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Performance Comparison of Multilevel Inverter Topologies for Closed Loop v/f Controlled Induction Motor Drive

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Abstract

This work focuses on investigating the closed loop model of Multilevel inverter fed Induction Motor Drive with constant V/f method. Multi level inverter generates stepped sinusoidal waveforms of lower harmonics with increasing levels. Cascaded MLI of 5 level and conventional VSI are synthesized using sinusoidal pulse width modulation (SPWM). The multi level inverter output so developed assuring the least THD is then passed through a filter to get a better sinusoid output. The filtered output is then fed to the induction motor, mathematically modeled using procedural sequence of equations. Induction motor speed control is employed by regulating the slip speed maintaining constant V/f. PI controller is implemented to ensure the motor speed at its reference speed. Closed loop scheme is tested for various reference speed and disturbances in dynamic load and speed. Comparative evaluation of transient and steady state performance characteristics, system efficiency and cost effectiveness is analyzed for closed loop MLI as well as VSI fed induction motor drive. MATLAB/SIMULINK setup, an effective tool for simulation is used for validating the results.

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Keywords: Cascaded H-Bridge Multilevel Inverter(CHBMLI); Induction motor;V/f control.

1. Introduction

Electrical drive is simply an electromechanical configuration bonded by energy synthesis for motion control[1].Drives have turned to be dominant player in the industrial sector and guarantee a path for wide explorations. Researchers nowadays emphasize the enhancement of sophisticated electric drive [2].Induction motor (IM) draws major attention for innovative progress in drives. In induction motor draws major attention for innovative progress in drives. In induction motors, stiff speed prevails with regard to load variances. A motor operates in extreme ranges with wide differential speed in absence of a drive. But speed regulation is ensured with drive, minimizing the extreme level operation and thus paves the way for necessity of drives. Induction motor follows various control schemes classified as; a) Scalar control b) Vector control

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Scalar controlled type drives being easier to build, are widely preferred in industries [2],[3],[4].Scalar control differs from vector control in its procedure of monitoring variables. Scalar control as its name reveals considers the magnitude change in variables and neglects the machine coupling effect. Vector/field oriented control is the scheme in which magnitude in addition to the alignment of phase needs to be controlled. Few scalar control options are Stator voltage control, Stator frequency control, Stator voltage and frequency control, Stator current control, Stator rotor-resistance control, and Slip energy recovery control[2],[3],[4],[5],[6].

Out of these schemes, variable voltage and frequency (V/f) is the easily implementable, simpler and popular scheme in industries. Any scheme can be in two modes either in open loop or closed loop. Closed loop outwits the open loop in the sense that closed loop yields precise control when load is applied. Supply configuration used for induction motor drive is the dc-ac converter. Voltage source inverter (VSI) and Multi-level inverter (MLI) are the major power circuits for induction motors. Any machine exhibits efficient performance with harmonic free sinusoidal supply. Three-phase VSI with six power switches, connected to DC input synthesize quite quasi-square waved line voltage inclusive of harmonics. MLI is the topology rooted as an initiative harmonic minimization, generating a stepped sinusoid. Let the levels in MLI numbered as ‘m’and harmonics be ‘h’, they are related as inversely proportional. The rise in ‘m’ reflects the output to intend better sinusoidal profile. MLIs are categorized as Cascaded H-Bridge, Diode Clamped, and Flying Capacitor. The proposed work is targeting on feasible electric drive suitable for variable speed applications in industries.

2. Cascade MLI fed Induction Motor

Three phase IM requires 3 phase ac supply in an attempt of limiting starter current and is powered using simplified cascaded MLI .It requires dc-inputs and transform it to alternating output wave with the triggering role of power-electronic switches. Mostly IGBTs occupy dominant choice compared to rest switches. For five level CHBMLI, five steps contribute to the output wave-shape. With V_{dc} as inputs, then the outputs take levels, $+2V_{dc}$, $+V_{dc}$, 0, $-V_{dc}$, $-2V_{dc}$. Fig.1 shows 5 level simple H-bridge cascaded MLI.

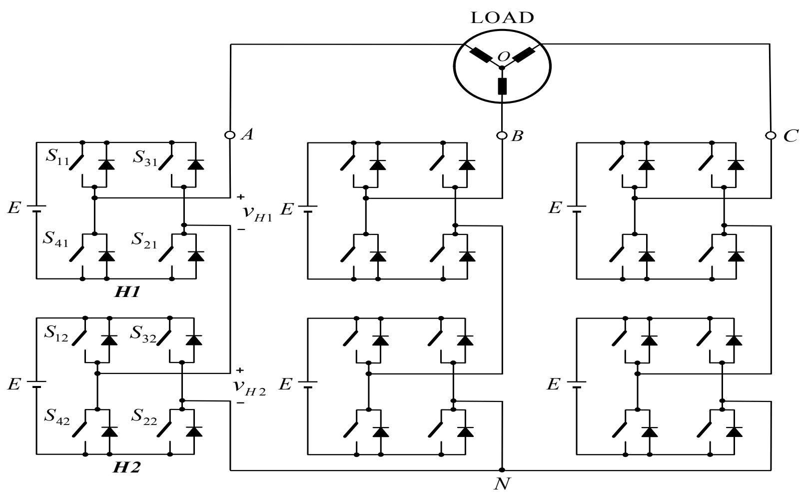


Fig. 1. Five level cascaded MLI

In brief, the MLI output levels , m= (2*i) + 1, where i = dc inputs. PWM leads the vital role in circuit action by firing the respective switches (IGBTs) at the exact instants to output the proper reaction. Various techniques exist and few are; Space vector, selective harmonic-elimination involving complex computations, Carrier PWMs etc. One adopts Carrier-based PWM (CB-PWM), if compactness is targeted. Reference sine and triangular carrier are compared to generate pulses. For m-leveled MLI, carriers must be (m-1) [12],[13]. The different CB-PWMs are Phase disposition (PD), Phase Opposition Disposition (POD), and Alternate Phase Opposition Disposition (APOD) [12],[13],[14],[15].

3. Mathematical modeling of Induction motor

Sequential steps are opted as follows to generate an approximate modeled induction motor powered by VSI/MLI [16], [17]. Classical techniques adopted are capable of expressing equations related to IM considering machine variables. Saturation and skin effects are neglected while modeling IM. The equations (1) to (8) are used for the purpose of modeling the machine are obtained from their equivalent circuits Fig. 2and Fig. 3.

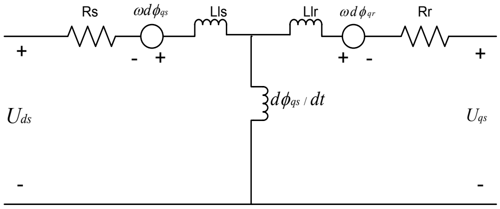


Fig. 2. Induction Motor circuit in d-axis

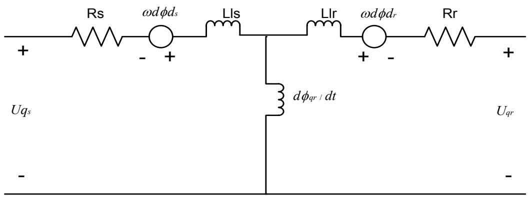


Fig. 3. Induction motor circuit in q-axis

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

Park's transformation matrix for converting αβ to dq reference frame [5],[11]. It helps in calculating the d-q voltage components given to machine. The symbols used are defined as:

ρ –angular displacement, ***Ψ***-phase angle, ***ω***-angular velocity

$$V_\alpha = V_m \cos\rho$$

$$V_\beta = V_m \sin\rho \quad (2)$$

$$i_\alpha = i_m \cos(\rho - \Psi)$$

$$i_\beta = i_m \sin(\rho - \Psi) \quad (3)$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\rho & \sin\rho \\ -\sin\rho & \cos\rho \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (4)$$

By using equations 1 to 4,we can transform from abc to dq frame. Transformation equations are

$$i_{qd0s} = k i_{abcs} \quad (5)$$

$$(i_{qd0s})^T = \begin{bmatrix} i_{qs} & i_{ds} & i_{0s} \end{bmatrix} \quad (6)$$

$$(i_{abcs})^T = \begin{bmatrix} i_{as} & i_{bs} & i_{cs} \end{bmatrix} \quad (7)$$

$$K_s = \frac{2}{3}\begin{bmatrix} \cos\rho & \cos\left(\rho - \frac{2\pi}{3}\right) & \cos\left(\rho + \frac{2\pi}{3}\right) \\ \sin\rho & \sin\left(\rho - \frac{2\pi}{3}\right) & \sin\left(\rho + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (8)$$

$$U_{dr} = R_r i_{dr} + \frac{d}{dt}\phi_{dr} - \omega_{dr}\phi_{qr} \quad (9)$$

$$U_{qr} = R_r i_{qr} + \frac{d}{dt}\phi_{qr} - \omega_{dr}\phi_{dr} \quad (10)$$

Uds ,Udr refers to stator ,rotor voltages acting in d-axis and Uqs, Uqr be that in q- axis. Flux linkage represented as :

$$\begin{bmatrix} \phi_{ds} \\ \phi_{qs} \\ \phi_{dr} \\ \phi_{qr} \end{bmatrix} = M \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} \quad (11)$$

$$M = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \quad (12)$$

Where, ids ,idr d-axis currents , and iqs, iqr -q axis currents. Ls- stator self-inductance, Lr – rotor self-inductance, and Lm-magnetizing inductance.
This induction motor mathematical model has been developed in Matlab / Simulink using the above equations and closed loop control is designed.

4. Closed control of MLI fed induction motor using V/f scheme

The block diagram of the MLI fed IM drive with closed loop V/f scheme is shown in Fig. 4.

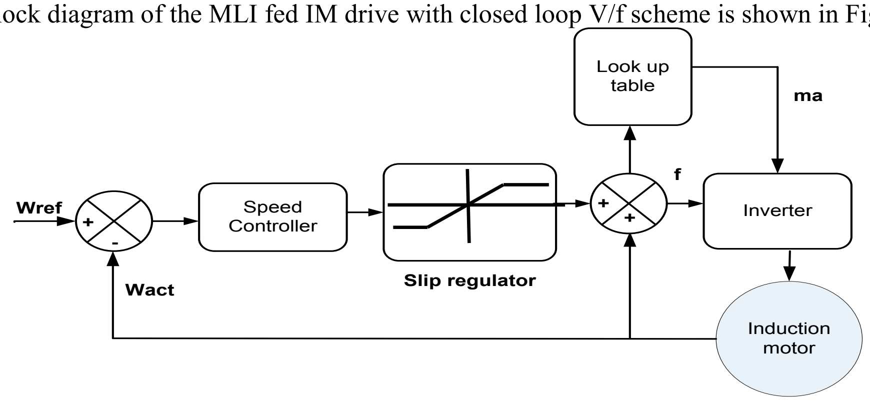


Fig. 4. Induction Motor closed loop speed control

Synchronous speed Ns=(120*f)/p, where f= frequency, p= pole pairs. A hike in frequency or less ‘p’ results in speed increment. Decrementing frequency enables speed reduction, thereby flux increase, impact in worse condition of pole saturation and rising magnetizing current relates with falling power factor[18],[19],[20].

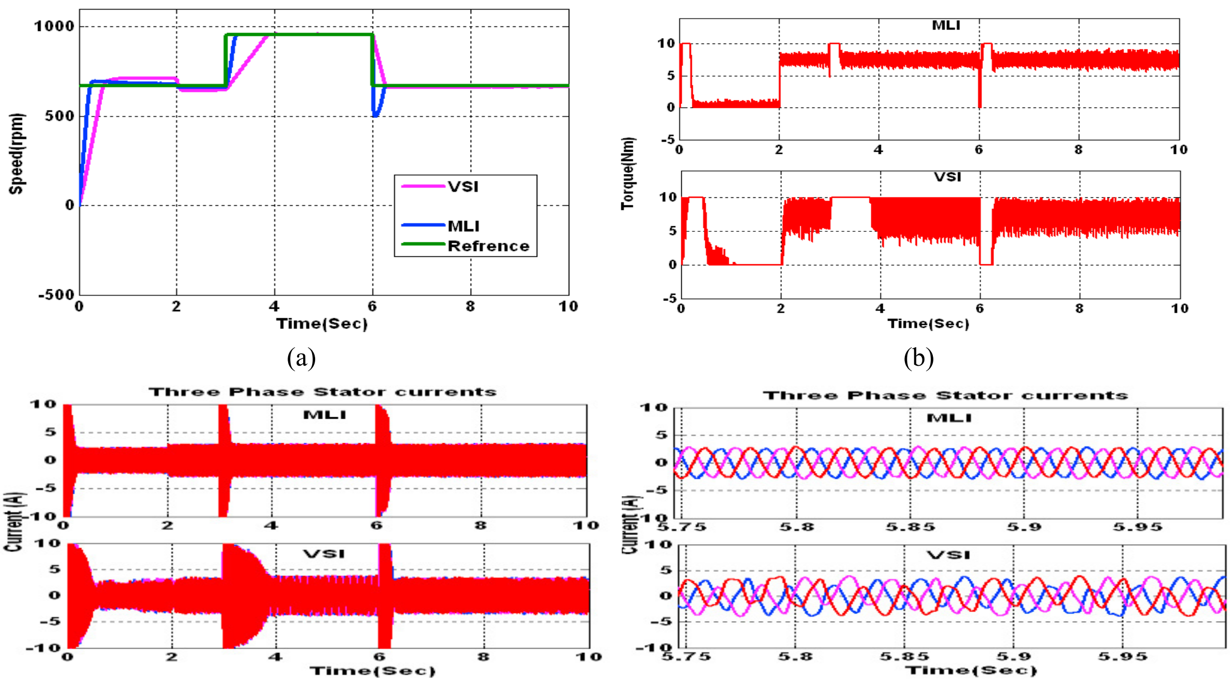
Mathematically designed IM in dq model is supplied with ac output from inverter (VSI/MLI) bypassed through passive filter (L=1.001mH, C=1000μF). The IM rotates and speed being tagged as ω_m, actual speed. PI controller is implemented to activate the closed loop action. It is fed with reference speed, ωr_{ef}. Then the error generated comparing reference and actual speed which is fed to the proportional block and then to integrator block. Gains K_p , K_i should be neither too low nor large. Selecting proper gain values becomes mandatory. Controller output is given to the slip regulator in order to limit the slip assuring the stator current and motor torque in its safe limits. The resulting slip command is then summed with the actual speed to create frequency command. It is then converted to voltage command through lookup table. Lookup table is developed assigning proper frequency values to corresponding changes in modulation index altering the reference wave amplitude. The corresponding voltage is then fed to MLI fed IM.

5. Simulation results and analysis

The closed loop control of the MLI fed induction motor has been designed and the results are observed for two different cases. They are Variable speed and constant torque condition and Constant torque and variable speed condition

CASE 1: REFERENCE SPEED CHANGE

The IM drive is operated with a constant load torque of 7.5 Nm. The drive reference speed is given a step change from 670 to 955 rpm at 4s and again to 670 rpm at 6s. The speed, torque and stator current responses of the MLI and VSI fed drive scheme are presented in Fig. 5. It is evident from the responses that the MLI fed drive is superior to the conventional VSI fed drive scheme. Further, it can be noted that the torque ripple and current ripple content is reduced significantly in the MLI fed drive scheme.

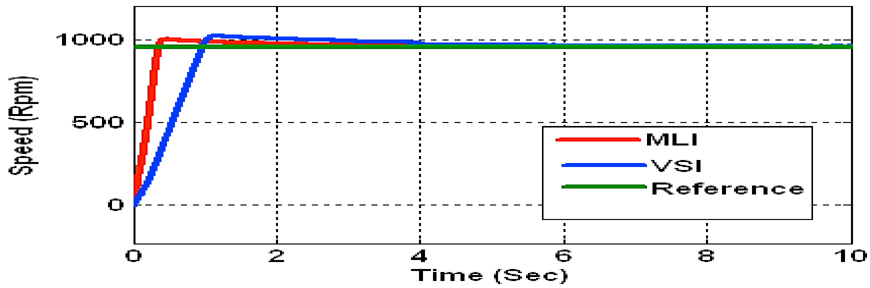


(c) (d)

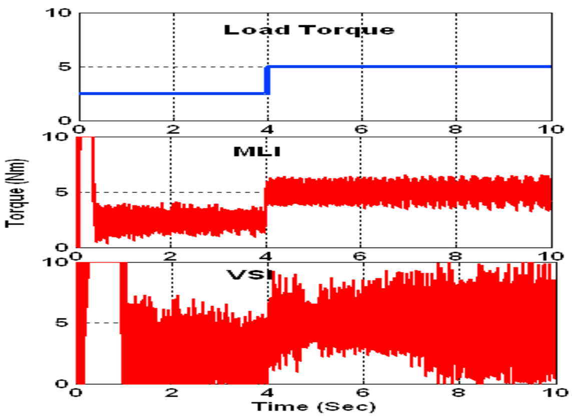
Fig. 5. MLI and VSI fed drive responses for change in speed (a) Speed (b) Torque (c) Stator current (d) Zoomed view of stator current

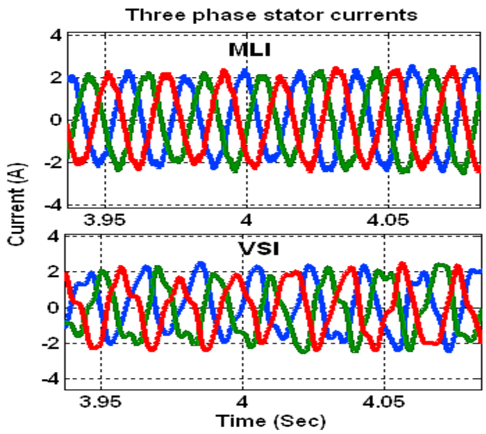
CASE 2: DYNAMIC LOAD CHANGE (a) Step change in torque

The IM drive is operated with a constant speed. The drive load torque is given a step change from 2.5 Nm to 5 Nm at 4s. The speed, torque and stator current responses of the MLI and VSI fed drive scheme are presented in Fig. 6. It is evident from the responses that the MLI fed drive is superior to the conventional VSI fed drive scheme. Further, it can be noted that the torque ripple and current ripple content is reduced significantly in the MLI fed drive scheme.



(a)



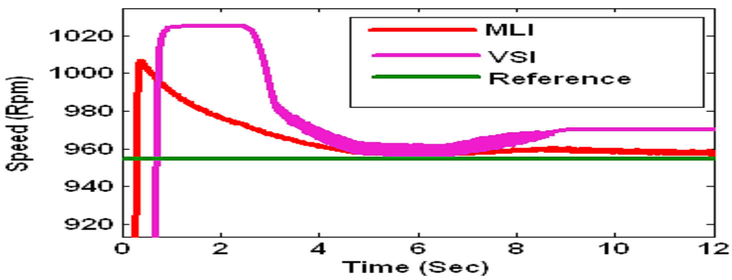


(b) (c)

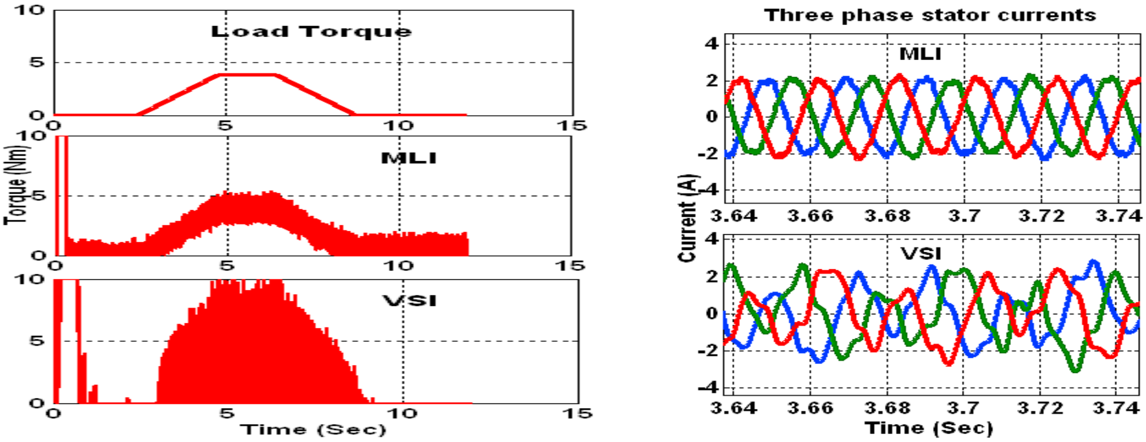
Fig. 6. MLI and VSI fed drive responses for step change in load torque (a) Speed (b) Torque (c) Stator current

CASE 2: DYNAMIC LOAD CHANGE (a) Trapezoidal change in torque

The IM drive is operated with a constant speed. The drive load torque is given a trapezoidal change from 0 Nm to 5 Nm. The speed, torque and stator current responses of the MLI and VSI fed drive scheme are presented in Fig. 7. It is evident from the responses that the MLI fed drive is superior to the conventional VSI fed drive scheme. Further, it can be noted that the torque ripple and current ripple content is reduced significantly in the MLI fed drive scheme.



(a)



(b) (c)

Fig. 7. MLI and VSI fed drive responses for trapezoidal change in load torque (a) Speed (b) Torque (c) Stator current

The performance of the MLI and VSI fed drive is compared for various conditions namely variable speed, variable load and constant speed. The response of the drive scheme based on the tracking time is presented in Table 1.

Table 1. Tracking time response of IM for various conditions

POWER CONVERTER	REFERENCE SPEED CHANGE	LOAD CHANGE	CONSTANT REFERENCE SPEED
	Tracking time	Tracking time	Tracking time
VSI	0.5sec	3.8sec	3.5sec
MLI	0.2sec	1.8sec	2sec

Table1 clearly indicates the IM response for different power converter. The tracking time corresponding to various conditions are tabulated. It is observed from the results that the MLI fed drive exhibits a better dynamic performance compared to conventional VSI fed drive.

6. Conclusion

The V/f closed loop control scheme for the induction motor has been developed in MATLAB/SIMULINK. The VSI fed drive scheme is conventionally used for the commercial applications. As the VSI fed drive suffers from the limitations such as high torque and current ripples, a search for a high performance inverter arises. So the MLI fed drive scheme is designed and developed in MATLAB with the V/f closed loop control scheme.The results of the VSI and MLI fed drive schemes have been analysed exhaustively. The results are presented for the various operating conditions such as dynamic load change and dynamic reference speed. From the results, it is observed that the MLI fed induction motor drive outperforms the VSI fed drive. In the MLI fed drive scheme, the torque and current ripples are reduced to a greater extent. Also the settling time is reduced in this case. Hence for the medium and high power applications, the MLI fed induction motor drive with V/f closed loop control scheme can be employed.

APPENDIX

The ratings of the induction motor used for simulation studies is given below.

415V, 6pole Squirrel cage IM

Rs=6.03;	Stator Resistance,	R r=6.085;	Rotor Resistance
Lm=0.4893;	Magnetizing Inductance,	fb=50;	Base Frequency
p=6;	Number Of Poles	J=0.05787;	Moment Of Inertia
B=0.0027;	Friction Coefficient	Lr=0.5192;	Rotor Self-inductance
Ls=0.5192;	Stator Self-inductance		

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