ANN CONTROLLED ENERGY SAVER FOR INDUCTION MOTOR DRIVE

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***Abstract**: In this paper, a new model for single phase induction motor is presented. A neural network based control scheme using pulse width modulation technique is developed. It is used to implement the energy-saving scheme of single-phase Induction motors when they operate under no load or small duty ratio load. The intention is to gather the information to decide possible installation scheme to save the energy in plants using induction motors. At no load, 58% of energy can be saved and the savings decrease with the increase in load. The neural network is trained to estimate the required voltage for different load conditions. To train the neural network a simulation program is written to obtain the duty ratio values for different load conditions. The need to improve the quality and reliability of the drive circuit is increased because of the growing demand in improving the performance of motor drives. With the increased availability of MOSFETs and IGBTs, PWM AC choppers can be used efficiently in low and medium power applications. From the simulation studies, it is seen that Pulse Width Modulated (PWM) AC chopper system has reduced harmonics than the Phase controlled AC chopper system and hence it is used in the present work. The energy can be saved using the proposed system.*

***Keywords:** PWM AC Chopper, Modeling of Single–phase Induction Motor, Energy saving, Neural Network Controller, Stator Voltage Control, Duty ratio.*

I Introduction

Single phase induction machine is most widely used in industry because of its simple construction, reliable operation, lightness and cheapness. In industrial complexes, most of the induction motors often run at no load. These motors are always connected to the mains irrespective of the load conditions. Due to the rated voltage at stator terminals, rated iron losses have to be supplied constantly to the motors. These losses mean a waste of some form of primary energy, whose availability of our planet is limited. If it is possible to reduce the voltage at stator terminals during no load or small duty ratio load conditions, then iron losses can be reduced and some electrical energy, hence primary energy might be saved. 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 firing angle, lagging power factor at input side and high lower-order harmonic contents in both load and supply voltages, currents.

Recent development in the artificial neural network technology has made it possible to train neural networks for non linear loads. Artificial neural networks represent simplified model of the human brain. It consists of large number of neurons which have weighted interconnections. Since artificial neural networks are highly parallel and distributed networks, they are extremely fault tolerant and insensitive to noise.

The recent developments in Power Electronics make it possible to improve power system utility interface. A developed control strategy for firing instances in pulse width modulated ac voltage regulators is presented in [1]. In [2], it is discussed that line commutated ac controllers can be replaced by Pulse Width Modulated ac voltage controllers, which have better overall performance. The simulation details and harmonic spectrum comparison with phase control scheme is not provided with this paper. An optimal control strategy for selecting firing and commutation angles in pulse width-modulated ac/ac chopper-type, single phase converters is proposed in [3]. An improved voltage controller and control strategy for efficiency improvement of single phase induction motors is presented in [4]. The application of neural networks to sensor less control of speed of an electric vehicle induction machine drive is described in [5]. A control scheme for the energy-savings of three-phase induction motors when they operate under long-term light-load or small duty ratio load is implemented in [6]. Different possibilities of employing a single-phase induction motor in a variable speed drive are surveyed in [7]. In [8], a new controller based on artificial neural networks for induction machines which maximizes efficiency is introduced and implemented. An energy saving scheme for single phase induction motor drives, which are operated with no load or partial load conditions is described in [9]. The problem of efficiency optimization in capacitor-run single-phase induction motors is investigated in [10].

In the literature [1] – [10], investigations on AC Chopper fed single phase Induction Motor controlled by neural network are not presented. Energy saving scheme has not been implemented using Neural Networks. In this work a new simulink model for single phase induction motor is developed and the same is used for simulation studies. To save energy during no load and partial load conditions, closed loop stator voltage control method is employed successfully using neural networks.

II Circuit Description and Principle of Operation

Block diagrammatic representation of neural network controlled AC chopper fed single phase induction motor is shown in Fig.1. The circuit can operate directly from a single phase line and the voltage across each switch is limited to the line voltage. Speed and stator current of the machine are sensed using speed and current sensors. In addition to these two signals, load torque and pulse width modulated output voltages are also considered to train the neural network. Based on these four parameters, neural network generates the driving pulses to the switches depending upon the load conditions to save the energy. Neural network is proposed for the stator voltage control. During each time, the weights and biases of the NN are updated using the back propagation algorithm.

The NN controller has 4-3-1 structure. This NN structure is the result of many repeated trials. For each load condition, the training data is obtained by the corresponding simulation programme.

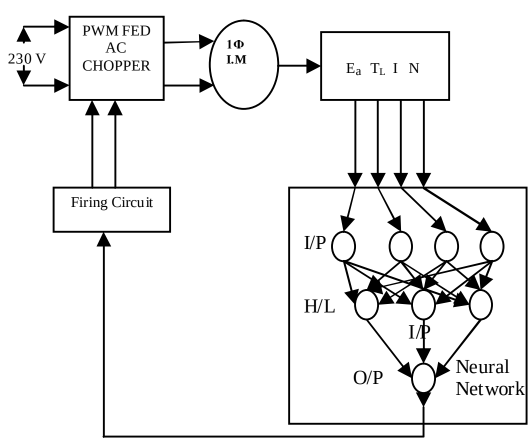

Fig. 1. Block Diagram of Neural Network based PWM AC Chopper fed Single Phase Induction Motor.

III Model of Single Phase Induction Motor

The simulink model of single phase induction motor is shown in Fig.2. Since the value of s is generally small, $r_2^1/2s$ is considerably higher than $r_2^1/[2*(2-s)]$. In general, the magnitude of V_0 is 90% to 95% of the applied voltage. Hence, to obtain the simplified model of single phase induction motor, the effect of backward field is neglected. Voltage across the variable rotor resistance is referred as V_1.

Current flowing through the stator is expressed as

$$I_1 = (V - V_0) / (r_1 + jx_1) \quad (1)$$

If the rotor current referred to stator is taken as I_2^1 then the iron-loss and magnetizing component of no-load current can be expressed as

$$I_0 = I_1 - I_2^1 \quad (2)$$

Current through the core loss component,

$$I_{0c} = I_0 - I_{0m} \quad (3)$$

The output voltage can be obtained from the expression

$$V_0 = I_{0c} * r_0 / 2 \quad (4)$$

Current through the magnetizing component,

$$I_{0m} = V_0 / (jx_0 / 2) \quad (5)$$

Current through the rotor component,

$$I_2^1 = [V_0 - V_1] / (jx_2^1 / 2) \quad (6)$$

Voltage across the variable resistance,

$$V_1(s) = R_2 * I_1(s) \quad (7)$$

Torque developed by the motor is given by the expression

$$T = (I_2^1)^2 * \frac{\left(\frac{r_2^1}{2s}\right)}{2\pi n_s} \quad (8)$$

The electromechanical equation is expresses as

$$T = J\frac{d\omega}{dt} + B\omega + T_L \quad (9)$$

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

By using the above set of equations, model of single phase induction motor was obtained.

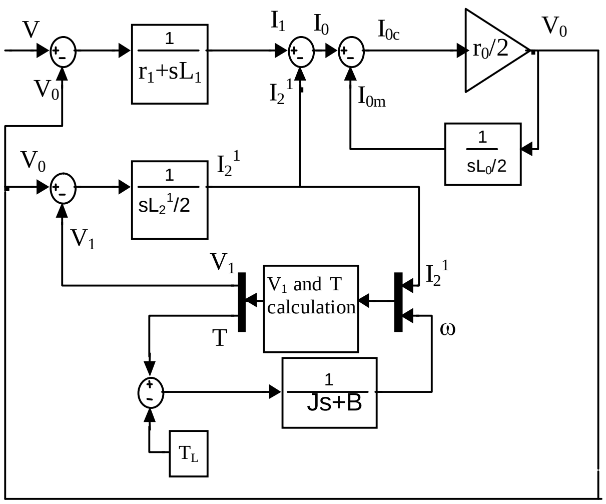

Fig. 2. Simulink model of single phase induction motor

A 1.5kW, 230V Single phase induction motor with the following parameters is modeled using above set of equations and the same is used for simulation.

$r_1=2\Omega$	$x_1=5.12\Omega$
$r_2=1.01\Omega$	$x_2=0.26\Omega$
$r_0=300\Omega$	$x_0=47.12\Omega$
$J=0.0146Kgm^2$	$B=0.007Nms$
Turns ratio=1.99	P=4 poles

VI Harmonic Analysis of AC Chopper

Harmonic analysis has been performed for the output of AC chopper system. Harmonic spectrum has been obtained for both Phase Controlled AC Chopper system and Pulse Width Modulated AC Chopper systems and they are shown in Fig.3. Using Fourier analysis, total harmonic distortion value has been calculated. Simulation has been performed for various delay angles of phase controlled AC Chopper system and different duty ratio values of Pulse Width Modulated AC Chopper system fed single phase Induction Motor. The results are presented in Figs.4 and 5 respectively.

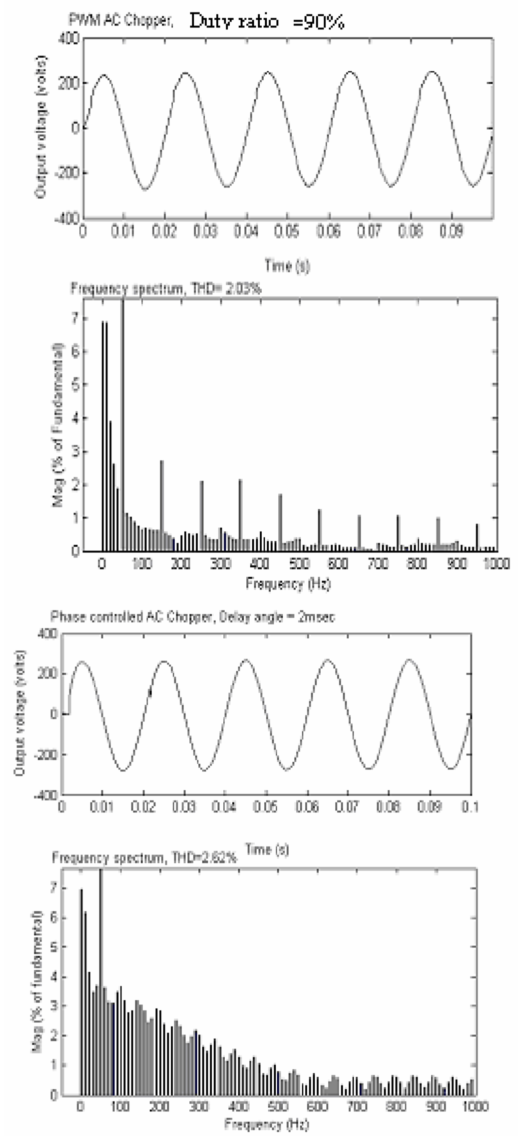

Fig. 3. Harmonic spectrum of Phase Angle Controlled AC Chopper and Pulse Width Modulated AC Chopper

In order to improve the harmonic spectrum, a filter is introduced at the output terminals. Filter parameters are designed such that the lower order harmonics are eliminated. For a modulation index of 90%, the value of THD is reduced from 4.6% to 2.03% by using an appropriate filter.

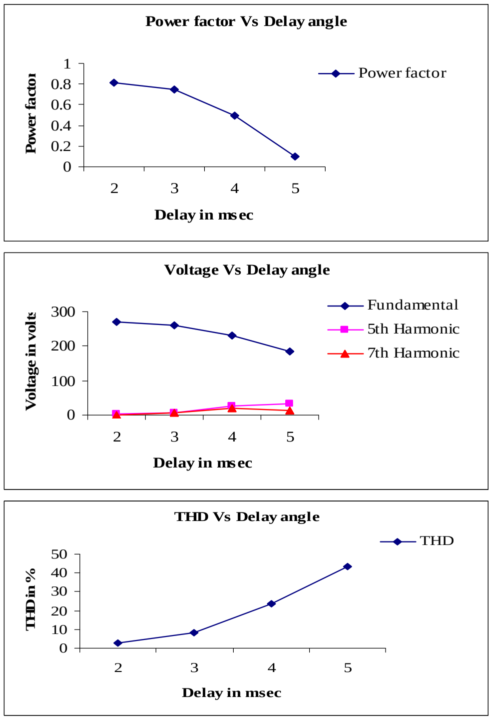

Fig.4. Harmonic analysis with Phase controlled AC Chopper

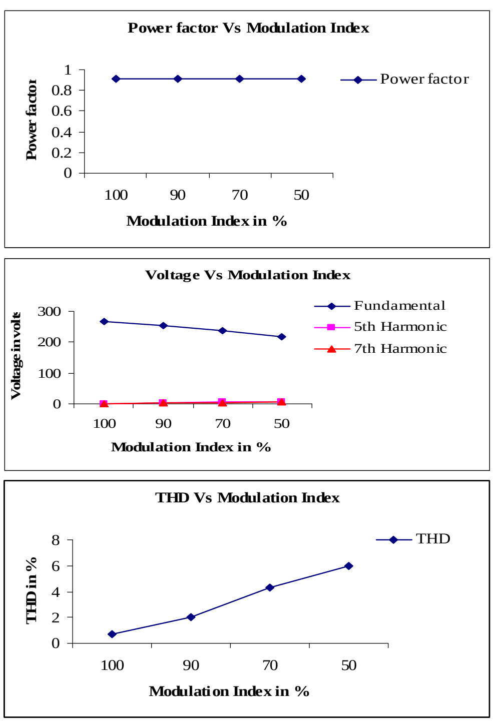

Fig.5. Harmonic analysis with PWM AC Chopper

From the frequency spectrum, it can be seen that, Phase controlled AC chopper has higher THD, poor power factor and higher magnitudes of fifth and seventh harmonic components. The THD value for PWM controlled AC chopper system is 6%. The power factor is improved and the magnitudes of fifth and seventh harmonics are very much reduced. Because of the improved waveforms produced by the PWM AC Chopper, the performance of single phase induction motor is improved.

V Neural Network Controller

Neural networks are simply a class of mathematical algorithms, since network can be regarded as a graphic notation for a large class of algorithms. Neurons are available with more than one layer. Output of one layer acts as an input to another layer. Fig.6 shows a typical two-layer neural network with three inputs, five hidden nodes and two outputs. Each node in a particular layer is connected to all nodes in adjacent layers with weights. The layer connected to the outputs is termed the output layer and all other layers are termed as hidden layers. Output of each hidden node j is given by

$$Y_j = a(Z_j) \tag{11}$$

Where a(.) is termed the activation function and

$$Z_j = \sum_i V_{ji} X_i + \mu_j \tag{12}$$

is termed the activation of node j and it is the weighted sum of the inputs X_i to that node and μ_j is termed the threshold of the node enable neural networks to approximate function with offsets. The most commonly used activation function is the sigmoid function:

$$a(Z) = 1/(1+e^{-z}) \tag{13}$$

The output of each output node is linear and is given simply by

$$O_k = \sum_j W_{kj} Y_j \tag{14}$$

Where V_{ji} and W_{kj} are weights of hidden and output layers.

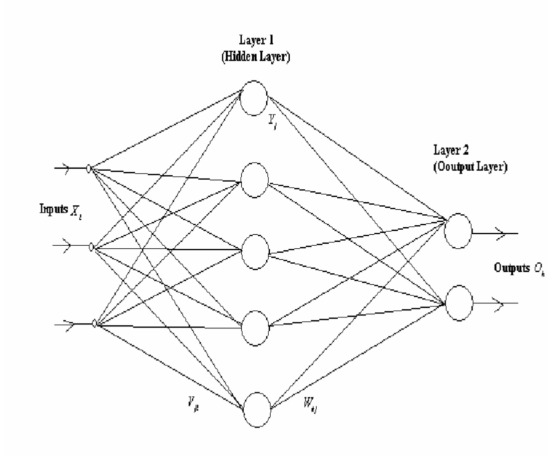

Fig. 6. Schematic representation of simple Neural Network

The output $\vec{O}$ of the neural network is a non-linear function of the inputs and the parameters (weights and thresholds) due to the sigmoidal activation functions of the hidden nodes, that is

$$\vec{O} = g(X, (\Theta)) \quad (15)$$

Where,

X is a vector containing the neural network inputs

(Θ) is a vector containing all the weights and thresholds of the neural network

g is a non-linear vector function.

The minimum number of nodes that are required in the hidden layer, in order for the neural network to successfully identify a particular function can only be determined by a heuristic approach. In the present work, error back propagation algorithm is used for training the neural network.

Each neural network has three layers, input layer, hidden layer and output layer. The number of neurons in input and output layers is equal to the number of inputs and outputs of the system. However the number of hidden layer neurons is variable and depends on the required training accuracy and often involves experimentation. The appropriate number of data required to train the neural network is approximately the number of neural network weights times the inverse of the accuracy parameter ξ [asaii (5)]. For example, if an accuracy level of 95% is desired that corresponds to ξ=0.05, the number of trained data should be approximately 20 times as many as the network 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 16 and 17 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.

$$Y = 1 \Big/ \left(1 + e^{-(V_{ji}.X + B_1)}\right) \quad (16)$$

$$O = W_{kj}.Y + B_2 \quad (17)$$

To provide the required data to train the neural network a simulation program was written to obtain the modulation index values for different load torques. Using this programme, 1,00,000 sets of training pattern such as pulse width modulated output voltage, stator current, speed of the machine, load torque and duty ratio values are obtained. The neural network system to estimate duty ratio of PWM AC Chopper fed single phase Induction Motor is shown in Fig.7.

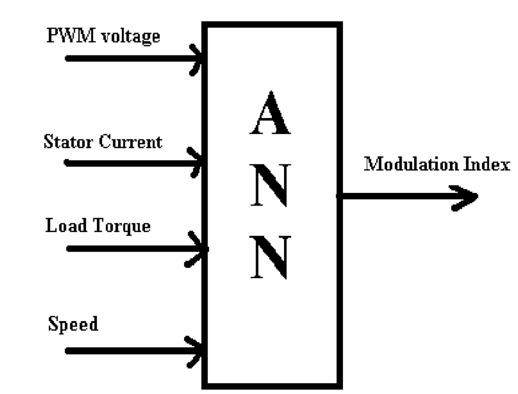

Fig.7. Neural Network system to estimate modulation index of PWM AC Chopper fed Single Phase Induction Motor

These patterns are used for training the neural network using error back propagation algorithm. After training the neural network successfully, the program is replaced by neural network controller and the simulation has been performed. Output of the neural network controller is used to vary the duty ratio of the PWM AC chopper.

VI Closed Loop Stator Voltage Controlled Single Phase Induction Motor

During no load condition, the supply voltage of Induction Motor was changed in steps from 20% to 100% of the rated voltage using pulse width modulation technique. During each step, the energy was measured. The results are plotted and shown in Fig.8. At no load condition, 20% of the rated voltage yields an energy saving of 58%. The power factor is improved from 0.31 to 0.81 with a slight reduction in speed.

During partial load conditions, the drive system is operated with various duty ratio values. From the studies, it is seen that from no load to 20% of the rated load, the savings in energy is modest. For the same model, simulation has been carried out for 20% of the rated load. It is found that, 23% of energy can be saved, when the machine is operated at 70% of the rated voltage.

From the above study, it is found that energy can be saved during no load and partial load conditions. In order to achieve the close loop control using neural network, the load torque is sensed continuously. Based upon the load torque values, the trained neural network adjusts the voltage applied to the stator of the induction motor. Neural network based energy saving scheme for single phase induction motor drive system used for simulation is shown in Fig.9. The power circuit used to generate Pulse Width Modulated AC voltage is modeled and used for simulation. Pulse Width Modulated AC voltage is applied to single phase induction motor. The neural network is trained to estimate the required voltage for different load conditions. Output of the neural network controller is used to vary the duty ratio of the PWM AC chopper. Based on the load torque applied to the machine, neural network controller controls the stator voltage. Hence the energy can be saved during no load and partial load conditions.

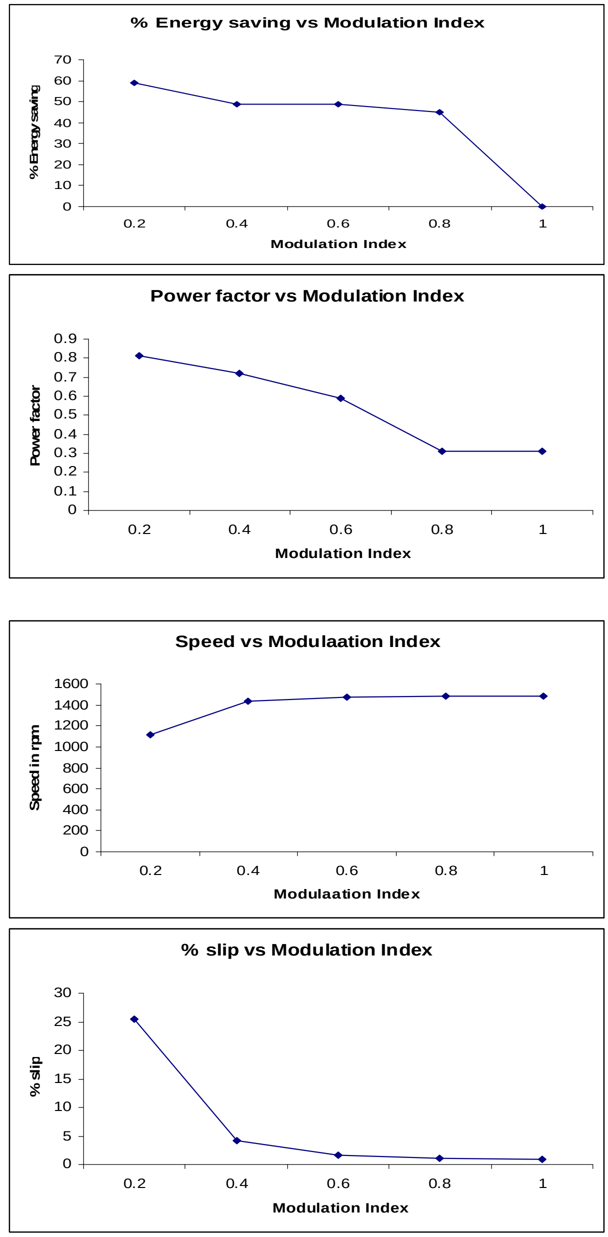

Fig.8. Performance characteristics of PWM AC chopper

For example, the model shown in Fig.9 is operated with full load condition for certain period. The load is reduced and it is operated with 20% of the rated load for some period and then it is further reduced to no load for the remaining period as shown in Fig.10.

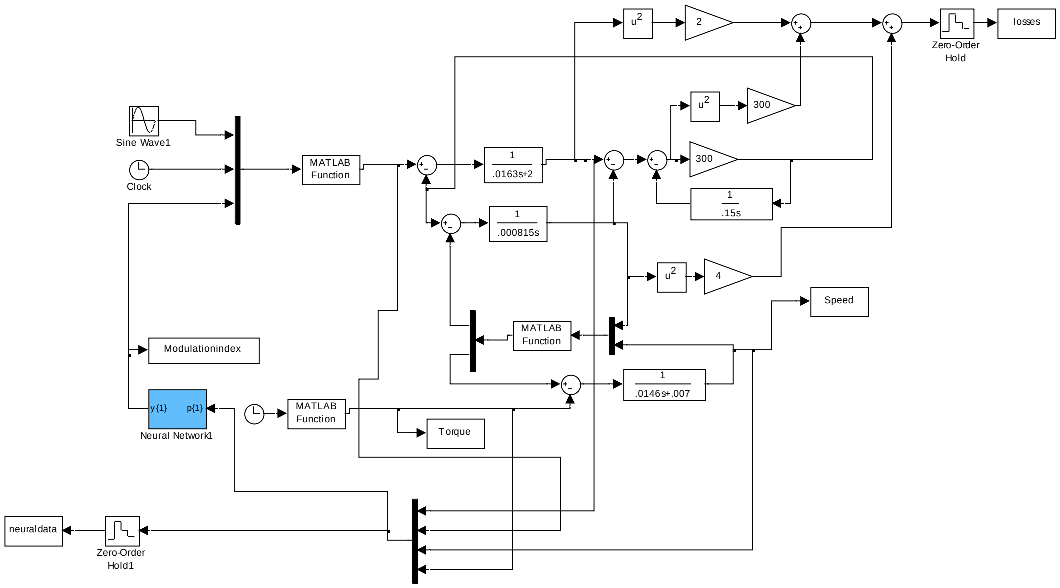

Fig.9. Simulink Model of Neural Network controlled Pulse Width Modulated AC Chopper fed Single Phase Induction Motor

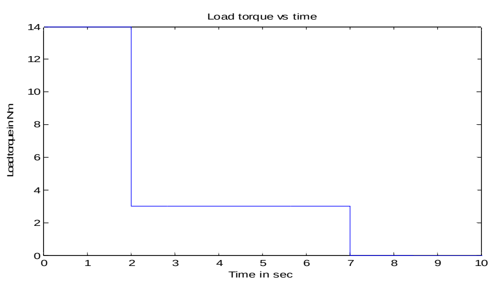

Fig.10. Variation in load torque

Neural network estimates the duty ratio values for different load conditions, such that the energy is saved during no load and partial load conditions as shown in Fig.11.

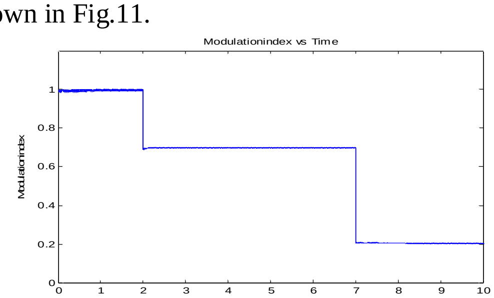

Fig.11. Variation in Modulation Index estimated by Neural Network

During various load conditions, the copper loss and iron loss are measured and the net electrical losses are shown in Fig.12. From the figure it is seen that, by varying the value of duty ratio, the losses during no load and partial load periods are much reduced. Hence energy can be saved at partial load and no load conditions.

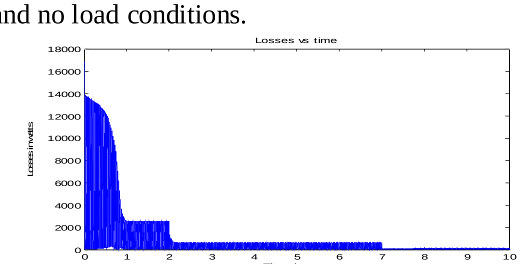

Fig.12. Losses with various load conditions

VII Conclusion

Pulse Width Modulated AC Chopper and Phase Angle Controlled AC Chopper fed Induction motor systems are simulated and their performances are compared. It is proved that Pulse Width Modulated AC Chopper has lesser Total Harmonic Distortion, better power factor and negligible harmonic components. Pulse Width Modulated AC Chopper fed single phase Induction motor system is modeled.

Systematic investigations on an induction motor with respect to energy saving led to the following results and conclusions: At no-load operation with reduced voltage, the energy saving is as high as 58% and the power factor is improved from 0.31 to 0.81. From no load to 20% of the rated load, the savings in energy is modest. At 20% of the rated load, 23% of energy can be saved with 70% of the rated voltage.

A Neural Network based closed loop control scheme to implement energy-saving of single phase induction motor drive system has been presented. This scheme changes the voltage with the variation in the load. Mathematical model of the Neural Network is presented.

REFERENCES

1. Addoweesh K.E., Mohamadein A.L.: Microprocessor based Harmonic Elimination in chopper type AC Voltae regulators. In: IEEE Transactions on Power Electronics, 1990, Vol.5, No.2, pp 191-200.
2. Ahmed N.A., Amei K. M.Sakuri, "A new configuration of single-phase symmetrical PWM ac chopper voltage controller. In: IEEE Transactions, Industrial Electronics, 1999,vol.46, No.5, pp 942-952.
3. Deib D.A., Will H.W.: Optimal harmonic reduction in ac/ac chopper converters. In: Proceedings of IEEE PESC'93, 1993, pp 1055-1060.
4. Joseph D.L., Thomas A.L.: A Single Phase Induction Motor Voltage Controller with Improved Performance. In: IEEE Transactions on Power Electronics, 1986, Vol,1, No.4, pp240-247.
5. Asaii B., Gosden D.F., Sathiakumar S.: Neural Network Applications in Control of Electric Vehicle Induction Machine Drives: In: IEE Transactions on Power Electronics and Variable Speed Drives, 1996, Conference publication No.429, pp273-278.
6. Xue X.D., Cheng K.W.E.: An Energy-Saving Scheme of Variable Voltage Control for Three-Phase Induction Motor Drive Systems. In: 2nd Internation Conference of power Electronics Systems and Applications, 2006, pp241-243.
7. Frede Blaabjerg, Florin Lungeanu, Kenneth Skaug and Andreas Aupke.: Comparison of Variable Speed Drives for Single –Phase Induction Motors. In: IEEE Transactions, 1996, PCC-Osaka, pp1328-1333.
8. Asaii B, Gosden D.F.,Sathiakumar.S.: A New technique for Highly efficient sensor-less control of Electric Vehicles by using Neural Networks. In: IEEE Transactions, 1996, , pp143-149.
9. Basanta B., Palit.: Energy saving operation of Induction Motors by voltage reduction at no and low partial-load. In: IEEE Transactions, (1989), pp147-151.
10. Christos Mademlis.: Optimization of Single-Phase Induction Motors- Part I: Maximum Energy Efficiency Control. In: IEEE Transactions on Energy Conversion, (2005), Vol. No 20, pp187-195.
11. Jamuna V., Rama Reddy S.: Neural Network controlled Energy Saver for Induction Motor Drive. In: International conference on Power Electronic Drives and Power systems POWER COIN, (2008), pp 36 – 37.

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