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Control of Modular Multilevel Converter Fed 3-Phase Induction Motor using DTC with PI Controller

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Abstract: In this paper 3-level Modular Multilevel Converter fed direct torque control (DTC) of Induction Motor (IM) is proposed. The proposed Modular Multilevel Converter (MMC) replaces a three-level Neutral Point Clamping (NPC) converter to drive an Induction Motor, because of its high voltage power range. The main drawback of the DTC of NPC fed IM using conventional PI controller is high torque, stator flux ripples and speed of IM is decreasing under transient and steady state operating conditions. The work of this paper is to study, evaluate and compare the techniques of the conventional DTC with NPC and DTC with MMC using PI controller, applied to the induction motor through MATLAB/Simulation.

Index terms —NPC-neutral point clamping, MMC-Modular Multilevel Converter, IM-Induction Motor, DTC-Direct Torque Controlling, Conventional PI controller THD-Total Harmonic Distortion.

I. INTRODUCTION

The induction motors have establishes extensive industrial applications due to the smooth construction, reliability, ruggedness, low cost and it can be used in combative atmosphere. The scalar control method give an efficient drive with acceptable steady state performance, but the transient performance may not be satisfactory controlled [1]. High performance drive applications usually require abrupt transient response. The upgrading in power semiconductor devices, digital data processing and control has led to huge improvements in torque response control of AC motors. Such controllers have good steady state and transient performance [1-2]. The vector control gives the abrupt transient response. It requires coordinate transformation, current control loops and pulse width modulation. The direct torque control technique has been developed as an alternate to the vector control technique to effectively control flux and torque in ac drives [3]. Direct torque control technique applies the vector relationships, but replaces the coordinate transformation concept of vector control technique and allows the fast torque response [4].

Direct Torque Controlling (DTC) was becoming more famous because of having ease of operation. In 1986 Takahashi was proposed direct torque controlling mechanism. The basics of this DTC were provided in [5]. Several advantages of this DTC were given in [6]-[7].

In past years for the constant speed operation induction motors and for variable applications DC motors were used but after the evolution of DTC method this was reversed. By calculating torque and flux from stator voltage and current, direct controlling was performed without changing any rotor parameters. This is one of the benefits for DTC method.

Researchers and industries are paying much attention on multilevel controllers because of having the capability of handling high voltages. These are having less voltage stress and generates high output with low level of harmonic content [8]-[10]. Even we are having three types of multilevel inverter topologies, Cascaded (H-bridge inverter), diode clamped (Neural Point Clamping) inverter and flying capacitor inverter. Neutral Point Clamping method is preferred as advantages having common DC-link, no need of extra sources (capacitors), the DC-link can be pre recharged and high efficient for fundamental frequency.

A simple control method for multilevel inverter can be utilized for direct torque control of induction motor without affecting it simplicity. In direct torque control method the sector of reference vector is identified, based on the required flux and torque the next vector is selected. Without any complex calculations it can be done using a switching table.

Modular Multilevel Converters (MMC) are using in major applications because of having high reliability. These MMCs can replace at two-level and three- level voltage applications [11]. This MMC can be applied in the study of wind farms. The main purpose of this paper is to improve the performance of direct torque control of three phase induction motor using 3-level modular multilevel converter and is implemented in MATLAB/Simulation.

II. GENERAL STRUCTURE

The main motto of this paper is to control the induction motor in an efficient manner. For this NPC converter and MMC were used which are shown in below fig.1
Induction motor can be controlled by Direct Torque Control method with the help of inverter circuit. The description regarding inverters was given below.

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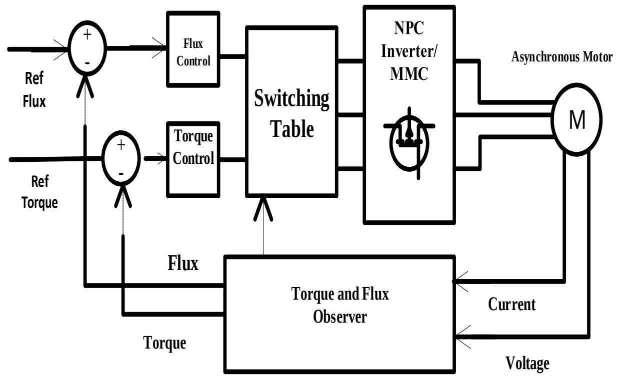

Fig.1 Basic structure of controlling of induction motor

NPC INVERTER

CONVENTIONAL STRUCTURE

The general structure of NPC was shown in below fig. 2. This structure was introduced in 1981 and used as one of the industrial applications and it is named as Diode clamping topology.

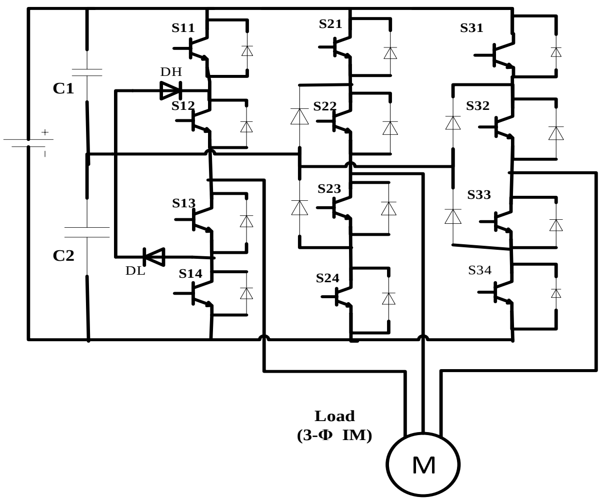

Fig.2 General Structure of neutral point clamping with 3-level inverter

The DC buses are having one DC source along with two Capacitors connected to it (C_1, C2). It acts as an input source to the inverter. Based on the action of the switches the levels can be determined. This switching state can be determined by using pulse width modulation (PWM) technique

DISADVANTAGES

1. It require more number of diode.
2. Voltage balancing at neutral point clamping across DC-link should achieve in all conditions.

By overcoming above disadvantages and to improve the less harmonic content, reliability and efficiency modular multi level converter (MMC) was introduced.

MODULAR MULTI LEVEL CONVERTER (MMC)

Modular Multilevel Converter (MMC) was observed in below figure.3.

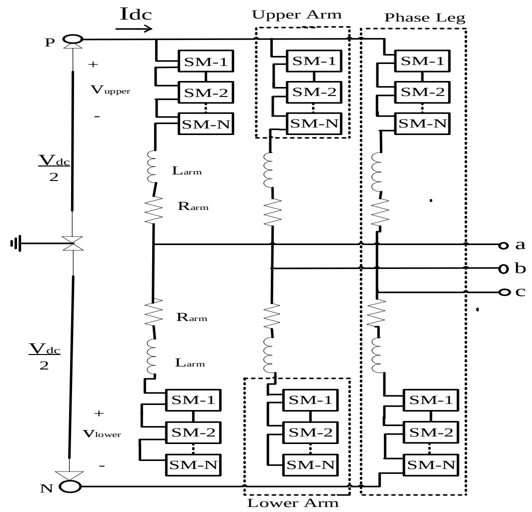

Fig.3 The basic structure of three-phase MMC topology

The MMC topology is mostly used for large power range. For medium and high power applications these can be extensively used because of having quality waveform, high efficient output. It can give solutions to the so many problems in power systems in terms of AC/AC, AC/DC, DC/AC, and DC/DC conversion. To maintain a grid without having any problems it is necessary. This can be variously used in HVDC transmission line, battery based systems and in FACTS devices (STATCOM), PV systems and Power electronic transformer (PET).

PROPOSED STRUCTURE: MMC

As per the diagram shown in fig.3 it is having a DC source and Both upper and lower arms will undergo pulse width modulation (PWM).

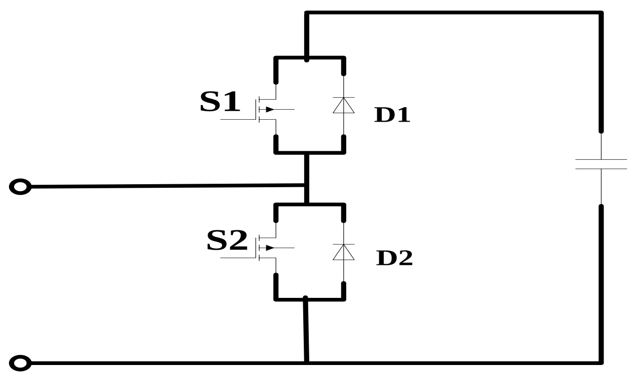

Fig.4 shows Half bridge SM

In this paper Half Bridge Sub Modules (SM) configuration shown in fig.4 were used due to its simplicity of circuit and low loss.

For Half Bridge Sub Modules (SM) [16]-[17] output voltages equal to the capacitor voltage and depends on switching configuration of S_1, S2. A half-bridge SM comprises two switching devices, two diodes and a DC energy storage element (i.e. capacitor, super-capacitor or battery) as illustrated in Fig.4. Each SM is acts as a controllable unipolar voltage source. The current flow through each SM can be bidirectional hence it gives two quadrant operation.

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For high voltage applications, multiples of such SMs are used and the terminals of these are cascaded to form one phase arm with the inductor mentioned above connected at one end as shown in Fig. 3.

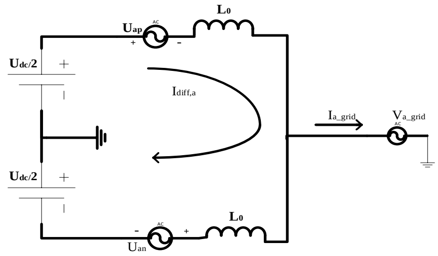
$$\begin{cases} i_{ap}(t) = \dfrac{i_{a-\text{grid}}}{2} + I_{\text{diff},a} \\ i_{an}(t) = -\dfrac{i_{a-\text{grid}}}{2} + I_{\text{diff},a} \end{cases} \quad (1)$$

Based on KVL ,the arm voltage can be expressed as

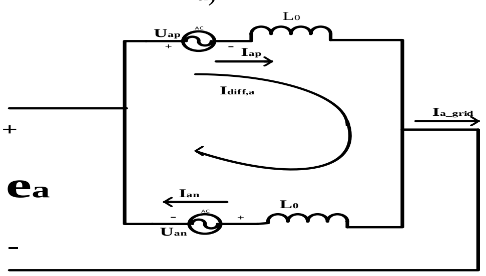
$$\begin{cases} U_{ap} = \dfrac{U_{dc}}{2} - L_o\dfrac{di_{\text{diff},a}}{2} - v_{a-\text{grid}} \\ U_{an} = \dfrac{U_{dc}}{2} - L_o\dfrac{di_{\text{diff},a}}{2} + v_{a-\text{grid}} \end{cases} \quad (2)$$

.

$$\begin{cases} U_{an} + U_{ap} = U_{dc} + 2u_{\text{diff},a} \\ U_{an} - U_{ap} = v_{a-\text{grid}} = e_a \end{cases} \quad (3)$$



a)



b)

Fig.5 shows a) the equivalent circuit for $U_{an} + U_{ap}$ b) the equivalent circuit for $U_{an} - U_{ap}$

TABLE-I
COMPARISION BETWEEN OTHER BRIDGES

SM structure	Voltage levels	DC-Fault management	Power Losses
Half-bridge	0,V_{dc}	NO	LOW
Full-bridge	0,V_{dc}	YES	HIGH
Clamp diode	0, V_{c1}, V_{c2}, (V_{c1}+V_{c2})	YES	MODERATE

.

CONTROL OF MMC

The energy exchange between input and output terminals can be done by SM capacitors whose capacitance can be controlled in steady state operation [18]-[19].When the MMC is constructed, the capacitance between capacitors, range of arms and its control and loss across the switches are to be considered for better operation. In recent studies [20]-[21], the principles and control scheme for variable speed AC motor drives with the MMC have been introduced.

For the controlling of MMC various pulse width modulation (PWM) techniques were considered.CB-PWM based technique (Fig.6) was preferred because of its easy nature. Again CB-PWM was classified into Phase-Shifted Carrier Pulse Width Modulation (PSC-PWM), Phase Disposition Pulse Width Modulation (PD-PWM) and Alternative Phase opposition Disposition (APOD-PWM) techniques as well as Phase Opposition Disposition (POD PWM).

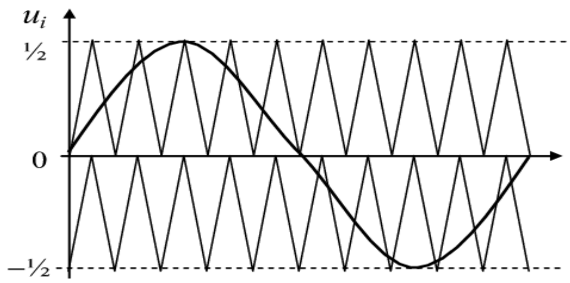


Fig.6 shows the carrier based PWM technique.

In carried based PWM ,the reference signal (sinusoidal, triangular, ramp.etc) are going to compare with the carrier signal (message signal) the gating pulses will generated and this generated pulses will trigger the switches in arms. The process of generating signal is called PWM technique. If the carrier signals of positive and negative cycles are shifted by 180^0, it is called POD-PWM.

INDUCTION MOTOR MODEL

The dynamic model of an induction motor in the stationary reference frame can be written in d-q frame variables .Stator voltage vector V_S of the motor can expressed as follows:

$$V_{ds} = \frac{d\Psi_{ds}}{dt} + R_s I_{ds} \quad (4)$$

$$V_{qs} = \frac{d\Psi_{qs}}{dt} + R_s I_{qs} \quad (5)$$

$$\overline{V_s} = \frac{d\overline{\Psi}}{dt} + R_s \overline{I_s} \quad (6)$$

The stator flux vector $\overline{\Psi_s}$ and components can be Written as

$$\Psi_{ds} = L_s I_{ds} + L_m I_{dr} \quad (7)$$

$$\Psi_{qs} = L_s I_{qs} + L_m I_{qr} \quad (8)$$

$$\overline{\Psi_s} = L_s\overline{I_s} + L_m \overline{I_r} \quad (9)$$

The rotor flux vector $\overline{\Psi_r}$ and components in the stator reference frame is

$$\Psi_{dr} = L_r I_{dr} + L_m I_{ds} \quad (10)$$
$$\Psi_{qr} = L_r I_{qr} + L_m I_{qr} \quad (11)$$
$$\overline{\Psi_r} = L_r\overline{I_r} + L_m \overline{I_s} \quad (12)$$

Where V_{ds} and V_{qs} are the ststor voltages; I_{ds} and I_{qs} are the stator currents; I_{dr} and I_{qr} are the rotor currents; Ψ_{ds} and Ψ_{qs} are the stator fluxes; Ψ_{dr} and Ψ_{qr} are the rotor fluxes; $\bar{I}_s$ and $\bar{I}_r$ are the stator and rotor currents vectors; R_s is the stator winding resistance., L_s ,L_r, L_m are stator,rotor self inductance and mutual inductance respectively. The electromagnetic torque T_e developed by the induction motor in terms of stator and rotor flux vectors can be expressed as

$$\begin{aligned} T_e &= \frac{3}{2} p \frac{L_m}{\sigma L_s L_r} \overline{\Psi_s} \times \overline{\Psi_r} \\ &= \frac{3}{2} p \frac{L_m}{\sigma L_s L_r} |\overline{\Psi_s}| \times |\overline{\Psi_r}| \\ &= \frac{3}{2} p \frac{L_m}{\sigma L_s L_r} |\overline{\Psi_s}| \times |\overline{\Psi_r}| \sin(\rho_s - \rho_r\ ) \\ &= \frac{3}{2} p \frac{L_m}{\sigma L_s L_r} |\overline{\Psi_s}| \times |\overline{\Psi_r}| \sin(\delta\ ) \qquad (13) \end{aligned}$$

Where $\sigma = 1 - \frac{L_m{}^2}{L_s L_r}$ is the leakage factor; p is the number of pole pairs; ρ_s , ρ_r are the stator and rotor flux angles respectively,and δ is the torque angle.

From the above equation, clearly the electromagnetic torque is cross vector product between the stator and rotor flux vectors. Therefore, torque control can be performed by controlling torque angle δ with constant amplitude of the stator and rotor fluxes.

DIRECT TORQUE CONTROL

Direct torque control is having much popularity to control asynchronous motor in recent years. It is having many advantages like cost, reliability, efficiency and speed control range.

In DTC method the total operation can be done by just two parameters (Torque, Flux). These two parameters can be identified by using voltage parameter.

Stator voltage can be taken as one carrier parameters and from this both torque and voltage can be found.

Stator voltage is $V_s = R_s i_s + \frac{d}{dt}\lambda_s$ (14)

To calculate torque

$$T_e = \frac{3}{2} p_n \lambda_s * i_s \qquad (15)$$

Stator linkage flux

$$\lambda_s = L_s i_s + L_m i_r = \frac{L_s}{L_m}(\lambda_r - \sigma L_r i_r) \qquad (16)$$

By using above formulae this method can be applied.

TRANSFORMATIONS

The three phase voltage is now converted into direct axis and quadrant axis format.

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(wt) & \cos(wt - \frac{2\Pi}{3}) & \cos(wt + \frac{2\Pi}{3}) \\ -\sin(wt) & -\sin(wt - \frac{2\Pi}{3}) & -\sin(wt + \frac{2\Pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix}$$

$$u_d = \frac{2}{3}[u_s \cos(wt) + u_b \cos\left(wt - \frac{2\pi}{3}\right) + u_c \cos(wt + \frac{2\pi}{3})]$$

$$u_q = -\frac{2}{3}[u_a \sin(wt) + u_b \sin\left(wt - \frac{2\pi}{3}\right) + u_c \sin(wt + \frac{2\pi}{3})]$$

$$u_0 = \frac{1}{3}[u_a + u_b + u_c]$$

Because of this conversion, there will be ease of calculation of torque and flux in both static and rotator reference frames.

Now the calculated parameters can be used to find the error with the help of reference parameters and the calculated error can be minimized via controllers.

Now this minimized error is going to convert in the form of gate pulses in order to trigger the switches. Thus pulse width modulation can be appeared here.

III. SIMULATION CIRCUIT AND RESULT

Below simulation diagram will control induction motor

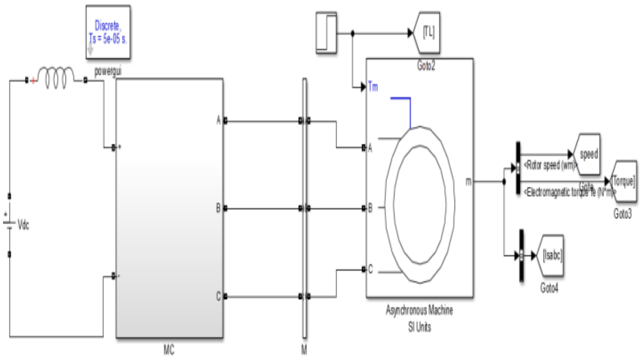


Fig. 7 shows the circuit in simulation view

In this paper 250 volts of dc supply was given to MMC topology to control the induction motor of 2238 nominal power.

TABLE- II LIST OF PARAMETERS

parameter	Ratings
Voltage Source	250V
Inductor	0.005H

TABLE-III INDUCTION MOTOR DETAILS

PARAMETER	RATINGS
Nominal Power	2238VA
Voltage $_{\text{line-line}}$	220V
Stator Resistance (Rs)	0.435 Ohm
Stator Inductance(L_{ls})	0.002 Henry
Rotor Resistance(R_r)	0.816 Ohm
Rotor Inductance(L_{lr})	0.002 Henry

TABLE-IV CONTOLLER DETAILS

Controller	Gain values
Torque	K_p=1.5,K_I=100
Flux	K_p= 250,K_I=4000

RESULTS OF CONVENTIONAL TOPOLOGY

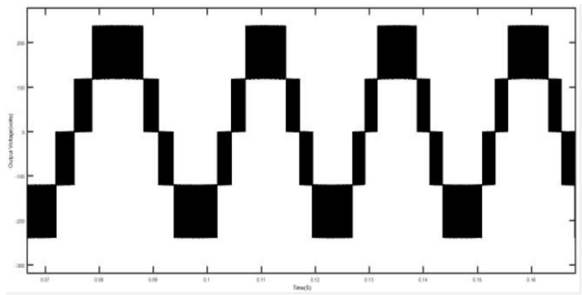


Fig.8 a) shows the Output Voltage of inverter

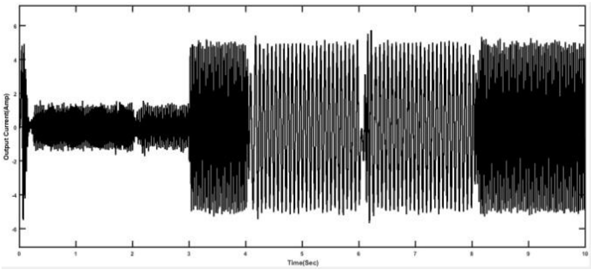


Fig.8.b) shows the output current of inverter.

Because of changing the value of torque at 3sec changes were occurred and after at 5sec slight flicker of current because of settle of torque value.

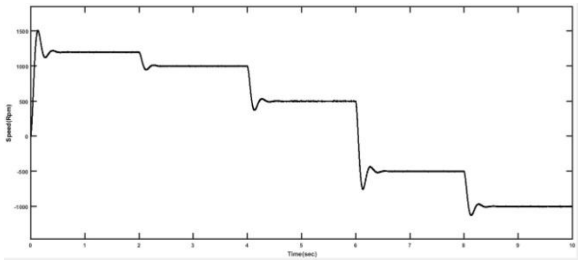


Fig.9 shows the speed of induction motor

There will be the considerable decrease in speed as time increases because of changing of torque.

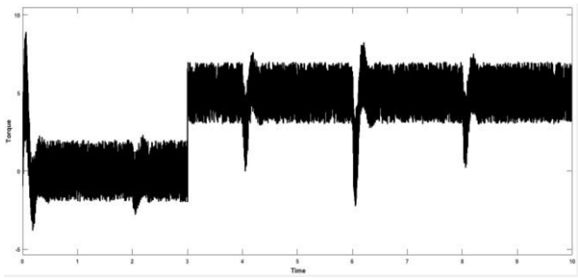


Fig.10 shows the torque values of motor

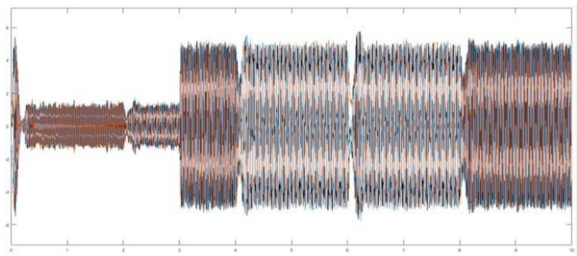


Fig.11.shows the stator current of IM

At it changes according to changes of torque value.

PROPOSED TOPOLOGY RESULTS

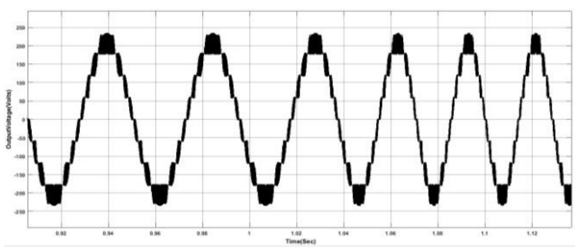


Fig.12 shows the values of Voltage at inverter.

In conventional we are getting 3-level inverter but in proposed topology the output is modular multilevel inverter (3-level).As level increases ripple percentage will decreases.

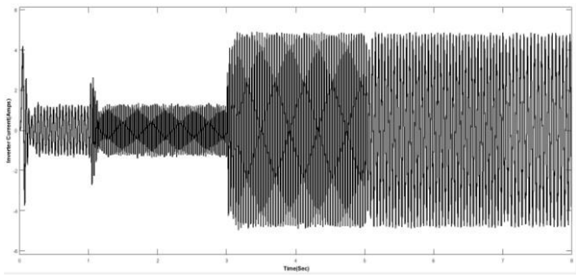


Fig13. Shows Current at inverter

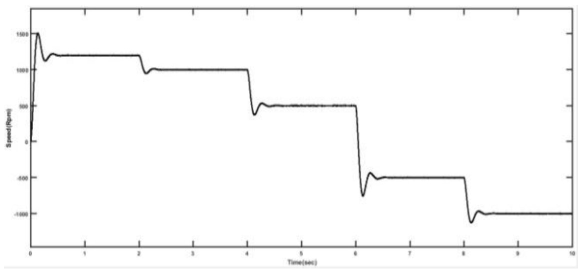


Fig.14 show the speed of IM

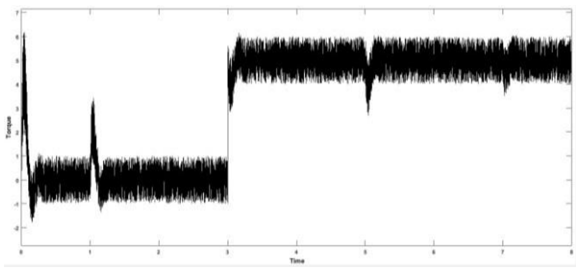


Fig.15 shows the torque VS time.

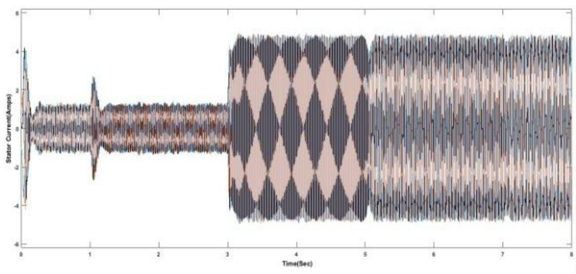


Fig.16 shows Stator current of IM.

COMPARISION OF BOTH TOPLOGIES

In NPC topology maximum voltage appeared at inverter is of 297.75 V and Current is 7.16A but in MMC, it is about to 297.75V and 6.71A respectively.

While comparing with speed the maximum speed attained is 991.9 rpm for NPC and 996 rpm for MMC and the reference speed considered is 1000rpm.

Similarly, for THD analysis NPC is having 83.03%, while MMC is maintaining 61.76% .

For NPC inverter Torque and Stator Current are 5.328 N-m and 4.932A whereas for MMC is about to 5.164 N-m and 4.719A respectively.

TABLE –V SHOWS THE COMPARISON OF CURRENT RIPPLE AND TORQUE RIPPLE BETWEEN NPC INVERTER AND MMC

Converter Name	Current ripple(p.u)	Torque ripple(p.u)
NPC Inverter	0.5	0.15
MMC topology	0.2	0.024

TABLE –VI SHOWS THE COMPARISON OF PEAK TIME AND SETTLING TIME BETWEEN NPC INVERTER AND MMC

Converter Name	Peak time(sec)	Settling time(sec)
NPC Inverter	0.136	0.39
MMC topology	0.129	0.286

IV. CONCLUSUION

In this paper Induction Motor Controlling with Modular Multilevel Converter by Direct Torque Control Method was simulated. From above Comparison table, MMC topology is having less Peak time and Settling Time than NPC Inverter and values of the MMC topology is giving much control and less harmonic content as compared with NPC Inverter. So MMC topology can control IM better than NPC Inverter.

REFERENCES

1. 1. M. Finch and D. Giaouris, "Controlled AC Electrical Drives",IEEE Transactions on Industrial Electronics, 2008, vol. 55, pp.481-491.
2. Giuseppe S. Buja and Marian P. Kazmier kowski, "Direct Torque Control of PWM Inverter-Fed AC Motors-A Survey", IEEETransactions on Industrial Electronics, 2000, vol. 51, No. 4, pp.744-757.
3. M. Deppenbrock, "Direct self control (DSC) of inverter-fed induction machine," IEEE Trans. Power Electron., vol. 3, July 1988, pp. 420-429.
4. Bose.B.K., Modern Power Electronics and AC Drives, Prentice Hall, 2002
5. I. Takahashi, T. Noguchi, (1986) "A new quick-response and high efficiency control strategy of an induction motor", IEEE Trans. Ind. Appl., Vol. IA-22, No 5, pp. 820-827
6. Del Toro X. Jayne M G. Witting P A, "New DTC control scheme for the induction motor fed with a three-level inverter," IEEE International Symposium on Industrial Electronics ISIE, Vol. 3, pp. 893 – 897, 2005.
7. Abdalla T Y. Hairik H A. Dakhil A M, "Direct torque control system for a three phase induction motor with fuzzy logic based speed Controller," 1st International Conference IEEE on Energy, Power and Control EPC-IQ, pp. 131 –138, 2010.
8. Tolbert. L.M and Pend.F.Z, "Multilevel Converter as a Utility Interface for Renewable Energy Systems," IEEE Power Engineering Society Meeting, Vol. 2, 2000, pp. 1271-1274.
9. Yue, F. and N. Elliott, " A simple modulation strategy to control the neutral point voltage deviation in three-level NPC inverters," *Power Electronics, Machines and Drives (PEMD)*, pp. 1-5, April 2010.
10. Srirattanawichaikul, W., et al, "A carrier-based PWM strategy for threelevel neutral-point-clamped voltage source inverters," *Power Electronics and Drive Systems (PEDS)*, pp. 948-951, Dec 2011.
11. Choudhury, A., P. Pillay, and S.S Williamson, "A performance comparison study of space-vector and carrier-based PWM technique for a 3-level neutral point clamped (NPC) traction inverter drive," *Power Electronics, Drives and Energy Systems (PEDES)*, pp. 1-6, Dec 2014.
12. Pou, J., et al., "A Carrier-Based PWM Strategy With Zero-Sequence Voltage Injection for a Three-Level Neutral-Point Clamped Converter," *IEEE Transactions on Power Electronics*, vol. 27, pp. 642-651, 2012.
13. Yin Li, Student Member, IEEE, Lingling Fan, Senior Member, IEEE, "Modular Multilevel Converter Based Induction Machine Drive" International Conference of North American Power Symposium(NAPS) on 4-6 Oct-2015, IEEE-2015.

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