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Dtc of 3-Level Npc Inverter and Mmc Fed 3-Phase Induction Motor

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Abstract: *Direct torque control is an utmost control technique to attain high performance of AC drives. This paper presents controlling of 3-phase Induction Motor (IM) fed from a 3-level Modular Multilevel Converter (MMC) topology which results in minimization of torque and flux ripples when compared to a 3-level Neutral Point Clamping (NPC) inverter based on Direct Torque Control(DTC). As well this in turn can reduce the Total Harmonic Distortion (THD) of the output current and voltage. In recent, modular multilevel converters are becomes popular due to their excellent scalability, redundancy and lesser harmonics for high power applications. The objective of this paper is to improve the steady state and dynamic performances of 3-phase induction motor fed from MMC with DTC using MATLAB/Simulation.*

Keywords *: Induction Motor (IM), Direct Torque Controlling (DTC), Neutral Point Clamping (NPC) Inverter, Modular Multilevel Converter (MMC), PI controller, THD-Total Harmonic Distortion.*

I. INTRODUCTION

The induction motor has very wide range of industrial applications due to its simple construction. The direct torque control (DTC) technique comes up as an alternative to Field Oriented Control (FOC) technique [1]-[2]. The DTC have simple in structure, gives fast torque response, free from the coordinate transformation and robustness against motor parameter variation [3]. DTC was proposed by Takahashi in 1986. DTC has a simple control design and give effective performance, and adaptability [4]-[5].

Multilevel inverters have become a very attractive solution for high power applications. DTC of induction motor using multilevel inverters provided in [6]-[7].

Modular Multilevel Converters (MMC) compensate at 2-level and 3- level voltage utilizations [8]. The objective of this paper is to enhance the performance of 3- phase IM with DTC using 3-level MMC by MATLAB/Simulation.

II. GENERAL STRUCTURE

The fig.1 shows the basic structure for controlling of 3-phase IM fed from 3-level NPC inverter / MMC based on direct torque control technique.

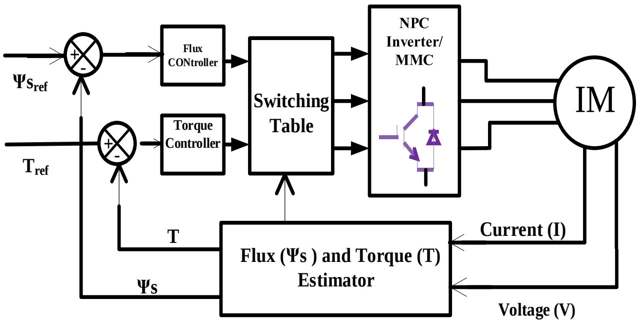

Fig. 1. Basic structure for control of 3- phase IM using DTC

III. NPC INVERTER

A 3-level Neutral Point Clamping (NPC) inverter is shown in Fig. 2.

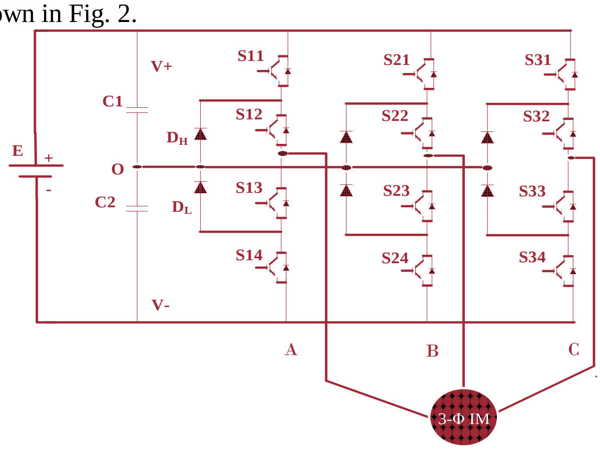

Fig. 2. A 3-Level NPC Inverter Circuit

It consists of 2 Capacitors, 12 power switches, 6 power diodes and a single DC source. The switching state for each switch is shown in Table I. The switching-states of fig.2 is represented as given in equation (1). The equation (2) and (3) represents the three phase voltage and current components in αβ transformation.

$$\begin{cases} S = (Sa, Sb, Sc), Sa, b, c \in \{-1, 0, +1\} \\ +1 \rightarrow S1, S2 \text{ are ON} \rightarrow = +V \\ 0 \rightarrow S2, S3 \text{ are ON} \rightarrow = 0 \\ -1 \rightarrow S3, S4 \text{ are ON} \rightarrow = -V \end{cases} \quad (1)$$

$$\begin{vmatrix} u_\alpha \\ u_\beta \end{vmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} \quad (2)$$

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$$\begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{l1} \\ i_{l2} \\ i_{l3} \end{bmatrix} \quad (3)$$

Where u_i *and* l_i $(i = 1,2,3)$ are three phase voltages at common coupling point (CCP), and load currents, respectively.

Table –I: Switch States of a Three-Level NPC Converter

Switch States				
S_1	S_2	S_3	S_4	Output Voltage
ON	ON	OFF	OFF	+V
OFF	ON	ON	OFF	0
OFF	OFF	ON	ON	-V

Disadvantages

1. Large number of diodes required.
2. The capacitor voltage cannot be maintained as selected switching pattern.
3. Real power flow is difficult because of the capacitors imbalance.

To eliminate the above drawbacks Modular Multilevel Converter (MMC) was introduced.

IV. MODULAR MULTI LEVEL CONVERTERS (MMC)

In this paper MMC topology was introduced to transform the DC into AC power. This MMC will trigger the switches according to the given sequence. The pulses can be given to trigger the circuit and thus pulses can be generated according to PWM method.The complete details of MMC, its types and controlling were given below.

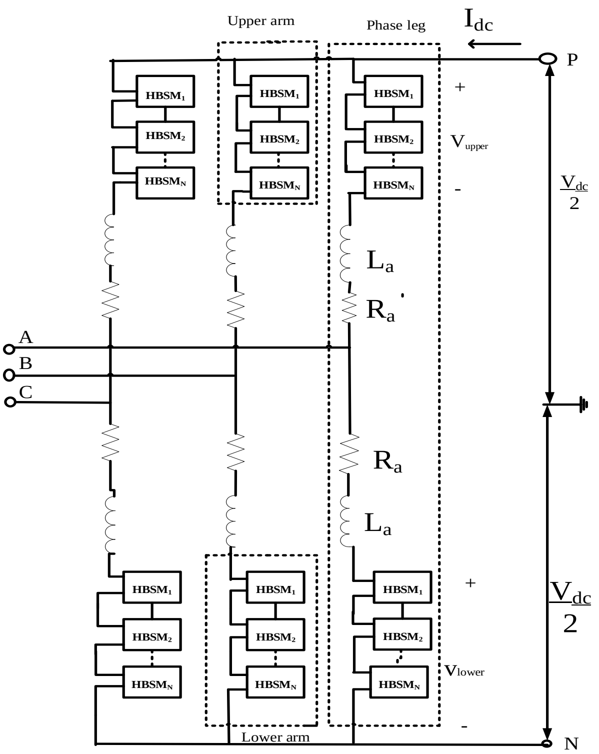


Fig. 3. Configuration of MMC topology

Generally MMC is a combination of cascade connected submodules which is having arms at upper and lower side as shown in Fig.3. Thus connected arm is having submodule and inside the submodule shown is a half bridge. There we are having three types in MMC as Half bridge, Full Bridge, clamp doubles. Among them the Half Bridge Sub Module (HBSM) grown into more famous and it is commercially used in the MMC based motor drives.

A. Mathematical Model of MMC

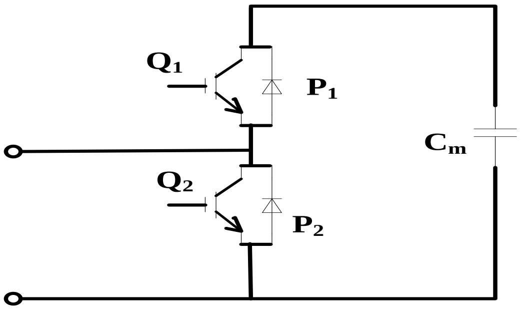


Fig. 4. Half Bridge Sub Module

The HBSM structure is shown in fig. 4. For HBSM [9]-[10], the output voltage can be controlled according to the gating composition of Q_1, Q_2. The mathematical model of MMC is analyzed by phase- A as the example. The per phase equivalent circuit of MMC is shown in fig.5, from Fig.5 (ii), the upper and lower arm currents of phase- A by KCL, i_{ua} and i_{la} expressed as

$$\begin{cases} i_{ua}(t) = \frac{i_{a.m}}{2} + I_{dif,a} \\ i_{la}(t) = -\frac{i_{a.m}}{2} + I_{dif,a} \end{cases} \quad (4)$$

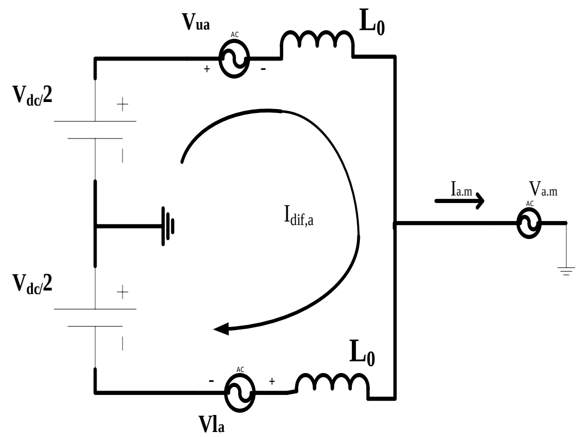
Where, $i_{dif,a}$ = Inside phase unit current,
$i_{a.m}$ = Output current of MMC, and both are symmetrical.
By KVL, from Fig.5 (i), the arm voltages are given as

$$\begin{cases} V_{ua} = \frac{V_{dc}}{2} - L_o \frac{di_{dif,a}}{2} - v_{a.m} \\ V_{la} = \frac{V_{dc}}{2} - L_o \frac{di_{dif,a}}{2} + v_{a.m} \end{cases} \quad (5)$$

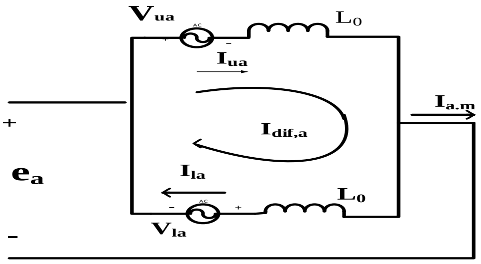
Here $v_{a.m}$ is the MMC output voltage and V_{dc} is the DC voltage source.

$$\begin{cases} V_{ua} + V_{la} = V_{dc} + 2u_{dif,a} \\ \frac{V_{ua} - V_{la}}{2} = v_{a.m} = e_a \end{cases} \quad (6)$$

Where, e_a= Internal emf and it is used as control voltage



(i)



(ii)

Fig.5. (i) Eq. circuit for $V_{ua} + V_{la}$ (ii) Eq. circuit for $V_{ua} - V_{la}$

B. Control of MMC

Submodule capacitors are used to transfer the power between the source and load [11]-[12]. In modern research [13] has been recommended the novel technique of control proposes for MMC in AC drives. In the governing of MMC different pulse width modulation (PWM) schemes are advised, are nearby level modulation (NLM), selective harmonic elimination (SHE) and carrier based PWM (CBPWM). CBPWM scheme (Fig.6) was adopted due to its accessible quality.

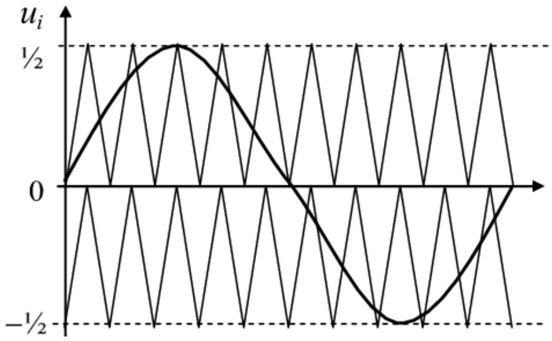


Fig.6. CBPWM technique

V. INDUCTION MOTOR MODEL

The dynamic model of an induction motor in the stationary reference frame can be written in d-q frame variables.

$$V_{ds} = \frac{d\Psi_{ds}}{dt} + R_s I_{ds} \quad (7)$$

$$V_{qs} = \frac{d\Psi_{qs}}{dt} + R_s I_{qs} \quad (8)$$

$$\bar{V_s} = \frac{d\bar{\Psi}}{dt} + R_s \bar{I_s} \quad (9)$$

$$\Psi_{ds} = L_s I_{ds} + L_m I_{dr} \quad (10)$$

$$\Psi_{qs} = L_s I_{qs} + L_m I_{qr} \quad (11)$$

$$\bar{\Psi_s} = L_s \bar{I_s} + L_m \bar{I_r} \quad (12)$$

$$\Psi_{dr} = L_r I_{dr} + L_m I_{ds} \quad (13)$$

$$\Psi_{qr} = L_r I_{qr} + L_m I_{qr} \quad (14)$$

$$\bar{\Psi_r} = L_r \bar{I_r} + L_m \bar{I_s} \quad (15)$$

The torque T_e developed by the induction motor can be expressed as

$$T_e = 1.5p \frac{L_m}{\sigma L_s L_r} \bar{\Psi_s} \times \bar{\Psi_r}$$

$$= 1.5p \frac{L_m}{\sigma L_s L_r} |\Psi_s| \times |\Psi_r|$$

$$= 1.5p \frac{L_m}{\sigma L_s L_r} |\Psi_s| \times |\Psi_r| \sin(\rho_s - \rho_r)$$

$$= 1.5p \frac{L_m}{\sigma L_s L_r} |\Psi_s| \times |\Psi_r| \sin(\delta) \quad (16)$$

Where,

V_{ds}, V_{qs} = stator voltages
I_{ds}, I_{qs} = stator currents
I_{dr}, I_{qr} = rotor currents
Ψ_{ds}, Ψ_{qs} = stator fluxes
Ψ_{dr}, Ψ_{qr} = rotor fluxes
$\bar{I_s}, \bar{I_r}$ = stator, rotor currents vectors
R_s = stator resistance
L_s, L_r, L_m = stator, rotor self inductance and mutual inductances.
p = number of pole pairs
ρ_s, ρ_r = stator and rotor flux angles.
δ = torque angle.
$\sigma = 1 - \frac{L_m^2}{L_s L_r}$ = leakage factor

A. Direct Torque Control(DTC)

DTC is superior to other techniques to control of 3-phase induction motor. The stator voltage, flux linkage and torque are,

$$V_s = R_s i_s + \frac{d}{dt}\lambda_s \quad (17)$$

$$T_e = \frac{3}{2} p_n \lambda_s * i_s \quad (18)$$

$$\lambda_s = L_s i_s + L_m i_r = \frac{L_s}{L_m}(\lambda_r - \sigma L_r i_r) \quad (19)$$

B. Transformation

Conversion of three phases to direct-quadrant-zero known as Park's transformation. However we are having one mathematical formula, which is shown below.

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos(w_e t) & \cos(w_e t - 120^0) & \cos(w_e t + 120^0) \\ -\sin(w_e t) & -\sin(w_e t - 120^0) & -\sin(w_e t + 120^0) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (20)$$

$$V_d = \frac{2}{3}[V_a \cos(w_e t) + V_b \cos(w_e t - 120^\circ) + V_c \cos(w_e t + 120^\circ)]$$

$$V_q = -\frac{2}{3}[V_a \sin(w_e t) + V_b \sin(w_e t - 120^\circ) + V_c \sin(w_e t + 120^\circ)]$$

$$V_0 = \frac{1}{3}[V_a + V_b + V_c] \quad (21)$$

By using the above transformation, the control of three phases can be done easily, and then we can convert the values from d- q- 0 to a- b- c and this transformation known as Inverse Park's transformation.

In DTC method, by using voltage and current parameters of stator we will calculate both torque and flux. These calculated parameters will undergo subtraction with reference values, there one rectified value will generate. This signal will undergo PWM technique.

VII. SIMULATION DIAGRAM AND RESULT ANALYSIS

The simulation circuit is shown in below fig.7

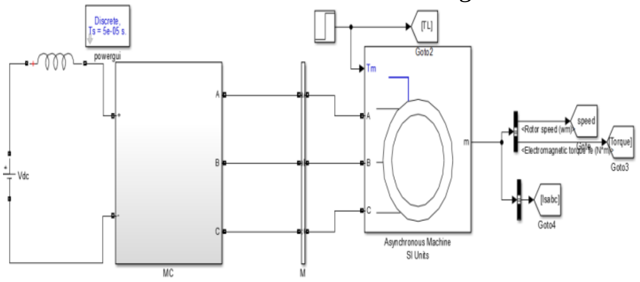


Fig. 7. Simulation circuit diagram

Table- II: Specifications of IM

PARAMETER	RATINGS
Power	2238VA
Source Voltage	250V
Inductor	0.005H
Number of poles(p)	6
Speed	1000 rpm
Voltage $_{line-line}$	220V
Stator Inductance(L_{ls})	0.002 Henry
Stator Resistance (Rs)	0.435 Ohm
Rotor Inductance(L_{lr})	0.002 Henry
Rotor Resistance(R_r)	0.816 Ohm

Table- III. Controller Specifications

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

A. Conventional NPC Inverter Topology

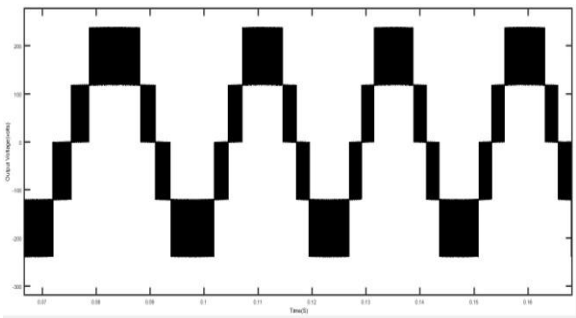


Fig.8. Output Voltage of NPC inverter

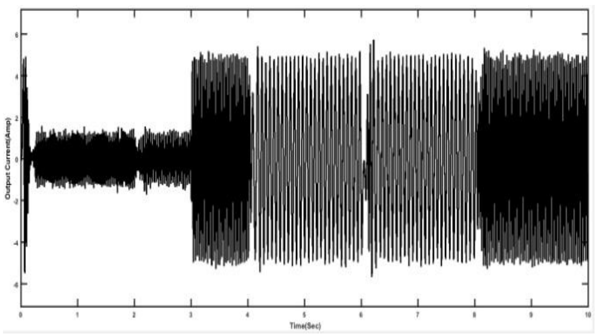


Fig.9. Output current of NPC inverter

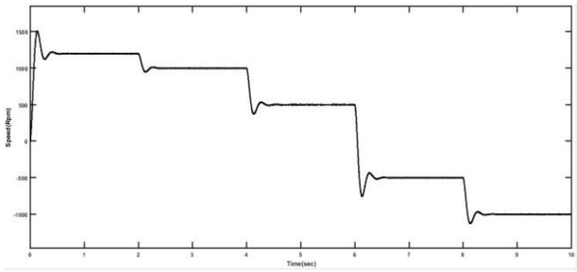


Fig.10. Speed of induction motor

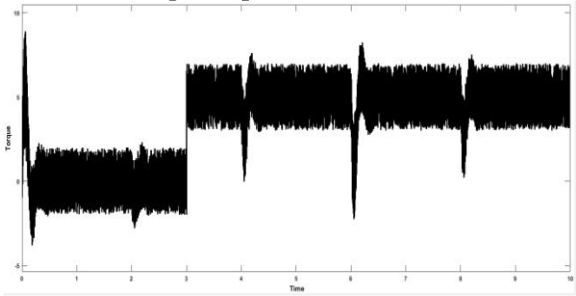


Fig.11. Torque values of motor

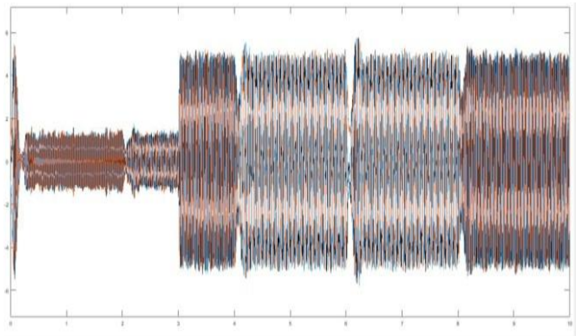


Fig.12. Stator current of IM

B. Proposed MMC Topology

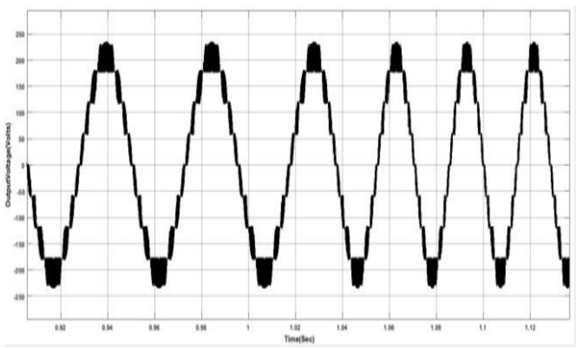


Fig.13. Output voltage of MMC

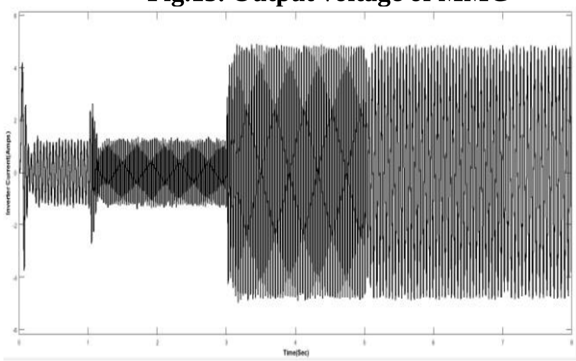


Fig.14. Output current of MMC

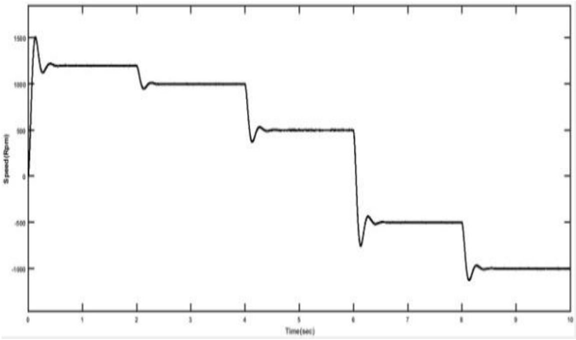


Fig.15. Speed of induction motor

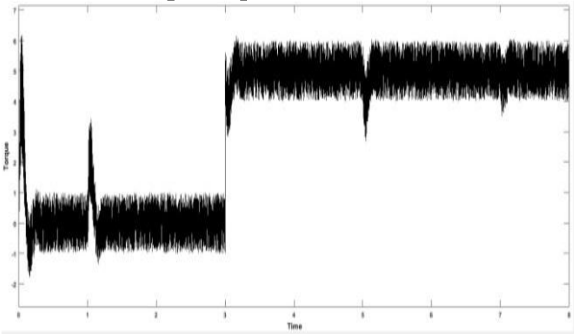


Fig.16. torque of induction motor

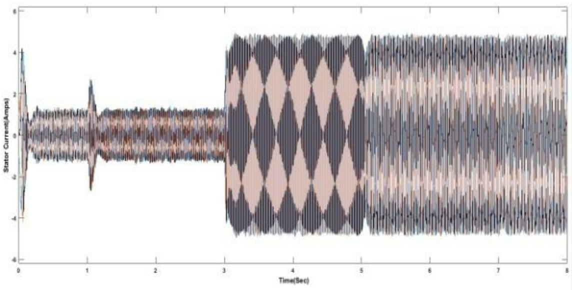


Fig.17. Stator current of induction motor

From the simulation results it is observed that the current and torque ripples are 0.5p.u and 0.15p.u respectively for the NPC inverter and where as for MMC are 0.2p.u and 0.24p.u respectively. And the peak time and settling times are 0.136s and 0.39s for NPC inverter and where as for MMC are 0.129s and 0.286s respectively. Various performance values are given in table -4.

Table – IV: Performance Comparison between NPC Inverter and MMC

S. No	Parameter	NPC Inverter	MMC
1	Voltage (V)	297.75	297.75
2	Current(A)	7.16	6.71
3	Speed (rpm)	991.9	996
4	Torque (N-m)	5.328	5.164
5	Stator Current(A)	4.932A	4.719
6	THD	83.03%	61.76%

VI. CONCLUSUION

In this paper DTC of 3-phase IM with NPC and Modular Multilevel Converter was presented. The simulation results of both are carried out and compared through MATLAB/SIMULATION. The simulation result shows lesser ripple content in both torque and flux, and lower harmonics presented from the MMC topology. In conclusion, MMC topology gives better supervision of induction motor as compared with NPC inverter based on DTC technique.

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