International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-1, October, 2019

Fuzzy Anti-Windup PID Controlled Induction Motor

K. Premkumar, T. Thamizhselvan, M. Vishnu Priya, S. B. Ron Carter, L. P. Sivakumar

Abstract**: *The Induction motor has been the centre of focus in many industrial applications. This is because the Induction motor has many advantages like high precision and high torque performance. The Induction motor speed control is very essential for various applications. Conventionally induction motor speed control was done using Proportional Integral controller. This project proposes the speed control of IM using Fuzzy- Anti Windup PID controller. Using this controller the saturation effect on the speed response of the Induction motor is reduced. A vector speed control Induction motor by Fuzzy-Anti Windup PID controller is simulated using MATLAB/ SIMULINK. The control system parameters of speed of the induction motor with PI controller, Anti Windup PID controller and the proposed controller are measured and compared. From the test results the Fuzzy-Anti Windup PID controller outperforms the other considered controller performance.***

Keyword **: *Anti Windup, Field Oriented Control, Fuzzy Logic Control, Induction motor, PID controller.***

I. INTRODUCTION

An induction or asynchronous motor is example for an AC electric motor. The current through the rotor is responsible for torque and it is obtained by law of electromagnetic induction from the interaction of magnetic field of the stator winding with rotor circuit. Separate excitation, mechanical commutation or self excitation is not required for induction motor like in universal, DC and large synchronous motors. Rotor of the induction motor can be categorized by wound rotor type induction motor and squirrel-cage type induction motor. Normally, squirrel cage type induction motor has more advantages than wound rotor type induction motor such as reliable, rugged, and economical and it is most utilized in the industrials drives. To design and develop the classical controller, the mathematical model of the system under control should be known. The typical method of estimation of mathematical model of a system under control is more complex when parameter of the system is varied or any disturbance occurred by the disturbance factor, the output response of the system is not sufficient. Generally, conventional PID controller is effectively utilized in the ac motor electrical drives. The design of conventional PID controller is more complex when this controller is used in the high rating electrical drives and hence increases the cost.

Soft computing techniques are used in the closed loop control of electrical system and it is known as advanced intelligent control. The intelligent control is playing a vital role today industries control. Nowadays, microprocessor and microcontroller has high computation ability and high speed of operation and intelligent control techniques can be implemented using this microprocessor and microcontroller. The high speed, low power and low cost advanced processors such as FPGA, DSP and ASIC IC's along with power semiconductor switches such as MOSFET, IGBT and GTO made the advanced control and widely utilized in electrical motor controls. Intelligent advanced control has better performance than conventional adaptive controls. In recent four decades, Fuzzy logic control, Neural Network control, neuro fuzzy control, fuzzy neuro control, evolutionary control such as genetic algorithm, PSO, BAT algorithm, etc are applied in the electrical motor control [11]-[21].

Fuzzy logic and neural networks controls are relatively dissimilar, and have distinctive ability function in information processing through stipulating numerical relationships among frequent variables in a complex system, performing mappings with measure of ambiguity, control of nonlinear system to a measure not possible with classical linear systems. Fuzzy logic is a method to represent human-behavioral judgment into a control system. A fuzzy controller can be designed to imitate human behavioral thinking, i.e., the course of action people use to deduce solutions from what they know. Fuzzy control has been principally useful to the control of system through fuzzy linguistic variables. The structure of Fuzzy inference system is depicted in Fig. 1.

Normally the induction motor speed is controlled using the PI controller, which produces saturation effect. The objective of this proposed work is to create a controller that is able to overcome the tuning problems and to reduce the saturation effect of PID and PI controller. The main part of this work presents the novel techniques to enhance the performance of the Anti Windup PID controller to enhance the speed response of the induction motor. The computer simulations carried out to demonstrate the proposed schemes have the low saturation effect, and proper tuning of the Anti

Revised Manuscript Received on October 30, 2019.
* Correspondence Author
K.Premkumar*, EEE department, , Rajalakshmi Engineering College, , Chennai, Tamilnadu, India. Email: prem.kamaraj@gmail.com
T.Thamizhselvan, EEE department, , Rajalakshmi Engineering College, Chennai, India. Email: tamilselvan84@gmail.com
M.Vishnu Priya, ECE department, Saveetha School Engineering, Chennai, Tamilnadu, India. Email: vish0790@gmail.com
S.B.Ron Carter, EEE department, , Rajalakshmi Engineering College, , Chennai, Tamilnadu, India. Email: roncarter.sb@rajalakshmi.edu.in
L.P.Sivakumar, EEE department, , Rajalakshmi Engineering College, , Chennai, Tamilnadu, India. Email: sivakumar.p@rajalakshmi.edu.in

Windup PID controller. More specifically, the objectives of the paper are following: To design the Fuzzy logic tuner, Design of Anti Windup PID controller, Performance analysis of proposed controller, and Comparative analysis between PI, Anti Windup PID controller.

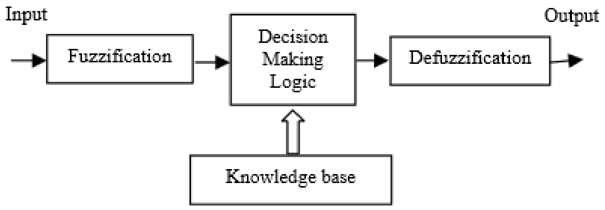

Fig. 1.Fuzzy Control System

This paper deals about the tuning of the anti windup PID controller using fuzzy tuner for speed control of induction motor. Induction motor speed by field oriented control is elaborated in section 2. The conventional controller and proposed controller scheme is explained in section 3. MATLAB simulink model of the conventional and proposed system is demonstrated in section 4. Investigation on simulation results and effectiveness of the proposed controllers are given in section 5. In section 6, concluding remarks and scope for future work is presented.

II. INDUCTION MOTOR CONTROL BY FIELD ORIENTED CONTROL

In field oriented control method, flux of the motor is controlled thus by decompose the current of the AC motor into component of flux and component of torque. These two components are processed independently and finally combined to generate the motor phase currents in actual form. This method provide the solutions for the problem of boost adjustment, effective control of torque and enhance the transient and stead state performance of motor. Various techniques have been developed for the control of maximum torque. In [3], stator flux inversely proportionally to the angular speed to provide the maximum torque than classical techniques. Conversely, in this technique, maximum torque cannot be produces for low speed region. Maximum torque of the induction motor is controlled by voltage control method in the region of field weakening region with taking into account of current and voltage constraints. But, this method ignores analysis of the stator resistor [1]-[2]. Instantaneous maximum-torque generation technique has been proposed for control of induction motor. In this method, the rotor flux is generated using input current and then torque is commutated. At time of rotor flux attain the final steady value, the torque component is developed using input current component current [4]-[5].

III. SPEED CONTROL OF INDUCTION MOTOR

The various control techniques for speed control of Induction motor are following,

A. PID Controller

The PID controller is accepted as a universal controller for the feedback system. PID controller is developed in the year 1940s and became a standard controller in the automatic governors control and manufacturing process control. In recent manufacturing industries is used PID controller in the control loops.

In proportional control action, steady state error of the control parameter is reduced by increasing proportional gain, conversely it is produces more oscillation in the control parameter. In integral control, the output error is completely eliminated by decreasing integral gain but it affects the performance at transient state. In derivative control action, system response damped out completely by increasing derivative parameter but damping effect decreases with high value of gain. Some of demerits of the PID Controller are given as, difficult to tune the parameter of the PID controller. It reduces robustness; consequently, it cannot provide optimal control for the system. When load varies it becomes unstable, and gives more overshoot, it produces saturation effect, and Due to the integral controller the response of PID controller produces windup phenomenon.

Saturation occurs in actuator due to control action provided by the controller cross limits of the capacities of the control actuator or control system. The apple of integral controller in the PID controller integrated with saturation of actuator will produces detrimental effects. If the higher error signal in the Integrator will saturates the actuator, the response loop will be not active due to saturated output from the actuator even if the control system response changes. The Integrator control action become unstable due to integration of the error signal to very high value and also the output takes a long time to go steady-state. While the error is lastly reduced, the integrator may be so high i.e., the integrator is taken more time for come back to the normal value. This result is known as Integrator windup [6]-[7].

To contract with integrator windup phenomenon, controller parameters are intended to neglect the actuator limits and an anti-windup control action system is included in the integral action. There are a number of methods existing to decrease the possessions of integrator windup. The anti windup regulator is used to conquer the windup occurrence. Three commonly used Anti windup schemes are as follows: Saturation feedback anti windup PID regulator can able to eliminate the saturation effect. It is depicted in the Fig.2, involves an additional feedback loop, decreasing the input to the Integrator by equal level of saturation error percentage. This is also known as a back calculation method. Back-calculation only requires tuning one parameter, the time constant T_t, but it only applies to PID control. Disadvantages of Anti windup controller are follows, Tuning methods are required to initialize the gain value of anti windup PID controller, Due to constant gain, and it will affect the control system performance of the system. In order to overcome the drawbacks of Anti windup PID controller, fuzzy based online tuner used in this work. Now a day, Fuzzy logic controller can be used as an online tuner, because Fuzzy logic incorporates the knowledge of human experts. The proposed Fuzzy Anti windup PID controller has been explained in the proceeding section.

Retrieval Number: A1113109119/2019©BEIESP
DOI: 10.35940/ijeat.A1113.109119
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

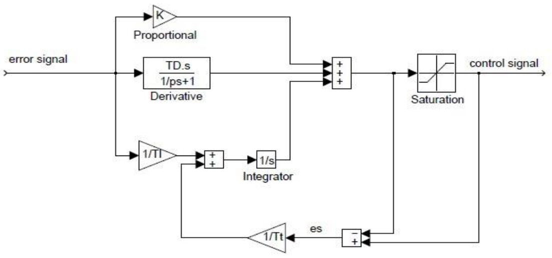

Fig. 2.Back Calculation Anti Windup PID controller

B. Fuzzy-Anti Windup PID Controller

The Fig.3 shows the block diagram of the Fuzzy Anti windup PID controller.

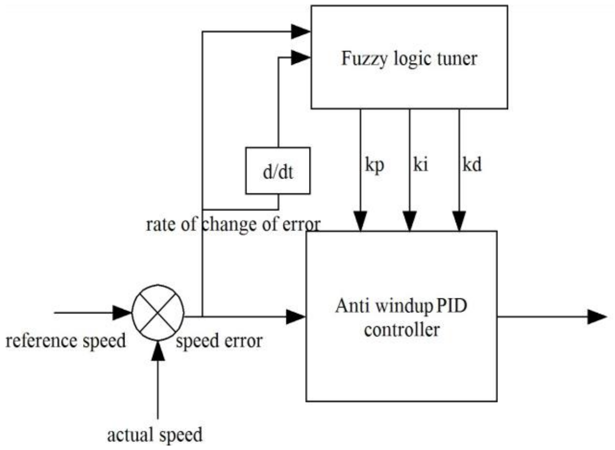

Fig. 3.Fuzzy Anti windup PID controller

Three coefficients kp, ki,and kd are optimized by using three fuzzy logic controller. As a result, the three individual fuzzy based proportional, fuzzy based integral and fuzzy based derivative controllers are combined to create the final fuzzy PID controller. The fuzzy PID controller receives two inputs that are error e (t) and rate of change of error de (t). The error and rate of change error are distributed between -150 to 150. The Fig.4 depicts the range of membership function of the input error. The error membership function is distributed from -150 to +150. The error membership function is divided into five bell shaped membership functions. The Fig.5 depicts the membership function of rate of change of error. The rate of change of error is also distributed as the same way of the error membership function. The Fig.6 shows the membership function of the proportional gain. The proportional gain membership function varies from 0 to 20. The membership function is distributed into five membership functions, i.e, small, medium, big, very big and very very big. The Fig.7 depicts the membership function of integral gain. The integral gain is distributed from 0 to 50. The Fig.8 depicts the membership function of derivative gain. The derivative gain is distributed from 0 to 2.

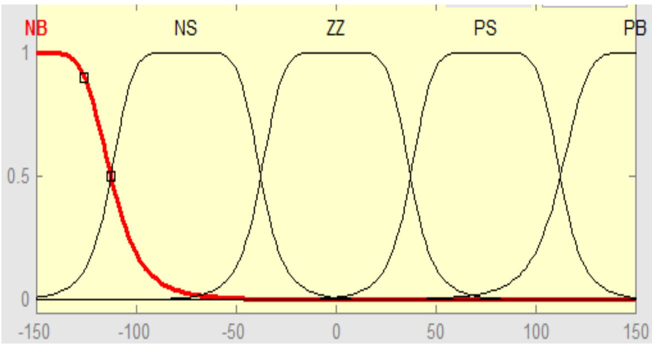

Fig. 4.Membership Function of the Input Error

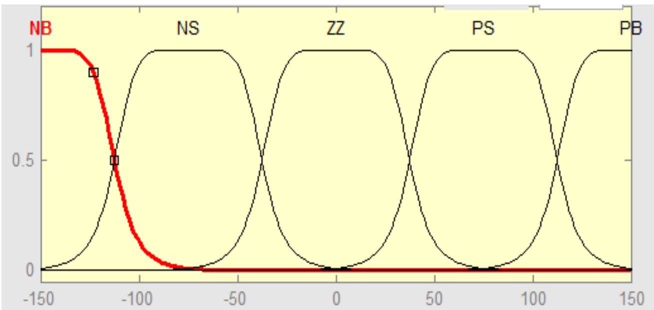

Fig. 5.Membership Function of Rate of Change of Error

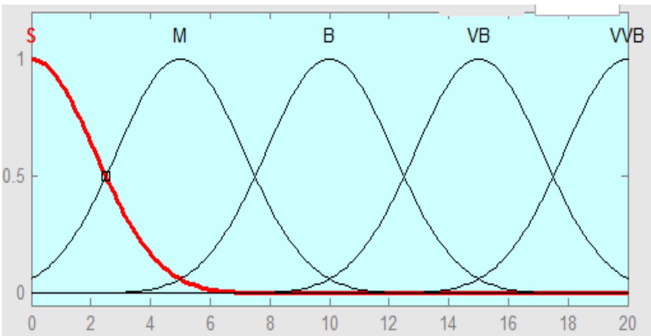

Fig. 6.Membership Function of proportional gain

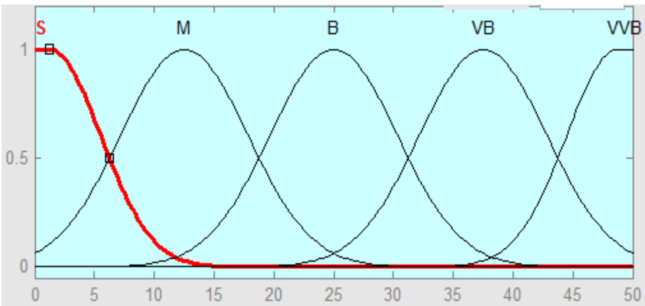

Fig. 7.Membership Function of integral gain

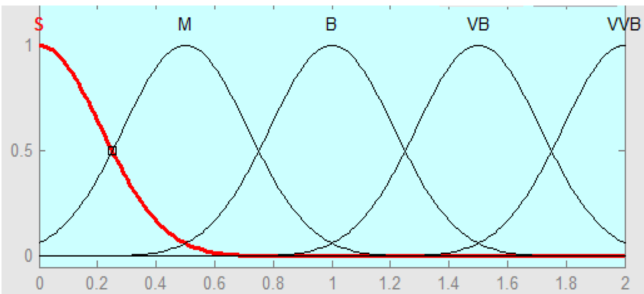

Fig. 8.Membership Function of derivative gain

Retrieval Number: A1113109119/2019©BEIESP
DOI: 10.35940/ijeat.A1113.109119
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

The Fig.9 shows the structure of Fuzzy online tuner.

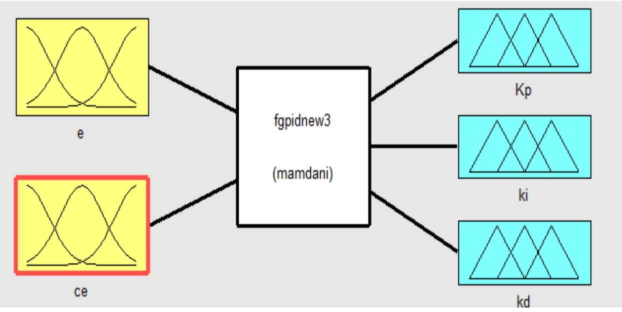

Fig. 9.Structure of Fuzzy online tuner

IV. SIMULATION MODEL

The Fig.10 depicts the simulink model of open loop control of Induction motor.

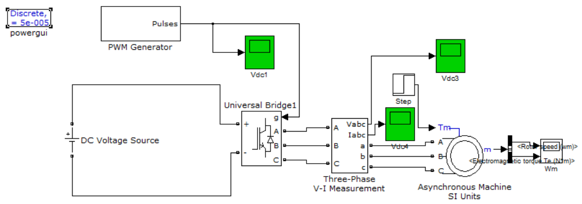

Fig. 10. Simulink model of open loop control of Induction motor

The DC voltage source is used to provide dc supply to the universal bridge. The Universal Bridge is a Series RC snubber circuits are connected in parallel with each switch device. The universal bridge is a converter circuit which can act as both inverter as well as a rectifier. Here the universal bridge is used as an inverter. The PWM generator is used to provide a pulse to the switches in the universal bridge. The three- phase V-I measurement block is used measure the voltage and current of the universal bridge. The asynchronous machine is the three phase Induction motor which is used as a load.

In the closed loop control the vector control of induction motor is used to the speed controller. The speed of the induction motor is taken as the actual speed and the reference speed is compared and speed error is calculated. The torque is converted into current and thus produces the pulses for the universal bridge. In the vector control there is theta calculation, Id calculation, flux calculation, ABC to dq calculation, dq to ABC calculation and Iqs calculation [8]-[10].

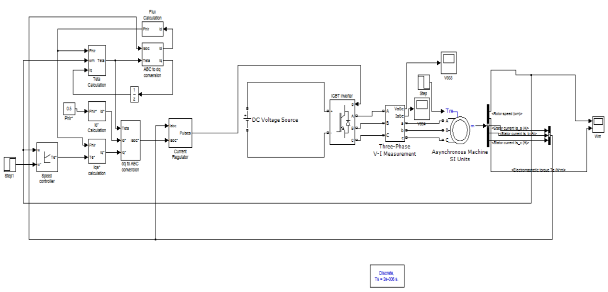

Fig. 11. Simulink model of closed control of Induction motor

Simulink model of PI controller, anti windup PID controller and Fuzzy tuned anti windup controller are shown in Fig.12, Fig.13 and Fig.14 respectively.

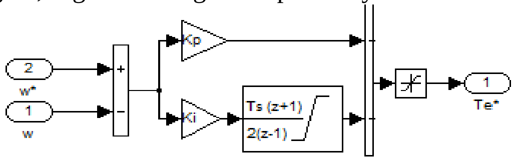

Fig. 12. Simulink model of PI Controller

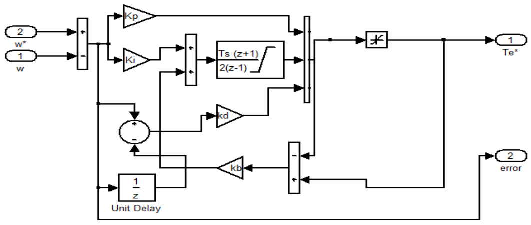

Fig. 13. Simulink model of Anti Windup PID Controller

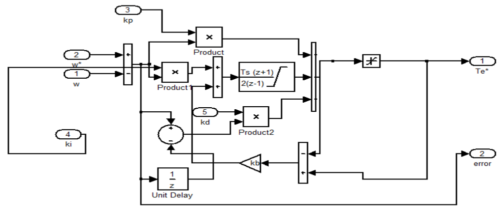

Fig. 14. Simulink model of Fuzzy Tuned Anti Windup PID Controller

V. SIMULATION MODEL

The Fig.15 shows the speed and torque response of the open loop control of Induction motor. The Fig.16 shows the speed and electromagnetic torque response of closed loop control using PI controller in the Induction motor. The Fig.17 shows the speed and electromagnetic torque response of Induction motor control using Anti windup PID controller.

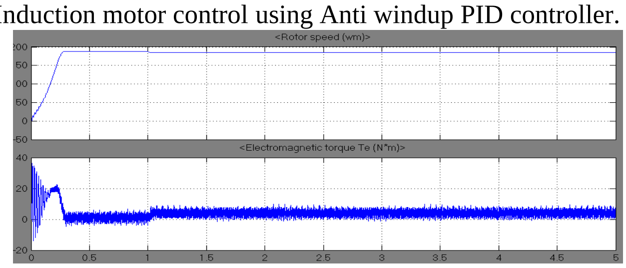

Fig. 15. Speed and torque response of the open loop control of Induction motor

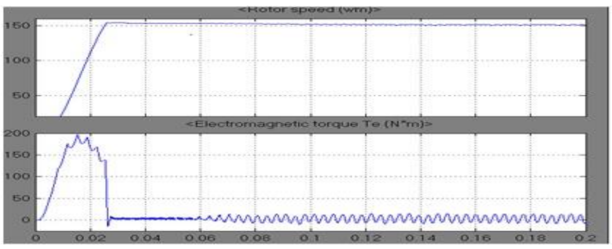

Fig. 16. Speed and torque response of closed loop control using PI controller

Retrieval Number: A1113109119/2019©BEIESP
DOI: 10.35940/ijeat.A1113.109119
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

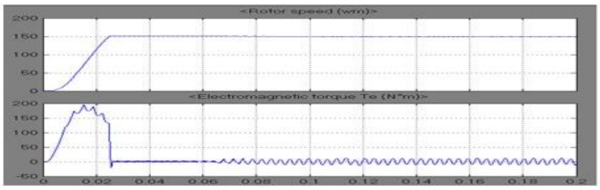

Fig. 17. Speed and torque response of Induction motor control using Anti windup PID controller

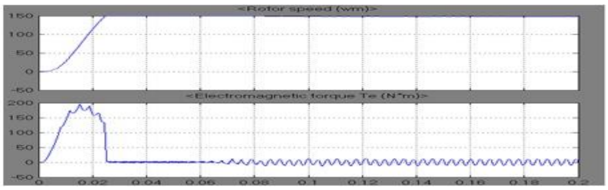

Fig. 18. Speed and torque response of Induction motor using Fuzzy anti windup PID controller

The Fig.18 shows the rotor speed and electromagnetic torque of Induction motor when controlled by Fuzzy anti windup PID controller. The figures show the pulse to the universal bridge, vector conversions, three phase voltage and current of the Induction motor output.

Table-I: Comparison of time domain specifications.

Time Domain Specification	PI Controller	Anti Windup PID	Fuzzy Anti Windup PID
Rise Time	0.0148	0.0145	0.0144
Settling Time	0.0266	0.0243	0.0241
Overshoot	2.1793	1.3025	0
Undershoot	0.1611	0	0
Peak value	154.1125	150.8707	150
Peak Time	0.0262	0.0254	-

From this comparison Table-I, it is clear that the Fuzzy Anti windup controller provides the best control system parameters like rise time, settling time. All other proposed controllers provide higher overshoot and undershoot. Where as in Fuzzy Anti windup PID controller there is no overshoot and undershoots. Therefore the Fuzzy Anti windup PID controller has the best steady state and transient response.

The sudden load is applied at step time 0.2 sec, and the load torque applied will be 0 to 20 for no load to full load. Where the full load torque will be applied at 0.2 sec. The load torque applied will be 20 to 0 for full load to no load. Where the no loads torque will be applied at 0.2 sec and corresponding speed and torque response is depicted in Fig.19, Fig.20, Fig.21, Fig.22, Fig.23 and Fig.24. The no load to full load torque, full load to no load torque will applied to the PI controller, Anti windup PID controller and Fuzzy Anti windup PID controller. This response shows that there is a undershoot; it takes some time to come back to the steady state performance.

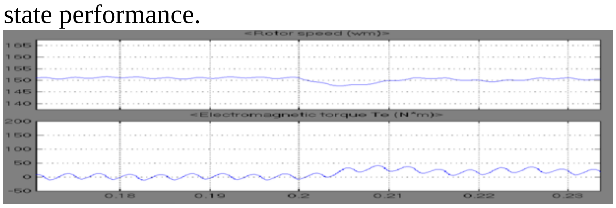

Fig. 19. Response of sudden load variation from no load to full load with PI controller

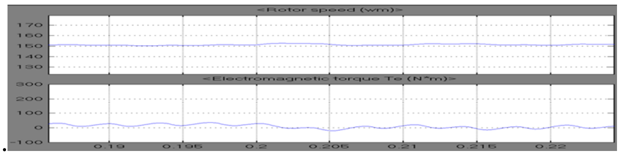

Fig. 20. Response of sudden load variation from full load to no load with PI controller

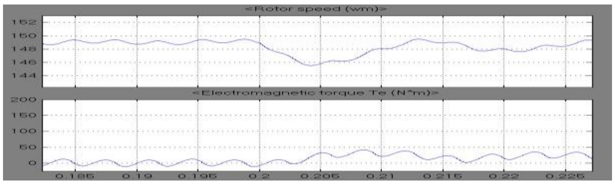

Fig. 21. Response of sudden load variation from no load to full load with Anti Windup PID controller

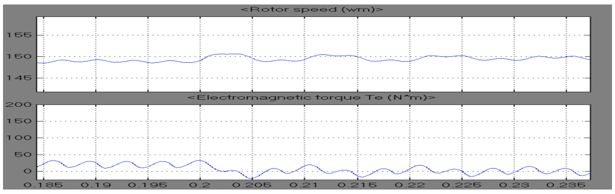

Fig. 22. Response of sudden load variation from full load to no load with Anti windup PID controller

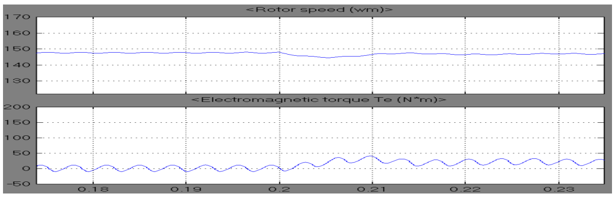

Fig. 23. Response of sudden load variation from no load to full load with Fuzzy tuned Anti Windup PID controller

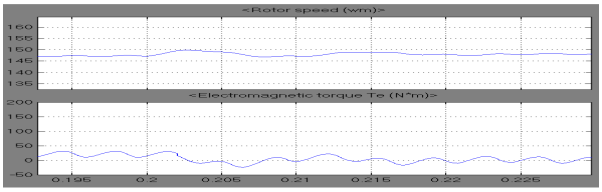

Fig. 24. Response of sudden load variation from full load to no load with Fuzzy tuned Anti windup PID controller

VI. CONCLUSION

The three phase Induction Motor speed control has been performed in MATLAB Simulink environment. The Induction motor speed has been controlled with PI controller, Anti windup controller, Fuzzy Anti windup controller. The simulation results shows that the Fuzzy Anti windup PID controller has clear better performance for providing settling time, overshoot, undershoot, peak and peak time in comparison with PI controller, Anti windup PID controller.

Retrieval Number: A1113109119/2019©BEIESP
DOI: 10.35940/ijeat.A1113.109119
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

REFERENCES

1. P.M. Menghal and A. Jaya Laxmi, “Fuzzy Based Real Time Control of Induction Motor Drive,” in Procedia Computer Science, vol. 85, 2016, pp. 228-235.
2. Faa-Jeng Lin and Rong-Jong Wai, "Hybrid control using recurrent fuzzy neural network for linear induction motor servo drive," in IEEE Transactions on Fuzzy Systems, vol. 9, no. 1, Feb 2001, pp. 102-115.
3. H. Sathishkumar and S.S. Parthasarathy, “A novel neuro-fuzzy controller for vector controlled induction motor drive,” Energy Procedia, vol.138, 2017, pp. 698-703.
4. M. Hafeez, M. N. Uddin, N. A. Rahim and H. W. Ping, "Self-Tuned NFC and Adaptive Torque Hysteresis-Based DTC Scheme for IM Drive," in *IEEE Transactions on Industry Applications*, vol. 50, no. 2, March-April 2014, pp. 1410-1420.
5. Abdelkarim Ammar, Abdelhamid Benakcha, and Amor Bourek, “Closed loop torque SVM-DTC based on robust super twisting speed controller for induction motor drive with efficiency optimization,” in International Journal of Hydrogen Energy, vol.42, no.28, 2017, pp. 17940-17952.
6. H. Shin and J. Park, "Anti-Windup PID Controller With Integral State Predictor for Variable-Speed Motor Drives," in *IEEE Transactions on Industrial Electronics*, vol. 59, no. 3, March 2012, pp. 1509-1516.
7. Bruno Leandro Galvão Costa, Clayton Luiz Graciola, Bruno Augusto Angélico, Alessandro Goedtel, and Marcelo Favoretto Castoldi, “Metaheuristics optimization applied to PI controllers tuning of a DTC-SVM drive for three-phase induction motors,” in Applied Soft Computing, vol.62, 2018, pp. 776-788.
8. S. Selvi and S. Gopinath, "Vector control of induction motor drive using optimized GA technique," in *IEEE 9th International Conference on Intelligent Systems and Control (ISCO)*, Coimbatore, 2015, pp. 1-7.
9. S. Chacko, C. N. Bhende, S. Jain and R. K. Nema, "A novel on line rotor resistance estimation technique using EA tuned fuzzy controller for vector controlled induction motor drive," *in IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT)*, Coimbatore, 2015, pp. 1-11.
10. M. N. Uddin, Z. R. Huang and A. B. M. S. Hossain, "Development and Implementation of a Simplified Self-Tuned Neuro–Fuzzy-Based IM Drive," in *IEEE Transactions on Industry Applications*, vol. 50, no. 1, Jan.-Feb. 2014, pp. 51-59.
11. K. Premkumar and B.V. Manikandan , “Stability and Performance Analysis of ANFIS Tuned PID Based Speed Controller for Brushless DC Motor,” in Current Signal Transduction Therapy, vol.13, no.1, 2018, pp. 19-30.
12. Premkumar, Kamaraj, Manikandan, Bairavan Veerayan, Kumar, and Chellappan Agees, “Antlion Algorithm Optimized Fuzzy PID Supervised On-line Recurrent Fuzzy Neural Network Based Controller for Brushless DC Motor,” Electric Power Components and Systems, vol.45, no.20, 2018, pp.2304-2317.
13. K. Premkumar and B.V. Manikandan , “GA-PSO optimized online ANFIS based speed controller for Brushless DC motor,” in Journal of Intelligent & Fuzzy Systems, vol. 28, no. 6, 2015, pp. 2839-2850.
14. K. Premkumar and B.V. Manikandan , “Online Fuzzy Supervised Learning of Radial Basis Function Neural Network Based Speed Controller for Brushless DC Motor,” in Lecture Notes in Electrical Engineering, vol.326, 2015, pp.1397-1405.
15. K. Premkumar and B.V. Manikandan, “Novel bacterial foraging-based ANFIS for speed control of matrix converter-fed industrial BLDC motors operated under low speed and high torque,” in Neural Computing and Applications, vol. 29, no.12, June 2018, pp.1411–1434.
16. M. John Prabu, P. Poongodi, and K. Premkumar, “Fuzzy supervised online coactive neuro-fuzzy inference system-based rotor position control of brushless DC motor,” in IET Power Electronics, vol.9, no.11, September 2016, pp.2229 – 2239.
17. K. Premkumar and B. V. Manikandan, "Adaptive fuzzy logic speed controller for brushless DC motor," in 2013 International Conference on Power, Energy and Control (ICPEC), Sri Rangalatchum Dindigul, 2013, pp. 290-295.
18. K. Premkumar, and B.V. Manikandan, “Speed control of Brushless DC motor using bat algorithm optimized Adaptive Neuro-Fuzzy Inference System,” in Applied Soft Computing, vol.32, 2015, pp.403-419.
19. K. Premkumar, and B.V. Manikandan, “Fuzzy PID supervised online ANFIS based speed controller for brushless dc motor,” Neurocomputing, vol.157, 2015, pp.76-90.
20. K. Premkumar, and B.V. Manikandan, “Bat algorithm optimized fuzzy PD based speed controller for brushless direct current motor,” in Engineering Science and Technology, an International Journal, vol. 19, no.2, 2016, pp.818-840.
21. K. Premkumar, and B.V. Manikandan, “Adaptive Neuro-Fuzzy Inference System based speed controller for brushless DC motor,” in Neurocomputing, vol.138, 2014, pp. 260-270.

AUTHORS PROFILE

Dr.K. Premkumar received the B.E. degree from Anna University, Chennai, Tamilnadu, India, in 2005, and M.E. degree from Anna University, Chennai, Tamilnadu, India, in 2007, all in faculty of electrical and electronics engineering. At present, he is doing Ph.D. in Anna University, Chennai, Tamilnadu, India. Also he is working as an Associate Professor in the Department of Electrical and Electronics Engineering of Rajalakshmi Engineering College, Chennai Tamilnadu, India. His current research interests include design of speed and current controller is based on PID controller, fuzzy logic controller, ANFIS controller and CANFIS controller for the special electrical machines.

Dr.Thamizhselvan T, Associate Professor in the Department of Electrical and Electronics Engineering has 12 years of teaching and research experience including 6 years of research experience in Power Electronics and Renewable Energy Systems. He received his B.E. from Meenakshi college of Engineering in 2005 and M.E in Power Electronics & Drives from SSN Engineering college in 2007 and Ph.D from Anna University, Chennai in 2018.He has published 12 research publications in international journals, 10 papers in the proceedings of refereed international and national conferences with 2 best paper awards.

M.Vishnu Priya B is an Assistant Professor in the faculty of Electronics and Communication Engineering in Saveetha School of Engineering, Chennai Tamilnadu, India. she got her Masters and Bachelors degree from Anna University, India. Her research area includes solar energy, power electronics, soft computing, and electrical machines. She is currently pursuing her Ph.D in the area of multilevel inverter at Saveetha University.

Ron Carter S B is an Assistant Professor in the faculty of Electrical & Electronics Engineering in Rajalakshmi Engineering College, India. He got his Masters and Bachelors degree from Anna University, India. His research area includes renewable energy, power converters, Control Engineering and ANN. Also, he has done consultancy projects in the relevant area.

Dr.P.Sivakumar was born in Tiruchirapalli, India on July 3, 1975. He did his U.G. and P.G. at Regional Engineering College, Trichy, India and SASTRA University, Tamil Nadu, India. He is presently working as an Associate Professor at Rajalakshmi Engineering College, Chennai, India. His current research interests include dispersed power generators based on PV and wind power generations, DG sourced power system optimization and power electronics control.