Metaidentification of the management system of the Polish Electric Power Exchange in terms of control theory and systems

Radosław Marlęga, Jerzy Tchórzewski

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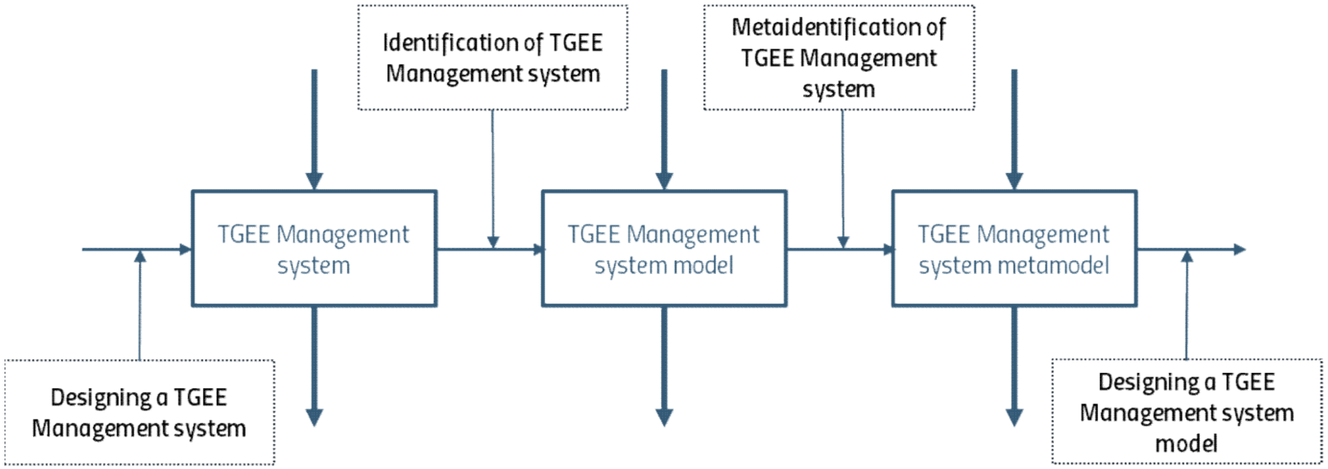
Modeling approach

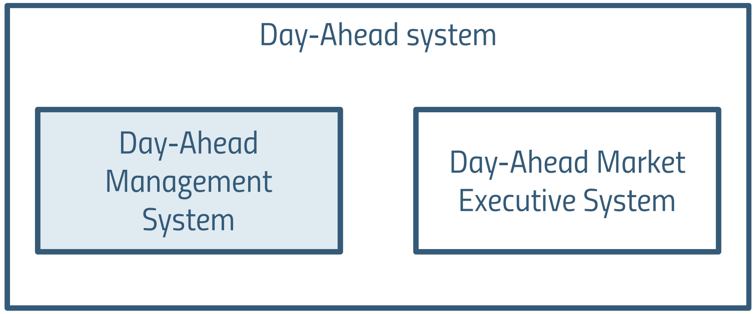
Modeling and metamodeling process of the TGEE management system



In order to obtain a model of the system, its modeling is carried out, which may be analytical, identifying or, recently, neural. Modeling always produces a system model. In the experiment under consideration, let it be the Day-Ahead Market (DAM) system operating at Towarowa Giełda Energii S.A. (TGE S.A.) regarding the conclusion of transactions for the sale of electrical energy (ee), which was called the Polish Electricity Power Exchange (PEPE).

Model structure

Experiment carried out in this study covers the Day-Ahead Management System as a subsystem of the Day-Ahead Market



Data for experiment were collected from the DAM on the PEPE in the form of the volume of electricity supplied and sold in each hour of the day and in the form of a volume-weighted average price obtained for electricity sold in each hour of the day, recorded in the period from 01.01. 2013 to April 31, 2016.

The other side of the experiment concerns the identification carried out on the parameters of models obtained for the same length of data periods moving in time with a fixed step of change (here one month) in order to obtain a model of the obtained system models, i.e. a metamodel

Definitions

Basic definitions used in this analysis

Def. 1. DAM management system - a subsystem in the DAM system that processes the information on the volume ee delivered to and quoted on the DAM (input quantity) into a decision on the amount of the received average price weighted by the volume of delivered and sold ee quoted on the DAM at each hour of the day (output value) - figure 2.

Def. 2. The DAM management system model - a substitute scheme of the DAM management system obtained as a result of the identification of the DAM management system, in the form of the arx parametric model based on the recorded values of the input quantities of the volume ee type in each hour of the day [MWh] and the output quantities of the average price weighted by volume ee received every hour of the day [PLN/MWh].

Def. 3. Metamodel DAM management system (model model) - a substitute diagram of the DAM management system model obtained as a result of meta-identification in the form of a parametric metamodel arx obtained on the basis of the values of the $B_i(q)$ polynomial coefficients for each hour of the day obtained as a result of the identification of the rolling values of the input quantities and obtained as a result of identifying the values of the output quantities, such as the values of the coefficients of the $A_i(q)$ polynomial for each hour of the day in the rolling model with an hour step

Def. 4. The implementation (executive) system of the DAM management system is a subsystem that performs tasks related to the supply of electricity on the DAM on PEPE and sale on the DAM

Expected results of experiment

Results of identification and meta-identification are stored in the **theta** format matrix (**th** matrix)

Theta format matrix (**th** matrix) contains all information about the model or metamodel, its structure and parameter estimators, along with their estimation by covariance.

The process of finding a representation of the matrix of measurement data in the form of a formalized identification or meta-identification of the RDN system is called:

$$Z^N = [output, input]$$

in a vector of model parameters [θ] stored in the form of the **th** matrix of **theta** format, where N is the number of ordered observations of successive values of the input variables and successive values of the output variables.

System, model & Metamodel of Day-Ahead Market System

Characteristics of the Day-Ahead Market System on the Polish Electricity Power Exchange System & description of models and metamodels

Characteristics of the Day-Ahead Market System

Day-Ahead Market System on the Polish Power Exchange

- Transactions on PEPE start operating on the Day-Ahead Market (DAM) on the day preceding the physical supply of electrical energy (ee), then their activity is extended to longer periods, from a week, a month to sometimes up to a year
- Due to the tendency to shorten the preparation time of generating units' work schedules, the Day-Ahead Electricity Market of the "day before" type changes to the "hour before" type market. This involves the possibility of submitting offers several times a day
- Transactions on the Day-Ahead Market as a contract form are placed between long-term bilateral contracts and transactions on the Balancing Market. The Day-Ahead Market in Poland has been operating since June 30, 2000 as a spot market for electricity.
- From the beginning of trading, prices on the DAM were a reference for electricity prices in bilateral contracts
- Under DAM, hourly and block contracts (base, peak and off-peak) are available for electricity transactions, with changes currently being interpreted by 6 price indices relating to the day and time of day of delivery
- In order to identify the PEPE system, it was downloaded from the website of Towarowa Giełda Energii S.A. (see: TGE S.A., 2020) figures for the DAM from the period from January 1, 2013 to April 30, 2016, creating correspondingly long contractual measurement periods

System, Model, Metamodel (1/3)

The management system subject to identification and metaidentification is the Day-Ahead Market System operating on the Polish Power Exchange

- Identification of the DAM system leads to obtaining the catalogue of DAM system models, and identification of the parameters of the DAM system model leads to obtaining metamodels of the DAM system.
- results of studies and research on the metaidentification of the Polish Power Exchange system as a management system were obtained on the basis of the results of identification carried out using data listed on the Day-Ahead Market regarding the volume of ee delivered and sold at particular hours of the day as input quantities and the weighted average unit price of energy electricity received at specific hours of the day.
- As a result of identification, 35 parametric models of discrete linear arx MISO type (with 24 input sizes and single output sizes) were obtained for each hour of the day, i.e. a total of 840 models.
- Model parameters, i.e. coefficients of polynomials A(z) and $B_i(z)$ were then used for the second identification called metaidentification, in which the input values were the parameters of polynomials related to the input quantities $B_i(z)$, and thus the volume of electricity supplied and sold in particular hours of the day, and output quantities parameters of the polynomial associated with output quantities, i.e. with average unit prices weighted by the volume of electricity supplied and sold on the DAM in each hour of the day.

System, Model, Metamodel (2/3)

The management system subject to identification and metaidentification is the Day-Ahead Market System operating on the Polish Power Exchange

- As a result of the metaidentification carried out in this way, a metamodel of the DAM system was obtained, just as the DAM system models were obtained as a result of the identification of the DAM system.
- It was assumed that the DAM management system model is the replacement scheme of the DAM management system, obtained as a result of identification of the DAM management system, as a parametric model, based on the *ee* volume input quantities recorded on the DAM in each hour of the day and the volume weighted average price output types *ee*.
- Further in line with the abovementioned models assume, among others, that the metamodel of the DAM management system is a substitute scheme of the DAM management system model obtained as a result of metaidentification of the DAM management system, as a parametric metamodel obtained in the results of the metaidentification process using the values of parameters of the catalogue of parametric models with input values the type of polynomial coefficients $B_i(q)$ for each hour of the day and the output quantities of the type of polynomial coefficients $A_i(q)$ for each hour of the day in the rolling model.

System, Model, Metamodel (3/3)

The management system subject to identification and metaidentification is the Day-Ahead Market System operating on the Polish Power Exchange

- Work also shows how to interpret the received state variables of PEPE models for particular hours of the day and selected elements of matrices **A**, **B** and **C**, because matrix **D** was a matrix of zero elements, where the interpretation of state variables was started from the equation of the output of the DAM state variable model, in which the output variable $y_1(t)$ was the volume-weighted average price obtained from the supply and sale of electricity in hours 0-1 in contractual 184 days resulting from the model identification period [PLN/MWh].
- Then, assuming that the c_{11} element of matrix **C** is expressed in units [PLN/MWh^2], then the state variable $x_5(t)$ was interpreted as electricity supplied and sold on PEPE in the hour 0-1 during the quotation period on the DAM [MWh], i.e. in the period from 01/01/2013 to 30/06/2013.
- On the basis of the state variable x5(t) and using the state equation to determine the state variable x1(t), the state variable x1(t) was interpreted as the power resulting from the ee delivered and sold in hours 0-1, interpreting element a11 as the frequency of its changes on the day of sale [1/day].
- Further, based on the state variable x1(t) and using the state equation for determining the state variable x2(t) and the state equation for determining the state variable x3(t), they were interpreted as state variables expressing electricity sold during the day, respectively.
- Finally, the interpretation of the state variable x4(t) results from the interpretation of the state variable x3(t) and the state equation for determining the derivative of the state variable x4(t), which was interpreted as electricity supplied to the stock exchange and sold during the measurement period, i.e. in within 184 days, i.e. from 01/01/2013 to 30/06/2013.

Metamodels in research

Metamodels of the commodity of the electric energy exchange in terms of control theory and systems engineering

Metaidentification as identification of DAM models

Example of input and output data waveform

The Day Ahead Market (DAM) Models on the Polish Electric Power Exchange in terms of control theory and systems engineering

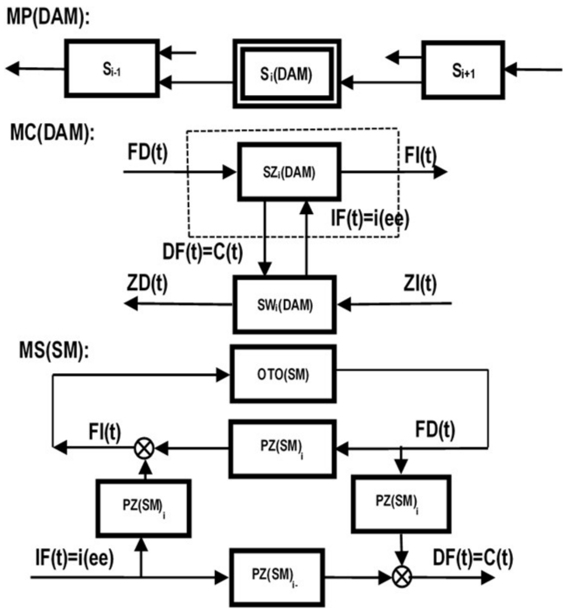


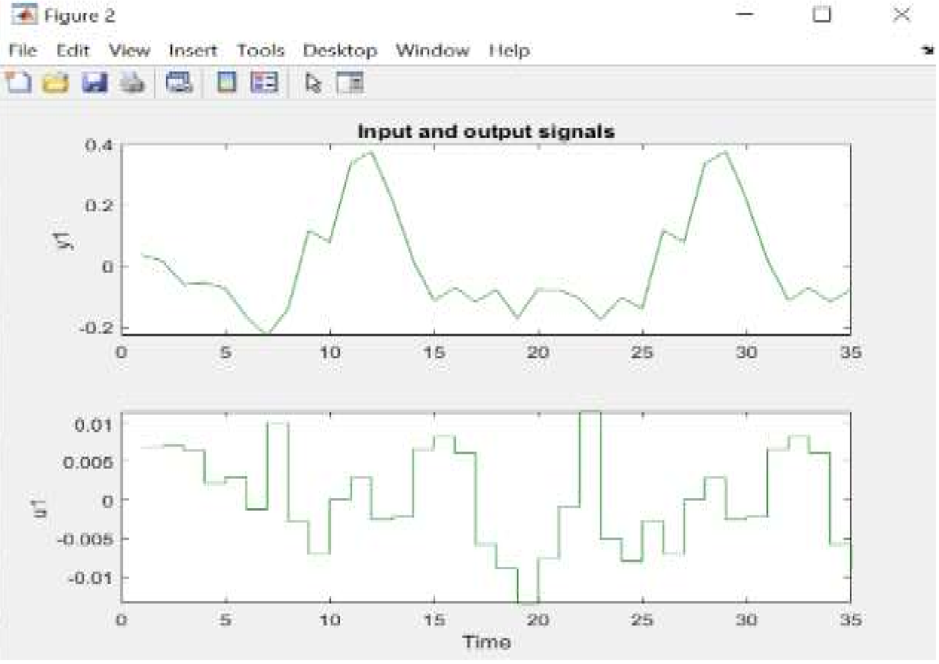
Figure presents three models of the Day Ahead Market system, i.e. the praxeological model of the Day Ahead Market system (marked as MP), the cybernetic model of the Day Ahead Market system (marked as MC) and the system model of the management system as a subsystem in the Day Ahead Market system (marked as MS). The following detailed designations were adopted:

- S_i(DAM) - i-th subsystem of Electricity Market as the Polish Power Exchange System,
- S_{i+1} - (i+1)- th subsystem of integrated electricity reception from DAM as the operating system for the DAM system,
- S_{i-1} - (i-1)-th subsystem of the integrated electricity supplier (power plant) at DAM as a security system for the DAM system,
- SZ_i(DAM) - management system in the DAM system as the i-th subsystem of EPM,
- SW_i(DAM) - executive system in the DAM system as in the i-th EPM subsystem,
- PK_i(MS, SM) - management subsystem in the Management System in the i-th DAM system,
- PW_i(SZ, SM) - executive subsystem in the Management System in the i-th DAM system,
- PI_i(PZ, SM) - information subsystem in the Management System in the i-th DAM system,
- PD_i(PZ, SM) - decision making subsystem in the Management System in the i-th DAM system,
- FD_i(DAM, t) - utility income stream in the i-th DAM system at time t,
- FI_i(DAM, t) - utility input stream in the i-th DAM system at time t,
- IF_i(DAM, t) - information stream in the i-th EPM subsystem as the DAM system at the moment t being information about the volume of electricity i delivered and sold to customers (DAM, ee),
- DF_i(DAM, t) - decision stream in the i-th EPM subsystem as the DAM system at the moment t being the decision on the average price for 1MW weighted by the volume of electricity supplied and sold to C (DAM, t).

Metaidentification as identification of DAM models

Example of input and output data waveform

DAM model changes coefficients for 35 contractual measurement periods (a1 coefficient standing at z-1 delay and b1 standing coefficient at z-1 delay)



Parametric metamodel of the DAM

Metaidentification was carried out using four coefficients of B1(z) polynomials as input quantities and one coefficient of A1(z) polynomials as the output quantity, with the values given in table

period	$B_1(z^{-1})$	$B_2(z^{-2})$	$B_3(z^{-3})$	$B_4(z^{-4})$	$A_1(z^{-1})$
p1	0.005455	0.01089	0.0006017	0.006013	-0.4456
p2	0.005572	0.001121	0.0034	0.002929	-0.4664
p3	0.005025	-0.004956	0.001012	0.001906	-0.5432
p4	0.000816	-0.0006004	-0.0000086	0.007244	-0.5367
p5	0.001582	- 0.006111	0.001007	0.005847	- 0.5567
p6	-0.002599	- 0.001136	0.002666	0.004478	- 0.6487
p7	0.008594	- 0.006689	0.001814	0.005702	- 0.7101
p8	-0.004250	0.006656	0.004926	0.001608	- 0.6217
p9	-0.008400	- 0.000507	0.005878	0.005528	- 0.3658
p10	-0.001345	0.004507	0.002137	0.001677	- 0.4035
p11	0.001526	0.0024	- 0.001671	0.003377	- 0.1471
p12	-0.003933	0.007045	- 0.00472	- 0.00268	- 0.1071
p13	-0.003672	0.008857	- 0.005701	0.00306	- 0.265
p14	0.005230	0.009797	- 0.007371	- 0.00031	- 0.4625
p15	0.006782	0.0108	- 0.005087	0.007766	- 0.595
p16	0.004715	0.01171	0.004841	0.008003	- 0.5533
p17	-0.007193	0.008944	0.006313	0.001716	- 0.5988
p18	-0.010380	0.005976	0.009154	0.002155	- 0.5602
p19	-0.014860	- 0.001821	0.002023	0.01029	- 0.6538
p20	-0.009000	- 0.004485	0.01131	0.01088	- 0.5578
p21	-0.002215	- 0.00174	0.01208	0.01367	- 0.5611
p22	0.010050	- 0.003868	- 0.00033	0.000134	- 0.5883
p23	-0.006413	0.0001901	0.007854	0.001096	- 0.6574
p24	-0.009362	0.007667	0.001022	- 0.00623	- 0.5849
p25	-0.00425	0.006656	0.004926	0.001608	- 0.6217
p26	-0.0084	- 0.000508	0.005878	0.005528	- 0.3658
p27	-0.001345	0.004507	0.002137	0.001677	- 0.4035
p28	0.001526	0.0024	- 0.00167	0.003377	- 0.1471
p29	-0.003933	0.007045	- 0.00472	- 0.00268	- 0.1071
p30	-0.003672	0.008857	- 0.005701	0.00306	- 0.265
p31	0.00523	0.009797	- 0.007371	- 0.00031	- 0.4625
p32	0.006782	0.0108	- 0.005087	0.007766	- 0.595
p33	0.004715	0.01171	0.004841	0.008003	- 0.5533
p34	-0.007193	0.008944	0.006313	0.001716	- 0.5988
p35	-0.01038	0.005976	0.009154	0.002155	- 0.56020

Example of $B_i(z)$ and $A_1(z)$ multinominate factors received for hours 0-1 binding entry values in 35 models of the DAM system is shown on table.

As a result of metaidentification, a discrete parametric arx linear model was obtained and presented below (arx discrete metamodel of the DAM system of p1 period (arxmmDAMp1z1441)):

$$A1(z)\,y(t) = B1(z)\,u(t) + e(t)$$

Then the discrete parametric model (1) was converted to a continuous parametric model to obtain (arx continue matamodel of the DAM system of p1 period (thmmDAM)):

$$A(s)\,y(t) = B(s)\,u(t) + C(s)\,e(t)$$

Metamodel in the state space of the DAM

Metamodel in the state space of the DAM management system

The continuous parametric model was then converted into a continuous model in the state space to obtain matrices:

$$\mathbf{A}=\begin{bmatrix} 0 & 0 & 0 & -1.2928 \\ 1 & 0 & 0 & 0.8074 \\ 0 & 1.0000 & 0 & -1.8284 \\ 0 & 0 & 4.0000 & -0.2411 \end{bmatrix},$$

$$\mathbf{B}=\begin{bmatrix} -0.5126 & 1.5547 & -3.3000 & 0.0037 \\ 0.2305 & 0.1467 & -3.4779 & -0.4816 \\ 0.8003 & 1.5406 & -0.5049 & -0.5000 \\ -1.4942 & -0.1643 & -1.8347 & 0.4694 \end{bmatrix},$$

$$\mathbf{C}=\begin{bmatrix} 0 & 0 & 0 & 8.0000 \end{bmatrix}$$

with the matrix **D** having all zero elements, and the vector **K** was in the form:

$$\mathbf{K}=\begin{bmatrix} -0.0949 \\ 0.1946 \\ -0.0149 \\ 0.1024 \end{bmatrix}.$$

Following metamodel was obtained in the state space, i.e. the state equation:

$$\dot{x}_{1m}(t) = -1.2929\, x_{1m}(t) - 0.5126\, u_1(t) + 1.5547\, u_2(t) - 3.3 u_3(t) + 0{,}0037\, u_4(t),$$

$$\dot{x}_{2m}(t) = x_{1m}(t) + 0.8074\, x_{4m}(t) + 0.2305\, u_1(t) + 0.1467\, u_2(t) - 3.4779\, u_3(t) - 0.4816\, u_4(t),$$

$$\dot{x}_{3m}(t) = x_{2m}(t) - 1.8284\, x_{4m} + 0.8003 u_1(t) + 1.5406 u_2(t) - 0.5049 u_3(t) - 0.5 u_4(t),$$

$$\dot{x}_{4m}(t) = 4.0 x_{3m}(t) - 0.2411 x_{4m}(t) - 1.4942 u_1(t) - 0.1643 u_2(t) - 1.8347 u_3(t) + 0.4694 u_4(t),$$

and output equation:

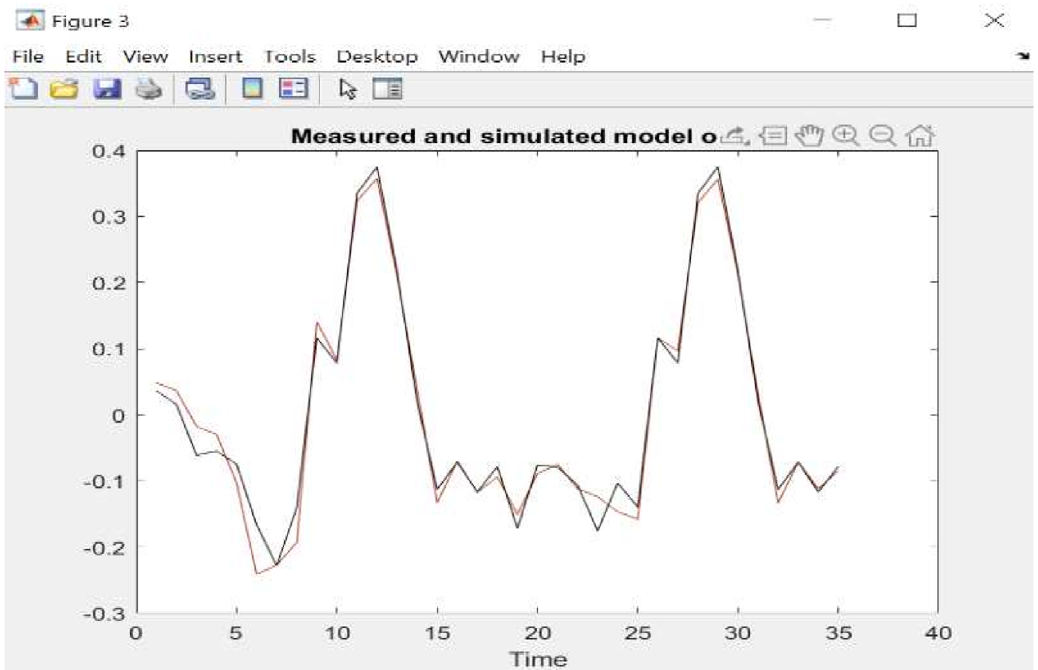
$$y_1(t) = 8.0 \cdot x_4(t)$$

It is possible to interpret the state variables of the DAM models as well as the state variables of the DAM metamodel be interpreted, but it is worth noting that in this case the inputs to the metamodel are the $B_i(z)$ polynomial coefficients of the DAM models, and the outputs are the coefficients of polynomials $A_1(z)$.

Metamodel in the state space of the DAM

Measured and simulated model

Example of metaidentification results in which the DAM system metamodel was obtained. Designations: X axis (Time) - long identification time [half-year], y axis - coefficient standing at the delay of z-1 in $A_1(z)$.



Conclusions and Directions of Further Research

Summary of research

Conclusions and Directions of Further Research

Summary of performed research

- It is possible to carry out meta-identification of the Polish Electric Power Exchange system using numerical data, e.g. on the Day-Ahead Market.
- With that aim 35 catalogues of DAM models were generated, whose parameters were used to carry out secondary identification, in which DAM models were subject to identification, not DAM systems.
- It was also shown that parametric models as well as variable state metamodel of the models of the DAM system can be obtained and then also basing on them a search for models of DAM systems.
- The research can be continued, especially in the field of interpretation of the obtained variables of the DAM metamodel

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Radosław Marlęga

University of Natural Sciences and Humanities, PhD Student at Computer Science Institute, 3 - Maja 54, 08-110 Siedlce

Jerzy Tchórzewski

University of Natural Sciences and Humanities, PhD Student at Computer Science Institute, 3 - Maja 54, 08-110 Siedlce