Delta T_e < +\mathrm{HB}_{T_e}$,

$H_{T_e} = -1 \; if \;\; \Delta T_e < -\mathrm{HB}_{T_e}$ ……… (9)

Direct flux control:

From equation 5, stator flux is directly dependent on voltage vector with respect to its time.

$\Delta\overline{\Psi}_s = \bar{V}_s.\Delta t$ ……… (10)

Flux can be controlled by applying appropriate switching voltage vector over a small period of time.

Direct torque control:

Incremental torque is expressed in terms of stator flux rotor flux and the angle between stator and rotor as wisely illustrated in eq^n 11. Due to large time constant rotor has no more role in torque production. Torque change is directly proportional to $\Delta\Upsilon$ and change in stator flux.

$\Delta T_e = \frac{3P}{4}\frac{L_m}{L_r L_s{}'}|\Psi_r||\overline{\Psi}_s + \Delta\overline{\Psi}_s|\sin\Delta\Upsilon$ ……… (11)

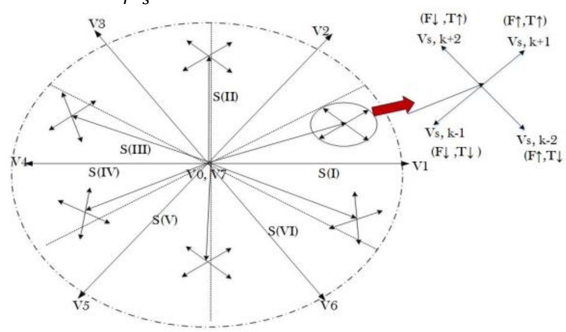


Figure 3: Selection of voltage vectors at changes in flux and torque [5]

Two level Voltage source inverter:

In steady state condition, losses increased in motor harmonics and occur acoustic noise due to use of current source inverter. In Figure 4 , basic configuration of 3-φ, 2L-VSI illustrated. S_{A1} is upper switch of lag A and S_{A2} is being complementary switch. This follows all the phases. Output voltage in the form of $+V_{dc}$ & $-V_{dc}$.

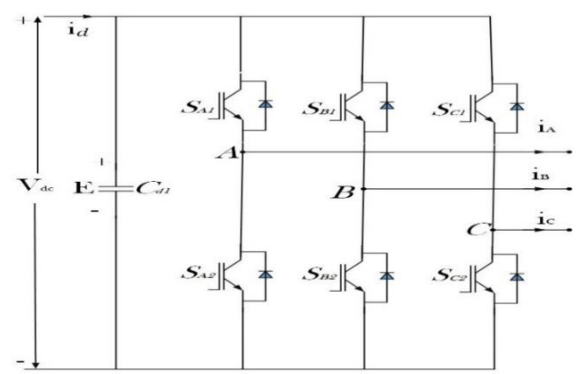


Figure 4: Circuit diagram of two level voltage source inverter

Inverter switching state pattern is divided into 6 segments for two level voltage inverter as follows:

-30 to + 30 degree each and as follows.

V_0, & V_7 are zero voltage vector has magnitude of zero.

V_1 to V_6 are non- zero (active) voltage vector having $\frac{2}{3}V_{dc}$ magnitude.

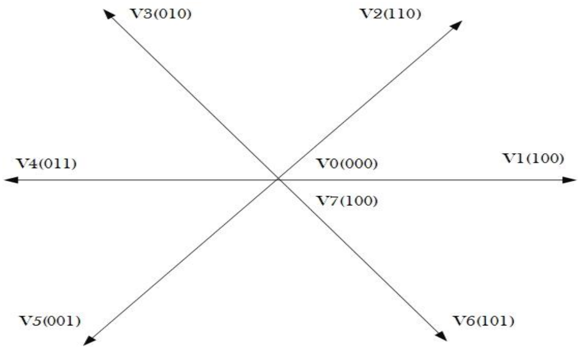


Figure 5: Voltage vector for two level inverter

Look up table for voltage switching selection of two level inverter in Table 1. For every sector, selection of voltage vector is dependent on increment and decrement of torque and flux which is comes at output of hysteresis controller.

Table 1: LUT for 2 level VSI fed DTC

Hψ	-1(↓)			1(↑)		
Te	-1(↓)	0	1(↑)	-1(↓)	0	1(↑)
S(I)	V5	V0	V3	V6	V0	V2
S(II)	V6		V4	V1		V3
S(III)	V1		V5	V2		V4
S(IV)	V2		V6	V3		V5
S(V)	V3		V1	V4		V6
S(VI)	V4		V2	V5		V1

DTC TECHNIQUE OF 3L-NPC

Figure 6 shows neutral point clamped inverter applied direct torque control is used. Here 5 Hp squirrel induction motor is used. Hysteresis band is 4 level for torque controller and 2 level for flux hysteresis band controller.

Here, 3level inverter has total 12 sectors are shown. Total number of voltage vectors are 27 including non-zero and zero state. According to magnitude of voltage vectors they are divided in following categories.

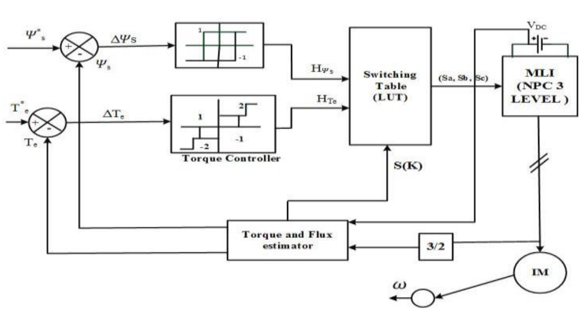


Figure 6: Block diagram of 3 level DTC technique

Zero voltage vectors (zero magnitude)- V0

Small voltage vectors (0. 33 Vdc magnitude)- V1-V6

Medium voltage vectors (0.57 Vdc magnitude)- V6-V12

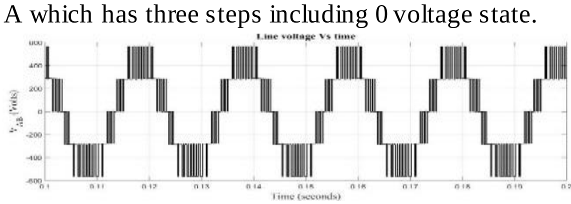
Large voltage vectors (0.66 Vdc magnitude)- V12-V18

Table 2: System parameters for simulation

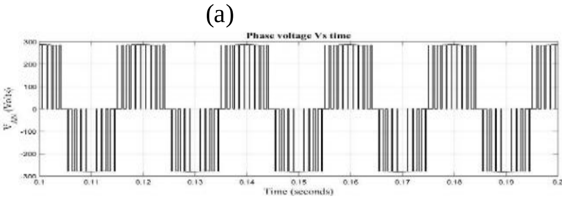
Sr. No.	Apparatus	Description
1	Induction motor	P=3750W, V_{ac}=400V, ω_r=1440 RPM, P=4, R_s=2.405Ω, R_r=2.395Ω, L_s= L_r = 6.839mH, L_m= 0.2722 H, J= 0.0711 kg.m^2
2	Inverter DC link voltage	Vdc=600V

SIMULATION & RESULTS

Various parameter comparison & analysis of two level and three level inverter fed IM by using Table 2 parameter at 10 N.m mechanical torque. Figure 7 shows voltage waveform of 3 level NPC multilevel inverter. Figure 7(a) line voltages of Phase A which has five steps & Figure 7(b) Phase voltages of Phase A which has three steps including 0 voltage state.



(a)



(b)

Figure 7: (a) Line voltage (b) Phase voltage of A phase of 3L-NPC fed IM

Table 4 gives the comparison of two level & three level inverter parameter including ripple and THD. It clearly shows three level has reduced valued of current THD in %.

Table 3: Comparison of 2 & 3 level inverter fed IM

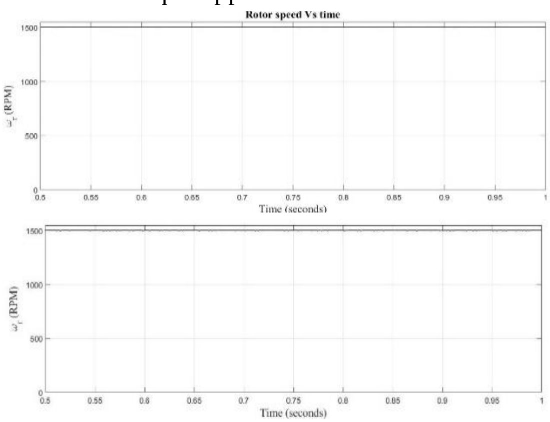
Level	Parameter		
	Ripples		THD%
	Torque(N*m)	Current (A)	Current
2 Level	7.9 to 12.9	-4.6 to 5.2	8.73
3 Level	8.7 to 12.2	-4.8 to 4.4	4.76

Two level & three level technique has sector selection is important to evaluate appropriate switching selection which should be 6 for two level and 12 for three level.

For variable frequency drive, speed should vary from lower to full speed range and applied mechanical torque can also from no load to full load. Hence, the output results of the motor in various situation divided in such cases:

Case 1**:** Rotor speed and electromagnetic torque at no load (0 N.m.)

At no load no change in rotor speed, electromagnetic has reduce torque ripple.



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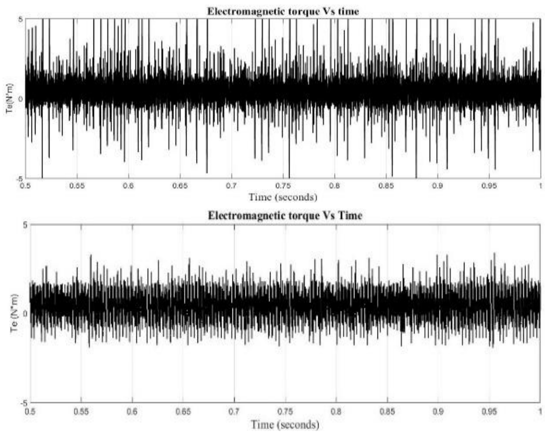

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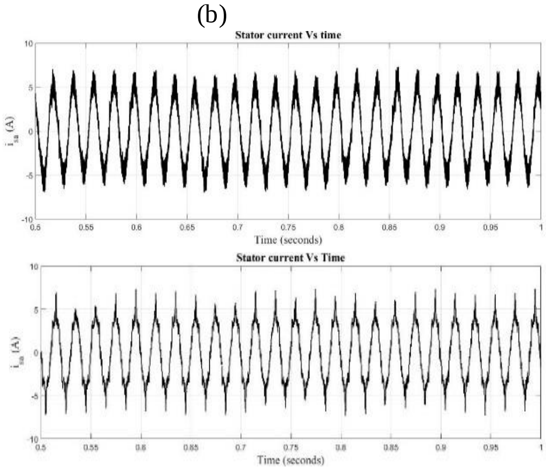
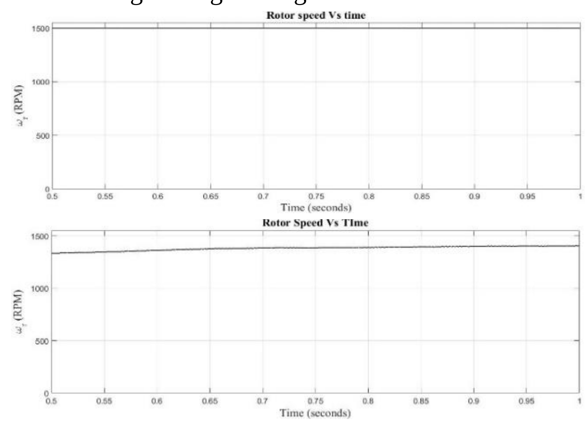


(c)

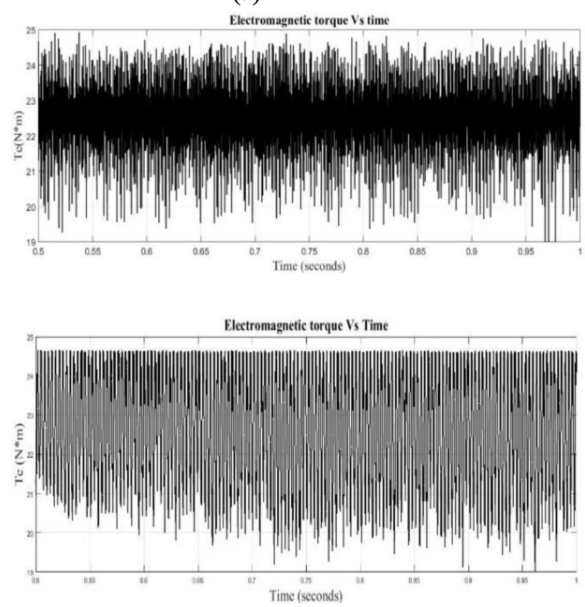
Figure 8: DTC of 2L-Inverter fed IM & 3L-NPC MLI fed IM at no load with full speed (a) Rotor speed, (b) electromagnetic torque & (c) stator current of phase A

Case 2: Rotor speed and electromagnetic torque at full load (22 N.m.)

Rotor speed has slight change in three level technique. Torque ripple minimized compared to two level no large charge change in stator current.



(a)



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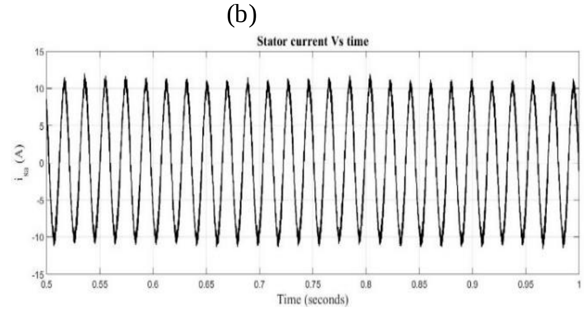

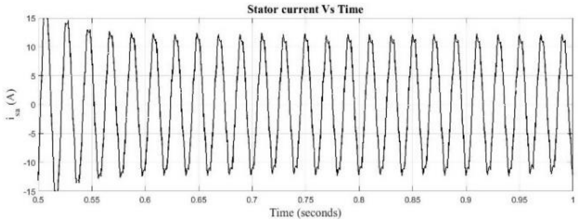

(c)

Figure 9: DTC of 2L-Inverter fed IM & 3L-NPC MLI fed IM at full load with full speed (a) Rotor speed, (b) electromagnetic torque & (c) stator current of phase A

Table 4: Results Comparison for both technique

Sr no	Technique	Torque (N.m.)	Speed (RPM)	Speed variation		Torque ripple		Current ripple	
				Min	Max	Min	Max	Min	Max
Constant speed and torque									
1	2 level	0	1500	1499	1500.5	-4	6	-8	6
	3 level			1500	1500.4	-4.5	5	-7	7
2	2 level	22	1500	1499	1499.8	18	25	-11.5	11.2
	3 level			1500	1500.2	19	23	-11	11
3	2 level	10	1500	1499.4	1500.4	6	16	-8	8
	3 level			1499.6	1500	7	15	-8.5	8

CONCLUSION

To minimize torque ripple, here comparison of two level and three level inverter fed DTC technique is applied. Two level has dynamic response but large torque ripple. Which is minimized by using three level inverter fed technique. Analysis comparison in various parameter at different load torque and for various rotor speed. Here no load and full load condition is applied and analyzed. Various parameter has been considered like speed, torque and current.

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