

# MACROMODELING OF LOCAL POWER SUPPLY SYSTEM BALANCE FORECASTING USING FRACTAL PROPERTIES OF LOAD AND GENERATION SCHEDULES

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**Abstract.** A method of forecasting the balance of electricity consumption of urban development objects, civil purposes using discrete macromodels is proposed. We consider the power supply system (PSS) of the district, which is characterised by power supply from general-purpose power grids, as well as having its own generation of electricity from renewable energy sources (RES). Such a local electric power system (LES) under certain conditions can be operated as an independent balanced electrical facility. For optimal operation of the LES under these conditions, it is necessary to predict its power consumption schedules. The proposed macromodelling method allows to develop deterministic models of power consumption with the required accuracy on the basis of retrospective information without the use of data preprocessing procedures. The solution to the problem of forecasting electricity consumption schedules is simplified by using only basic or deterministic characteristics in the construction of the model. These include fractal properties of PSS load schedules

**Keywords:** power supply system, urban development, power consumption forecasting, macromodelling, fractal properties

## MAKROMODELOWANIE PROGNOZOWANIA BILANSU LOKALNEGO SYSTEMU ELEKTROENERGETYCZNEGO Z WYKORZYSTANIEM FRAKTALNYCH WŁAŚCIWOŚCI PLANÓW OBCIĄŻENIA I GENERACJI

**Streszczenie.** Zaproponowano metodę prognozowania bilansu zużycia energii elektrycznej przez obiekty miejskie o przeznaczeniu cywilnym z wykorzystaniem makromodeli dyskretnych. Rozważany jest system zasilania (SZ) dzielnicy, który charakteryzuje się zasilaniem z sieci ogólnego przeznaczenia, a także posiada własną produkcję energii elektrycznej z odnawialnych źródeł energii (OZE). Taki lokalny system elektroenergetyczny (LES) w pewnych warunkach może być eksploatowany jako niezależny, zrównoważony obiekt elektryczny. Aby zapewnić optymalne działanie LES w takich warunkach, konieczne jest przewidywanie jego harmonogramów poboru mocy. Proponowana metoda makromodelowania pozwala na opracowanie deterministycznych modeli poboru mocy z wymaganą dokładnością na podstawie informacji retrospektywnych bez stosowania procedur wstępnego przetwarzania danych. Rozwiązanie problemu prognozowania planów zużycia energii elektrycznej jest uproszczone poprzez wykorzystanie w konstrukcji modelu jedynie podstawowych lub deterministycznych charakterystyk. Obejmują one fraktalne właściwości harmonogramów obciążenia SZ.

**Słowa kluczowe:** system zasilania, rozwój miast, prognozowanie zużycia energii, makromodelowanie, właściwości fraktalne

### Introduction

Macromodelling [1, 4, 8] is used in the evaluation of complex systems, which include power supply systems (PSS). Such SES models are distinguished by the fact that they describe only the external characteristics of the modelled system and are intended for its general evaluation. Problem solving is simplified without losing adequacy due to the use of only the main or defining characteristics in the construction of the model [9]. Such characteristics that characterise the SES load schedules include their fractal properties [2, 5, 7].

That is, self-affine structures – fractals are used, each part of which repeats in its development the development of the whole model as a whole. Such models are useful for obtaining preliminary estimates of the system, for example, in pre-design decisions. However, the problem is that the forecasting of powerful power systems, industrial enterprises does not allow to take into account the composition, specificity and technological features of the mode of operation of electrical consumers and power consumption of urban buildings.

Therefore, the aim of the article is to develop an effective, sufficiently accurate for practical application forecasting method using fractal properties for SES of urban buildings.

### 1. Highlighting essential properties of SES in the macromodelling method

Residential electrical loads are random, depending on the agenda of the occupants and the availability of a set of electrical appliances (EA). They vary significantly during

the day and depending on the season. In addition, localised SESs have to take into account the instability of RES generation that is part of their electricity supply. All this creates difficulties in forecasting the power consumption schedules of SES. Thus, the determination of forecasted electrical loads is the basis for the design of internal and urban grids [1, 6].

The main group of consumers in residential areas are residential buildings. The electrical load of houses is determined by the lighting of flats and various household appliances used by the population. In practice, the value of electricity consumption is influenced by the most powerful electrical appliances of everyday use. These include air conditioners, washing machines, dishwashers, electric heaters such as boilers, electric cookers, heating systems, etc.

Fig. 1 shows the structural diagram of the models designed to predict the electricity consumption of civilian objects of urban development.

1. Autoregressive models are time series models in which the values of a time series at a given moment depend linearly on previous values of the same series. An autoregressive process of order  $p$  is defined as

$$X_t = c + \sum_{i=1}^p a_i X_{t-i} + \varepsilon_t \quad (1)$$

where  $a_i$  – model parameters (autoregressive coefficients);  $c$  – constant (often equal to zero for simplification);  $\varepsilon_t$  – white noise.

Autoregressive models can be used to model seasonality, in which case the number of model coefficients will correspond to the number of cyclically changing factors that are taken into account.

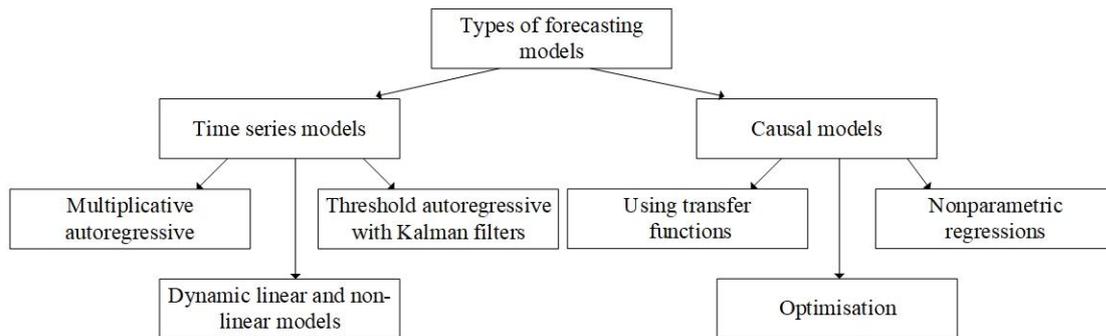


Fig. 1. Types of electricity consumption forecasting models

In order to forecast electricity consumption, the following form of autoregressive model can be applied:

$$L(t, d) = \sum_{k=1}^4 a_k L_k(t, d) \quad (2)$$

where  $a_k$  – linear weights that provide the optimal combination of the four individual predictions;  $L_1(t, d)$  – forecast  $L(t, d)$  based on a first-order autoregressive model with a delay of one hour;  $L_2(t, d)$ ,  $L_3(t, d)$ ,  $L_4(t, d)$  – the same with a delay of 24 hours, a week and a year respectively.

2. Generalised exponential smoothing that can be applied to predict total hourly electricity consumption:

$$L(t) = a^T f(t) + \varepsilon(t) \quad (3)$$

where  $a^T$  – the transposed vector of exponentially smoothed weights;  $f(t)$  – vector of smoothing functions.

3. Neural networks and fuzzy logic is one of the new approaches used to solve the problem of forecasting based on fuzzy logic and neural networks. The method involves the use of a priori information, allows the use of new information in the construction process and takes into account the properties of the modelled process. It can also use previously known information, subjected to training and sufficiently visual for the observer. Neural networks are able to identify complex dependencies between input and output data and perform generalisation of existing but hidden properties and relationships. This is where the ability of a trained neural network to predict follows, to anticipate the future value of a particular sequence based on several previous values or currently existing factors.

This way of applying neural networks for forecasting will not lose performance under the condition of incomplete input information, but requires considerable time for training. Application of systems with fuzzy logic, i.e. sets with a set of elements of arbitrary nature, which do not clearly define belonging to a certain set, allows to eliminate the disadvantages of artificial neural networks [3].

Modelling with application of fuzzy sets is expedient in case of research of too complex technical system or process.

Modern mathematical statistics, long claimed to be the main tool for data analysis, is not always suitable for solving problems from real diverse life. This happens because averaged sample characteristics are used, which often turn out to be fictitious values. Therefore, the methods of mathematical statistics are useful for testing pre-formulated hypotheses.

## 2. Building a macromodel of forecasting

The essence of alternative forecasting based on macromodelling is the process of building a model of electricity consumption at such stages shown in Fig. 2.

The first stage of the analysis procedure involves the collection and processing of data on the electrical consumption of the real object under study. The system of organisation of collection and registration of information on electric load of the object was carried out with the help of the automated

system of commercial electricity metering (ASCEM). Electricity metering devices of residential buildings, public buildings and their complexes are recommended to be united in the ASCEM, which promotes its use as a tool for energy audit and control of energy resources saving issues through the introduction of appropriate measures [10]. The use of ASCEM promotes the economical use of energy resources through careful control of electricity consumption and development of appropriate measures.

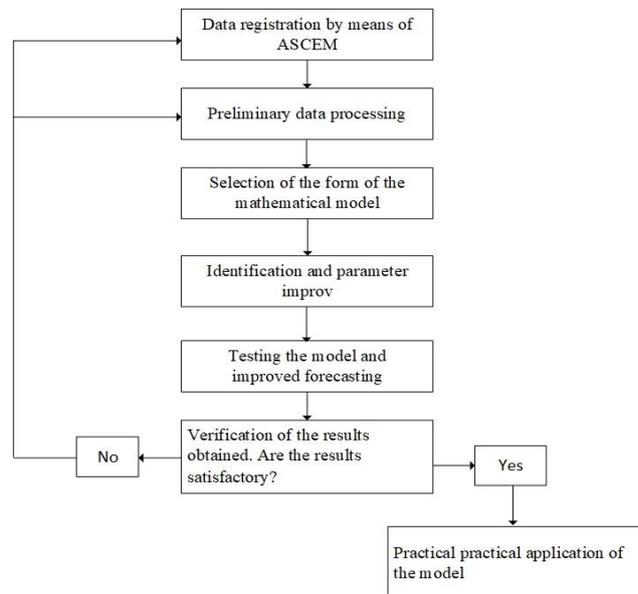


Fig. 2. Stages of building a macro model of forecasting

The collected information is displayed as continuous graphs (Fig. 3) or digitally. Based on the information obtained, the maximum electrical load is determined (on the graphs of Fig. 3 it is 95 kW). Graphs of electric load have a probabilistic character and change during the day, have maximums in the morning from 7 to 9 and evening from 19 to 23 hours, which is due to the modes of operation of a variety of electrical consumers.

Preliminary data processing involves selection of the time period for which forecasting is carried out and the period of further data verification. Filtering is carried out when there is a significant amount of information on electricity consumption in order to select the form of the model and simplify the forecasting procedure.

The choice of model form may involve mathematical macromodelling using discrete autonomous macromodels in the form of a „black box“. The process is derived from the recorded characteristics of electricity consumption by using homogeneous differential or difference equations of state in form (4).

$$\begin{cases} \frac{d\vec{x}}{dt} = \vec{f}(\vec{x}) \\ \vec{y} = \vec{g}(\vec{x}) \end{cases} \quad (4)$$

$$\begin{cases} \vec{x}^{(k+1)} = \vec{f}(\vec{x}^{(k)}) \\ \vec{y}^{(k+1)} = \vec{g}(\vec{x}^{(k)}) \end{cases} \quad (5)$$

where  $\vec{x}$  is a vector of state variables;  $\vec{y}$  is a vector of output variables;  $\vec{f}(\cdot), \vec{g}(\cdot)$  are vectors functions selected using optimisation algorithms.

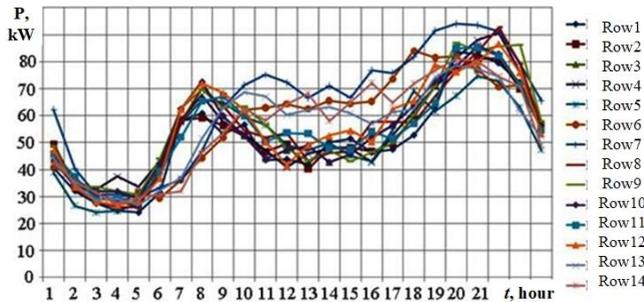


Fig. 3. Example of daily electric load graphs of a residential building (day of the month coincides with the row number)

Since there is no explicit vector of input variables when building the electricity consumption model, we consider the case when the initial value of the state variables of the modelled object is zero. Let's choose the form of macromodel description in the following form:

$$\begin{cases} \vec{x}(k+1) = F \vec{x}(k) + \Phi(\vec{x}(k), \vec{v}(k)) \\ \vec{y}(k+1) = C(\vec{x}(k+1)) \end{cases} \quad (6)$$

The initial state of the modelled object is described by the zero discrete vector of state variables  $\vec{x}^{(0)}$ . Therefore, the components of this vector must be added to the set of unknown model coefficients. However,  $\vec{x}^{(0)}$  one cannot simply enter in the set of model parameters, as each dynamic process will have its own independent value of  $\vec{x}^{(0)}$ . To take this fact into account, we need to divide the vector of unknown coefficients  $\vec{\lambda}$  into two parts: the first, which includes coefficients that are the same for all processes, and the second with an independent set of elements of the vector  $\vec{x}^{(0)}$  for each process, which increases the unknown number of coefficients and complicates the optimisation problem.

When using the proposed macromodel, a problem arises in determining the zero discretisation of the vector  $\vec{x}$ , since the components of this vector, as a rule, are not directly measured experimentally, but are determined through certain values of the initial elements  $\vec{y}$ . In general, this means that it is necessary to find additionally a linear or non-linear dependence  $\vec{x}^{(0)}$  on the experimentally measured values of  $\vec{y}$ .

In particular, in forecasting problems this dependence is constructed as a function of several first discretises of initial values:

$$\vec{x}^{(0)} = \vec{f}(\vec{y}^{(1)}, \vec{y}^{(2)}, \dots, \vec{y}^{(l)}) \quad (7)$$

where  $l$  – number of samples used to find the zero sample of the vector  $\vec{x}$ .

The optimisation approach due to its universality with respect to the form of representation of macromodels can be used to find additional dependencies. This means that the elements of the vector  $\vec{x}^{(0)}$ , added to the unknown coefficients,  $\vec{\lambda}$  should be replaced by the coefficients of expression (3), i.e., actually introduce this expression into the model itself.

If the model looks like (7), we get:

$$\begin{cases} \vec{x}^{(k+1)} = F \vec{x}^{(k+1)} + \Phi(\vec{x}^{(k)}) \\ \vec{y}^{(k+1)} = C \vec{x}^{(k+1)} \\ \vec{x}^{(0)} = \vec{f}(\vec{y}^{(1)}, \vec{y}^{(2)}, \dots, \vec{y}^{(l)}) \end{cases} \quad (8)$$

which will contribute to the validation of the macro-model of electricity consumption.

In order to verify the performance of the proposed approach, a macro model of the daily electricity consumption of a 9-storey 216-apartment residential building is constructed, using input data on average daily electricity consumption and weeks (Fig. 4 and 5).

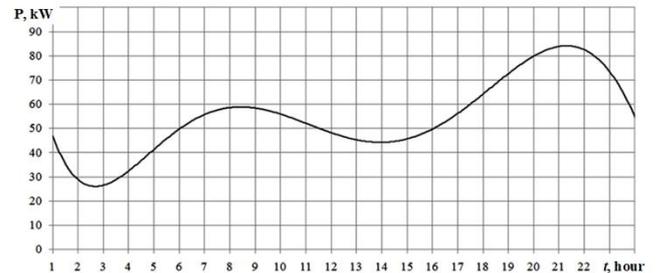


Fig. 4. Example of daily electric load graphs of a residential building (day of the month coincides with the row number)

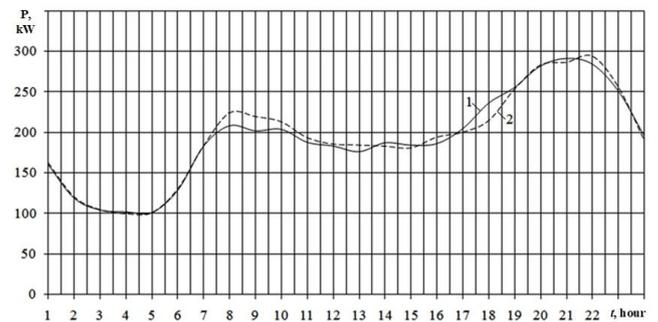


Fig. 5. Example of daily electric load graphs of a residential building (day of the month coincides with the row number)

A discrete macromodel of the electrical consumption of a residential building is created in the form of such a ratio:

$$\begin{cases} \vec{x}^{(i+1)} = F \vec{x}^{(i)} \\ \vec{y}^{(i+1)} = C \vec{x}^{(i+1)} \end{cases} \quad (9)$$

The input data of daily electricity consumption during the first and second weeks were used to build the macromodel. The initial value of the state variables was determined based on a linear dependence on the level of electricity consumption at randomly selected times, namely at 9, 20 and 22 hours:

$$\vec{x}^{(0)} = S \begin{pmatrix} y_9 \\ y_{20} \\ y_{22} \end{pmatrix} \quad (10)$$

Verification of the stand-alone macromodel was performed on an independent data set. For this purpose, the input data of electricity consumption of the residential building for the third week and the created macromodel of electricity consumption for the third week were used (Fig. 6).

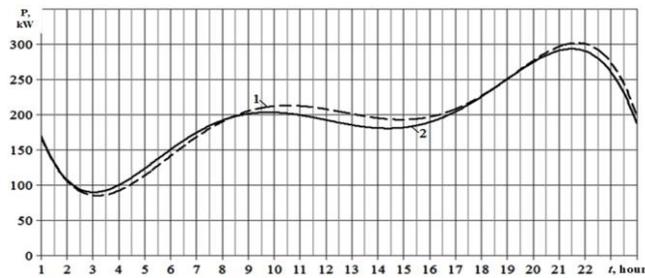


Fig. 6. Input data (curve 1) and macromodel response for week 3 (curve 2)

Comparison of the mean square error of forecasting by the regression model for forecasting electricity consumption of a residential building and by using a neural network showed the following. According to the retrospective information of residential building electricity consumption, the regression model for forecasting is as follows:

$$w = 55t + 4562 \quad (11)$$

The mean-square error of electricity consumption forecasting by the regression model was 6.0%.

Comparing the actual value of electricity consumption of the residential building for the 3rd week of October with its macro-modelling value, the RMS error of forecasting is about 3.1%. Thus, forecasting by macro-modelling better approximates the adequacy of the process than by regression model.

### 3. Conclusions

The proposed forecasting method allows to develop with sufficient accuracy deterministic models of power consumption on the basis of retrospective data without using data preprocessing procedures, which is typical for other methods. Forecasting of LES power consumption schedules is simplified by using only basic and deterministic characteristics in the construction of the macromodel. These include fractal properties of PSS load schedules.

Using the example of residential building power consumption forecasting, it is shown that the autonomous macromodelling approach, effectively using a priori information, is able to learn and, at the output, provide clear and adequate information about the LES power consumption process. Using the ASCEM information, it is possible to obtain a number of illustrative daily electric load schedules and generalise them for the future. Due to the use of fractal properties of LES load graphs in macromodelling, the accuracy of electricity consumption forecasting is improved and the term of satisfactory forecast increases.

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