IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 15, Issue 3 Ser. II (May – June 2020), PP 56-63
www.iosrjournals.org

Performance Analysis of ANFIS and PI based Symmetrical Six phase Induction Motor Operating under Normal and Faulty Conditions

Md. Ershad Ali[1] and Bashudeb Chandra Ghosh[2]
[1]*Student EEE Department, Khulna University of Engineering & Technology, Khulna, Bangladesh*
[2]*Professor EEE Department, Khulna University of Engineering & Technology, Khulna, Bangladesh*

Abstract: *A simplified Direct Torque Control (DTC) strategy for symmetrical six phase induction motor drives with ANFIS and PI controller is discussed in this paper. The coils of the six phase induction motor are symmetrically arranged and angle between two consecutive phases is 60°. A simplified DTC technique is used to regulate the torque and hence control the speed. The simulation was conducted at starting, speed reversal, speed change, sudden load torque disturbances and faulty conditions. Comparison of the results establish the acceptable performance of both the ANFIS and PI controllers obtained after simulation of the Drive System in C++ environment.*

Keywords: *Six Phase Induction Motor, Direct Torque Control (DTC), ANFIS and PI Controller, Parameter Changes, Phase fault condition.*

Date of Submission: 06-06-2020 Date of Acceptance: 22-06-2020

I. Introduction

Three phase induction motors are widely used industrial motor due to their simple structure, efficient smooth power conversion characteristic, lower cost and ready availability of three phase power supply. These motors suffer from one serious disadvantage of its failure to operate due to fault in a phase that causes single phasing and the motors fail to produce useful mechanical power. However, an inverter fed three phase induction motor produce torque oscillation and requires power semiconductor devices of higher rating. The problem can be solved using multiphase induction machines. These machines provide additional freedom of control, lower rating of semiconductor switches, smooth torque profile and reliable operation in case of faults in one or more phases. Due to advancement of semiconductor technology, power is conveniently generated for more than three phases fed to higher number of phase machines.

Application of dual three phases or multiple three phase machines was the start up journey of multiphase induction machines. Later on applications of 5, 6 and 7 phase motors were introduced. A review paper [1] describes the progress made in multi-phase induction machine drive research and development since its inception. The paper attempts to highlight the current and future issues involved for the development of multi-phase induction machine drive technology for future applications. The paper [2] describes an application of fuzzy logic and sliding mode controls in order to obtain a high-accuracy positioning of a 6-Phase IM rotor in both healthy and faulted modes. The two control strategies were completely different from a theoretical point of view, but the final objectives were to remove the drawbacks of the specific fault on interest. The experimental results obtained on a dedicated setup based on a 6-phase IM coupled with a variable mechanical load demonstrated functioning of the drive system to supply some mechanical load for which up to three phases can be removed. By injecting third harmonic current additional torque can be produced [3]. Also, increasing phase number to at least five (or more) enables completely independent vector control of two (or more) multiphase machines that are supplied from a single current-controlled voltage source inverter [4]. Vector control of a symmetrical six phase induction machine with a novel configuration designed in a simple way that uses only three current sensors is presented in [5]. Analytical equations are extracted in the paper to show that some of the current components which do not contribute in torque production may be eliminated as described in the proposed scheme. Two separate models have been used in [6] to analyze the dynamic behavior of machines for balanced and unbalanced excitation due to open circuit. These models are silent about the analysis of unbalanced condition caused by the short circuit at stator terminals. The mathematical model of a six phase six-step voltage-fed induction motor with 30° angle between the 2 sets of three phase windings is presented in [7].

Constant V/f control was extensively studied in the early days of the multiphase variable-speed induction motor drive development. A drive system described in [8] using voltage source inverters with quasi square-wave current output for a six phase induction motor. The paper [9] is presented a Direct Torque Control for a Six Phase Induction Machine drive using a PI regulator. The control scheme allows direct and independent electromagnetic torque and flux control, selecting an optimal switching vector. The simulation results show that the DTC present a good dynamics performances. A DTC-SVM scheme [10] has been presented for unsymmetrical six-phase IM. The decoupled torque and stator flux is achieved in the IM stator flux field orientation reference frame using conventional PI regulators. In this control scheme, the rotor speed and stator resistance are estimated by simple estimation methods. In addition, the stator phase voltages are estimated by using the SVPWM inverter switching times and the dc link voltage. The paper [11] presents a new configuration for direct torque control (DTC) of six-phase induction motor (SPIM). In it direct torque and flux control are applied to the six phase induction motor using matrix converter with the conventional three-phase source as its input. The proposed DTC scheme for SPIM benefits the advantages of both DTC and matrix converter. The simulation results show the effectiveness of the proposed method in both dynamic and steady state response. Application of DTC is shown in [12]. Their test results demonstrate that torque ripple in six phase induction machine is possible only if a three phase group is open circuited.

Normally used fuzzy inference system (FIS) reflects the actual process of mapping from a given input to output using fuzzy logic. The fuzzy system and neural networks are thought as complementary technologies. The most important reason for combining fuzzy systems with neural networks is to use learning capability of neural network which is an advantage from the view point of a fuzzy system, that additionally facilitate the combined system [13]. Because a neuron-fuzzy system is based on linguistic rules, we can easily integrate prior knowledge in to the system, and this can substantially shorten the learning process. One of the popular integrated systems is an ANFIS (Adaptive Neuro Fuzzy Inference System) [13]. Modern control systems are designed imparting artificial intelligence. This paper investigates on number and shape of membership functions. The study considered four membership functions of which Gaussian function appeared to be the best providing higher degree of accuracy according to their experiment. Adaptive Neuro-Fuzzy Inference System (ANFIS) is a combination of Artificial Neural Network (ANN) and Fuzzy Logic (FL) which is an effective method for predicting motor performance. This model is trained by the Levenberg-Marquardt (LM) training algorithm and performance is compared between ANFIS and Fuzzy PID control system. It also has compared with experimental data based on two- axis inertial stabilized platform [14]. The paper [15] proposes ANFIS based controller and it consists of the combination of Artificial Neural Network (ANN) and Fuzzy Logic (FL), which uses learning techniques to control the PMBLDC motor. The performance of ANFIS depends on only two factors such as number of parameters and shape of membership function. ANN is a system which processes information from one neuron to other neuron like biological neural connected human brain. PI controller is tuned by Ziegler-Nichols method. The performance of drive systems were compared with both control systems. Motor drive system is simulated in a C++ environment in discrete form.

In this paper our objective is to study the functionality of an ANFIS based Direct Torque Control with a simplified algorithm of switching control for the symmetrical six phase induction motor. This multiphase machine has simplified mathematical model and reduced control system complexity. The study covers normal, disturbance and faulty conditions. Simulations results indicate improved performance indicate applicability of the drive system for industrial purposes.

II. Mathematical model of the symmetrical six phase induction motor

A symmetrical six phase induction motor requires a six phase inverter for its excitation. Let us consider a symmetrical six phase induction motor with star-connected stator phase coils. The rotor coils are also assumed star connected. The arrangement of stator coils of such a machine is shown in Fig1. The rotor is star connected and the machine is fed from a six phase inverter having six legs marked as 1,2,3,4,5 and 6. The motor inverter system of a symmetrical six phase machines shown in Fig. 2. It is to be noted that the coils of a six phase induction motor are symmetrically arranged and angle between two consecutive phases is 60^{o}.

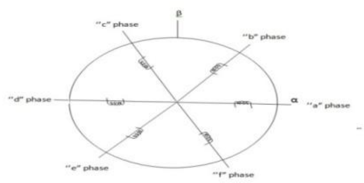
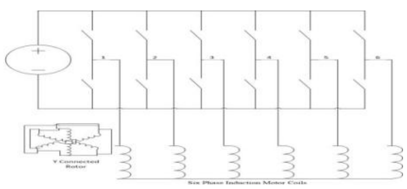


Fig.1 Stator Coil Arrangement of a Symmetrical Six Phase Induction Motor



Rotor

Fig. 2 Inverter and six phase Symmetrical Induction Motor

For symmetrical six phase induction machines all the coils are identical. Mathematical modeling is done neglecting the flux fringing and saturation. Parameters are also considered constants. Under this condition, **c**onsidering power invariant transformation we can write the following generalized transformation:

$$\begin{bmatrix} Y_a \\ Y_\beta \\ Y_0 \end{bmatrix} = \sqrt{\frac{2}{6}} \begin{bmatrix} 1 & cos\alpha & cos2\alpha & cos3\alpha & cos4\alpha & cos5\alpha \\ 0 & sin\alpha & sin2\alpha & sin3\alpha & sin4\alpha & sin5\alpha \\ 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} Y_a \\ Y_b \\ Y_c \\ Y_d \\ Y_e \\ Y_f \end{bmatrix} \quad (1)$$

Where, angle between two consecutive phases is α=60^o for symmetrical six phase machine.
For control system design purpose multiphase induction machines are described in synchronously rotating dq arbitrary frame. The stator voltage equations of the six phase induction machine can be written as:

$$v_{ds} = R_s i_{ds} + \frac{d}{dt}\psi_{ds} - \omega_e \psi_{qs} \quad (2)$$

$$v_{qs} = R_s i_{qs} + \frac{d}{dt}\psi_{qs} + \omega_e \psi_{ds} \quad (3)$$

Similarly, the rotor circuit equations are written as:

$$v_{dr} = R_r i_{dr} + \frac{d}{dt}\psi_{dr} - (\omega_e - \omega_r)\psi_{qr} \quad (4)$$

$$v_{qr} = R_r i_{qr} + \frac{d}{dt}\psi_{qr} + (\omega_e - \omega_r)\psi_{qr} \quad (5)$$

The flux linkage expressions are written as

$$\psi_{ds} = l_{ls} i_{ds} + L_m(i_{ds} + i_{dr}) \quad (6)$$

$$\psi_{dr} = l_{lr} i_{dr} + L_m(i_{ds} + i_{dr}) \quad (7)$$

$$\psi_{qs} = l_{ls} i_{qs} + L_m(i_{qs} + i_{qr}) \quad (8)$$

$$\psi_{qr} = l_{lr} i_{qr} + L_m(i_{qs} + i_{qr}) \quad (9)$$

In stationary reference frame α-β the voltage equations in stator and rotor side are:

$$v_{\alpha s} = R_S i_{\alpha s} + p\psi_{\alpha s} \quad (10)$$

$$v_{\beta s} = R_S i_{\beta s} + p\psi_{\beta s} \quad (11)$$

$$v_{0s} = R_S i_{0s} + p\psi_{0s} \quad (12)$$

$$v_{\alpha r} = R_r i_{\alpha r} + p\psi_{\alpha r} \quad (13)$$

$$v_{\beta r} = R_S i_{\beta r} + p\psi_{\beta r} \quad (14)$$

Where the flux linkages can be written as;

$$\psi_{\alpha s} = l_{ls} i_{\alpha s} + L_m(i_{\alpha s} + i_{\alpha r}) \quad (15)$$

$$\psi_{\beta s} = l_{ls} i_{\beta s} + L_m(i_{\beta s} + i_{\beta r}) \quad (16)$$

$$\psi_{\alpha r} = l_{ls} i_{\alpha r} + L_m(i_{\alpha s} + i_{\alpha r}) \quad (17)$$

$$\psi_{\beta r} = l_{ls} i_{\beta r} + L_m(i_{\beta s} + i_{\beta r}) \quad (18)$$

Where, $L_m = \frac{n}{2}M$ and M is the maximum value of the stator to rotor mutual inductances in the phase-variable model. The torque equation used for simulation model in general is written as:

$$T_d = \sqrt{\frac{6}{2}} P_p(\psi_{\beta r}(\psi_{\alpha r} - L_m i_{\alpha s}/L_r) - \psi_{\alpha r}(\psi_{\beta r} - L_m i_{\beta s}/L_r)) \quad (19)$$

With T_l as load torque, J as inertia coefficient and B as friction coefficient at motor mechanical speed ω_m, the torque balance equation is given by

$$T_d = T_l + J\frac{d\omega_m}{dt} + B\omega_m \quad (20)$$

The state space representation of the system for simulation is described below in matrix form with two stator currents and two rotor flux linkages as state variables.

$$\frac{d}{dt}\begin{bmatrix} i_{\alpha s} \\ i_{\beta s} \\ \psi_{\alpha r} \\ \psi_{\beta r} \end{bmatrix} = \begin{bmatrix} \frac{-R_s}{\sigma L_s} + \frac{R_r(1-\sigma)}{\sigma L_r} & 0 & \frac{L_m}{\sigma L_s L_r}\frac{R_r}{L_r} & \frac{L_m}{\sigma L_s L_r}\omega_r \\ 0 & \frac{-R_s}{\sigma L_s} + \frac{R_r(1-\sigma)}{\sigma L_r} & \frac{L_m}{\sigma L_s L_r}\omega_r & \frac{L_m}{\sigma L_s L_r}\frac{R_r}{L_r} \\ L_m\frac{R_r}{L_r} & 0 & \frac{R_r}{L_r} & -\omega_r \\ 0 & L_m\frac{R_r}{L_r} & \omega_r & \frac{R_r}{L_r} \end{bmatrix} \begin{bmatrix} i_{\alpha s} \\ i_{\beta s} \\ \psi_{\alpha r} \\ \psi_{\beta r} \end{bmatrix} + \frac{1}{\sigma L_s}\begin{bmatrix} v_{\alpha s} \\ v_{\beta s} \\ 0 \\ 0 \end{bmatrix} \quad (21)$$

Where, $\sigma = \frac{1-L_m^2}{L_s L_r}$ and $v_{\alpha s}$ and $v_{\beta s}$ are the equivalent two phase voltages.

III. Direct torque control of symmetrical six phase induction machine

Direct Torque Control of Induction Machines requires flux error, torque error and flux position for its implementation. For this reason actual value of flux and torque need to be calculated. The actual values are calculated sensing the physical variables such as phase voltages and currents. From the actual values of phase variables the stationary two phase quantities are calculated using transformation in (1).

3.1 Stator flux calculation

It is normal practice for DTCof induction motors is to use rotor flux as reference and actual value. The actual values of stator flux components are calculated using the following equations:

$$\psi_{\alpha s} = \int (v_{\alpha s} - R_S i_{\alpha s})dt \qquad (22a)$$

$$\psi_{\beta s} = \int (v_{\beta s} - R_S i_{\beta s})dt \qquad (22b)$$

The actual rotor flux components are given by:

$$\psi_{\alpha r} = \left(\frac{L_r}{L_m}\right)\psi_{\alpha s} - \sigma L_s I_{\alpha s} \qquad (23a)$$

$$\psi_{\beta r} = \left(\frac{L_r}{L_m}\right)\psi_{\beta s} - \sigma L_s I_{\beta s} \qquad (23b)$$

Magnitude of actual rotor flux is calculated as:

$$\psi_r = \sqrt{\psi_{\alpha r}^2 + \psi_{\beta r}^2} \qquad (24)$$

3.2 Angular position of flux vector

The sector is determined from position of rotor flux position.

The angular position $\boldsymbol{\theta}$of the stator flux vector is calculated as:

$$\theta = tan^{-1}\frac{\psi_{\beta r}}{\psi_{\alpha r}} \qquad (25)$$

3.3 Torque calculation by the controller

The controller calculates the developed torque using only the stator variables those can be measured and is given by the following equation:

$$T_{ed} = \frac{\sqrt{3}}{2}P_p(\psi_{\alpha s} i_{\beta s} - \psi_{\beta s} i_{\alpha s}) \qquad (26)$$

3.4 Voltage Vectors and Switching Table

For a symmetrical six phase machine distinctly we have six voltage vectors shown in Fig.3. The six voltage vectors are calculated based on six bit digital system with upper switches “ON=1” and lower switches “ON=0” thus generating binary number converted to decimal values as indicated below the switching table. Switching Table 1 is required for DTC operation.

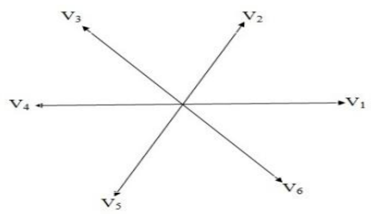


Fig.3 Voltage Vectors of a Symmetrical Six Phase Induction Motor

DTC Switching Table 1

Δψ	ΔT_e	Sector1	Sector2	Sector3	Sector4	Sector5	Sector6
-1 or 0	-1	5	6	1	2	3	4
	0	7	0	7	0	7	0
	+1	3	4	5	6	1	2
+1	-1	6	1	2	3	4	5
	0	0	7	0	7	0	7
	+1	2	3	4	5	6	1

1,2,3,.. are voltage vectors. Digital values of voltage vectors are V_1=49; V_2=56; V_3=28; V_4=14; V_5=7;

3.5 Reference Values Generated by the Controller

In this study we consider only operation in the base speed region and reference flux is assumed constant. The reference torque is calculated from the speed error using an ANFIS type controller that provides promising result. The sensing, axes transformation, error processing, sector searching and switching logic generation are done to implement the DTC control scheme as shown in Fig.4 below.

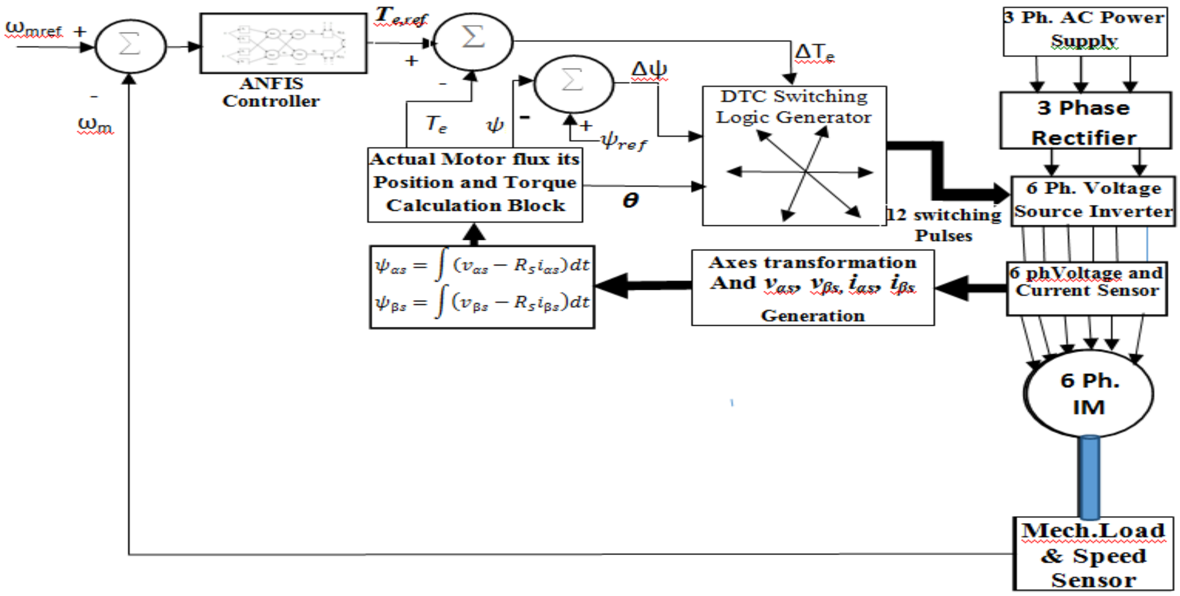


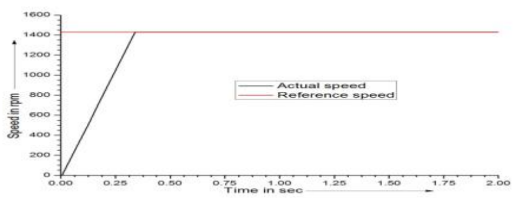
Fig. 4 Control Circuit Block Diagram

IV. Simulation results

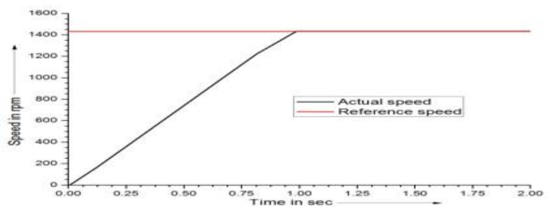
The drive system was simulated in computer program C++ software using code block. The ANFIS and PI controllers are tuned under different operating conditions and plotting the curve using Origin 8.0 software package. The six phase machine performance were tested under starting condition, speed reversal, speed variation, load torque change and fault condition.

4.1 Starting transient

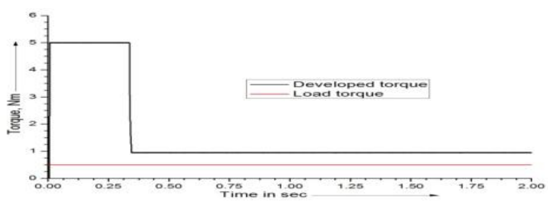
The motor performance tested from rest condition with load torque 0.5 Nm and reference speed 1432.4 rpm for ANFIS and PI controller. The motor drive with ANFIS reach the set speed at 0.36sec and with PI controller reach the set speed at 0.97sec shown in Fig.5(a) and Fig.5(b). From Fig.5 (a) of ANFIS controller observed that there is no overshoot, undershoot or oscillation and taken less time to compare with PI controller of Fig.5 (b). The torque characteristics much better in ANFIS controller and variation of developed torque higher in PI controller which depicted in Fig.5(c) and Fig.5 (d). Both the controller the rotor flux profile are very similar shown in Fig.5 (e) and Fig.5 (f).



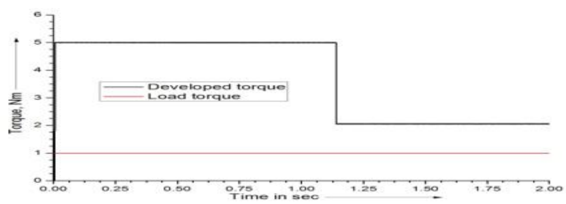
(a) Starting Speed with ANFIS Controller



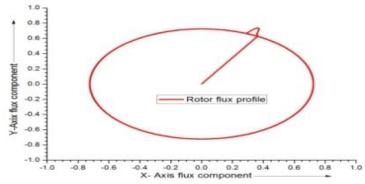
(b) Starting Speed with PI Controller



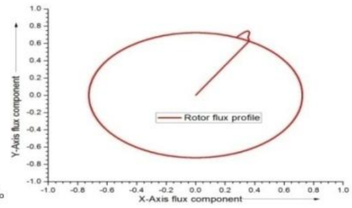
(c)Developed Torque at Starting with ANFIS Controller



(d)Developed Torque at Starting with PI Controller



(e)Rotor flux profile with ANFIS Controller

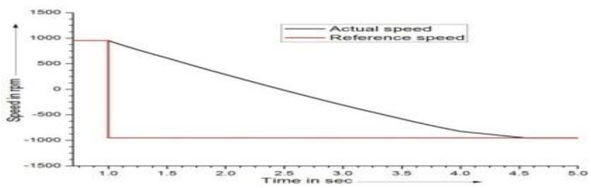


(f)Rotor flux profile with PI Controller

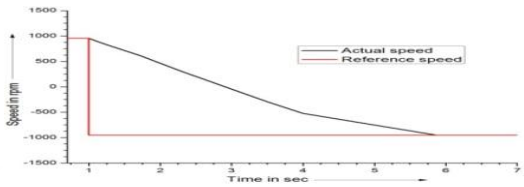
Fig.5 Starting performance of six phase direct torque control of symmetrical six phase induction motor with ANFIS and PI controller

4.2 Speed reversal

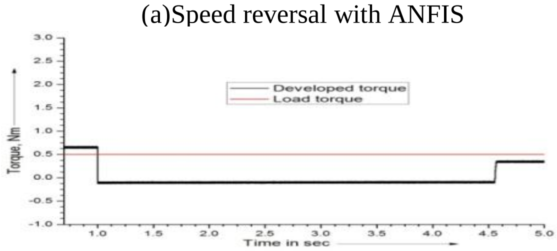
Both the drive systems were tested for speed reversal. The motors were running at steady state and set speed command was applied from +954 rpm to -954 rpm. The drive with ANFIS controller required 4.5 sec and PI controller take more time to reach reference speed of -954 rpm which presented in Fig.6 (a) and Fig.6(b). The torque characteristics with ANFIS controller is better than PI and less variation with ANFIS controller also shown in Fig.6(c) and Fig.6 (d). The rotor field angle for the controller depicted in Fig.6 (e) and Fig.6 (f).



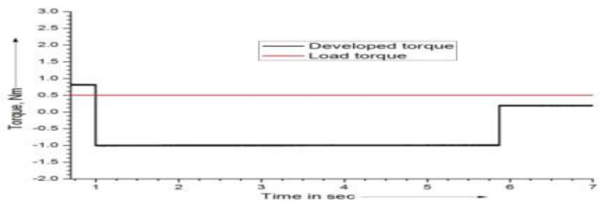
(a)Speed reversal with ANFIS



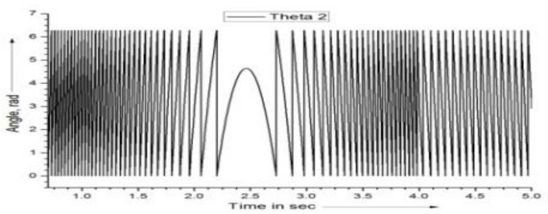
(b) Speed reversal with PI Controller



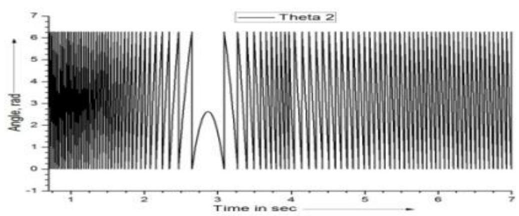
(c)Torque characteristics for speed reversal with ANFIS Controller



(d)Torque characteristics for speed reversal with PI Controller



(e)Rotor field angle for speed reversal with ANFIS Controller

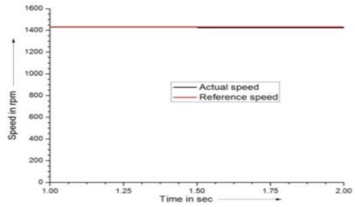


(f)Rotor field angle for speed reversal with PI Controller

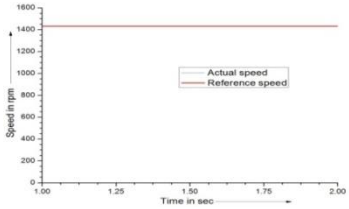
Fig. 6 Speed reversal characteristics with ANFIS and PI controller

4.3 Sudden load torque change

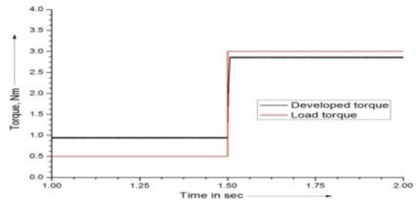
The drive performance was tested for sudden load torque change. The motor was running with a set speed of 1432 rpm and load torque 0.5 Nm. At time t=1.5 sec the load torque was suddenly increased from 0.5 to 3.0 Nm for both the controllers. Both the drive systems overcome the sudden load change without any speed oscillations as shown in Fig.7 (a) and Fig.7 (b). Also the torque characteristics are shown in Fig.7(c) and Fig.7 (d).No speed oscillation is observed. Slip speed for load torque disturbance with ANFIS controller are presented in Fig.7 (e)



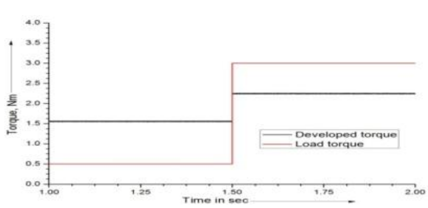
(a)Speed for load torque disturbance with ANFIS Controller



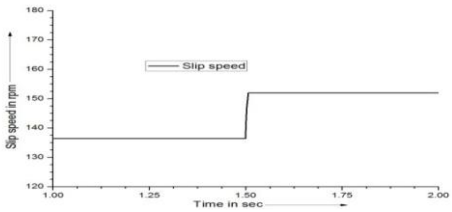
(b) Speed for load torque disturbance with PI



(c) Torque characteristics for load torque disturbance with ANFIS Controller



(d) Torque characteristics for load torque disturbance with PI Controller

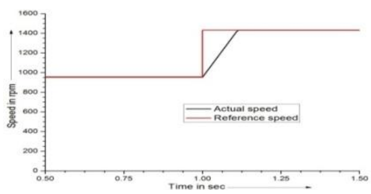


(c)Slip speed for load torque disturbance with ANFIS controller

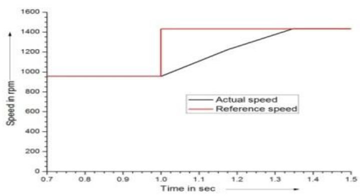
Fig. 7 Effect of sudden load torque disturbance with ANFIS and PI controller

4.4 Speed variation

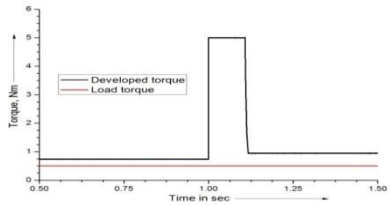
Both the drive system running at steady state at a speed of 955 rpm. At time t=1.0 sec the new set speed was adjusted to 1432 rpm for both the controller. The drive with ANFIS controller taken to less time to reach the reference speed which presented in Fig.8 (a) and Fig.8 (b). The developed torque also fast in stable condition compare with PI controller depicted in Fig.8 (c) and Fig.8 (d). The Rotor flux profile for both the controllers are identical as shown in Fig.8 (e) and Fig.8 (f).



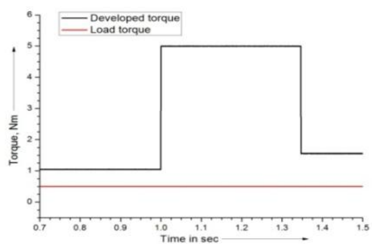
(a)Speed variation with ANFIS Controller



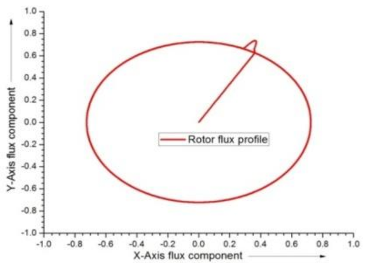
(b)Speed variation with PI



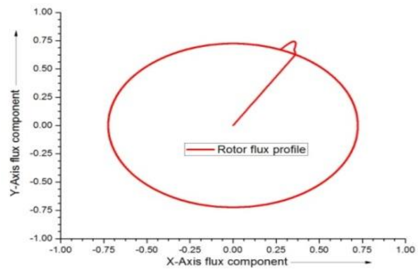
(c)Torque characteristics for speed variation with ANFIS Controller



(d)Torque characteristics for speed variation with PI Controller



(e)Rotor flux profile with ANFIS Controller

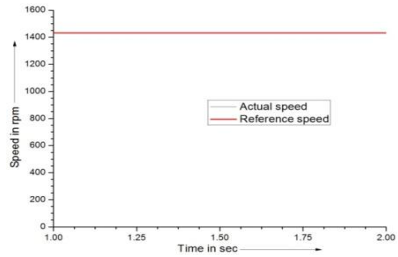


(f)Rotor flux profile withPI Controller

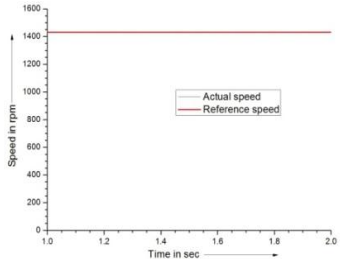
Figure 8: Drive performance at speed variation with ANFIS and PI controller

4.5 Performance with asymmetrical operation (one phase open due to fault)

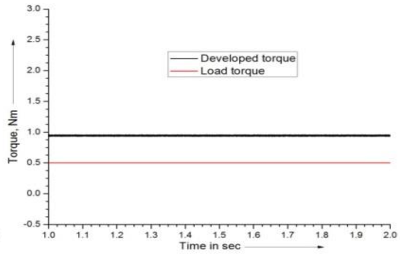
The drive system were tested under fault conditions created one of six phases open at t=1.5sec for the controller. The speed response for ANFIS and PI controller is identical and no change in speed due to opening 'a' phases (ie. Va=0) which is shown in Fig.9 (a) and Fig.9 (b). The shape of the developed torque curve is also unaffected due to sudden fault condition as depicted in Fig.9 (c) and Fig.9 (d).This indicates the advantages for multiphase machines for reliable operation. The phase voltages for both controller presented in Fig.9 (e) and Fig.9 (f)



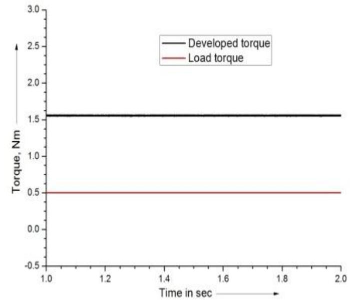
(a) One phase open with ANFIS Controller



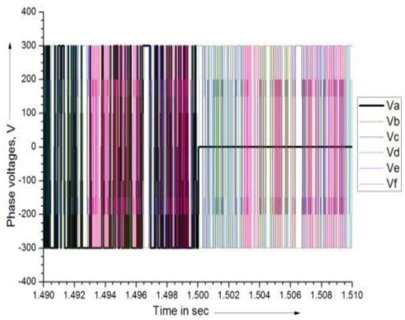
(b) One phase open with PI Controller



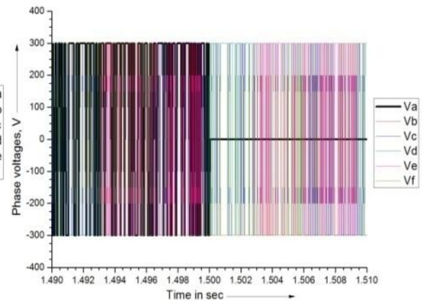
(c)Torque characteristics for one phase open with ANFIS Controller



(d)Torque characteristics for one phase open with PI Controller



(e)Phase voltages with ANFIS Controller



(f)Phase voltages with PI Controller

Fig. 13 Performance test with one of six phases open with ANFIS and PI controller

V. Conclusion

From the starting condition, we have observed that ANFIS controller based six phase induction motor's speed and torque responses are faster than PI controller and these are controlled as well. Speed reversal time by ANFIS torque control is better than PI. The machine with ANFIS controller can provide faster response and controlled accurately during normal and abnormal conditions like parameter changes and fault conditions.

References

[1]. G. K. Singh, "Multi-Phase Induction Machine Drive Research– a Survey", Electric Power Systems Res., vol. 61, issue 2, pp. 139-147 2002.

[2]. M. A. Fnaiech, F. Betin, G. A. Capolino, and F. Fnaiech, "Fuzzy Logic and Sliding-Mode Controls Applied to Six phase Induction Machine With Open Phase," IEEE Trans. on Ind. Electron., vol. 57, no. 1, pp. 354-364, 2010.

[3]. R.O.C. Lyra, and T.A. Lipo, "Torque density improvement in a six phase induction motor with third harmonic current injection", IEEE Trans. on Ind. Appl., vol. 38, no. 5, pp. 1351–1360, 2002.

[4]. E. Levi, M. Jones, S.N. Vukosavic, and H.A. Toliyat, "A novel concept of a multiphase, multimotor vector controlled drive system supplied from a single voltage source inverter", IEEE Trans. on Power Electron., vol. 19, no. 2, pp. 320 – 335, 2004.

[5]. Hamidreza PairodinNabi, PooyaDadashi and Abbas Shoulaie, "A Novel Structure for Vector Control of Symmetrical Six phase Induction Machines with Three Current Sensors," ETASR - Engineering, Technology & Applied Science Research, vol. 1, no. 2, pp. 23-29, 2011.

[6]. Y. Zhao, and T.A. Lipo, "Modeling and control of multi-phase induction machine with structural unbalance, part I-Machine modeling and multi-dimensional current regulation", IEEE Trans. on Energy Conversion, vol. 11, no. 3, pp. 570–577, Sep. 1996.

[7]. Abbas, M.A., Christen, R., and Jahns, T.M., "Six- phase voltage source inverter driven induction motor," IEEE Trans. on Ind. Appl., vol. 20, no. 5, pp. 1251-1259, 1984.

[8]. Andrese, E., and Bienick, K., "6-phsae induction motors for current-Source inverter driver," Proc. IEEE Industry Application Society Annual Meeting IAS, Philadelphia, PA,1981pp.607-618.

[9]. RadhwaneSadouni, AbdelkaderMeroufel and Salim djriou," Study and Simulation of Direct Torque Control (DTC) for a Six Phase Induction Machine (SPIM)," International Journal of Energy, Issue 2, Vol. 7, 2013, pp. 31-37.

[10]. G. R. Arab Markadeh, J. Soltani, N. R. Abjadi, M. Hajian," Sensorless Control of a Six-Phase InductionMotors Drive Using FOC in Stator Flux Reference Frame," World Academy of Science, Engineering and Technology 58 2009, pp 553-559.

[11]. Reza Kianinezhad, SeyyedGhodratollahSeyfossadat, Vali Talaeizadeh and AbdelmajidHasani,"A New DTC of Six Phase Induction Machines using Matrix Converter,"Conference Paper · ACTEA 2009 July 15-17, 2009 ZoukMosbeh, Lebanon, August 2009.

[12]. R. Kianinezhad and A. Hajary,"Investigating Direct Torque Control of Six-Phase Induction Machines Under Open Phase Fault Conditions,"AUT Journal of Electrical Engineering, September 2017,pp.151-159.

[13]. Jang, J. ANFIS: Adaptive-network-based fuzzy inference system. Transactions on Systems, Man, and Cybernetics Vol.23, No.3, 1993. pp. 665-685.

[14]. Feng Liu, Hua Wang, Qingli Shi, Hengxian Wang, Mengyin Zhang and Hailong Zhao," Comparison of an ANFIS and Fuzzy PID Control Model for Performance in Two-Axis Intertial Stabilized Platform," IEEE ACCESS, Vol.5,2017,PP- 12951-12962.

[15]. Md. BelalHossen and Bashudeb Chandra Ghosh, "Performance Analysis of a PMBLDC Motor Drive based on ANFIS Controller and PI Controller," International Conference on Electrical, Computer and Communication Engineering (ECCE),7-9 February, 2019,978-1-5386-9111-3/19/$31.00 ©2019 IEEE.