Speed Vector Control (FOC) of Induction Motor using Artificial Neural Networks

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Abstract: This paper explores a new control design based on artificial neural networks and fuzzy systems to attain torque and speed operating point there exists only one set of voltage amplitude and frequency that control the machine at optimum efficiency. Field oriented control is the one of the most efficient vector control of induction motor due to simplicity of designing and construction. Field oriented control gives the high dynamic performance compared to characteristic of a dc motor. The simulation results confirm the adjust in motor load torque, the dynamic changes of speed curve, which demonstrated that the real system can be well simulated with fast dynamic response speed, steady state small of static error used and strong ability of anti-load disturbance.

Keywords: Induction motor [IM], Field orient control [FOC], Artificial intelligence [AI], Artificial Neural Networks [ANN], Fuzzy logic controller [FLC].

I INTRODUCTION

A .ANN Control of Induction Motor

Artificial Neural Network (ANN) control is an architecture that applies sophisticated control technologies with communication capabilities to motor control devices with helping to improve system performance and to gain operation efficiencies. With the ability to quickly gather, organize and analyze information from the operations. Artificial neural networks are relatively crude electronic models based on neural structure of human brain and it is a type of intelligent control system. Artificial intelligence based methods are simple to exhibit and less dependent on the machine parameters and have became very useful in induction motor drives.

Neural networks are collected of simple elements operating in parallel. These elements are stimulated by genetic nervous system. The elementary processing element of neural network is a neuron. Artificial neural networks are relatively simple electronic models based on neural structure of human brain. Human brain is a non-linear and complex structure. The unique possessions of neural network are that it can still perform its overall function even if some of the neurons are not functioning. That is, they are very robust to error or failure. Neuron is a fundamental processing component of neural network. Once the network is structured, network is ready to train and to calculate operating torque, motor speed and flux. Block model of induction motor shown in figure.1.

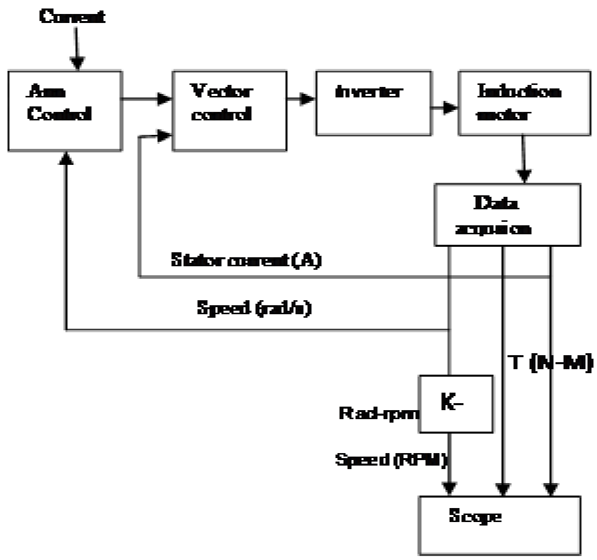

Fig 1: vector control of induction motor using ANN control.

The vector control algorithm is based on the flux and torque producing currents. An induction motor can be modeled most simply using two quadrature currents rather than the recognizable three phase currents actually applied to the motor. These two currents are called direct current and quadrature currents are producing flux and torque respectively in the motor. The two components are d-axis i_{ds} analogs to armature current, and q-axis i_{qs} analogs to the field current of a separately exited dc motor. From the figure-1, the rotor flux linkage vector aligned along the d-axis of reference frame

In a dc machine, neglecting the armature reaction effect and field saturation, the developed torque is given by [1].

$$T_{em} = K_a I_a \Phi(I_f) \quad (1)$$

$$\lambda_{qr}^{'e} = L_m i_{qs}^{e} + L_r^{'} i_{qr}^{'e} \text{ wb.turn} \quad (2)$$

$$i_{qr}^{'e} = -\frac{L_m}{L_r^{'}} i_{qs}^{e} \quad (3)$$

With $\lambda_{qr}^{'e}$ = zero the developed torque is

$$T_{em} = -\frac{3}{2}\frac{P}{2}\lambda_{dr}^{'e}\lambda_{qr}^{'e} \text{ N-m} \quad (4)$$

From the equations [3-4] we get desired form of torque as

$$T_{em} = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r'}\lambda_{dr}'^{e}\, i_{qs}^{e} \text{ N-m} \tag{5}$$

If the rotors flux linkage, $\lambda_{dr}'^{e}$ is not disturbed the torque can be independently controlled by adjusting the stator q component current, i_{qs}^{e}. For $\lambda_{qr}'^{e}$ to remain unchanged at zero, $p\lambda_{qr}'^{e}$ must be zero, in which case, the q-axis voltage equation of the rotor winding with no applied rotor voltages reduces to

$$V_{qr}'^{e} = r_r' i_{qr}'^{e} + p\lambda_{qr}'^{e} + (\omega_e - \omega_r)\lambda_{dr}'^{e} \text{ V} \tag{6}$$

$V_{qr}'^{e} = p\lambda_{qr}'^{e} = 0$. We get the slip as

$$(\omega_e - \omega_r) = \frac{r_r' i_{qr}'^{e}}{\lambda_{dr}'^{e}} \text{ Electr.rad/s} \tag{7}$$

Also if, $\lambda_{dr}'^{e}$ is to remain unchanged, $p\lambda_{qr}'^{e}$ must be zero. Using this condition and that of $\lambda_{qr}'^{e}$ being zero in d-axis rotor voltage equation, we will obtain the condition that $i_{dr}'^{e}$ must be zero, that is

$$V_{dr}'^{e} = r_r' i_{dr}'^{e} + p\lambda_{dr}'^{e} - (\omega_e - \omega_r)\lambda_{qr}'^{e} \text{ V} \tag{8}$$

By substituting the values $i_{dr}'^{e} = V_{dr}'^{e} = p\lambda_{dr}'^{e} = 0$ and $\lambda_{dr}'^{e} = L_m i_{ds}^{e}$ the relationship between slip and the stator q-d current components for the d-axis of the synchronously rotating frame to be aligned with the rotor field;

$$(\omega_e - \omega_r) = \frac{r_r' i_{qs}'^{e}}{L_m' i_{ds}^{e}} \text{ Elect.rad/s} \tag{9}$$

Magnitude of rotor flux can be controlled by i_{ds}^{e}, and the orientation of d-axis to the rotor field can be maintained by keeping either slip speed or i_{qs}^{e} in accordance to equation [9]. With proper field orientation, the dynamic of $\lambda_{dr}'^{e}$ will be confined to the d-axis and is determined by the rotor circuit time constant as shown in the equation [8]. By replacing $i_{dr}'^{e}$ with $\frac{\lambda_{dr}'^{e} - L_m i_{ds}^{e}}{L_r'}$

$$\text{That is } \lambda_{dr}'^{e} = \frac{r_r' L_m}{r_r' + L_r' p} i_{ds}^{e} \tag{10}$$

Field orient control schemes for induction motor is referred as direct type with angle, ρ as shown in figure-1, the direct method relies on the sensing of air gap flux. The measured flux in the air gap is the resultant or mutual flux. It is not the same as the flux linking the rotor winding, whose angle, ρ, is the desired angle for field orientation.

We can determine the value of ρ and the magnitude of rotor flux. The measured stator currents are first transformed to the stationary q-d currents using

$$i_{qs}^{s} = \frac{2}{3} i_{as} - \frac{1}{3} i_{bs} - \frac{1}{3} i_{cs} \text{ A} \tag{11}$$

$$i_{ds}^{s} = \frac{1}{3}(i_{cs} - i_{bs}) \quad (12)$$

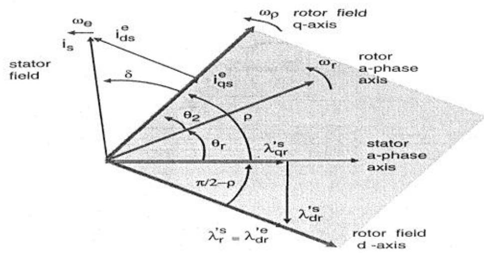

Fig 2: properly oriented q-d synchronously rotating frame

Adding and subtracting a $L_{lm}^{'} i_{qs}^{s}$ term to the right hand side, the rotor q-axis flux linkage in the stationary reference frame may be expressed as

$$\lambda_{qs}^{'s} = \left(L_m + L_{lr}^{'} - L_{lr}^{'}\right) i_{qs}^{s} + \left(L_m + L_{lr}^{'}\right) i_{qs}^{'s} \text{ wb.turn} \quad (13)$$

Where $\lambda_{dr}^{'s} = (i_{qs}^{s} + i_{qs}^{'s})$

Then $\lambda_{qr}^{'s} = \frac{L_r^{'}}{L_m} \lambda_{mq}^{s} - L_{lr}^{'} i_{qs}^{s}$ (14)

Similarly $\lambda_{dr}^{'s} = \frac{L_r^{'}}{L_m} \lambda_{md}^{s} - L_{lr}^{'} i_{ds}^{s}$ wb.turn (15)

Using $\lambda_{dr}^{'s}$ and $\lambda_{qr}^{'s}$ we determine the cosine and sine of ρ by the following geometrical relations that are deducible from the figure.1

$$\sin\left(\frac{n}{2} - \rho\right) = \cos\rho = \frac{\lambda_{dr}^{'s}}{|\lambda_{r}^{'s}|} \quad (16)$$

$$\cos\left(\frac{n}{2} - \rho\right) = \sin\rho = \frac{\lambda_{qr}^{'s}}{|\lambda_{r}^{'s}|} \quad (17)$$

$$\left|\lambda_{r}^{'e}\right| = \left|\lambda_{r}^{'s}\right| = \sqrt{\lambda_{qr}^{'s\ 2} + \lambda_{dr}^{'s\ 2}} \quad (18)$$

These above equations are executed in the field orientation block, the torque and flux controllers are the command values, i_{qs}^{e*} andi_{qs}^{e*}, and the following transformations are

$$i_{qs}^{qs} = i_{qs}^{e*} \cos\rho + i_{ds}^{e*} \sin\rho \quad \text{A} \quad (19)$$

$$i_{ds}^{s*} = -i_{qs}^{e*} \sin\rho + i_{ds}^{e*} \cos\rho \quad \text{A} \quad (20)$$

$$i_{ds}^{*} = i_{qs}^{s*} \quad \text{A}$$

$$i_{bs}^{*} = -\frac{1}{2} i_{qs}^{s*} - \frac{\sqrt{3}}{2} i_{ds}^{s*} \quad (21)$$

$$i_{cs}^{*} = -\frac{1}{2} i_{qs}^{s*} + \frac{\sqrt{3}}{2} i_{ds}^{s*} \quad (22)$$

Hence the electromagnetic torque developed by the motor is expressed in terms of rotor flux and stator current.

C. Neural network speed observer

By replacing stator flux with its expression and eliminating the rotor current equation (1), we obtain

$$\begin{aligned} V_{qs} &= r_s i_{qs} + d\phi_{qs} dt^{-1} \\ V_{ds} &= r_s i_{ds} + d\phi_{ds} dt^{-1} \\ 0 &= r_r i_{qr} + d\phi_{qr} dt^{-1} + \omega\phi_{dr} \\ 0 &= r_r i_{dr} + d\phi_{dr} dt^{-1} - \omega\phi_{qr} \end{aligned} \quad (23)$$

Based on this equation, we can recognize the Voltage model and the Current model.
The equality between the rotor fluxes deduced from the models, we obtain

$$\begin{aligned} L_r M^{-1}[v_{qs} - [r_s + L_s\sigma s] i_{qs}] &= M\tau_r^{-1} i_{qr} - \tau_r^{-1}\phi_{qr} - \omega\phi_{dr} \\ L_r M^{-1}[v_{ds} - [r_s + L_s\sigma s] i_{ds}] &= M\tau_r^{-1} i_{dr} - \tau_r^{-1}\phi_{dr} - \omega\phi_{qr} \end{aligned} \quad (24)$$

Multiplying the above equations with ϕ_{qr} and ϕ_{dr}, we obtain

$$\omega = L_r M^{-1}[v_{ds}\phi_{qr} - [r_s + L_s\sigma s] i_{ds}\phi_{qr} - [v_{qs}\phi_{dr} - [r_s + L_s\sigma s]\phi_{dr} i_{qs}] - M\tau_r^{-1}\left(\phi_{qr} i_{\beta s} - \phi_{dr} i_{qs}\right)]\left|\phi_r\right|^{-2} \quad (25)$$

ϕ_{qr} And ϕ_{dr} are constants. Hence,ω varies with respect to v_{qs}, v_{ds}, i_{qs} *and* i_{ds}. The significant inputs which determine completely the rotor speed v_{qs}, v_{ds}, i_{qs} *and* i_{ds}.Hence the AI Techniques are most suitable for motor drive applications which are simple to development and obtain information in complex systems. By using artificial neural networks are modulated with ease performance without non linearity's and uncertainties and the parameters used in ANN control are shown in the Table-1

Table-1
Parameters used in Simulation/Matlab

Parameters	Value
Stator resistance	14.6Ω
Rotor resistance	12.76
Stator leakage Inductance –Lls{H}	8.37(2*pi*60)
Rotor leakage Inductance –LlR{H}	19.53(2*pi*60)
Mutual inductance-Lm{H}	111.7/(2*pi*60)
Stator poles of Induction motors	4
Rated frequency	60
Inertia-J{kg.m^2}	0.01
Damping Coefficient	0.000124
Torque control for ANN control{N-m}	12

D. Results and discussions

The simulation results of vector control of an induction motor when applying artificial neural estimators of the speed and magnetizing current, respectively. The performance characteristics of ANN control technique is shown as compared with PI and FUZZY logic control from the following responses.

From the figure.4 the performance characteristic of static current for vector control of an induction motor are controlled at an initial values of t = 2.16sec, I=5A for PI control , t = 2.14 sec , I=4.9A for FUZZY control and t = 2.1sec, I=4.8A for ANN control respectively. By comparing all the controls schemes ANN control given the best performance of static current

From the figure-5 the performance characteristic of static current for vector control of an induction motor are controlled at an initial values of t = 0.576sec, I=6A for PI control , t = 0.56 sec , I=5A for FUZZY control and t = 0.55sec, I=4A for ANN control respectively. By comparing all the controls schemes ANN control given the best performance of current command.

From the figure-6 the performance characteristic of static current at low load condition for vector control of an induction motor are controlled at an initial values current at I = -2A for PI control , I = 4A for FUZZY control , I = 1A for ANN control. By compared all the controls current is controlled by ANN control at initial value of current I = 1A.

From the figure-7 the performance characteristic of static current at no load condition for vector control of an induction motor are controlled at an initial values of rise time at t = 0.02sec and stable at I=0.21A for PI control, rise time t = 0.02 sec and stable at I=0.15A for FUZZY control and rise time at t = 0.02sec and stable at I=0.1A for ANN control respectively. By comparing all the controls schemes ANN control given the best performance at 0.1A at no load condition.

From the figure-8 the performance characteristic of static current at high load condition for vector control of an induction motor are controlled at an initial values of rise time at t = 0.91sec and stable at I=4A for PI control, rise time t = 0.91 sec and stable at I=3.8A for FUZZY control and rise time at t = 0.91sec and stable at I=1.5A for ANN control respectively. By comparing all the controls schemes ANN control given the best performance at 1.5A at high load condition.

From the figure-9 the performance characteristic of speed response for vector control of an induction motor by PI control at speed of 1010 rpm at rise time t = 0.11sec, for FUZZY control at speed of 1000 rpm at rise time t = 0.12sec and for ANN control speed at 1000 rpm at rise time t = 0.1sec. Decrease time is at 2.2 sec for ANN control.

From the figure-10 the performance characteristic of speed command for vector control of an induction motor by PI control at speed of 1000 rpm at rise time t = 0.58sec, for FUZZY control at speed of 1000 rpm at rise time t = 0.56sec and for ANN control speed at 1000 rpm at rise time t = 0.45sec and maintained continuously at 1500rpm.

From the figure-11 the performance characteristic of speed at low load condition for vector control of an induction motor is controlled at 1510rpm constant at rise time 1.01sec for all the controls but compared to all controls ANN gives the constant speed with slight increase in speed and maintained constant at 1500rpm speed.

From the figure-12 the performance characteristic of speed response at no load condition for vector control of an induction motor by PI control at speed of 1000 rpm at rise time t = 0.02sec, for FUZZY control at speed of 1000 rpm at rise time t = 0.145sec and for ANN control speed at 1000 rpm at rise time t = 0.09sec. By comparison ANN control gives the low rise time of 0.09sec at 100rpm.

From the figure-13 the performance characteristic of speed response at high load condition controlled at 1500rpm at 1.5sec and decreased between at 1.51 to 1.7sec at 1480rpm and stable at 1.7sec at 1500rpm.

From the figure-14 the performance characteristic of speed response of induction motor Ann controls speed decreases from 1500 to 0rpm from 2sec to 2.09sec with constant value. ANN control gives the zero speed response at 2.09sec compared to PI and Fuzzy control.

From the figure-15 performance characteristics of Torque response of induction motor .compared to PI & fuzzy rise time is low for Ann at 0.01s and controlled torque at 5 Nm

From the figure-16 performance characteristics of Torque command response of induction motor. Compared to PI & fuzzy rise time is low for Ann at 0.5s at 12.1Nmand controlled torque at 12Nm to 0Nm in 0.5 to 0.55s

From the figure-17 performance characteristics of Torque response of induction motor at low load condition compared to PI & fuzzy torque controlled from 0 to
-5Nm value with stable decrease.

From the figure-18 performance characteristics of Torque response of induction motor at high load condition. Compared to Pi, fuzzy rise time of ann. control is low at 1.51s from 0 to 5Nm value.

From the figure-19 performance characteristics of Torque response of induction motor at no load condition .ANN rise time is 0.01s from 0 to 7Nm,and decreases to 5Nm and again rises at 0.02s from 5Nm to 15Nm and controlled to no load at 0.1s which is low compared to Pi, fuzzy

From the figure-20 performance characteristics of Torque response of induction motor, torque controlled at 1.8 to 2 at constant value 5Nm, decreases at 2 to 2.1sec to -1.4Nm and rises at 2.1 to 5Nm and maintains constant torque value. PI FUZZY have more rise time and has no constant torque.

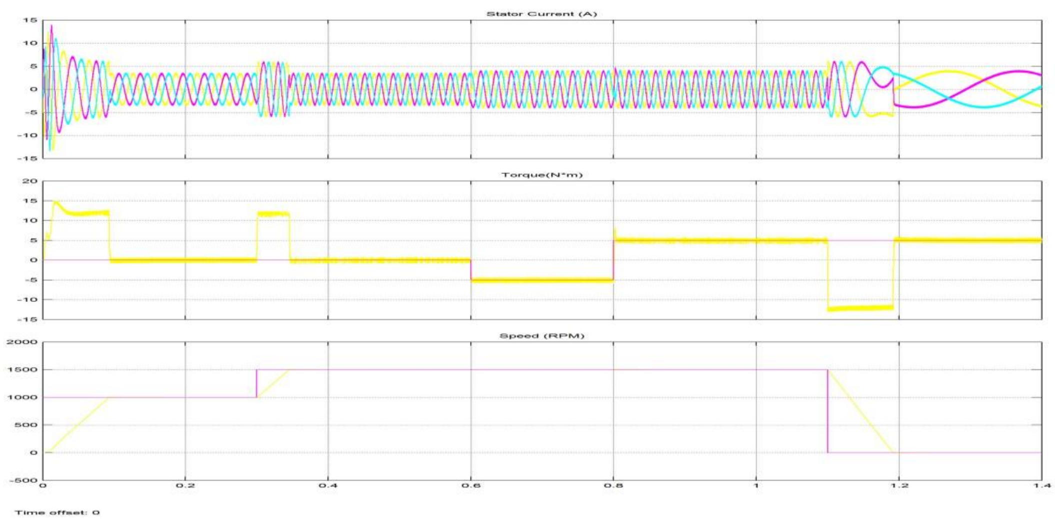

Fig 3: Response of Current, Torque, Speed for Induction motor using ANN control

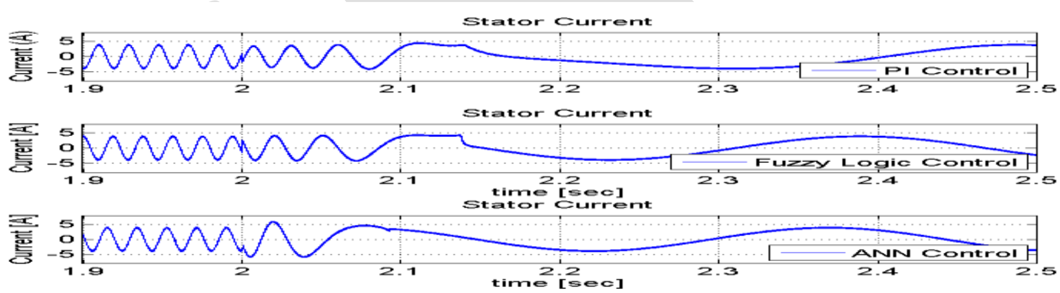

Fig 4: Performance characteristics of static current of induction motor for PI, FUZZY logic and ANN controls.

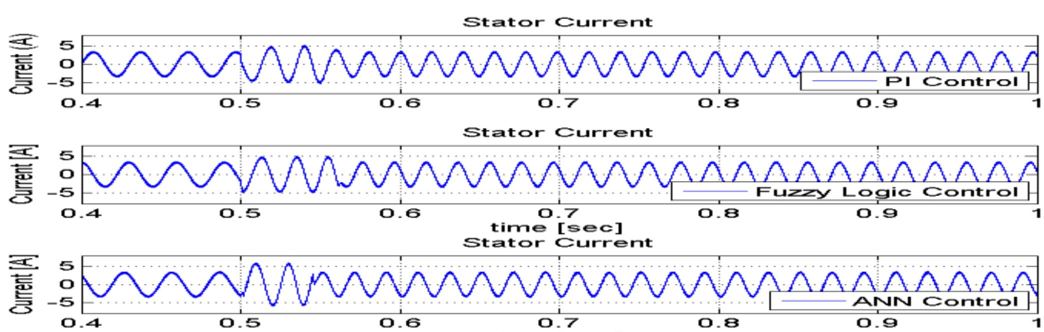

Fig 5: Performance characteristics of static current of induction motor for PI, FUZZY logic and ANN control

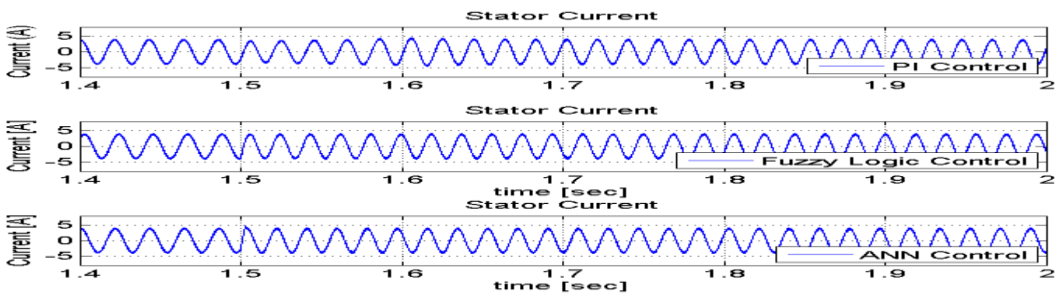

Fig 6: Performance characteristics Stator current at low load condition of induction motor for PI, FUZZY logic and ANN control.

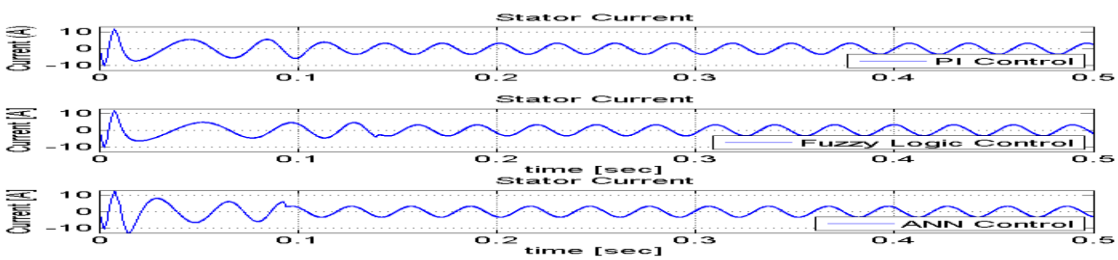

Fig 7: Performance characteristics of Stator current at no load condition for PI, FUZZY logic and ANN control

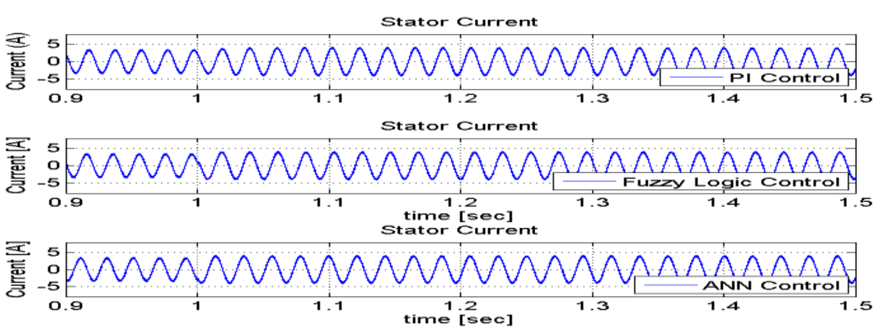

Fig 8: Performance characteristics of Stator current at high load condition of induction motor for PI, FUZZY logic and ANN control.

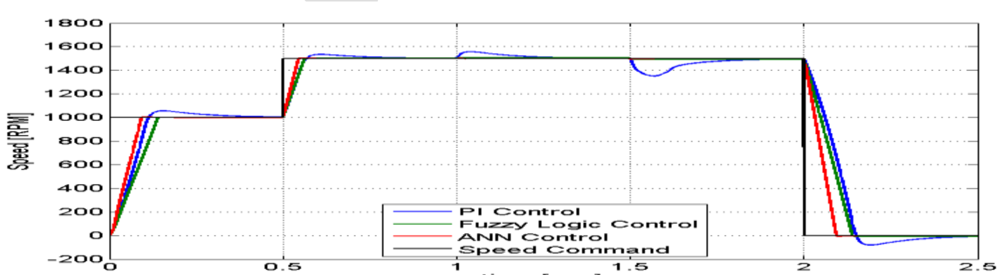

Fig 9: Performance characteristics of speed response of induction motor for ANN, PI, and FUZZY control.

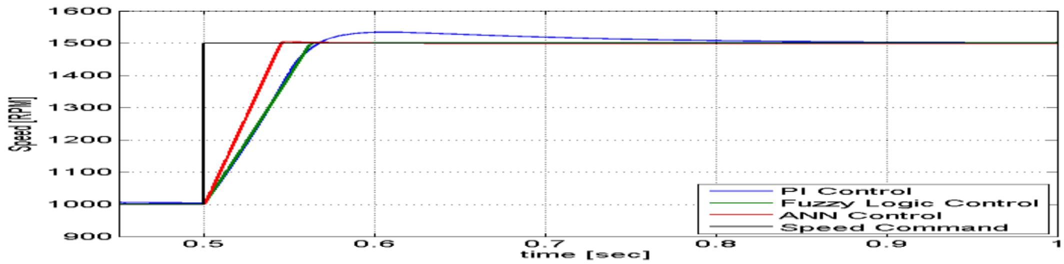

Fig 10: Performance characteristics of speed command response of induction by ANN, PI, FUZZY

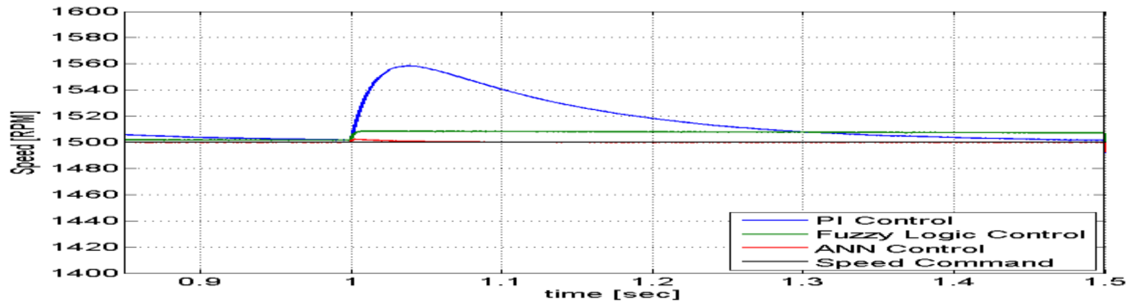

Fig 11: Performance characteristics speed response of induction motor at low load condition for PI, ANN, and FUZZY controller.

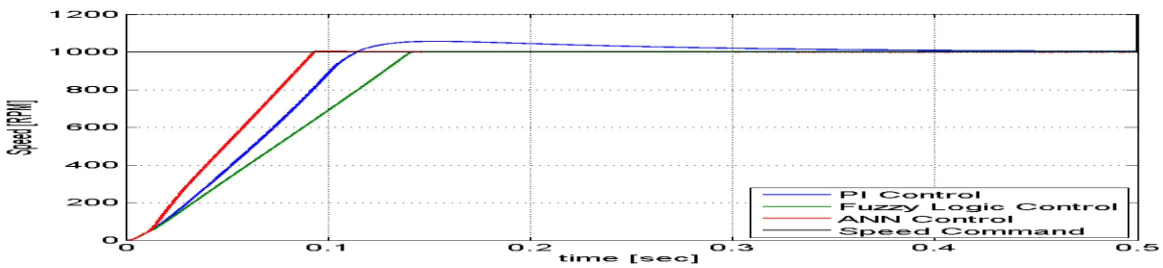

Fig12: Performance characteristics of speed response of induction motor at no load condition for PI, ANN and FUZZY control.

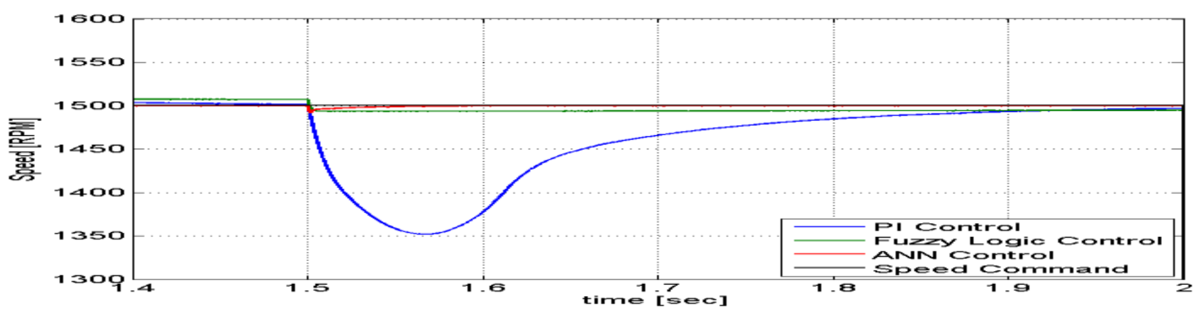

Fig 13: Performance characteristics of speed response of induction motor at high load condition for PI, ANN, and FUZZY controller.

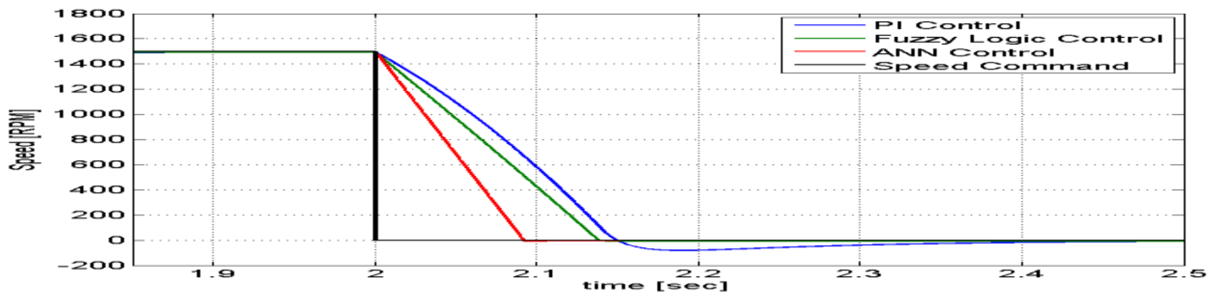

Fig 14: Performance characteristics of speed response of induction motor for PI, ANN, and FUZZY control.

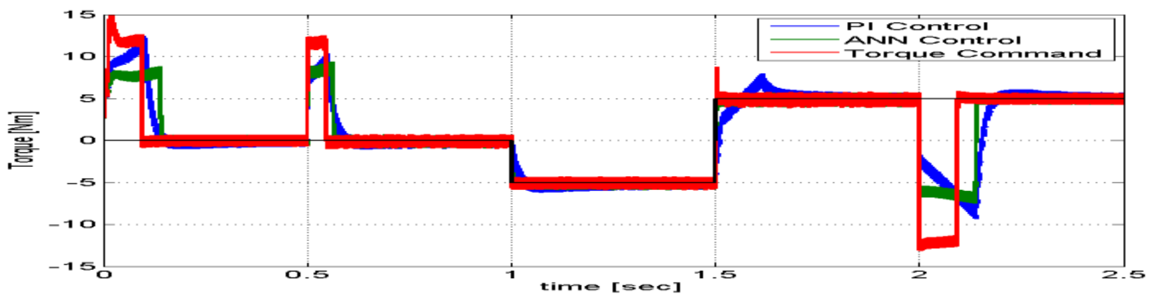

Fig 15: Performance characteristics of Torque response of induction motor for PI, ANN, and FUZZY control.

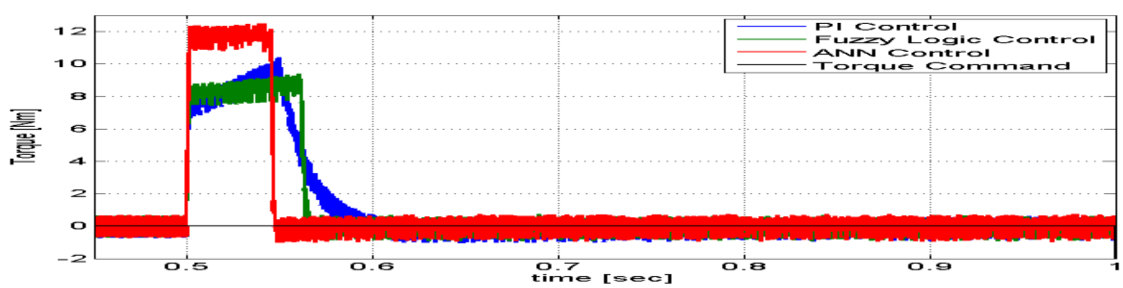

Fig 16: Performance characteristics of Torque command response of induction motor for PI, ANN, and FUZZY control.

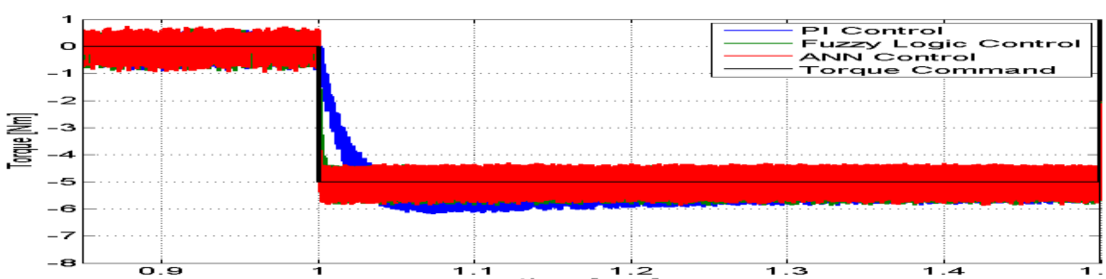

Fig 17: Performance characteristics of Torque response of induction motor at low load condition for PI, ANN, and FUZZY control.

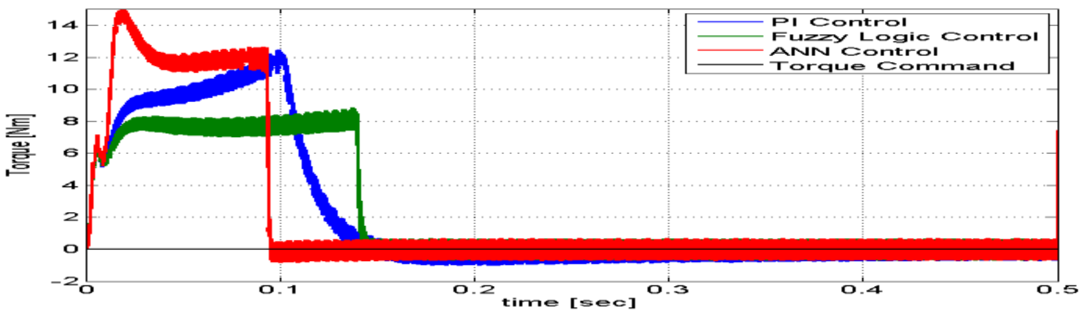

Fig 18: Performance characteristics of Torque response of induction motor at no load condition for PI, ANN, and FUZZY control

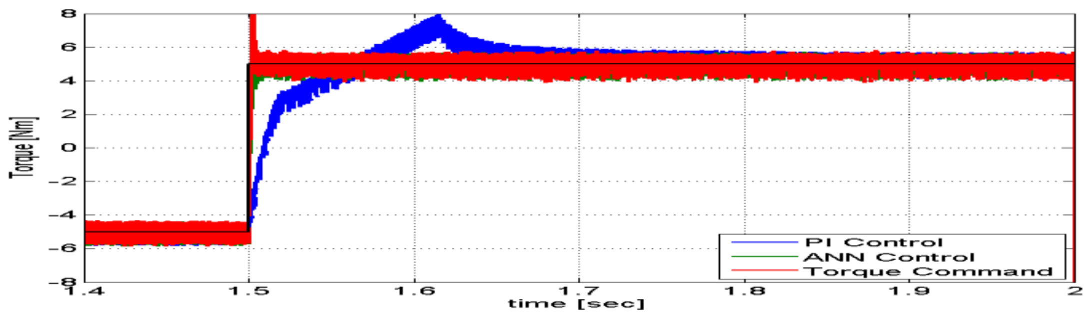

Fig 19: Performance characteristics of Torque response of induction motor at high load condition **for** PI, ANN, and FUZZY controller

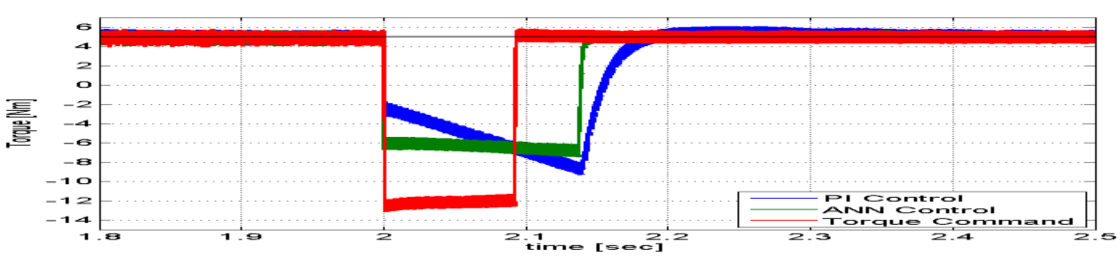

Fig 20: Performance characteristics of Torque response of induction motor for PI, ANN, and FUZZY controller

Conclusion

The estimator estimates rotor speed truly when machine parameters are changed or motor is loaded. The ANN controller has been designed and trained for various operating environment. The drive scheme is simulated with the designed ANN controller and the results are observed for a range of I/O sets. The performance of PI, FUZZY and ANN controller in terms of rise time, settling time and overshoots are exhibit for all conditions. The controller is performed well but when compared by PI and FUZZY the ANN control shows the better performance and the low overshoot when compared with PI and FUZZY controller.

References

[1] Bose, Bimal K. (June 2009). "The Past, Present, and Future of Power Electronics". *Industrial Electronics Magazine, IEEE* **3** (2): 11.Doi: *0.1109/MIE.2009.932709*.

[2] Tze-Fun Chan and Keli Shi. "Applied Intelligent Control of Induction Motor Drives", First Edition. This edition first published *2011 IEE press* John Wiley & Sons (Asia) Pte Ltd.

[3] C. Schauder, "Adaptive speed identification for vector control of induction motor without rotational transducers," *IEEE Trans. on Industrial Applications*, vol. 28, no. 5, pp. 1054-1061, October 1992.

[4] Holtz, J., 1998, Sensor less Position Control of Induction Motors - An Emerging Technology. *IEEE Trans. on Industrial Electronics,* Vol. 45, No. 6 December.

[5] Kioskeridis and N.Margaris,"Loss minimization in induction motor adjustable speed drives", *IEE Transactions on industrial electronics,* vol 43, No.1, 1996, PP 226-231.

[6] M.-H. Shin, D.-S. Hyun, S.-B. Cho and S.-Y. Choe, "An improved stator flux estimation for speed sensor less stator flux orientation control of induction motors," *IEEE Transactions on Power Electronics,* vol. 15, no. 2, pp. 312–318, March 2000.

[7] Ohtani, T., Takada, N., Tanaka, K., 1992, Vector Control of Induction Motors without Shaft Encoder. *IEEE Trans. On Ind app*, Vol. 28.

[8] Rubai. A., Kotaru, R., Online Identification and Control of Dc Motor using Learning Adaptation of Neural Networks, *IEEE Trans. On Ind*. Applica. Vol: 36, No: 3.

[9] P M .Menghal, A Jaya Laxmi, "Adaptive Neuro Fuzzy Based Dynamic Simulation of Induction Motor Drives," *IEEE International Conference Fuzzy Systems, 7-10 July 2013*, pp 1-8.

[10] Simulation of Induction Motor Drives" IOSR Journal of Electrical and Electronics Engineering *(IOSR-JEEE)* ISSN: 2278-1676 Volume 3, Issue 5 (Nov. - Dec. 2012), pp 37-45.

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