

Online Rotor Resistance Evaluation of Induction Motor Using ANN

Ganesh Shirsat¹, Ashok Kumar Jhala²

P.G. Student, Dept. of Electrical & Electronics Engineering, RKDF College of Engg., Madhya Pradesh, India¹

Associate Professor, Dept. of Electrical & Electronics Engineering, RKDF College of Engg., Madhya Pradesh, India²

ABSTRACT: The goal of this paper is to estimate the parameters of squirrel-cage induction motor with the help of Artificial Neural Network (ANN). Firstly presented mathematical modeling of nonlinear multivariable control system of squirrel-cage induction motor. Feed forward and recurrent network of ANN is used to remember the identified parameters at steady state and compute during transient state. The simulation and ANN based mathematical modeling results of Induction motor are analyzed. The performance of given two methods is evaluated.

KEYWORDS: Squirrel-cage Induction motor, ANN (Artificial neural network), Rotor resistance, Mutual inductance, Parameter identification.

I. INTRODUCTION

In recent days Induction motor is widely used in industrial and domestic applications. It is nonlinear dynamic control systems in which parameters are vary with respect to temp, frequency, operating point and saturation. The rotor resistance can vary up to 150% over the continuous operation. The efficiency and accuracy (i.e overall performance) of induction motor are mainly depend on parameters. Therefore it is necessary to develop algorithm for online parameter estimation. ANN is used for evaluation of parameter identification of induction motor. Flux evaluation is based on luenberger observer system and rotor speed evaluation based on speed observer system. Rotor parameters playing very important role in control mechanism of induction motor. Evaluation of rotor parameter is put forward by estimating the rotor temperature because its impact on fundamental frequency compensation of terminal voltage for given input current. Many papers have shown the effect of motor parameters on the quality of flux and speed [4].

Online evaluation of rotor resistance and mutual inductance based on ANN is presented. Advantage of ANN is to approximate a wide range of nonlinear functions to high degree of accuracy. ANN not only runs in parallel with other system but also time require for computation is reduced. ANN also has fault tolerant capabilities and immunity to harmonic ripples. So ANN is used to identify and control the nonlinear dynamic control system.

Since 1990's, several applications of neural networks in the field of electrical machine and power electronics have appeared. Now a day's ANN is used in modulation system, control, and estimation of state variables and evaluation of induction motor parameters. Two types of ANN design are available one is based on machine model and direct speed evaluation by stator current and voltages. In this paper ANN is developed as memory for remembering the calculated values during steady state and compute during transient state. So the accuracy in performance evaluation of induction motor is improved by using online evaluation of machine parameter in sensor less control system.

II. MATHEMATICAL MODELLING OF NONLINAR INDUCTION MOTOR

The mathematical model of a squirrel-cage induction motor in a stationary coordinate system is expressed in the form of differential equations for the rotor-flux vector components and stator-currents are presented as follows

$$\frac{d\Psi_{rx}}{d\tau} = a_1\Psi_{rx} - \omega_r\Psi_{ry} + a_2i_{sx} \quad (1)$$

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$$\frac{d\Psi_{ry}}{d\tau} = a_1\Psi_{ry} + \omega_r\Psi_{rx} + a_2 i_{sy} \quad (2)$$

$$\frac{d\omega_r}{d\tau} = \frac{L_m}{L_r J}(\Psi_{rx}i_{sy} - \Psi_{ry}i_{sx}) - (1/J)m_o \quad (3)$$

$$\frac{di_{sx}}{d\tau} = a_3i_{sx} + a_4\Psi_{rx} - a_5\omega_r\Psi_{ry} + a_6u_{sx} \quad (4)$$

$$\frac{di_{sy}}{d\tau} = a_3i_{sy} + a_4\Psi_{ry} - a_5\omega_r\Psi_{rx} + a_6u_{sy} \quad (5)$$

Where,

Ψ_{rx} = rotor-flux vector component in x stationary coordinate,

Ψ_{ry} = rotor-flux vector component in y stationary coordinate,

i_{sx} = stator-current vector component in x stationary coordinate,

i_{sy} = stator-current vector component in y stationary coordinate,

u_{sx} = stator-voltage vector component in x stationary coordinate,

u_{sy} = stator-voltage vector component in y stationary coordinate,

ω_r = Angular speed of the rotor shaft,

L_m = Mutual inductance,

J = Moment of inertia,

m_o = the load torque,

Furthermore the constants are

$$a_1 = -\frac{R_r}{L_r}, \quad a_2 = \frac{R_r L_m}{L_r}, \quad a_3 = -\frac{R_s L_r^2 + R_r L_m^2}{L_r w_\sigma}, \quad a_4 = \frac{R_r L_m}{L_r w_\sigma}, \quad a_5 = \frac{L_m}{w_\sigma}, \quad a_6 = \frac{L_r}{w_\sigma}$$

$$w_\sigma = L_r L_s - L_2$$

Where,

R_s = stator resistances

R_r = rotor resistances

L_s = stator inductance

L_r = rotor inductance

τ = time in per unit (p.u.).

III.INDUCTION MOTOR FEEDBACK LINEARIZATION FED BY VSI

Induction-motor drive is fed by voltage-source inverters (VSIs), but the control signals are voltage vector components therefore four novel state variables are recommended to describe the motor model [6]. The new variables may be taken as the rotor angular speed, scalar and vector product of rotor flux vectors and stator current, and square of the rotor flux linkage

$$x_{11} = \omega_r \quad (6)$$

$$x_{12} = \Psi_{rx}i_{sy} - \Psi_{ry}i_{sx} \quad (7)$$

$$x_{21} = \Psi_{rx}^2 + \Psi_{ry}^2 \quad (8)$$

$$x_{22} = \Psi_{rx}i_{sx} + \Psi_{ry}i_{sy} \quad (9)$$

After taking into account the new state Variables, differential equations for new model of the induction motor is obtained [6].

$$\frac{dx_{11}}{dt} = \frac{L_m}{J L_r} x_{12} - \frac{1}{J} m_o \quad (10)$$

$$\frac{dx_{12}}{dt} = -\frac{1}{T_v} x_{12} - x_{11} \left(x_{12} + \frac{L_m}{w_\delta} \right) + \frac{L_r}{w_\delta} u_1 \quad (11)$$

$$\frac{dx_{21}}{dt} = -2 \frac{R_r}{L_r} x_{21} + 2R_r \frac{L_m}{L_r} x_{22} \quad (12)$$

$$\frac{dx_{22}}{dt} = \frac{1}{T_v} x_{22} + x_{11} x_{12} + \frac{R_r L_m}{L_r w_\delta} x_{21} + R_r \frac{L_m}{L_r} \frac{x_{12}^2 + x_{22}^2}{x_{21}} + \frac{L_r}{w_\delta} u_2 \quad (13)$$

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Where,

$$\frac{1}{T_v} = \frac{R_r w_\delta + R_s L_r^2 + R_r L_m^2}{w_\delta L_r} \quad (14)$$

$$u_1 = \Psi_{rx} u_{sy} - \Psi_{ry} u_{sx} \quad (14)$$

$$u_2 = \Psi_{rx} u_{sy} + \Psi_{ry} u_{sx} \quad (15)$$

The compensation for nonlinearities in equations (11) and (13) forms the following expressions with the new input variables m_1 and m_2 :

$$u_1 = \frac{w_\delta}{l_r} \left[x_{11} \left(x_{22} + \frac{L_m}{w_\delta} x_{21} \right) + m_1 \right] \quad (16)$$

$$u_2 = \frac{w_\delta}{l_r} \left(-x_{11} x_{12} - \frac{R_r L_m}{L_r w_\delta} x_{21} - \frac{R_r L_m}{L_r} \frac{x_{12}^2 + x_{22}^2}{x_{21}} + m_2 \right) \quad (17)$$

The new speed observer system was recently proposed and it is used for the rotor-speed estimation. The rotor-flux linkages of the induction motor may be estimated by using the modified Luenberger observer system.

IV. IDENTIFICATION OF ROTOR-RESISTANCE

The value of the rotor resistance used in the observer is very importance to obtain more accuracy in rotor-speed estimation using the observer system. A simple algorithm provides large errors during the identification of the rotor resistance this can be improved by using extra procedures. The identification of the rotor resistance using modified algorithm was tested by computer simulation and experiments. These experimental results of nonlinear control system give the necessity of feed forward neural network system for remembering the identified rotor resistance. To minimize the estimated errors of the stator-current components in the Luenberger observer, it is possible to assume that

$$i_{sx} \approx \hat{i}_{sx} \quad (18)$$

$$i_{sy} \approx \hat{i}_{sy} \quad (19)$$

$$\frac{di_{sx}}{d\tau} \approx \frac{d\hat{i}_{sx}}{d\tau} \quad (20)$$

$$\frac{di_{sy}}{d\tau} \approx \frac{d\hat{i}_{sy}}{d\tau} \quad (21)$$

Where $\hat{}$ symbol indicates the variables estimated by the speed observer.

Therefore, taking these relations from the motor model and observer system into account yields

$$-R_r L_m^2 \dot{i}_{sx} + R_r L_m \psi_{rx} + \omega_r \omega_\sigma \psi_{ry} = -R_r^* L_m^2 \dot{\hat{i}}_{sx} + R_r^* L_m \widehat{\psi}_{rx} + \omega_r^* \omega_\sigma \widehat{\psi}_{ry} \quad (22)$$

$$-R_r L_m^2 \dot{i}_{sy} + R_r L_m \psi_{ry} - \omega_r \omega_\sigma \psi_{rx} = -R_r^* L_m^2 \dot{\hat{i}}_{sy} + R_r^* L_m \widehat{\psi}_{ry} - \omega_r^* \omega_\sigma \widehat{\psi}_{rx} \quad (23)$$

Where

R_r = rotor resistance

The parameters with the superscript * denote the estimated parameters. The left sides of above equations are derived from the motor model and the right sides are obtained from the observer system. The rotor angular speed varies slowly and could be assumed as a constant parameter in the variable-estimation system. Equations (22) and (23) are valid at steady state, particularly for the instants τ_1 and τ_2 . The instantaneous values of the rotor-flux components are not accessed for direct measurement. However, it is possible to determine the difference between the values of the rotor-flux components for the instants τ_1 and τ_2 . This makes it possible to determine the values of rotor resistance from the following equations, assuming that the rotor angular speed is constant and known:

$$R_r L_m (-L_m \Delta i_{sx} + \Delta \psi_{rx}) + \omega_r \omega_\sigma \psi_{ry} = \Delta z_x \quad (24)$$

$$R_r L_m (-L_m \Delta i_{sy} + \Delta \psi_{ry}) + \omega_r \omega_\sigma \psi_{rx} = \Delta z_y \quad (25)$$

$$\Delta i_{sx} = i_{sx}(\tau_2) - i_{sx}(\tau_1) \quad (26)$$

$$\Delta i_{sy} = i_{sy}(\tau_2) - i_{sy}(\tau_1) \quad (27)$$

$$\Delta \psi_{rx} = \psi_{rx}(\tau_2) - \psi_{rx}(\tau_1) \quad (28)$$

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$$\Delta \psi_{ry} = \psi_{ry}(\tau_2) - \psi_{ry}(\tau_1) \quad (29)$$

$$\Delta z_x = -R_r^* L_m^2 (\hat{i}_{sx}(\tau_1) - \hat{i}_{sx}(\tau_2)) + R_r^* L_m (\widehat{\Psi}_{rx}(\tau_2) - \widehat{\Psi}_{rx}(\tau_1)) + \omega_r \omega_\sigma (\widehat{\Psi}_{ry}(\tau_2) - \widehat{\Psi}_{ry}(\tau_1)) \quad (30)$$

$$\Delta z_y = -R_r^* L_m^2 (\hat{i}_{sy}(\tau_2) - \hat{i}_{sy}(\tau_1)) + R_r^* L_m (\widehat{\Psi}_{ry}(\tau_2) - \widehat{\Psi}_{ry}(\tau_1)) - \omega_r \omega_\sigma (\widehat{\Psi}_{rx}(\tau_2) - \widehat{\Psi}_{rx}(\tau_1)) \quad (31)$$

Using the motor equations, the next relations could be obtained

$$\Delta \psi_{rx} = \frac{L_r}{L_m} \Delta \psi_{sx} - \frac{\omega_\sigma}{L_m} \Delta i_{sx} \quad (32)$$

$$\Delta \psi_{ry} = \frac{L_r}{L_m} \Delta \psi_{sy} - \frac{\omega_\sigma}{L_m} \Delta i_{sy} \quad (33)$$

The rotor flux of induction motor cannot measure directly. Therefore stator flux estimation by voltage integration provides more error in voltage and current signal. These errors can be minimize by evaluating the difference between stator flux component at stages τ_1 and τ_2 as

$$\Delta \psi_{sx} = \int_{\tau_1}^{\tau_2} (-R_s i_{sx} + u_{sx}) d\tau \quad (34)$$

$$\Delta \psi_{sy} = \int_{\tau_1}^{\tau_2} (-R_s i_{sy} + u_{sy}) d\tau \quad (35)$$

Above two additional integrators proposed in the estimation system at a specified time with initial values. The outputs of these integrators at instant τ_2 will be the incremental value of the stator-current vector components. The rotor resistance at vector component x and y can be calculated from equation (36) and (37) as follows:

$$R_{rx} = \frac{\Delta z_x - \omega_r L_r^2 \Delta \psi_{ry}}{L_m (-L_m \Delta i_{sx} + \Delta \psi_{rx})} \quad (36)$$

$$R_{ry} = \frac{\Delta z_y - \omega_r L_r^2 \Delta \psi_{rx}}{L_m (-L_m \Delta i_{sy} + \Delta \psi_{ry})} \quad (37)$$

Where,

R_{rx} =Rotor-resistance on x axis stationary reference frame

R_{ry} =Rotor-resistance on y axis stationary reference frame

In the next calculation of algorithm the resistances R_{rx} and R_{ry} are assumed as follows. At instant τ_1 , the values of the flux and current during running condition of integrators are evaluated in Luenberger observer system. The integration period has been assumed to 50 periods of transistor switching (about 7.5 ms). At instant τ_2 , with the help of voltage model in equation (34) and (35), flux is calculated also the incrementing values of flux are computed by using equations (32) and (33) and by using Luenberger observer. Additionally, resistances R_{rx} , R_{ry} and Δz_x , Δz_y , are computed. The calculated values of resistances are filtered and put again in speed observer systems and Luenberger observer systems. In next 50–100 switching periods of observer evaluated values are stabilized. Then, at instant τ_1 , makes the integrators once again zeroed, and start the process from the beginning. Approximated relationship gives equations (36) and (37) and these equations are used to rotor resistance R_r , with the error depends on the value of the rotor resistance R_r^* assumed in estimation algorithm.

If the denominator of equation (36) and (37) may be small or zero, then calculated rotor resistance R_r is with large error. This gives incremented variables. In some special cases values of periodic variables could be same and the incremented values would be zero. If the calculated rotor resistance exceeds the assumed limit then these values are rejected. By calculating the average rotor resistance R_{rav} with the help of two phases, effect of above errors can be minimized.

$$R_{rav} = 0.5 \times (R_{rx} + R_{ry}) \quad (38)$$

V. SPEED OBSERVER ERRORS DURING ROTOR-RESISTANCE IDENTIFICATION

The mean-square averaged error E of speed estimation was calculated for an exact calculation of the effect of rotor-resistance on the operation of the speed control system of the induction motor. The square of difference between the measured and the estimated speeds is assumed as a criterion. Assuming Euler's integration method, the criterion may be defined as

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$$E = \int_{t=0}^{t=tN} [(\omega r - \hat{\omega} r)^2] dt = \frac{\sum_{i=1}^N (\omega r - \hat{\omega} r)^2}{N} \quad (39)$$

The rotor speed was estimated by using and without using the ANN correction. During the investigations of these two methods, it is observed that error in speed estimation decreased by almost 50%.

VI. MODELLING AND SIMULATION OF INDUCTION MOTOR

INDUCTION MOTOR WORKING IN DISCRETE MODE

The basic SVPWM based vector control block diagram of the proposed drive system of the Induction motor is shown in fig.1. The system comprises of the following modules:

- SVPWM based voltage source inverter (VSI) module.

SVPWM based voltage source inverter module provides less harmonic distortion in the output voltages or current applied to the phase of AC motor to provide more efficient use of supply voltage. SVPWM is a digital modulating technique where the objective is to generate PWM load line voltages that are in average equal to a given load voltage.

- Three phase Induction motor module.

Inside the PMSM module three phases are converted into two phase time invariant with the help of abc to xy transformation through Bus selector which gives five outputs required for further calculation.

- Computation of mathematical equations to estimate R_{r_s} .

R_{rx} and R_{ry} are, respectively, the rotor-resistance x- and y-axis components in the stationary reference frame. These variables are framed in the form of simulink model.

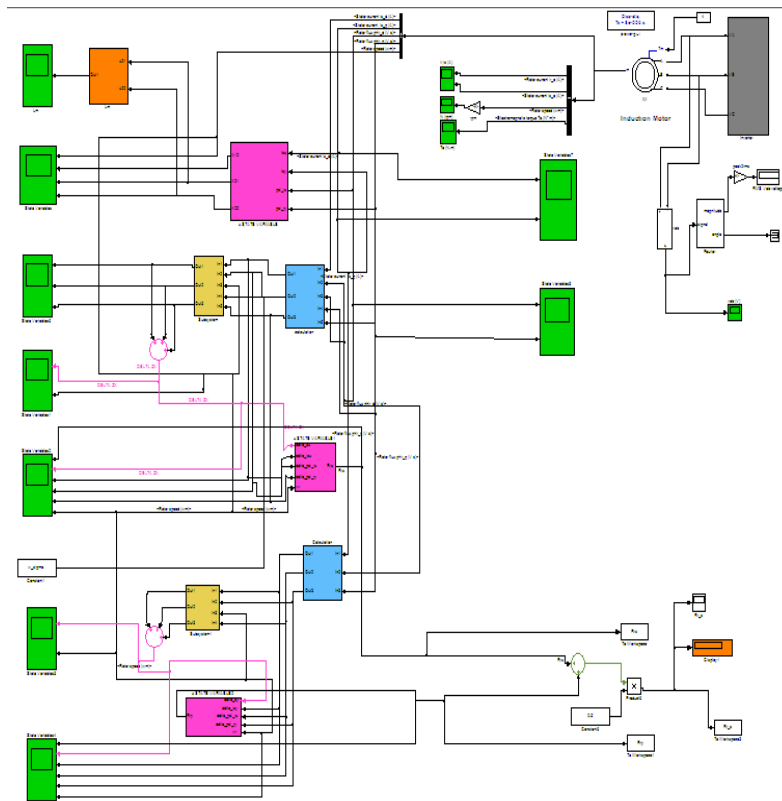


Fig.1. Simulation model of Induction motor in discrete mode

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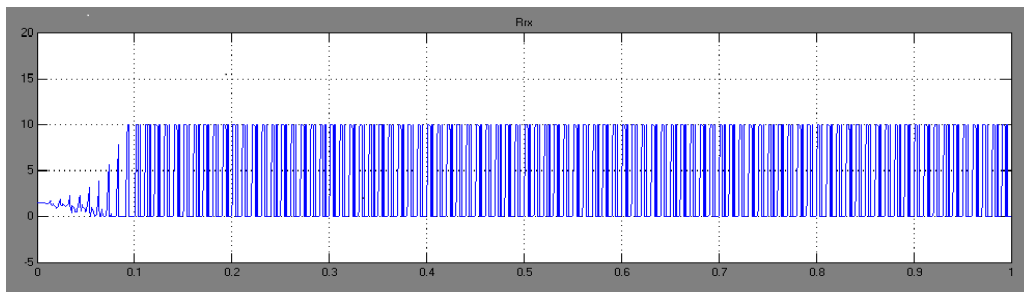
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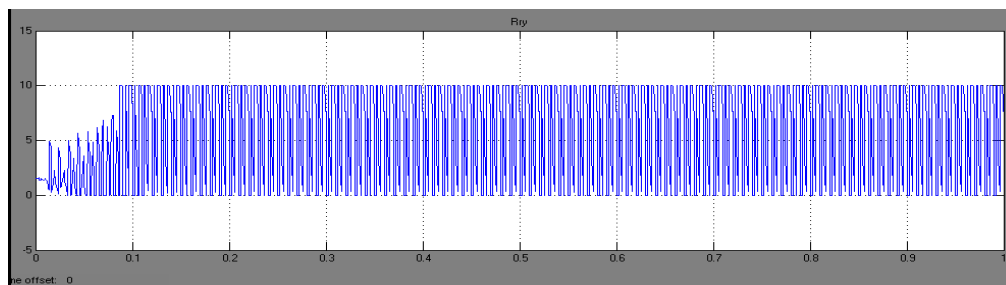
SIMULATION OF MOTOR IN DISCRETE MODE

Simulation of Induction motor during load condition has been observed. The simulation results are given in the form of following Figures:

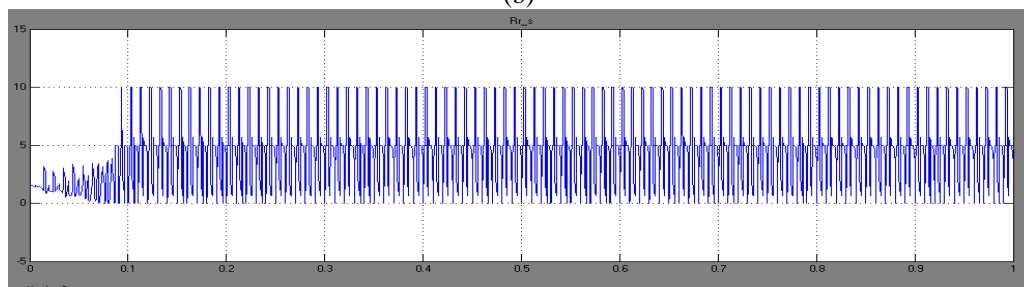
1. Rotor Resistance in X axis Rr_x .
2. Rotor Resistance in Y axis Rr_y .
3. Average Rotor Resistance Rr_s .
4. Angular speed Wr .



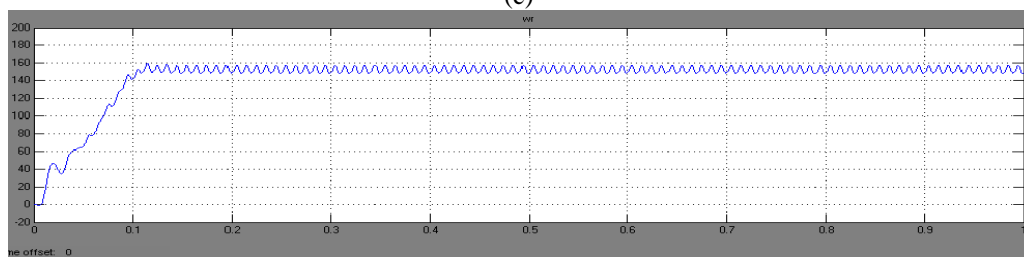
(a)



(b)



(c)



(d)

Fig.2. Graph of (a) Rotor resistance in x axis (b) Rotor resistance in y axis (c) Average rotor resistance (d) Angular speed or

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ESTIMATION OF ROTOR RESISTANCE WITH ANN

a) Estimation of Rotor Resistance with ANN

The rotor resistance as mathematical parameter of the machine model is not constant and changes with the time, temperature, and speed. During transients, which is when the speed changes, the resistance estimation algorithm shows a large estimation error (30%) although filtering is used. Artificial Neural Network (ANN) can be used for remembering the rotor resistance at the steady states and is determined during transients.

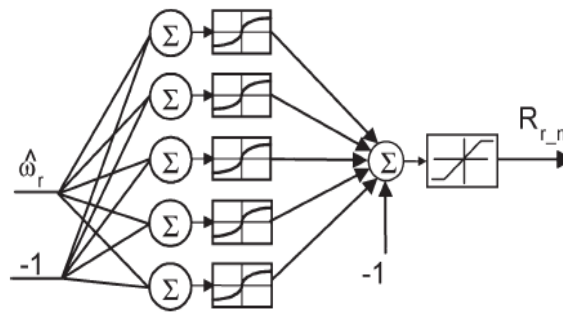


Fig. 3: ANN architecture for remembering the rotor resistance: feed forward ANN.

b) Rr_n estimation results using ANN.

Training input data of Induction motor using ANN has been observed. The simulation results are given in the form of following Figures:

- a) Rotor speed ω_r
- b) Estimated Rotor Resistance Rr_s .
- c) Rotor resistance calculated by ANN Rr_n .

Due to the use of an ANN, Rotor resistance Rr_n in the steady-state error was decreased nearly to zero. After nearly zeroing the error, small oscillations are observed. However, as a result of using the ANN corrector, it does not exceed 2.5%.

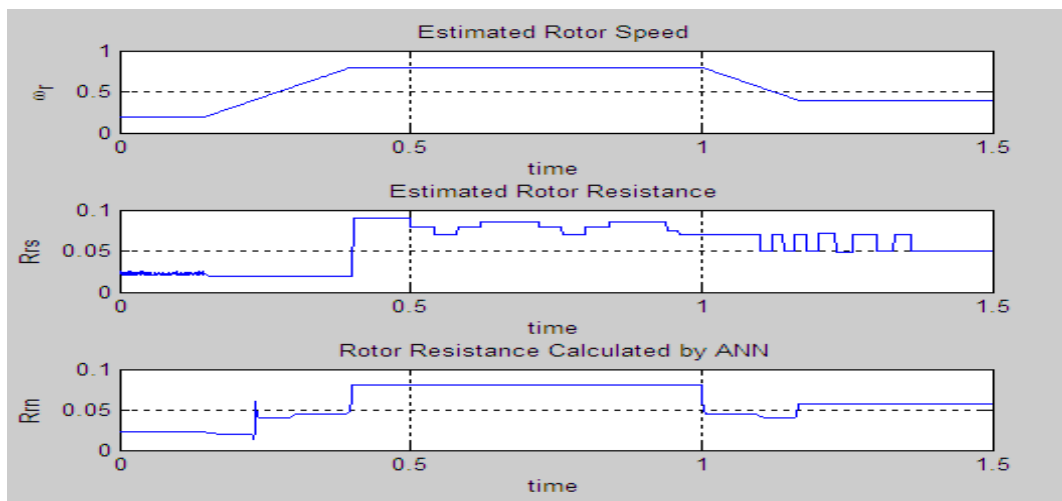


Fig.4: Graph of ω_r , Rr_s & Rr_n Vs Time

The some oscillations observed during the estimated value Rr_s shown in above Fig.4.during steady state condition

Rotor resistance R_{r_s} under no load and load condition

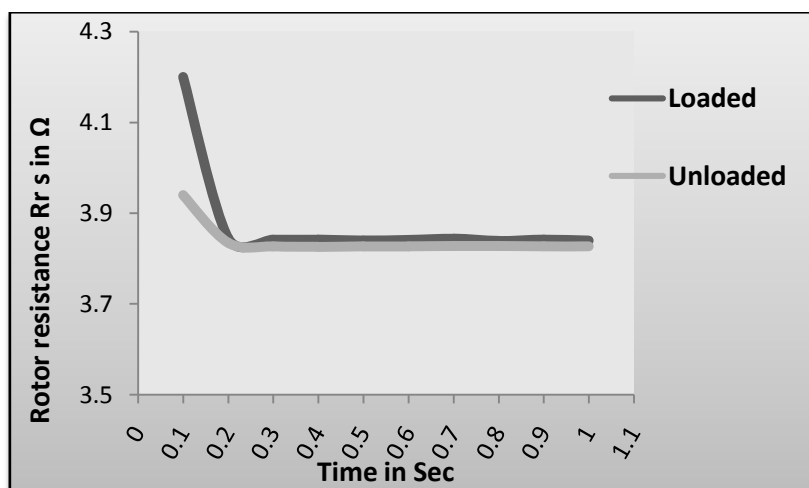


Fig.5: Graph of R_{r_s} Vs Time

VII. CONCLUSION

The online parameter evaluation is essential for improved static and dynamic performance for drives in electric and hybrid vehicles. The methods for evaluating the online rotor resistance of induction motor are presented. ANN tool is implemented for remembering the evaluated rotor resistance during steady state and compute it during transients. These methods are applied to the closed-loop sensorless nonlinear control of induction motors. From the results obtained, it is observed that error in evolution is within certain limit and the speed evaluation process was appreciably improved. The proposed system is useful for high performance applications.

REFERENCES

- [1] Dr P.S. Bhimra, "Generalized theory of Electrical Machine", ch.no.8, pp-421-620.
- [2] P. Vas, "Sensorless Vector and Direct Torque Control" New York: Oxford Univ. Press, 1998
- [3] Miroslaw Wlas, Zbigniew Krzeminski, and Hamid A. Toliyat, "Neural-Network-Based Parameter Estimations of Induction Motors" IEEE transactions on industrial electronics, vol. 55, issue no. 4, Pages: 1783 – 1794, April 2008.
- [4] Hamid A. Toliyat, Emil Levi and Mona Raina, "A Review of RFO Induction Motor Parameter Estimation Techniques", IEEE transactions on energy conversion, vol. 18, issue no. 2, Pages: 271 – 283, June 2003.
- [5] Bimal K. Bose, "Neural Network Applications in Power Electronics and Motor Drives—An Introduction and Perspective", IEEE transactions on Industrial Electronics, vol. 54, issue no. 1, Pages: 14 – 33, 2007.
- [6] Wlas, M., Krzeminski, Z., Guzinski, J., Abu-Rub, H., Toliyat, H.A., "Artificial-Neural-Network-Based Sensorless Nonlinear Control of Induction Motors", IEEE Transactions on Energy Conversion, vol. 20, issue no. 3, Pages: 520 – 528, 2005
- [7] M. Ebrahimi**, E. Rezaei, B. Vaseghi And M. Danesh, "Rotor Resistance Identification Using Neural Networks For Induction Motor Drives In The Case Of Insensitivity To Load Variations" Iranian Journal of Science & Technology, Transaction B, Engineering, Vol. 30, No. B2, 2006.
- [8] Haithem Abu-Rub, Jaroslaw Guzinski, Zbigniew Krzeminski, and Hamid A. Toliyat, "Speed Observer System for Advanced Sensorless Control of Induction Motor", IEEE Transactions on Energy Conversion, vol. 18, issue no. 2, Pages: 219 – 224, 2003.
- [9] Afef Fekih and Fahmida. N. Chowdhury, "On Nonlinear Control of Induction Motors Comparison of two Approaches" Proceeding of the 2004 American Control Conference Boston, Massachusetts June 30 - July 2, 2004.
- [10] Bambang urwahyudi, Soebagio and M. Ashari, "RNN Based Rotor Flux and Speed Estimation of Induction Motor" International Journal of Power Electronics and Drive System (JPEDS) Vol.1, No.1, September 2011, pp. 58–64 ISSN: 2088-8694.