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STATE-SPACE MODEL AND IMPLEMENTATION POLISH POWER EXCHANGE IN MATLAB AND SIMULNK ENVIRONMENTS

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This work contains selected results of research on modelling identification of Polish Power Exchange (TGEE) on the example of the figures quoted on the Day Ahead Market (DAM) on TGEE in Poland. In order to obtain a model of the TGEE system on the beginning it was conducted to identify the figures for the period 01.01.2013-31.12.2015 obtaining discrete parametric model arx in MATLAB and Simulink environments using System Identification Toolbox (SIT). The resultant model was converted to a continuous parametric model, and that one on a continuous model in the state space. On the basis of obtained equations of state and outputs, there was interpreted a state variables and parameters of the selected model, i.e. selected elements of the matrix **A** and matrix **B**. Research continues.

Keywords: Business Intelligence, Parametric Model, Identification Modeling, MATLAB and Simulink Environment, Simulation Research, State Space

1. Introduction

Models of state variables are used for many years, especially in technical sciences and economics, especially in automation, robotics and electrical engineering. They were used at the various models and methods for the preparation of models of state variables depending on the object of research. One of the older and still current position is work of S. H. Żak named “On state-space models for systems described by partial differential equations” [27], in which a comparative analysis was performed and proposed usage of partial differential equations in state variables models.

Works of other authors [2, 10, 12-15] are related to systems and linear systems or brought to the linear systems modelled using equations of state and output for different specific situations. For example, in work entitled “A Self-Organizing State Space Type Microstructure Model for Financial Asset Allocation” [2] is shown self-assembled state space, which was used to model the allocation of financial assets.

On the other hand, in [10, 12-15] there were shown typical modelling solutions in state space using various methods of describing domain systems. An interesting approach in this area was proposed by T. Kwater & P. Krutys in their work [5], which presented a proposal for a systematic division of the object for the purpose of decentralization of the calculations, which is associated with the so-called. synthesis estimators and conducting a calculation of the last subsystem.

Author of this article is also focused on usage of modelling in the state space, who has published, among others, work related to modelling of Polish Power Exchange (TGEE) [7-8, 16, 21] inspired by the work relating to, among others, use of modelling methods in the state space in the power and energy sector, including modelling power exchanges [17-20, 22-24].

This work is an attempt to continue the previously published works of authorship or co-related to the identification and parametric modelling in the state space of TGEE [7-8, 16, 21], in which it is shown, inter alia, that in order to perform system identification TGEE there were downloaded figures from the website Power Exchange related to the DAM for the period starting from 01.01.2013 until 31.12.2015 and highlighting 24 input variables related to the total volume of delivered and sold electrical energy (ee) of all transactions on the trading session for a given hour of the day in different hours of the day [MWh] and a single-sized output on the resulting average volume weighted price ee of all transactions on the trading session for a given hour of the day [PLN / MWh] to give baseline for creating MISO type models[1] [1, 9, 25].

Afterwards, there was performed identification modelling in order to receive discrete parameter TGEE system model for each hour of the day while adopting different accounting periods with the progress of one year or progression of one hour for all the input quantities and a single output.

These models were converted to continuous parametric models, and there resulting models were converted on a continuous state space using MATLAB and Simulink environments [3-4, 15-18, 21-24].

[1]MISO – Multi Input Single Output.

2. Parametric model of TGEE system

As a result of identification there was obtained a total of 35 models of development, wherein detailed interpretation was delivered under the present study using 24 MISO type models. A total of 35 distinguished 6-month periods covering conventional 184 days each of them having progress of one month[2]. As a first of models, there was obtained parametric discrete linear type arx model (discrete-time arxp1441 model)[3], as for example p1 for the period lasting from 01 January 2013 up to 30 March 2013 (θ_1 period) obtaining discrete parametric model arxp1441 in form of:

$$A_1(z)\cdot y_1(t)=\sum_{i=1}^{24}B_i(z)\cdot u_i(t)+e(t), \qquad (1)$$

where:

$A_1(z)=1-0{,}4456\cdot z^{-1}-0{,}2834\cdot z^{-2}+0{,}07714\cdot z^{-3}-0{,}09293\cdot z^{-4}$,

$B_1(z)=0{,}00546\cdot z^{-1}+0{,}0109\cdot z^{-2}+0{,}0006017\cdot z^{-3}-0{,}006013\cdot z^{-4}$,

$B_2(z)=-0{,}0049\cdot z^{-1}+0{,}0049\cdot z^{-2}+0{,}01305\cdot z^{-3}+0{,}01078\cdot z^{-4}$,

………………………………………………………………….,

$B_{24}(z)=-0{,}003674\cdot z^{-1}-0{,}006143\cdot z^{-2}+0{,}0001805\cdot z^{-3}-0{,}002492\cdot z^{-4}$,

t – days, t=1-184,
z – discrete time shift operator,
i – hours of a day (0-1, 1-2, ..., 23-24), i=1-24,

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[2] In the absence of suitable days in the months of the considered period, data was supplemented from a day of the previous period.

[3] It is estimate parameters of discrete arx model using least squares, where syntax is next: sys = arx(data,[na nb nk]), sys = arx(data,[na nb nk],Name,Value), sys = arx(data,[na nb nk],_,opt). arx does not support continuous-time estimations. Use tfest instead.
sys = arx(data,[na nb nk]) returns an ARX structure polynomial model, sys, with estimated parameters and covariances (parameter uncertainties) using the least-squares method and specified orders.
sys = arx(data,[na nb nk],Name,Value) estimates a polynomial model with additional options specified by one or more Name,Value pair arguments.
sys = arx(data,[na nb nk],___,opt) specifies estimation options that configure the estimation objective, initial conditions and handle input/output data offsets.
Data - Estimation data. Specify data as an iddata object, an frd object, or an idfrd frequency-response-data object.
[na nb nk] - Polynomial orders.
[na nb nk] define the polynomial orders of an ARX model, na — Order of the polynomial $A(q)$.
Specify na as an *Ny*-by-*Ny* matrix of nonnegative integers. *Ny* is the number of outputs, nb — Order of the polynomial $B(q)$ + 1, nb is an *Ny*-by-*Nu* matrix of nonnegative integers. *Ny* is the number of outputs and *Nu* is the number of inputs, nk — Input-output delay expressed as fixed leading zeros of the *B* polynomial.
Specify nk as an *Ny*-by-*Nu* matrix of nonnegative integers. *Ny* is the number of outputs and *Nu* is the number of inputs.
Estimation options, opt is an options set that specifies estimation options, including: input/output data offsets, output weight. Use arxOptions to create the options set.

$u_i(t)$ – i-th input of a model concerning a volume of electricity (ee) delivered and sold in i-th hour of a day [kWh],

$y_1(t)$ – output of a model for the average price received in a volume of electricity (ee) sold in hour 0-1 of a day,

e(t) – error of discrete model.

The structure of obtained polynomials appears in works [6-7,16,21]. This was followed by the conversion of a linear discrete parametric model arx441 to a continuous parametric linear th model[4] resulting tharxp1 model in form:

$$A_1(s)\cdot y_1(t)=\sum_{i=1}^{24} B_i(s)\cdot u_i(t)+e(t), \tag{2}$$

where:

$A_1(s) = s^5 + 2{,}861\cdot s^4 + 14{,}67\cdot s^3 + 22{,}2\cdot 3^2 + 28{,}03\cdot s + 4{,}432,$

$B_1(s) = -0{,}02115\cdot s^4 + 0{,}02865\cdot z^3 - 0{,}1368\cdot z^2 + 0{,}3446\cdot s + 0{,}1899,$

$B_2(s) = 0{,}02829\cdot s^4 - 0{,}05832\cdot s^3 + 0{,}2267\cdot s^2 - 0{,}5493\cdot s + 0{,}0{,}4137,$

……………………………………………………………………,

$B_{24}(s) = -0{,}0108\cdot s^4 + 0{,}006151\cdot s^3 - 0{,}1018\cdot s^2 - 0{,}04904\cdot s - 0{,}2106,$

$C(s) = s^5 + 3{,}532\cdot s^4 + 15{,}51\cdot s^3 + 30{,}02\cdot s^2 + 38{,}12\cdot s + 17{,}36,$

t – days, t=1-184,

z – continue time shift operator,

i – hours of a day (0-1, 1-2, …, 23-24), i=1-24,

$u_i(t)$ – i-th input of a model concerning a volume of electricity (ee) delivered and sold in i-th hour of a day [kWh],

$y_1(t)$ – output of a model for the average price received in a volume of electricity (ee) sold in hour 0-1 of a day,

e(t) – error of continue model.

[4] d2c - Convert discrete-time LTI models to continuous time. Syntax: sysc = d2c(sysd), sysc = d2c(sysd,method) Description. d2c converts LTI models from discrete to continuous time using one of the following conversion methods: 'zoh'.Zero-order hold on the inputs. The control inputs are assumed piecewise constant over the sampling period, 'tustin'Bilinear (Tustin) approximation to the derivative, 'prewarp'. Tustin approximation with frequency prewarping, 'matched' - Matched pole-zero method of [1] (for SISO systems only). The string method specifies the conversion method. If method is omitted then zero-order hold ('zoh') is assumed. See "Continuous/Discrete Conversions of LTI Models" for more details on the conversion methods.

3. Model of TGEE system in state space

Subsequently, continuous parametric model tharxp1 was converted to continuous linear model in states space ss, obtaining eventually matrixes in states space in following form as i.e. for period p1 (matrixes are described in details in section 4):

$$
\mathbf{A(p1)} = \begin{bmatrix} 0 & 0 & 0 & 0 & -0{,}5540 \\ 0{,}5000 & 0 & 0 & 0 & -1{,}7521 \\ 0 & 1{,}0000 & 0 & 0 & -1{,}7521 \\ 0 & 0 & 4{,}0000 & 0 & -3{,}6676 \\ 0 & 0 & 0 & 4{,}0000 & -2{,}8606 \end{bmatrix}
$$

(3)

$$
\mathbf{B}(\mathrm{p1}) = \left[\begin{matrix} \begin{bmatrix} 0{,}0119 & 0{,}0259 & -0{,}0480 & 0{,}0134 & -0{,}0146 & 0{,}0039 & -0{,}0001 & 0{,}0091 & 0{,}0133 & 0{,}0108 & -0{,}0218 & -0{,}0159 \\ 0{,}0108 & -0{,}0172 & 0{,}0139 & 0{,}0020 & -0{,}0099 & 0{,}0103 & -0{,}0037 & -0{,}0021 & -0{,}0122 & 0{,}0089 & 0{,}0056 & -0{,}0012 \\ -0{,}0043 & 0{,}0071 & -0{,}0149 & 0{,}0079 & 0{,}0010 & 0{,}0001 & 0{,}0017 & 0{,}0016 & 0{,}0021 & 0{,}0079 & -0{,}0134 & -0{,}0002\ldots \\ 0{,}0036 & -0{,}0073 & 0{,}0136 & -0{,}0055 & 0{,}0003 & -0{,}0012 & -0{,}0007 & -0{,}0045 & -0{,}0019 & 0{,}0010 & 0{,}0016 & 0{,}0063 \\ -0{,}0106 & 0{,}0141 & -0{,}0316 & 0{,}0177 & 0{,}0020 & 0{,}0019 & 0{,}0034 & 0{,}0053 & 0{,}0026 & 0{,}0139 & -0{,}236 & -0{,}0037 \end{bmatrix} \\ \\ \begin{bmatrix} 0{,}0266 & -0{,}0049 & -0{,}0176 & 0{,}0219 & -0{,}0083 & 0{,}0068 & 0{,}0196 & -0{,}0184 & -0{,}0043 & 0{,}0041 & 0{,}0139 & -0{,}0132 \\ -0{,}0099 & 0{,}0089 & 0{,}0001 & -0{,}0013 & -0{,}0094 & 0{,}0100 & -0{,}0031 & -0{,}0051 & 0{,}0128 & -0{,}0042 & 0{,}0077 & -0{,}0015 \\ \ldots 0{,}0027 & 0{,}0030 & 0{,}0005 & 0{,}0034 & -0{,}0006 & -0{,}0037 & 0{,}0050 & -0{,}0024 & -0{,}0011 & -0{,}0008 & 0{,}0028 & -0{,}0032 \\ -0{,}0118 & 0{,}0035 & -0{,}0007 & 0{,}0023 & -0{,}0048 & 0{,}0071 & -0{,}0036 & -0{,}0013 & 0{,}0083 & -0{,}0008 & 0{,}0032 & 0{,}0008 \\ 0{,}0101 & 0{,}0045 & 0{,}0031 & 0{,}0024 & 0{,}0021 & -0{,}0118 & 0{,}0097 & -0{,}0023 & -0{,}0064 & -0{,}0018 & 0{,}0024 & -0{,}0054 \end{bmatrix} \end{matrix} \right]
$$

$$
\mathbf{C}(p1) = [0 \quad 0 \quad 0 \quad 0 \quad 2],
$$

$$
\mathbf{D}(p1) = 0.
$$

and thereby into continuous model in the states space form:

$$
\begin{aligned}
\frac{dx_1}{dt} = -0{,}5540 * x_5 &+ 0{,}0119 * u_1 + 0{,}0259 * u_2 - 0{,}0480 * u_3 + 0{,}0134 * u_4 \\
&- 0{,}0146 * u_5 + 0{,}0039 * u_6 - 0{,}0001 * u_7 + 0{,}0091 * u_8 \\
&+ 0{,}0133 * u_9 + 0{,}0108 * u_{10} - 0{,}0218 * u_{11} - 0{,}0159 * u_{12} \\
&+ 0{,}0266 * u_{13} - 0{,}0049 * u_{14} - 0{,}0176 * u_{15} + 0{,}0219 * u_{16} \\
&- 0{,}0083 * u_{17} + 0{,}0068 * u_{18} + 0{,}0196 * u_{19} - 0{,}0184 * u_{20} \\
&- 0{,}0043 * u_{21} + 0{,}0041 * u_{22} + 0{,}0139 * u_{23} - 0{,}0132 * u_{24}
\end{aligned}
$$

$$
\begin{aligned}
\frac{dx_2}{dt} = 0{,}5000 * x_1 - 1{,}7521 * x_5 &+ 0{,}0108 * u_1 - 0{,}0172 * u_2 + 0{,}0139 * u_3 \\
&+ 0{,}0020 * u_4 - 0{,}0099 * u_5 + 0{,}0103 * u_6 - 0{,}0037 * u_7 \\
&- 0{,}0021 * u_8 - 0{,}0122 * u_9 + 0{,}0089 * u_{10} + 0{,}0056 * u_{11} \\
&- 0{,}0012 * u_{12} - 0{,}0099 * u_{13} + 0{,}0089 * u_{14} + 0{,}0001 * u_{15} \\
&- 0{,}0013 * u_{16} - 0{,}0094 * u_{17} + 0{,}0100 * u_{18} - 0{,}0031 * u_{19} \\
&- 0{,}0051 * u_{20} + 0{,}0128 * u_{21} - 0{,}0042 * u_{22} + 0{,}0077 * u_{23} \\
&- 0{,}0015 * u_{24}
\end{aligned}
$$

(4)

$$
\begin{aligned}
\frac{dx_3}{dt} = {} & 0{,}1000 * x_1 - 1{,}3873 * x_5 - 0{,}0043 * u_1 + 0{,}0071 * u_2 - 0{,}0149 * u_3 \\
& + 0{,}0079 * u_4 + 0{,}0010 * u_5 + 0{,}0001 * u_6 + 0{,}0017 * u_7 \\
& + 0{,}0016 * u_8 + 0{,}0021 * u_9 + 0{,}0079 * u_{10} - 0{,}0134 * u_{11} \\
& + 0{,}0002 * u_{12} + 0{,}0027 * u_{13} + 0{,}0030 * u_{14} + 0{,}0005 * u_{15} \\
& + 0{,}0034 * u_{16} - 0{,}0006 * u_{17} - 0{,}0037 * u_{18} + 0{,}0050 * u_{19} \\
& - 0{,}0024 * u_{20} - 0{,}0011 * u_{21} - 0{,}0008 * u_{22} + 0{,}0028 * u_{23} \\
& - 0{,}0032 * u_{24}
\end{aligned}
$$

$$
\begin{aligned}
\frac{dx_4}{dt} = {} & 4{,}000 * x_3 - 3{,}6676 * x_5 + 0{,}0036 * u_1 - 0{,}0073 * u_2 + 0{,}0136 * u_3 \\
& - 0{,}0055 * u_4 + 0{,}0003 * u_5 - 0{,}0012 * u_6 - 0{,}0007 * u_7 \\
& - 0{,}0045 * u_8 - 0{,}0019 * u_9 + 0{,}0010 * u_{10} + 0{,}0016 * u_{11} \\
& + 0{,}0063 * u_{12} - 0{,}0118 * u_{13} + 0{,}0035 * u_{14} - 0{,}0007 * u_{15} \\
& + 0{,}0023 * u_{16} - 0{,}0048 * u_{17} + 0{,}0071 * u_{18} - 0{,}0036 * u_{19} \\
& - 0{,}0013 * u_{20} + 0{,}0083 * u_{21} - 0{,}0008 * u_{22} + 0{,}0032 * u_{23} \\
& + 0{,}0008 * u_{24}
\end{aligned}
$$

$$
\begin{aligned}
\frac{dx_5}{dt} = {} & 4{,}000 * x_4 - 2.8606 * x_5 - 0{,}0106 * u_1 + 0{,}0141 * u_2 - 0{,}0316 * u_3 \\
& + 0{,}0177 * u_4 + 0{,}0020 * u_5 + 0{,}0019 * u_6 + 0{,}0034 * u_7 \\
& + 0{,}0053 * u_8 + 0{,}0026 * u_9 + 0{,}0139 * u_{10} - 0{,}0236 * u_{11} \\
& - 0{,}0037 * u_{12} + 0{,}0101 * u_{13} + 0{,}0045 * u_{14} + 0{,}0031 * u_{15} \\
& + 0{,}0024 * u_{16} + 0{,}0021 * u_{17} - 0{,}0118 * u_{18} + 0{,}0097 * u_{19} \\
& - 0{,}0023 * u_{20} - 0{,}0064 * u_{21} - 0{,}0018 * u_{22} + 0{,}0024 * u_{23} \\
& - 0{,}0054 * u_{24}
\end{aligned}
$$

where:

$x_1(t)$ - the state variable x_1 as the power resulting from the delivered and sold ee in 0-1 hours, while interpreting the element a_{11} as the frequency of its changes in the date of sale [1 / day],

$x_2(t)$, $x_3(t)$ - state variables respectively expressing the electricity sold per day,

$x_4(t)$ - the electricity supplied to the power exchange and sold during the period of measurement,

x_5 (t) - the power resulting from the delivered and sold ee in 0-1 hours, while interpreting the element a_{11} as the frequency of its changes in the date of sale [1 / day].

On the basis of the state variable x_5 (t) and using the equation for determining the state variable x_1 (4) it is possible to interpret the state variable x_1 as the power resulting from the delivered and sold ee in 0-1 hours, while interpreting the element a_{11} as the frequency of its changes in the date of sale [1 / day].

Further, on the basis of the state variable $x_1(t)$ and using the equation for definition of state variable $x_2(t)$ and the state variable $x_3(t)$ it is possible to interpret them as state variables respectively expressing the electricity sold per day. Finally, the interpretation of the state variable $x_4(t)$ results from the interpretation of the state variable x_3(t) as well as from the equation for the determination of the fourth state variable and can be interpreted as the electricity supplied to the power exchange and sold during the period of measurement, which is stated as 184 days [8, 16].

4. Interpretation of selected results

Based on control and systems theory, matrix **A** corresponding to the degree of internal organization of the TGEE system binds state vector with the derivative of the state vector [4, 20]. Based on equations of state (4) and resulting therefrom block diagram shown on Fig. 1, it can be seen, inter alia, that derivatives of all state variables are dependant of state variable x_5, also derivative of the state variable x_2 and derivative of the state variable x_3 are dependant of state variable x_1 and derivative of the state variable x_4 is dependant of state variable x_3 and derivative of the state variable x_5 is dependant of state variable x_4.

Based on control and systems theory, it can be also noticed that, matrix **B** corresponding to the level of control demonstrates the effect of all input variables for all state variables, wherein the effect is of some size and negative input from others positive.

Due to the fact that the matrix **C** has only one nonzero component (fifth one), thus the output equation is of the form:

$$y(t) = 2 \cdot x_5(t). \tag{5}$$

Analysing a change trends of matrix **A**, **B**, **C** and **D** dimensions can be concluded that during the examined period there were structural changes and change trends of values of their elements can be concluded, that there occurred parametric changes, hence the important issue is to obtain a catalogue of models of state variables for defined periods of time, for example with one year progresses. Resulting matrix **A** occurring in the individual stages of development is presented in Table I, and the matrix **B** in Table II.

Changes of values for element a11 in 24 periods of TGEE system development are shown on Fig. 2, wherein it can be noticed, inter alia, that there were changes in the above mentioned periodical matrix elements of internal organization of the process (matrix **A**) around value 0,35000, where minimum value of it occurred in eight period of development (01.08.2013-31.01.2014) and was 0,1250 and maximum value did not exceed 0,50000, a_{21} element of the matrix **A** expresses the impact strength of a state variable x_1 on the derivative of the state variable x_2.

Moreover, on Fig. 3 shows a changes od periodical values of a_{15} element in 24 periods of TGEE system development around value -0,25, wherein minimum value of element a_{15} was achieved in periods 1 and 16, while maximum value of this element was achieved in periods: 8, 12-13 and 19-22, where this maximum value was respectively: 0,19 and zero, and on Fig. 4 are shown interesting changes of a_{55} element in 24 periods of TGEE system development around value equalled -3,0. It can be noticed that this element never had positive values, while maximum value was zero in periods of 12-13 and 19-22, while minimum value in periods 5-6 and 13-14.

Table 1. Summary of selected elements values of the matrix **A** corresponding to the degree of internal organization of TGEE

Description of the model		Values of selected elements of the matrix **A**								
θ	period	a_{21}	a_{32}	a_{43}	a_{54}	a_{15}/a_{14}	a_{25}/a_{24}	a_{35}/a_{34}	a_{45}/a_{44}	a_{55}
p1	01.01.2013-30.06.2013	0,5000	1,000	4,000	4,000	-0,5540	-1,3873	-1,7521	-3,6676	-2,8676
p2	01.02.2013-31.07.2013	0,5000	2,000	2,000	8,000	-0,2797	-1,0252	-1,4958	-2,0157	-3,2727
p3	01.03.2013-31.08.2013	0.2500	2.0000	2.0000	8.0000	-0.2448	-1.0996	-1.5389	-2.1386	-3.5517
p4	01.04.2013-30.09.2013	0.5000	2.0000	2.0000	4.0000	-0.3395	-2.0844	-2.1985	-4.0978	-3.3050
p5	01.05.2013-31.10.2013	0.5000	2.0000	2.0000	4.0000	-0.3468	-2.1622	-2.2256	-4.2055	-3.5186
p6	01.06.2013-30.11.2013	0.5000	2.0000	0.2000	8.0000	-0.2911	-1.1024	-1.4506	-2.2901	-4.1016
p7	01.07.2013-31.12.2013	0.2500	2.5000	2.0000	4.0000	-0.4140	- 1.2566	-1.9227	-3.3819	-2.3759
p8	01.08.2013-31.01.2014	0.1250	2.0000	2.0000	4.0000	0.1846	-1.4084	-0.9899	-3.2601	-1.6988
p9	01.09.2013-28.02.2014	0.2500	2.0000	2.0000	4.0000	-0.3694	-1.6132	-1.1822	-3.3317	-1.6709
p10	01.10.2013-31.03.2014	0.2500	2.0000	2.0000	4.0000	-0.3163	-1.3743	-1.0224	-3.1449	-1.2903
p11	01.11.2013-30.04.2014	0.5000	2.0000	2.0000	4.0000	-0.4147	-2.2887	-2.1859	-3.8134	-2.4452
p12	01.12.2013-31.05.2014	0,2500	2.0000	4.0000	0.0000	**-0.3860**	**-1.3351**	**-1.8590**	**-2.5671**	0.0000
p13	01.01.2014-30.06.2014	0.5000	2.0000	4.0000	0.0000	**-0.2430**	**-1.8984**	**-2.1113**	**-3.8843**	0.0000
p14	01.02.2014-31.07.2014	0.5000	2.0000	4.0000	8.0000	-0.3852	-1.4672	-1.9734	-4.2235	-7.5991
p15	01.03.2014-31.08.2014	0.5000	2.0000	2.0000	8.0000	-0.3851	-1.5451	-2.5042	-2.7603	-5.0615
p16	01.04.2014-30.09.2014	0.2500	2.0000	2.0000	8.0000	-0.5057	-1.4762	-2.2659	-2.5861	-4.6380
p17	01.05.2014-31.10.2014	0.2500	2.0000	4.0000	4.0000	-0.3099	-0.9250	-1.3556	-3.9836	-3.2402
p18	01.06.2014-30.11.2014	0.2500	2.0000	2.0000	4.0000	-0.2378	-1.8966	-2.1137	-3.8883	-2.9390
p19	01.07.2014-31.12.2014	0.5000	2.0000	4.0000	0.0000	**-0.2747**	**-0.7153**	**-1.4383**	**-2.3307**	0.0000
P20	01.08.2014-31.01.2015	0.2500	2.0000	4.0000	0.0000	**-0.3392**	**-0.8070**	**-1.4815**	**-2.3178**	0.0000
P21	01.09.2014-28.02.2015	0.5000	1.0000	4.0000	0.0000	**-0.3268**	**-1.2904**	**-1.4913**	**-1.934200**	0.0000
P22	01.10.2014-31.03.2015	0.5000	2.0000	4.0000	0.0000	**-0.3948**	**-0.8319**	**-1.7686**	**-2.6376**	0.0000
P23	01.11.2014-30.04.2015	0.2500	2.0000	2.0000	4.0000	-0.2414	-1.8164	-2.0733	-3.9265	-3.1011
P24	01.12.2014-31.05.2015	0.5000	2.0000	2.0000	8.0000	-0.3131	-1.2087	-1.6871	-2.3750	-4.2163

Source: Own elaboration in MATLAB and Simulink environments [3]

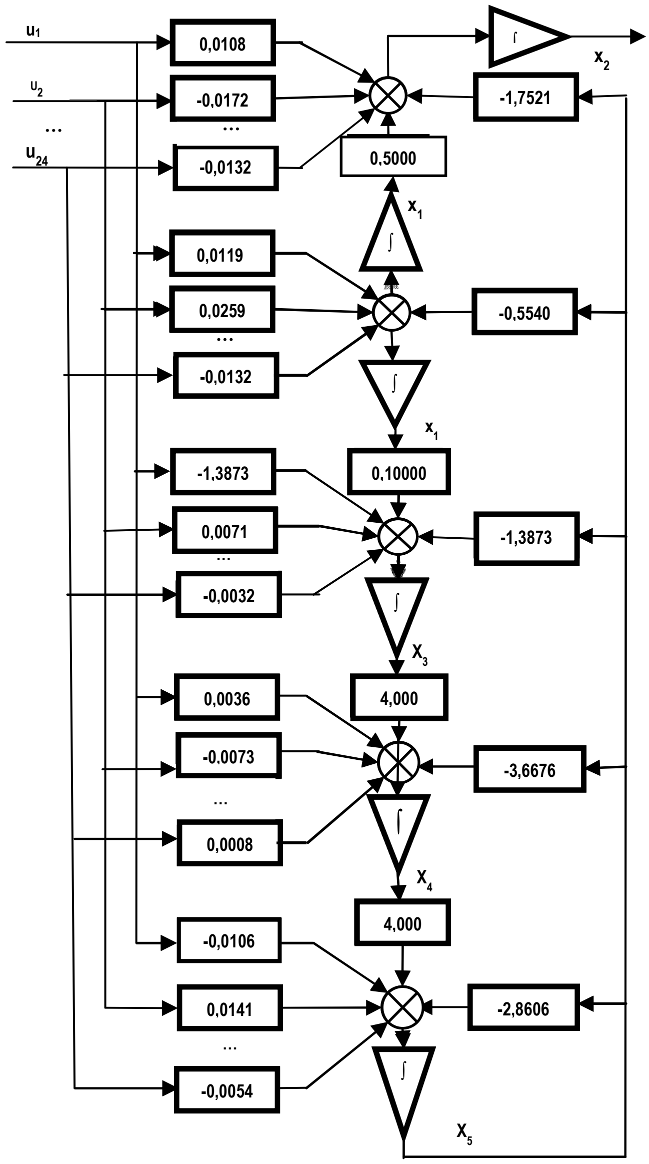

Figure 1. Block diagram of system state variables TGEE model for 24 input variables related to the volume of electricity sold in the specific hours of the day with medium price of electricity generated in an hour 0-1 for periods of measurement p_i, where $i = 1 - n$
Source: Own elaboration in Simulink [3]

Table 2. Summary of selected elements values of the matrix **B** corresponding to the TGEE control level

Description of the model		Values of selected elements of the matrix **B**				
θ	period	b_{21}	b_{32}	b_{43}	b_{54}	b_{15}
p1	01.01.2013-30.06.2013	-0,0810	-0,0004	0,0130	0,0095	0,0007
p2	01.02.2013-31.07.2013	0,0003	-0,0007	0,0164	0,0902	0,0015
p3	01.03.2013-31.08.2013	0,0004	-0,0009	0,0039	0,0392	-0,0068
p4	01.04.2013-30.09.2013	-0,0058	0,0001	0,0022	0,0211	0,0098
p5	01.05.2013-31.10.2013	-0,0056	-0,0021	-0,0003	0,0098	0,0272
p6	01.06.2013-30.11.2013	-0,0087	-0,0053	-0,0044	0,0387	0,0118
p7	01.07.2013-31.12.2013	-0,0004	0,0004	0,0047	0,0075	0,0692
p8	01.08.2013-31.01.2014	0,0082	0,0290	0,0211	0,0378	0,0106
p9	01.09.2013-28.02.2014	0,0331	0,0544	0,0278	0,0850	-0,0151
p10	01.10.2013-31.03.2014	0,0180	0,0569	0,0138	0,0719	-0,0347
p11	01.11.2013-30.04.2014	-0,0007	0,0092	0,0056	-0,0122	0,0173
p12	01.12.2013-31.05.2014	0,0016	0,0200	0,5340	0,0000	0,0180
p13	01.01.2014-30.06.2014	-0,0020	0,0192	0,0007	0.0000	0,0164
p14	01.02.2014-31.07.2014	0,0063	0,0146	-0,0221	0,0482	-0,0200
p15	01.03.2014-31.08.2014	0,0007	0,0088	0,0108	0,0525	-0,0614
p16	01.04.2014-30.09.2014	-0,0043	0,0051	-0,0006	0,0124	0,0011
p17	01.05.2014-31.10.2014	-0,0040	0,0174	0,0033	0,0368	-0,0343
p18	01.06.2014-30.11.2014	-0,0107	0,0081	-0,0038	0,0015	-0,0711
p19	01.07.2014-31.12.2014	-0,0205	-0,0140	-0,0406	0,0000	0,0149
P20	01.08.2014-31.01.2015	-0,0105	-0,0163	-0,0764	0,0000	0,0185
P21	01.09.2014-28.02.2015	-0,0164	-0,0237	-0,0592	0,0000	0,0202
P22	01.10.2014-31.03.2015	0,0075	-0,0061	0,0173	0,0000	0,0428
P23	01.11.2014-30.04.2015	-0,0078	0,0033	-0,0069	0,0183	0,0037
P24	01.12.2014-31.05.2015	-0,0003	0,0286	-0,0157	0,0590	0,0501

Source: Own elaboration in MATLAB and Simulink environments using SIT [3]

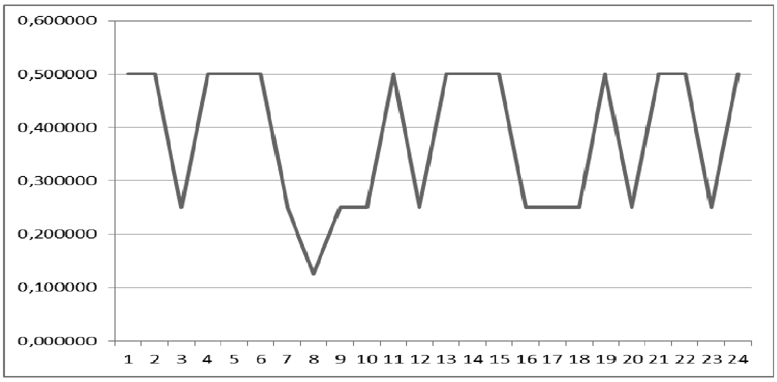

Figure 2. Changes of a_{21} element of **A** matrix in 24 periods of TGEE development.
Symbols: X axis – long time, Y axis – changes of a_{21} element of A matrix
Source: Own elaboration in MATLAB and Simulink environments using SIT

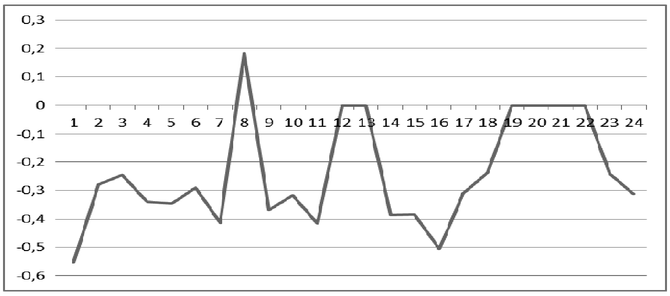

Figure 3. Changes of a_{15} element of **A** matrix in 24 periods of TGEE development.
Symbols: X axis – long time, Y axis – changes of a_{15} element of **A** matrix
Source: Own elaboration in MATLAB and Simulink environments using SIT

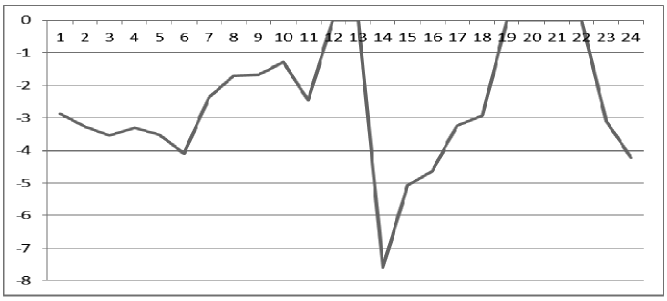

Figure 4. Changes of a_{55} element of **A** matrix in 24 periods of TGEE development.
Symbols: X axis – long time, Y axis – changes of a_{55} element of **A** matrix
Source: Own elaboration in MATLAB and Simulink environments using SIT

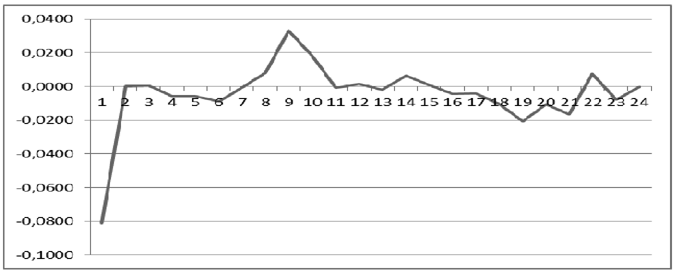

Figure 5.. Changes of b_{21} element of **B** matrix in 24 periods of TGEE development.
Symbols: X axis – long time, Y axis – changes of b_{21} element of **B** matrix
Source: Own elaboration in MATLAB and Simulink environments using SIT

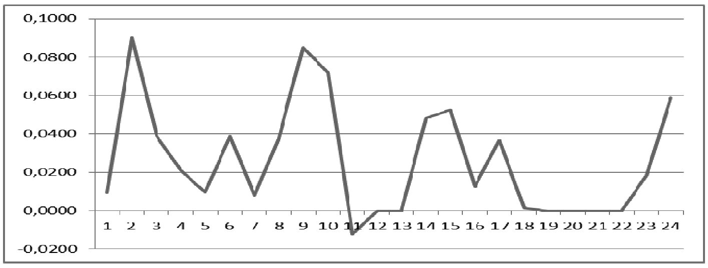

Figure 6. Changes of b_{54} element of **B** matrix in 24 periods of TGEE development.
Symbols: X axis – long time, Y axis – changes of b_{54} element of **B** matrix
Source: Own elaboration in MATLAB and Simulink environments using SIT

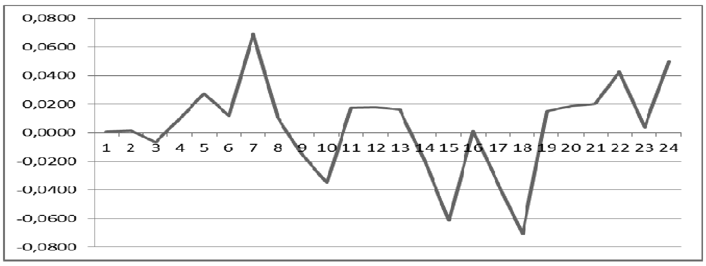

Figure 7. Changes of b_{15} element of **B** matrix in 24 periods of TGEE development.
Symbols: X axis – long time, Y axis – changes of b_{15} element of **B** matrix
Source: Own elaboration in MATLAB and Simulink environments using SIT

Individual elements of the matrix **A** and **B** can be given a specific interpretation that results from the interpretation of the state variables, while interpretation of state variables is convenient to start from the equation output (5) [19]. Variable output in this is an average price obtained from the sale of electricity in hours 0-1 in conventional 182 days resulting from the identification period of model [PLN / MWh], and then, assuming that element c_{11} of matrix **C** is expressed in units of [PLN / MWh^2], then the state variable $x_5(t)$ can be interpreted as electricity energy delivered and sold at TGEE during 0-1 hour in relevant period of trading on the DAM [MWh]. The elements of the matrix A in Fig. 2 - a21, Fig. 3 - a15, on fig. 3 - a55 take constant values for some models in subsequent periods measured for this reason that the relationship between a derivative of one variable state and another state variable respectively have not changed, which means that during this period there has been no corresponding change in the system of internal organization DAM, which requires in-depth study of structural-parametric, eg. using root lines Evans.

On the basis of the state variable x_5 (t) and using the equation for determining the state variable x_1 (4) it is possible to interpret the state variable x_1 as the power resulting from the delivered and sold ee in 0-1 hours, while interpreting the element a_{11} as the frequency of its changes in the date of sale [1 / day].

Further, on the basis of the state variable $x_1(t)$ and using the equation for definition of state variable $x_2(t)$ and the state variable $x_3(t)$ it is possible to interpret them as state variables respectively expressing the electricity sold per day. Finally, the interpretation of the state variable $x_4(t)$ results from the interpretation of the state variable $x_3(t)$ as well as from the equation for the determination of the fourth state variable and can be interpreted as the electricity supplied to the power exchange and sold during the period of measurement, which is stated as 184 days [8, 16].

5. Conclusions And Future Research

It is possible to receive a real system model as an equivalent block diagram of TGEE in the process of parametric identification using figures quoted on the DAM TGEE. In the process of stepping identification it was obtained 35 types of parametric discrete linear TGEE models which were further converted to 35 parametric continuous models and afterwards to 35 continuous models in state space.

For the 24 models, there were examined changes of all non-zero elements of the matrix A and selected five elements of the matrix B noticing interesting regularities of TGEE development. We found further that based on the received models it is possible to interpret the test results, including state variables and parameters - elements of the matrix A and matrix B, not to mention the possibility of carrying out extensive research using methods of economic analysis are described, among others, at J. Paska work "Ekonomika w elektroenergetyce" [11], or system analysis described at works of J. Tchórzewski [18-20] taking into account the risk management strategy for the power exchange [26]. Research continues.

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