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Neuro-Fuzzy Based Speed Controller For Permanent Magnet Synchronous Motor

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Abstract— The conventional Proportional-Integral (PI) speed control has been widely used in industrial motor controls due to its capabilities in controlling linear plants. However, motor behaves as non-linear plant where the PI speed control may not be able to provide precise speed responses. With the fast growing of artificial intelligent in motor controls, the fuzzy logic and Adaptive Network Fuzzy Inference system (ANFIS) is available in more precise motor controls. Nevertheless, there are still many disputes on the superiority of PI and fuzzy logic controls. The fuzzy logic controller with rules-based is limited to a particular load torque due to its output membership functions, on the other hand, PI controller has better adaptability over load torque variation and has a smaller steady-state error even though it incurs the overshoot and has longer settling time. In this paper, a comparative analysis of PI, fuzzy logic, and ANFIS has done in the MATLAB SIMULINK environment

Keywords— PMSM, PI, Fuzzy Logic, ANFIS, Speed Control

I. INTRODUCTION

The development of permanent magnet materials began in early 20th century, first with magnetic steel in 1930 which was useful for electro-mechanical devices. This was an aluminium-nickil-cobalt alloy AlNiCo which has major drawback of low coercive force Hc. In 1950, ferrite permanent magnets SrO 6(Fe_2O_3) was developed, which was significantly cheaper and had remarkably higher coercive force and energy product $(BH)_{max}$[1][2][3].

The next milestone in advances of permanent magnetism was the development of sintered rare-earth cobalt magnets around 1970, in samarium-cobalt alloys SmCo. The neodymium-iron-boron NdFeB magnets developed in 1983.Even being the cheaper than SmCo and of higher energy density, NdFeB is not always superior due to its lower thermal stability and its reactivity which leads for instance to corrosion problems. But these drawbacks can be overcome by embedding the rare-earth powders in a matrix, for instance resin. Fig.1 shows a qualitative hysteresis curve of a magnet suitable for high performance PMSMs in which a B is representing the field density in Tesla and H is representing the Magnetizing field in kA/m. Shaded rectangular is showing the magnetic energy product calculated for magnetic material required for constructing permanent magnet in PMSMs[4], [5].

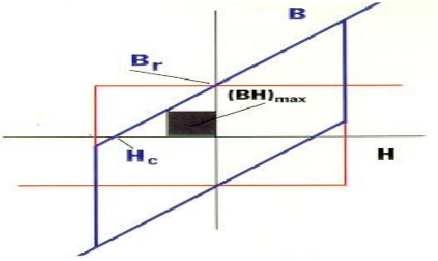


Fig. 1 Principal Hysteresis Curve of Permanent Magnet Material

II. DYNAMIC D-Q MODELLING OF PMSM

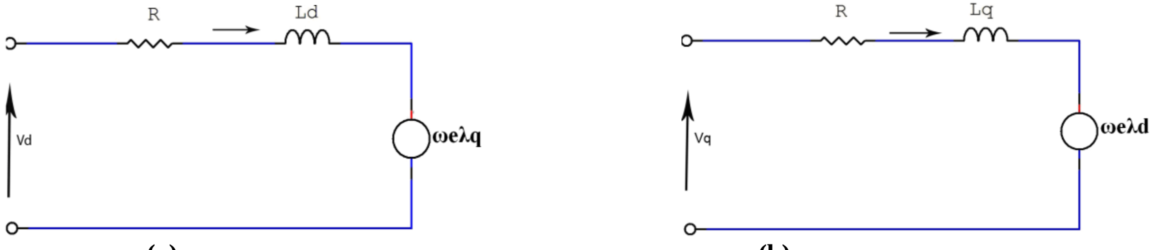
The d, q model of the PMSM has been used to examine the transient behavior of a high performance vector controlled PMSM servo drive. Following assumptions are made in the derivation:[6][7]

(i) Saturation is neglected although it can be taken into account by parameter changes
(ii) The back emf is sinusoidal.
(iii) Eddy current and hysteresis losses are negligible.

With these assumptions the stator d, q equations in the rotor reference frame of the PMSM are:

$v_d = Ri_d + p\lambda_d - \omega_r\lambda_q$ --- (1.1)
$v_q = Ri_q + p\lambda_q - \omega_r\lambda_d$ ---- (1.2) where
v_d, v_q = d, q axis voltages (in volts)
λ_d, λ_q = d, q axis flux linkages (in webers)

R = Stator resistance (in Ohms)
ω_r = Rotor speed (in rpm)
p = Derivative operator and
$\lambda_d = L_d i_d + \lambda_{af}$
λ_{af} is the magnetic mutual flux linkage.
The Electric Torque $Te = 3P [\lambda_{af}\, i_q + (L_d - L_q) i_d\, i_q]/2$ --- (1.3)
where L_d, L_q = d, q axis inductances (in henry)
Fig. 2 shows the equivalent circuit of PMSM derived from the equations (1.1) and (1.2).[8]



(a) **(b)**

Fig. 2 PMSM Equivalent Circuit From Dynamic Equations
(a) Equation for d-axis Voltage (b) Equation for q-axis Voltage

III. SIMULATION OF PMSM DRIVE INCORPORATED WITH PI CONTROLLER

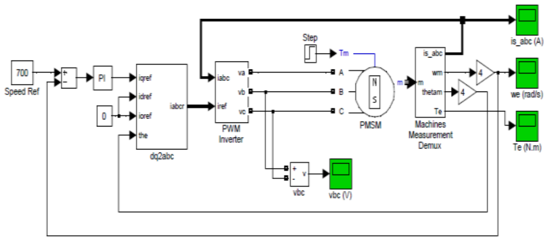


Fig. 3 Simulink Block Diagram of PMSM with PI Controller

Simulink block diagram of PMSM with PI Controller is shown in Fig. 3. A PI controller block is used, which provides reference quadrature axis current (i_{qref}). This i_{qref} is further fed to the reference current generator block. The selected values of proportional gain (K_p) and integral gain (K_i) are 2.5 and 250 respectively. The limiter is used to limit the maximum value of output of speed controller. The maximum motor rated current and device current of the converter dictate the limit[9] [10].

IV. SIMULATION OF PMSM DRIVE INCORPORATED WITH FUZZY LOGIC CONTROL (FLC) BASED SPEED CONTROLLER

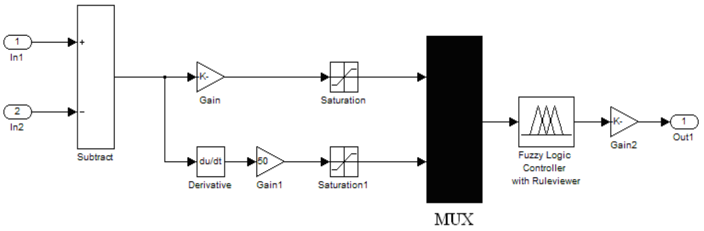


Fig. 4 Fuzzy Logic Controller (FLC) Model

The fuzzy logic controller used here to control PMSM takes two inputs i.e. E (error) and CE (change in error) and gives controlled output. A fuzzy logic controller with rule viewer block is used to control the output of PMSM. In this block FIS file is saved which includes input and output membership functions and fuzzy set of rules. Different membership functions can be selected to control the output variable. The Simulink model of FLC is shown in Fig.4.

Membership functions for two inputs of Fuzzy Controller are Error (E) and change in error (CE) and one output i.e. current output (CU) are shown in Fig. 5 (a), (b) and (c).

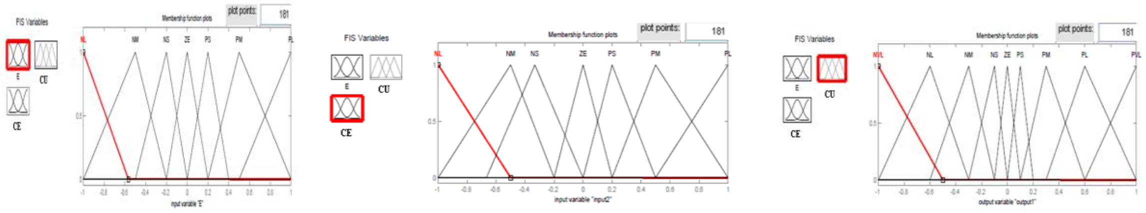


Fig. 5 (a) Membership Function Plot for Input-1 Data (Error- E)

(b) Membership Function Plot for Input-2 Data (Change in Error-CE)
(c) Membership Function Plot for Output Data (Current Output-CU)

Each universe of discourse is divided into seven fuzzy sets as followings;

NL: Negative Large PL: Positive Large ZE: Approximately Zero
NM: Negative Medium PS: Positive Small PM: Positive Medium
NS: Negative Small

Two additional fuzzy variables are used for the output signals, namely "Positive Very Large" (PVL) and "Negative Very Large" (NVL). These two additional fuzzy variables optimized the output signals [11] [12].

The fuzzy rules are summarize in the form of a table as shown in Table 1.1

E/CE	***NL***	***NM***	***NS***	***ZE***	***PS***	***PM***	***PL***
NL	NVL	NVL	NVL	NL	NM	NS	ZE
NM	NVL	NVL	NL	NM	NS	ZE	PS
NS	NVL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PVL
PM	NS	ZE	PS	PM	PL	PVL	PVL
PL	ZE	PS	PM	PL	PVL	PVL	PVL

Table 1.1 Fuzzy Rules Matrix for PMSM Controller

V. DEVELOPMENT OF SIMULATION FOR ADAPTIVE NEURO FUZZY INFERENCE SYSTEM (ANFIS)

This section summarizes the methodology that was adopted to develop the adaptive FTAG FIS speed control algorithm for the PMSM, which can be subdivided into two phases.

Phase –I: Reference PMSM Model

Fig.6 shows the layer diagram of ANFIS controller. The general ANFIS control structure for the control of any plant is presented here as follows. This structure contains the same components as the FIS, expect for the NN block. The structure of the network is composed of a set of units (and connections) arranged into five connected network layers.[13]

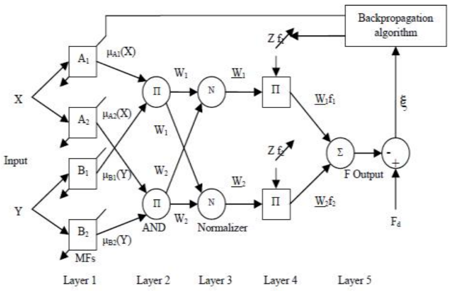


Fig. 6 Corresponding ANFIS Structure for a Sugeno Fuzzy Inference System.

The ANFIS structure is tuned automatically by least-square-estimation & the back propagation algorithm. The algorithm shown above is used in the next section to develop the ANFIS controller to control the various parameters of the induction motor. Because of its flexibility, the ANFIS strategy can be used for a wide range of control applications.

Phase –II: Development of ANFIS Training Data

The network is trained using off-line learning algorithm in Matlab SIMULINK. Firstly, the simulation results (input and output data) of fuzzy logic controller were collected as training data set.

The desired output will be trained using the Matlab toolbox function 'ANFIS'. From the training, a Fuzzy Inference System with adjusted membership functions of inputs E and CE are shown in Figure 7, and Figure 8.[14]

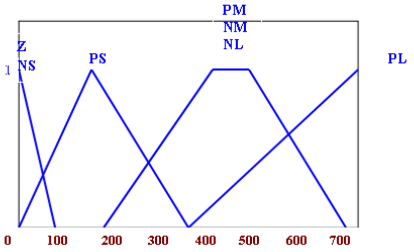


Fig. 7 Input Error (E) Membership Function after ANFIS Training

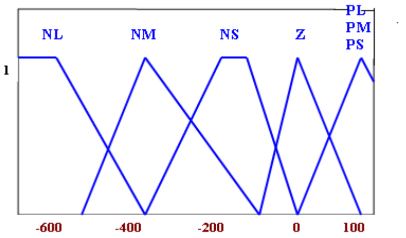


Fig. 8 Input Change of Error (CE) Membership Function after ANFIS Training

The new inputs as shown in Fig.7 and Fig.8 were obtained after the training of ANFIS, that best allow the associated fuzzy inference system to track the given input and output system and are used in simulation to get the results.

VI. RESULTS AND DISCUSSIONS

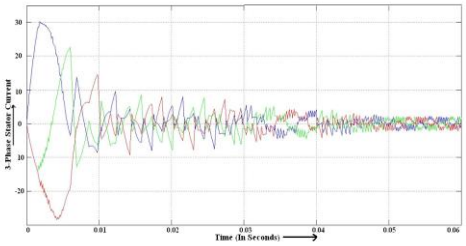


Fig. 9 Variation of Stator Currents (I_{sabc}) Time (rad/sec) with PI controller

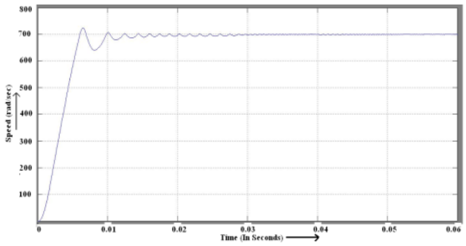


Fig. 10 Variation of Speed of PMSM with respect to with respect to Time with PI Controller

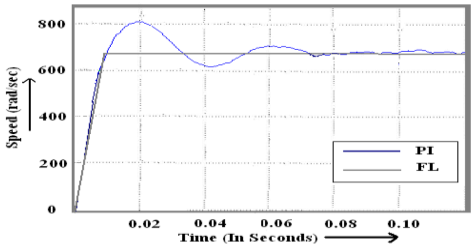


Fig. 11 Response at speed of 700 rad/s with Fuzzy Logic Controller

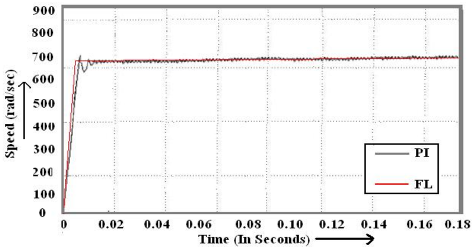


Fig. 12 Effect on Speed after Disturbance of Torque from 3 Nm to 7 Nm at the instant of 0.03 seconds Fuzzy Logic Controller

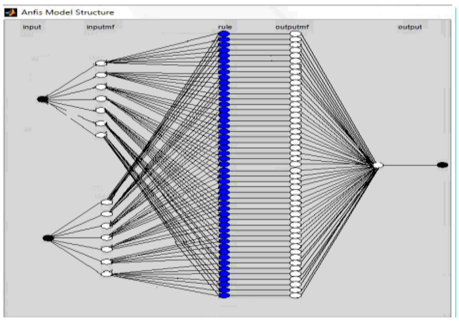


Fig. 13 ANFIS Model Structure with 2 Inputs and 1 Output with 4 Layers of ANN Architecture

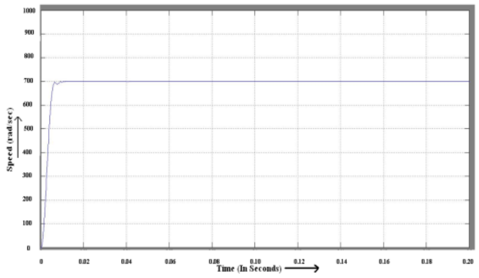


Fig. 14 Variation of Speed (rad/sec.) with respect to Time with ANFIS Controller

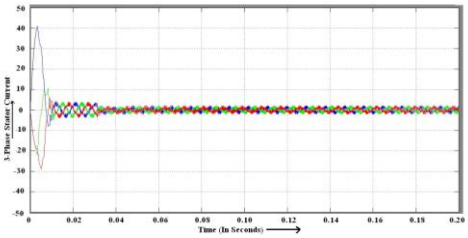


Fig. 15 Variation of Three phase Stator Current with respect to time with ANFIS Controller

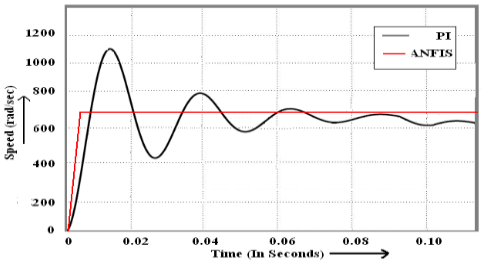


Fig. 16 Step Response at speed of 700 Rad/sec with ANFIS Controller

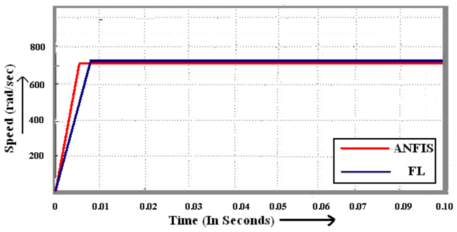


Fig. 17 Step Response for Fuzzy logic and ANFIS Controller

VII. CONCLUSIONS

From the simulation results, it is found that the ANFIS controller produces better speed response than PI, and Fuzzy Controllers in terms of rise time, overshoot, settling time and steady state. ANFIS controller has significantly reduced the overshoot as well as the settling time in comparison to rest of controllers. It also cancelled the disturbance effects such as speed and torque change and maintained steady-state accuracy. The ANFIS Controller has significantly reduced the time for designing an optimal Neuro-Fuzzy Controller.

REFERENCES

[1] Pillay Pragasan, Krishnan R. “Modelling of Permanent Magnet Motor Drives”, IEEE Transactions on Industrial Electronics, Vol 35, No. 4, November 1988.

[2] Krishnan R., Beutler A.J., “Performance and Design of an Axial Field Permanent Magnet Synchronous Motor Servo Drive”, in Proceedings. IEEE Annual. Meeting, pp- 634-640, March 1985.

[3] Krøvel Øystein, “Design of Large Permanent Magnetized Synchronous Electric Machines”, Ph.D thesis, Norwegian University of Science and Technology, Trondheim, pp 6-10, 14-15 Feb 2011.

[4] Dolec Radovan, Novak Jaroslav, Cerny Ondrej “Traction Permanent Magnet Synchronous Motor Torque Control with Flux Weakening” IEEE Transactions on Radio-Engineering, Vol. 18, No 4, December 2009.

[5] Shen J.X., Zhu Z.Q., Howe David, ”Improved Speed Estimation in Sensor less PM Brushless AC Drives” IEEE Transactions on Industry Applications, Vol.38,No. 4, July/August 2002.

[6] Krause P. “Analysis of Electric Machinery”, New York, McGraw-Hill, 1986.

[7] Pillay Pragasan, Krishnan R. “Modeling Analysis and Simulation of a High Performance Vector Controlled PMSM Drive”, Proceedings of the IEEE Annual Meeting, Atlanta April 1987.

[8] Dehkordi A.B., Gole A.A. and Maguire T.L., “Permanent Magnet Synchronous Machine Model for Real-Time Simulation”, Conference on Power System Transients (IPST’05) June 19-23, 2005, Paper No.IPST05-159.

[9] Tezic B., Jadric M.,“Design and implementation of the Extended Kalman Filter for the Speed and Rotor Position Estimation of BLDC”, IEEE Transactions on Industrial Elect. Vol. 48, pp 1065-1073. December 2001.

[10] Stularajter Marek, Hrabovcova Veleria, Franko Marek, “Permanent Magnets Synchronous Motor Control Theory”, Journal of Electrical Enginering, Vol. 58,No. 2, pp 79-84, Sep 1992.

[11] Jong-Sun Ko, Hyunsik Kim, and Seong-Hyun Yang, “Precision Speed Control of PMSM Using Neural Network Disturbance Observer on Forced Nominal Plant”, IEEE Transactions of Electrical Engineering, Vol. 3, pp-1746-1752, June 2004.

[12] Sharma A.K. Gupta R.A. and Srivastava Laxmi “Implementation of Neural Network in Energy Saving of Induction Motor Drives With Indirect Vector Control”, Journal of Theoretical and Applied Information Technology, Vol 4, No.6,pp-498-502, June 2008.

[13] Bose Bimal K., “Neural Network Applications in Power Electronics and Motor Drives-An Introduction and Perspective”, IEEE Transactions on Power Electronics, Vol. 54, No. 1, Feb 2007.

[14] Kaewjinda weera and Konghirun Mongkol, “Vector Control Drive of Permanent Magnet Synchronous Motor Using Resolver Sensor”, ECTI Transactions of Electrical Engineering, Electronics and Communications Vol.5,No. 1 Feb 2007.

[15] Merzoug M.S. and Naceri F., “Comparison of Field Control and Direct Torque Control for PMSM, Proceedings of World Academy of Science, Engineering and Technology, Vol. 35, Nov 2008.

[16] Jong Sn Ko, Hynsik Kim and Seong Hyn Yang, “Precision Position Control of PMSM Using Neural Network Disturbacne Observer on Forced Nominal Plant” IEEE Transactions of Electrical Engineering, Vol. 6,No.2, pp-316-320, May 1989.