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Design and Simulation of an Efficient Neural Network Based Speed Controller For Vector Controlled Induction Motor Drive

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Abstract—This project work start with the development of simulation model of rotor magnetic field oriented vector control system based on MATLAB software. This paper proposes the development of a Neural Network controller in place of PI controller commonly used in the vector control structure for efficient speed control and smaller settling time. After successful implementation of proposed Neural Network controller, the results obtained, which shows the superior performance of NN controller over conventional PI controller. In addition to this, It is also shown by the resultant response that, the proposed modified vector control structure based on Neural Network controller smoothen out the ripples in the motor torque and stator current as fine as will provide best speed regulation with smaller settling time requirement.

Keywords-*Induction motor; neural network; PI controller; Speed control; Vector control.*

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I. INTRODUCTION

Induction motors are the most commonly used electric drives in the industries due to its robustness, less maintenance, and low cost. The electric drives must possess good dynamic response to respond to very small changes in the load or in the reference speeds. By using field oriented control of induction motors this requirement is achieved easily.[1] The induction motor is run like a separately excited DC motor using the field oriented control. The advantages of the AC drives over DC drives are unchanged. Thus a drive system with a high-quality dynamic response is developed. [2] This work proposes a neural network controller in place of PI controller commonly used in the vector control structure for efficient speed control and smaller settling time. It is expected that the proposed modified vector control structure based on neural network controller smoothens out the ripples in the motor torque and stator currents as well as will provide best speed regulation with smaller settling time requirement.

Vector control Technology is regard as major control method on high performance induction motor speed control system. [2] In conventional field oriented control, a PI controller is provided for controlling the speed of the induction motor drive. The use of PI controller induces many problems like high overshoot, oscillation of speed and torque due to sudden changes in load and external disturbances. This behavior of the controller causes deterioration of drive performance. To overcome this disadvantages an intelligent controller based on Neural Network is proposed in the place of the conventional PI controller.[3]

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II. INDIRECT FIELD ORIENTED VECTOR CONTROL OF INDUCTION MOTOR

The indirect vector control method is essentially same as the direct vector control except the unit vector is generated in an indirect manner using the measured rotor speed ωr and the slip speed ω_s. The field orientation was made according to the rotor flux vector.[6]

The rotor flux magnitude is obtained using a flux observer, but the frequency of the rotor field is neither computed nor estimated but it is imposed depending on the load torque value i.e. the slip frequency, and then integrated to obtain the imposed rotor flux position (angle λ_r). A field weakening system is used to control the speed of the motor when the speed rises above the nominal value. The mathematical model of induction motor is given by-

$$\theta e = \int \omega e = \int (\omega r + \omega sl) = \theta r + \theta sl \qquad ..(1)$$

The rotor circuit equation-

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r}R_r i_{ds} - \omega_{sl}\psi_{qr} = 0 \qquad ..(2)$$

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r}R_r i_{qs} - \omega_{sl}\psi_{dr} = 0 \qquad ..(3)$$

For decoupling control, the stator flux component of current ids should be aligned on the de axis, and the torque component of current i_{qs} should be on the qe axis, that leads to $\psi_{qr} = 0$ and $\psi_{dr} = \psi_r$ then:

$$\frac{L_r}{R_r}\frac{d\psi_r}{dt} + \psi_r = L_m i_{ds} \qquad ..(4)$$

As well, the slip frequency can be calculated as:

$$\omega_{sl} = \frac{L_m R_r}{\psi_r L_r} i_{qs} \quad ..(5)$$

It is found that the ideal decoupling can be achieved if the above slip angular speed command is used for making the field orientation. the control rotor flux ψr and $\frac{d\psi_r}{dt} = 0$ can be substituted in equation (2) , so that rotor flux set as

$$\psi_r = L_m i_{ds} \quad ..(6)$$

The electromagnetic torque developed in the motor is given by-

$$Te = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\psi_r i_{qs} \quad ..(7)$$

III. PROPOSED METHODOLOGY.

The vector control or field oriented control (FOC) of ac machines makes it possible to control ac motor in a manner similar to the control of a separately excited dc motor. In ac machines, the torque is developed by the interaction of current and flux. In induction motor the power is given to the stator only, the current responsible for flux production, and the current responsible for torque production are not easily separate.[3] The main criteria of vector control is to separate the components of stator current responsible for flux production, and the also the torque. The vector control in an ac machines is obtained by controlling the magnitude, frequency, and stator current phase, by inverter control scheme.[8] As, the control of the motor is obtained by controlling both magnitude and phase angle of the current, this control method is given a name i.e; vector control. In order to achieve independent control of flux and torque in induction machines, the stator (or rotor) flux linkages phasor is maintained constant in its magnitude and its phase is stationary with respect to current phasor.[7]

The vector control structure can be classified in: 1. direct control scheme, when the flux position orientation is determined with the flux sensors and 2. indirect control scheme, then the flux position orientation is estimated using the measured rotor speed. For indirect vector control, the induction machine will be represented in the synchronously rotating reference frame. And even For indirect vector control the control equations can be derived with the help of d-q model of the motor in synchronous reference frame.[4]

The block diagram of the rotor flux oriented control a VSI induction machine drive is presented in Fig. 1.[7]

Generally, a closed loop vector control scheme results in a complex control structure as it consists of the following components:

1. PI controller for motor flux and toque,
2. Current and/or voltage decoupling network,
3. Complex coordinate transformation,
4. Two axis to three axis transformation,
5. Voltage or current modulator ,
6. Flux and torque estimator,
7. PI speed controller

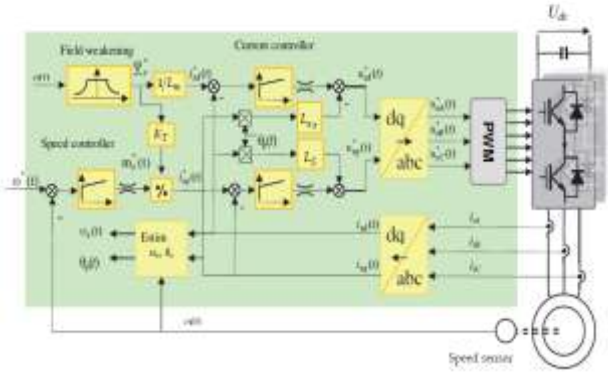

Figure. 1 indirect Vector control of induction Motor

The controllability of speed and torque in an induction motor without any peak overshoot and less ripples with good transient and steady state responses are the main criteria's in the designing of a controller. However, PI controller is able to achieve these up to some extent but having some drawbacks. The gains cannot be increased beyond certain edge so as to have an improved response. Moreover, it causes non linearity into the system making it more complex for analysis. Also it reduces the controller performance.[3]

Now with the advent of new techonology as artificial intelligent techniques, these drawbacks can be reduced. One such technique is the use of neural network in the design of controller. This project work proposes the development of a neural network controller in place of PI controller commonly used in the vector control structure for efficient speed control and smaller settling time. It is expected that the proposed modified vector control structure based on neural network controller smoothens out the ripples in the motor torque and stator currents as well as will provide best speed regulation with smaller steeling time requirement. Fig. 2[7] shows the block diagram representation of proposed Neural Network Controller (NN Controller) based indirect vector control of induction motor.

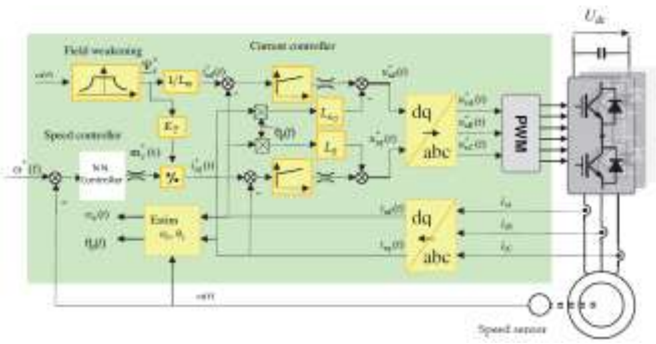

Figure. 2 Proposed NN controller based indirect Vector control of induction motor

IV. IMPLEMENTATION OF INDIRECT VECTOR CONTROLLED INDUCTION MOTOR

This subsection deals with the implementation of the complete system for speed control of induction motor using indirect vector control technique as shown in figure1. To implement this system MATALB 2012 b Simulink platform has been

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utilized. For the efficient implementation as most as possible, inbuilt MATLAB blocks has been utilized. The description of the developed model is as follows:

The developed model consists an induction motor of 50 HP, 460 volt and 1750 RPM, is fed by a current-controlled PWM inverter which is built using a Universal Bridge block available in Simulink library. A 780 volt dc source is connected with the Universal Bridge block. The motor drives a mechanical load which is characterized with the inertia (J), friction coefficient (B), and load torque (T_L).

The speed control loop uses a proportional-integral (PI) controller to produce the quadrature - axis current reference i_q* which controls the motor torque. The direct-axis current reference id* is controls the motor flux. Block DQ-ABC is used to convert i_d* and i_q* into current references i_a*, i_b*, and i_c* used for the current regulator. For visualization purpose the Current and Voltage Measurement blocks are there to provide signals. At the output of the Asynchronous Machine' block the motor current, speed and torque signals are also available.

Table 1 Important parameter used for Simulation.

Induction Motor Parameters	
Power Rating	50 HP
Voltage Rating	460 V
Speed Rating	1750 RPM
Stator Resistance	0.087 Ohm
Stator Inductance	0.8x10-3 H
Rotor Resistance	0.228 Ohm
Rotor Inductance	0.8x10-3 H
Mutual Inductance	3.47E-02
Inertia	1.662
Friction Factor	0.1
Pole Pairs	2
PI Controller for Speed Regulator	
Kp, Ki, Torque Limit	13, 26, 300 Nm

Finally figure (3), shows the simulation model for the speed control of induction motor using indirect vector control technique equipped with PI controller.

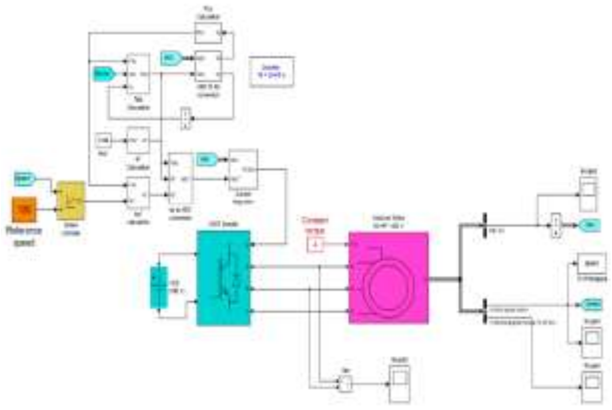

Figure. 3 Simulation model of indirect field oriented vector control of induction motor

The indirect vector controller implemented for speed control of induction motor is shown in figure (4).

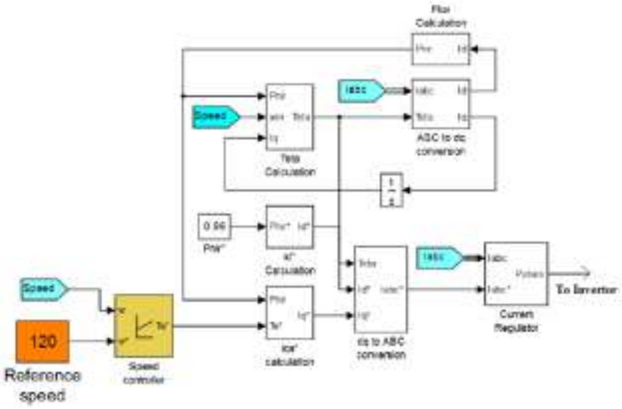

Figure. 4 Indirect vector controller developed

V. Implementation of Proposed Neural Network Based Indirect Vector Controlled Induction Motor

In the previous sub section we have successfully implemented an indirect vector controlled induction motor speed control system; the speed control ability of that system will be analyzed in the results section. This subsection deal with the proposed neural network controller based indirect vector controller for speed control of induction motor. The basic idea is to replace the PI controller used in the speed regulator block by an efficient neural network controller. Hence the first part is to development and training of neural network controller. For the development and implementation of the proposed work same simulation model with identical parameter is used as given in previous sub section.

To model required NN controller the first necessary step is to analyze the deficiency of PI controller during control processes. To analyze the control signal generated by PI controller let us take reference speed to 120 rpm. After simulation of the model shown in figure (3), Figure (6) shows the error signal generated by speed subtractor and Figure (5) shows control signal generated by PI controller in response to error signal.From Figure (6) it is clearly observable that the control signal generated by PI controller not contains many fluctuations to providing stable speed control signal. This is the very important information obtained for modeling and training of NN controller.

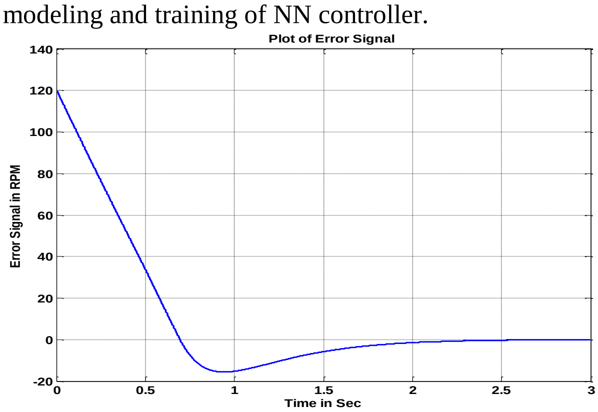

Figure. 5 Error signal

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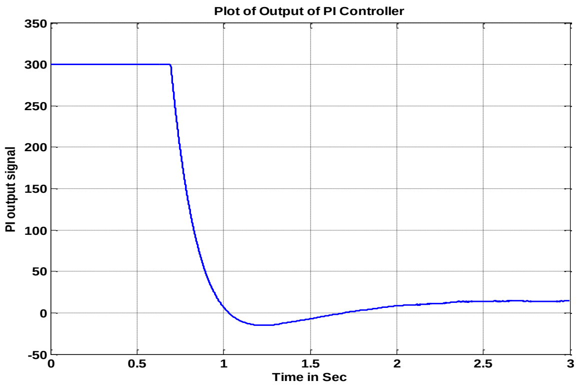


Figure. 6 Figure 6 PI controller output

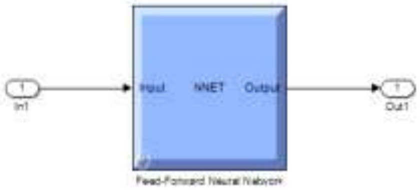
During the analysis of neural network controllers it is found that, for real time processing complex neural network structures are not reliable, therefore in this project a simple feed forward NN is developed for real time speed control. For the development of the NN controller the reference speed 120 RPM. The fundamental steps taken for NN controller modeling are as follows:

Step 1: - Analyze the input for the NN controller.

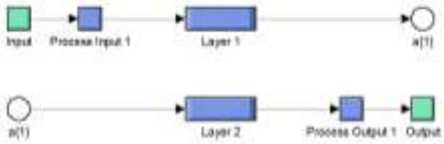
Step 2:- Select the type of NN.

Step 3:- Analyze the desired output for the NN controller.

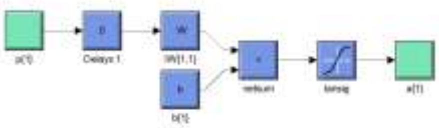
Figure (7) shows the developed simulation model of NN controller and its consequent parts.



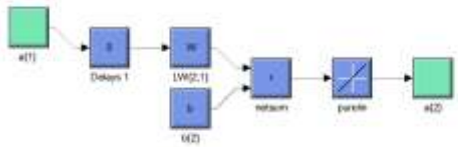
(a) Simulation model of developed NN controller



(b) Internal architecture of NN controller



(c) Internal architecture of Layer one



.(d) Internal architecture of second Layer

Figure. 7 Developed Neural Network Controller and its consequent parts

The training and testing scenario of NN controller is shown in the following figures:

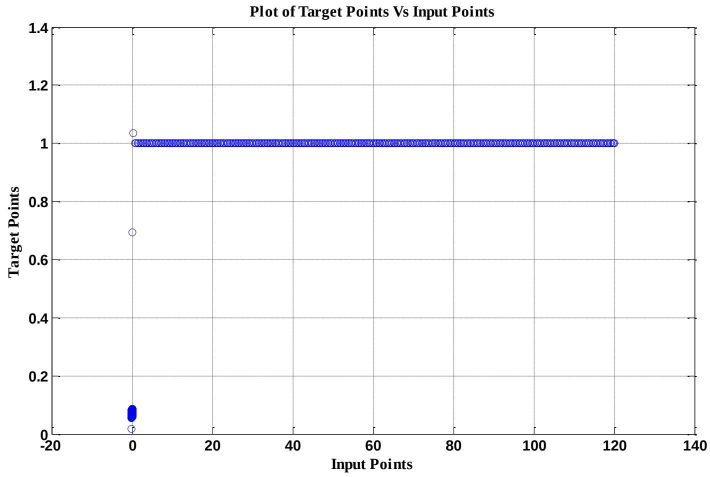


Figure. 8 Figure (8) Plot of Target Vs Input Points.

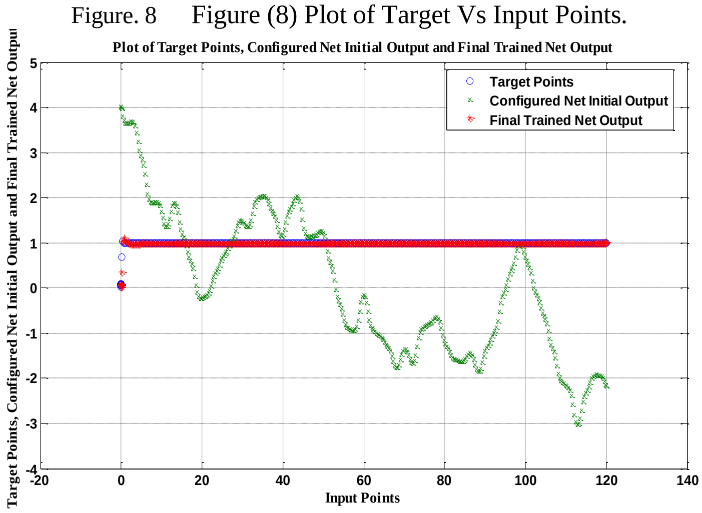


Figure. 9 Trained NN output

Now figure (5.10) shows the complete simulation model of the proposed work

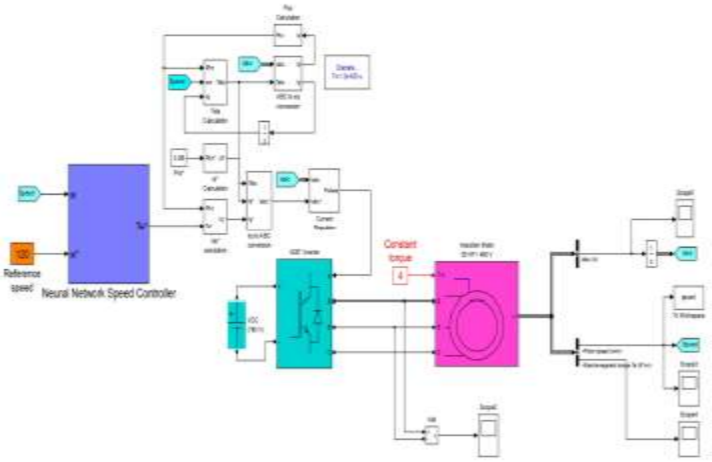


Figure. 10 Simulation model for the speed control of induction motor using NN controller based indirect vector control technique.

VI. SIMULATION RESULTS OF INDIRECT VECTOR CONTROLLED INDUCTION MOTOR SPEED CONTROL AND COMPARATIVE ANALYSIS

This section presents results obtained after simulation of two developed models: first is the simulation model developed for the indirect vector controlled induction motor speed control and the second model developed for the proposed work that is neural network based indirect vector controlled induction motor speed control. For the comparative analysis a comparison between PI controller and developed NN controller is also presented in this section.

To analyze the performance of PI controller and Developed NN controller, let us vary the reference speed from 80 rpm to 150 RPM in 20 RPM step change. Figure (11) to Figure (12) shows the comparative analysis of PI and NN controller.

Case1: For Reference Speed = 80 RPM.

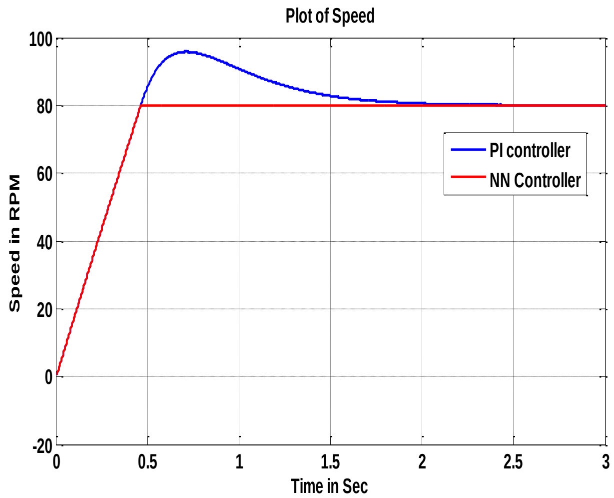


Figure. 11 Comparison of speed control of induction motor using PI and NN controllers based indirect vector control for reference speed = 80 rpm.

Case2: For Reference Speed = 100 rpm.

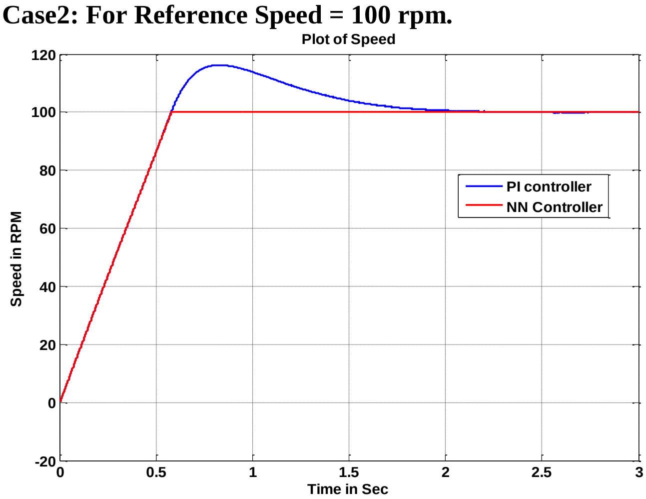


Figure. 12 Comparison of speed control of induction motor using PI and NN controllers based indirect vector control for reference speed = 100 rpm.

Case3: For Reference Speed = 120 rpm.

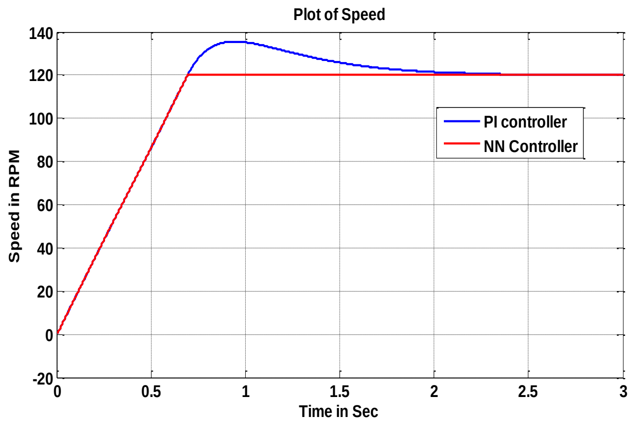


Figure. 13 Comparison of speed control of induction motor using PI and NN controllers based indirect vector control for reference speed = 120 rpm

Case4: For Reference Speed = 140 rpm.

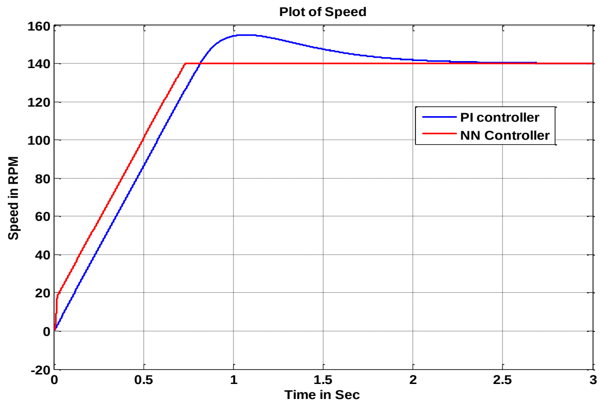


Figure. 14 Comparison of speed control of induction motor using PI and NN controllers based indirect vector control for reference speed = 140 rpm.

The results shown in the above figures, deployes that the developed algorithm is able to provide higly efficient speed control in trasient as well as steady state operation, while figures also shows that, conventional PI controller is not able to provide controlled speed in the transient state because it provides high overshoot in the transient state operation.

VII. CONCLUSIONS AND FUTURE SCOPES

Vector control Technology is the important control method on high performance induction motor speed control system. According to the basic principles of induction motor vector control, this project work started with the development of simulation model of rotor magnetic field oriented vector control system based on the MATLAB Software. The controllability of speed and torque in an induction motor without any peak overshoot and less ripples with good transient and steady state responses are the main criteria's in the designing of a controller. . However, PI controller is able to achieve these up to some extent but having some drawbacks. The gains cannot be increased beyond certain edge so as to have an improved response. Moreover, it causes non linearity into the system making it more complex for analysis. Also it reduces the controller performance. Now with the advent of new techonology as artificial intelligent techniques, these drawbacks can be reduced. One such technique is the use of neural network in the design of controller. This project work proposes the development of a neural network controller in place of PI controller commonly used in the vector control structure for efficient speed control and smaller settling time. It is expected that the proposed modified vector control structure based on neural network controller smoothens out the ripples in the motor torque and stator currents as well as will provide best speed regulation with smaller steeling time requirement. It is shown in the result section that, the proposed modified vector control structure based on neural network controller provides sooth speed in both the transient and steady state regions, as well as it also smoothens out the ripples in the motor torque and stator currents. Therefore the proposed controller provides best speed regulation with smaller steeling time requirement as compare to available state of the art techniques.

In addition to this a comparative analysis of results obtained for conventional PI controller based indirect vector controller and developed neural network based indirect vector controller is also discussed in earlier section. from comparative study done in earlier section it has been found that developed NN controller is not only able to provide efficient speed control in steady state as well it provides efficient speed control in transient stage. which is the shortcoming of PI controller. Hence the developed technique provides efficient speed control as compare to available PI controller based indirect vector controller.

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