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# Modelling and Simulation of DTC of PMSM Drive using Artificial Neural Network

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**ABSTRACT**

An improved direct torque flux control (DTC) of Permanent Magnet Synchronous Motor (PMSM) Drive using Artificial Neural Network (ANN) for the reduction of torque ripples is investigated in this paper . Electro-magnetic torque developed in conventional PMSM drives produce high torque ripples which creates vibrations to the motor that may lead to components loss and bearings failure as well. The main demerits of the conventional Permanent Magnet Synchronous Motor Drive are high torque ripples and speed reduction of PMSM under dynamic and transient operating state. This demerit is reduced by using proposed control technique. In this improved control technique the Proportional Integral (PI) controller and ANN are regulating the speed and reducing the torque ripples of the PMSM drive respectively. MATLAB Simulink is used for simulation of conventional PMSM drive.

***Keywords:*** Artificial Neural Network (ANN); Direct Torque Control (DTC); Permanent magnet Synchronous motor drive (PMSM); MATLAB Simulink.

## 1. INTRODUCTION

In recent years PMSM has acquired more & more applications because of its properties like light weight, small size and inertia, high efficiency, rotor with no heating problem, etc. DTC is an advance control methods compared to conventional vector controls method which disposes of decoupling consideration of vector control, and uses directly stator flux linkage for controlling the torque & flux linkage of the motor. Thus it makes the response of the system very fast. The DTC control technique applied for PMSM Drive to get better torque characteristics of the motor, and in present scenario it has acquired the widespread attention of the people In permanent magnet synchronous motor (PMSM) Drives, the controlling algorithm

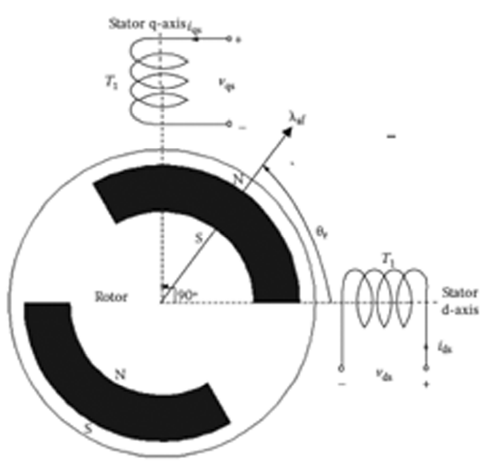


**Figure 1: 2- phase PMSM**

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becomes a key feature where high performance is required, such as in weakening of field or in high torque application [11].

## 2. PERMANENT MAGNET SYNCHRONOUS MOTOR

PMSM have been a popular choice for transportation systems, including hybrid and plug-in hybrid vehicles, aerospace, and military applications. With growing electrification in hybrid vehicles, a significant requirement for reliability and fault-tolerant operation has been seen in addition to high power density and high efficiency. This is particularly the case for mission-critical applications in military and aerospace applications, where the current failure or position sensor at the time of operation may go to failure of the whole system. This paper uses a new concept of universal sensors using search coils is proposed, to give the PMSM's drive system a "+1" fault tolerance [6, 7, 10, 11].

A 2- phase PMSM shown in fig. 1 and the windings are spaced by 90 degrees electrical and the rotor windings at an angle θr from the d-axis winding of stator. It is supposed that the d-axis lags the q-axis in a clockwise direction of rotor rotation. θr is the instantaneous electrical rotor position obtained by multiply pairs of electrical poles by mechanical rotor position. The stator voltages of *q* and *d* axes are found as the sum of the derivative of the flux linkages in the own windings and the resistive voltage drops [12].

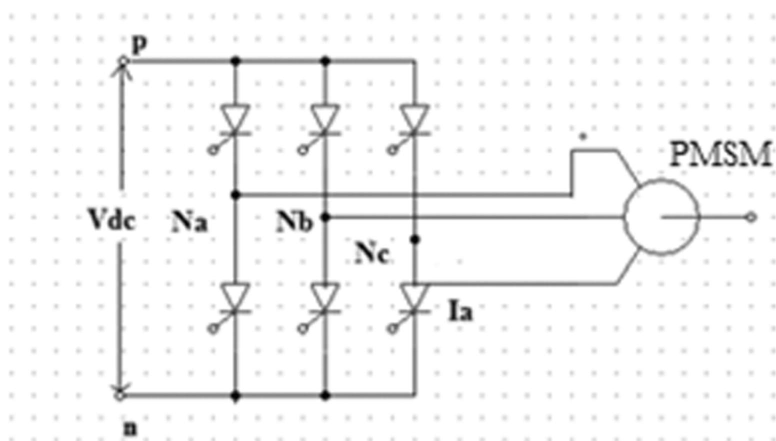



**Figure 2: Schematic diagram of voltage source inverter (VSI).**

## 3. DIRECT TORQUE CONTROL (DTC) & MODELLING OF PMSM

Schematic diagram of VSI is shown in Fig. 2. The 8 possible voltage space vectors which include 6 ($V_1$-$V_6$) active voltage vectors & two zero voltage vectors ($V_7$ and $V_8$) as shown in Fig. 3. These eight vectors are the combination of three switching modes $N_a$, $N_b$ and $N_c$. When the upper switches $N_a$, $N_b$ and $N_c$ are ON, then three combination is called 'p' and when the lower switches $N_a$, $N_b$ and $N_c$ are ON, then three combination is called 'n'.

$$\overline{V_{s,k}} = \frac{2}{3} V_{dc} \left[ N_a + aN_b + a^2 N_c \right] \tag{1}$$

where $V_{dc}$ = inverter dc voltage, $a = e^{j2\pi/3}$

Equation of stator output phase voltages is following

$$\begin{bmatrix} V_a^s \\ V_b^s \\ V_c^s \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} N_a \\ N_b \\ N_c \end{bmatrix} \tag{2}$$

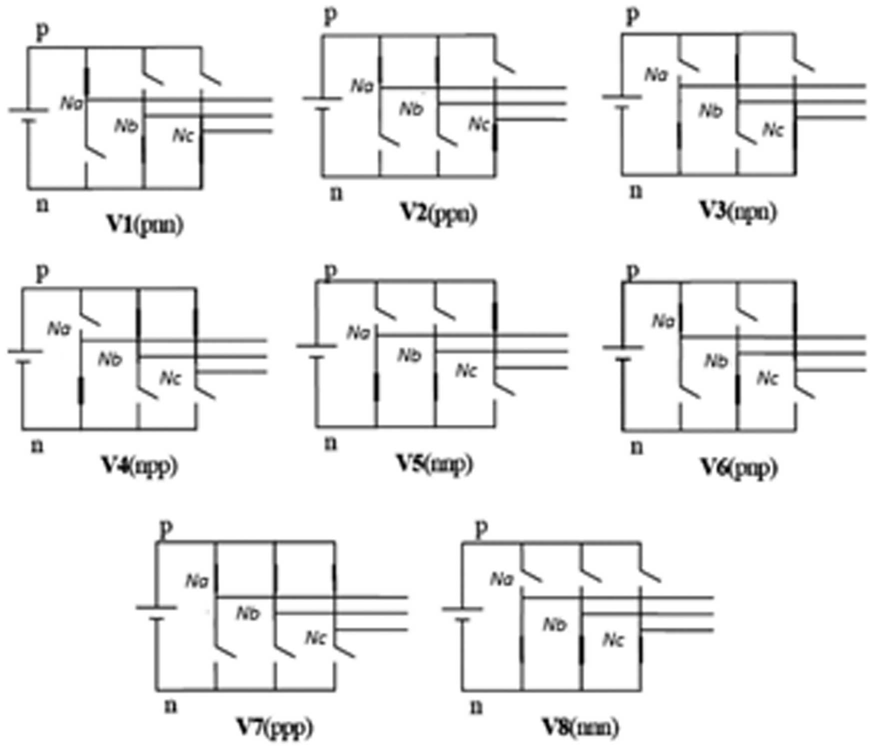



**Figure 3: Eight voltage vector switching configuration**


**Figure 4: Inverter voltage vectors**

The equations of conversion from $V_a^s$, $V_b^s$ and $V_c^s$ to $V_{ds}^s$ and $V_{qs}^s$ are following equations (3), and (4).

$$V_{ds}^s = \frac{2}{3}N_a - \frac{1}{3}N_b - \frac{1}{3}N_c \tag{3}$$

$$V_{qs}^s = -\frac{1}{\sqrt{3}}N_b + \frac{1}{\sqrt{3}}N_c \tag{4}$$

The representation of the behavior of PMSM drive using DTC is described in the stator stationary reference frame by following equations

$$V_{ds}^{s} = R_s i_{ds}^{s} + \frac{d}{dt}\lambda_{ds}^{s} \tag{5}$$

$$V_{qs}^{s} = R_s i_{qs}^{s} + \frac{d}{dt}\lambda_{qs}^{s} \tag{6}$$

The $q$ stator flux linkage and $d$ stator flux linkage are described as

$$\psi_{qs} = L_{qq} i_{qs} + L_{qd} i_{ds} + \lambda_{af} \sin\theta_r \tag{7}$$

$$\psi_{ds} = L_{qq} i_{qs} + L_{qd} i_{ds} + \lambda_{af} \sin\theta_r \tag{8}$$

Where θr = instantaneous position of rotor. Balanced winding with their resistances are Rs = Rq = Rd. The d and q voltages of stator written as

$$V_{qs} = R_s i_{qs} + i_{qs} PL_{qq} + L_{qq} Pi_{qs} + L_{qd} Pi_{ds} + i_{ds} PL_{qd} + \lambda_{af} P \sin\theta_r \tag{9}$$

$$V_{ds} = R_s i_{ds} + i_{qs} PL_{qd} + L_{qd} Pi_{qs} + L_{dd} Pi_{ds} + i_{ds} PL_{dd} + \lambda_{af} P \cos\theta_r \tag{10}$$

where $L_{qq}$ & $L_{dd}$ are the self-inductances of the $q$ axes winding & $d$ axes winding. L is denoted by mutual inductances between two windings. The mutual inductance $L_{qd}$ and $L_{dq}$ are equal. The inductance due to saliency, i.e., when $L_q \neq L_d$. PMSM surface is mount by magnet, then inductances L are equal and, therefore, $L_2$ is zero. Equation is written as

$$\begin{bmatrix} V_{qs} \\ V_{ds} \end{bmatrix} = R_s \begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix} + \begin{bmatrix} L_1 & 0 \\ 0 & L_2 \end{bmatrix} d/dt \begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix} + \lambda_{af}\omega_r \begin{bmatrix} \cos_{\theta r} \\ \sin_{\theta r} \end{bmatrix} \tag{11}$$

The instantaneous electromagnetic torque ($T_e$)

$$T_e = \frac{3}{2}\frac{P}{2}\left[\psi_{af} + \left(L_d - L_q\right) i_{dr}\right] i_{qr} \tag{12}$$

Voltage vectors are at random chosen from hexagon when a hysteresis controller is used. That hexagon contains seven possibilities is shown in Fig. 4, $v_1$-$v_6$ corresponds to 6 active switching state vectors, whereas $v_1$ & $v_8$ both are zero voltage vector. The consequent phase voltages which is a function of $V_{dc}$ are planned in Table 1 ($T_1$, $T_2$ & $T_3$ are the switching devices).

**Table 1**
**Inverter Switching States**
**with corresponding voltage vectors**

| $T_1$ | $T_2$ | $T_3$ | $V_k$ | $V_a$ | $V_b$ | $V_c$ |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | $V_8$ | 0 | 0 | 0 |
| 1 | 0 | 0 | $V_1$ | 2Vdc/3 | -Vdc/3 | -Vdc/3 |
| 1 | 1 | 0 | $V_2$ | Vdc/3 | Vdc/3 | -2Vdc/3 |
| 0 | 1 | 0 | $V_3$ | -Vdc/3 | 2Vdc/3 | -Vdc/3 |
| 0 | 1 | 1 | $V_4$ | -2Vdc/3 | Vdc/3 | Vdc/3 |
| 0 | 0 | 1 | $V_5$ | -Vdc/3 | -Vdc/3 | 2Vdc/3 |
| 1 | 0 | 1 | $V_6$ | Vdc/3 | -2Vdc/3 | Vdc/3 |
| 1 | 1 | 1 | $V_7$ | 0 | 0 | 0 |

## 4. CONVENTIONAL PMSM DRIVE MODEL

AC6 block of the Sim Power Systems electric drives library models a permanent magnet synchronous motor drive with a braking chopper for a 100kW motor. Conventional models a flux deteriorating vector control for a 12500 rpm, 100 kW, salient pole Permanent Magnet Synchronous Motor powered by a 288 Vdc source. The mechanical system is represented by externally. The input of the motor is the speed and the output is the electromagnetic torque. Fig. 5 shows block diagram of conventional PMSM drive [4].

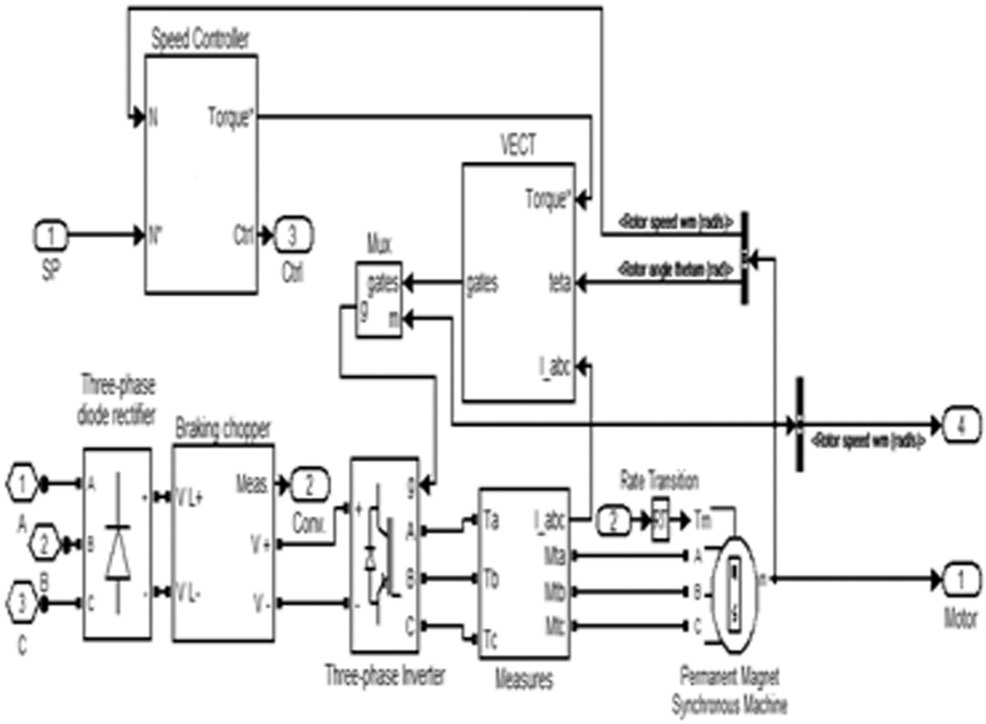



**Figure 5: Block diagram of conventional permanent magnet synchronous motor (PMSM) drives.**

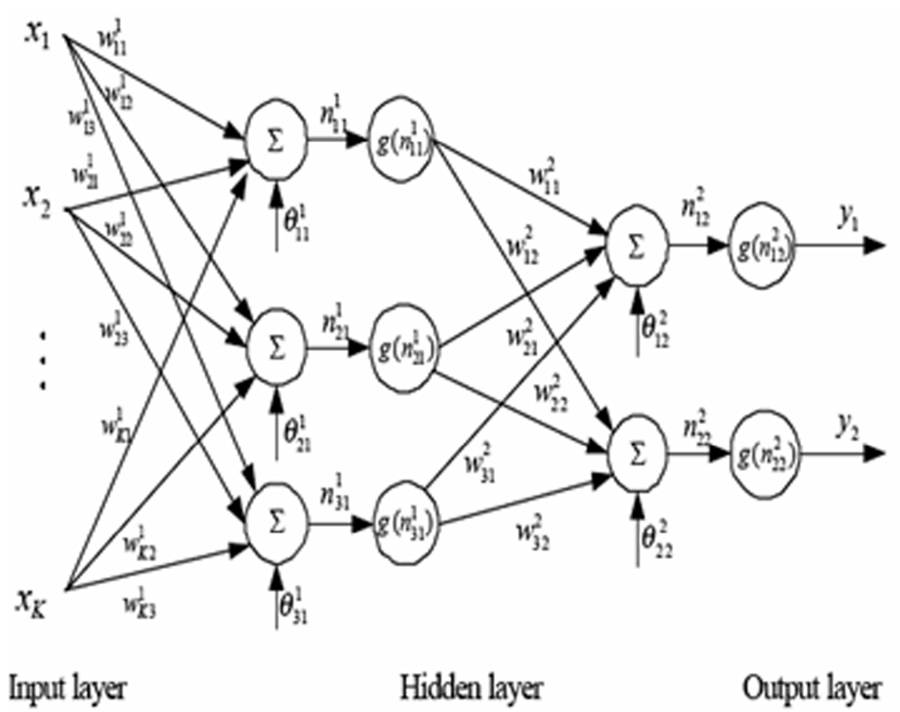



**Figure 6: MLP network with 1 hidden layer**

# 5. PROPOSED TECHNIQUE

## 5.1. Artificial Neural Network's (ANN) Principles

Artificial neural network (ANN) use a compact inter-connection of computed nodes approximation of nonlinear function. All nodes constitute a neuron and multiply its input signals by sum up the outputs, constant weights and maps the summing nonlinear function g; then its output is transfer to its main output. Neural network (NN) training is shown in fig. 7. A forward ANN is prepared in layers: an input layer, too many hidden layers and an output layer [1,4,5].

The inputs $x_k$, $k = 1 \ldots k$ to the neuron are multiply by weights $w_{ki}$ and sum up together with the constant $\theta_i$. The resulting *i n* is the input to the '*g*'. The '*g*' was firstly chosen by a sigmoid function [1, 4, 5].

$$y_i = g_i = g\left(\sum_{i=1}^{N} w_{ji} x_j + \theta_i\right) \tag{14}$$

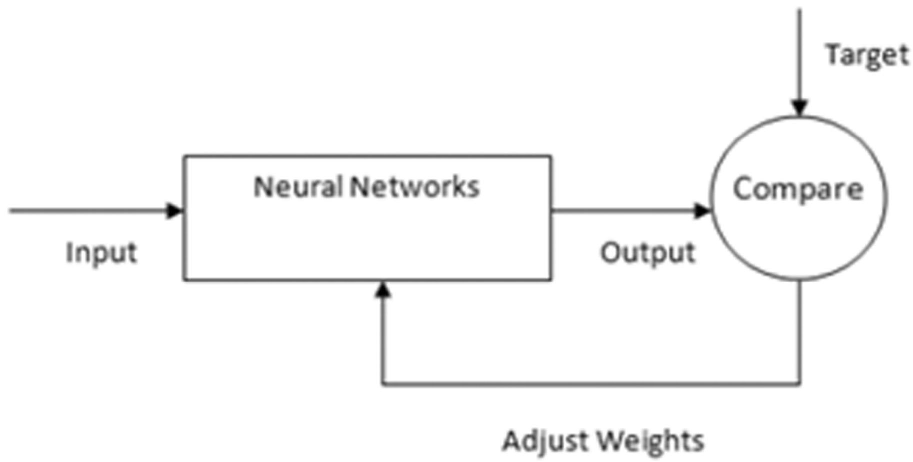



**Figure 7: Neural network.**

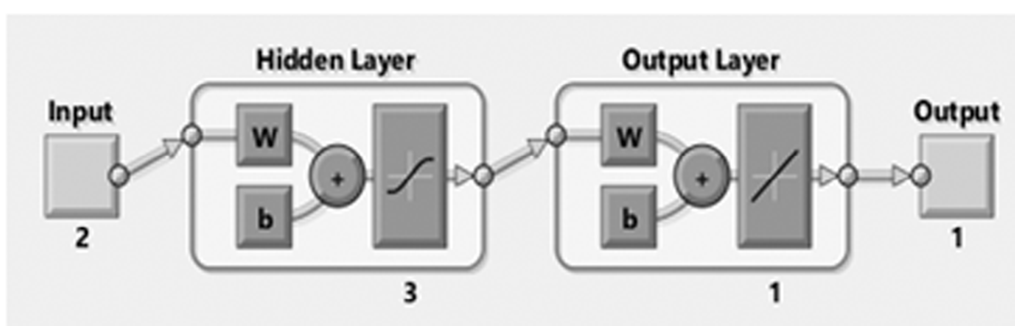



**Figure 8: Neural Network architecture Proposed DTC PMSM motor**

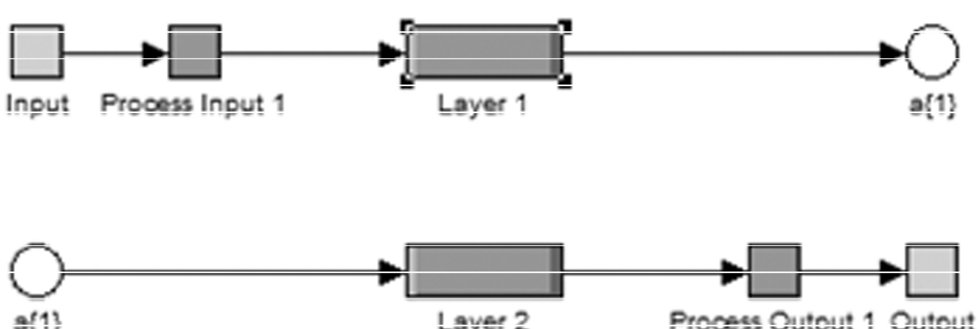



**Figure 9: Block Hidden Layer**

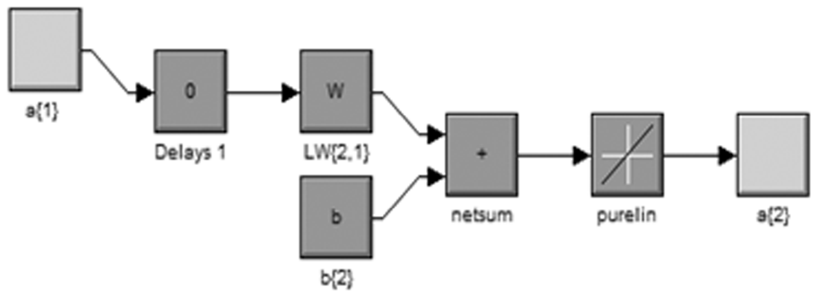
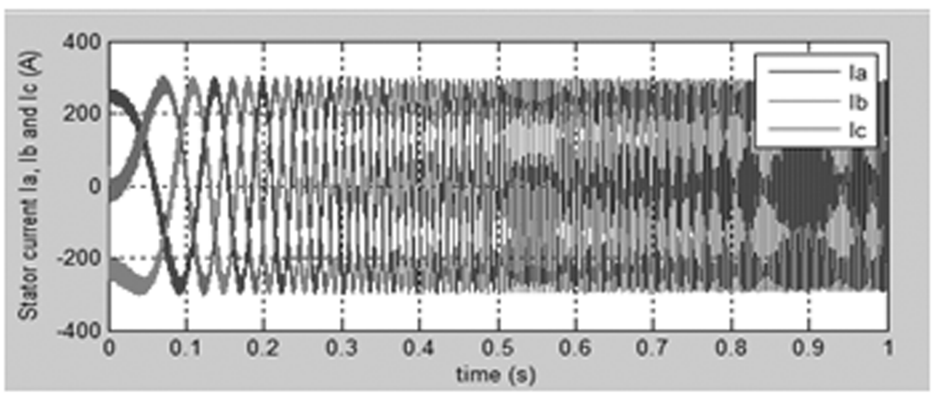


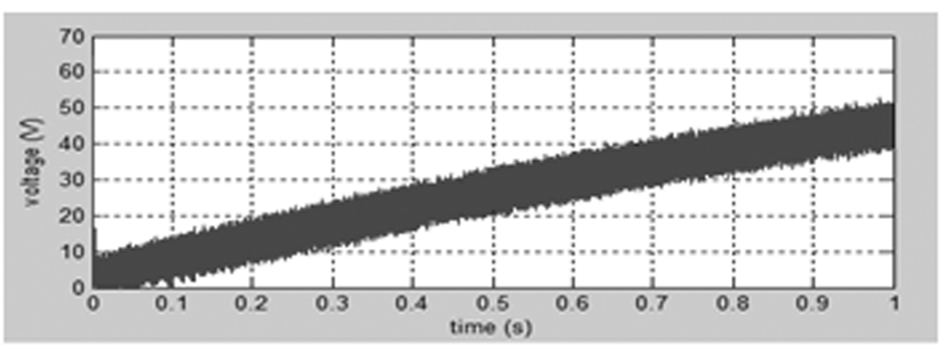

**Figure 10: Open Block of Hidden Layer**

## 6. SIMULATION RESULTS

The conventional and Proposed Artificial Neural Network (ANN) based PMSM drives MATLAB model are found for 3hp PMSM drives where Voltage Source Inverter input DC voltage is 220 Volts. The parameters of PMSM drive are shown in Table 2. The conventional and proposed Artificial Neural Network (ANN) simulation results are shown in Fig. 11 and Fig. 12, respectively. By comparing the results of electromagnetic




(i)

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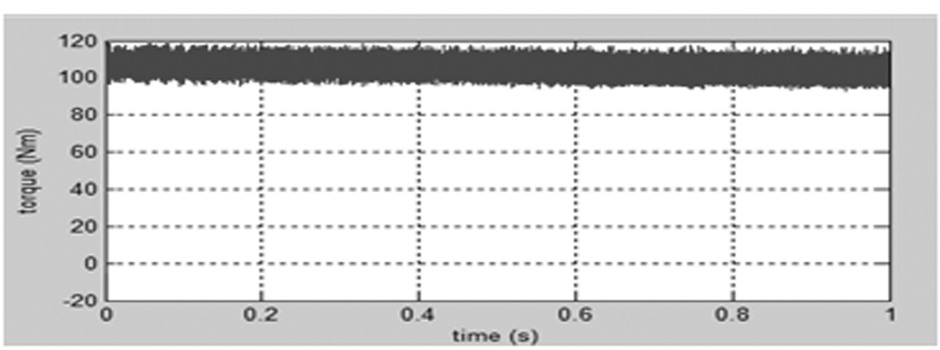


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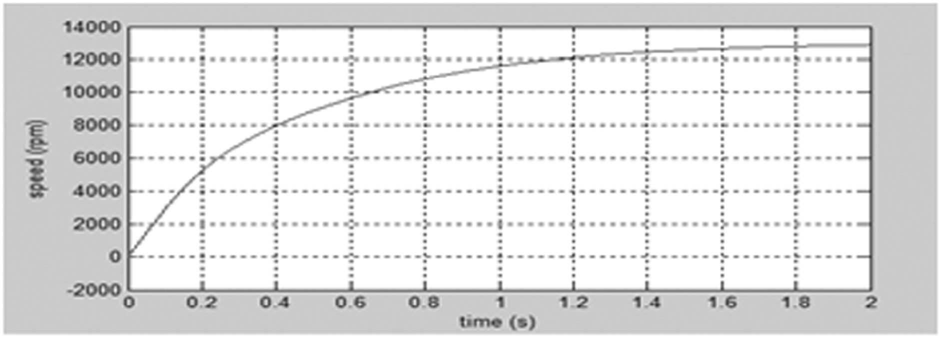


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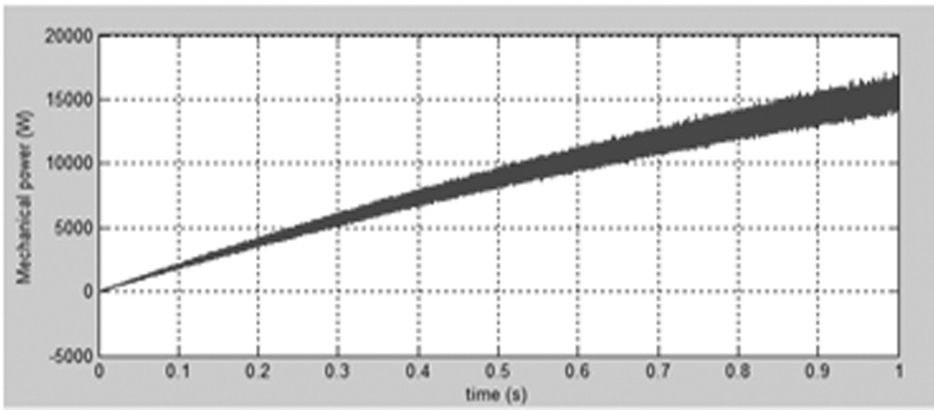
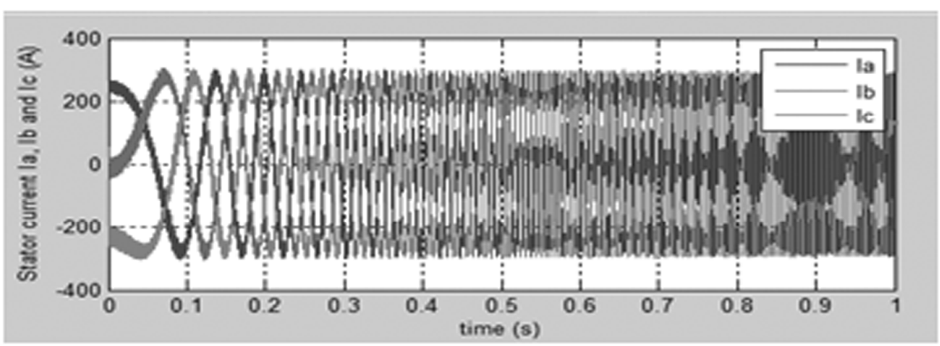
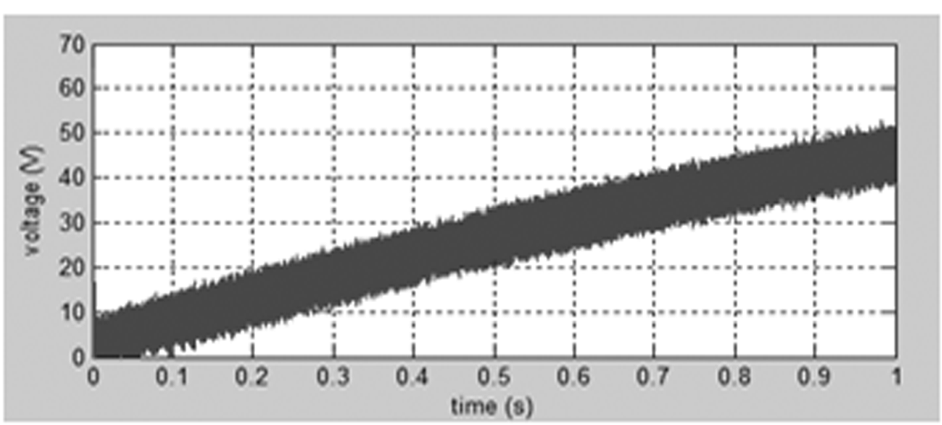



**(v)**

**Figure 11: Conventional 3hp PMSM drives (i) Stator Current Ia, Ib and Ic (ii) Voltage Vq and Vd (iii) Electromagnetic torque Te (iv) Speed (v) Mechanical Power**




**(i)**

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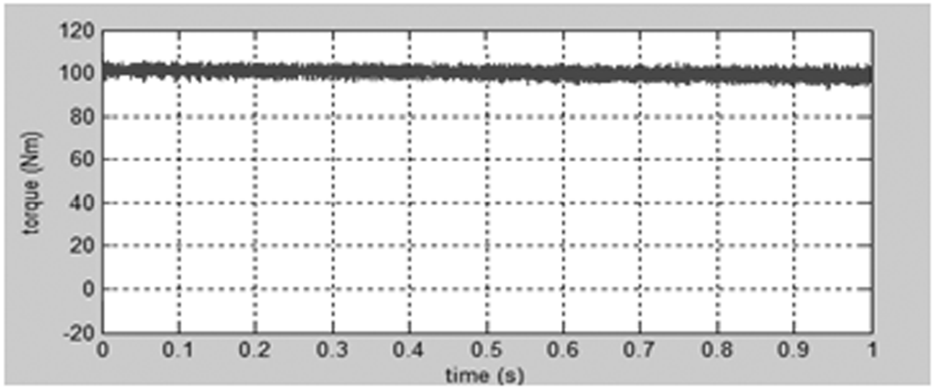
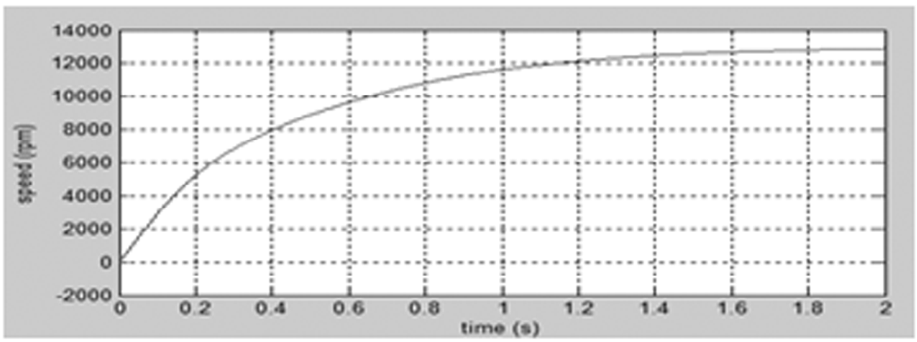
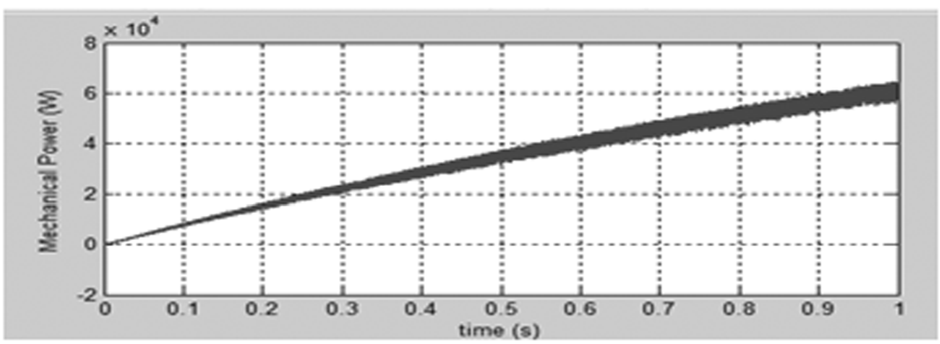



**(iii)**




**(iv)**




**(v)**

**Figure 12: Proposed ANN based PMSM drives (i) Stator Current Ia, Ib and Ic (ii) Voltage Vq and Vd (iii) Electromagnetic torque (iv) Speed (v) Mechanical Power**

**Table 2**
**Permanent Magnet Synchronous Motor Drive Parameter**

| *Parameters (3hp)* | *Nominal values* |
|---|---|
| Resistance (R) | 0.008296Ω |
| Inductance (Ld) | 0.17415845761mH |
| Inductance (Lq) | 0.29268882377mH |
| Pole pair | 4 |
| Voltage (V) | 288V |
| Speed | 1250RPM |

torque waveforms achieved through Conventional PMSM drive and Artificial neural network (ANN) based PMSM drive is peak-to-peak ripples of 120 – 100 Nm (20 Nm) in Conventional PMSM drive and 107 – 100 Nm (7 Nm) in Proposed method as shown in Table 3.

**Table 3**
**Comparison Between Conventional & Proposed PMSM Drives**

| *S. no.* | *Parameter* | *Conventional* | *Proposed PMSM* | *Remarks* |
|---|---|---|---|---|
| 1 | Torque Ripples | 20 Nm | 7 Nm | Reduced |
| 2 | Speed | No change | No change | Same |
| 3 | Current | No change | No change | Same |
| 4 | Voltage | No change | No change | Same |

## 7. CONCLUSION

From the control side, proposed technique is used here to minimize the torque ripples in PMSM drives. Based on the appropriate machine parameters information, torque pulsations are minimized using advanced methods of applied control technique in this paper. The resultant smooth operation of a PMSM drive is a pre-requisite for it to be used for any application. The proposed ANN technique is shown to achieve this effectively through different control techniques.

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