Vector Control of Induction Motor Using Neural Networks Based Lookup Table for Reduced CMV

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Abstract: This paper confers a vector control (VC) perspective for induction motor drives by combining the principles of vector and direct torque control (DTC) methods. In classical vector control, the switching states will be chosen dependent on current hysteresis regulators. Based on the instantaneous current waves, the hysteresis controllers generate the switching specimen. But, the classical DTC selects the pertinent voltage vector from lookup table extracted from the flux and torque error signals and sector information. The proposed perspective combines both VC and DTC techniques. In this paper d and q-axis current errors and sector information, the lookup table chooses an appropriate voltage vector. Moreover, to select the befitting voltage vector Neural Network (NN) based approach is presented in this paper. Also, to reduce the common mode voltage (CMV) variations, NN based lookup tables are proposed. To substantiate the proposed NN based vector control, simulation studies have been conveyed and results are collated.

Keywords:

1. Introduction

With an origination of power electronic converters, the Variable Speed Drives (VSD) is gaining more importance in various industry applications. The introduction of VC in 1970s leads to the renaissance in variable speed drive applications [1]. Subsequently the VC is becomes popular in various applications as described in [2-3]. The improvements in the field of vector controlled drives was explained in detailed in [2-3] and also clarified the significance of space vectors and electronic control. Then in 1980s, Takahashi introduced the DTC, which decreases the intricacy in implementation [4]. The DTC or direct self control (DSC) creates the pulse patterns by using the torque and flux controllers and sector information [4-5]. The rigorous comparison among VC and DTC was concluded in [6] and deduced that both gives swift and vigorous response. But, the VC gives superior steady state response when compared to DTC. Alike to DTC, a novel lookup table approach was put in to the space vector based current controllers in [7]. In view of diminishing the harmonic distortion, different lookup tables were used for DTC in [8] based on NN. The principles of VC and DTC are combined and applied the induction motor (I.M.) drive in [9]. This method generates the current vectors dependent on the principle of VC and develops the pulse pattern alike to DTC based on lookup table.

However, these approaches use zero voltage vectors, which increase the CMV variations due to which common mode current (CMC) also increases. Due to these CMV and CMC bearing currents will stream through the motor, which affects the execution of the drive system as explained in [10-12]. The detailed analysis on various effects also has been done in [10-12]. The CMV can be reduced by using the filters, which shall escalate the outlay and size of the system as clarified in [13]. To diminish the cost and size, novel methods dependent on the lookup tables were applied to the DTC drive in [14-15]. These methods will not use any filters and give rise to the pulse pattern based on lookup tables without using zero states that results in diminished CMV variation with faintly increased ripple in steady state.

To diminish the intricacy in the execution and CMV, this paper presents NN based lookup tables to the vector controlled drives. The outcomes show the value of the proposed technique.

2.Proposed Six-Sector Based Vector Controlled Drive:

To diminish the intricacy in the classical VC approach, a elementary approach using lookup tables has been presented in this paper. The torque expression of an induction motor is

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\left|\bar{\psi}_r\right|\left|\bar{i}_s\right|\sin\eta \qquad (1)$$

Where, η is the angle among current and rotor flux. From (1), it is seen that the torque of an induction motor can be changed by evolving the η, which is the principle concept for the proposed method. Thus, by rotating d-and q-axes current vectors, the torque can be adjusted. The stator current expression for a tiny time interval of Δt can be expressed as [9],

$$\Delta\bar{i}_S = \frac{1}{\sigma L_S}\bar{v}_S\Delta t \qquad (2)$$

From (2), it is perceived that the rotation of $\bar{i}_S$ depends on the amplitude of $\bar{v}_S$. Hence, by applying an appropriate voltage vector, the $\bar{i}_S$ can be rotated in the required direction. For Δt, by applying a $\bar{v}_S$ in the forward direction, the angle and hence torque can be increased as shown in Fig.1. Here the rotor flux is nearly unchanged due to its large time constant.

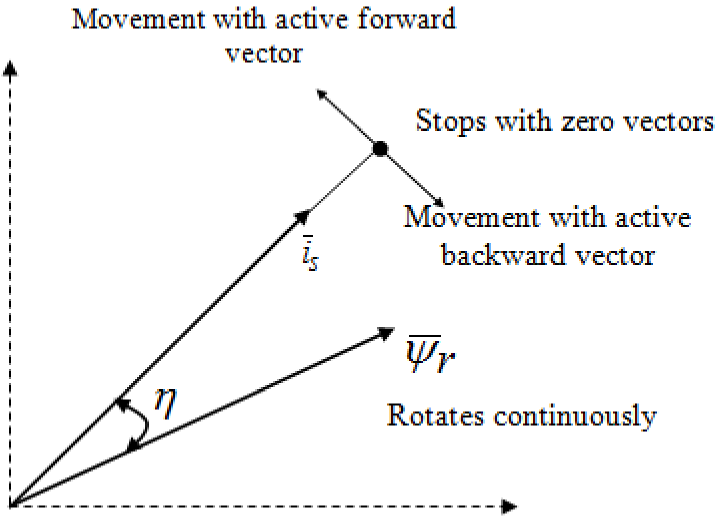


Fig.1 Movement of $\bar{i}_S$ with the different voltage vectors

The Main diagram of proposed VC drive is as shown in Fig. 2.

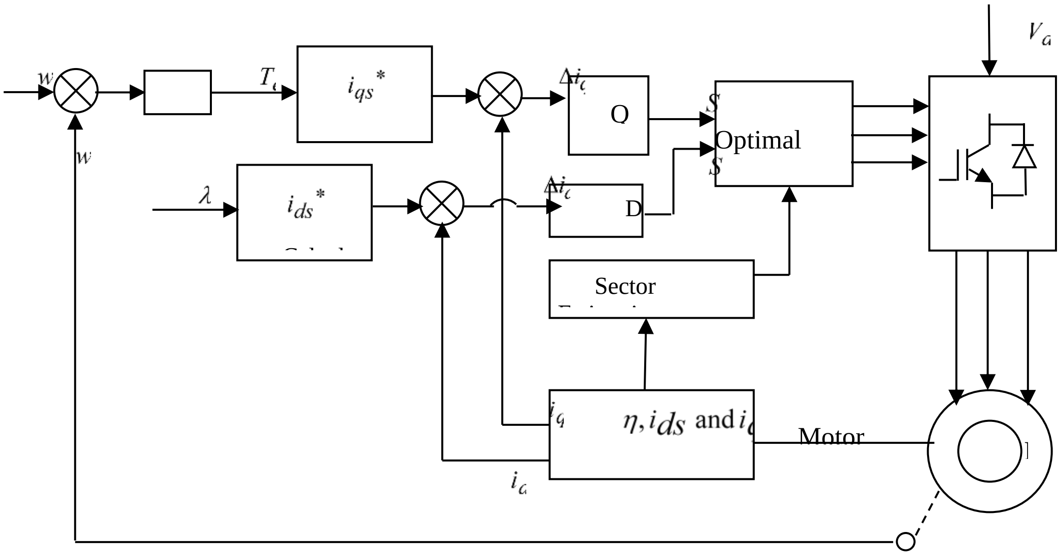


Fig. 2 Main diagram of proposed VC drive

In the proposed strategy, the current chunks are at synchronous speed and derived as per the classical vector control approach. By looking at the genuine and estimated current components, the error signals will be derived. This error signals will be provided to 3-level quadrature-axis hysteresis and 2-level direct axis hysteresis (QHC and DHC) comparators. Dependent on the magnitude of error signals, the digitized values are derived. Based on these values and orientation of current vector (sector information), acceptable vector of voltage will be adopted.

For a 2-level inverter, eight voltage vectors are produced as shown in Fig.3. In the proposed technique, the sector division is similar to classical DTC method. Based on the location of $\bar{i}_S$ including outputs of QHC and DHC, acceptable voltage vector is selected to control both $\bar{i}_{ds}$ as well as $\bar{i}_{qs}$.

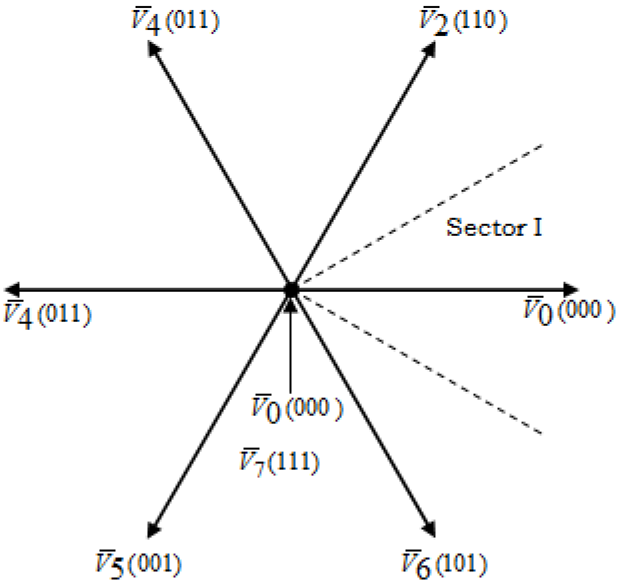


Fig. 3 Voltage vectors of a 2-level inverter

In proposed method, the error signals magnitudes are bounded within their respective bands. If increase in $\bar{i}_{ds}$ or $\bar{i}_{qs}$, then the comparators generates output as 1. For decrement of $\bar{i}_{ds}$, the DHC generates '0'. For decrement and no change, the QHC generates '-1' and '0' as given in Table-1.

Table. 1 The output values of the Comparators

Controller	Condition	Output of the controller
DHC	$\bar{i}_{ds} \le \bar{i}^*_{ds} - \Delta\bar{i}_{ds}$	$S_d = 1$
	$\bar{i}_{ds} \ge \bar{i}^*_{ds} + \Delta\bar{i}_{ds}$	$S_d = 0$
QHC	For anti-clockwise rotation	
	$\bar{i}^*_{qs} - \bar{i}_{qs} \ge \Delta\bar{i}_{qs}$	$S_q = 1$
	$\bar{i}_{qs} \ge \bar{i}^*_{qs}$	$S_q = 0$
	For clockwise rotation	
	$\bar{i}_{qs} \le \bar{i}^*_{qs}$	$S_q = 0$
	$\bar{i}^*_{qs} - \bar{i}_{qs} \le -\Delta\bar{i}_{qs}$	$S_q = -1$

Based on the output values and sector information, appropriate voltage vector is selected from lookup table as shown in Table-2.

Table. 2 Selection of voltage vector from lookup table

Sector S_d	S_q	I	II	III	IV	V	VI
1	1	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_1$
	0	$\overline{V}_7$	$\overline{V}_0$	$\overline{V}_7$	$\overline{V}_0$	$\overline{V}_7$	$\overline{V}_0$
	-1	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_5$
0	1	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_2$
	0	$\overline{V}_0$	$\overline{V}_7$	$\overline{V}_0$	$\overline{V}_7$	$\overline{V}_0$	$\overline{V}_7$
	-1	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_4$

The output voltage of inverter are not pure sinusoidal and hence, it causes for the raise of common mode voltage (CMV) variations. The active vectors will generate the CMV of $\pm\frac{V_{dc}}{6}$ and zero states will generate $\pm\frac{V_{dc}}{2}$. Hence, to reduce the CMV, it is better to avoid the application of zero states. Hence, in the proposed methodology, to diminish the CMV the lookup table is modified as shown in Table-3.

Table. 3 Selection of voltage vector from lookup table

Sector S_d	S_q	I	II	III	IV	V	VI
1	1	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_1$
	-1	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_5$
0	1	$\overline{V}_3$	$\overline{V}_4$	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_2$
	-1	$\overline{V}_5$	$\overline{V}_6$	$\overline{V}_1$	$\overline{V}_2$	$\overline{V}_3$	$\overline{V}_4$

In order to perform the VC satisfactorily a NN is selected with three linear input nodes, 12 neurons in the hidden layer, and 3 neurons in the output layer as shown in Fig. 4.

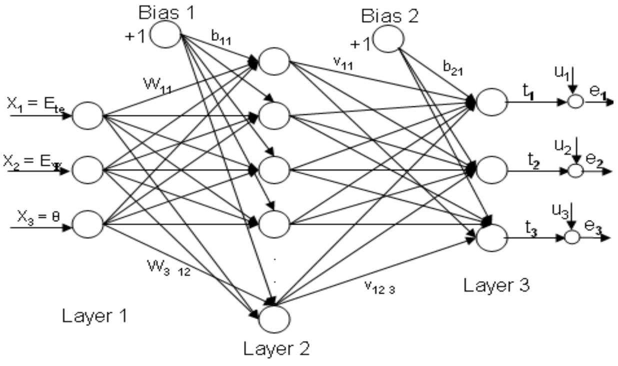


Fig. 4 Structure of neural network

Based on the error signals of current components and sector information are the inputs to the NN and based on the input values, the NN will generate the suitable output. The Levenberg-Marquardt algorithm is used to train the NN, which is an approximation to the Hessian matrix in the following Newton-like update [8]:

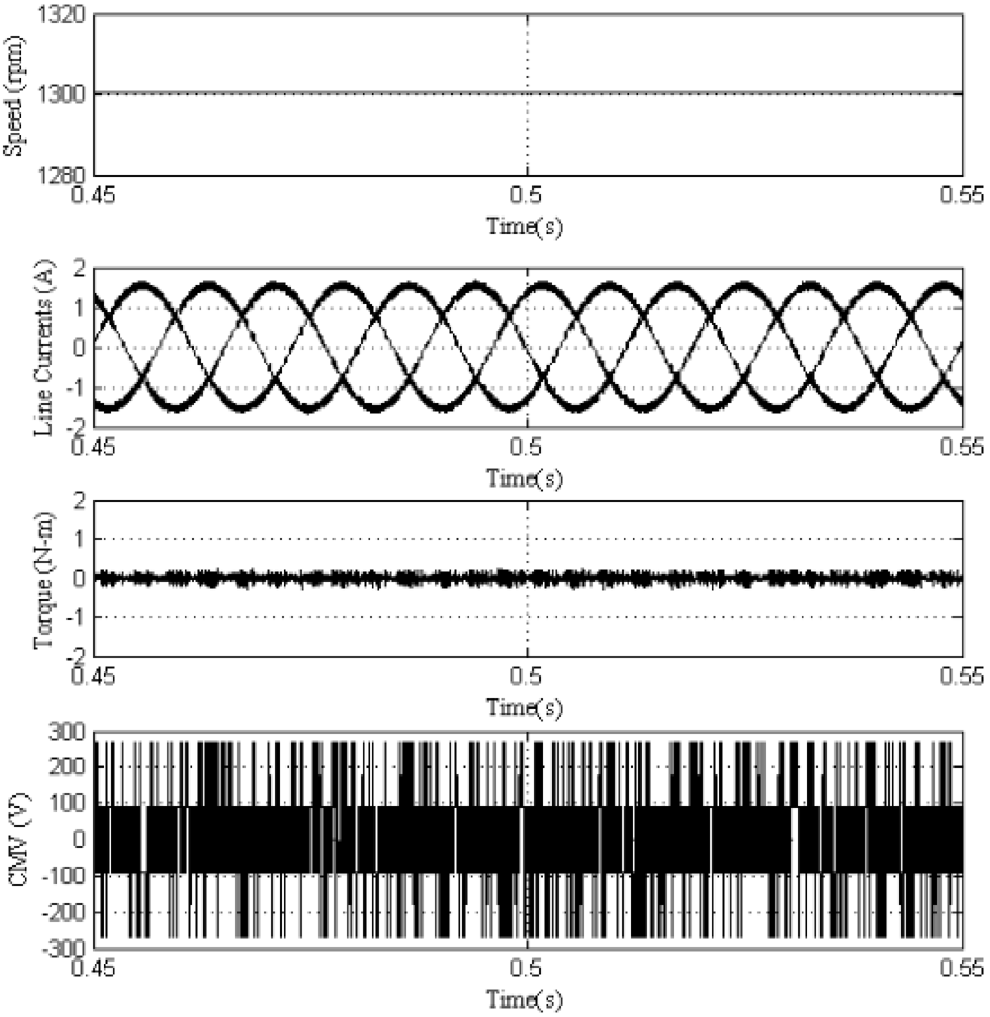
$$X_{k+1} = X_k - \left[J^T J + \mu I\right]^{-1} J^T e \tag{3}$$

If, the scalar μ is zero, this is a Newton's method, and uses the approximate Hessian matrix. If μ is high, this becomes gradient descent with a small step size. Newton's method is swift and more accurate near minimum error. Thus, μ is declined after each successful step.

3.Simulation Results and Discussion:

To evaluate the proposed NN algorithm, the numerical simulation scrutinizes have been accomplished on vector controlled I.M. drive. The stipulations of the induction motor are as follows: 400 Volts, 1.5 hp, 4-pole, 1460 RPM, 50 Hz.,Rs=4.1 Ω, Rr =2.5Ω, Ls=0.545 H, Lr=0.542 H, Lm =0.510 H and J = 0.04 Kg.m^2 . The steady state results of proposed NN based vector control I.M. drive at 1300 rpm are exhibit in from Fig. 5 to Fig. 11. From the simulation outcomes it can observe that common mode voltages can be reduced in proposed NN algorithm by using look up table, but there is slightly increase in THD compared to conventional algorithm.

Fig.5 Steady state analysis of conventional VC IM drive



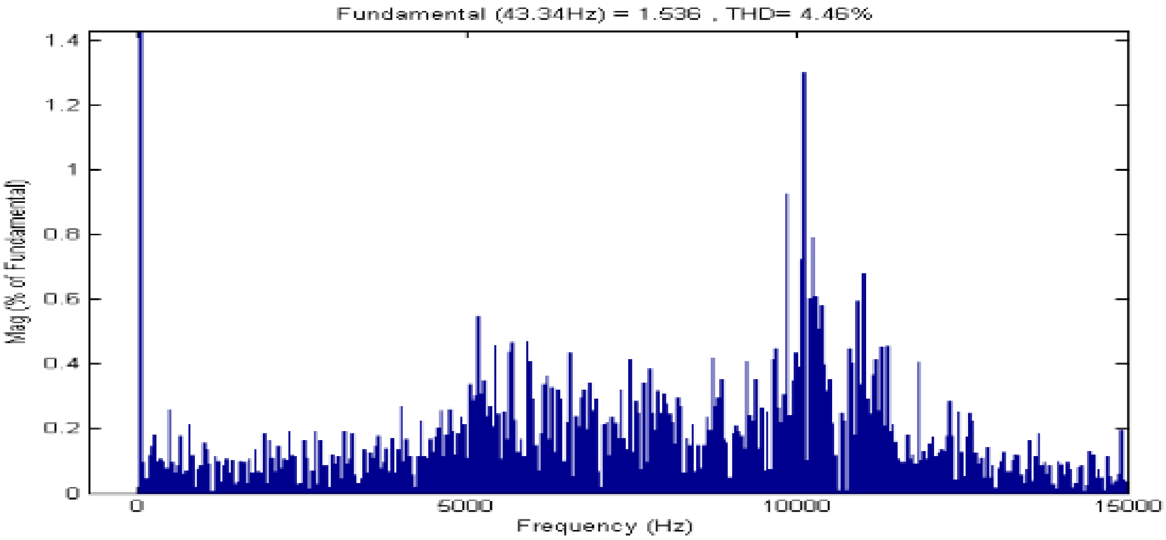


Fig.6 THD analysis of conventional VC IM drive

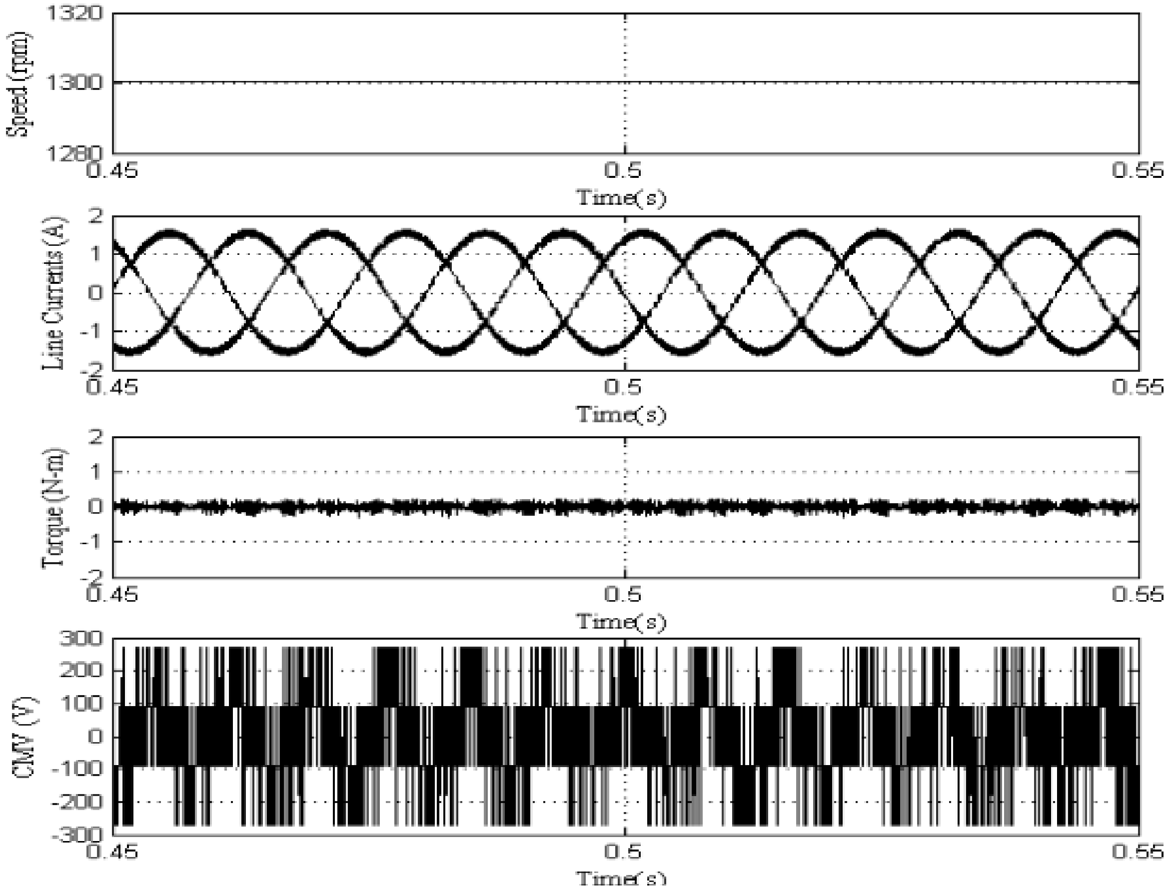


Fig.7 Steady state analysis of conventional ANN based VC IM drive

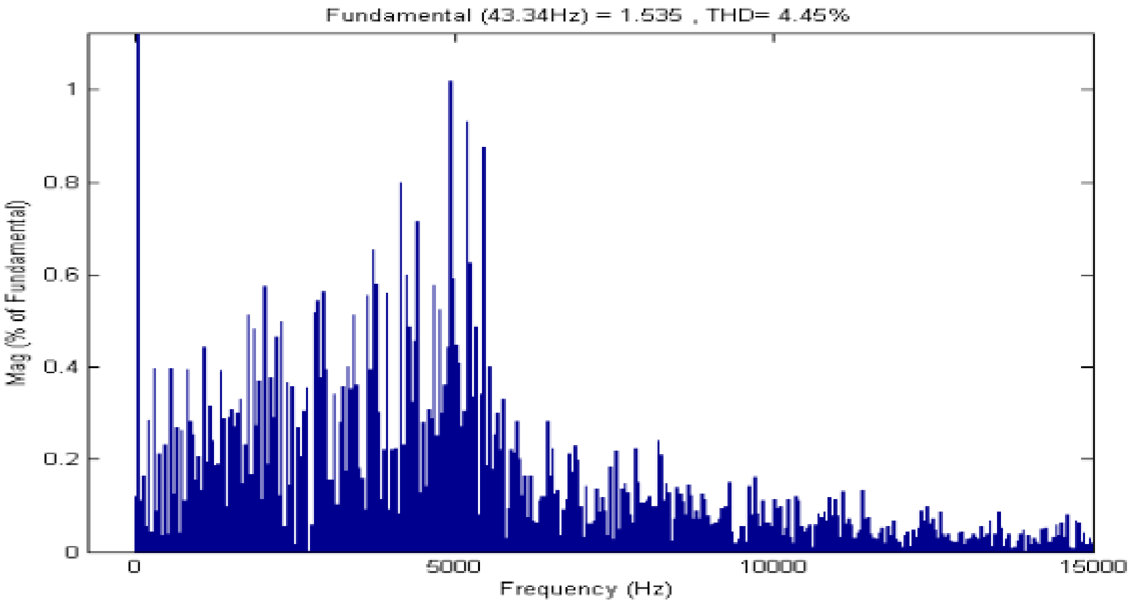


Fig.8 THD analysis of conventional ANN based VC IM drive

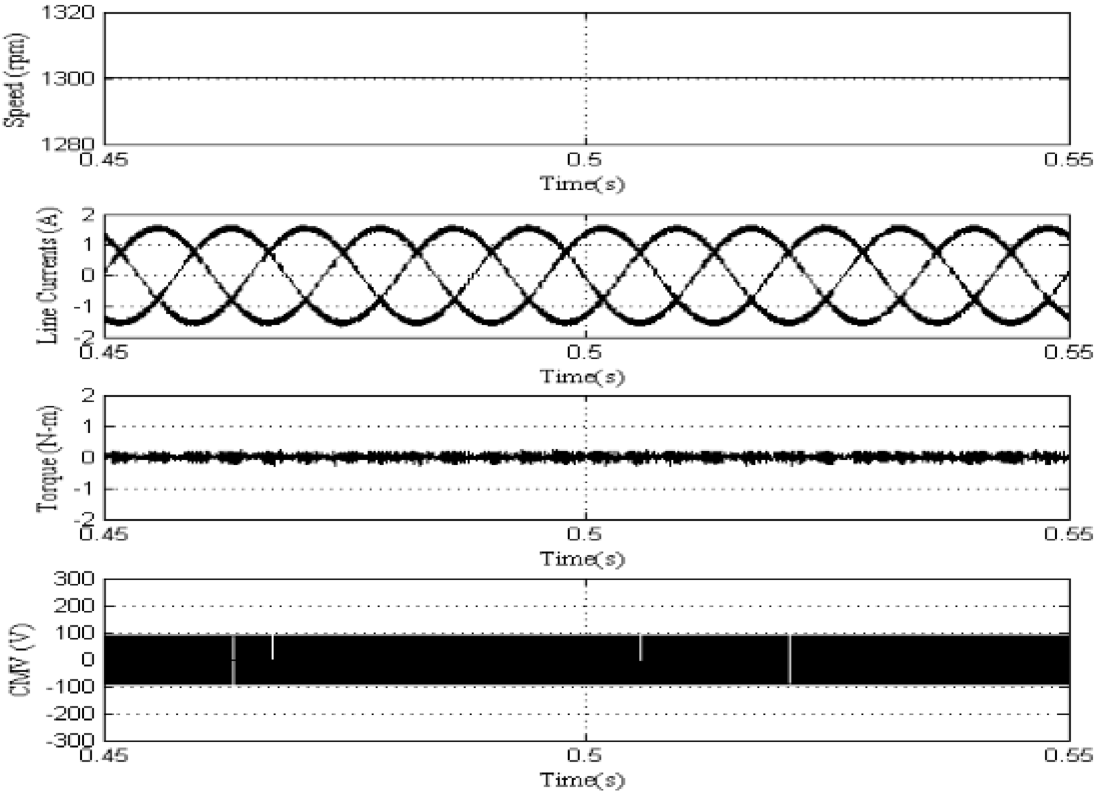


Fig.9 Steady state analysis of Six Sector ANN based Reduced CMV VC I.M. drive

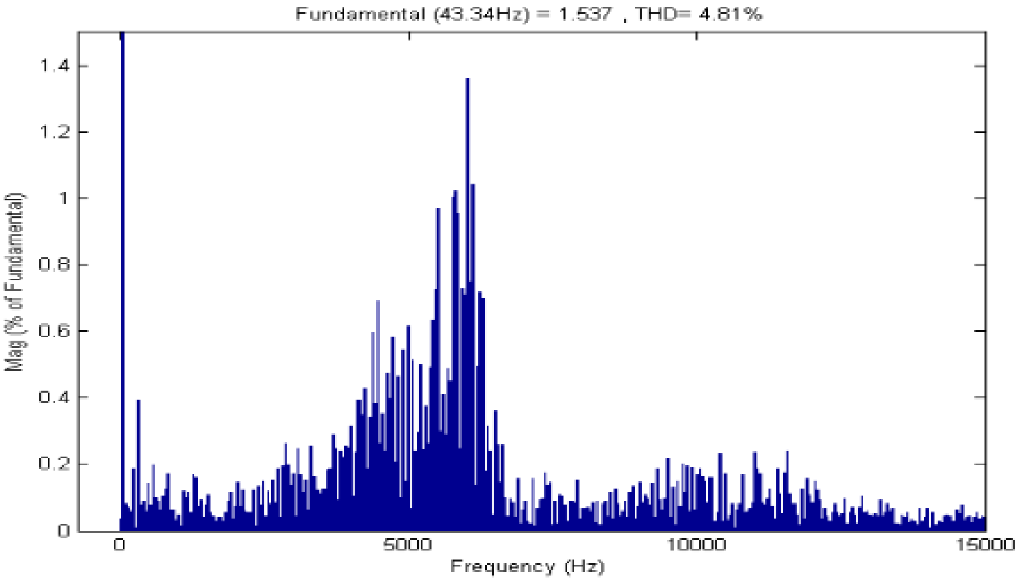


Fig.10 THD analysis of Six Sector ANN based Reduced CMV VC IM drive

4.Conclusion:

An improved lookup table based approach is introduced for vector controlled drives by consolidating the fundamentals of VC and DTC. This method uses both active and zero states to command the torque and flux of motor. But, the zero states generate more CMV, which leads to the stream of CMC and causes for bearing currents. Hence, to reduce the CMV another lookup table is proposed without employing the zero states. Finally, to build the effectiveness and accuracy, neural network approach is extended to the lookup tables. To observe the effectiveness of the proposed lookup tables, simulation scrutinizes have been completed and results are obtained. From the results, it is observed that with proposed lookup table, CMV can be reduced.

References

1. F. Blaschke “The principle of field orientation as applied to the new transvector closed loop control system for rotating-field machines," Siemens Review, 1972, pp 217-220.
2. W. Leonhard, “30 years of space vectors, 20 years of field orientation, 10 years of digital signal processing with controlled AC-drives, a review (Part1)". EPE Journal, No. 1, July 1991, pp. 13-20.
3. W. Leonhard, “30 years of space vectors, 20 years of field orientation, 10 years of digital signal processing with controlled AC-drives, a review (Part 2)". EPE Journal, No. 2, Oct, 1991, pp. 89-102.
4. Isao Takahashi and Toshihiko Noguchi, “A new quick-response and high-efficiency control strategy of an induction motor,” IEEE Trans. Ind. Appl.., vol. IA-22, no.5, Sep/Oct 1986, pp. 820-827.
5. M. Depenbrock, "Direct-self control (DSC) of inverter-fed induction machine," IEEE Trans. Power Electron., vol. 3, no. 4, Oct.1988, pp. 420-429
6. Domenico Casadei, Francesco Profumo, Giovanni Serra, and Angelo Tani, “FOC and DTC: Two Viable Schemes for Induction Motors Torque Control” IEEE Trans. Power Electron., vol. 17, no.5, Sep, 2002, pp. 779-787.
7. Marian P. Kaimierkowski, Maciej A. Dzieniakowski, and Waldemar Sulkowski, “Novel Space Vector Based Current Controllers for PWM-Inverters” IEEE Trans. Power Electronics, vol.6, no.1, Jan, 1991, pp. 158-166.
8. Y.V. Siva Reddy M. Vijaya Kumar and T. Brahmananda Reddy “Direct Torque control of induction motor using sophisticated look-up tables based on neural networks” ICGST Trans. on AIML journal, vol.7, issue.1, June, 2007.
9. K. Sathyanarayana, J. Amarnath, J.Kailasa Rao, T. Brahmananda Reddy, "Simplified vector control algorithm for induction motor drives based on sophisticated lookup tables" International Review on Modelling and Simulation, vol.3, no.5, October, 2010, pp. 817-826.
10. S.Ogasawara and H.Akagi, “Modelling of high frequency leakage currents in PWM inverter- fed Ac motor drive systems” IEEE Trans. Ind. Appl., Vol. 32, No.4, pp. 1105-1114, Sep/Oct, 1996.
11. S. Ogasawara, H. Ayano, and H. Akagi, “Measurement and reduction of EMI radiated by a PWM inverter-fed ac motor drive system,” IEEE Trans. Ind. Applicat., vol. 33, no. 4, pp. 1019–1026, 1997.

12. Erdman, J.M, Kerkman, R.J, Schlegel, D.W, and Skibinski, G.L, “Effect of PWM inverters on AC motors bearing currents and shaft voltages” IEEE Trans. Ind. Appl., Vol. 32, No.2, pp. 250-259, March/April, 1996.
13. S. Ogasawara, H. Ayano, and H. Akagi, “An active circuit for cancellation of common-mode voltage generated by a PWM inverter,” IEEE Trans. Power Electron., vol. 13, no. 5, pp. 835–841, Sep. 1998.
14. M. Cacciato, A. Consoli, G. Scarcella and A. Testa, “Reduction of common-mode currents in PWM inverter motor drives,” IEEE Trans. on Industry Applications, vol. 35, no 2, pp. 469 – 476,March-April 1999.
15. Maurizio Cirrincione, Marcello Pucci, Gianpaolo Vitale and Giansalvo Cirrincione, “A new direct torque control strategy for the minimization of common-mode emissions” IEEE Trans. Ind. Appl.,vol.4, no.2,Mar/Apr, 2006, pp. 504-517.