International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-2, July 2019

Electrical Drive System Modeling for Real-Time Digital Simulation Applications

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***Abstract*: In this paper the digital simulation of physical system in MATLAB-SIMULINK for real-time applications is simulated for partial-scale or full-scale and validated simulation results with the existing system. One of the applications is AC drive systems with speed adjustability not only limited to equipment's of electrical. The proper selection of AC motor drive is one of the main resolves of this paper. The efficient control of speed and torque is the second aim by considering the flux weakening regions.**

***Index Terms*: Induction motor, Vector control, Flux-weakening region, Artificial Intelligent controllers.**

I. INTRODUCTION

Depending upon the types of loads now days the growing demand is increased and the complexity also increased. The main objective and challenging is testing and verification of the loads and drive system. The realistic calculations and simulation studies are done with varying loads of mechanical. There are many learning and exhaustive algorithms of controllers to control the electric drives and control irrespective of the power specifications. Several experimental and laboratory experiments and tests are been conducted.

For high-power electric drives with all customized controllers for different applications by varying electric drive is designed and tested [1]. To use fully real-time digital simulation a recent alternative way of testing that is fast becoming is quite popular. Interfacing of these simulations with industrial controllers, thus saving a lot of cost of the investment amount and an economic tool is allowed for testing of drive controller in all power ranges and offering the machine simulations flexible [2].

"Online data and signal process for analysis purposes" of the use of virtual system drive systems enables relatively easier interface to the computer and faster and Earlier hardware which replaces the equivalent model of the drive system. The commonly used drive systems are induction motor, stepper motor, servomotor and synchronous motor and the same has been tested with different conventional and AI controllers, the hardware. Recently real time systems in fully digital simulation tested with regulator as well as experimental using a simulation [1] With the problem of modeling and real-time simulation, a converter starts and stops the drive for variable speeds and applications to develop models for electric vehicles and electric hybrids [3]. Proposal for the modeling of the drive system by block diagram representation and state space

Analysis, which is simulated in MATLAB, which is an easy to use software. State stability and production tests play an important role for variable conditions [3]. The attributes of induction machines are inherently very interesting for drive applications. They are cheap, resistant and do not have sliding contacts to use and build. When variable speed drives are used, the difficulty of induction machines and servomechanisms is that they are "difficult to control", the torque-speed ratio is analyzed and, therefore, complexity and non-linearity are analyzed [4]. An AC induction motor for more than 100 years of three-phase has proved extremely reliable when using an electromechanical conversion device. However, to act as frequency changers with modern power electronics and digital electronics to perform the required arithmetic and logic control function, induction machines are seeing increasing use in inverter applications [5]. Its characteristics have been well defined and standardized for the vast majority of that time period, it has evolved as a constant speed device operating from a constant frequency sinusoidal public service energy source and constant voltage.

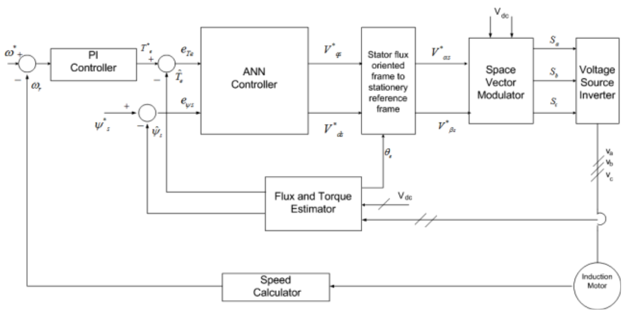

Fig 1: ANN based MTC of IM Drive

II. FOCV CONTROL THEORY

The control of FOC strategy which produces and used for improving IM-drive ability [1].

The novel controller of basic amounts of: the rotor flux vector $\bar{\psi}_r$ of the modeling of IM and x-y stationary coordinate system and the equations are:

Revised Manuscript Received on 30 July 2019.

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$$\overrightarrow{\psi_r} = \psi_r e^{j\alpha\psi} \quad (1.a)$$

i.e. it can be characterized as a vector with ψ_r magnitude and α_ψ angle, and can be designed quite convolutely.

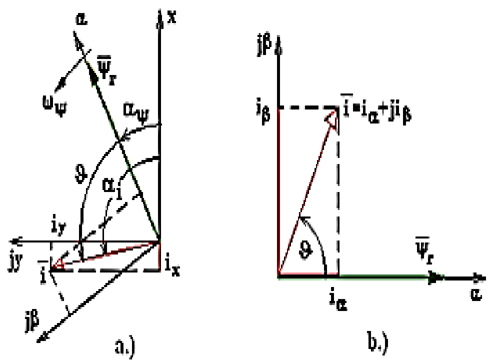

Fig 2: I_s vector and $\overrightarrow{\Psi r}$.) in xy coordinate, b.) α-β field coordinate system.

The FOC or VC systems are used for the stationery and revolving frames of the AC IM - drives and its applications to electric and hybrid electric vehicles. So, modeling of the IM drive is necessary/. The transformations like abc to dqo and inverse transformations are also necessary.

To appreciate the governor persistence - that is defined in $\alpha - \beta$ coordinate system for the $i\,\alpha$ and $i\,\beta$ current mechanisms, in xy coordinate system the conforming

$$\bar{i} = ie^{j\alpha_i} = ie^{j(\alpha_i + \vartheta)} \quad (1.b)$$

Negative torque can be developed with negative i_β component or ϑ negative torque angle.

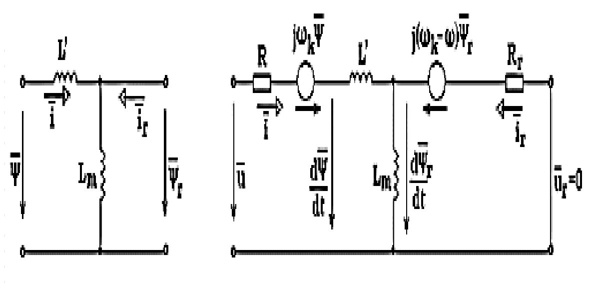

Fig 3: corresponding circuit of the, a.) ψ, b.) voltages.

To use Voltage equations for dynamic conditions, here the two loops which give clear explanation of the modeling of IM (direct and indirect loops):

$$\vec{u} = R\vec{i} + \frac{d\vec{\psi}}{dt} + j\omega_k \vec{\psi} \quad (2)$$

$$\overrightarrow{u_r} = R_r \overrightarrow{i_r} + \frac{d\overrightarrow{\psi}}{dt} + j(\omega_k - \omega)\overrightarrow{\psi_r} = 0 \quad (3)$$

Flux equations:

$$\bar{\psi} = L\bar{\iota} + L_m(\bar{\iota} + \bar{\iota_r}) \quad (4)$$

$$\overline{\psi_r} = L_m(\bar{\iota} + \bar{\iota_r}) \quad (5)$$

To eliminate rotor current non-measurable quantities, the rotor voltage equation by substituting $\bar{\imath}_r$ from the flux equation:

$$\bar{\iota_r} = \frac{\overline{\psi r}}{L_m} - \bar{\iota} \quad (6)$$

$$\vec{u}_r = \frac{\vec{\psi}_r}{T_{r0}} - R\vec{i}_r + \frac{d\vec{\psi}}{dt} + j(\omega_k - \omega)\vec{\psi}_r = 0 \quad (7)$$

Where $Tr0 = Lm/Rr$

From the inductances of stator, rotor and mutual and leakage, the voltage equations are categorized. The fluxes and currents are articulated with real and imaginary components[2].

$$\omega_k = \omega_\varphi = \frac{d\alpha_\varphi}{dt} \text{ and } \omega_k = \omega_\varphi - \omega$$

According to ψ_r is fixed to the real axis, consequently the ψ_r.

Each quantity has α-β components. $\vec{\psi}_r = \psi_\alpha = \psi_r$,

the I_{stator} is: $\bar{\iota} = i_\alpha + ji_\beta = ie^{j\vartheta}$ (8)

$V_{terminal}$ is: $\bar{u} = u\alpha + ju\beta$, etc.

The equation is obtained in terms of transformations:

$$\frac{\psi_r}{T_{ro}} - R_r i_\alpha + \frac{d\Psi_r}{dt} = 0 \quad (9)$$

rearranging $\psi_r + T_{ro}\frac{d\Psi_r}{dt} = L_m i_\alpha$ (10)

This meaning is alike to SE-DC motors, how their flow can vary contingent on the excitation current. The magnitude of ψr may vary slowly; Slowly follow the change of $L_m\, i_\alpha$ with several tenths of a second T_{ro} constant time. The magnitude of the rotor current vector be contingent only on the component $i\,\alpha, i\,\beta$ has no influence on it.

The torque that produces β can be calculated from the β components and is similar to separately excited DC [3].Several methods in machine modeling have different configurations and different parameters which exist to calculate ψr, $\alpha\,\psi$, $\omega\,\psi$ and the m torque. One method which uses stator voltage equation in stationary $(\omega\, k = 0)$ x-y coordinate system. The real and imaginary parts of equation are:

$$\frac{d\psi_{rx}}{dt} = \frac{L_m i_x \psi_{rx} - \omega T_{ro}\psi_{ry}}{T_{ro}} \quad (11)$$

$$\frac{d\psi_{ry}}{dt} = \frac{L_m i_y \psi_{ry} - \omega T_{ro}\psi_{rx}}{T_{ro}} \quad (12)$$

The machine model that the measured values of $i\,a$, $i\,b$, $i\,c$ phase currents and ω rotor speed uses the equations.

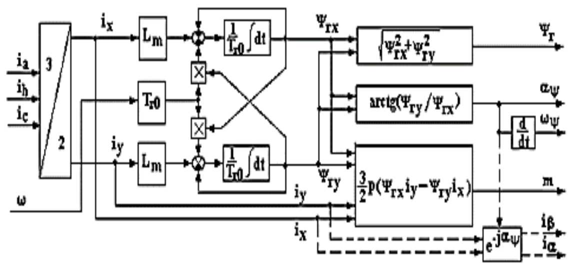

Fig 4: Machine modeling for I-ψ relation

III. CONTROL TECHNIQUES H

A. Maximal utilization of the rotor flux

To the SE-DC motors, high self-motivated drive system can be realized by FOC induction motor it is well-defined for the rotor flux ψr . The speed choices vary from low, normal and high speeds for the IM, it is: $\omega 0n \approx \omega n$.

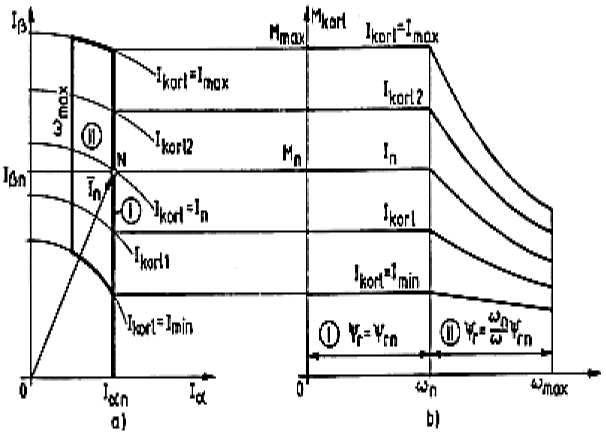

Fig 5: Motor mode control ranges of Field concerned with fa.) Current trajectory range, b.) M-ω limit.

The difficulty of controlling the speeds of low, medium and high to compensate with the loads and by compensating and reducing the flux weakening problems in different modes are to be controlled by using maximum torque control and constant torque methods[4, 5].

In regenerative braking mode, the control fields are reflected on the parallel axis, with the alteration that normally in the decelerating mode a slighter maximum current is allowed compared to the motor mode. The torque that can be reached by the Imax reductions hyperbolically.

B. Energy-efficient rotor flux control

The iron losses are required to be decreased with the self-motivated changes in the load and flux variations of the induction motor machine for different automobile applications. To get energy efficiency by using FOC [6].

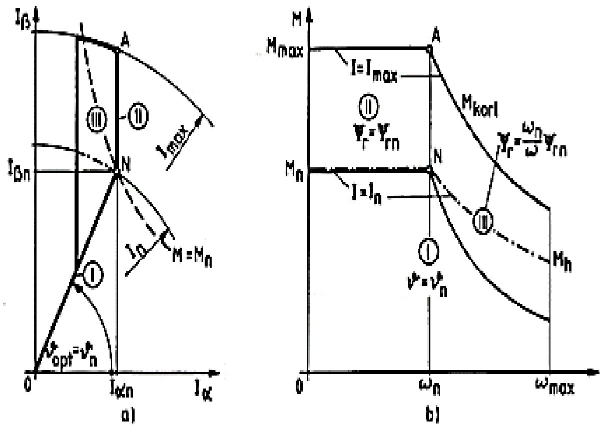

Fig 6: motor mode a.) Current vector range, b.) M-ω limit characteristics.

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IV. MODELLING

Consider a Y_S^S space vector of stator voltage, current and flux linkage.

$$Y_S^S = (2/3)(Y_a + \alpha Y_b + \alpha\, 2\, Y_c) \quad (13)$$

Where $\alpha = exp\,(j2\Pi/3)$

The above convert being reversible

$$Y_a = \mathrm{Re}\,(Y_S^S),\, Y_b = \mathrm{Re}\,(\alpha\, 2\, Y_S^S) \quad (14)$$

$$Y_c = \mathrm{Re}\,(\alpha\, Y_S^S) \quad (15)$$

Voltage equations on the stator with respect to stationary reference frame

$$V_S^S = \mathrm{Rs}\, I_S^S + \mathrm{p}\, \delta_S^S \quad (16)$$

Voltage equations for rotor on rotor reference frame are:

$$V'_r = R_r I'_r + p\lambda'_r = 0 \quad (17)$$

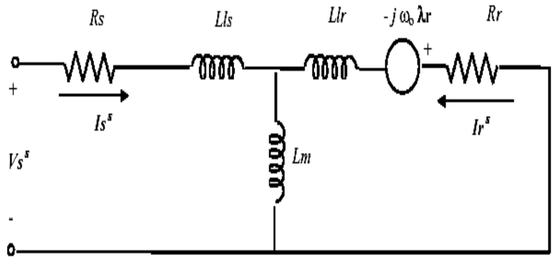

Fig 7: Dynamic Equivalent Circuits on a Stationary Reference Frame

It is very suitable to convert actual rotor variables (V'_r, I'_r, λ'_r) on a rotor reference frame into new variables $(V_r^S, I_r^S, \lambda_r^S)$ on a stator reference frame.

Rotor reference frame to stator reference frame is:

$$I_r^S = (1/n)\,\exp\,(j\theta)\, I_r \quad (18)$$

$$\lambda_r^S = n\,\exp\,(j\theta)\lambda_R \quad (19)$$

$$R_r = n^2 R_r \quad (20)$$

Consequently, the stator equation with respect to stationary reference frame is:

$$V_S^S = R_s I_S^S + p\,\lambda_S^S \quad (21)$$

The rotor equation with esteem to stationary reference frame is:

$$0 = R_r I_r^S + (p - j\omega 0)\lambda_r^S \quad (22)$$

Where $\omega_0 = p\theta_0$; speed of motor in electrical frequency unit

The flux linkage equations are given as:

$$\lambda_s^s = L_s I_s^s + L_m I_r^s \qquad (23)$$

$$\lambda_r^s = L_m I_s^s + L_r I_r^s \qquad (24)$$

Where, $L_s = L_{1s} + L_m$

$$L_r = L_{1r} + L_m \qquad (25)$$

Dynamic model of IM on a stationary reference frame

$$V_s^s = (R_s + L_s^p) I_s^s + L_m^p I_r^s \qquad (26)$$

$$0 = (R_r + L_r(p - j\omega_o)) I_r^s + L_m(p - j\omega_0) I_s^s \qquad (27)$$

For an arbitrary reference frame rotating at a speed ω_a

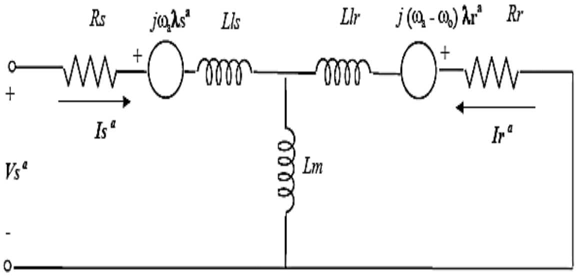

Fig 8: Equivalent Circuit on an Uninformed Reference Frame revolving at ω.

$$Y_a = \exp(-j\,\omega_a)\,Y_s \qquad (28)$$

Recreating the equations:

$$V_s^a = (R_s + L_s^p) I_s^a + L_m^p I_r^a + j\omega_a \lambda_s^a \qquad (29)$$

$$0 = (R_r + L_r^p) I_r^a + L_m^p I_s^a + j(\omega_a - \omega_0)\lambda_r^a \qquad (30)$$

$$\lambda_s^a = L_s I_s^a + L_m I_r^a \qquad (31)$$

$$\lambda_r^a = L_m I_s^a + L_r I_r^a \qquad (32)$$

It can be written the above equations as:

$$V_s^a = R_s I_s^a + p\lambda_s^a + ja\,\lambda_s^a$$

$$= R_r I_r^a + p\lambda_r^a + j(\omega_a - \omega_0)\lambda_r^a \qquad (33)$$

V. ARTIFICIAL INTELLIGENT CONTROLLERS

A. PI Controller

The conventional controllers like P, I, D, PI, PD and PID. The parameters tuning like Kp, Ki, Kd and Ti, Td. The fine-tuning of PID to accomplish convinced performance guide for structure response is presented. To be transformed for defining the PI constants of the controller, called *Regulation*, depends upon the self-motivated reply of the plant.

This error is manipulated by the controller (PI):

$$U(s) = K_p(1 + 1/\,\tau i_s) \qquad (34)$$

Or in time domain

$$U(t) = K_p\,[e(t) + (1/\tau\, i)\int edt] \qquad (35)$$

The gain *K* resemble to the stable state value of the output C_{ss}. The value of Kp, Ti and Td of the regulators can then be planned as below:

$$KP = 1.2(T/L)\,\tau i = 2L$$

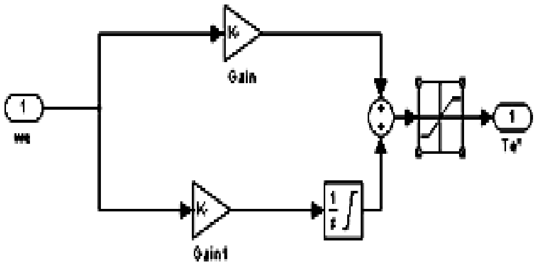

Fig 9: Mathematical Model

B. ANN Controller

the network function is resolute basically by the contacts between the elements. These elements are inspired by biological neural schemes [14]. ANN are composed of simple elements that operate in parallel.

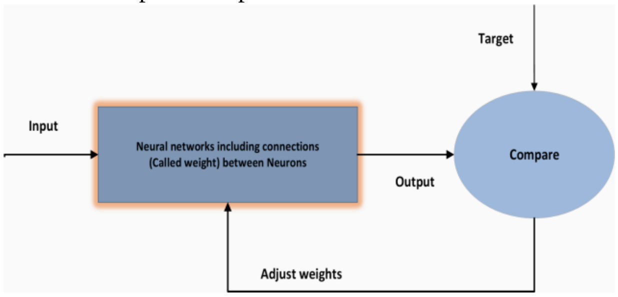

Fig 10. Block diagram of Neural Network

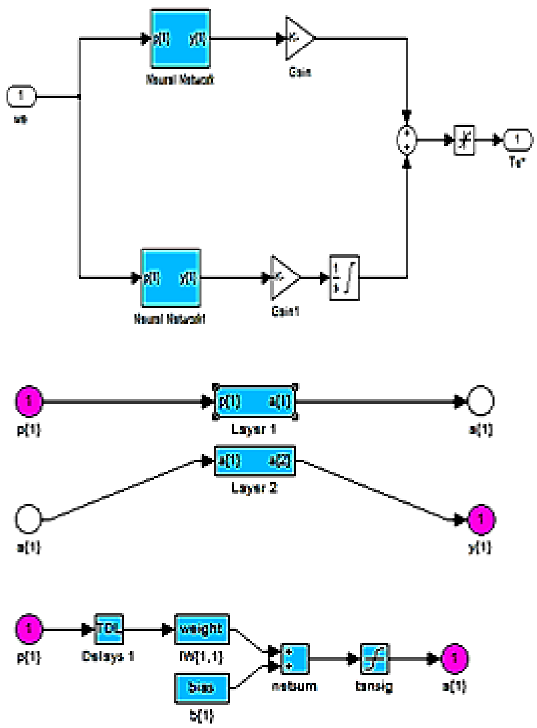

Fig 11: Sub system of NN controller

C. *Parameters:*

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W_{ref} = 120 to 150 rad/sec (step time = 1 sec)
Stator resistance = 0.087 ohm
Stator & rotor leakage inductance = 0.8e-3H
Rotor resistance = 0.228 ohm
Magnetizing reactance = 34.7e-3 H
No. of Poles = 4
T_L = 200 N-m

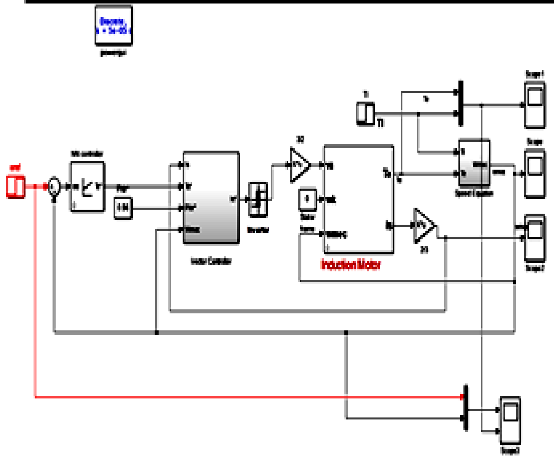
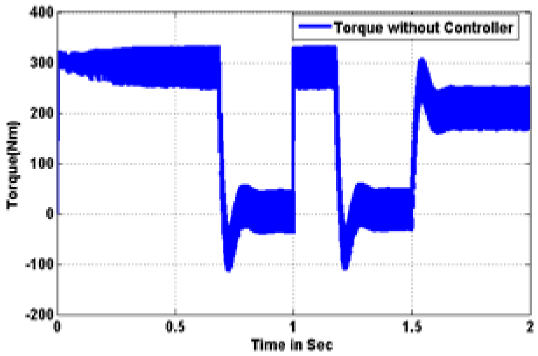
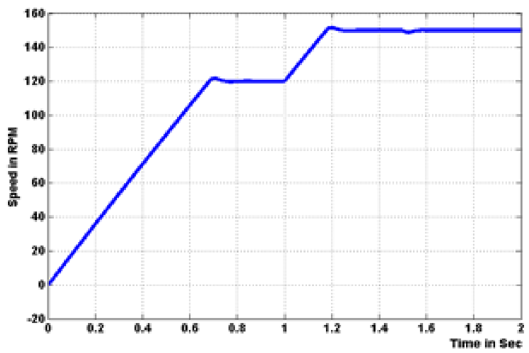


Fig 12: Simulation Model of Induction Motor

VI. SIMULATION RESULTS





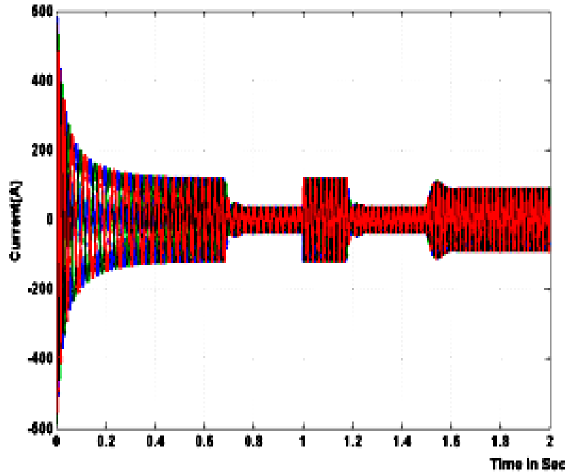
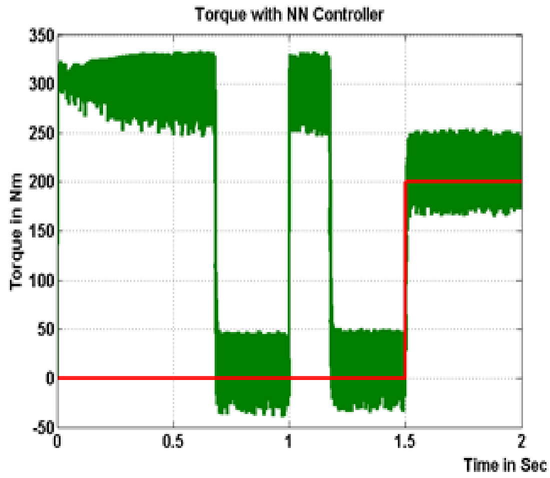
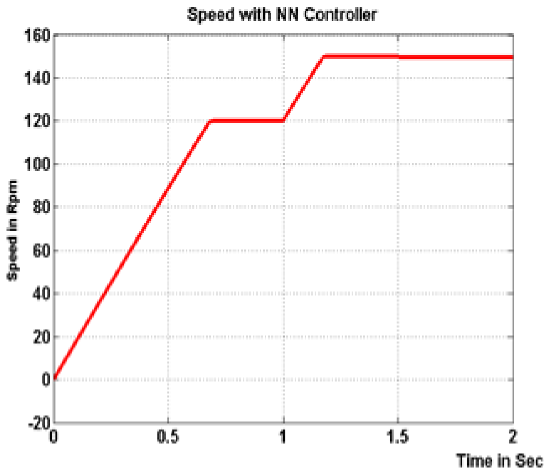


Fig 13: Speed, torque and currents for without controller





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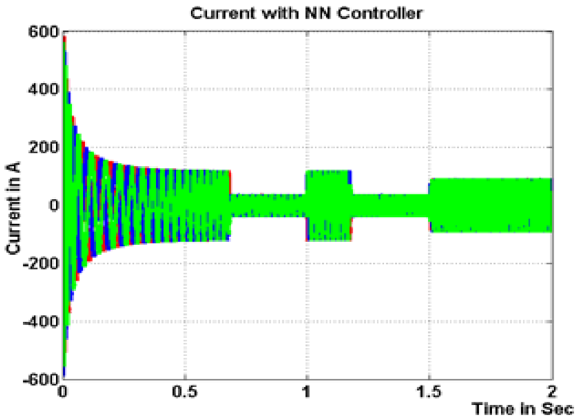

Fig 14: Speed, torque and currents for real-time data with NN controller

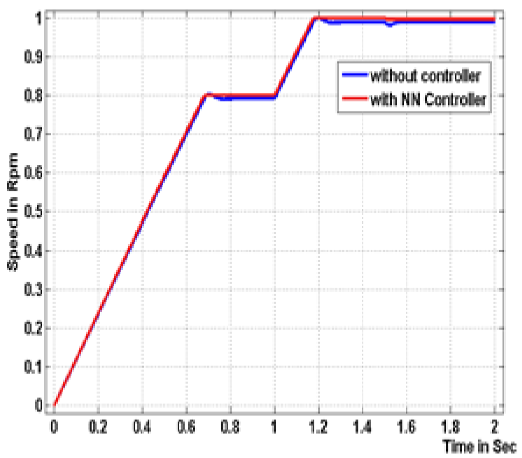

Fig.15.Speed without and with Controller

Table 1: With Magnetizing Reactance: 34.7e-3 H and Different Artificial Intelligent Controllers

	Speed (rad/sec)		Torque (N-m)	
	% Mp	ts (secs)	% Mp	ts (secs)
No Controller	30	0.88	150	4e-3
PI Controller	1.8	0.79	50	7e-3
NN Controller	**1.2**	0.685	**14**	3.5e-3

Table 2: Comparison Table:

Magnetizing Inductance	NN Controller			
	Speed (rad/sec)		Torque (N-m)	
	% Mp	ts (secs)	% Mp	ts (secs)
20e-3H	1.5	0.77	100	3.6e-3
34.7e-3H	1.2	0.685	14	3.5e-3
50e-3H	0.02	0.675	14.5	3.5e-3
100e-3 H	1.99	0.638	32	3.7e-3

VII. CONCLUSIONS

It should be noted that in the engineering and residential sectors, induction machines have been widely used in a variety with consideration of reliability, compactness and low cost. There are different types of control techniques that are adopted. Commonly used control strategies such as DOL, V / F and DTC and vector control. The performance of the intelligent controller was consulted via digital simulation with the MATLAB-SIMULINK software. The traditional PI controller demoralizes overall system performance. To overcome this problem, an intelligent controller based on ANN is proposed. From the comparison of the results, it is observed that the overshoot time% and the adjustment are minimum for the NN controller

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