Mathematical Model Of 3ϕ Induction Machine Connected To Cascaded H-Bridge Five Level Inverter

Vilas Bugade, Ganesh Patil

Abstract: This paper introduces a mathematical modeling of induction machine connected to a five-level inverter cascaded H-Bridge. A five-level inverter is designed to reduce the loss of swapping power, harmonic distortion, and electromagnetic fields caused by power electronic devices switching operation. These days, multilevel inverters have attracted massive involvement in business ventures. Cascade multilevel inverter requires fewer switching devices without additional clamping diodes or voltage matching capacitor among different types of multilevel inverter configurations and also has simple circuit layout. Using SPWM technique, the control signals for this multilevel inverter are applied to provide less output distortion.

Keywords : Multilevel Inverter (MLI), Sinusoidal Pulse Width Modulation(SPWM), Power Electronics, Induction Machine

1. INTRODUCTION

Nowadays, MLI is used for medium and high-power applications in most industries. MLI have advantages like less switching loss, electromagnetic compatibility, higher voltage competence, and lower harmonics do to this it gained considerable attention in recent times. [1][3] Several MLI configurations are presented; the diode clamp flying capacitor, and cascade H-bridge structures were the most well-known. The cascade H-bridge MLI design is beneficial because the complexity and layout of the circuit configuration is simple because there are no superfluous clamping diodes or flying condensers compared to the diode clamping and flying condenser MLI configuration. [2] There will be extra steps for the multilevel inverter as the level summation intensifies output waveform and we can get nearly the sinusoidal wave output which contains lower harmonic distortion. [4][6]. Over the past few years, power electronics and electrical equipment have been a major change in industrial applications, including electrical, hybrid and plug-in vehicles (EVs) in the automotive industry, photovoltaic (PV) and wind energy conversion systems (WECS) in the renewable energy industry, or high voltage direct current (HVDC) and compact ac transmission systems (FACTS).[5] In particular, a two-level three-phase voltage source (VSI) inverter is considered to be a mature technology and becomes an industry standard for energy saving demand.[7][9] Since 1975, it has introduced the idea of multi-level inverters. MLI is an electronic power converter built from various DC voltage levels to achieve the desired frequency and magnitude of AC voltage. Multilevel For industrial applications, the use of three-phase induction machines is defined by: simplicity of design, low cost quality, high operational safety and high technical performance (starting torque, high efficiency, etc.). [12] It is necessary to change the voltage and frequency according to device requirements in order to improve the performance of the induction machine to increase the drive speed. [18][19] In this paper presents mathematical modeling of three phase induction motor is implemented and it is connected to an H-Bridge five level inverter.

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2. CASCADED H-BRIDGE MULTILEVEL INVERTER

The circuit arrangement of a cascaded H-Bridge 5-level inverter is described in Fig.1. Every phase has its own dc source. Every branch of an H-Bridge inverter is linked to different dc source. The number of output phase voltage is characterized by equation

$$P = 2q + 1 \quad (1)$$

Where, q is the number of dc sources.

The 5-level cascaded H-Bridge inverter comprises of 2 H-Bridges in every phase. The output of these bridges is referred as V_1 and V_2 respectively, and the output voltage of the cascaded multilevel inverter is the addition of two voltages.

$$V = V_1 + V_2 \quad (2)$$

3. SPWM TECHNIQUE

A sinusoidal reference signal is equated with a triangular carrier wave of frequency F_r in the technique of sinusoidal pulse width modulation. The output frequency F_r is interdependent on frequency of triangular wave frequency. Fig 2. depicts the gating signal applied to the semiconductor devices. The reference signal and carrier signal are equated with each other and the output waveforms are applied in the form of pulses.

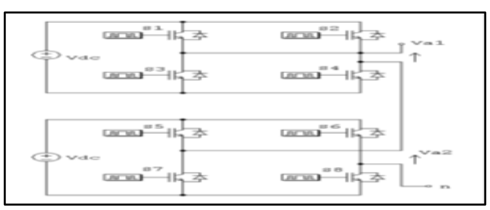

***Fig. 1** : (a) Cascaded H-Bridge Multilevel Inverter*

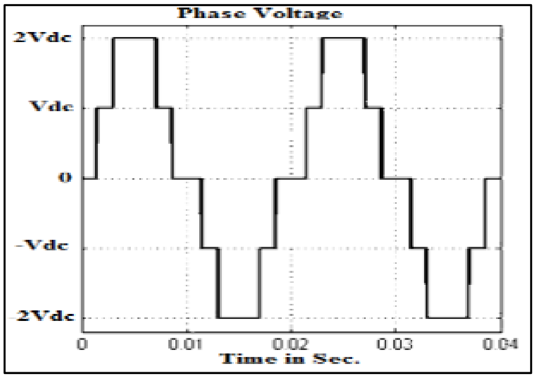

Fig. 1: (b) *Output waveform of 5-level Inverter*

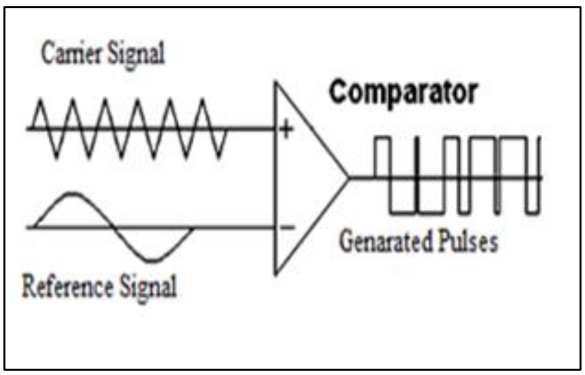

Figure 2: *PWM generation*

GTOs (switches) can be switched ON and OFF depending upon the pulses applied. Better harmonic profile can be obtained by turning on and off the GTOs numerous times. [10] [11] The implementation of SPWM phenomena is done by equating reference waveform with the excessively repeating triangular waveform and the desired output voltage is achieved. Alternative positive and negative voltages are applied to the semiconductor switches which are dependent on reference and carrier signals. Throughout the time interval of one triangular wave, the mean voltage given to the switches is relative to the maximum displacement of the periodic wave of the signal during this span. The pulses for inverter switches is shown in fig.3

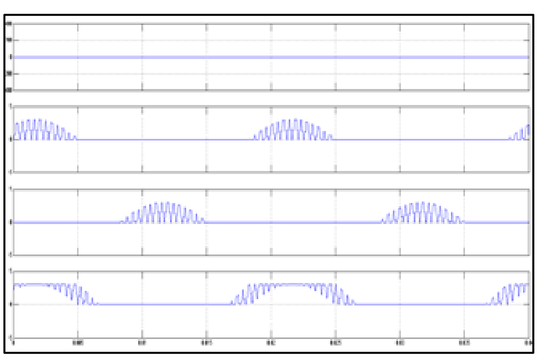

Figure 3: *SPWM Pulses for inverter.*

4. MODELING OF 3Φ INDUCTION MOTOR

The induction motor voltage and torque equations contains mutual inductances which are time varying. Analysis of dynamic behavior with time varying parameters is too complex, to avoid this dynamic model of induction motor is developed where in 3-phase quantities are transformed to 2-phase dynamic quantities for control purpose[18].

Three phase stator voltages of an induction motor under balanced condition are as follows:

$$V_{as} = V_m \sin(2\pi f t) \quad (3)$$

$$V_{bs} = V_m \sin(2\pi f t - {}^{2\pi}/_{3}) \quad (4)$$

$$V_{cs} = V_m \sin(2\pi f t + {}^{2\pi}/_{3}) \quad (5)$$

The transformation matrix to transform 3ϕ stator variables $(V_{as}, V_{bs}, V_{cs},)$ into two-phase stationary reference frame ds-qs variables in given in equation (6),

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & \frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix}\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} \quad (6)$$

Where $\emptyset = \frac{2\pi}{3}$; V_s, V_b, V_s, are stator phase voltages. V_d and V_q presents direct and quadrature axis stator voltages respectively with V_{os}: zero sequence component.

Stator side voltage equations in ds and qs reference frame are given as follows:

$$V_{qs} = Rsi_{qs} + \frac{d}{dt}\Psi_{qs} \quad (7)$$

$$V_{ds} = Rsi_{ds} + \frac{d}{dt}\Psi_{ds} \quad (8)$$

$$V_{xs} = R_s\ i_{xs} + \frac{d}{dt}\Psi_{xs} \quad (9)$$

$$V_{ys} = R_s\ i_{ys} + \frac{d}{dt}\Psi_{ys} \quad (10)$$

$$V_{0s} = R_s\ i_{0s} + \frac{d}{dt}\Psi_{0s} \quad (11)$$

Rotor side voltage equations in dr and qr reference frame are given as:

$$V_{qr} = Rri_{dr} + \frac{d}{dt}\Psi_{qr} - w_r\Psi_{dr} \quad (12)$$

$$V_{dr} = Rri_{dr} + \frac{d}{dt}\Psi_{dr} + w_r\Psi_{qr} \quad (13)$$

$$V_{xr} = R_r\ i_{xr} + \frac{d}{dt}\Psi_{xr} \quad (14)$$

$$V_{yr} = R_r\ i_{yr} + \frac{d}{dt}\Psi_{yr} \quad (15)$$

$$V_{0r} = R_r\ i_{0r} + \frac{d}{dt}\Psi_{0r} \quad (16)$$

From equations (7)-(8) and (12)-(13), flux linkages are found using equations (18)-(21),

$$\psi_{qs} = \int (V_{qs} - Rs \cdot i_{qs})dt \quad (18)$$

$$\psi_{ds} = \int (V_{ds} - Rs \cdot i_{ds})dt \quad (19)$$

$$\psi_{qr} = \int (V_{qr} - Rr \cdot i_{dr} + w_r\psi_{dr})dt \quad (20)$$

$$\psi_{dr} = \int (V_{dr} - Rr \cdot i_{dr} - w_r\psi_{qr})dt \quad (21)$$

Flux equations of stator side and rotor side of five phase induction motor are given by,

$$\psi_{ds} = (L_s.i_{ds} + L_m i_{dr}) \quad (22)$$

$$\psi_{qs} = (L_s.i_{qs} + L_m i_{qr}) \quad (23)$$

$$\psi_{dr} = (L_s.i_{dr} + L_m i_{ds}) \quad (24)$$

$$\psi_{qr} = (L_s.i_{qr} + L_m i_{qs}) \quad (25)$$

The currents of 5ϕ induction motor are given by:

$$i_{ds} = \left(\frac{L_r}{L_s L_r - {L_m}^2}\right) x\ \psi_{ds} - \left(\frac{L_m}{L_s L_r - {L_m}^2}\right) x\ \psi_{dr} \quad (26)$$

$$i_{qs} = \left(\frac{L_r}{L_s L_r - {L_m}^2}\right) x\ \psi_{qs} - \left(\frac{L_m}{L_s L_r - {L_m}^2}\right) x\ \psi_{qr} \quad (27)$$

$$i_{dr} = \left(\frac{L_r}{L_s L_r - {L_m}^2}\right) x\ \psi_{dr} - \left(\frac{L_m}{L_s L_r - {L_m}^2}\right) x\ \psi_{dr} \quad (28)$$

$$i_{qr} = \left(\frac{L_r}{L_s L_r - {L_m}^2}\right) x\ \psi_{qs} - \left(\frac{L_m}{L_s L_r - {L_m}^2}\right) x\ \psi_{qr} \quad (29)$$

From the above equations the electromechanical torque developed and rotor speed can be determined using the equations (30) & (31) respectively.

$$T_e = \frac{P}{2} \times \frac{3}{2} \times (\Psi_{ds}.i_{qs} - \Psi_{qs}.i_{ds}) \quad (30)$$

$$\omega_r = \int \frac{Te - TL}{J} dt \quad (31)$$

Where,
P - is the number of poles
J - Moment of inertia;
Tl - Load Torque;
Te- Electromechanical torque and
ω_r- Rotor Speed.

5. MATLAB SIMULINK MODEL

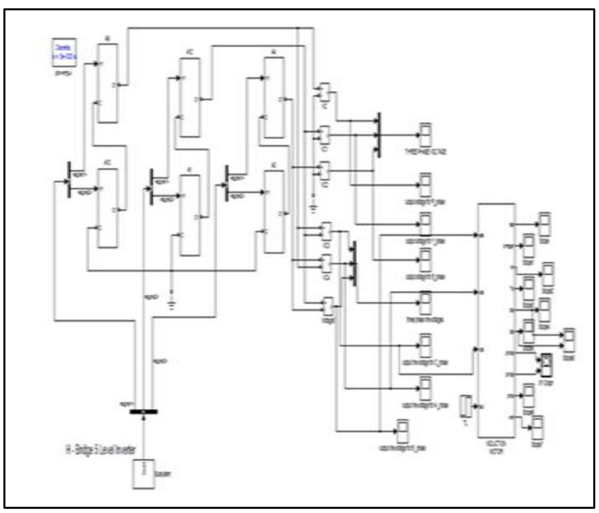

Figure 4: *Simulation of H-bridge 5 level inverter.*

6. SIMULATION RESULTS

The simulation is done using Matlab /simulink 3ϕ induction motor specifications are given in Table 1. The simulation circuit is shown in Fig 4. The inverter output voltage for various configurations is given in Table 2. From Table 2, it is observed that in proposed five level cascaded H-bridge inverter has THD 15 % which is better than the conventional inverter (21%) which is modulated using SPWM technique eliminates the lower order harmonics to a greater extent.

TABLE 1: *MOTOR SPECIFICATIONS*

Rated voltage (V)	*300 (Phase)*
Rated Power (Hp)	*1*
Frequency (Hz)	*50*
Poles	*4*
Rated Speed (rpm)	*1440*
Stator resistance (Rs)	*10 Ω*
Rotor resistance (Rr)	*6.3 Ω*
Stator inductance (Ls)	*0.42 mH*
Rotor inductance (Lr)	*0.41 mH*
Mutual inductance (Lm)	*0.41 mH*
Moment of Inertia (J)	*0.00468 kg.m^2*
Friction coefficient (B)	*0.001 N.m.s*

TABLE 2: *INVERTER OUTPUT FOR AN INPUT VOLTAGE OF 300 V DC*

Configurations	*Cascaded H-bridge inverter*	*Conventional inverter*
THD in Phase Voltage (Van) in percentage	*15*	*21*
RMS Value of Phase Voltage (Van) in volts	*203*	*200*

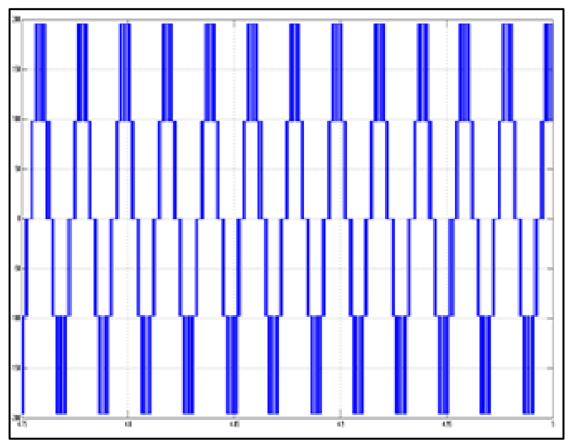

Figure 5: *Output voltage waveform of R phase*

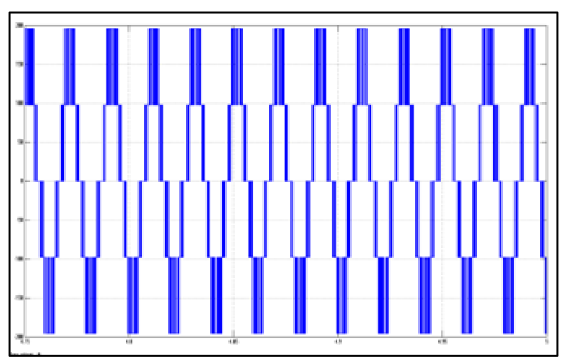

Figure 6: *Output voltage waveform of Y phase*

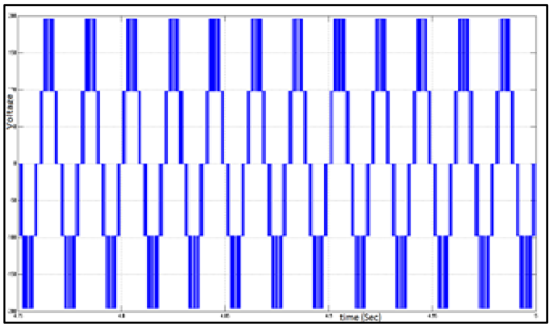

Figure 7: *Output voltage waveform of B phase.*

The electromagnetic torque developed in shown in Fig.8 and the motor speed is shown in Fig.9

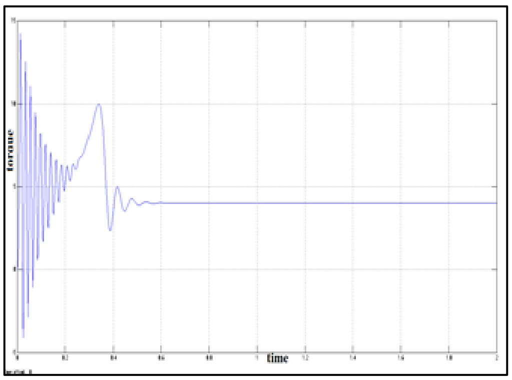

Figure.8*:* *Motor torque*

Fig.8 shows that there is variation in torque during starting because of heavy inrush current .The torque attained steady state condition after 0.6 sec. At no load the motor speed is equal to the rated speed.

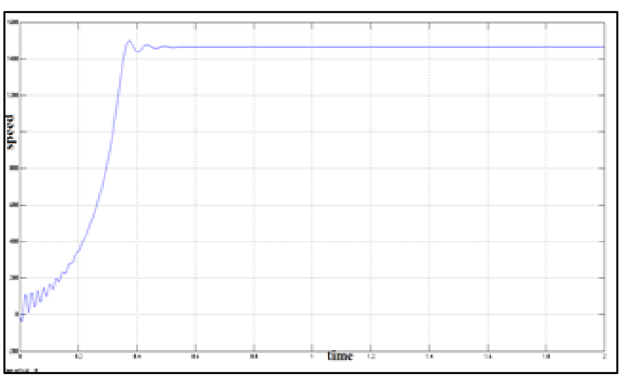

Figure.9: *Motor speed*

From starting to running condition variation in rotor speed is shown in Fig.9. The small over shoot in the speed response is observed.

7. CONCLUSION

The proposed 5-level cascaded H-bridge inverter has THD 15 percent better than the traditional inverter (21 percent) that is modulated using SPWM technique removes the harmonics of the lower order to a greater extent. The system offers a satisfactory response in terms of the stator current, torque and speed characteristics when the output of this inverter is fed to the mathematical model of the three-phase induction motor. This model is simulated using d- and q- frames in MATLAB / Simulink. The three phase machine variables are converted into d-axis and q-axis variables that help decouple the parameters and provide the benefit of independent parameter control. The model has been tested under no state of load. The conclusion is that the MATLAB / Simulink is an efficient way to analyze and model induction motor behavior using reference frame theory. This research paper also incorporates a five-level inverter. This DC to AC converter's obtained voltage is controlled using the modulation control strategy of the sinusoidal pulse width to obtain voltage of the desired frequency and magnitude. The simulation result shows that this inverter removes to a greater extent the harmonics of low order. This allows us to obtain highly efficient and competent inverters.

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