

MODELING AND SPEED CONTROL OF INDUCTION MOTOR DRIVES USING NEURAL NETWORKS

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Abstract: Speed control of induction motor drives using neural networks is presented. The mathematical model of single phase induction motor is developed. A new simulink model for a neural network-controlled bidirectional chopper fed single phase induction motor is proposed. Under normal operation, the true drive parameters are real-time identified and they are converted into the controller parameters through multilayer forward computation by neural networks. Comparative study has been made between the conventional and neural network controllers. It is observed that the neural network controlled drive system has better dynamic performance, reduced overshoot and faster transient response than the conventional controlled system.

Keywords: Pulse width modulation, Induction motor modeling, Dynamic performance, Neural networks, Transient response.

1 INTRODUCTION

The single-phase induction motor plays an important role in the life of industries. The advantages of this motor over other types of motor are, its simplicity, reduced cost, low maintenance and robustness. Traditionally, phase angle control and Integral cycle control of thyristors are used in ac voltage regulators. They suffer from inherent disadvantages such as retardation of the firing angle, lagging power factor on the input side and high lower-order harmonic contents in load and source currents. Recent developments in Power Electronics make it possible to improve the power system utility interface. A symmetrical PWM ac chopper is designed to operate with single phase inductive loads with a reduced number of controlled switches (Ahmed et al., 1999). The performance characteristics such as average input power/slip, motor input/slip, torque/slip and power factor/slip at different values of the duty cycle of a symmetrical PWM AC chopper controller-fed single-phase induction motor drive are evaluated (Ahmed et al., 2000).

A single phase bi-directional AC power control circuit using power MOSFET embedded discrete component four quadrant switch realizations that operate in a high frequency chopping mode, is presented (Arvindan et al., 2006). M.J.Meco-Gutierrez et al (2007) have described an alternative technique, which involves the same number of commutations per unit time, and therefore, causes the same amount of heating in the transistors, while generating an output signal with an appreciable increase in the fundamental component and a significant reduction in the lower order harmonics, which are most difficult to filter. A motor connected to the converter undergoes less overheating and vibrations, thereby improving its performance. To achieve this, the modulating wave is compared with a triangular carrier with variable frequency over the period of the modulation. It is therefore convenient for the modulating signal to have a lot of sinusoidal 'information' in the areas of greater sampling.

The performance of a single-phase induction motor using the microcontroller M68HC11E-9 is investigated. The microcontroller senses the speed's

feedback signal and consequently provides the pulse width variation signal that sets the gate voltage of the chopper, which in turn, provides the required voltage for the desired speed (Bashi et al., 2005).

The PWM chopper has advantages compared with the traditionally used SCR voltage controller, mainly concerning the lesser harmonic content and lesser additional losses (Veszpremi et al., 2000). A switched mode AC voltage regulator to maintain constant voltage across a medium size domestic or commercial appliance has the capability of delivering sinusoidal input current with nearly unity power factor and with higher efficiency (Md.Raju Ahmed et al., 2006). The importance of the pulse width modulation scheme for a three phase circuit is presented (Hunyar et al., 2001). A novel harmonic elimination pulse width modulation technique for ac choppers has the advantage of eliminating all low order harmonic voltage contained in the ac mains without the need for processing harmonic frequency (Yu Hongxiang et al., 2004). The simulation details and harmonic spectrum comparison with the phase control scheme are not provided in these papers.

A modular simulink implementation of an induction machine model is described (Burak Ozpineci et al., 2003). The robust controller design of the induction motor control scheme can be applicable to time delay systems such as network-based control systems (Hong-Hee Lee et al., 2003).

An improved voltage controller and control strategy for efficiency improvement of single phase induction motors is presented (Joseph. et al., 1986). An optimal control strategy for selecting the firing and commutation angles in pulse width-modulated AC/AC chopper-type, single phase converters is proposed (Deib et al., 1993).

A control technique based on a neural network is proposed here for the constant speed control of the single phase induction motor drive. In the industry, the PI controller is widely used. These controllers exhibit excellent ability if a simple control is to be implemented. However, they have low reliability because these control results are sensitive to change in system parameters and do not react rapidly to parameter changes. Also, these controllers show a maximum overshoot and settling time. To solve these problems, a neural network that adjusts itself to control circumstances, is studied.

The principles of neural networks and their applications to the estimation of static feedback signals for a vector drive, space vector PWM for a two-level voltage-fed inverter and voltage model flux vector estimation are discussed (Bose.B.K, 2001). Jun Oh Jang (2007) discussed about the neural network compensation scheme for systems with

actuator saturation. He has designed a proportional derivative-tracking loop with an adaptive neural network system in the feed forward loop for actuator nonlinearity compensation. The saturation-compensation signal is inserted into the actuator-control signal. Using non-linear stability techniques, the bound on the tracking error is derived from the tracking-error dynamics. Neural network weights are tuned online, and the overall system performance is guaranteed using the Lyapunov function approach.

The application of neural networks to sensorless control of the speed of an electric vehicle induction machine drive is described (Asaii.B et al., 1996). The possibilities of applying off-line trained artificial neural networks at creating the system inverse models that are used at designing control algorithms for non-linear dynamic systems are presented. The ability of cascade feed forward neural networks to model arbitrary non-linear functions and their inverse is exploited (Jaroslava Zilkova et al., 2006). An adaptive neural network model with reflection can implement adaptive processes (Yoshiaki Tsukamoto et al., 1996). Neural network based speed control of single phase induction motor for linear loads is described (Jamuna et al., 2009). They have not considered the non-linear loads and also an internal structure of neural network is not presented.

In the above literatures, a model for neural network controlled closed loop AC Chopper fed single phase Induction Motor is not reported. In this paper, the speed control of induction motor drives using neural networks is proposed for pump and fan loads. A new simulink model for a neural network-controlled bidirectional chopper fed single phase induction motor is developed. The single phase induction motor is modeled using double field revolving theory. The parameters of the controller corresponding to various drive parameter sets are found off-line and stored as the training patterns. Under normal operation, the true drive parameters are real-time identified and they are converted into the controller parameters through multilayer forward computation by neural networks. In which, the connection weights of the multilayer feed forward network are estimated by back propagation learning algorithm. A comparative study has been made between the conventional and neural network controllers. It is observed that the neural network controlled drive system has better dynamic performance; reduced overshoot and faster transient response than the PI controlled system.

2 PULSE WIDTH MODULATED AC CHOPPER WITH THREE SWITCHES

Fig.1 depicts the circuit configuration of the single phase symmetrical pulse width modulated AC

chopper with three switches. This circuit has the following characteristics. The circuit can operate directly from a single phase line, the voltage across each switch is limited to the line voltage, and the number of switches has been reduced to three. In the present scheme, the power circuit is composed of a DC chopper switch across a diode bridge rectifier connected in series with the load, and two switches with two freewheeling diodes are connected in parallel across the load.

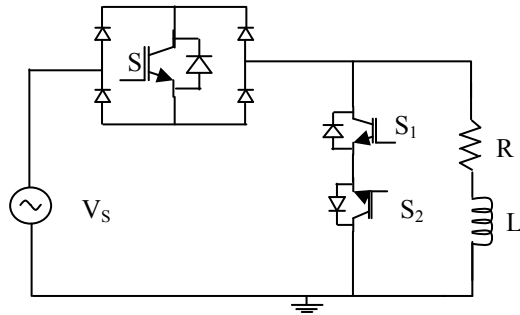


Fig.1. Power Circuit Diagram of a Pulse Width Modulated AC Chopper with Three Switches

The series-connected switch is used periodically to connect and disconnect the load to the supply, i.e., it regulates the power delivered to the load. The parallel switches provide a freewheeling path for the load current to discharge the stored energy of the load inductance when the series switch is turned off. The basic reason to use a diode with each parallel switch, is to enable it to be used in a circuit where a reverse voltage is encountered, and to complete the freewheeling current paths. The scheme of the present work uses the IGBT as controlled switches, and the gating of these switches is based on the equal pulse width modulation technique or the constant pulse width method.

The switching patterns of the controlled switches are decided by the polarity of the source voltage and the load current in such a way as to provide a path for the load current. Table 1 gives the sequence of the turning on and off of switches, in which the chopper switch S is always modulated with a constant duty cycle.

When the supply voltage and the load current are of equal polarity, normal switching takes place, in which one of the parallel switches S_1 or S_2 is completely turned on and the other is completely turned off, according to the polarity of the supply voltage. In other words, when the supply voltage and the load current are positive, S_2 is turned on and S_1 is turned off, and vice-versa.

When the voltage and current are of a different polarity, one switch from the parallel switches is gated by the complementary signal of the modulated switch S instead of continuous conduction. Normal switching is resumed at the instant when the load current reverses its direction. By such switching patterns, a continuous current path always exists, regardless of the load current direction. Since only a single switch is modulated and due to the fact that a single freewheeling switch is turned on during the majority of the half period of the voltage source, the switching losses are significantly reduced and consequently high efficiency can be achieved.

The modes of operation or operating modes are divided into two: active and freewheeling modes. The active mode is defined when the modulated switch S is turned on; during the active mode, the inductor current is forced to flow through the voltage source via the modulated switch during its on-state periods.

In the freewheeling mode the modulated switch S is turned off and the inductor current paths can be formed by the direction of the load current; i.e., in the freewheeling mode, the load current freewheels and naturally decays through the switch S_2 with the help of the body diode of S_1 or through the switch S_1 with the help of the body diode of switch S_2 , according to the direction of the load current.

Table 1 Switching Sequence of Driving Signal for Three Switches

State	Switch S	Switch S_1	Switch S_2
$V_s > 0, I_L > 0$	1	0	1
	0	0	1
$V_s < 0, I_L > 0$	1	0	0
	0	0	1
$V_s < 0, I_L < 0$	1	1	0
	0	1	0
$V_s > 0, I_L = 0$	1	0	0
	0	1	0

Switch State: 0 - Open, 1 - Closed

For the design of the control circuit, the following requirements must be satisfied:

- i. Generated gating signals must be synchronized with the supply and the load current.
- ii. The duty cycle of the gating pulse should be flexible.

The logic circuit for actuating the controlled switches is shown in Fig. 2.

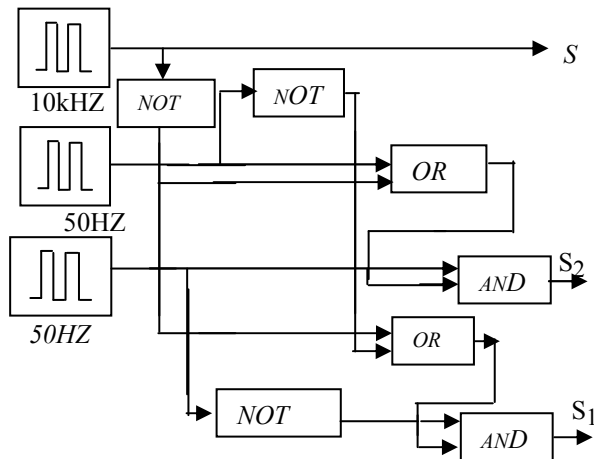


Fig.2. Control Scheme for a Pulse Width Modulated AC Chopper with Three Switches

3. BIDIRECTIONAL CHOPPER FED INDUCTION MOTOR

A block diagrammatic representation of a neural network controlled AC chopper fed single-phase induction motor is shown in Fig.3. The circuit can operate directly from a single phase line and the voltage across each switch is limited to the line voltage.

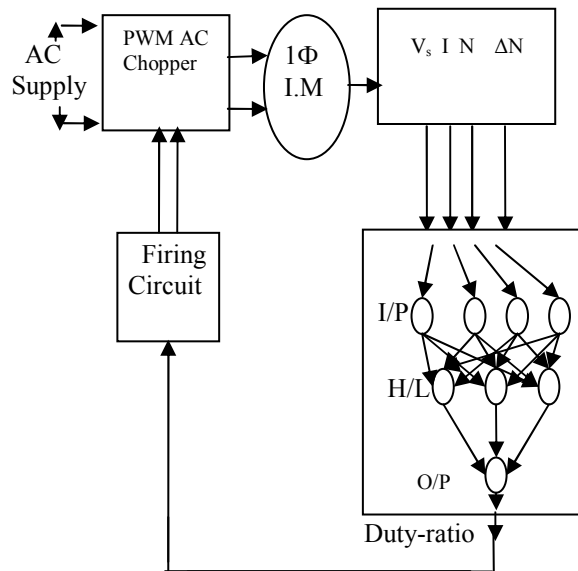


Fig. 3. Block Diagram of Single Phase Induction Motor with Neural Network

Various parameters, namely, pulse width modulated input voltage, stator current, speed and error in speed are sensed and given to the neural network. It generates the driving pulses to the switches in order to maintain the speed of the machine at reference value. A neural network is proposed for speed regulation. During each time, the weights and biases of the NN are updated using the back propagation algorithm to make the error between the desired outputs and actual outputs of the NN less than the predefined value.

The NN controller has a 4-3-1 structure. This NN structure is the result of many repeated trials. For each load, the training data is obtained by tuning the PI controller parameters such as k_p , k_i to optimal values in order to obtain a small steady-state error. The NN network controller is capable of maintaining a good steady-state and dynamic responses, and shows a significant improvement in reducing the distortion of the output voltage under non-linear loading conditions. It is suitable for the applications where the load undergoes periodic distortions.

4 SIMULINK MODEL OF SINGLE PHASE INDUCTION MOTOR

The simulink model of the single phase induction motor is shown in Fig.4. Since the value of s is generally small, $r_2/2s$ is considerably higher than $r_2/[2*(2-s)]$. In general, the magnitude of V_0 (Output voltage due to forward field effect) is 90% to 95% of the applied voltage. Hence, to obtain the simplified model of a single phase induction motor, the effect of the backward field is neglected.

Current flowing through the stator is expressed as

$$I(s) = \frac{(V_i(s) - V_0(s))}{(R_1 + sL_1)} \quad (1)$$

Current flowing through the stator can be expressed as

$$I(s) = I_1(s) + I_2(s) \quad (2)$$

If the rotor current referred to the stator is taken as I_2 , then the iron-loss and magnetizing component of the no-load current can be expressed as

$$I_1(s) = I(s) - I_2(s) \quad (3)$$

The forward field voltage can be obtained from the expression

$$V_0(s) = I_1(s) * \left\{ \frac{sR_0L_0}{(R_0 + sL_0)} \right\} \quad (4)$$

It can be rewritten as

$$V_0(s) = I_1(s) * \left\{ R_0 - \left[\frac{R_0^2}{(R_0 + sL_0)} \right] \right\} \quad (5)$$

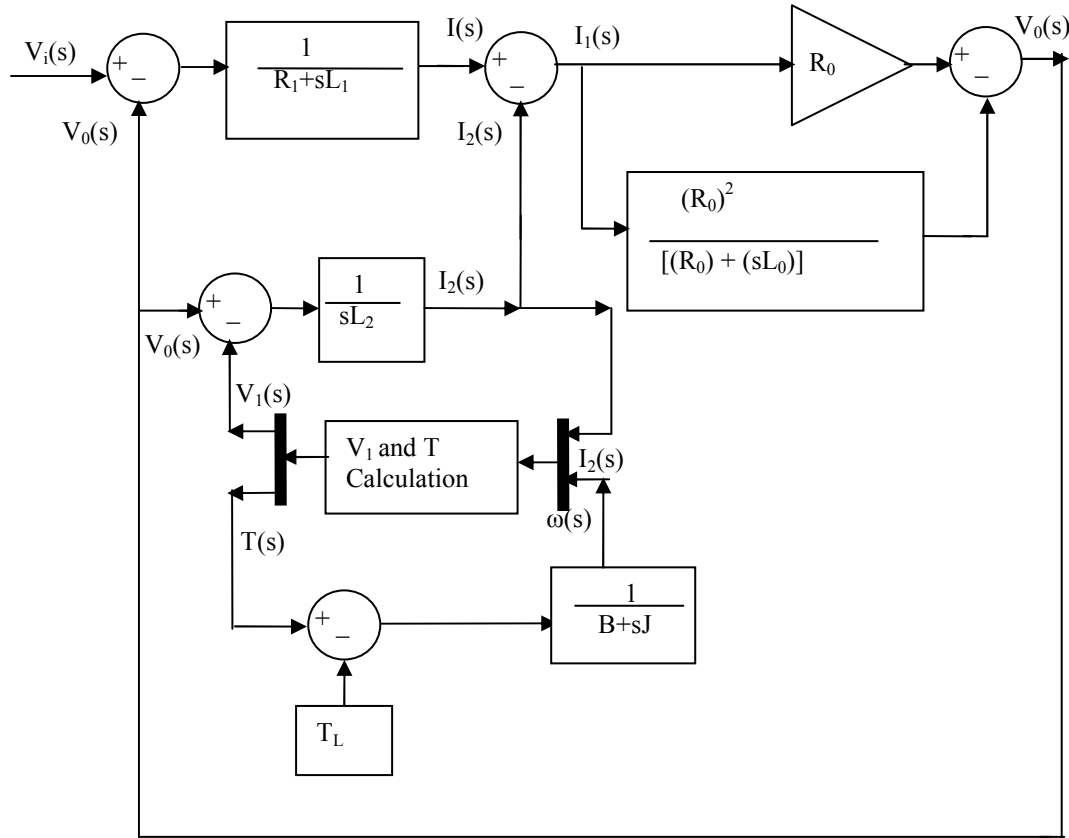


Fig. 4 Simulink model of single phase induction motor

Voltage across the rotor inductance is expressed as

$$V_1(s) = V_0(s) - I_2(s) * \left(\frac{R_2}{s} \right) \quad (6)$$

The rotor current referred to stator can be expressed as

$$I_2(s) = \frac{[V_0(s) - V_1(s)]}{sL_2} \quad (7)$$

Torque developed by the motor is given by the expression

$$T(s) = I_2(s) * \frac{\left(\frac{R_2}{s} \right)}{2\pi n_s} \quad (8)$$

The electromechanical load balance equation is given by

$$\omega(s) = \frac{(T(s) - T_L(s))}{Js + B} \quad (9)$$

$$\text{where, } \omega = \frac{d\theta}{dt} \quad (10)$$

By using the above set of equations the model for the single phase induction motor is obtained.

A 1 HP, 230V Single phase induction motor with the following parameters is used for simulation.

$R_0=1000\Omega$	$L_2=0.000815\text{Henry}$
$J=0.0146\text{Kgm}^2$	$B=0.001\text{Nms}$
$R_1=2\Omega$	$L_1=0.0163\text{Henry}$
$R_2=1.6\Omega$	$L_2=0.3\text{Henry}$

5 NEURAL NETWORK CONTROLLER

Neural networks are simply a class of mathematical algorithms, since a network can be regarded as a graphic notation for a large class of algorithms. An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. It is composed of a large number of highly interconnected processing elements (neurons) working in unison to solve specific problems. An ANN is configured for a specific application, speed control or energy saver, through a learning process.

To train a neural network to perform some task, the weights of each unit are adjusted in such a way that the error between the desired output and the actual output is reduced. This process requires the neural network to compute the error derivative of the weights (EW), i.e. it must calculate how the error

changes as each weight is increased or decreased slightly. The backpropagation algorithm is the most widely used method for determining the error derivative of the weights.

The hidden layer transfer function is log-sigmoid or tan-sigmoid and the output transfer function is usually linear. Here, the tan-sigmoid is used as the hidden layer transfer function followed by the linear transfer function for the output layer. Equations 8 and 9 show these transfer functions, where X is the input vector, Y and O are the output vectors of the hidden layer and output layer respectively, V_{ji} , W_{kj} are the weight matrices, and B_1 and B_2 are the bias vectors. The neural network system to estimate the duty ratio of ac chopper fed single phase Induction Motor is shown in Fig. 5.

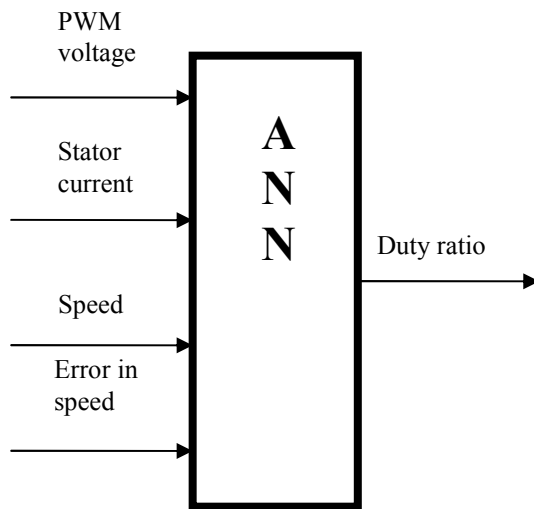


Fig. 5. Neural Network system to estimate duty ratio of PWM AC Chopper fed Single Phase Induction Motor

$$Y = \frac{1}{1 + e^{-(V_{ji} \cdot X + B_1)}} \quad (11)$$

$$O = W_{kj} \cdot Y + B_2 \quad (12)$$

6 CLOSED LOOP STATOR VOLTAGE CONTROLLED SINGLE PHASE INDUCTION MOTOR

The neural network based closed loop stator voltage control of a single phase induction motor system is shown in Fig. 6. The power circuit used to generate

the Pulse Width Modulated AC voltage is modeled and simulated.

PWM AC voltage is applied to the single phase induction motor and the speed is sensed by using a speed sensor. The actual speed of the motor is compared with the reference speed, which can be set by the industrial user according to his requirement. The error in speed is given to the PI controller with a saturator. Initially, PI controllers are used to control the voltage applied to the single phase induction motor. The values of k_p and k_i are tuned for various load conditions.

For each load, the PI controller is tuned to obtain a constant speed, and parameters like pulse width modulated output voltage, stator current, speed of the machine, error in speed and duty ratio are estimated. Around 1,00,000 sets of training patterns are obtained. These patterns are used for training the neural network, using the error back propagation algorithm. After training the neural network successfully, the conventional PI controller is replaced by the neural network controller and the simulation is performed.

Neural networks have a built in capability to adapt their synaptic weights to the changes in the surrounding environment. In particular a neural network trained to operate in a specific environment can be easily retrained to deal with minor changes in the operating environmental conditions. Moreover, when it is operating in a non-stationary environment, a neural network can be designed to change its synaptic weight in real time.

The command net = newff is used to create a feed-forward network with two layers. The first layer has three transsig neurons and the second layer has one purelin neuron. The feed forward network is simulated and graphs are plotted between input test samples and output. Thus, in the model for the closed loop speed control of the induction motor using neural networks, variable load is applied and the generated neural network block is used to form the feedback loop. The input to the neural network block is from the multiplexer to which test samples are given and the output of the neural network is given to the saturation block which imposes upper and lower bounds on the signals and the output is fed back as the duty ratio to the chopper circuit.

The output of the neural network controller is used to vary the duty ratio of the PWM AC chopper. Non-linear exponential load is considered. The neural network is trained to estimate the required voltage for different load conditions. The output of the neural network controller is used to vary the duty-ratio of the PWM AC chopper. The internal structure of the trained neural-network used for the simulation is shown in Fig. 7.

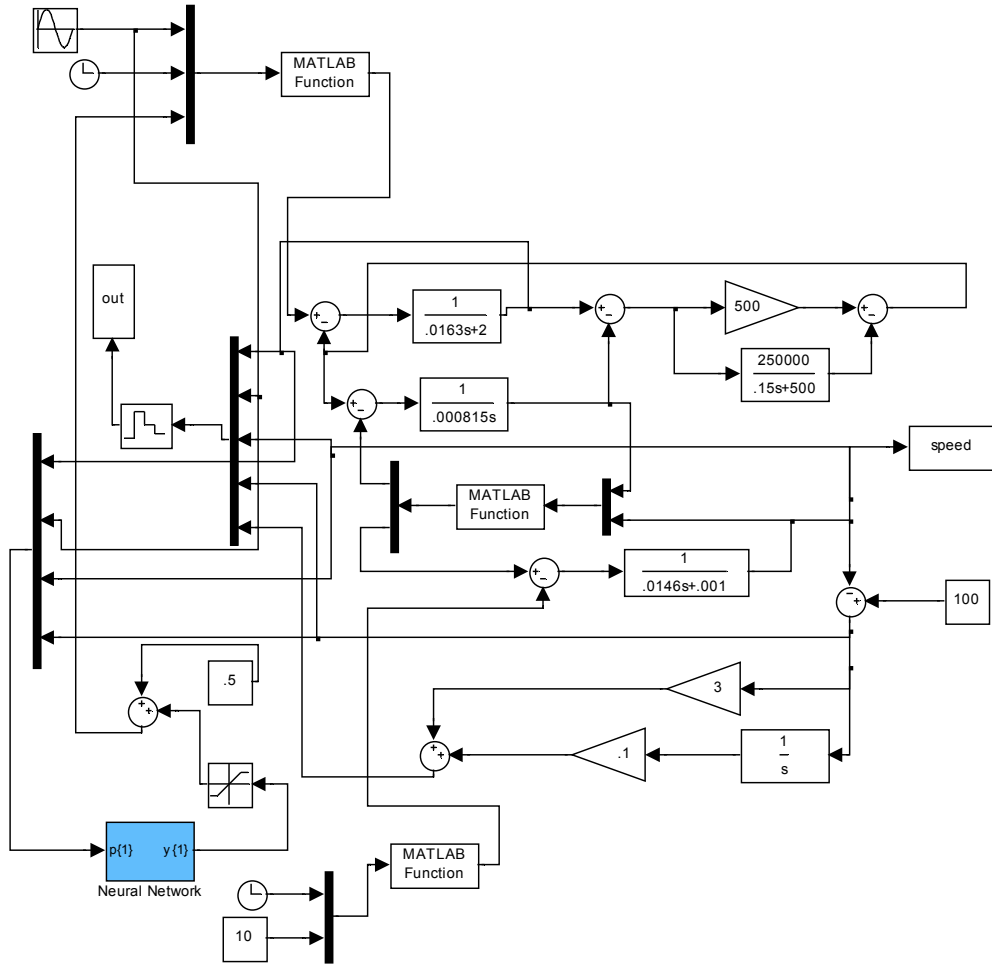


Fig.6. Model of Pulse Width Modulated AC Chopper fed Single Phase Induction Motor

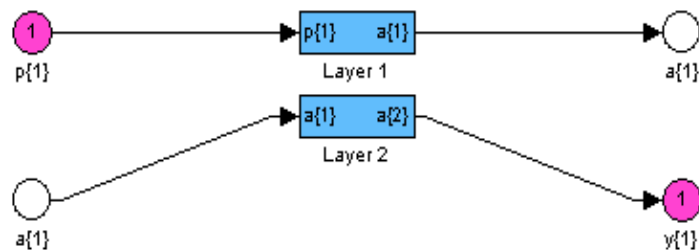


Fig. 7a. Internal Structure of Neural Network

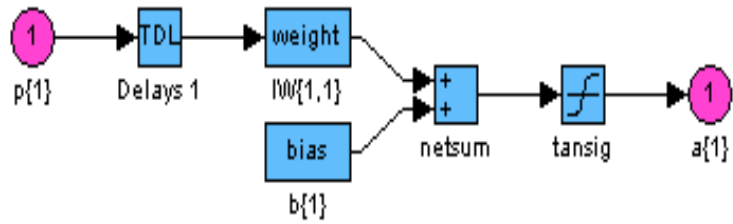


Fig. 7b. Internal structure of layer 1

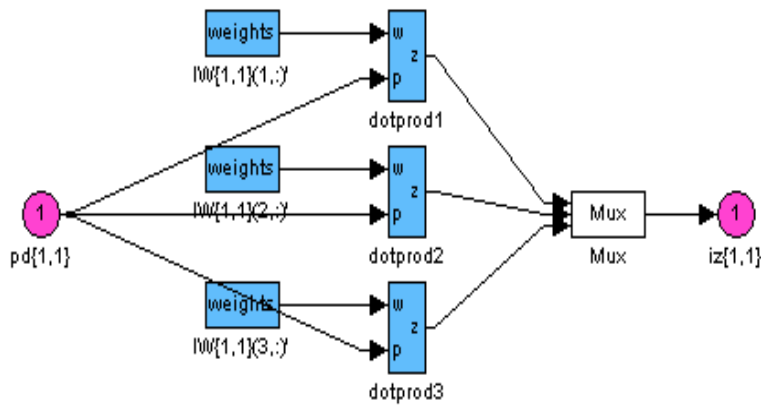


Fig. 7c. Internal structure of weight for layer 1

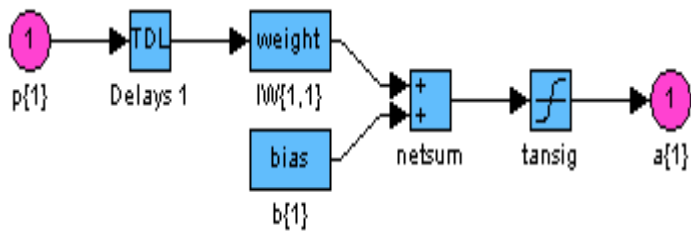


Fig. 7d. Internal structure of layer 2

The speed response for the open loop system from no load to maximum load torque is shown in Fig. 8. From Fig. 8, it can be seen that the speed is not constant in the open loop system. The speed at no load is 156.4rad/sec. As the load is increased, the speed decreases, and finally, it reaches 153.2rad/sec for full load.

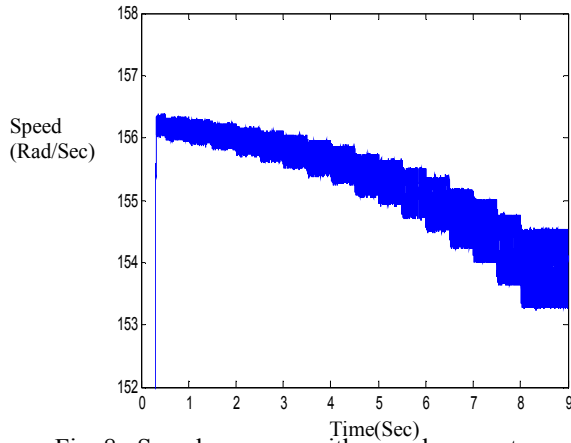


Fig. 8. Speed response with open loop system

The speed is maintained at reference value irrespective of the load torque with a closed loop stator voltage control. The speed is maintained constant as shown in Figs 9 and 10 for non-linear variation of load torque. The simulation is carried out for a reference speed of 100 rad/sec.

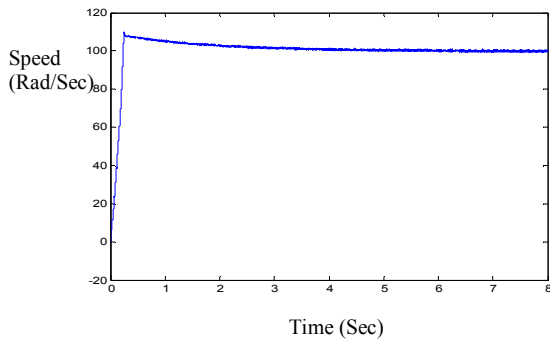


Fig. 9. Speed response with PI Controller

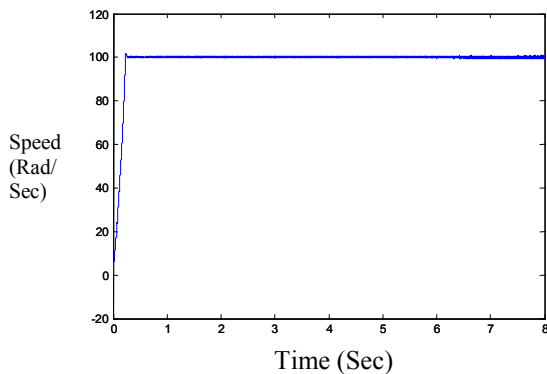


Fig.10 Speed response with Neural Network

The speed is maintained at 100rad/sec using PI and NN controllers. The steady state error is reduced. Thus, the closed loop system is capable of maintaining the speed at constant value. The simulation results obtained by using the neural network and PI controllers are given in Table 2. From the above table, it can be seen that the neural network has lesser peak overshoot, reduced rise and settling time.

Table 2 Comparison of Neural Network and PI Controller based Induction Motor Drive Systems

PARAMETERS	NEURAL NETWORK CONTROLLER	PI CONTROLLER
Rise time(sec)	0.2	0.274
Settling time(sec)	0.2636	4
Peak Overshoot (%Mp)	1.9608	9.091

7 CONCLUSION

The Pulse Width Modulated AC Chopper and the Phase Angle Controlled AC Chopper fed Induction motor systems are simulated and their performances are compared. It is proved that the Pulse Width Modulated AC Chopper has lesser total harmonic distortion, better power factor and negligible harmonic components.

Modeling of an Induction Motor has been done using double field revolving theory and the closed loop control has been analyzed using conventional and neural network controllers. Neural network is trained successfully using error back propagation algorithm. An intelligent control system using a neural network controller has reduced peak overshoot, rise time and settling time compared to the system with a PI controller. It is observed that the speed of the machine remains constant with reduced overshoot by using the neural network-based controller.

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