Comparison of Harmonics and Current Ripple Reduction Using Various PWM Techniques in Indirect Vector Control

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Summary
In this paper we present a comparative study on dynamic reduction of stator current ripples using various pulse width modulated control techniques applied in the induction motor drives. The Stator current ripple is one of the major issues that affect the efficiency of the induction motors. So, we considered this stator current ripple for analysis using a novel PWM technique applied to the inverter of the induction motor drive. We have used the indirect vector control strategy for studying the given issue. The analyses of Stator current ripple is carried out with the PWM techniques like Sinusoidal Pulse Width Modulation (SPWM), Space Vector Pulse Width Modulation (SVPWM), Common Mode Voltage (CMV) elimination or Near Space vector Pulse Width Modulation (NSPWM) and Hysteresis control. These techniques are compared and tabulated for Stator Current Ripples and Total Harmonic Distortions.

Key words: Stator Current Ripple, Indirect Vector Control, and Common Mode Voltage

1. Introduction

Field oriented Control (FOC) being the most researched and most inducted control technique on induction motors[1-2] we take this technique to further it. It allows, a induction motor to achieve the dynamic performance that can be measured close to that of the DC motor or Brushless motor.This is achieved by means of co-ordinate transformation that decouples the electromagnetic torque control from the rotor flux.Also called as Indirect Vector control this technique, takes the variables like voltage and current to be transformed into a reference frame in which the control variables behave like DC quantities. The decoupling control between the flux and torque allows induction motor to achieve fast transient response. Hence, is preferably used in high performance motor applications.

Nevertheless the control boils down to the quality of the output voltage of the inverter that feed the induction motor, which is determined by pulse width modulation (PWM) strategy. The variable frequency introduced because of the hysteresis control due to peak to peak current comparison causes harmonic impedance variation and higher THD [3-5]. The Sinusoidal PWM (SPWM) will sometimes negotiate the problem of over modulation that will introduce the lower order harmonics in the wave. The harmonic is reduced if a constant switching frequency is introduced in the PWM technique that was introduced by the SVPWM method. The SVPWM technique being superior in terms of reduction of the harmonic distortion reduction would divide equally the zero voltage vector among the two zero voltage vectors [5-7]. This SVPWM technique has better dc bus utilization [7] and easy for the digital implementation [8]. The common voltage gets dynamic characteristics and because of that there will be prohibitive amount of common mode current in the induction motor. EMI and interferences are introduced because of these common mode currents. So, in order to get rid of this inconvenience to the induction motors we introduce the Common Mode Voltage (CMV) elimination method. This paper presents a comparative analysis of the CMV elimination with SVPWM, Hysteresis Current Control in the indirect field orientation technique. The parameters taken for analysis are THD, Stator current ripple and efficiency.

This paper is organized as follows. The Hysteresis based vector control is dealt in section 2.SPWM; SVPWM and NSPWM control techniques in Section 3,4 and 5 respectively. The simulation results and discussion with the tradeoff analysis is dealt in detail in section 6.

2. Hysteresis Based Vector Control

The high frequency gating pulses generated by the inverter would generate a controlled voltage and frequency for the induction motor's control.The space vector for the VSI has got eight vectors ,six active and two zero voltage vectors.The generation of the vectors from the flux fed back gives it the name direct vector control.The control of induction motors need more dynamism as there is lot of non linearity in the induction model and also its sensitivity towards temperature and skin effect.The Hysteresis method also called as nonlinear current control method reacts to the change in stator current vector.The sinusoidal set points of the phase currents are taken from the coordinate

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transform . The current error from the comparator would decide the switching of the corresponding phase .Either it would connect to the '+' or the '-' of the DC supply of the inverter according to the error .

The hysteresis controller or the current controller has been the traditional technique that was used for the dynamic operation of AC drives system.The hysteresis controller would force the load current to follow a reference current wave .

In the vector control this command current is measured from a totally decoupled loop of flux and torque dependent currents i_{qs}^e and i_{ds}^e .These currents are derived from the desired torque and flux for attaining the desired speed at the situation or sample taken.The torque generated due to this current control is given by equation (1).

$$T_e = \frac{3 P L_m}{4 L_r} \left(\lambda_{dr}^e i_{qs}^e - \lambda_{qr}^e i_{ds}^e \right) \quad (1)$$

Where L_m is the magnetizing inductance L_r the rotor equivalent leakage inductance . i_{ds}^e And i_{qs}^e are the stator current quadrature and direct component respectively. T_e the generated electromagnetic torque. λ_{dr}^e and λ_{qr}^e are the rotor flux components.The decoupled control have to have the quadrature flux to be made zero. It is analysed in the induction motor characteristics that the rotor flux is directly proportional to i_{ds}^e and it is maintained constant.The electromagnetic torque developed T_e is directly proportional to i_{qs}^e and hence we get a faster response.

The load current after sensing is compared with the command currents by the hysteresis comparators having the hysteresis band (HB) .The difference signal that is generated in this comparator activates the switches according to the difference.

But this method is exposed to disadvantages like variable switching frequency, high interference, harmonic content in switching side band, and irregularity in modulation pulse position [14]. These drawbacks will lead to higher current ripples.

3. Vector controller with PI controlled Triangular comparison technique

The reference of this method goes back to the ramp comparison constant frequency PWM [13].

In order to overcome the variable frequency switching of the hysteresis controller we prefer triangular comparison method. This method utilizes the natural intersection points of voltage from the PI controller with triangular wave to realize PWM. Here the block of hysteresis is replaced by the triangular comparison technique .The constant frequency pulse generation due to this technique is the major update here that would decrease the THD automatically because of decreased number of components of frequency in the output waveform. This would indirectly reduce the current ripple in the stator. The irregularity in the modulation pulse will be only the source of THD in this method

4. SVPWM Based Indirect Vector Control

The torque equation in the space vector based vector control is given as follows

$$T_e = \frac{3 P L_m}{4 L_r} \left(\lambda_{dr}^e i_{qs}^e - \lambda_{qr}^e i_{ds}^e \right)$$

(2)

The rotor components are expressed as

$$\lambda_{dr}^e = L_r i_{dr}^e + L_m i_{ds}^e \quad (3)$$

$$\lambda_{qr}^e = L_r i_{qr}^e + L_m i_{qs}^e \quad (4)$$

where P is the number of poles , L_m is the magnetizing inductance λ_{dr}^e , λ_{qr}^e , i_{ds}^e , i_{qs}^e are the rotor flux and the stator current direct (d) and quadrature (q) components respectively and

$$L_r = L_m + L_{lr} \quad (5)$$

L_{lr} being the rotor equivalent leakage inductance.

The flux command for every speed reference is taken and calculated using the equation

$$i_d^* = \frac{\lambda_r^*}{L_m} \quad (6)$$

The q axis reference current is generated by comparing the reference and the actual speed of the motor .The error speed is proportionated to reference electromagnetic torque using the PI controller and then the q axis reference current is calculated using the following formula

$$i_q^* = 0.341 \cdot \left(\frac{T_e^*}{\lambda_r^*} \right) \quad (7)$$

where T_e^* is the reference electromagnetic torque calculated, λ_r^* is the reference rotor flux given.

For SVPWM technique both d-axis and q-axis stator current is measured and are compared with the reference d and q axis current .The error between these currents are proportionated to get the reference voltage that would be fed to the d,q to α,β conversion and this output to the SVPWM generator. The SVPWM can be implemented by determinining Vref and angle $\propto$ and time duration T_1, T_2 and T_0. The SVPWM uses two neighbouring effective vectors and null vectors of the eight basis space voltage vector and their different acting time to obtain the equivalent space voltage vector, as shown in Fig 1.

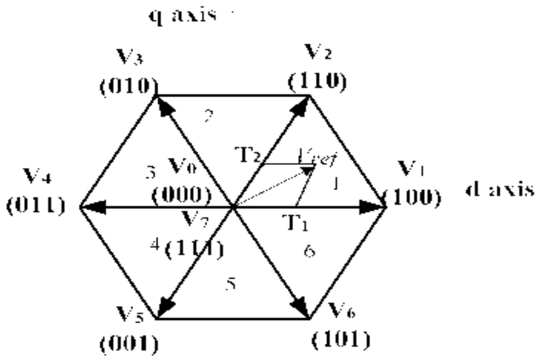

Fig 1. SVPWM hexagon

The sector selection table is as given below in table 1
The equations for finding the reference voltage ,time T1,T2 and the angle are given as follows

$$V_{ref} = \sqrt{v_\alpha^2 - v_\beta^2} \quad (8)$$

$$\alpha = \arctan\left(\frac{v_\beta}{v_\alpha}\right) \quad (9)$$

$$T_1 \quad \frac{\sqrt{3}\, T_z V_{ref}}{V_{dc}}\left(\sin\frac{N}{3}\pi\cos\alpha \quad \cos\frac{N}{3}\pi\sin\alpha\right) \quad (10)$$

$$T_2 \quad \frac{\sqrt{3}\, T_z V_{ref}}{V_{dc}}\left(\sin\frac{N \quad 1}{3}\pi\cos\alpha \quad \cos\frac{N \quad 1}{3}\pi\sin\alpha\right) \quad (11)$$

$$T_0 = T_z - (T_1 - T_2) \quad (12)$$

where N is any sector between 1 to 6, α is the angle between 0° to 60°, T_z is the sampling time.

Table1:Switching time calculation at each sector

Sector	Upper Switches (S1,S3,S5)	Lower Switches (S4,S6,S2)
1	S1=T1+T2+T0/2 S3=T2+T0/2 S5=T0/2	S4=T0/2 S6=T1+T0/2 S2=T1+T2+T0/2
2	S1=T1+T0/2 S3=T1+T2+T0/2 S5=T0/2	S4=T2+T0/2 S6=T0/2 S2=T1+T2+T0/2
3	S1=T0/2 S3=T1+T2+T0/2 S5=T2+T0/2	S4=T1+T2+T0/2 S6=T0/2 S2=T1+T0/2
4	S1=T0/2 S3=T1+T0/2 S5=T1+T2+T0/2	S4=T1+T0/2 S6=T1+T2+T0/2 S2=T0/2
5	S1=T2+T0/2 S3=T0/2 S5=T1+T2+T0/2	S4=T1+T0/2 S6=T1+T2+T0/2 S2=T0/2
6	S1=T1+T2+T0/2 S3=T0/2 S5=T1+T0/2	S4=T0/2 S6=T1+T2+T0/2 S2=T2+T0/2

5. NSPWM Technique in vector control

It is observed that in the SVPWM technique the null vector placement plays a major role in the control of the effective time for which the switch must be switched.But the major drawback here is the introduction of the null vector which would indirectly create non linearity .Introduction of a deadbeat in the sinusoidal wave is a curse for any healthy AC system.The NSPWM technique would eliminate the common mode voltage or the null vector.Instead it would introduce parts of different vectors in to its responsive time.

6. Simulation Results And Discussion:

Simulation has been carried out by using MATLAB/SIMULINK for 50 HP, 1780 rpm three phase inductions motor with the following parameters.
Rs=.09961Ω Rr=.05837Ω, Ls= 0.000867H, Lr= 0.000867H, Lm= 0.03039H,J= 0.4Kg /m^2.Load applied = 10nm.
The induction motor is run in two modesThe first mode is making the motor run in a constant load and the second one is to make the motor run with dynamic change in the load.
In both the modes the waveform for the quadrature axis flux versus the direct axis flux ,quadrature axis current vs the direct axis current,speed vs time,phase to phase voltage,three phase current wave are taken in to consideration for the analysis of the performance of different PWM techniques in the indirect vector control of the induction motor.The Fourier transform response of the stator current will help us analyse the THD present in each of these PWM technique.

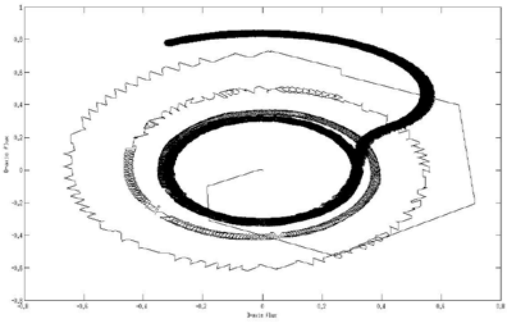

Fig .2 Quadrature axis flux vs Direct axis flux in Hysteresis controller based Indirect control of induction motor

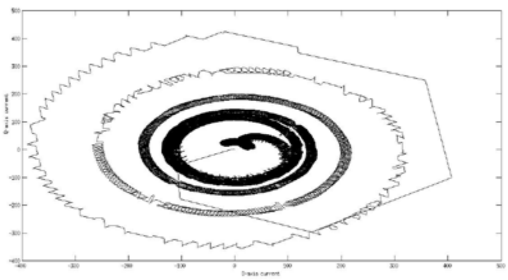

Fig .3 Quadrature axis current vs Direct axis current in Hysteresis controller based Indirect control of induction motor

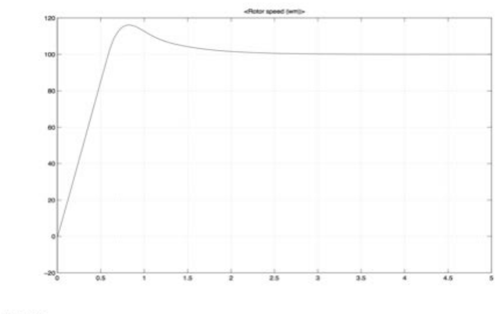

Fig.4 Speed response with Hysteresis controller

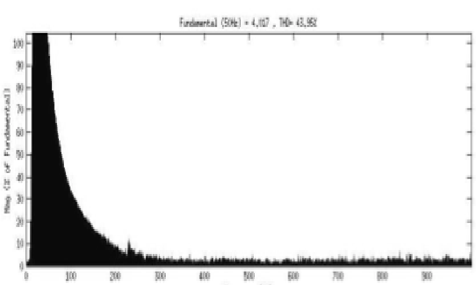

Fig.5 Fast Fourier Transform response with hysteresis controller

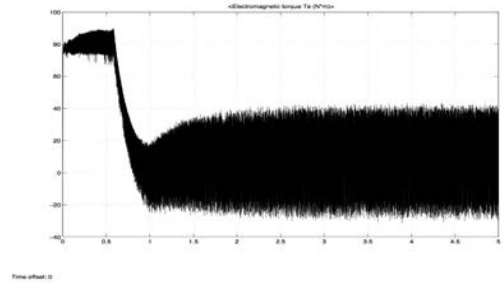

Fig.6 Torque response using Hysteresis Controller

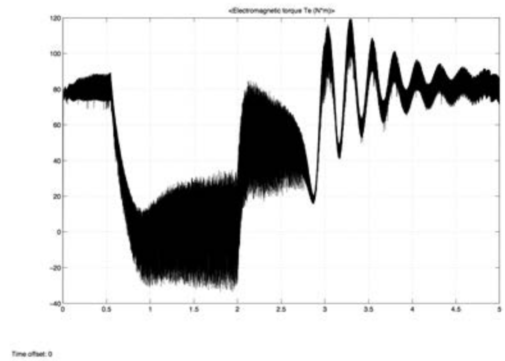

Fig.6 Torque response using Hysteresis Controller with load change

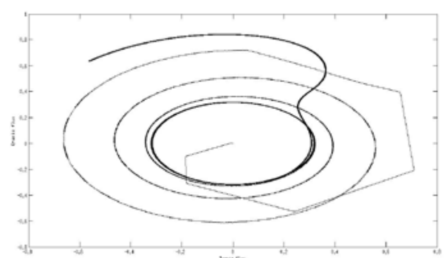

Fig .7 Quadrature axis flux vs Direct axis flux in SPWM controller based Indirect control of induction motor

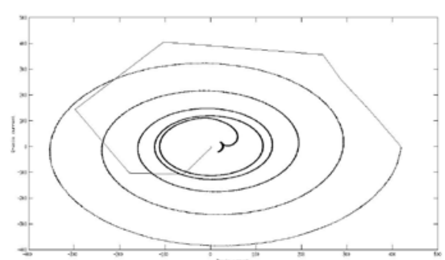

Fig.7 Quadrature axis current vs Direct axis current in SPWM controller based Indirect control of induction motor

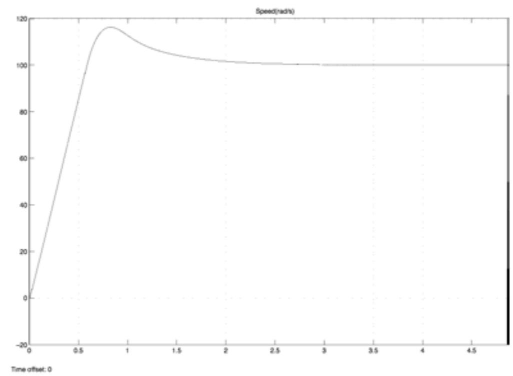

Fig.8 Speed response with SPWM controller

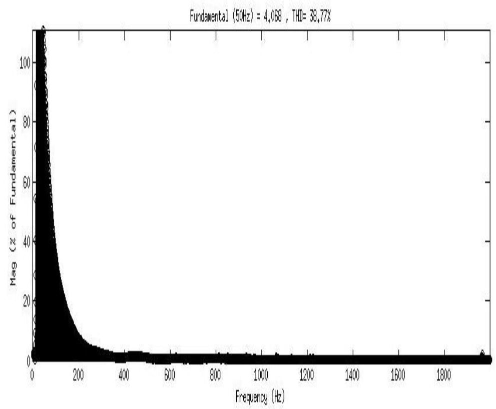

Fig.9 Fast Fourier Transform response with SPWM controller

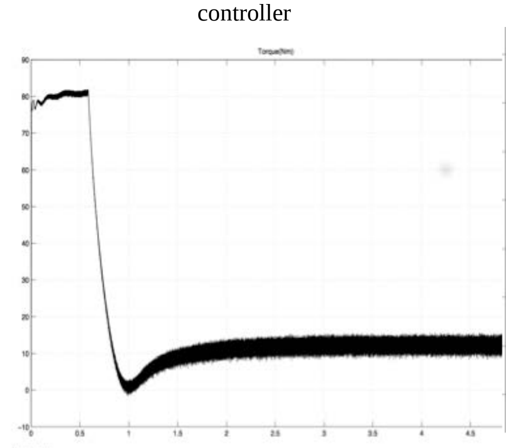

Fig.10 Torque response using SPWM PWM

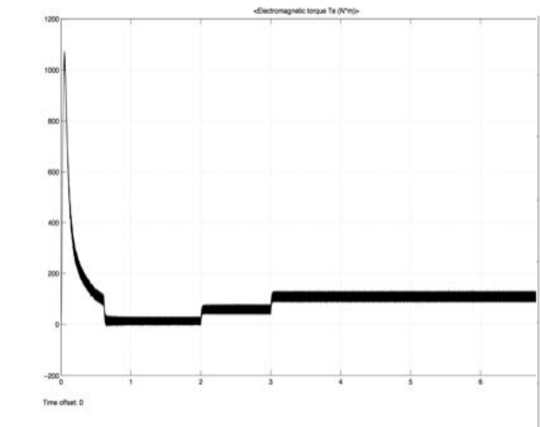

Fig.11 Torque response using SPWM with load change

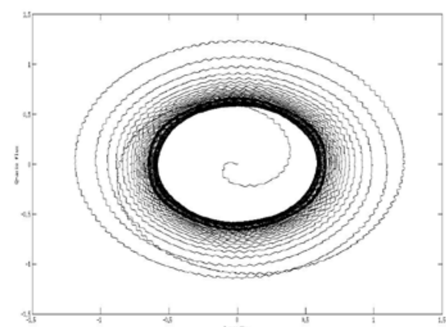

Fig .12 Quadrature axis flux vs Direct axis flux in SVPWM controller based Indirect control of induction motor

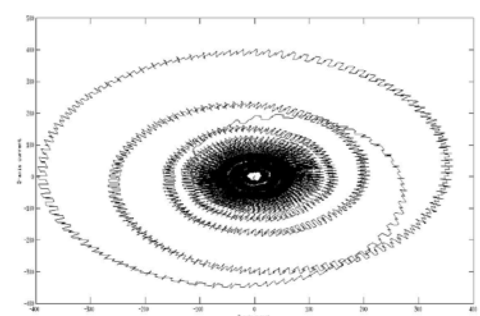

Fig.13 Quadrature axis current vs Direct axis current in SVPWM controller based Indirect control of induction motor

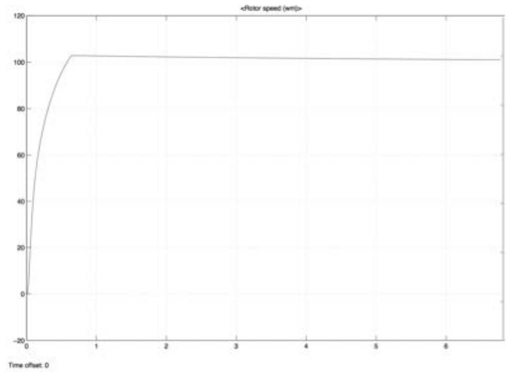

Fig .14 Speed response for SVPWM Technique

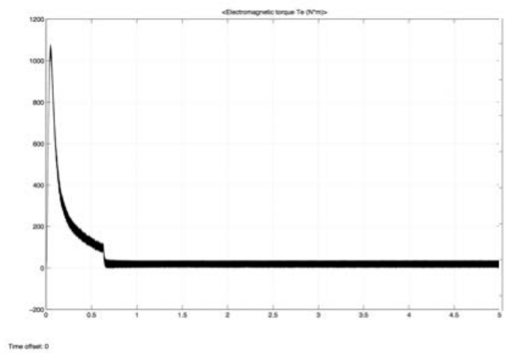

Fig .15 Torque response for SVPWM technique

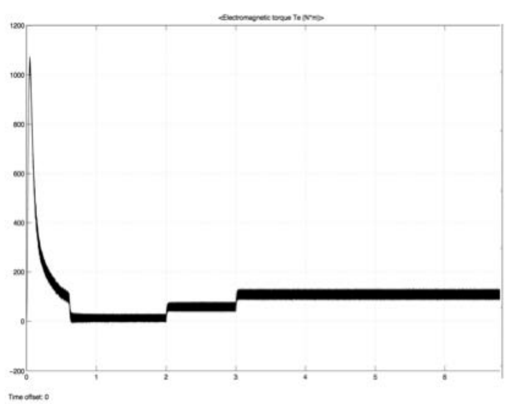

Fig .16 Torque response for SVPWM technique with load change

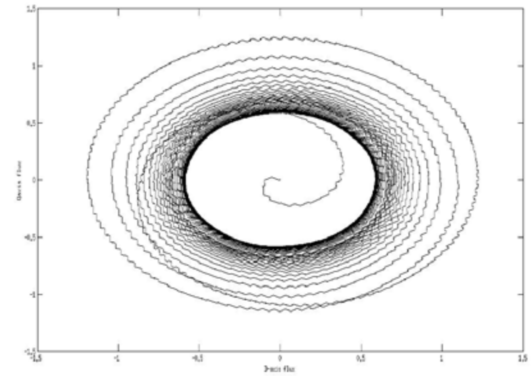

Fig .17 Quadrature axis flux vs Direct axis flux in NSVPWM controller based Indirect control of induction motor

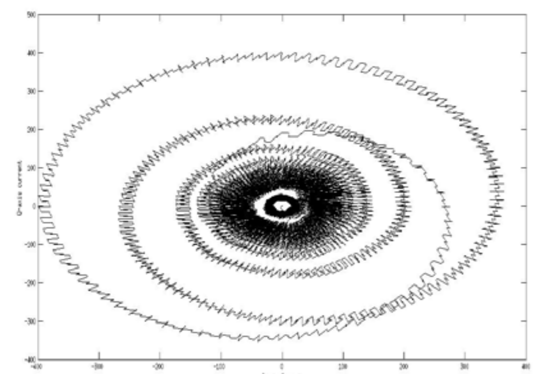

Fig .18 Quadrature axis current vs Direct axis current in NSVPWM controller based Indirect control of induction motor

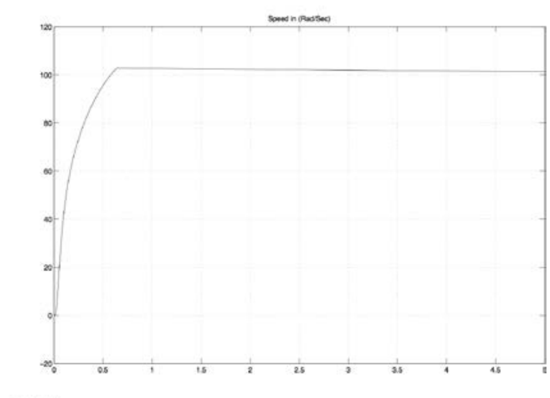

Fig. 19 Speed response with NSVPWM technique

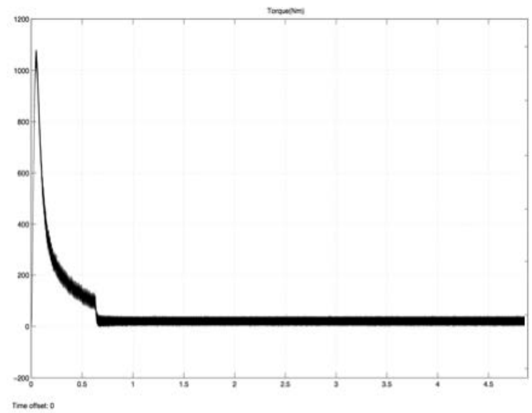

Fig .20 Torque response with NSVPWM

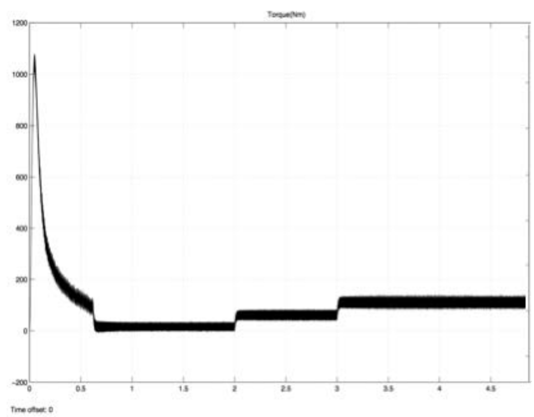

Fig .21 Torque response with NSVPWM with load change

It is observed that in hysteresis controller which does not have much mathematics becomes a simple method of implementation,but it has been a burden because of the torque ripple and the current ripple that it produces.If the power usage or the usage of the motor is less then Hysteresis controller can be considered but not if there is a need for more accuracy and increase in efficiency .Then we have to check for the tradeoffs.The SPWM technique has given a smoother torque and current ripple of all the methods but the transient in the speed response present in the hysteresis is present in SPWM technique also.Though SVPWM technique is complex it has been the most used because it has always been giving a smooth dynamic speed and current response.But the only disadvantage is when there is a load change these ripples has been considerable.But the NSPWM method has bettered in the dynamic speed response and also the improvement of the THD.The removal of the common mode voltage has benefitted in the reduction of the THD and as it is basically a SVPWM technique the current ripple and the torque considerably reduced.

The THD ,Current ripple and the Torque ripple in percentage is taken and tabulated for comparison.

Table2: THD and current ripple

Control Technique	THD (%)	Current ripple(% of rated current)	Torque ripple(%)
Hysteresis	17.19	0.428	~40%
SPWM	38.77	0.0526	~5%
SVPWM	32.36	0.0416	~4%
NSVPWM	30.12	0.0215	~2%

7. Conclusion

In this paper, an field oriented control of three phase induction motor using hysteresis current band, SPWM ,SVPWM and NSPWM technique was implemented using MATLAB/SIMULINK. The comparative performances between both techniques were presented. From the simulation results, it can be confirmed that the NSPWM technique gives improved performance in terms of elimination of the stator current harmonics and reduction of the torque ripple.

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