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Simulation and Performance Analysis of Dual Loop Speed Controller for Efficient Speed Control of PMSM using Neural Network

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Abstract: **There are a variety of ac servo drives on the market with both the brush machine and others ac servo drives. Two types of permanent-magnet ac motor drives are available in the drives industry. These are the permanent magnet synchronous motor (PMSM) drive with a sinusoidal flux distribution, and the brushless dc motor (BDCM) drive with a trapezoidal flux distribution. This paper deals with the simulation and performance analysis of developed Neural Network (NN) based dual loop speed controller for efficient speed control of PMSM drives. The basic idea came from inability of PI controllers observed during practical situations. It has been observed that PI controllers are widely used for speed control of PMSM drives, although a PI controller provides a good speed control once motor reaches in the steady state. However it shows good performance in steady state but highly suffered from speed ir-regulation problem in transition state. To overcome this problem this paper includes a dual loop controller, in which inner loop is used for regulation of motor stator current using Pulse Width Modulation (PWM) technique and a neural network based controller is used in the outer loop to provide efficient speed regulation to replace conventional PI controller. The results obtained after simulation and performance analysis of developed technique shows the high efficiency of speed control.**

Key Words: PI controller, PMSM, Neural Network, NN Controller, Efficient Speed Control.

I. INTRODUCTION

The permanent magnet synchronous motor (PMSM) has numerous advantages over other machines that are conventionally used for ac servo drives. The stator current of an induction motor (IM) contains magnetizing as well as torque-producing components. The use of the permanent magnet in the rotor of the PMSM makes it unnecessary to supply magnetizing current through the stator for constant air-gap flux; the stator current need only be torque producing. Hence for the same output, the PMSM will operate at a higher power factor (because of the absence of magnetizing current) and will be more efficient than the IM. The conventional wound-rotor synchronous machine (SM), on the other hand, must have do excitation on the motor, which is often supplied by brushes and slip rings. This implies rotor losses and regular brush maintenance, which implies downtime.

Note that the key reason for the development of the PMSM [1]-[3] was to remove the foregoing disadvantages of the SM by replacing its field coil, power supply, and slip rings with a permanent magnet [4]-[8]. To analyse the advantages of NN dual loop based PMSM drives without facing speed ir-regulation this paper presents a healthy performance analysis of developed technique.

II. PMSM MATHEMATICAL MODEL

II.I Basic Model

The main constitute parts of a permanent magnet synchronous are stator and rotor. Three-phase stator windings produce a rotating magnetic field through the three-phase AC supply. Rotor is usually equipped with high-performance permanent magnet in surface or inside of ferromagnetic materials. Such as neodymium iron boron or rare earth magnetic materials to obtain a strong magnetic field, etc. And the rotor magnetic field to distribute for the sine or look likes a sine wave form. The interaction between the stator and rotor magnetic field generated torque when the stator three-phase inverter with access to electricity generated in the motor rotating magnetic field. Then the torque pushes synchronization of the rotor to the stator magnetic field rotation speed to achieve the purpose of frequency control. In order to facilitate analysis, the motor to make the following assumptions: the stator winding three-phase symmetrical, uniform air gap, ignoring the end effect; neglected magnetic saturation and iron loss, magnetic circuit is linear; converter provides an ideal three-phase power, ignoring higher harmonics ; ignore the rotor shaft friction. Figure 2.1 show a cross section of the rotor and stator of a PMSM.

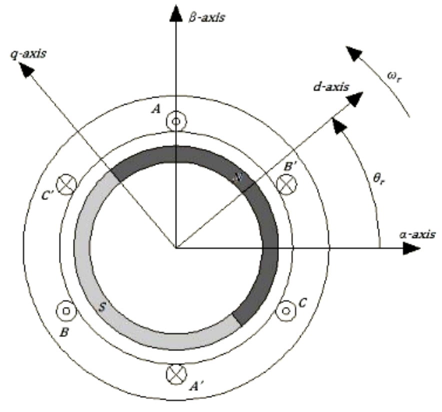

Figure 2.1: View of a three phase, two-pole PMSM.

Considering a two-pole three phase PMSM, the voltage equation in the dq domain (reference frame transformation is explained in *Appendix A. Reference frame conversion*) is expressed as follows [2]:

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$$\overrightarrow{u_{dq0s}} = R_s\overrightarrow{i_{dq0s}} + p\overrightarrow{\lambda_{dq0s}} \qquad ...(2.1)$$

Where *p* is the differentiating operator d/dt. The indexes *d*, *q* and *0* denote direct axis, quadrature axis and zero component of the variables respectively. The flux linkage in the *dq* frame can be calculated as follows:

$$\overrightarrow{\lambda_{dq0s}} = L_{dq0}\overrightarrow{i_{dq0s}} + \overrightarrow{\lambda_{dq0,m}} \qquad ...(2.2)$$

Where the inductance matrix is expressed:

$$L_{dq0} = \begin{bmatrix} L_d & 0 & 0 \\ 0 & L_q & 0 \\ 0 & 0 & L_0 \end{bmatrix} = \begin{bmatrix} L_s & 0 & 0 \\ 0 & L_s & 0 \\ 0 & 0 & L_0 \end{bmatrix} \qquad ...(2.3)$$

For SMPM, the *d* and *q* components of the inductances are the same. The notation *dq* is change for *s*, which refers to the stator. The magnetizing flux has the following expression:

$$\lambda_{dq0,m} = [\lambda_{pm} \;\; 0 \;\; 0]^T \qquad ...(2.4)$$

A usual way to write the equation (2.1) is in its expanded form. As far as the stator windings are wye-connected (with a neutral point) and supplied with balanced three phase currents, the zero-axis components are neglected [2]. The voltage equations for d and q axes are:

$$u_{ds} = R_s i_{ds} + L_s\frac{di_{ds}}{dt} - \omega_r L_s i_{qs} \qquad ...(2.5)$$

$$u_{qs} = R_s i_{qs} + L_s\frac{di_{qs}}{dt} + \omega_r\left(L_s i_{ds} + \lambda_{pm}\right) \qquad ...(2.6)$$

Where R_S is the stator resistance, L_S the stator inductance, ω_r the rotor rotational speed and λ_{pm} the permanent magnet flux. The electromagnetic torque of the machine can be expressed, in the *dq* reference frame, as follows:

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}\right) \qquad ...(2.7)$$

If the equation (2.2) is substituted in the torque equation, it is obtained:

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left(\lambda_{pm} i_{qs} - (L_q - L_d) i_{qs} i_{ds}\right) \qquad ...(2.8)$$

Considering a non-salient rotor, where the inductances are equal, the final expression of the electromagnetic torque is:

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\lambda_{pm} i_{qs} \qquad ...(2.9)$$

This result is quite interesting. It shows that the only component involved in torque production in a PMSM without saliency is the stator q-axis current. The AC permanent magnet synchronous motor is a multi-variable coupled and nonlinear time-varying system in last type. Direct use of traditional linear control theory cannot achieve effective control of it. Therefore, it must be possible to transform and simplify the use of classical control theory regulator design.

III. PULSE-WIDTH MODULATION (PWM)

PWM is a modulation technique that conforms the width of the pulse, formally the pulse duration, based on modulator signal information. Although this modulation technique can be used to encode information for transmission, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off periods, the higher the power supplied to the load is. The PWM switching frequency has to be much faster than what would affect the load, which is to say the device that uses the power. Typically switching has to be done several times a minute.

The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on. The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.[14]

III.I Principle of PWM

Pulse-width modulation uses a rectangular pulse wave whose pulse width is modulated resulting in the variation of the average value of the waveform. If we consider a pulse waveform f(t) with a low value y_{min}, a high value y_{max} and a duty cycle D (see figure 1), the average value of the waveform is given by:

$$\bar{y} = \frac{1}{T}\int_0^T f(t)\,dt \qquad (3.1)$$

As f(t) is a pulse wave, its value is y_{max} for $0 < t < D.T$ and y_{min} for $D.T < t < T$. The above expression then becomes:

$$\begin{aligned}\bar{y} &= \frac{1}{T}\left(\int_0^{DT} y_{max}\,dt + \int_{DT}^{T} y_{min}\,dt\right)\\ &= \frac{D\cdot T\cdot y_{max} + T\,(1-D)\,y_{min}}{T}\\ &= D\cdot y_{max} + (1-D)\,y_{min}.\end{aligned} \qquad (3.2)$$

This latter expression can be fairly simplified in many cases where $y_{min} = 0$ as $\bar{y} = D.y_{max}$. From this, it is obvious that the average value of the signal ($\bar{y}$) is directly dependent on the duty cycle D. figure(1) shows a pulse wave, showing the definitions of ymin, ymax.

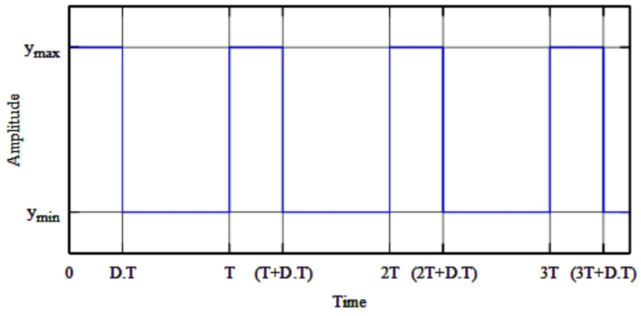


Figure (1)

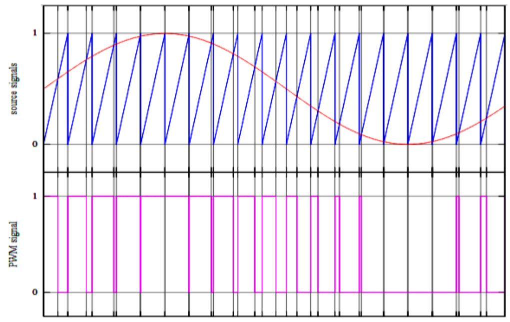


Figure (2)

The simplest way to generate a PWM signal is the interceptive method, which requires only a saw tooth or a triangle waveform (easily generated using a simple oscillator) and a comparator. When the value of the reference signal (the red sine wave in figure 2) is more than the modulation waveform (blue), the PWM signal (magenta) is in the high state, otherwise it is in the low state.

IV. MODELING OF NEURAL NETWORK CONTROLLER FOR PMSM (OUTER LOOP)

A neural net work is a generalized approach of making the learning algorithm and making a decision for accurate controlling operation in various applications. The approach of neural net work basically works on the provided priories information and makes a suitable decision for a given testing input based on the provided training information. This approach is analogous to the human controlling approach where all the past observations are taken as the reference information and are used as a decision variable. As already discussed in previous section this paper include a dual loop control for PMSM speed control. This section deals with the modeling and simulation of neural network controller for outer loop control. 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 paper a simple feed forward NN is developed for real time speed control. The fundamental steps taken for NN controller modeling are as follows:

Step 1: - Analyse the input for the NN controller.
Step 2:- Select the type of NN.
Step 3:- Analyse the desired output for the NN controller.

Figure (3) shows the developed simulation model of NN controller and its consequent parts.

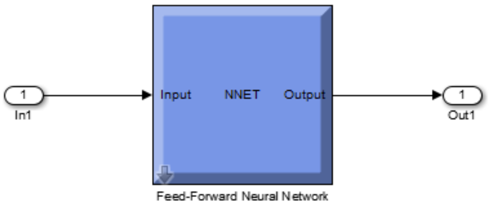
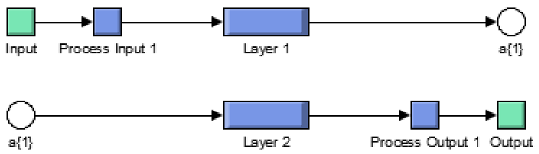


Figure (3)(a) Developed simulation model of NN controller



Figure(3)(b) Internal architecture of NN controller

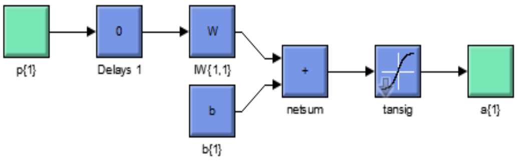


Figure (3)(c) Internal architecture of Layer one

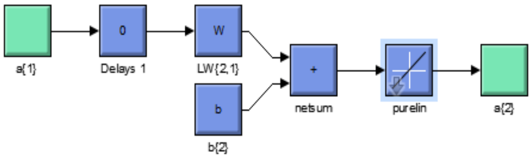


Figure (3)(d) Internal architecture of second Layer

V. METHODOLOGY

Earlier lots of work have been done for speed control of drives but this area is still lacking for an efficient and real time speed control. This paper deals with a dual loop controller, in which inner loop is designed for regulation of motor stator current using Pulse Width Modulation (PWM) technique and a neural network based controller is in the outer loop to provide efficient speed regulation to replace conventional PI controller. This section briefly describes the developed algorithm with help of block diagram shown in figure (4).

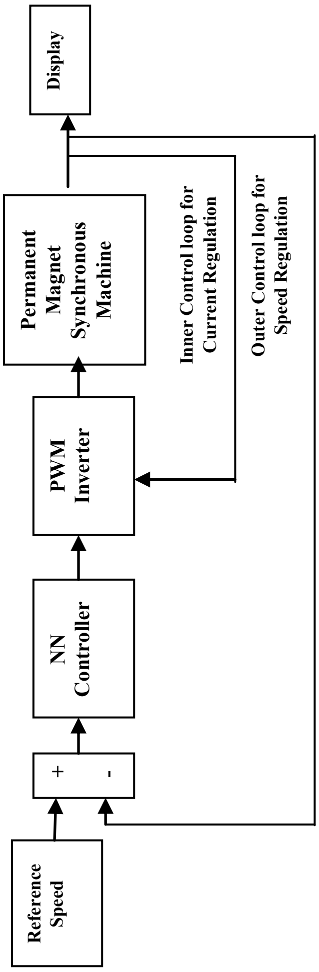


Figure (4) Block diagram of developed Method [1].

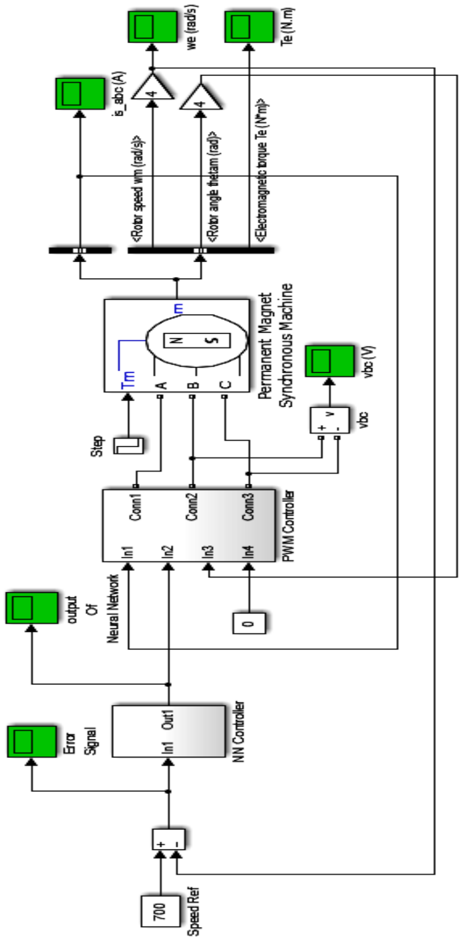


Figure (5) Actual Simulation Model of developed Method [1].

VI. RESULTS AND DISCUSSION

This section presents results obtained after simulation of developed method. For the comparative analysis a comparison between PI controller and developed NN controller is also presented in this section. Let us first analyse the drawback of PI controller during speed regulation. Figure (6) shows resultant speed curve when PI controller is used in outer loop. From figure (6) it is clear that, during the transient periode PI controller provides some oscillation, this leads to defficiency of PI controller in speed control. Figure (7) shows a magnify view of speed during transient periode.

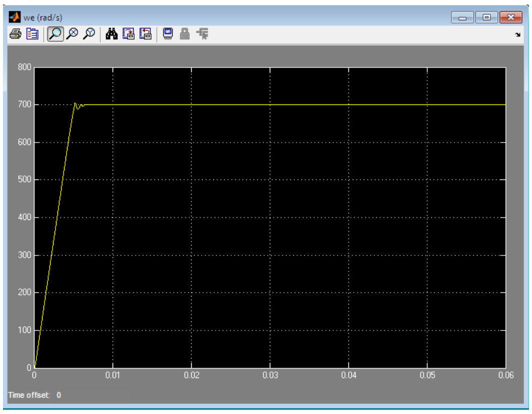


Figure (6) Speed Using PI controller

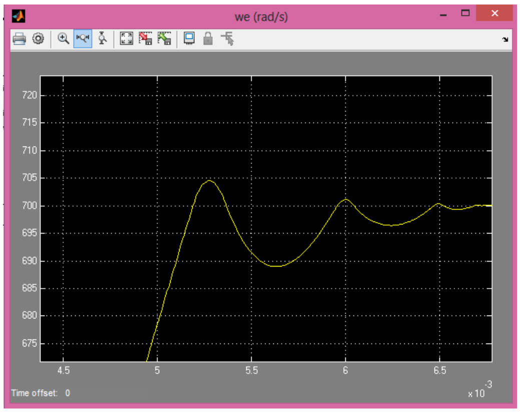


Figure (7) Magnify View.

Therefore the main aim of our technique is to provide stable and smooth speed curve using Neural Network based speed controller. the result of speed curve using NN controller in outer loop is shown in figure (8).

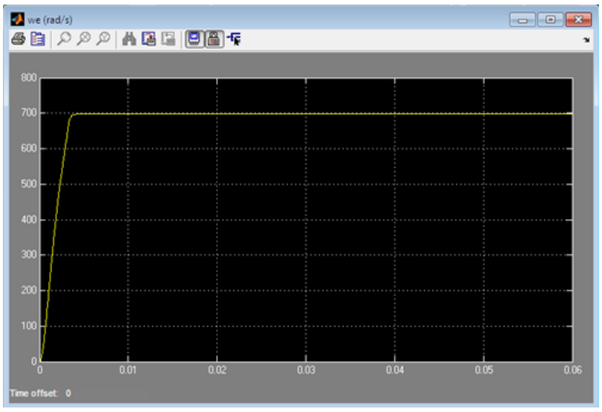
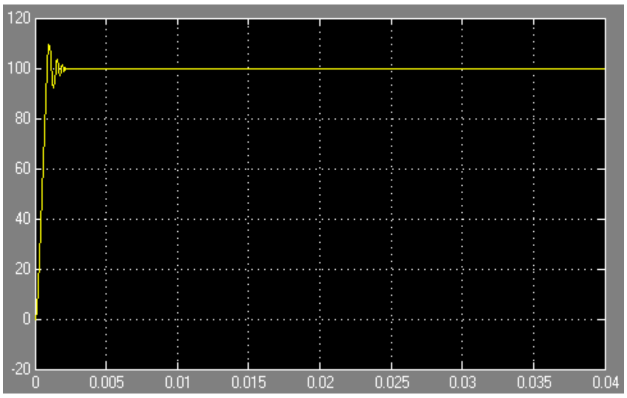


Figure (8) Speed using NN Controller.

From figure (8) it is clerily evident that the developed dual loop controller provides efficient speed control for PMSM drive. Now in the next part of this section , includes comparative performance analysis of the normal PI and developed NN based dual loop controller for different reference speeds.

1) For Reference Speed = 100 rpm



Figure(9) Output of PI controlled PMSM

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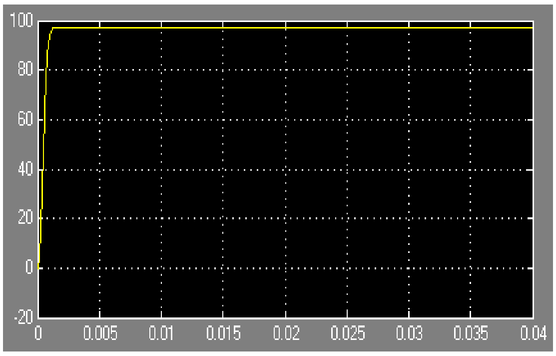
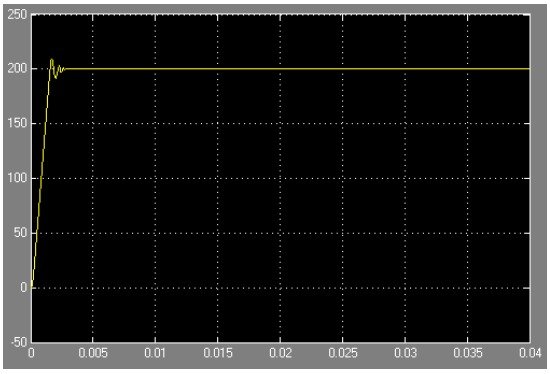
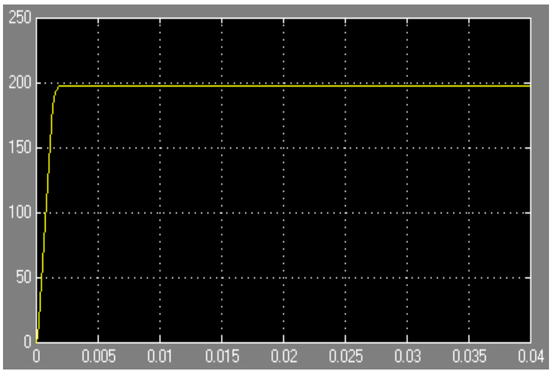


Figure(10) Output of NN dual loop controlled PMSM

2) For Reference Speed = 200 rpm

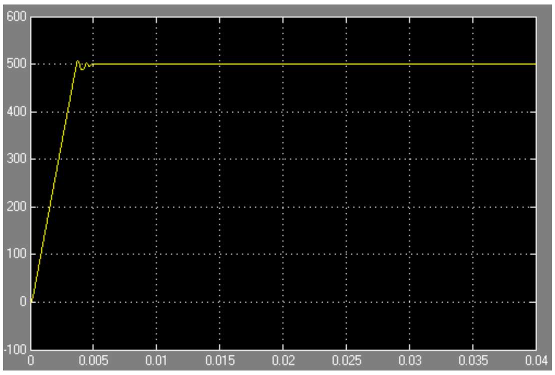


Figure(11) Output of PI controlled PMSM

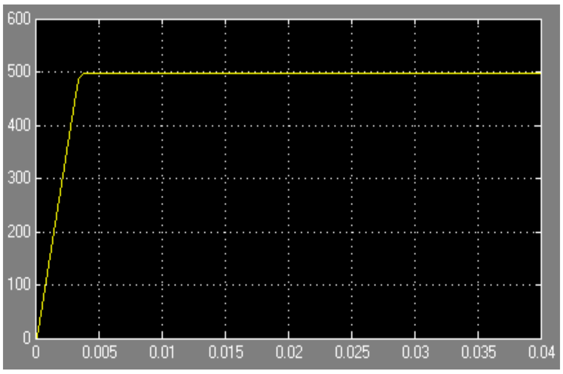


Figure(12) Output of NN dual loop controlled PMSM

3) For Reference Speed = 500 rpm

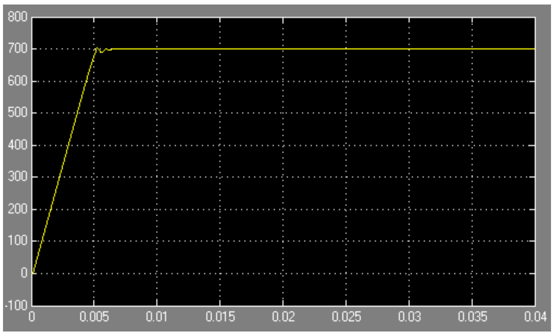


Figure(13) Output of PI controlled PMSM

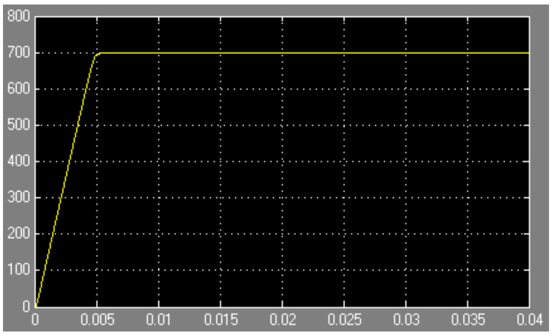


Figure(14) Output of NN dual loop controlled PMSM

4) For Reference Speed = 700 rpm

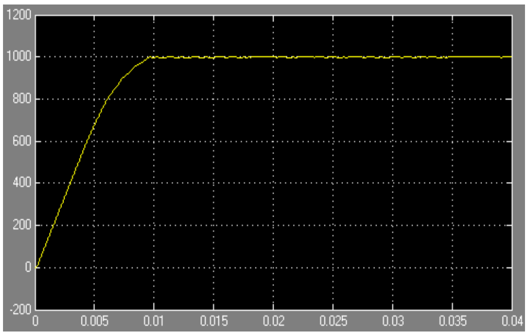


Figure(15) Output of PI controlled PMSM

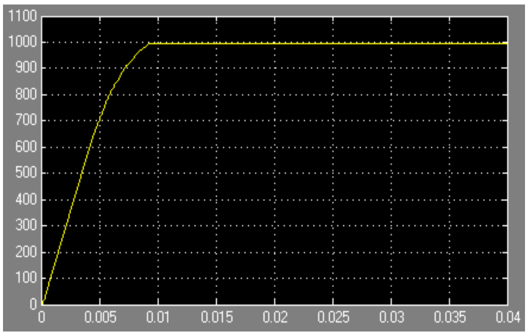


Figure(16) Output of NN dual loop controlled PMSM

1) For Reference Speed = 1000 rpm



Figure(17) Output of PI controlled PMSM



Figure(18) Output of NN dual loop controlled PMSM

VII. CONCLUSIONS

PMSM drive is the most commonly used motor for not only industrial as well as other areas. Therefore the speed regulation for PMSM plays a crucial role in its applicable areas. In this paper a new method for efficient speed control of PMSM drive is successfully implemented in MATLAB Simulink.

In addition to this a comparative analysis of results obtained for conventional PI controller and developed NN controller is also discussed in previous section. from comparative analysis done in previous 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 period, which is the drawback of PI controller. Hence the developed technique provides efficient speed control as compare to available PI controller.

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