Time series prediction in the case of nonlinear loads by using ADALINE and NAR neural networks

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Abstract. This paper presents a study regarding the time series prediction in the case of an electric arc furnace. The considered furnace is a three phase load and it is used to melt scrap in order to obtain liquid steel. The furnace is powered by a three-phase electrical supply and therefore has three graphite electrodes. The furnace is a nonlinear load that can influence the equipment connected to the same electrical power supply network. The nonlinearity is given by the electric arc that appears at the furnace between the graphite electrode and the scrap. Because of the disturbances caused by the electric arc furnace during the elaboration process of steel it is very useful to predict the current of the electric arc and the voltage from the measuring point in the secondary side of the furnace transformer. In order to make the predictions were used ADALINE and NAR neural networks. To train the networks and to make the predictions were used data acquired from the real technological plant.

1. Introduction
In the present the steel is used in the whole world in many domains such as: alimentary, chemically, constructions, marine and automobile industries. The steel has the main advantage that it can be melted many times and used again without losing its properties. The main equipment used to obtain liquid steel is the electric arc furnace (EAF). This kind of equipment is mainly characterized by its capacity, its power level and its productivity.

The EAF can be classified into two categories: AC or DC furnaces. Indifferent of what type is the furnace the basic operating principle is the same: the electric arc struck from one or more electrodes to a metallic charging material [1]. The charging material in the EAF’s tank has different shape and dimension, so in the initial melting period the operation of the furnace cannot be in the steady state. Because this kind of EAF is a nonlinear load it produces significant electrical disturbances such as voltage fluctuations, flicker, harmonics and unbalance between phases [2], [3]. Therefore it is necessary to develop accurate and reliable models which can be voltage-current characteristic predictors. The prediction can improve the productivity of steel and also can reduce the negative effects that can influence the other equipment connected to the same power system. The voltage flicker has randomly character and also depends on both operation mode and type of the furnace [4].

In the scientific literature have been presented the following models of the electric arc:

- models based on the nonlinear and time-varying resistors [5];
- models based on the linear approximation of the voltage – current characteristic of the electric arc [6-11];
• models where the voltage and the current are related by hyperbolic functions (using the diameter or length of the arc) [8], [12-15];
• advanced models which use the artificial neural networks [1], [16-18].

In this paper is performed a study regarding the time series prediction in the case of an AC EAF. In order to make the predictions were used ADALINE (adaptive linear neuron) and NAR (nonlinear autoregressive) neural networks. To train the networks and to make the predictions were used data acquired from the real technological plant.

The networks learn to predict the voltage-current characteristic of the EAF taking into consideration the measurements used to train the networks. It can be noticed that by choosing the proper network architecture and by using a suitable learning algorithm both networks have the capability to perform one-step or multi-steps ahead prediction.

2. Development of the EAF Models

The EAF is a complex system with multi-variable process and time-varying parameters. Also, the EAF is a nonlinear load, this nonlinearity being caused by the electric arc. Therefore, the artificial neural network (ANN) fits well for the modelling of the behaviour of this installation.

The purpose of this paper is to develop a model that can be used to accurately represent the variation of the electrical parameters that characterise the EAF. In order to train the network can be used any of the following parameters: supply voltage or furnace transformer current and voltage. The behaviour of the EAF is represented within a neural network by biases, weights, transfer function and the type of network. By modifying the neural network architecture (structure of the network, number of neurons, connections, weights, biases or different learning algorithms) a network can be trained to perform a specific function.

In this paper are developed two types of networks such as ADALINE and NAR neural networks. For both of the networks the training data set contains 500 samples of the acquired current and voltage from the secondary side of the furnace transformer. The testing data set contains also 500 samples of the acquired current and voltage from the secondary side of the furnace transformer but this set is different by the training data set. For this new data set is tested the capability of the network to predict the voltage and current from the secondary side of the furnace transformer. The network is trained and tested for a single phase because the behaviour is the same for the other two.

3. ADALINE Neural Network

The ADALINE neural network used in this paper is similar to the perceptron, so having one input layer and one output layer, but its transfer function is linear rather than hard-limiting. In this way the output of the ADALINE network can take on any value as compared to the perceptron output that can be either 0 or 1. The ADALINE networks use the least mean squares (LMS) or Widrow-Hoff learning rule. The learning rule algorithm adjusts the weights and biases of the network.

The ADALINE network is used in this paper as an adaptive filter by adjusting the weights and biases during network training taking into consideration new input and target vectors and also a tapped delay line of the input signal.

3.1. EAF Current and Voltage Prediction

The ADALINE neural network was created by using linearlayer function from Matlab. The input delay is 5 and the learning rate is 0.2. The input of the network is a current or a voltage. In order to use the adaptive training of the ADALINE is used the adapt function. In this case the network receives one step at a time from the sequence of the input and the weights and biases are updated after each step, before being received a new step from the sequence. In order to test the capability of the network to perform prediction of a sequence of the input, the network is simulated for a new data set containing different values as compared to the ones used for adaptive training of the network.

In Figure 1 is illustrated the adaptive training in the case of current for 500 samples, respectively the obtained error during network training. It can be noticed that the ADALINE neural network has
the capability to learn this data set. The error decreases while the network uses more steps from the training data set.

In Figure 2 is represented the response of the network when this is simulated for a new data set. In this case are used the weights and biases obtained after performing the adaptive training. It can be observed that the response of the network follow precisely the acquired current and the error has small values even smaller as compared to the training.

![Figure 1](image1.png)

**Figure 1.** a) Adaptive training in the case of electric current, b) Obtained error during network training

![Figure 2](image2.png)

**Figure 2.** a) Prediction of electric current for a new data set, b) Obtained error during network prediction

Figure 3 illustrates the adaptive training in the case of voltage for a data set of 500 samples, respectively the obtained error during network training. It can be noticed that, even for this parameter, the ADALINE neural network has the capability to learn the data set.

In Figure 4 is represented the response of the network when is simulated for a new data set that contains 500 new samples of voltage. For this case also are used the weights and biases obtained after
performing the adaptive training. It can be observed that the response of the network follow the acquired voltage but the prediction presents some errors because the voltage is more distorted as compared to the current.

![Graph showing adaptive training in the case of voltage and obtained error during network training.](image1)

**Figure 3.** a) Adaptive training in the case of voltage, b) Obtained error during network training

![Graph showing prediction of voltage for new data set and obtained error during network prediction.](image2)

**Figure 4.** a) Prediction of voltage for new data set, b) Obtained error during network prediction

In Figure 5 is represented the voltage-current characteristic of the furnace that is obtained by plotting the voltage and current from the secondary side of the furnace transformer for both adaptive training of the network and prediction case taking into consideration measured and simulated data.
4. NAR Neural Network
The NAR neural network can be used to predict a time series from the same series past values. This network is a dynamic network with feedback that can be transformed between open-loop and close-loop.

In this paper the NAR neural network is used to simulate a network that is trained up to the present with some known values of a time-series in the open-loop mode and then is switched to the closed-loop mode in order to perform multi-steps ahead predictions. In the closed-loop the network makes predictions by using internal feedback because the external one isn’t known by the network for the new data set. When the network is transformed into a closed-loop one the network is turned into a parallel configuration.

4.1. EAF Current and Voltage Prediction
The NAR neural network is created by using narnet function from Matlab. The input delay is 5, the feedback delay is 12 and the number of the hidden neurons is 6. The input of the network is a current or a voltage.

Input and target time series data is prepared for the network training by using the preparets function. By using this function the input and target time series are shifted as many steps are needed to fill the initial input and layer delay states. After training process the network is transformed into a closed-loop network by using closeloop function and the delay is removed by using removedelay function. In this way the network can be tested to notice the capability of the network to learn the behaviour of the input.

In order to test the capability of the network to perform prediction of a sequence of the input, the network is simulated for a new data set containing different values as compared to the ones used for the network training.

In Figure 6 is illustrated the network training in the case of current for 500 samples, respectively the obtained error during network training. It can be noticed that the NAR neural network has the capability to learn this data set very accurately.

In Figure 7 is represented the response of the network for a new data set. It can be observed that the response of the network follow precisely the acquired current and the error has small values.

Figure 8 illustrates the training in the case of voltage for a data set of 500 samples, respectively the obtained error during network training. It can be noticed that the NAR neural network has the capability to learn this data set very accurate.
Figure 6. a) Training in the case of electric current, b) Obtained error during network training

Figure 7. a) Prediction of current for new data set, b) Obtained error during network prediction
In Figure 9 is represented the response of the network when is simulated for a new data set that contains 500 samples of voltage. It can be observed that the response of the network follow precisely the acquired voltage, the prediction being accurate.

In Figure 10 is represented the voltage-current characteristic of the furnace that is obtained by plotting the voltage and current from the secondary side of the furnace transformer for both training and prediction of the network taking into consideration measured and simulated data.

![Figure 8](image1.png)

**Figure 8.** a) Training in the case of voltage, b) Obtained error during network training

![Figure 9](image2.png)

**Figure 9.** a) Prediction of voltage for new data set, b) Obtained error during network prediction
Figure 10. Voltage-current characteristic of the furnace for a) modelled data and b) predicted data

5. Conclusions
In this paper was described the development of two architecture of neural network such as ADALINE and NAR neural networks. In order to develop the networks was used Matlab 2012 environment.

The simulation results are compared with acquired data from a real electric arc furnace in order to validate the two models. The training data set was used to notice the capability of the network to learn the behavior of the electric arc furnace while the testing data set was used to obtain the capability of the network to perform generalization.

Obtained results illustrate that the NAR neural network performs a better prediction as compared to the ADALINE neural network. The results obtained from training and testing of the network can be used to estimate the voltage-current characteristic of the furnace for different meltdown stages.

These two networks illustrate the possibility of neural network to model the nonlinear and time-varying system such as electric arc furnace without using equations. Developed networks can be considered as adaptive networks.

Both networks can make prediction on multi-steps ahead and can be used to perform a particular function such as prediction or noise cancelation so can be used in signal processing and control systems.

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