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THE USE OF ALTERNATIVE REGRESSION MODELS TO DETERMINE PEAK LOADS IN RURAL TRANSFORMER STATIONS

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Summary. The paper presents models of combining peak loads in rural 15/0.4 kV transformer stations with the annual electric power consumption by end users connected to these stations, with the use of artificial neural networks based on fuzzy set theory, as well as chaos theory. Further on, it verifies feasibility of the mentioned theories for forecasting purposes. On the basis of error analysis, it was confirmed that all the alternative models show satisfactory quality, and the best quality of forecasting is provided by the fuzzy model.

Key words: peak load, transformer station, alternative regression model.

INTRODUCTION

Apart from the network performance, a credible forecast of peak loads is usually a starting point in the planning of electric power network development. The peak load is the maximum value of average 10-minute active power present during the analyzed time period. For example, a distribution of maximum voltage variations which is quite significant in the programming of distribution network development can be predicted on the basis of peak load forecasts [Dudek 2004].

An interest in possibilities of alternative forecasting methods has been growing together with the development of free market mechanisms and power market competition. Artificial neural networks (ANN) [Dudek 2000; Lula 2000; Piotrowski 2007; Siwek 2001; Zaleski 1998], fuzzy set theory [Marzecki 2006; Trojanowska, Małopolski 2004, 2005, 2008], as well as chaos theory [Dobrzańska 2002; Trojanowska 2006a, 2006b, 2006c], are all becoming more and more popular in forecasting.

Determining peak loads is a difficult task, particularly in low voltage networks due to the limited possibilities for the provision of power measurements in these networks. A research conducted [Marzecki 2006; Trojanowska 2003; Trojanowska, Nęcka 2007; Zaleski 1998] indicated that the value most correlated with a peak load in a transformer station is an electric power consumed by the end users connected to that station.

The purpose of the research was to check feasibility of alternative regression models for determination of peak loads in rural 15/0.4 kV transformer stations, on the basis of the annual consumption of electric power by the end users connected to those stations.

MATERIAL AND METHODS

The work was executed based on the author's research, including full day measurements of active power loads with the use of specialized AS-3 recording meters. The measurements were conducted in transformer stations located in rural areas of Southern Poland, used principally to supply households and farms.

The work encompassed feasibility of forecasting the annual peak loads in 15/0.4 kV rural transformer stations for the following models:

- with the use of artificial neural networks (ANN),
- based on fuzzy set theory,
- based on determined chaos theory.

RESULTS

Models using artificial neural networks

A program called *Statistica Sieci Neuronowe* was selected to develop a model designated to determine value of the rural transformer station annual peak loads using artificial neural networks. The program was basically used to check the forecast feasibility for various types of networks having a variability of architectural patterns. Neural networks with radial base functions (RBF), multilayer perceptrons (MLP), as well as linear networks were analyzed.

It was assumed that on the basis of the information pertaining to the annual consumption of electric power, a neural network is able to determine values of the annual peak load with an accepted accuracy. A set vector of the input signal, necessary to be present in the process of learning with a teacher, contained values determining electric power consumption for each 15/0.4 kV transformer station. Apart from a variable input value, the learning set contained also variable output values, namely peak load values. A network response could be determined upon entering of the variable input values through the input neurons. The value obtained in this way was compared with a real value stored within the learning set. If the compared values were not equal, the network parameters (the weights) had to be modified in such a way that the network response would become similar to the real value. The learning process relied then on a multiple presentation of learning standards and a modification of corresponding weights.

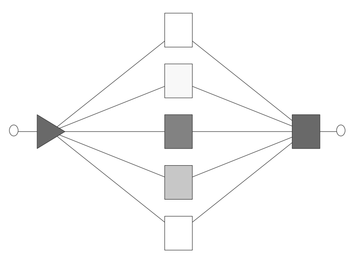

Fig. 1. Diagram of MLP neural network for determination of peak load in rural transformer station based on annual consumption of electric power

The error values of neural networks developed for modeling of the same process may differ considerably from each other due to a random performance of the network learning process. For this reason, it is necessary to assume a criterion for selection of the best obtained neural model. A minimalization of the forecast ex-post φ mean absolute percentage error according to Formula 3 was taken into consideration during the selection of the numbers of hidden layers and numbers of neurons assigned to those layers. The developed diagram of MLP type neural network featuring the least error was shown in Figure 1.

Models based on fuzzy set theory

A forecast of peak loads in rural transformer stations developed in accordance with the fuzzy set theory was performed with the use of Matlab® Simulating program, utilizing a Sugeno model available within *Fuzzy Logic Toolbox* library for this purpose. The models with a single input variable and a single output variable were taken into consideration within the solution spaces. Values corresponding to annual consumption of electric power were entered to a fuzzy controller input, while values of annual peak load were expected to be obtained in the output.

The fuzzy Sugeno model was exposed to teaching by using the methods applicable for neural networks. For this reason the model was converted to an equivalent multilayer neural network (multilayer perceptron). The model tuning was executed by means of the ANFIS interface developed by Jang [1993].

Converted fuzzy models in neural networks are represented by six consecutive layers of neurons (Fig. 2). The first layer represents values of the input function (entered input value corresponding to the annual consumption of electric power). Layer two pertains to fuzzification of the input values and represents membership functions included in assumptions (inputmf – Trimf functions were selected due to minimalization of the learning criterion in developed models (Fig. 3)). Layer three (rule layer) represents the rules, therefore a degree of an appropriate rule activation is defined at the output of each layer of the neurons. Two remaining layers (outputmf and output – depict a value of the annual peak load) carry out a defuzzification formula for the Sugeno model.

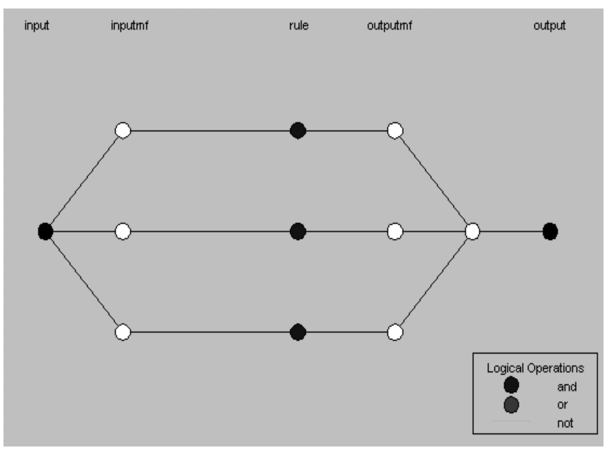

Fig. 2. Visualization of Sugeno model structure upon conversion into equivalent neural network, where input variable is an annual consumption of electric power

A process of the neural network learning was carried out on the basis of the learning data. In order to accomplish minimalization of the learning criterion, the network weights were gradually changed by means of the error back propagation algorithm and gradient method, in combination with the least square method (a hybrid method). A minimalization of the network output mean square error related to the learning data was assumed as a learning criterion.

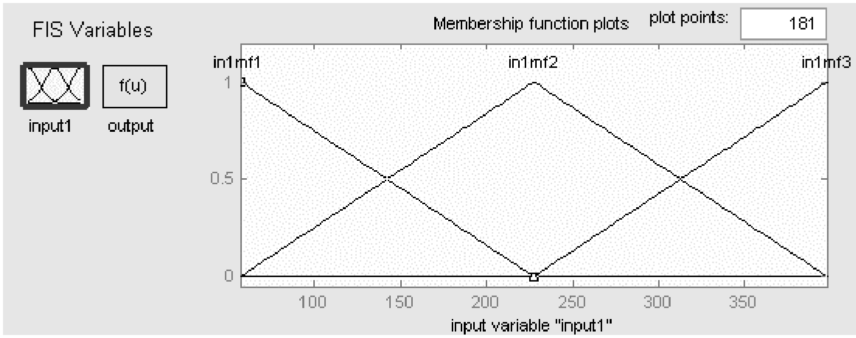

Fig. 3. Plot of function membership to subsets, where input variable is an annual consumption of electric power

In this way, it was possible to determine the fixed structure models (self-tuning fuzzy models), i.e. models with the set input variables and models with a constant rule base and constant number of sets, fuzzified in assumptions as well as polynomials in conclusions. Therefore, only the assignment function parameters and polynomial coefficients in conclusions were the subject of change (subject of tuning).

Models based on determined chaos theory

Also the models based on fractal dimension, originating from a determined chaos theory, were used to forecast the annual peak loads in rural transformer stations [Dobrzańska 2002]. A forecast model of the peak load for station P_{szrt} in function of the annual peak consumption of electric power E_r depicted during the work, is shown below:

$$P_{szrt} = C_r \cdot E_r \,, \tag{1}$$

where:

$$C_r = \frac{\sum_{i=1}^{n} P_{szrti} \cdot E_{ri}}{\sum_{i=1}^{n} E_{ri}^2}. \tag{2}$$

Analysis of forecast admissibility

The issue of the resulting forecast quality is one of the most important subjects pertaining to forecasting. In order to evaluate quality of the resulting forecasts, their admissibility was checked by determining the errors of the expired forecasts, according to the following formula [Cieślak 1999]:

$$\varphi = \frac{1}{n_s} \sum_{m=1}^{n_s} \frac{\left| P_{szrtm} - P_{szrtm}^{*} \right|}{P_{szrtm}} \cdot 100, \tag{3}$$

where:

P_{szrt} – real value of transformer station annual peak load,

P_{szrt}*– forecast value of transformer station annual peak load,

n_s – number of transformer stations.

In evaluation of the forecast admissibility, it was assumed that if the absolute percentage error of the forecast meets the following inequality [Zeliaś at all 2004]:

- $\varphi \leq 3\%$, then the forecast is very good,
- $3\% \leq \varphi \leq 5\%$, then the forecast is good,
- $5\% \leq \varphi \leq 10\%$, then the forecast is satisfactory,
- $\varphi > 10\%$, the forecast should be rejected.

In order to enable both individual and comparative evaluations for the need of forecast error analysis, the error distribuants were developed. Distribuants of absolute percentage errors for forecasts of the annual peak load in transformer stations 15/0.4 kV, developed on the basis of annual consumption of the electric power usage, are presented in Figure 4. Table 1 presents average absolute percentage error values of ex post forecasts and their standard deviations determined with the use of various methods.

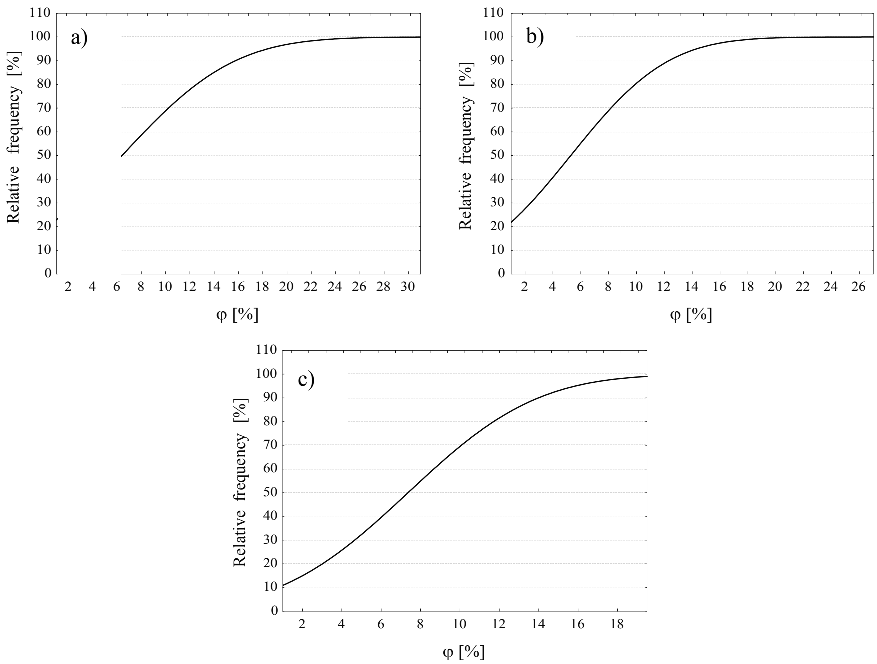

Fig. 4. Distribuants of expired absolute error forecasts for annual peak loads in 15/0.4 kV transformer stations as determined, based on annual consumption of electric power in accordance with the following models: a) using ANN, b) based on fuzzy sets theory, c) based on the determined chaos theory

Table 1. Mean absolute errors of ex post annual peak load forecasts for 15/0.4 kV transformer stations and their standard deviations for developed models

Model:	Mean error [%]	Standard error deviation
using ANN	6.4	7.1
based on fuzzy set theory	5.3	5.4
based on determined chaos theory	7.4	5.0

The analysis of graphs clearly proves that the error values do not exceed 30% for all the developed forecasts. The error values up to 10% constitute a 77% part of population on the average, and vary from 70% for the model based on determined chaos theory up to 84% for the model based on fuzzy sets theory. Table 1 shows that the mean error of expired forecasts did not exceed 10% for any of the developed models which allows to consider them to be admissible [Zeliaś at all 2004].

CONCLUSIONS

Based on the conducted forecast error analysis, it has been confirmed that all the developed models combining maximum electric power demand with its annual consumption as determined with alternative methods using artificial neural networks, fuzzy sets theory and the determined chaos theory are certainly useful for the forecasting of annual peak loads in rural 15/0.4 kV transformer stations. A fuzzified regression model appeared to be the most suitable for this purpose, since only 16% of the forecast errors determined with the use of this model exceeded the value of 10%. at the mean absolute ex-post value of errors slightly exceeding 5%.

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WYKORZYSTANIE ALTERMATYWNYCH MODELI REGRESYJNYCH DO WYZNACZANIA OBCIĄŻEŃ SZCZYTOWYCH WIEJSKICH STACJI TRANSFORMATOROWYCH

Streszczenie. W pracy zbudowano modele wiążące obciążenie szczytowe wiejskich stacji transformatorowych 15/0,4 kV z rocznym zużyciem energii elektrycznej przez odbiorców zasilanych z tych stacji przy wykorzystaniu sztucznych sieci neuronowych, opartych na teorii zbiorów rozmytych oraz na teorii chaosu zdeterminowanego oraz sprawdzano ich przydatność do celów predykcyjnych. Na podstawie analizy błędów stwierdzono, że wszystkie alternatywne modele są zadowalającej jakości, a najlepszą jakość prognozy zapewnia model rozmyty.

Słowa kluczowe: obciążenie szczytowe, stacja transformatorowa, alternatywny model regresyjny.