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Artificial Neural Network in Field Oriented Control for Matrix Converter Drive

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Abstract: Matrix Converters are becoming popular in industrial applications due its better performance than the conventional VSI converters. The advantages of Matrix Converters are bidirectional current flow, adjustable displacement angle and sinusoidal input current and output voltage. Two control schemes used to control the speed of Induction motor. They are Field Oriented Control and Direct Torque Control systems. The Direct Torque Control system uses hysteresis controllers for flux and torque control because of which the ripples in the stator current and torque are more. Also the conventional Direct Torque Control system uses lookup table method to select the switching vectors which reduces the accuracy of the system. In the Field Oriented Control system the torque and flux components are separately controlled using PI controllers and then recombined to create the motor phase current. This gives better control than the conventional DTC system. The system uses Space Vector Modulation Circuit to choose the switching vectors for Matrix Converter. In this paper the Artificial Neural Network is introduced to replace the SVM in Field Oriented Control system. The complete Field Oriented Control system using ANN for in Matrix Converter Drive is simulated using MATLAB/SIMULINK. It is observed that in the ANN system the speed of the motor tracks the reference speed without any overshoot and speed control is achieved with zero steady state error.

Key words: Artificial Neural Network · Matrix Converter · Field Oriented Control · Direct Torque Control · Induction Motor

INTRODUCTION

Matrix Converters have received interest in the industrial and research area due its advantages over conventional Voltage Source Converters (VSI) in variable speed control applications. The cost, reliability and fault tolerance attracts Induction Motors in industrial applications. Field Oriented Control (FOC) and Direct Torque Control (DTC) are commonly used closed loop systems in speed control of Induction Motor. The DTC system is less sensitive to parameter detuning and has simple control structures. In this method the flux and torque are decoupled and controlled individually. In the DTC system co-ordinate transforms, current regulators are not used. It uses hysteresis controllers for stator flux and electromagnetic torque. This two and three level hysteresis controller introduces large ripples in torque and flux curves. Also the distortion in the stator current is high. The switching frequency is very high and uncontrollable in DTC system.

The conventional FOC system uses indirect vector control method. The three phase stator current is transformed into synchronously rotating dq reference frame. The dq reference frame is aligned with rotor flux. The d axis component of stator current controls the rotor flux and the q axis component of stator current controls the electromagnetic torque. The torque and flux components from the stator current are decoupled and controlled individually using PI speed and current controllers. It is then transformed into dq – abc and then fed into the Space Vector Modulation (SVM) unit. The SVM circuit selects the switching vector for Matrix Converter. For achieving variable speed operation indirect field oriented control is best suited because in the FOC

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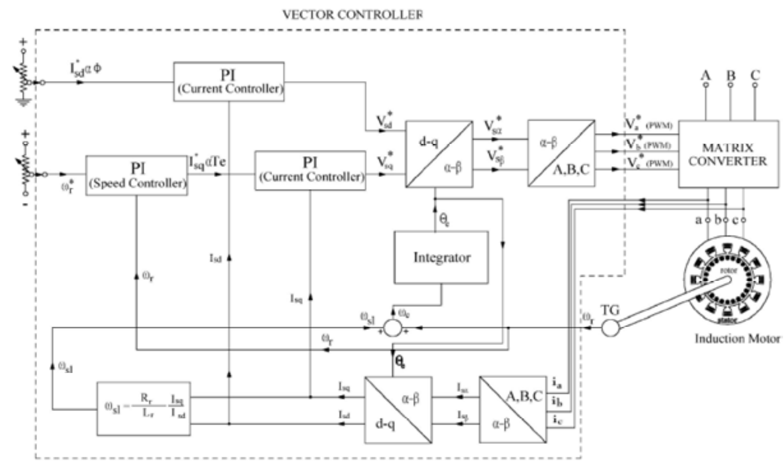

Fig. 1: Conventional FOC system [5]

system the induction motor can be controlled easily as a separately excited DC motor. Also the torque and flux response in FOC system is faster than the DTC system. The dynamic performance of FOC system is less than the DTC system because it is high sensitive to parameter variation. Also it the selection of switching state is dependent on the computation of parameters.

Hence to avoid the disadvantages of the indirect FOC system and to make it effective in speed control applications with induction motors, many researches are going on in the area of using intelligent controllers. A fuzzy learning enhanced speed control [1] method in which the machine follows the reference model to achieve the speed performance. The effect of rotor resistance on the speed performance and rotor resistance estimation using fuzzy logic controller [2] is also studied. The PI controllers are replaced by FLC [3] and the performance is investigated. The simulation results show that the FLC performance is better than PI controller performance for sudden change in load torque. An Adaptive Neuro Fuzzy Inference System based [4] vector control for Matrix Converter is proposed. This combines the advantages of fuzzy and neural techniques. Most of the proposed systems concentrate on parameter tuning and/or controller tuning.

In this paper, Artificial Neural Network (ANN) is introduced to select the switching vectors for Matrix Converter. Since the selection of switching vectors depends on the input from PI speed and current controllers and not on the motor parameters, the ANN can be trained off-line. Therefore the inputs of the SVM circuit are converted into digital signals to reduce the training pattern and to increase the executing period of the training process. After the weights and biases are calculated from the training process, it is inserted in the ANN controller. Then the ANN controller replaces the SVM module in the system.

This paper is organized in six sections. Section 2 describes the details of conventional FOC system. In section 3, the training and implementation of ANN controller is described. The section 3 shows the complete simulation model of ANN based speed control of Induction Motor. The parameters and results of the system are discussed in Section 5. The last section 6 concludes the work carried in this paper and gives the scope for future work.

Conventional Field Oriented Control System: The block diagram of conventional FOC system is shown in Fig. 1. The closed loop system uses inner current control loop and outer speed and flux control loops. For decoupling control, the stator current components i_{sa}, i_{sb} and i_{sc} are transformed into dq axis components using Clarke transformation. The d axis is aligned with the stator flux component i_{sd} and the q axis is aligned with the torque component i_{sq}. The indirect vector control equations are given as: [4].

$$\theta_e = \int \omega_w dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl} \tag{1}$$

Where, ω_r is rotor speed and ω_{sl} is slip frequency.

For decoupling control, the rotor circuit equations are given as.

$$\frac{d\psi_{dr}}{dt} + R_r i_{dr} - (\omega_e - \omega_r)\psi_{qr} = 0 \tag{2}$$

$$\frac{d\psi_{qr}}{dt} + R_r i_{qr} + (\omega_e - \omega_r)\psi_{dr} = 0 \quad (3)$$

$$\psi_{dr} = L_r i_{dr} + L_m i_{ds} \quad (4)$$

$$\psi_{qr} = L_r i_{qr} + L_m i_{ds} \quad (5)$$

$$i_{dr} = \frac{1}{L_r}\psi_{dr} - \frac{L_m}{L_r} i_{ds} \quad (6)$$

$$i_{qr} = \frac{1}{L_r}\psi_{qr} - \frac{L_m}{L_r} i_{qs} \quad (7)$$

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r}\psi_{dr} - \frac{L_m}{L_r} R_r i_{ds} - \omega_{sl}\psi_{qr} = 0 \quad (8)$$

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r}\psi_{qr} - \frac{L_m}{L_r} R_r i_{qs} - \omega_{sl}\psi_{dr} = 0 \quad (9)$$

For decoupling control,

$$\psi_{qr} = 0 \text{ and } \frac{d\psi_{qr}}{dt} = 0$$

Hence, the total flux $\hat{\psi}$ is directed in d axis.

$$\frac{L_r}{R_r}\frac{d\hat{\psi}_r}{dt} + \hat{\psi}_r = L_m i_{ds} \quad (10)$$

$$\omega_{sl} = \frac{L\ R_r}{\hat{\psi}_r L_r} i_{qs} \quad (11)$$

Where $\hat{\psi} = \psi_{dr}$ has been substituted.
If rotor flux $\hat{\psi}$ is constant, then

$$\hat{\psi} = L_m i_{ds} \quad (12)$$

The rotor flux angle and speed is estimated using dq model of induction motor. The i_{sd} and i_{sq} components are compared with the reference flux and reference torque values respectively. The reference torque value i_{sqr} is obtained from a PI speed controller which compares the reference speed with the motor speed. The output of the speed controller is applied to the PI torque (current) controller. The flux component i_{sd} is compared with the reference flux i_{sdr} and controlled using a PI flux (current) controller. The outputs of the two PI current controllers are V_{sdr} and V_{sqr}. It is then transformed into $V_{s\alpha}$ and $V_{s\beta}$ by using inverse park transformation. The $V_{s\alpha}$ and $V_{s\beta}$ are the stator voltage vectors in α and β reference frames

Table 1: Matrix Converter Switching vector

$\overline{V_0}$ \ $\overline{I_i}$	1.	2.	3.	4.	5.	6.
1.	+1−3 −4+6	+2−3 −5+6	−1+2 +4−5	−1+3 +4−6	−2+3 +5−6	+1−2 −4+5
2.	−7+9 +1−3	−8+9 +2−3	+7−8 −1+2	+7−9 −1+3	+8−9 −2+3	−7+8 +1−2
3.	+4−6 −7+9	−8+9 +5−6	−4+5 +7−8	−4+6 +7−9	−5+6 +8−9	+4−5 −7+8
4.	+4−6 −1+3	+5−6 −2+3	−4+5 +1−2	+1−3 −4+6	+2−3 −5+6	+4−5 −1+2
5.	−1+3 +7−9	−2+3 +8−9	+1−2 −7+8	+1−3 −7+9	+2−3 −8+9	−1+2 +7−8
6.	+7−9 −4+6	+8−9 −5+6	−7+8 +4−5	+4−6 −7+9	+5−6 −8+9	+7−8 −4+5

Table 2: Switches to be fired

Switching Configurations	Matrix Converter Switches to be fired		
	Phase A	Phase B	Phase C
-1	S_{Ba}	S_{Ab}	S_{Ac}
+1	S_{Aa}	S_{Bb}	S_{Bc}
-2	S_{Ca}	S_{Bb}	S_{Bc}
+2	S_{Ba}	S_{Cb}	S_{Cc}
-3	S_{Ba}	S_{Ab}	S_{Bc}
+3	S_{Aa}	S_{Bc}	S_{Ac}
-4	S_{Aa}	S_{Bb}	S_{Ac}
+4	S_{Aa}	S_{Ab}	S_{Bc}
-5	S_{Ba}	S_{Cb}	S_{Bc}
+5	S_{Ca}	S_{Bb}	S_{Cc}
-6	S_{Ca}	S_{Ab}	S_{Cc}
+6	S_{Aa}	S_{Cb}	S_{Ac}
-7	S_{Aa}	S_{Ab}	S_{Bc}
+7	S_{Ba}	S_{Bb}	S_{Ac}
-8	S_{Ba}	S_{Bb}	S_{Cc}
+8	S_{Ca}	S_{Cb}	S_{Bc}
-9	S_{Ca}	S_{Cb}	S_{Ac}
+9	S_{Ca}	S_{Cb}	S_{Ac}
0_a	S_{Aa}	S_{Ab}	S_{Ac}
0_b	S_{Ba}	S_{Bb}	S_{Bc}
0_c	S_{Ca}	S_{Cb}	S_{Cc}

respectively. These are the inputs to the Space Vector Modulation block. The SVM block identifies the corresponding switching vector as shown in Table 1 [7]. The Matrix Converter has 27 switching vectors as shown in Table. 2 and the voltage vectors can be categorised as zero voltage vectors, fixed magnitude and phase angel, variable magnitude and phase angle. The voltage and frequency output of the Matrix Converter controls the stator voltage and current of the induction motor and hence the speed of the induction motor is controlled accordingly.

Artificial Neural Network Controller: Neural Networks are very sophisticated modeling technique that can model extremely complex functions. The Artificial Neural Network is a powerful tool that can work out the nonlinear relationships between the input and output. The artificial neuron receives number inputs. The neurons are highly interconnected and are connected by weighted links. The weighted links carry the signal. Each neuron has a single threshold value. The weighted sum of the input in formed and then subtracted from the threshold value to get the activation signal of the neuron. The activation signal is passed through an activation function to produce the output signal. The artificial neural network (ANN) technique is based on learning process. The use of Artificial Neural Network improves the performance of system control. Hence it widely used for applications in power electronics.

Generally multi-layer feed forward network trained by back propagation method to calculate the output. The training process changes the synaptic weight of each interconnection and updates it until the target error value is achieved. The back propagation method uses 3 layers. The first layer is called input layer which receives the input pattern. The inputs propagate forward until they reach the output units where they produce the actual output or predicted output pattern. The outputs are presented in the output layer. While propagating the inputs passes through many layer called hidden layer where the weights are adjusted to reach the target error value. The back propagation algorithm is a supervised

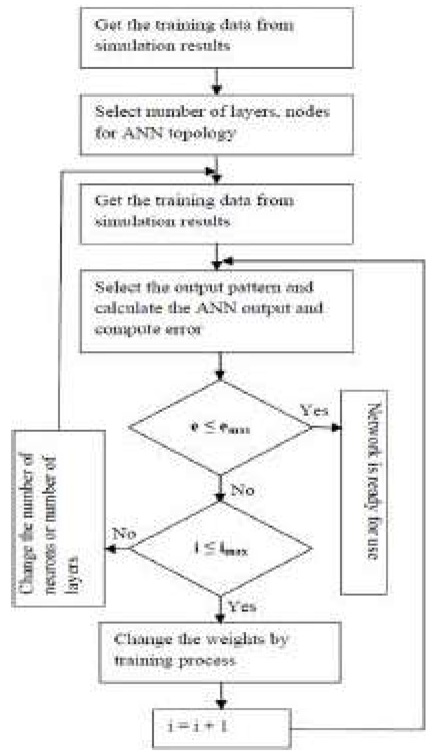

Fig. 2: ANN training Algorithm

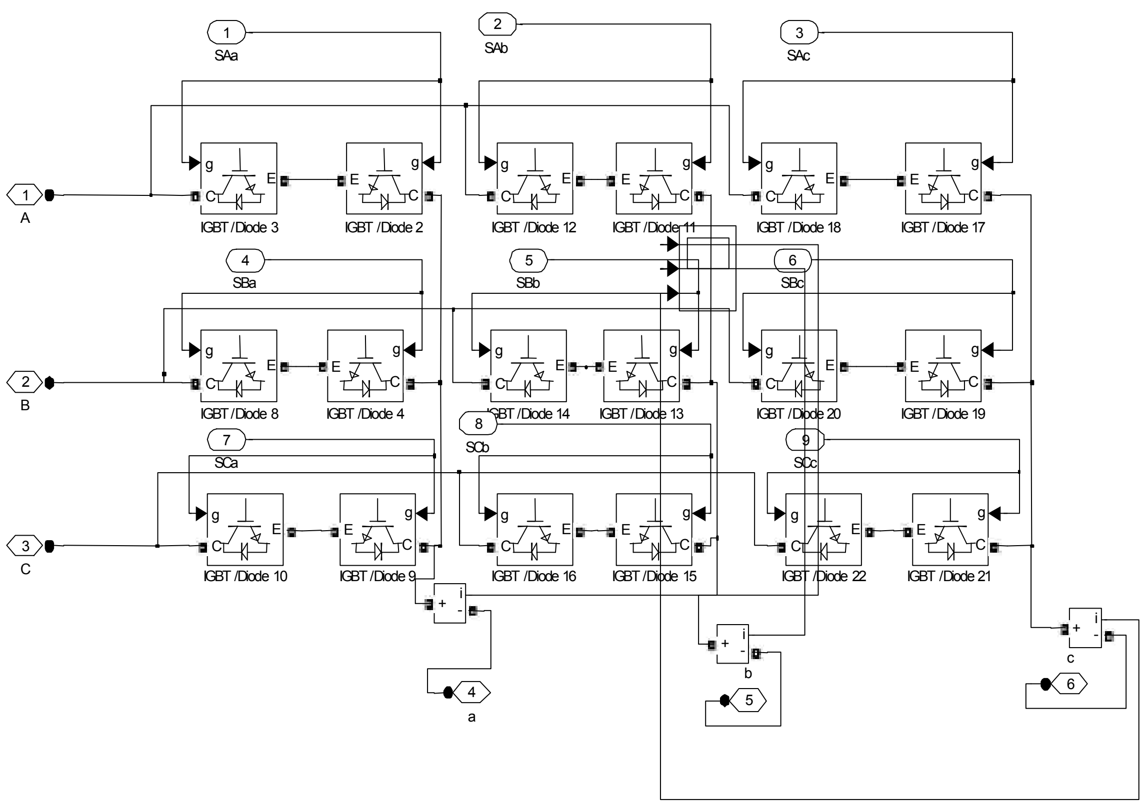

Fig. 3: Matrix Converter Switches Arrangement

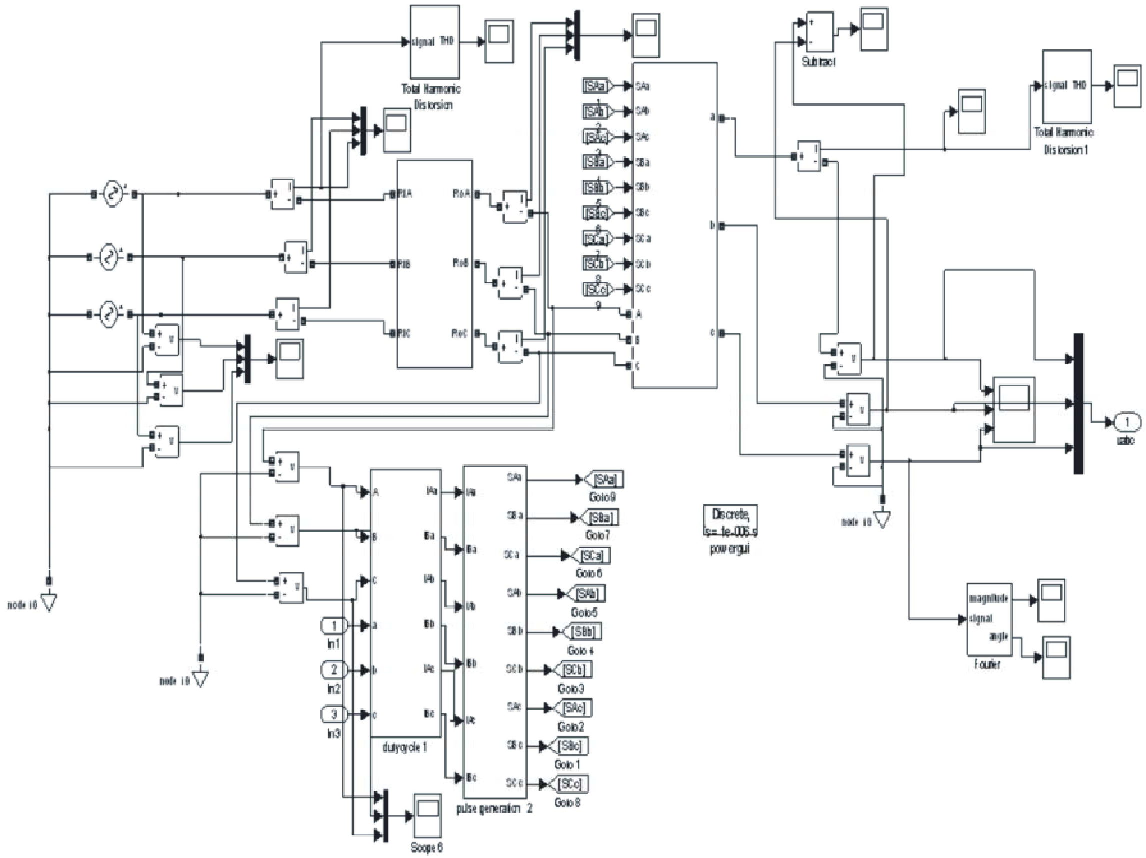

Fig. 4: Matrix Converter arrangement

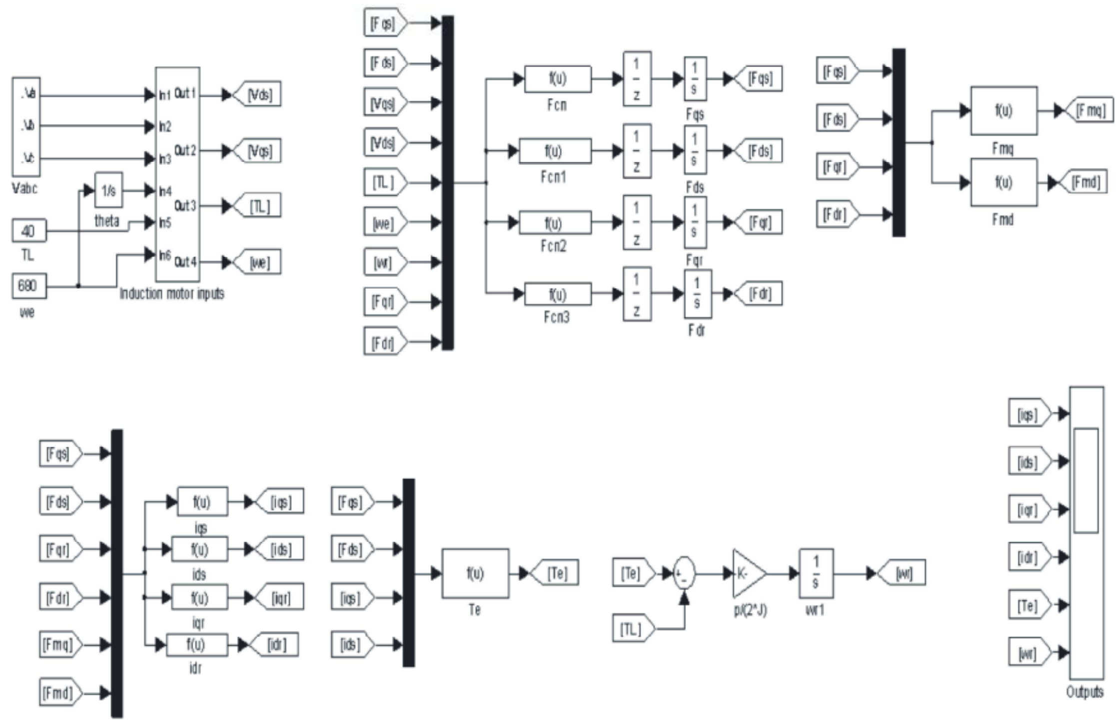

Fig. 5: d-q model of IM

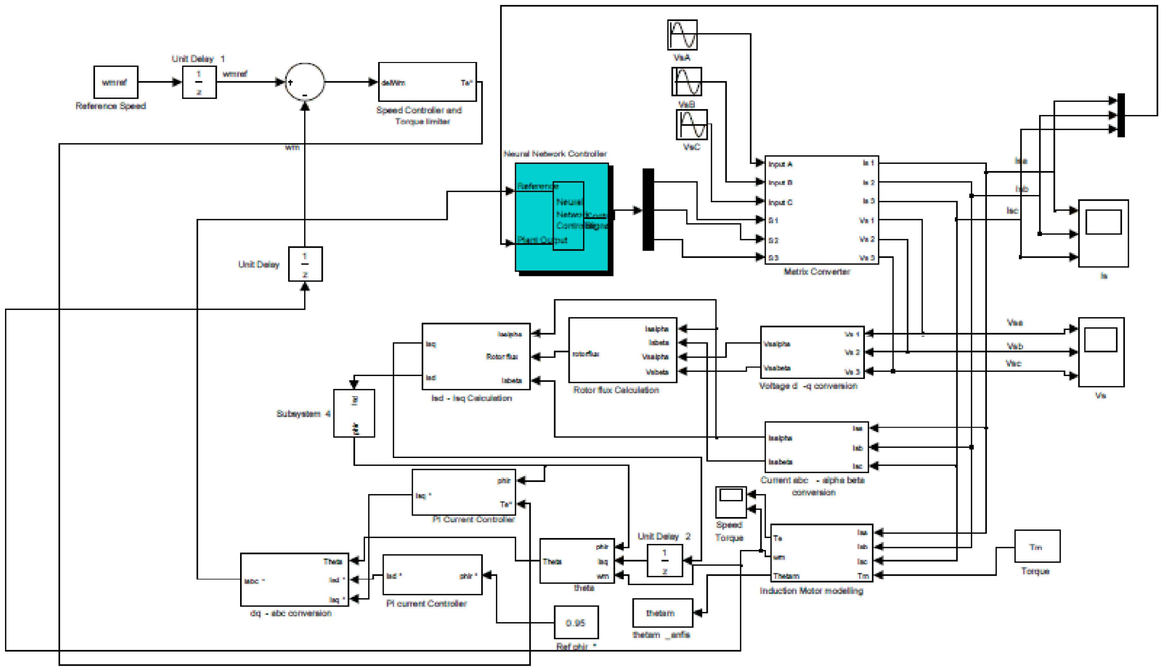

Fig. 6: Complete system with ANN controller

learning system. Hence the desired outputs are given during training. The actual output is then subtracted from the desired output to get the error signal. The error signals are then passes back through the neural network to adjust the weights and to compute the new error value. This process continues until the error saturation occurs. After the completion of training process, the offline performance of the network with arbitrary input pattern is tested. After ensuring satisfactory results, the weights and biases are downloaded to the neural controller and are inserted in the FOC system to produce the switching vectors.

The inputs the ANN network are V_a, V_b and V_c. The outputs from the ANN network are the switching voltage vectors V_{ab}, V_{bc} and V_{ca}. The training algorithm for neural network is shown in Fig. 2.

Simulation Diagram: The field oriented control system using ANN as switching state selector for Matrix Converter is simulated using Matlab/Simulink. The direct AC-AC matrix converter is designed with nine bi-directional IGBT switches as shown in Fig. 3. The complete matrix converter system designed with SVM algorithm is shown in Fig. 4. The dq model of induction motor is designed as shown in Fig. 5 to analyze the rotor flux and stator current. The ANN controller is designed with three layers and Lavenberg Marquertd back propagation algorithm is used for training procedure. The training inputs are taken from the standard SVM based Matrix Converter system. The performance of induction motor is tested for various reference speed and torque values.

RESULTS AND DISCUSSION

The proposed ANN controller based Field Oriented Control for Matrix Converter is simulated in Matlab/Simulink. The speed control curve of the ANN system is shown in Fig. 7. The torque of ANN system is shown in Fig. 8. It can be seen that motor speed follows the reference speed and the overshoot which usually occurs in PI controller is reduced in ANN system. Also the settling time taken by the ANN system is largely reduced compared to PI controller. It can be seen from Fig. 7, that the reference speed of 500rpm is applied at 1.5µsec with no load torque. With a transient time of 1.2µsec the motor speed reaches the reference speed of 1000rpm. It can be seen from Fig. 8 that during the speed transient, the torque curve settles at 300Nm and comes to 0Nm when the motor speed reaches 1000rpm. At 3msec, reference speed changes to 500rpm the torque curve settles at -300Nm during speed transient and then the settles at 0Nm when the motor speed settles at the reference speed of 500rpm at 3.7µsec. With the applied

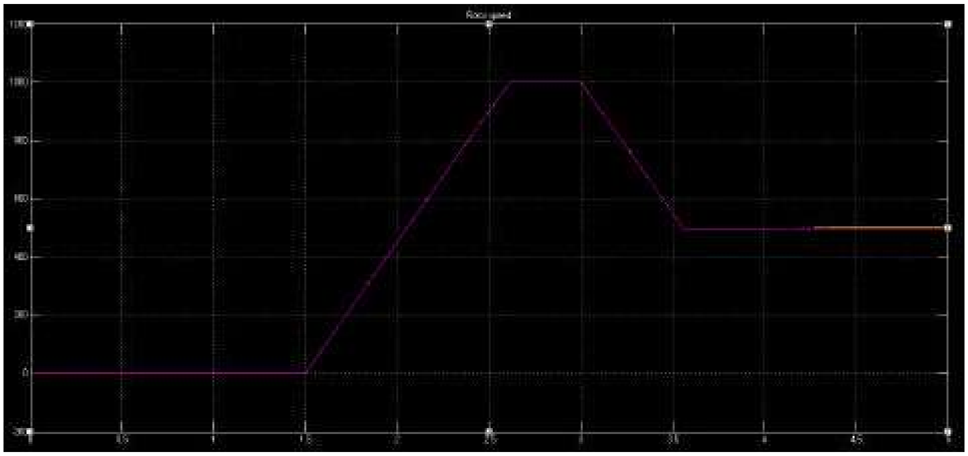

Fig. 7: Speed curve with at no load torque

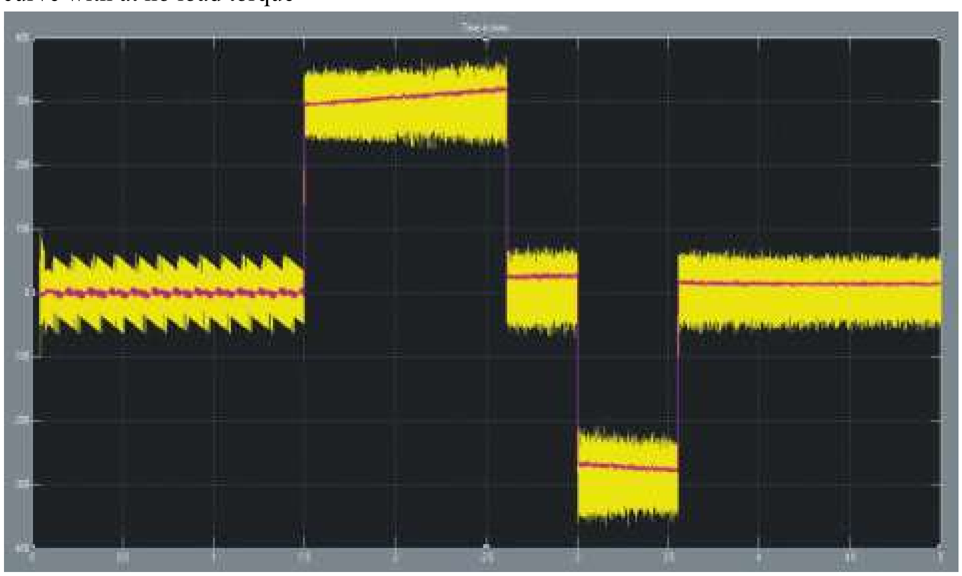

Fig. 8 Torque curve with zero reference torque

Fig. 9 Torque variation with applied reference torque

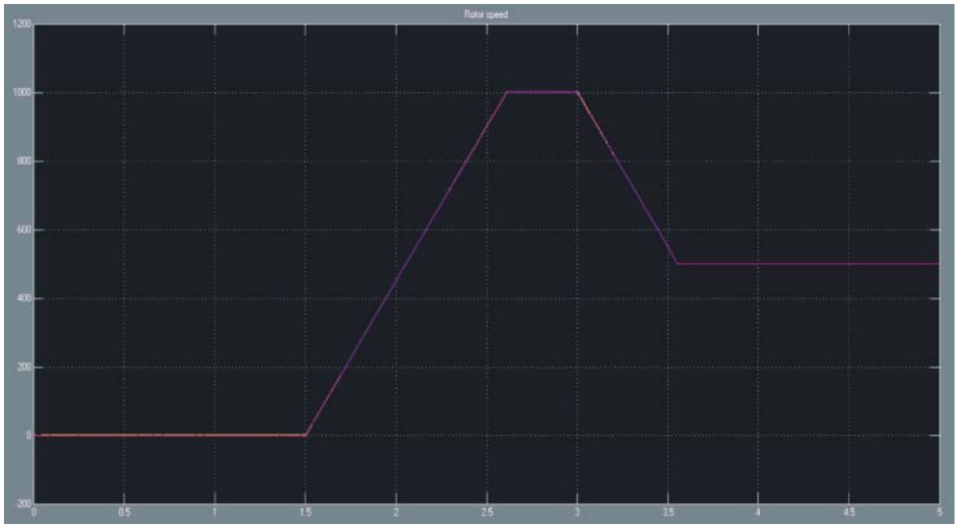

Fig. 10 Speed curve with applied reference torque

load torque of 500Nm at 1.5µsec, it can be seen from Fig. 9 that the torque curve rises to 800Nm and then settles at reference torque of 500Nm at 2.7µsec. Also when the torque change of -500 is applied at 3µsec, the torque curve settles at -500 at 3.6µsec. It can be seen from Fig. 10 that the variation in the load torque does not affect the speed curve.

The speed curve shows that the motor speed follows the reference speed at no load torque and with applied torque. The transient time taken by the speed curve is high. This can be reduced by further improving the training process of ANN.

CONCLUSION

This paper brings the concept of implementing ANN controller in Field Oriented Control system for Matrix Converter drive. The ANN controller replaces the Space Vector Modulation model in the FOC system. The settling time of the system is high. In ANN optimization is based on the training system. It eliminates the mathematical calculation of parameters and hence the response speed of the system is increased. Since the inputs to ANN controller are not fuzzified the accuracy of the system is limited. The study can be further extended to implement fuzzy controllers and fuzzy/neural corrector to increase the accuracy of the system.

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