V/f Control of Three Phase Induction Motor using 7-Level Cascaded H-Bridge Inverter

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Abstract: Cascaded H-bridge Multilevel Inverters (CHBMLI) are having potential application in controlling the speed of Induction Motor Drives. This paper proposes a new modulation wave for PWM control strategy which improves the overall performance of the CHBMLI. The performance of 7- level CHBMLI with proposed PWM scheme is analysed for three phase induction motor drive as load. The proposed modulation scheme results in increased output of 13% compared to conventional method and also reducing the harmonics. The simulation is carried out on MATLAB/SIMULINK platform and the results were compared with conventional method to validate the proposed scheme.

Keywords: Cascaded Inverter, Speed Control, PDPWM, Modulation Index, Induction Motor.

Introduction

Induction motors were formerly used for constant speed drives since variable speed drives were governed by DC drives. The main snag of DC motors is the presence of brush and commutator which requires periodic maintenance and they are not suitable for explosive environment, Gopal K Dubey [1].

Due to the advancement in the power electronics field and control system, the induction motors are now being the first priority for variable speed drives in the industry as it is economic, reliable, more sturdy and suitable for explosive and dirty environment. The induction motor has various applications such as: fans, cranes, blowers, traction, conveyers etc.,

Among the different methods available for speed control of induction motor, the very well known v/f speed control technique has resulted in increasing popularity of induction motor for variable speed control applications as they have the advantages of providing good speed control range, shows good transient and running performance, requires low starting current, operating region are stable and easy to implement and economical, J.B Gupta [2].

The CHBMLI is the most suitable topology for high power and medium voltage drives. It consists of series connected multiple H-bridge power cells. The power quality of the inverter output depends on the number of the output levels. The Multicarrier PWM (MCPWM) technique is most popular PWM technique for CHBMLI. Among the three main variants of MCPWM technique, Phase Disposition PWM (PDPWM) technique has gained more popularity because of its better output voltage quality, Indrajit Sarkar and B. G. Fernandes [3].

In this paper, the performance of induction motor drive is investigated for 7-level output voltage of CHBMLI. A new modulating wave, elliptical wave, Chinmayi, Dr. B.G.Shivaleelavathi [4],and , Chinmayi, B.G.Shivaleelavathi [5] has been utilized for MCPWM technique. The performance of elliptical modulating wave is compared with traditional sine modulating wave for 7 – level CHBMLI with three phase induction motor drive as load. Working of the proposed modulation technique has been carried out on MATLAB/SIMULNIK platform.

CHBMLI Fed Induction Motor Drive

Cascaded H-Bridge MLI and Control Technique

The block diagram for CHBMLI fed induction motor drive is shown in Fig. 1. The CHBMLI block consists of three single phase CHBMLI, out of which one single phase CHBMLI is shown in Fig. 2. The number of output levels of CHBMLI is given by :

$$m = 2h + 1 \quad (1)$$

Where, h is the number of H-bridges and m is the output level, T. Poompavai , A. Chitra , C. Srinivas , K. Giridharan [6].

For the PDPWM technique for m output level (m-1) carriers with same frequency f_c and same amplitude A_c are placed as shown in Fig. 3. The modulating wave is compared with each carrier signal to generate PWM signal.

The frequency modulation index and amplitude modulation index can be expressed by;

$$m_f = \frac{f_c}{f_m} \quad (2)$$

$$m_a = \frac{A_m}{(m-1)A_c} \quad (3)$$

V/f method of Speed Control of Induction Motor

The speed of the Induction Motor can be expressed by [2].

$$N = \frac{120f}{p}(1-S) \quad (4)$$

From the equation (4), the speed of the induction motor depends on supply frequency (f), number of poles (p) and slip (S). Among the stator side control method, the variation in supply frequency is one of the method used to control the speed. If an Induction Motor is operated at variable frequency, the supply voltage also need to be varied accordingly to maintain the constant values of power factor, efficiency, overload capacity and a constant slip with iron unsaturated. The relationship between frequency, supply voltage and torque is given by,

$$\frac{V'}{V} = \frac{f'}{f}\sqrt{\frac{T'}{T}} \quad (5)$$

Where v' and T' are the voltage and torque corresponding to the frequency f' and v and T to the frequency f.

For constant torque, T'=T

$$\frac{V'}{V} = \frac{f'}{f} \quad (6)$$

That is, the voltage applied to the stator must vary in proportion to the frequency.

Hence, the variation of applied voltage and frequency of the three phase induction motor can be easily achieved by varying the modulation index, ma and fundamental frequency, f of modulating wave of PDPWM technique to achieve the desired speed of the motor.

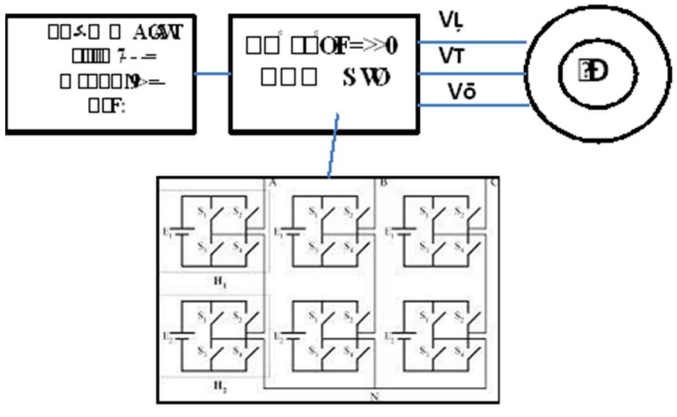

Figure 1. The Block Diagram of Proposed work

Table 1. The switching state of seven level CHBMLI

Switches when turn ON	Voltage level
S1, S2, S7, S8	3Vdc/2
S1, S4, S7, S8	Vdc
S3, S4, S7, S8	Vdc/2
No switches are ON	0
S1, S2, S5, S6	-Vdc/2
S1, S4, S5, S6	-Vdc
S3, S4, S5, S6	-3Vdc/2

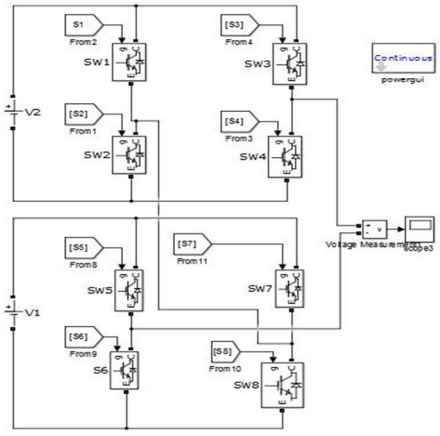

Figure 2. Single Phase CHBMLI

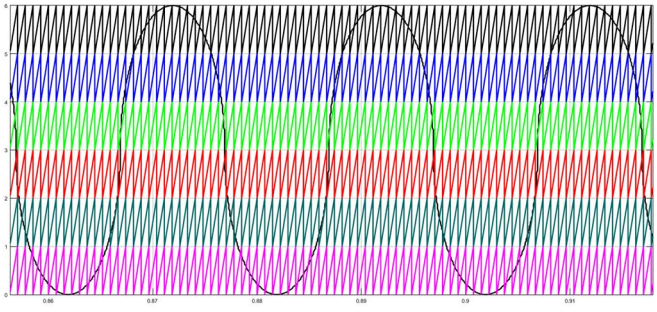

Figure 3. PDPWM Technique with elliptical modulating wave

Simulation Results

To investigate the performance of proposed elliptical modulating wave [4] for different load conditions of CHBMLI, a three phase induction motor is connected across the output of CHBMLI. Fig. 4 shows the simulation circuit of three phase 7-level CHBMLI, Anuradha Singh, Mohit Jain and Suman Singh [7], fed to three phase induction motor drive. A three phase induction motor (asynchronous motor) of 5.4 H.P., 400V, 50Hz and 1430 RPM rated speed is selected from simulink library. In Fig. 4, red, yellow and blue blocks constitute three single phase inverter together forming three phase CHBMLI. The input DC voltage of each single phase H-Bridge is set to V_1=243.75V and V_2=81.25V to obtain 7 level of output voltage. The switching states of IGBT switches to obtain the desired output level are shown in Table 1. The switching frequency of IGBT is set to 1350Hz and that of modulating wave frequency to 50Hz. Fig. 5 shows the switching pulses generated from PDPWM technique with elliptical modulating wave for single phase circuit shown in Fig. 2. Table 2 shows the performance comparison of three phase CHBMLI for sine modulating and elliptical wave at No-load. The comparison has made for line voltage, phase voltage and total harmonic distortion at different modulation index at fundamental frequency of 50Hz. The results clearly show that the elliptical wave is able to produce more output voltage from the same DC bus voltage at the same modulation index as in the case of sine modulating wave. At m_a = 1, the output of proposed elliptical modulating wave produces a line voltage of 457.8V when compared to traditional sine modulating wave which is producing 404.3V. There is almost 13.33% increase in the output line voltage of inverter from the proposed scheme, as equivalent by getting a square wave inverter or by third harmonic injection method. At the same time the harmonic spectrum also been reduced at all modulation index in the proposed PWM technique.

Fig. 6 shows the line voltage of the three phase induction motor fed by 7-level CHBMLI at modulation index, ma=1. Fig. 7 shows the waveforms of Speed, stator current, load torque and stator voltage at modulation index, ma=1. The performance of the two modulating wave of PDPWM technique for three phase 7-level CHBMLI with induction motor as load is compared in the graph shown in Fig. 8. Graph shows the enhanced performance of CHBMLI producing line voltage of 458.2V with %THD of 12.32% with elliptical modulating PDPWM technique when compared to conventional sine modulating wave producing line voltage of 404.7V with %THD of 13.07% for the induction motor drive.

The total harmonic distortion of output line voltage in two PWM techniques is shown in Fig. 9. At modulation indices from 1 to 0.6 the proposed modulation technique has reduced harmonics. At m_a=0.4, the proposed PWM technique results in more harmonics compare to traditional sine PWM method.

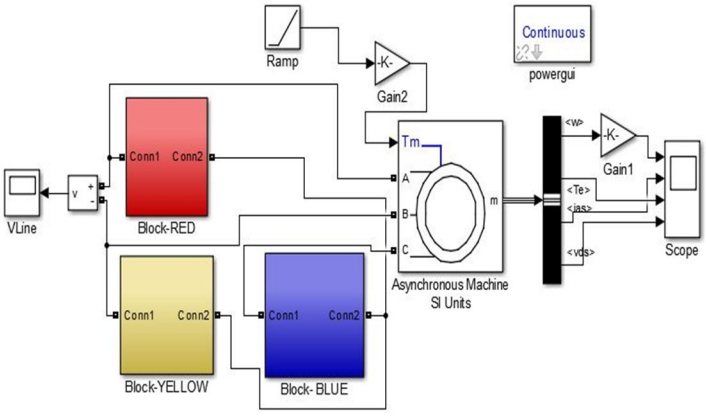

Figure 4. Simulation Circuit of Three phase 7-Level CHBMLI fed to Induction Motor Drive

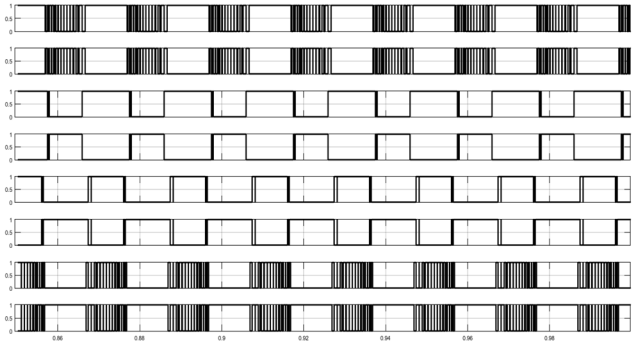

Figure. 5. Switching Pulses from PDPWM Technique with elliptical modulating wave

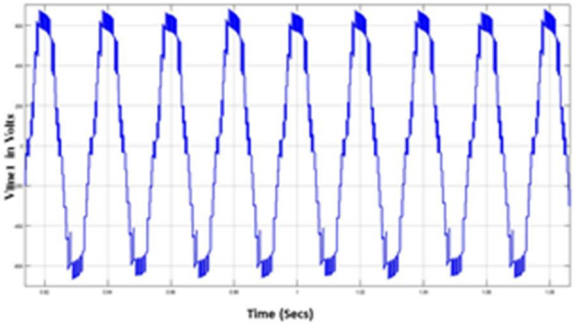

Figure. 6. Line Voltage of Three Phase Induction Motor with Elliptical modulating wave at modulation index, m_a=1

Table 2. Performance of Three phase 7-level CHBMLI at no-load

Modulating Wave for PDPWM	Ma	Three Phase Induction Motor fed with 7-Level CHBMLI		
		Vline	%THD	Vphase1
Sine wave	1	404.3	13.07	233.7
	0.8	333.3	15.22	192
	0.6	236.8	24.13	136.4
	0.4	128	35.6	73.6
Elliptical wave	1	457.8	12.67	266.5
	0.8	383.4	14.39	223.7
	0.6	276.1	23.88	161.6
	0.4	148	36	86.05

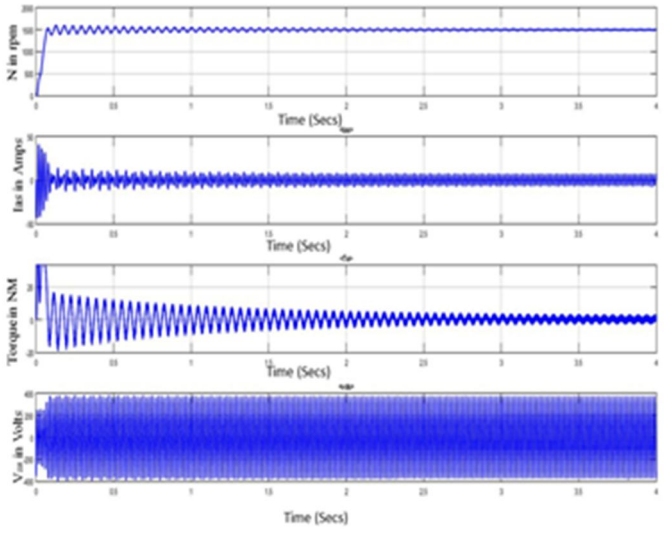

Figure. 7. Output of Three Phase Induction Motor with Elliptical modulating wave at modulation index, m_a=1

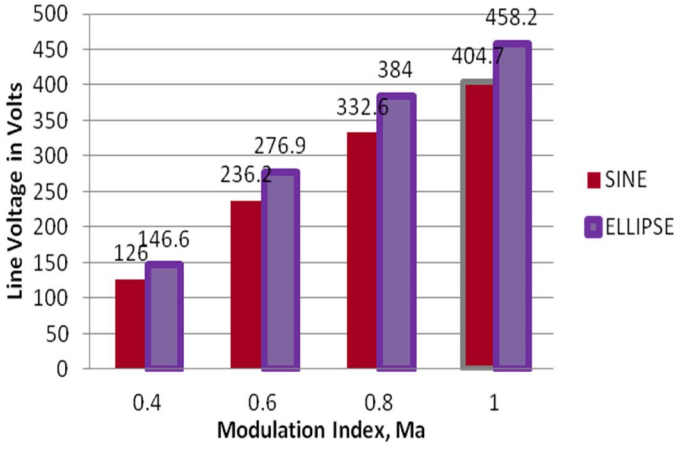

Figure. 8. Line Voltage Comparison CHBMLI for two modulating waves with Induction motor load

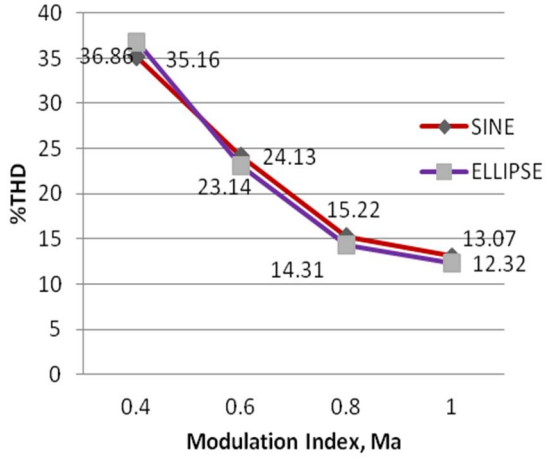

Figure. 9. %THD Comparison of output line Voltage of CHBMLI for two modulating waves with Induction motor load

The performance of the proposed PWM technique is further verified for v/f speed control of induction motor by varying terminal voltage (modulation index) in proportion to frequency of the supply in such a way that v/f ratio remains same, in turn the flux produced by the stator remains constant. Hence the load torque is maintained constant at various speeds. Table. 3 shows the performance of three phase 7-level CHBMLI for different modulation index and frequency under zero percent load toque.

Table 3. Performance of Three phase 7-level CHBMLI for different m_a and frequency under zero percent load torque

Modulation Index	Frequency (Hz)	Speed in (rpm)
0.9	50	1500
0.8	44.44	1350
0.7	38.88	1175
0.6	33.33	1000
0.5	27.77	820
0.4	22.22	660

Conclusion

This paper investigates the performance of three phase 7-level CHBMLI fed induction motor drive. PDPWM technique with elliptical modulating wave is used with a switching frequency of 1350Hz. The various readings of line voltage and %THD noted at different modulation index shows that the proposed elliptical wave produces enhanced output line voltage of 13% and reduced THD when compared to conventional method. The performance of proposed PWM technique is further verified by carrying v/f method of speed control of induction motor.

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