Electricity Consumption Prediction Model using Neuro-Fuzzy System

Rahib Abiyev, Vasif H. Abiyev, and Cemal Ardil

Abstract—In this paper the development of neural network based fuzzy inference system for electricity consumption prediction is considered. The electricity consumption depends on number of factors, such as number of customers, seasons, type's of customers, number of plants, etc. It is nonlinear process and can be described by chaotic time-series. The structure and algorithms of neuro-fuzzy system for predicting future values of electricity consumption is described. To determine the unknown coefficients of the system, the supervised learning algorithm is used. As a result of learning, the rules of neuro-fuzzy system are formed. The developed system is applied for predicting future values of electricity consumption of Northern Cyprus. The simulation of neuro-fuzzy system has been performed.

Keywords—Fuzzy logic, neural network, neuro-fuzzy system, neuro-fuzzy prediction.

I. INTRODUCTION

FUZZY systems have found a number of practical applications in identification, control, prediction and diagnosing. It is widely use for modeling complex nonlinear systems. Traditionally, to develop a fuzzy system, human experts often carry out the generation of IF-THEN rules by expressing their knowledge. In case of complicated processes it is difficult for human experts to test all the input-output data, to find necessary rules for fuzzy system. To solve this problem and simplify the generating of IF-THEN rules, several approaches have been applied [1-3]. Nowadays for this purpose the use of neural networks take importance. The combination of fuzzy system and neural network allows the increase computational efficiency of the software products. Neuro-fuzzy system combines the learning capabilities of neural networks with the linguistic rule interpretation of fuzzy inference systems. The synthesis of neuro-fuzzy inference system includes the generation of knowledge base rules that have IF-THEN form. Here, the problem is to find the optimal definition of the premise and consequent part of fuzzy IF-THEN rules through the training capability of neural networks, evaluating the error response of the system. In the paper neuro-fuzzy structure is applied to solve electricity consumption prediction problem.

The prediction of the future state of a system is made by knowing the present measurements and recent historical states. This process has nonlinear character and can be described chaotic time series. Chaotic time series were

Rahib Abiyev is with Department of Computer Engineering, Near East University, P.O. Box 670, Lefkosha, TRNC, Mersin-10, Turkey (fax: 0392-223-6622; e-mail: rahib@neu.edu.tr).

Vasif H. Abiyev is with Department of Economics, Hacettepe University, Turkey.

Cemal Ardil is with the Azerbaijan National Academy of Aviation, Baku, Azerbaijan (e-mail: cemalardil@gmail.com).
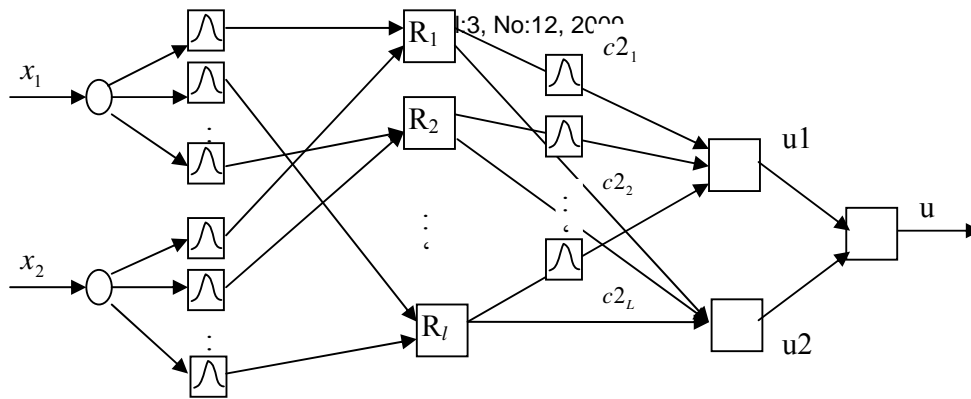
modeled and predicted by neural networks [4-7]. Neural networks prediction capability exceeds the conventional methods. In [6] neural network is interpreted as the decomposition of the time-series into different frequency components and prediction is achieved by reconstruction this frequency components. In the work to reduce the searching space and time for achieving optimal solution, the combination of neural networks with fuzzy knowledge base is used for electricity consumption prediction.

II. NEURO-FUZZY INFERENCE SYSTEM

In Fig. 1 the structure of neuro-fuzzy inference system is given. The input signals applied to the network at time k are $x_i(k)$ (i=1..N) and output signal of the network are u(k). N is number of neurons in the input layer.

In first layer the number of nodes is equal to the sum of external inputs. In second layer each node corresponds to one linguistic term. For each input signal entering the system the membership degree to which input value belongs to a fuzzy set is calculated. To describe linguistic terms the Gaussian membership function is used.

$$\mu 1_j(x_i) = e^{-\frac{(x_i - c1_{ij})^2}{\sigma 1_{ij}^2}} \qquad \text{i=1..n, j=1..J} \qquad (1)$$

$c1_{ij}$ and $\sigma 1_{ij}$ are the center and width of the Gaussian membership function of the *j*th term of *i*th input variable, respectively. $\mu 1_j(x_i)$ is membership function of i-th input variable for j-th term. n is number of external input signals. J is number of linguistic terms assigned for external input signals x_i, P is number of linguistic terms assigned for one-, two-,…, D- delayed output signal of network.

In the third layer the number of nodes corresponds to the number of rules. Each node represents one fuzzy logic rule. Here to calculate the values of output signals of the layer AND (min) operation is used.

$$\mu_l = \prod_j \mu 1_j(x_i), \qquad \text{l=1..L, j=1..J+P, } i=1,..,n \qquad (2)$$

Here Π is min operation.

These μ_l signals are input signals for the next last layer. This layer is a consequent layer. In this layer the output signals of previous layer are multiplied to the weight coefficients of network and sum of this product is calculated. Weight coefficients of recurrent neuro-fuzzy system are represented by fuzzy set of output variables.

Fig. 1 Structure of neuro-fuzzy inference system

They are described by Gaussian function. If as a defuzzification operation we use "center of average" then only the center of Gaussian function is used in the next layer for defuzzification. In this case during development of control system the width of Gaussian function is not used. In formula (3) the parameters $c2_l$ will represent the center of fuzzy coefficients. Output of fifth layer is calculated as:

$$u1 = \sum_{l=1}^{L} \mu_l * c2_l , \quad l=1..L \qquad (3)$$

After the sum of output signals of the third layer $u2 = \sum_{l=1}^{L} \mu_l$ is determined. Using the values of calculated variables and m the output of the fuzzy system is determined.

$$u = \frac{\sum_{l=1}^{L} \mu_l * c2_l}{\sum_{l=1}^{L} \mu_l} \qquad (4)$$

The unknown parameters of the system are $c2_l$ parameters of last layer and membership functions of first layer of recurrent neuro-fuzzy system. To define the accurate values of unknown parameters supervised learning algorithm is used:

$$c2_l(t+1) = c2_l(t) + \gamma \frac{\partial E}{\partial c2_l} \qquad (5)$$

here γ is learning rate.

$$E = \frac{1}{2} \sum_{i=1}^{m} (u_i(t) - u_i^d(t))^2 \qquad (6)$$

where $u_i(t)$ and u_i^d are current and desired outputs of the system, m is number of outputs. For given case m=1.

The adjusting of the membership functions of input layer is carried out by correction unknown coefficients $c1_{ij}$ and $\sigma1_{ij}$. The following formulas can be used for learning these coefficients.

$$c1_{ij}(t) = c1_{ij}(t) + \gamma \frac{\partial E}{\partial c1_{ij}}, \qquad (7)$$

$$\sigma1_{ij}(t) = \sigma1_{ij}(t) + \gamma \frac{\partial E}{\partial \sigma1_{ij}}, \qquad (8)$$

Using (10) - (13) the learning of the coefficients of recurrent neuro-fuzzy system is carried out.

III. SIMULATION

Neuro-Fuzzy system is applied for constructing prediction model of electricity consumption. The statistical data were obtained from KIB-TEK reports for the period of 1996-2004. It was important to know in what volume of electricity will be used in the near future (next month or after one-two month), even an approximate value will be sufficient.

In Fig. 2 the plot of electricity consumption for the period 1996-2004 is shown. As shown electricity consumption has high order nonlinearity.

The neuro-fuzzy structure and its learning algorithm is used to construct prediction model. In prediction problem it is needed to predict the value of electricity consumption in near future x(t+P) on the base of sample data points {x(t-(D-1)Δ),…..,x(t- Δ),…..,x(t)}. In the work the four input data points are used [x(t-4) x(t-3) x(t-2) x(t)] for prediction model. In other words since the electricity consumption is taken monthly then the value that is to be predicted will be after 3 months. Then the output training data correspond to x(t+3). The training input/output data for the prediction system will be a structure whose first component is the four dimension input vector, and second component is the predicted output.
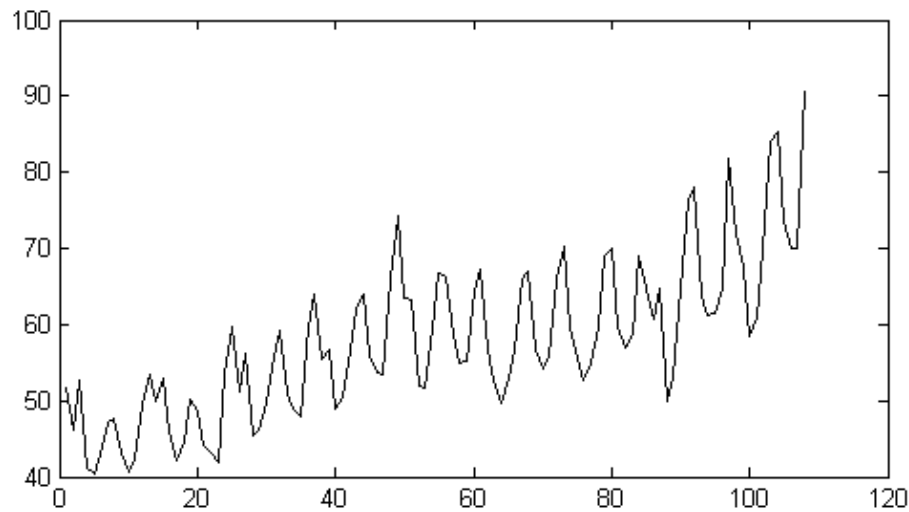
Fig. 2 9 Plot of input data samples

To start the training, the neuro-fuzzy structure is generated. It includes four input and one output neuron. The 48 hidden neurons (rules) are used in third layer. Second layer of system includes Gaussian membership functions for each input signal.

All input and output data are scaled in interval 0÷1. The initial values of membership function are generated in equally spaced and cover the whole input space. The training of the parameters was performed using supervisory algorithm. In the result of training the values of parameters of neuro-fuzzy system were found. In Fig. 3 the output of neuro-fuzzy system and predicted value of electricity after three month are shown.

The plot of prediction error is shown in Fig. 4. The training is carried out for 1000 epochs.
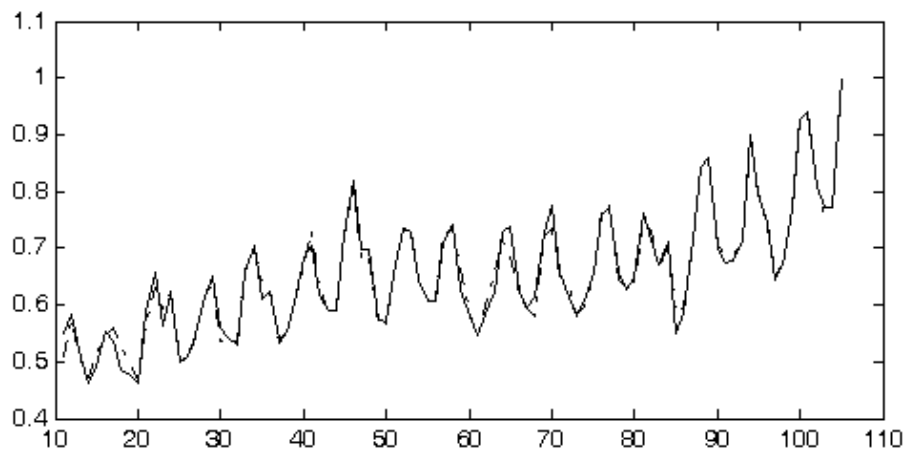

Fig. 3 Plot of output signals: generated by NFIS (dotted line) and predicted signal (solid line)
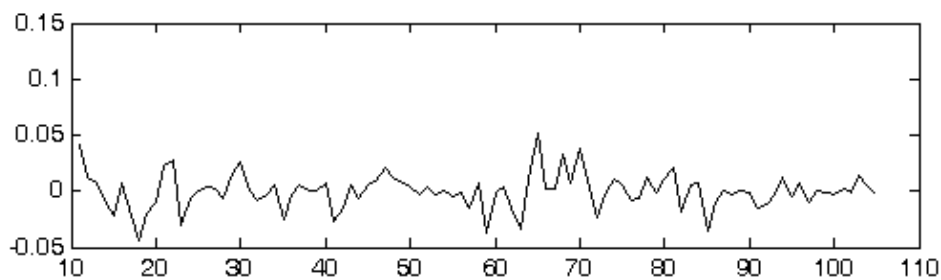

Fig. 4 Plot of prediction error

TABLE I
COMPARATIVE RESULTS OF SIMULATION

	Neural network based model	Neuro-fuzzy based model
Epochs	10000	1000
Sum of absolute values of errors $\sum_{i=1}^{n}\left|e_i\right|$	2.8703	1.0624

The result of simulation of neuro-fuzzy prediction model is compared with result of simulation of prediction model based on neural network. To estimate performance of neural and neuro-fuzzy prediction systems the sum of absolute values of errors between predicted and current output signal is taken.

$$J = \sum_{i=1}^{n}\left|e_i\right|$$

In Table I the comparative results of simulations are given. As shown from table the performance of neuro-fuzzy prediction is better than other model.

The obtained result from the simulation satisfies the efficiency of application of neuro-fuzzy technology in constructing prediction model of electricity consumption.

IV. CONCLUSION

In this paper the development of neuro-fuzzy system for constructing time-series prediction model is given. The structure and learning algorithms of neuro-fuzzy system is applied to develop model predicting future values of electricity consumption. The simulation of developed neuro-fuzzy system has been performed. Test results of developed system satisfy the efficiency of used methodology.

REFERENCES

[1] Yager R.R., Zadeh L.A.(Eds).”Fuzzy sets, neural networks and soft computing”, Van Nostrand Reinhold, New York, 1994.
[2] Kosko B,”Neural networks and fuzzy systems. A dynamical system approach to machine intelligence”, Prentice- Hall International Inc., Englewood Cliffs. 1993.
[3] Witold Pedryz, editor,“Fuzzy Modelling: Paradigms and Practice”, Kluwer Academic Publisher, Boston, 1996.
[4] Smaoui N. An Artificial Neural Network Noise Reduction Method for Chaotic Attractors. Intern J. Computer Math., Vol.73,pp.417-431.
[5] Lapades A, Farber R. Nonlinear Signal Processing Using Neural Networks: Prediction and Signal Modeling. Los Alamos. 1987.
[6] Ying-Qian Zhang, Lai-Wan Chan. Fourier Recurrent Networks for Time series Prediction. Proceeding of International Conference on Neural Information Processing, ICONIP 2000, Tacjon, Korea, pp 576-582, 2000.
[7] Nunnari G, Nucifora A, Randieri C. The application of neural techniques to the modeling of time series of atmospheric pollution data. Ecological Modelling 111; 187-205, 1998.
[8] Tang Z., de Almeida C., Fishwick P.A. Time-series forecasting using neural network versus Box-Jenkins methodology. Simulation, 57, pp. 303-310, 1991.
[9] Rahib Abiyev, “Controllers based on Soft computing elements”, Electrical, Electronics and Computer Engineering Symposium NEU-CEE2001 and Exhibition,. Nicosia, TRNC, Turkey, pp.182-188, May, 2001.