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# ALTERNATIVE METHODS OF ESTIMATING RURAL CONSUMERS' DAILY DEMAND FOR ELECTRICAL ENERGY

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**Summary**. In this paper, the author presented fuzzy models with the inference of the Takagi-Sugeno type regarding trapezoidal adherences functions in models input spaces of hourly predicted demands for electrical energy for rural consumers, as the characteristic group of consumers, and also checked their usability to load predictions calculated in twenty-four hours' advance. Because of the load inconstancy character, the author elaborated separate models for typical week days. They demonstrated that fuzzy models satisfactorily describe electrical energy hourly demand for rural consumers even in periods of time characterized by large variability of this demand and those predictions let to construct good quality prognoses.

**Key words:** electricity, short-term forecasting, fuzzy models.

## INTRODUCTION

Distributional companies, dealing with transfer and distribution of electrical energy are entering into contracts on the electrical energy market regarding electricity purchase. Ordering unsuitable quantity of energy increases consumer service costs, and in the perspective, has an unfavorable effect on the quality of service performed by those companies. The basis for the strategy regarding electrical energy purchase are forecasts concerning demands for electricity. Therefore quality of demand forecasts regarding electrical energy, especially the quality of short-term forecasts, has a significant effect on a company's financial performance. Thus, researches are undertaken of more and more effective predictive methods. Over the recent years researchers were interested with a possibility of application of alternative methods, used for forecasting demand for the electrical energy, particularly methods of artificial intelligence.

From among artificial intelligence methods used to forecasting demand for electrical energy, most often artificial neural networks are used. However, little attention was paid to the predictive purposes theories of fuzzy sets, though this is a convenient mathematical tool for describing uncertainty and inaccuracy of input data – always accompanying the process of forecasting.

The objective of this work was the utilization of the fuzzy sets theory to short-term forecasting regarding demand for electrical energy. As fuzzy models most commonly used to predictive purposes are Takagi-Sugeno models, this paper is limited only to this type of models. Particularly, the author compiled models that make it possible to predict hourly demands for electrical energy and checked their usabilities to loads prediction in twenty-four hours' advance. Objectives were realized on the example of rural consumers, as a characteristic group of electric energy users.

## MATERIAL AND METHOD

The process of formulating fuzzy system model consists of three phases: fuzzification, fuzzy inference and defuzzification. Before the beginning of fuzzification phase certain universes of discourse for input variables are defined. These are sets of all numeric values, which can accept variables in the examined system. Every universe of discourse is split into fuzzy subsets that have exactly defined qualitative (kind of function) and quantitative (parameters) functions of belongings. Within the framework of fuzzification, degrees of belongings regarding input variables of the model to each set are calculated. Fuzzy inference phase consists of determining, by means of rule bases, fuzzy output variables on the basis of fuzzy input variables. Rule base contains logical rules determining reason-result dependencies existing in the system between input and output fuzzy sets. For needs of fuzzy inference phase, universe of discourse and their fuzzy subsets must be fixed for output variable, and similarly for input variables. Defuzzification phase consists of qualifying a non-fuzzy value of the output system based on a fuzzy output variable.

Conducted researches examined models with *r* input variables and *one* output variable. Universe of discourse of input variables for the given system are divided into fuzzy subsets with trapezoidal functions of belongings fulfilling the condition of unity partition.

The manner of fuzzy sets selection of the rule base applied in the research has the following form:

$$\text{R1: IF } (x_1 \text{ is } A_{11}) \text{ I ... I } (x_r \text{ is } A_{r1}) \text{ THEN } (y = f_1(x) = a_{10} + a_{11}x_1 + ... + a_{1r}x_r), \tag{1}$$

$$\text{Rm: IF } (x_1 \text{ is } A_{1m}) \text{ I ... I } (x_r \text{ is } A_{rm}) \text{ THEN } (y = f_m(x) = a_{m0} + a_{m1}x_1 + ... + a_{mr}x_r),$$

where:
$x_1,..., x_r$ – input variable,
y – output variable,
$a_{ik}$ ,… $a_{ir}$ – coefficient of linear functions,
$A_{ki}$ – fuzzy sets in input variable universe of discourse,
i = 1,…, m ; k = 1,..., r.

Output of the system *y* was calculated as the weighted mean of the function values $f_1(x)$,..., $f_m(x)$, where weights were activation degrees of rules $R_1$,…, $R_m$ [Piegat 1999].

Fuzzy inference phase was realized using MAX-MIN method, and during defuzzification phase the method of height was used [Driankov ***at al.*** 1996; Piegat 1999].

Results of measurement of the hourly demand for electrical energy for rural consumers registered in years 2003-2005, in the so-called Main Feeding Point (MFP), were used for the adoption of fuzzy models and to prove their usefulness to prediction purposes. The analyzed MFP supplies approx. 10 thousand consumers with electric energy, and most of them are rural households and farms consuming 2 MWh of electrical energy yearly.

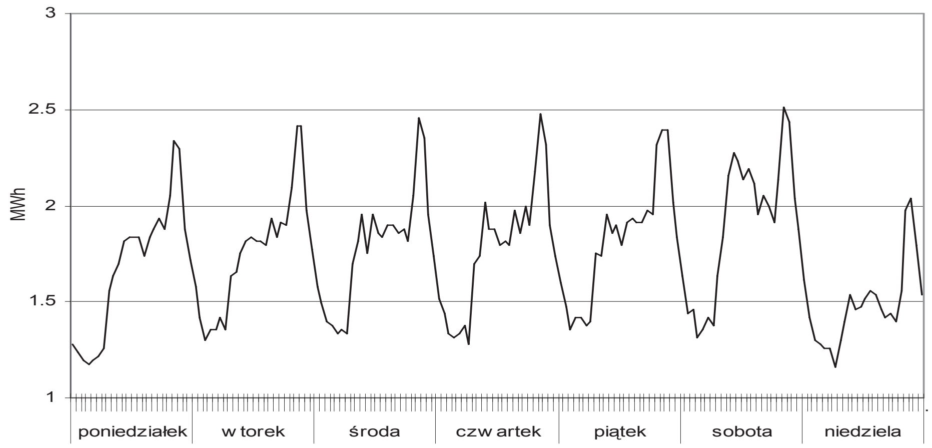


Fig. 1. Example diagram of the hourly demand for electrical energy for country-side consumers supplied with energy from chosen MFP point

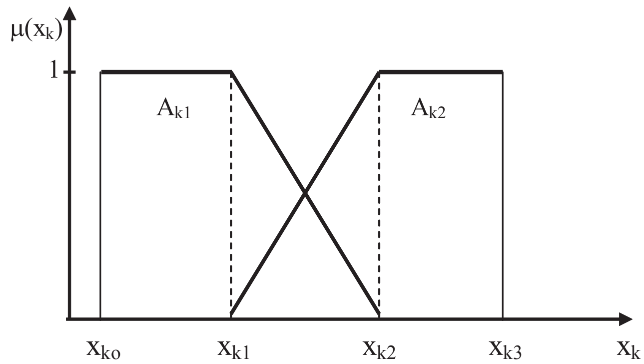


Fig. 2. Division of universe of discourse of input k-variable into two fuzzy subsets, μ(xk) – membership function of fuzzy set Aki

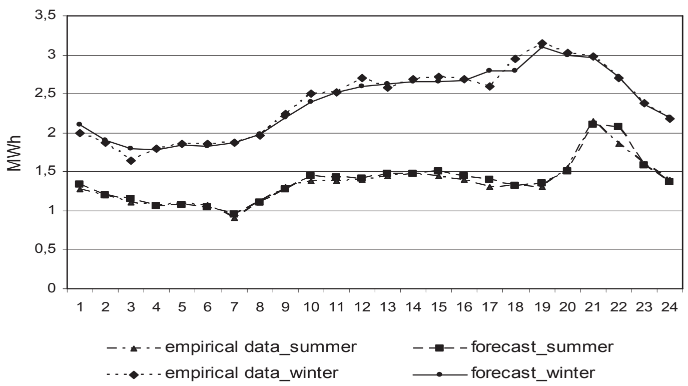


Fig. 3. Diagram of the hourly demand for electrical energy and ex post forecasts of demand for electricity calculated for the chosen (twenty-four hour) days on the basis of TK models

Table 1. Twenty-four hours forecasts errors regarding country-side consumers demand for the electrical energy calculated on the basis of TK models

| Data type | Forecasting period | MAPE [%] |
|---|---|---|
| teaching | 2003 | 3,9 |
| | 2004 | 4,2 |
| testing | 2005 | 4,8 |
| all | 2002-2004 | 4,4 |

## RESULTS

An analysis of Polish electric-energetic loads variability shows that the hourly demand for electrical energy is dependent on a range of factors in which, among other things, we can include type of day and value of demand for energy in earlier hours and days [Siwek 2001]. On the basis of the demand for electric energy variability in the examined local system (Fig. 1) three types of days was marked, i.e. business day (from Monday to Friday), Saturday and Sunday for which separated fuzzy models were built. Input variables for these models are load values in earlier hours, which were chosen basing on the algorithm introduced by Małopolski [2007] during utilization of the method called analysis of coefficients correlation [Dąsal 2002]. For every type of the day, four input variables were fixed. For example, for the business day this load registered 1, 24, 25 and 186 hours earlier. Every universe of discourse of input variables was divided into two fuzzy subsets (Fig. 2). The structure of models was calculated basing on the constructive rule [Małopolski 2007; Piegat 1999], obtaining models with 16 rules each.

Because the database concerning hourly demand for electrical energy was large, for the needs of the model we separated approx. half of the data, taken from years 2003-2004. The remaining part and the values of hourly demand for electrical energy in 2005 were used for model testing purposes.

Basing on the adopted models, we marked ex post forecasts that were compared with real demands for electrical energy. Particularly, we examined the quality of load mappings and calculated values of the mean absolute percentage error (MAPE) for ex post forecasts. Since energy companies prepare forecasts of hourly demand for electrical energy with a 24-hour anticipation, during research we analyzed twenty-four hours' forecasts errors. It was proved that absolute values of these errors had changed from 2 to 17% with MAPE error not exceeding 5% (Tab. 1).

All the predicted forecasts are good quality [Zeliaś *at al.* 2004], and they can be found acceptable and right all the more, that the accepted prognostic models accurately map the course of demand on electrical energy in time. Examples of such mappings are presented in Fig. 3. The only concern is an increase of errors for the forecasts predicted for year 2005 compared to the errors from earlier years. Probably, the higher level of errors for year 2005 is a result of a greater contribution of days with unstable and non-typical loads.

The conducted calculations showed that prediction errors were characterized by large variability. Therefore, we analyzed an influence of such factors as the season and type of day on the accuracy of 24-hour forecasts. It was proved that for most of the months, 24-hour forecasts regarding demand for electrical energy were good. Only in case of winter-spring months, especially in April, we noted MAPE errors exceeding 5%. Analyzing the influence of day type on prediction accuracy the author ensured that the best accuracy of forecasts was obtained for business days, especially for Fridays. MAPE errors of these forecasts are commonly 20% smaller than for Sundays. Thus, the received results confirmed the legitimacy of separating the three types of week days.

The methods most frequently used by companies responsible for electrical energy supply for short-term forecasts are: from artificial intelligence methods – artificial neural networks method, and from classical methods – Box-Jenkins model. Errors of forecasts calculated basing on fuzzy model are the same as errors calculated on the basis of the neuronal model [Małopolski 2007] and smaller than those calculated with classical methods [Walczyk 2006]. Competitiveness of fuzzy models in relation to neural networks lies in the fact, that rule bases of fuzzy models contain important information on the modeled systems, which neural networks do not have.

## SUMMARY

The fuzzy models with Takagi-Sugeno inference type, constructed during the research, satisfactorily describe the hourly demand for electrical energy of country-side consumers even in periods characterized by large demand variability, and therefore difficult for forecasting. They allow to calculate values of hourly demand for electrical energy of country-side consumers with sufficient accuracy and for constructing useful forecasts for companies responsible for electrical energy supplies.

The usefulness of the presented models was checked by forecasting demand for electrical energy of country-side consumers. However, these models can also be applied to forecasting of energy demands for other groups of receivers.

Short-term forecasts based on the above-presented fuzzy models seem to be competitive compared to other methods, including also the prediction method using artificial neural networks and considered to be the most accurate so far.

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