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Speed Estimation of A.C. Drive by Artificial Neural Networks (ANN)

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Abstract: -Artificial neural networks have been studied for many years in the hope of achieving human like performance in various fields of engineering. This paper details a proposed scheme to identify the use of neural network model for the estimation of the speed of the rotating shaft driven by voltage controlled induction motor drive. The speed identification of rotating shaft is based on the conventional analog type of electro-mechanical sensors like tachometer, optical pyrometer etc. The conventional adaptive control schemes are complicated and need excessive computational effort for real time implementation. This paper proposes how the highly parallel building blocks that illustrate neural net components and design principles can be used to track more systems like in speed identification of induction motor drive. Computational elements or nodes are connected via weights that are typically adapted to improve performance. The decisions region required by any classification algorithm can be generated in a straight-line forward manner by three-layer feed-forward nets. It details about the preferable use of contact less ANN sensors over the conventional ones, which are mounted on the shaft of the rotating motor. Moreover, the paper gives relevant data about the simulation, training and testing of an ANN network. The verification of the proposed work through physical experimentation obviously suggests the use of neural networks to solve the above problems by mimicking the adaptive control architecture in human brain.

Key Words: Neural Network, Estimator, Back-Propagation, Induction Motor, Tachometer.

I. INRODUCTION

Artificial neural network models or simply 'Neural Nets' go by many names such as connectionist models, parallel distributed processing models and neuromorphic systems **[1]**. Whatever be the name, these models attempt to approach near to the working of a human brain. ANN is one of the soft computing methods like fuzzy logic and artificial intelligence which executes the data in an almost similar manner like that of human brain. The emergence of the field of neuro computing is a new non –algorithmic approach to information processing. In a conventional algorithmic approach to information processing a computer can be programmed to carry out the processing of a particular function. This approach is based on some mathematical model. However, in more complex systems it is virtually impossible to obtain a mathematical model by a series of logical or arithmetic steps. Even if the mathematical modeling is done with some linear approximation, it becomes laborious and cumbersome to obtain its solution. These are the limitations of designing the software based on the conventional approach. In such cases neuro-computing is the first alternative to algorithmic programming. Thus, neuro-computing is concerned with non-programming adaptive information processing systems called 'Neural Networks' that develop association between objects in response to their environment .

The basic building block of all biological brains is the nerve cell or neuron. Each neuron acts as a simplified numerical processing unit. There are millions of such cells in the brain heavily inter connected and operating in parallel. In the brain each neuron takes input values from other neurons, applies the transfer function and sends its output to the next layer of neurons. This output is send to the other layers in a cascading fashion. In a similar manner artificial neural network model is formed by a collection of various processing elements. A very small ANN with three layers is illustrated in the figure 1.

An interesting feature of neural network, (Refer figure 1.) is that every processing element is connected with inter connections called as weights. Each weight has its own transfer function. It determines the strength or influence of an inter connection. Memory is stored in the strength of these interconnections. It is stored in the local memory of the processing element and used to amplify, attenuate and possibly change the sign of signal. The weights are not fixed but may change.

Most transfer functions include a learning law: an equation that modifies all or some of the weights in the local memory in response to the input signals and the values specified by transfer function. In effect, learning law allows the

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processing element response to change with time, depending upon nature of input signals. It is the means by which network adopts itself to the answers desired and so organizes information within itself in short learns. The classification of neural networks is simply on the basis of the training algorithm it adopts for the updatement of these weights.

Electric drives offer a convenient means for controlling the operation of different devices used in industry. Their high reliability and versatility have resulted in their wide application. In the proposed work it is intended to estimate the rotating speed of the shaft driven by an induction motor under variable voltage controlled mode by means of neural network **[3]**. At the preliminary stage the work involves the simulation of multi-layer neural network model as described above on the digital computer with the use of suitable software tool. The simulation process based on the particular training algorithm involves the training and testing of the network with the various patterns of input / output real time data. The processing of real time data to the simulated network is done through PC as a host computer.

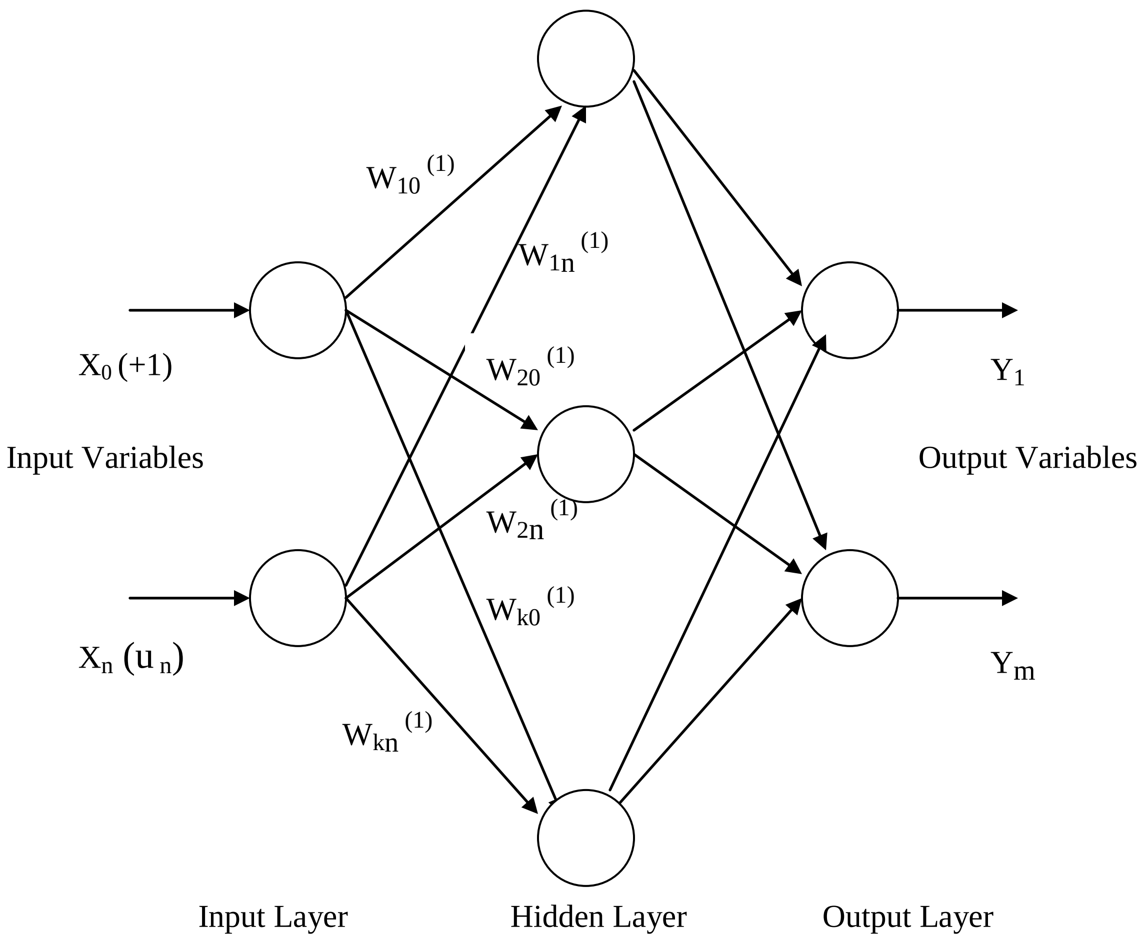

Fig. 1. Three Layer Neural Network Model

The minimum necessary hardware infrastructure essential to carry out the required training process is comprise of an induction motor of suitable horse power rating (5 HP), PC as a host computer with real time data software tool box, conventional analog type of sensor element, voltage/current sensing elements, hardware interface in the form of electronic comparator, A/D and D/A converter.

II. SIMULATION OF NEURAL NETWORK MODEL ON A COMPUTER.

First step towards the development of the contact less type of speed estimator for identification of the rotating speed of an induction motor drive is to simulate a three layer neural network model as shown in figure 1. on the digital computer. Before constructing the physical components of a neural network, its data is fed in a digital computer. This host computer contains all the mathematical functions and relations and proposes a simulated model or design for the neural network. Various inputs are given to it and the corresponding outputs are checked. It is done to check how the actual network will work and what could be the shortcomings in the network in order to prevent it from any drawbacks. It checks how the real system will perform in different working environments. Thus based on the performance of the simulated model only final

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architecture of the network is designed. The Matlab neural network software tool box in conjunction with Simulink block set is used for the simulation of a neural network model on a digital computer.

III. BACK PROPAGATION TRAINING ALGORITHM

Simulation of a three layer neural network model as shown in figure 1. is done on the basis of back propagation training algorithm for the correct estimation of the speed of the rotating shaft driven by voltage controlled A. C. induction motor driven under variable load condition **[4]**. The input layer is consists of two input nodes. The first input node receives the input voltage signal as an variable operating voltage applied across the stator windings. The second input node receives the current input signal representing the current dragged by motor under variable load condition. The output layer is comprise of one output node to provide the output signal representing the estimated rotating speed of the shaft driven by an induction motor.The processing that each element does is determined by a transfer function – a mathematical formula that defines the element output signal as a function of whatever input signals have just arrived and the adaptive coefficients present in the local memory **[5,6]**. The 'Sigmoid Function' is used as a transfer function as shown in figure 2.

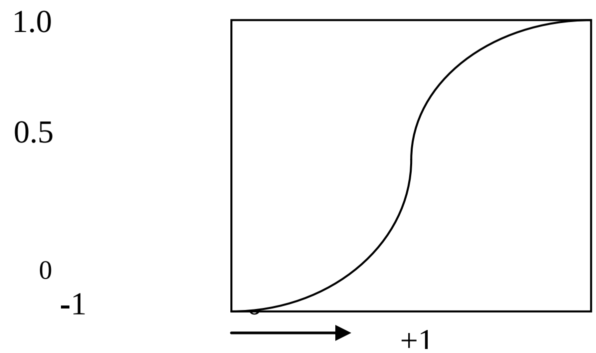

Fig.2Weighted Sum of Inputs

A. Weight initialization

Set all weights and node thresholds to small random numbers. Note that the node threshold is the negative of the weight from the bias unit (whose activation level is fixed at 1).

B. Calculation of activation

1. The activation level of an input unit is determined by the instance presented to the network.
2. the activation level *Oj* of a hidden and output unit is determined by

$$Oj = F\left(\sum WjiOi + \theta j\right) \quad (1)$$

Where *Wji* is the weight from an input *Oi, θj* is the node threshold and *F* is a sigmoid function:

$$F(a) = 1/(1+e^{-a}) \quad (2)$$

C. Weight assignment

1. Start at the output units and work backward to the hidden layers recursively. Adjust weights by

$$Wji(t+1) = Wji(t) + \Delta Wji \quad (3)$$

Where *Wji(t)* is the weight from unit *i* to unit *j* at time *t* (or t^{th} iteration) and *ΔWji* is the weight adjudstment.

2. The weight change is computed by

$$\Delta Wji = \eta\, \delta jOi \quad (4)$$

Where η is a trial-independent learning rate (0< η <1) and *δj* is error gradient at unit *j*. convergence is sometimes faster by adding a momentum term:

$$Wji(t+1) = Wji(t) + \eta\delta jOi + \alpha[Wji(t) - Wji(t-1)] \quad (5)$$

Where 0<α<1.

3. The error gradient is given by:

for the output units;

$$\delta j = Oj(1-Oj)(Tj-Oj) \quad (6)$$

Where *Tj* is the desired (target) output activation and *Oj* is the actual output activation at output unit *j*.

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for the hidden units:

$$\delta j = Oj(1 - Oj)\sum_{k} \delta k Wkj \qquad (7)$$

Where δk is the error gradient at unit k to which a connection points from hidden unit j.

4. Repeat iterations until convergence in terms of the selected error criterion. Iteration includes presenting an instance, calculating activations, and modifying weights.

III. APPLICATIONS OF NEURAL NETWORKS

Basically, most application of the neural networks fall into the following five categories:

- Prediction – Uses input values to predict the output.
- Classification- Uses input values to determine the classification.
- Data association-Like classification but it also recognizes data that contains errors.
- Data Conceptualization- Analyzes the input so that grouping relationships can be inferred.
- Data filtering – Smooth an input signal.
- Industrial neurotech.

The fully connected network used in this paper has following structure:
Input Layers: one with 320 units or nodes
Hidden Layers: one with seven units or nodes.
Output Layers: one with 1 unit or node.

IV. HARDWARE IMPLEMENTATION OF NEURAL NETWORK MODEL

Application of ANN for speed estimation of voltage controlled induction motor drive is presented. The squirrel cage induction motor is basically a simple, less costly and reliable and can provide excellent characteristics at a constant shaft speed. Generally, the speed is measured using a sensor, which affects the ruggedness and the simplicity of the drive system. Further the elimination of sensor reduces the drive cost and size. For these reasons, now a days sensor-less speed control schemes are developed for variable voltage and frequency induction motor drives. Such schemes make use of either model reference adaptive control or neural networks.

The scheme presented here is based on input-output relations obtained experimentally and does not involve machine equations. Hence the error due to parameter variations does not arise and so improved accuracy is achieved. A multi-layer back-propagation neural network is trained off-line to learn the dynamics of the system with a no priori knowledge. The ANN is trained with adaptive learning and momentum rule. The function approximation capability of a feed forward ANN is used for motor speed identification. The scheme for training the network is shown in figure 3.

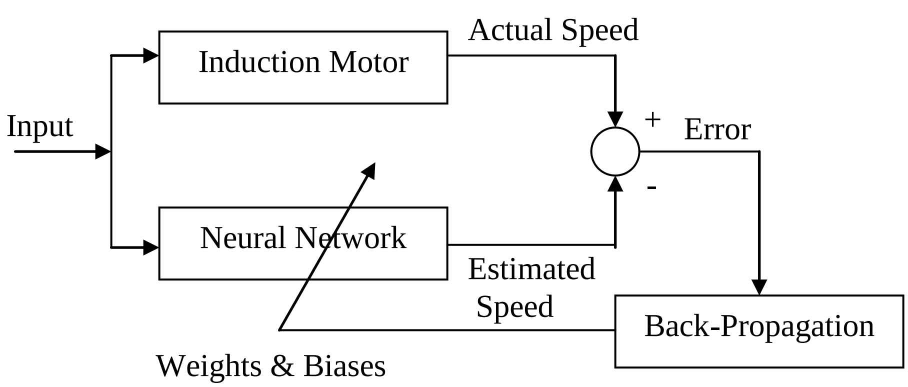

Figure3. Training of Neural Network as Motor Speed Estimator.

The details of three-phase induction motor are: 415V, 7.1 Amps, 1440 rpm, 5 H. P. and 50 Hz **[3]**. The input is applied to the motor under test and to neural network. For a sine wave input the per phase equivalent circuit of a three-phase induction motor is shown in figure 4. A close examination of figure 4. Reveals that the motor power factor is decided only by the motor slip **[3,4]**. Hence the speed estimation can be done with the mere knowledge of motor power factor. However with different voltages, variation of magnetizing parameters causes errors in speed identification due to non-linearity. For the test machine it is clear that exact computation of speed requires the knowledge of magnetizing components, thus making the computations very tedious. Since the magnetizing elements are functions of stator voltage, the speed estimation therefore requires the knowledge of voltage also.

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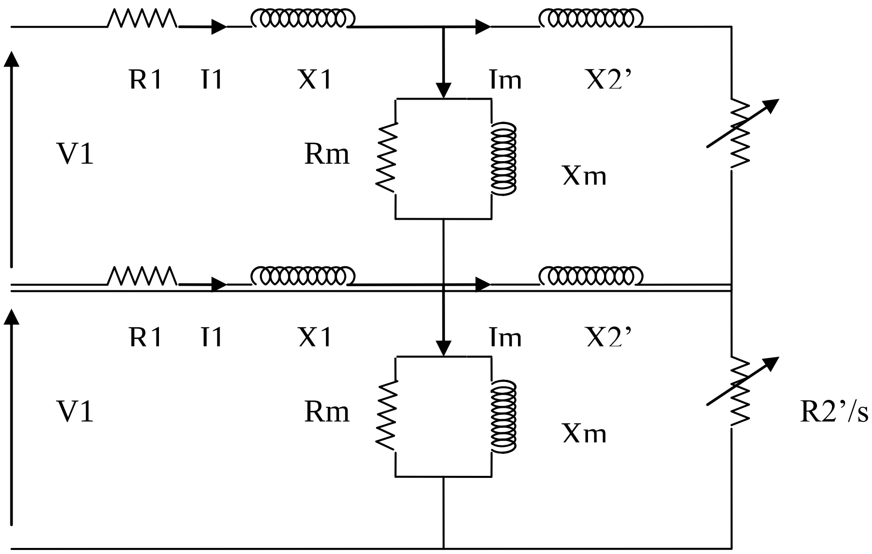

Figure 4. Per Phase Equivalent Circuit of Three Phase Induction Motor

For a given power factor and stator voltage, there are two different values of speed **[4].** Hence the motor voltage and power factor will not precisely define the motor speed at all loads requiring an additional input to the neural network. Therefore variation in motor current is also referred to as an input variable. Further for simplicity it is suggested to make use of peak value instead of r. m. s. value of the motor current. The inputs to ANN are limited to a few, which in turn reduces the hardware cost and the network size **[**7]. Both the voltage and the current signals are easy to measure, readily reduced to a low level by means of stationary elements like current and potential transformer respectively.

The real time processing of these input signals can be done through A/D converter, scaling and normalization circuits with PC as a host computer. The output signal at the output node indicates the operating speed for various input patterns. The D/A signal conditioning of output signal measures the estimation of the speed by a neural network, which is continuously compared against the analog output signal from tachometer. The electronic comparator circuit in the form of a building block of operational amplifier operates in differential amplifier mode compares the actual measurement of speed determined by the conventional tachometer sensor and the estimation of the speed determined by the neural network. The output of the electronic comparator provides the error signal, which is feedback to the network. This error signal is back propagated from an output to input layer for numbers of iterations till the error converges to value within a specified limits.

This kind of supervised training based on back propagation training algorithm of simulated neural network model is done with the several combinations of repeated input/output patterns till the time when network is fully trained to give the correct estimation of the speed. The testing of the network is done by means of application of another set of desired input/output patterns. With successful testing of the neural network as speed estimator, the conventional analog type of sensor like tachometer can be replaced by neural network. The physical experimentation of this proposed work will give the verification of the use of neural network as a non- contact type of sensor element for the identification of the speed of rotating shaft driven by an A. C. induction motor driveThe hardware realization is then only possible for practical use of such speed sensor.

IV. CONCLUSION

The paper details the suggested approach for the identification of the speed with the use of neural network. It describes the methodology of the work oriented towards the hardware implementation for the training of neural network model as a speed estimator. The work deals with the design and implementation of the back propagation-training algorithm for a simulation of three-layer network on digital computer. The ANN used here has a input layer with two input nodes, one hidden layer with three neurons and an output layer with one output node. The inputs to the network are motor voltage and peak motor current and the desired output is rotor speed. A sigmoid transfer function is used for the neurons, whose output is scaled to unity. The neural network is trained with normalized inputs and output in the entire range of operating voltage variation. The motor voltage reduction must be limited to 60% of rated voltage to avoid stalling of the motor. The training of neural network is terminated when the sum- squared error (SSE) reaches the error goal.

The trained ANN is then used for speed prediction for different peak currents at a constant voltage and the results should be compared with the actual measurements done with the conventional sensor. The tracking capability of the neural network scheme suggested here will be justified only when the estimated results as obtained by ANN coincide with the

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experimental results. The parallel combination, non-linear mapping and learning abilities of neural network un-doubtly make them suitable for such applications.

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