

Multilevel Inverter Application for Speed Control of Induction Motor

[Mangesh M. Kore, Ambadas S. Mane]

Abstract— As industry applications are increasing day by day, Power Electronics is playing measure role for conversion of electrical energy. It helps in supplying the electrical system with reliable and effective power. This paper presents the performance analysis of Diode Clamped Multilevel Inverter for speed control of single-phase induction motor in open loop as well as in closed loop system. The speed is controlled by constant V/F control method. Speed is controlled over wide range by taking torque Constant. Using a closed-loop PI controller, the SPWM modulation technique is utilized to regulate the inverter's output and the motor's input. In that PD-SPWM technique is used to control the voltage magnitude and frequency of the output of Diode Clamped Multilevel Inverter (DCMLI). Simulation of open loop and closed loop model in software MATLAB/SIMULINK.

Keywords— *Diode Clamped Multilevel Inverter, Induction Motor, PI Controller, PD-SPWM Introduction (Heading 1)*

I. Introduction

Today, almost every industry needs high-performance equipment. There are many industrial applications as induction motors that require high power in the megawatt and medium voltage range. Single semiconductor switch cannot be blocked high voltage. To solve this problem, Multilevel inverter (MLI) has been developed [8]. Multilevel inverter can be used instead of conventional inverter. In applications including traction, power systems, industrial drives, low harmonic content, and low switching frequency output waveforms, multilevel inverters are frequently utilized. [12]. Simply, MLI is a power electronics converter that can be used DC input voltage to provide the appropriate AC output voltage level. The switching technique allows multi-level power converters to achieve significantly lower output harmonics and higher voltage level. Output of the MLI is smooth and can be given to the motor drives so that it can operate smoothly [4]. Using MLI induction motor speed can be controlled. There are additional techniques to regulate an induction motor's speed, but these methods are inefficient and not easy to control. This paper presents the analysis of DCMLI and speed regulation of induction motor (IM) in open loop as well as in closed loop. Induction motor is cheaper and robust in nature. There are many ways to regulate the speed of an induction motor, but if the torque is constant, a constant V/F control method is used [2]. Constant V/F is controlled by controlling the modulation of inverter. For that phase deposition SPWM modulation technique is used [11], which is easy to control and gives better harmonic performance for neutral point clamped multilevel inverter. In closed loop PI controller is used as it is

more stable compare to PID controller. DCMLI output have less THD with PI controllers [1].

Speed of the induction motor is controlled by stator side or by rotor side. The most effective and simple approach for controlling single phase induction motors is the constant V/F

control method. It has wide range of speed with less consumption of energy. The voltage and frequency can be controlled easily by using SPWM technique [6].

Neutral point clamped multilevel inverter faces problem of balancing the neutral point and DC capacitor voltage for 5 level and more than 5 level. For 5 level NPC Inverter two inner capacitors goes into continues discharging mode and two outer capacitor goes into continues charging mode. This can be balanced by various methods like introducing some passive element in the circuit, by using some new modulation technique or by using buck boost converter [7][10].

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II. Multilevel Inverter

Multilevel inverter can be mainly classified into 3 types which are

1. Diode Clamped Multilevel Inverter (DC-MLI)
2. Flying Capacitor Multilevel Inverter (FC-MLI)
3. Cascade H-bridge Multilevel inverter (CHB-MLI)

Neutral Point Clamped Multilevel Inverter and DCMLI are equivalents. Numerous constructions have been developed using the NPC model. To raise the level of the output voltage, NPC uses capacitors and diodes. As level increase THD also decreases. It can be operated with low dv/dt ratio and at very

low THD. It has less disturbance compared to conventional inverter. Compared to other MLI, NPC switches experience less voltage stress, and switch management is straightforward [9].

For ‘n’ level of output voltage Diode Clamped Multilevel Inverter needs

$$(2n-2) = \text{Switching devices}$$

$$(n-1) = \text{DC input voltage sources (capacitors)}$$

$$(n-1) * (n-2) = \text{diodes}$$

Therefore 5 level diode clamped needs 8 IGBT, 4 capacitors and 12 as shown in fig.1.

For switching there are many techniques depending on the controlling method, the PWM system can be classified into many forms. However, the primary objective of all of these kinds of systems is to provide a superior sinusoidal output voltage waveform with the necessary fundamental frequency and amplitude. Sinusoidal PWM, Selective Harmonic Elimination PWM, Space Vector PWM are the some switching methods.

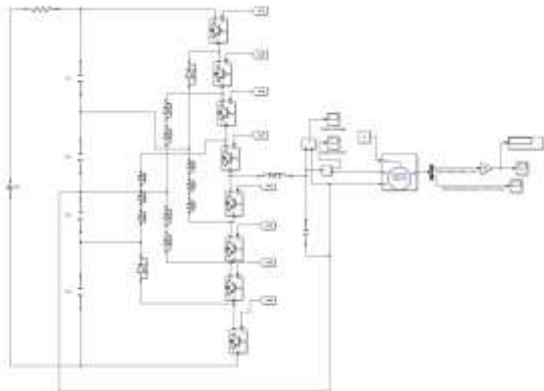


Fig. 1. Five-Level Diode Clamped Multilevel Inverter

SPWM modulation technique is most popular method and easy method. With SPWM, the modulated signal is compared to the carrier signal. Because it produces less THD, Phase Disposition Pulse Width Modulation (PD-PWM), as depicted in fig. 2, is more advantageous in NPC than Phase Shifted Pulse Width Modulation (PS-PWM). While the CHB-MLI and FC-MLI benefit more from PS-PWM.

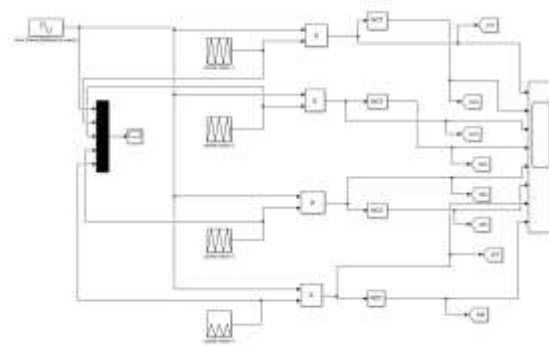


Fig. 2. PD-PWM of 5-level DCMLI

Table.1. Switching Table of 5-Level DCMLI

Switching States	Device Switching Status								Inverter terminal voltage
	S1	S2	S3	S4	S5	S6	S7	S8	
1	1	1	1	1	0	0	0	0	+Vdc/2
2	0	1	1	1	1	0	0	0	+Vdc/4
3	0	0	1	1	1	1	0	0	0
4	0	0	0	1	1	1	1	0	-Vdc/4
5	0	0	0	0	1	1	1	1	-Vdc/2

I. SIMULATION MODEL AND SIMULATION RESULTS

A. Open loop simulation

Both the stator side and the rotor side of an induction motor can regulate the motor's speed. For single phase speed is controlled by controlling input voltage of the motor from stator side. But this method has less efficiency, as speed range increases losses of the motor also increases. So, for single phase constant V/F control method can be used. This method is easy to control the speed of IM and speed can be controlled for wide range. It is also an energy efficient method for a wide range of speeds compared to other speed control methods.

The V/F control method is scalar control method because it relies on the magnitude of the stator voltage.

Synchronous Speed (N_s) of Induction Motor is given by:

$$N_s = 120f/P \quad (1)$$

Where f = frequency of the motor and P = Number of poles. So, the equation of the stator circuit is:

$$V = RI + j\psi\omega \quad (2)$$

By neglecting voltage drop over stator resistance,

$$\psi = \frac{V}{\omega} \approx \frac{V}{f} \quad (3)$$

Flux can be maintained constant using equation 3, this method only controls the speed, it has no explicit torque control.

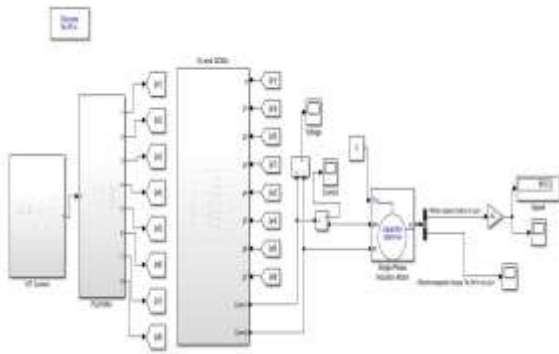


Fig. 3. Open loop simulation model of DCMLI for speed control of IM with V/F control

Fig. 3. Shows the complete simulation model of open loop DCMLI for speed control of IM. The SPWM here modulates the inverter's output. When using SPWM, the reference wave's magnitude and frequency are both directly proportional to the output voltage's magnitude and frequency, respectively. The inverter's switching frequency and the carrier wave frequency are same. To maintain the V/F ratio constant of the input of induction motor, ratio of the magnitude to the frequency of reference wave i.e., sine wave should be kept constant. The Slider gain block is added as shown in fig.4 to maintain the ratio of the gain frequency constant hence V/F will be constant. As we vary slider gain, frequency and gain of the reference wave varies with constant ratio, as it varies frequency of the output of inverter so that speed can be varied, with constant V/F ratio. Lookup table is added to limit the input voltage of the induction motor.

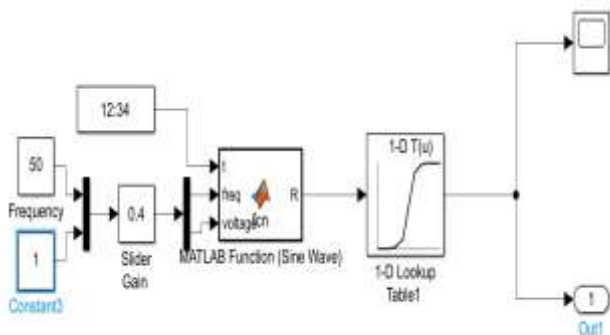


Fig. 4. V/F Control Block (Sine Wave Generation)

For induction motor at lower speed, the value of lower voltage should be minimum 20% of the rated voltage and for above rated speed as voltage increases flux get saturated so losses increases, it become difficult to get constant V/F ratio.

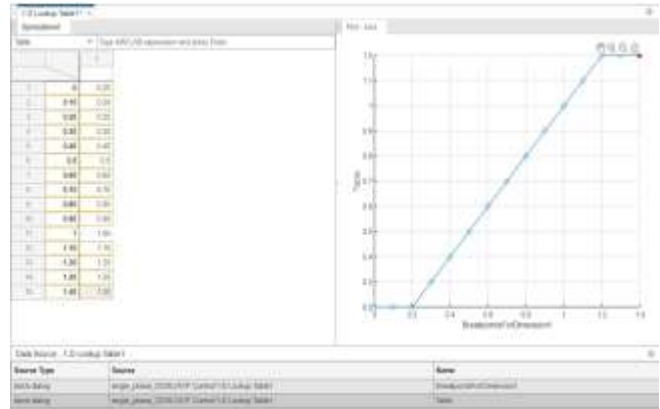


Fig. 6. Lookup Table

The rotor speed of 50Hz IM is 1476 rpm as per the fig. 7 which is less than the synchronous speed of the motor equal to 1500 rpm. So, from this the slip of IM is coming 1.6% which is good as the slip of IM should maintained below 5% as per the IEEE standards. Figure 8 illustrates the PWM switching pulses that are provided to the inverter. THD of the output voltage of 5-level DCMLI is 2.59%, As per the IEEE standard THD should be less than 5%. If THD increases then supply voltage will get disturbed, it may cause the heating of the machine and also system may become unstable. As the level of the multilevel output voltage increases filter size decreases.

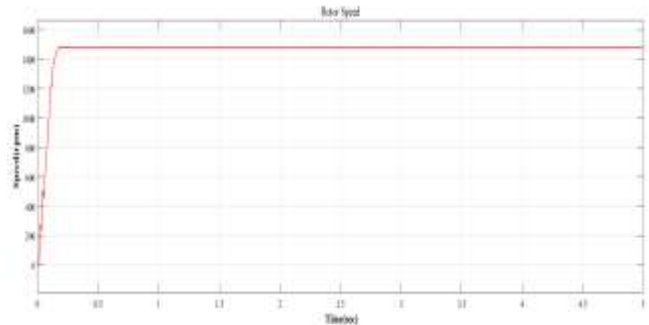


Fig.7 Speed of the IM at 50 Hz Frequency

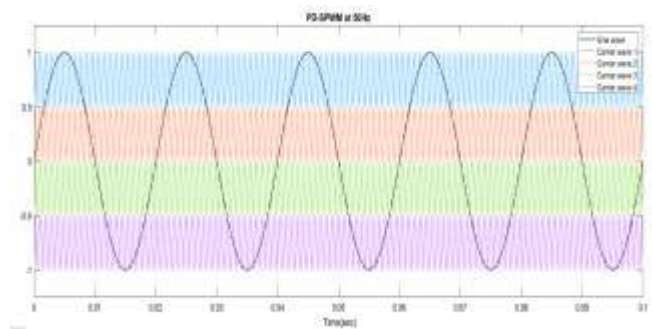


Fig. 8 PD-PWM Technique at 50Hz Frequency

It is observed that by changing the magnitude and frequency of the sine wave of PD-PWM, output changes hence speed changes. Fig. 10 shows the motor speed 1173 RPM for 40Hz frequency by taking V/F ratio constant. Slip of the motor is 2.3% is PWM waveform for 40Hz can be observed in Fig.11. as speed changes THD also changes. As we change the speed, other parameter also changes, the change in THD and speed of the motor with respect to the changes in magnitude and frequency of Modulating sine wave is observed in the table (2).

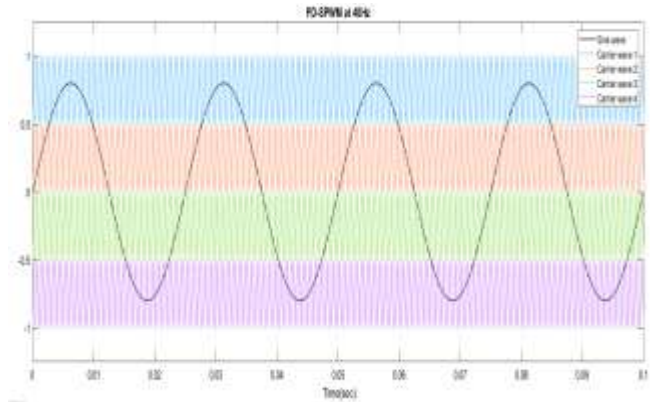


Fig. 11. PD-SPWM at 40 Hz Frequency

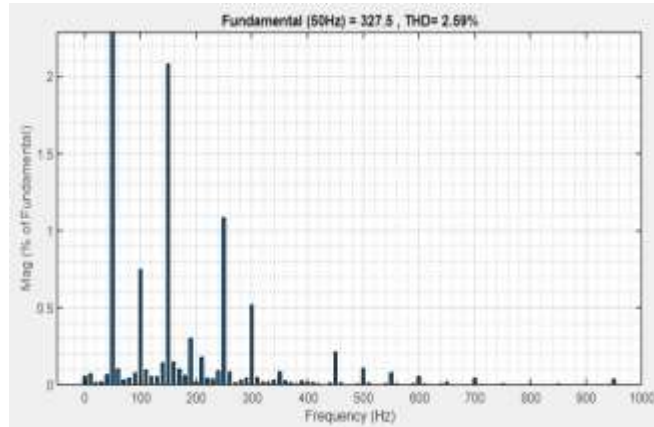


Fig. 9. Output voltage THD at 50Hz.

Table.2 Induction Motor speed analysis

Sr. No.	Frequency	Nr	Ns	Slip
1	20	575	600	0.042
2	25	721	750	0.038
3	30	863	900	0.041
4	35	998	1050	0.049
5	40	1173	1200	0.023
6	45	1325	1350	0.02
7	50	1476	1500	0.016
8	55	1627	1650	0.014
9	60	1715	1800	0.047

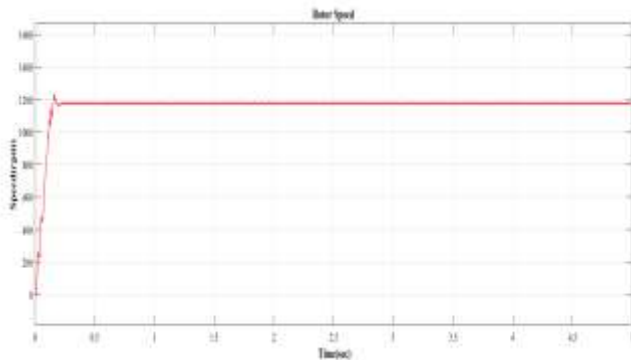


Fig. 10. Speed at 40Hz

B. Closed loop simulation

The feedback signal and reference signal are compared in a closed loop, and the resultant error is delivered to the PI controller. The sine block receives the output from the PI controller. Motor speed is given as feedback and it is compared with the reference speed; error is given to PI controller as shown in fig.12. Output of the PI controller is divided in two signals to control the voltage and frequency of the sine function as shown in fig.13, hence it will control the switching of the inverter which operate the output of multilevel inverter. In this control V/F ratio is maintained constant. As given reference speed will be achieved using PI controller.

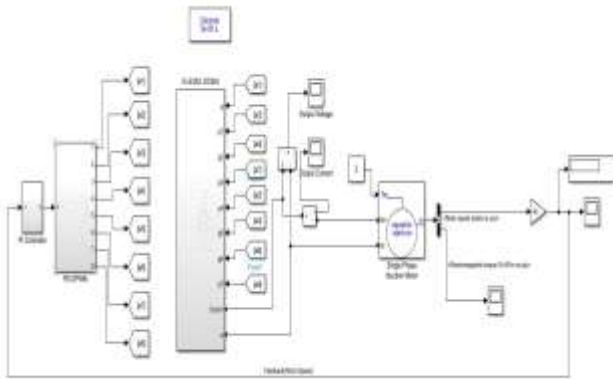


Fig.12 Closed loop Simulation model of DCMLI for speed control of IM using PI Controller

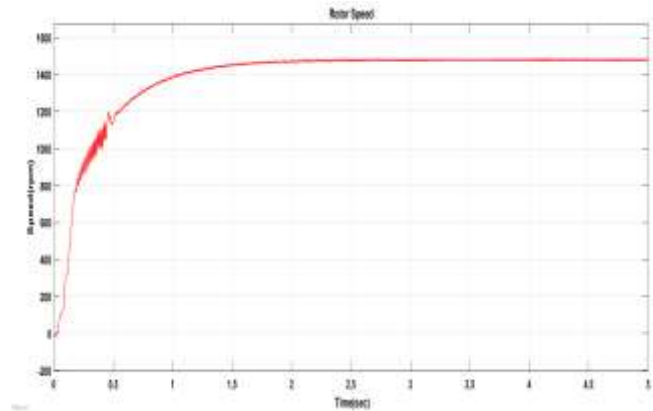


Fig.14. Closed loop speed when reference speed is 1480 rpm

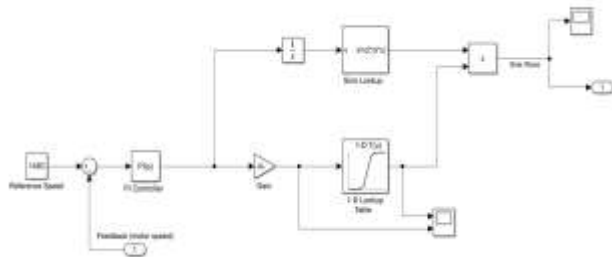


Fig. 13. PI controller block

In closed loop it is observed that Induction Motor speed follows the given reference speed. In the Fig.14. it is observed that motor is running at 1481 rpm as it has given the reference speed 1480 rpm, also speed is observed at this speed THD of the output voltage of the DCMLI is 3.12%. it is observed that as speed changes THD of the multilevel inverter changes. It is minimum at its rated speed. For wide range of speed THD of the output voltage changes, it increases for lower speed range.

By choosing an appropriate filter size, THD of the inverter's output voltage can be reduced. The filter size can also be fixed, and the speed range can be determined based on

the application's speed requirements. For rated speed THD is 3.12%.

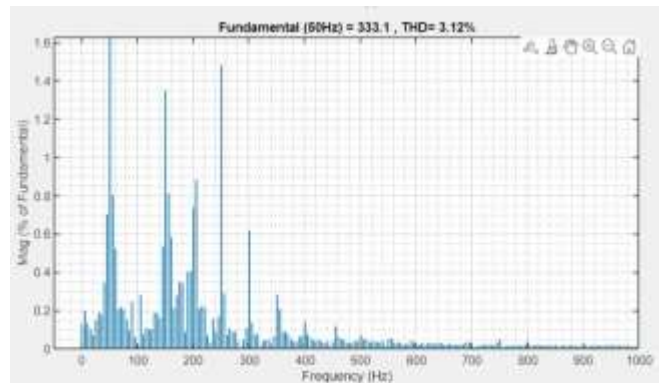


Fig.15. THD at 50Hz

The reference speed of 1300 rpm is given to the motor which is followed by the motor speed having some steady state error as shown in the fig. 16. for variable reference speed the motor actual speed is observed and from this is concluded that motor speed follows the reference speed accurately.

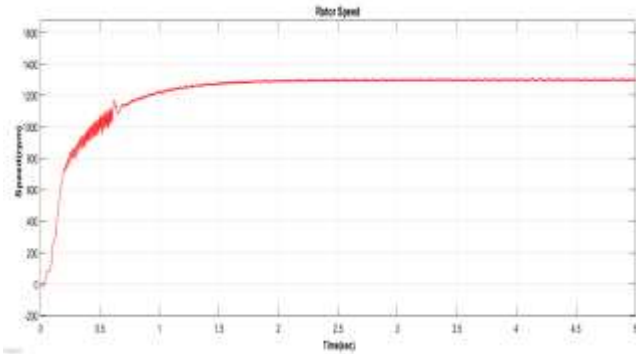


Fig.16. Speed at 1300 rpm

The above closed loop system is capable of giving accurate speed as given to the reference speed. So, it can be applied for wide range of speed by taking torque constant. Depending on the loading, current increases or decreases. As current value changes filter value changes. So, to reduce filter value level of the inverter output can be increased.

II. CONCLUSION

Multilevel inverters have been used to analyse the induction motor's speed regulation. It has been found that the constant V/F method is a simple and effective way to control the speed with a multilevel inverter. The induction motor performance is observed for wide speed range. In open loop system speed is observed from 20Hz to the 60Hz frequency range. In that frequency range, speed of the induction motor is easily adjusted by controlling the output of the multilevel

inverter and also slip is less than 5%. In the closed loop system, it is observed that motor speed tracks the reference speed accurately and this accuracy also maintained for wide speed range. Multilevel inverter output is smooth and have less THD compared to conventional converter. THD of the closed loop is less than 5% for rated speed and also near to the rated speed, but THD increases slightly more than 5% for lower speed range. Single phase induction motor is used in industrial as well as in light commercial applications for variable speed drive with low cost and high efficiency.

III. References

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