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Comparative Analysis of Fuzzy And Neural Network Based Hybrid Asymmetric Svpwm For Dtc Based Induction Motor Drive

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ABSTRACT

The performance of the direct torque control based induction motor drive, can be improved by using constant switching frequency. This constant-switching frequency has achieved by using hybrid asymmetric space vector modulation. Hybrid PWM scheme is the combination of conventional SVPWM and Asymmetric SVPWM schemes. Hybrid PWM scheme is the combination of conventional SVPWM and Asymmetric SVPWM schemes. Artificial intelligent technique helps to find the suitable voltage vectors in HASVPWM. In this paper, a comparative analysis of fuzzy and neural network based asymmetric vector algorithm for DTC based induction motor drive has presented. The performance of the two control schemes are compared in terms of torque ripples, speed settling time, flux error and transient responses for induction motor drive. Comparative based on individual role of fuzzy and neural networks. Both control schemes are analyzed by MATLAB simulation.

Keywords: Pulse Width Modulation; Direct Torque Control; Fuzzy control; Neural Networks;

INTRODUCTION

Vector control strategies use an induction motor to achieve an accurate speed and torque control for both in steady state operation and transient operation. The dynamic performance can be achieved by vector control strategies which equals to the dynamic performance offered by DC motor drives. In Vector control strategies, direct torque control (DTC) is a well-known control scheme of induction motor (IM) drives. In DTC method, the torque is controlled by varying the angle (δ) between the two flux vectors. DTC implementation contains a flux control loop and a torque control loop. Common limitations in conventional DTC are high torque ripple and slow transient response to the step changes in torque during starting condition, pulsating torque, pulsating flux and the increased harmonic loss. Takahashi and Noguchi introduced DTC which operated by variable switching technique. But it has some issues i.e the variation of the switching frequency depends upon the amplitude of the hysteresis band comparator & motor operating speed and Selection of voltage vectors is not optimized inside the flux hysteresis band. These issues create a current harmonic spectrum with large values. This harmonic current creates acoustic noise in induction motor. For minimize the acoustic noise level, it is necessary to reduce the harmonic current as much as possible[1]-[5],[14][15],[18][19]. In this DTC, electromagnetic torque and flux are independently controlled by selection of optimum inverter switching modes. The selection of optimum inverter switching limited by electromagnetic torque and flux linkage errors. By using multilevel inverters to minimize the torque ripples. But DC

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link capacitor located inside the multilevel inverter produced fluctuating neutral point. This fluctuation can be eliminated by

using H- Bridge topology, but it requires more number of isolated power supplies. There is an alternate option by using SVM technique in DTC, the switching frequency can be maintained at constant and torque ripple is also reduced with low switching losses. The Sinusoidal PWM technique is very popular for industrial converters. It is the simplest modulation scheme to understand but it is unable to fully utilize the available DC bus supply voltage. Space vector Modulation technique has become the most popular and important PWM technique for Three Phase Voltage Source Inverters for the control of AC Induction motor. Space vector modulation which offers 15% better bus utilization and 33% fewer commutations per cycle than conventional PWM[5]-[8].

The conventional SVM based DTC has only limited number of sector. Moreover in conventional switching algorithm, complexity increases to further reduce these ripples. To overcome these difficulties, modified hybrid vector algorithm has been developed. Hybrid PWM is to removal of mismatching pulses which will be done by comparing the Asymmetric SVPWM pulses with the conventional SVPWM pulses. The mismatching pulses are removed by calculating its rise time and fall time of the pulses with magnitude. Artificial intelligent technique helps to find the suitable voltage vectors in hybrid SVPWM. Further development of the DTC, we can replace PI controller instead of hysteresis controller for digital implementation[13]. These controllers can easily calculate the required stator voltage vector, averaged over a sampling period. The voltage vector is finally synthesized by any number of sectors in vector modulation. This paper presents the comparative study of fuzzy and ANN approach in hybrid asymmetric space vector modulation scheme and also investigates performance of drive.

2. Hybrid Asymmetric Space Vector PWM:

Hybrid Asymmetric Space Vector PWM (HASVPWM) is used for analyzing the dynamic switching state of the DTC. The switching state of the ASVPWM implementation steps are denoted in Fig.1. In general, three phase Voltage source inverters (VSI) have eight distinct switching losses, where state 1 to 6 are active states, 0 and 7 are inactive switching states. In HASVPWM, asymmetric voltage vectors are represented as V_{ni}, V_{nj} and V_{nk} where n=1, 2, 3, 4, 5…24 and it is shown in Fig.1. HASVPWM has two non-zero vectors (V_1 and V_2) and two zero vectors (V_0 and V_7) in each vector will be used for the vector 90^0. HASVPWM is implemented based on the State Transition Matrix (STM). Dynamic switching operation of the inverter is formed the product of state vector at an initial time t_0. The active switching state of original voltage sector is denoted as δ and the weights of the state transition voltage vectors are w_1, w_2, w_3, w_4, w_5 and w_6. Inactive voltage vectors are w_0 and w_7 , The corresponding voltage vectors are v_0 and v_7. Here hexagon voltage magnitudes as weights.

The state matrix δ is defined in the following equation.

$$\delta = [W_1 W_2 \text{.....} W_6] X [T_1 T_2 \text{.....} T_6]^T \quad (1)$$

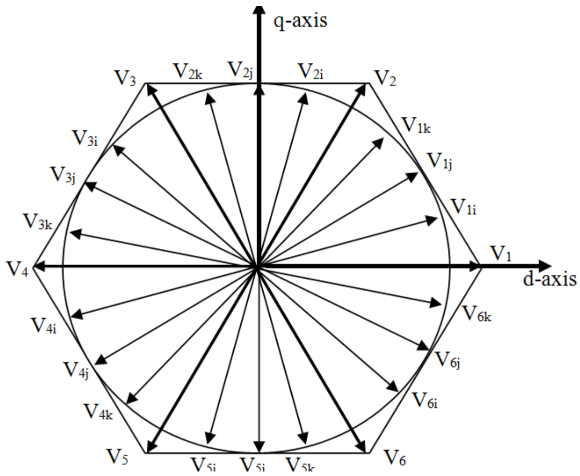

Fig. 1: Structure of ASVPWM Hexagon.

Here, the additional three voltage vectors *(i, j and k)* are added between 20^0 angle differences. Hence the 18 additional voltage vectors are included. The switching states of additional sectors are determined from the weight of the original sectors are determined from the weight of the original sectors[8],[13]. The control logic of HASVPWM generation for DTC control is given in Fig.2. The values of magnitude of sectors depend on the sector angle. The formulas for calculating the magnitude is given below.

$$V_{nx} = \frac{2V_{dc}}{3}\cos\alpha_{nx} \quad (2)$$

x= i,j,k

3. Direct Torque Control:

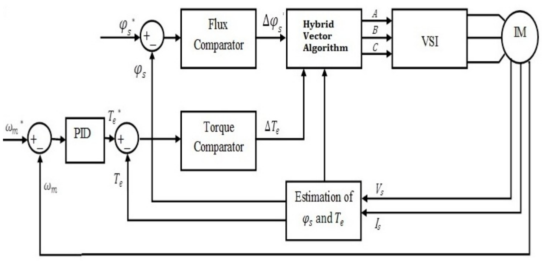

Fig. 2: DTC based induction motor

Direct torque control (DTC) is one method used in variable frequency drives to control the torque (and thus finally the speed) of three-phase AC electric motors. This involves calculating an estimate of the motor's magnetic flux and torque based on the measured voltage and current of the motor. Stator flux linkage is estimated by integrating the stator voltages. Torque is estimated as a cross product of estimated stator flux linkage vector and measured motor current vector. The estimated flux magnitude and torque are then compared with their reference values. If either the estimated flux or torque deviates from the reference more than allowed tolerance, the transistors of the variable frequency drive are turned off and on in such a way that the flux and torque will return in their tolerance level as fast as possible. PI comparators used for torque and flux comparator and switching's calculated by space vector modulation to improve the performance of system and achieved constant switching frequency. The magnitude of stator flux and electric torque calculated are compared with their reference values in the PI comparators and then the outputs of the comparators are fed to a switching table to select an appropriate inverter voltage vector. The switching table determines the voltage vector to apply based on the position of the stator flux and the required changes in stator flux magnitude and torque. The selected voltage vector will be applied to the induction motor at the end of the sample time. In VSI, there are six equally spaced voltage vectors having the same amplitude and two zero voltage vectors. In direct torque control (DTC) method, the torque is controlled by varying the angle (δ between the two flux vectors. Any DTC implementation contains a flux control loop and a torque control loop. The reference torque value is calculated by a speed controller; while the flux reference is determined as a function of the reference speed. The machine voltages and currents are sensed to estimate the torque and the stator flux vector. The flux vector estimation gives information about the sector. The flux and torque errors generate digital signals through the respective comparators. A three-dimensional look-up table then selects the most appropriate voltage vectors to satisfy the flux and torque demands. DTC ensures fast transient response and generates simple implementations due to the absence of the closed-loop current control, traditional PWM algorithm and the vector transformations. It can be implemented with speed sensor as well as in sensor less configurations. However, the drawbacks of DTC are the pulsating torque, pulsating flux and the increased harmonic loss[1]-[5][14][15].

A. Stator flux based calculation:

By using terminal voltages, the air gap torque, flux and field angle can be computed with stator flux linkages. In stator flux based calculator, computational steps and dependence on many motor parameters could be very much reduced by using the stator flux linkages and stator currents. Then only stator resistance is employed in the computation of the stator flux linkages, thereby removing the dependence of mutual and rotor inductances of the machine on its calculation. This algorithm depends only on the stator resistance rather than on many other motor parameters [2].

Sensitivity of the stator resistance will affect the accuracy of stator flux linkages. Dynamic operation at low speed is not efficient in stator flux linkage algorithm.

$$\lambda_{ds} = \int \left(V_{ds} - R_s i_{ds}\right)\cdot dt \quad (3)$$

$$\lambda_{qs} = \int \left(V_{qs} - R_s i_{qs}\right)\cdot dt \quad (4)$$

$$\lambda_s = \sqrt{(\lambda_{ds})^2} + \sqrt{(\lambda_{ds})^2}\angle\theta_{fs} \quad (5)$$

$$\theta_{fs} = \tan^{-1}\left(\lambda_{ds} / \lambda_{qs}\right) \quad (6)$$

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(i_{qs}\lambda_{ds} - i_{ds}\lambda_{qs}\right) \quad (7)$$

$$V_q = T_{ref} - T_{estimated} \quad (8)$$

$$T_{ref} = \omega_{ref} - \omega_{estimated} \quad (9)$$

B. Torque control:

Torque control is exercised by comparison of the command torque to the torque measured from the stator flux linkages and stator currents as T_e.The error torque is processed through a window comparator to produce digital outputs S_T. δT_e is the torque window acceptable over the commanded torque. When the error exceeds δT_e, it is time to increase the torque,denoting it with a +1 signal. If the torque error between +ve and –ve torque windows , then the voltage phasor could be at zero state. If the torque error is below –ve torque windows, its amount to calling for regeneration.(signed by -1 logic). Combining the flux error output S_λ, the torque error output S_T and the sextant of the flux phasor S_θ, a switching table can be realized to obtain the switching states of inverter [2][4].

$$V_q = T_{ref} - T_{estimated} \quad (10)$$

$$T_{ref} = \omega_{ref} - \omega_{estimated} \quad (11)$$

4. Fuzzy based HASVPWM Scheme for DTC drive:

In conventional set theory based on Boolean logic. But Fuzzy set theory based on fuzzy logic, a particular object has a degree of membership in a given set that may be anywhere in the range of 0 to 1. This property helps fuzzy logic deal with non-statistical uncertain situations in a fairly natural way. The Fuzzy Logic Controller (FLC) owes its popularity to linguistic control. Here, an exact mathematical model for the system to be controlled is not required. Hence, Fuzzy logic basically tries to reproduce the human thought process in its control algorithm. Fuzzy control has gained much popularity owing to its knowledge based algorithm, better non-linearity handling features and independence of plant modeling. A fuzzy logic controller also makes good performance in terms of stability, precision, reliability and rapidity achievable. Fuzzy logic used to find the suitable voltage vectors in HASVPWM. Most the researchers recommended Fuzzy logic for the process control system. Because of its simple design and multi valued logics processing capability. The functional block diagram of fuzzy logic is shown in Fig.3.

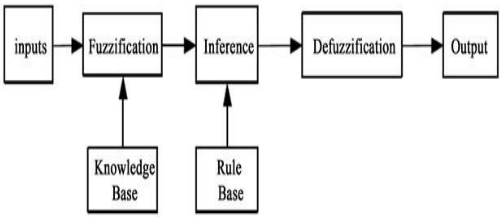

Fig. 3: Functional Block diagram of Fuzzy Logic

Fuzzy logic system describes to what degree the rule applies, while the conclusion assigns a fuzzy function to each of one or more output variables. These Fuzzy Expert Systems allow more than one conclusion per rule. The set of rules in a fuzzy expert system is known as knowledge base [2],[4],[5].

Table I: Fuzzy Logic Rules to select suitable sector in HASVPWM

CE\E	NB	NS	ZE	PS	PB
NB	NB	NB	NS	NS	ZE
NS	NB	NS	NS	ZE	PS
ZE	NS	NS	ZE	PS	PS
PS	NS	ZE	PS	PS	PB
PB	ZE	PS	PS	PB	PB

5. Neural Network based HASVPWM Scheme for DTC drive:

ANNs have gaining interest ever past day in many fields including motion control, system modeling, parameter estimation and have been used modeling of non-linear systems in many kind of applications due to their unique abilities like processing of data at all network, learning ability and working with incomplete data etc. ANN-DTC scheme that we have proposed, has two different feed forward ANNs to select switching states and determine stator flux sector. ANN is nonlinear model that is easy to use and understand compared to statistical methods. ANN has an ability to learn from the previous trained data. Hence, the major advantage of ANN is to train a system with large amount of data sets. The output performance will depend upon the trained parameters and the data set relevant to the training data. In this paper, ANN is used to estimate the suitable sector of HASVPWM. ANN is used to determine the sector number for the estimated value of θ_e. There are total of 24 sectors, each sector of 15 degree. Again three layers of neurons are used but with a 5-4-1 feed forward configuration. Input layer is of log sigmoid transfer function, hidden layer is of hyperbolic tangent sigmoid function and the output layer is of linear transfer function. Levenberg -Marquardt back propagation based training method is used for train the neurons. As soon as the training procedure is over, the neural network gives almost the same output pattern for the same or nearby values of input [2],[4],[5]. This tendency of the neural networks which approximates the output for new input i.e. angle theta since sector selection is purely based on theta. This may use in DTC based IMD to find suitable voltage vectors to the HASVPWM scheme.

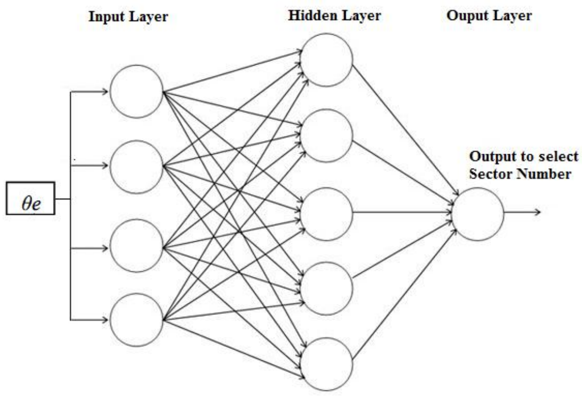

Fig. 4: ANN Feed forward structure for sector estimation

Algorithm:

1. Initialize the Speed and Load torque to the DTC controller
2. Get feedback of three phase stator voltage and current signals from Induction motor to the DTC.
3. Perform three phase to alpha-beta and d-q (Park) conversion.
4. Estimate the stator flux and torque components based on the d-q current and voltage components.
5. Estimate the rotor flux and torque components.
6. Estimate the error values of flux and torque components
7. Generation of reference signal to the HASVPWM controller by performing d-q to abc (Inverse park) conversion.
8. Estimate the sector angle based on the reference signal from DTC.
9. Assign the sector numbers based on the sector angle
10. Generate sets of non-dominated fronts
11. Calculate the time constants T_1, T_2 and T_0 for SVPWM.
12. Based on the sector angle and time, calculate the sector values S_1, S_2 and S_3 estimation
13. Repeat the same procedure for ASVPWM signal time calculation. Intelligent control algorithm Fuzzy or ANN applied in choosing the suitable sector.
14. Based on the best suitable sector angle and time, the sector values S_1, S_2 and S_3 estimated for ASVPWM scheme.
15. Compare reference sectors S_1, S_2 and S_3 of SVPWM and ASVPWM; find the suitable sector values by omitting the mismatches.
16. Compare final hybridized reference sectors S_1, S_2 and S_3 with constant carrier frequency f_s.
17. Generation of HASVPWM signal to the Voltage Source Inverter Switches.
18. Analyze the performance of DTC drive based on the torque ripple reduction.

RESULTS AND DISCUSSION

The simulation analysis of DTC base induction motor drive is done using MATLAB Simulink environment.

Table II: DTC Simulation Parameters

Parameters	Value
RMS line voltage	230V
Switching frequency	10 kHz
DC-link voltage	650 V
DC-link capacitance	2200 μF

The induction motor used in this work is about 0.7 KW, 1440 rpm, 4-pole, 3-phase induction motor having the following parameters: R_s= 7.83 Ω, R_r= 7.55 Ω, L_s= 0.4751 H, L_r= 0.4751 H, L_m= 0.4535 H, J = 0.06 Kg.$m^{2.}$ B = 0.01 N - m.sec/rad. Various conditions such as starting, steady state, Speed forward and speed reversal are simulated. The proposed fuzzy and ANN based hybrid vector control algorithm compared in terms of the Current ripples, Speed settling time, Torque variations, Total Harmonic distortion in both voltage and Current. Switching pulses and flux patterns.

Speed settling time of induction motor with Fuzzy based HASVPWM in fig 5 is about 2 sec, ANN based HASVPWM in fig 6 is about 1.5 sec. Settling time at starting period may be reduced around 0.5 sec. During speed reversal, settling time of induction motor with Fuzzy based HASVPWM from 5 sec to 7 sec. It takes around 2 sec, ANN based HASVPWM from 5 sec to 6.5 sec. It takes around 1.5 sec. ANN based HASVPWM introduced dead time during the transition from forward to reverse but Fuzzy based HASVPWM does not provide any dead time for speed change. if the speed reversal happens within the short interval of time then the response of the controller is poor and this creates large amount ripples in the load current This may leads to higher switching losses and higher THD.

The torque developed in the DTC based induction motor drive with fuzzy-HASVPWM is shown in figure 7. The Electromagnetic torque was continuously after setting the load torque because machine does not settle in proper time. At the starting period, there was a torque. When machine started to rotate in forward direction and reached its rated speed at 2 sec, from 2 sec to 3 sec, torque completely downer. During the speed transition (machine reversal) period i.e 3 sec to 7 sec, again torque was developed in the machine. When machine reached in reverse settle position, torque again reached down.

The torque developed in the DTC based induction motor drive with ANN-HASVPWM is shown in figure 8. The Electromagnetic torque characteristics different than Fuzzy-HASVPWM. Torque does not continuously, after setting the load torque because machine settled in proper time. At the starting period, there was a torque. When machine started to rotate in forward direction and reached its rated speed at 2 sec, from 2 sec to 3 sec, torque completely downer. During the speed transition (machine reversal) period i.e 3 sec to 7 sec, again torque was developed in the machine. When machine reached in reverse settle position, torque again reached down. The torque developed in the DTC based induction motor drive with ANN-HASVPWM is shown in figure. The Electromagnetic torque characteristics different than Fuzzy-HASVPWM. Torque does not continuously, after setting the load torque because machine settled in proper time. At the starting period, there was a torque. When machine started to rotate in forward direction and reached its rated speed at 1.5 sec, from 1.5 sec to 3 sec, torque completely downer. During the speed transition period i.e 3 sec to 4.5 sec, again torque was developed in the machine. When the rest period i.e 3 sec to 4.5 sec, both speed and torque completely downer. During the reverse period i.e 4.5 sec to 6.5 sec, again torque was developed in the machine. When machine reached in reverse settle position, torque again reached down.

In Fig 9 & 10, the voltage and current THD spectrum for both proposed DTC drive with fuzzy based HASVPWM and ANN based HASVPWM taken for load conditions. Voltage THD for both cases is similar behavior. But current THD in fuzzy based HASVPWM is higher than ANN based HASVPWM.

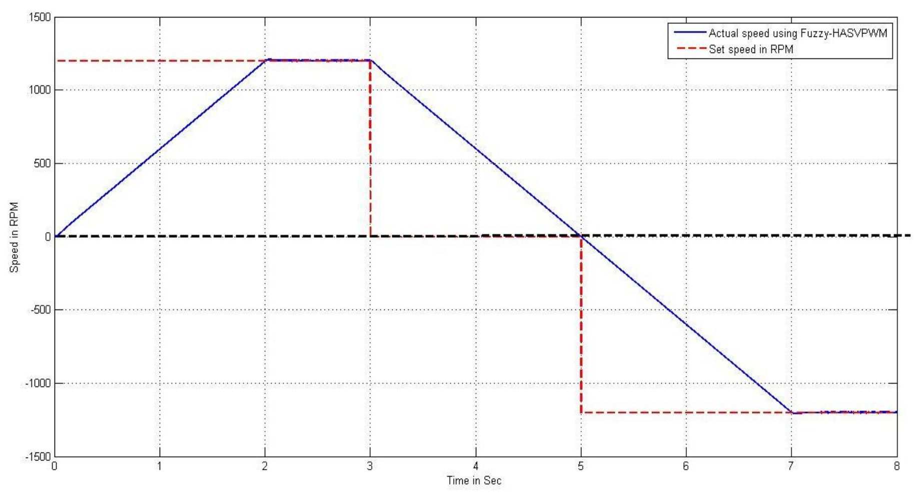

Fig. 5: Speed curve in DTC using Fuzzy-HASVPWM

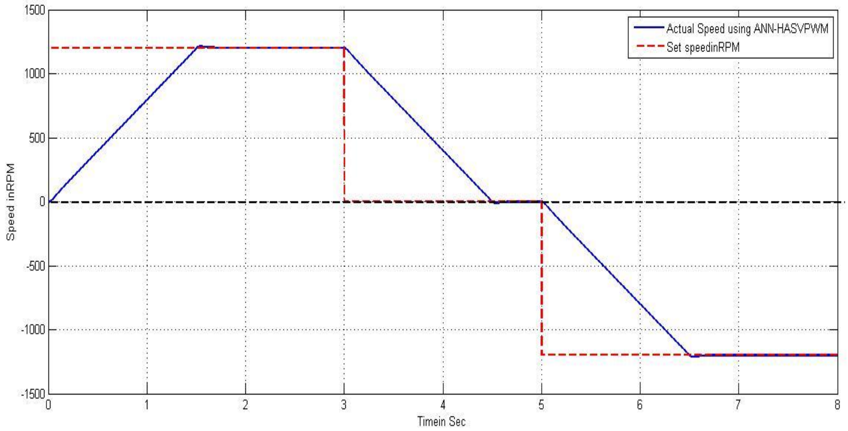

Fig. 6: Speed curve in DTC using ANN-HASVPWM

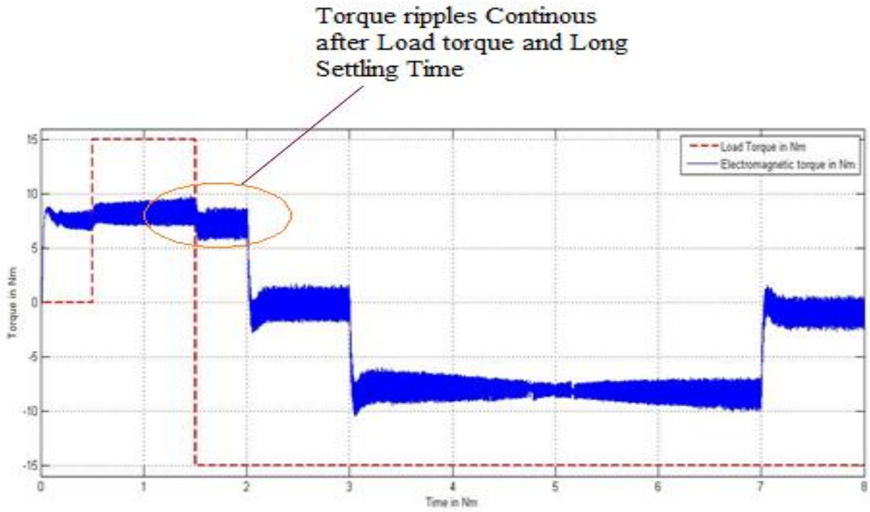

Fig. 7: Torque developed in DTC using Fuzzy-HASVPWM

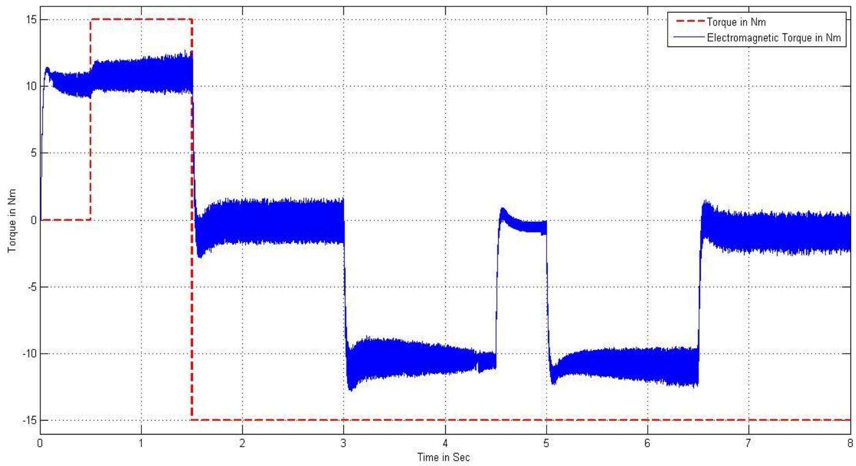

Fig. 8: Torque developed in DTC using ANN-HASVPWM

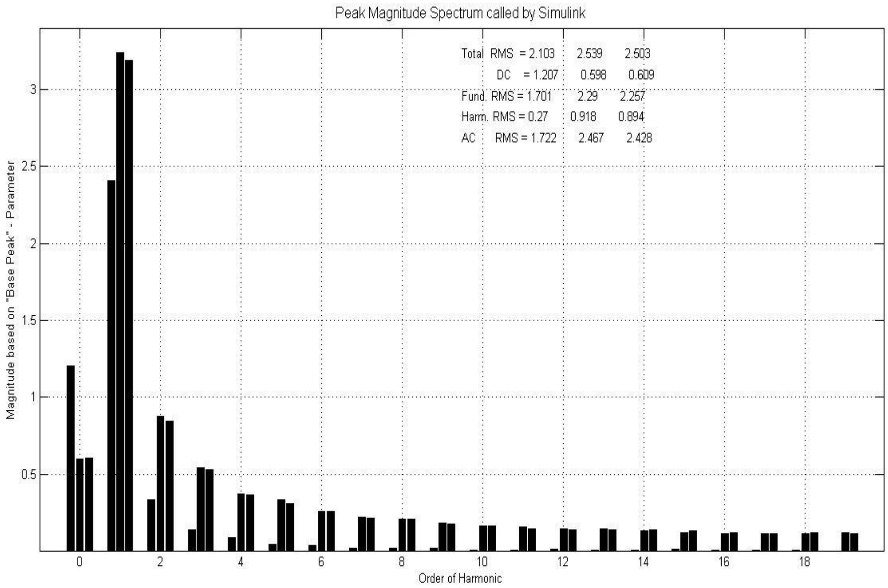

Fig. 9: ITHD in DTC using Fuzzy-HASVPWM

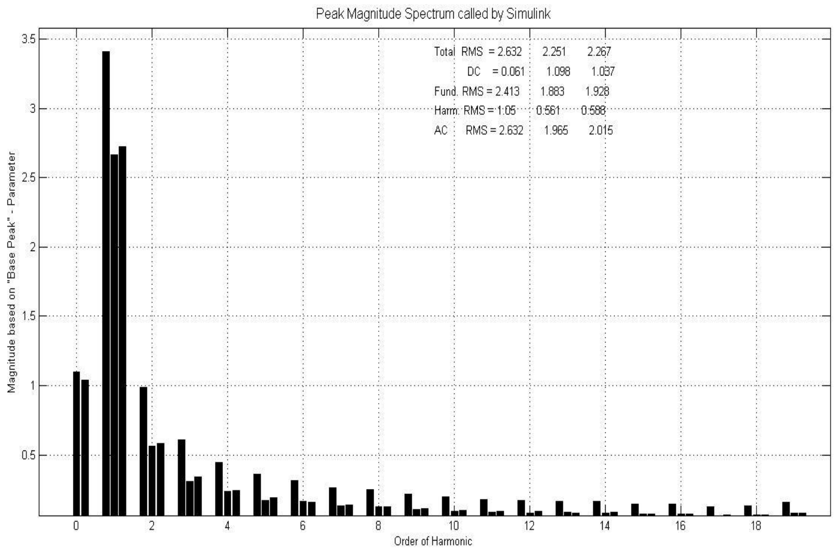

Fig. 10: ITHD in DTC using ANN-HASVPWM

Conclusion:

HASVPWM in direct torque control drive can be achieved either by using Fuzzy logic control or Artificial Neural Network (ANN) control. Compare with Fuzzy Logic, ANN has an ability to learn from the previous trained data. Hence, the major advantage of ANN is to train a system with large amount of data sets. Fuzzy based HASVPWM has an ability to provide faster switching sector angle for PWM generation. But it fails to change its state for the sudden change in the inputs, due its input and output boundaries. The output performance will depend upon the trained parameters and the data set relevant to the training data. Compare with Fuzzy logic control, ANN control in HASVPWM is able to identify the suitable voltage vector and its angle for minimizing the torque ripples, speed settling time, flux error and transient responses and THD, under various operating conditions like speed forward, reversal and loading conditions.

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