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Radosław MARLĘGA[1]**,**
ORCID: 0000-0003-0174-5074

Jerzy TCHÓRZEWSKI[2]
ORCID: 0000-0003-2198-7185

[1] Red Ocean Sp. z o. o.
Grzybowska 80/82, 00-844 Warszawa, Poland

[2] Siedlce University of Natural Sciences and Humanities
Faculty of Exact and Natural Sciences
Institute of Computer Science
ul. 3 Maja 54, 08-110 Siedlce, Poland

Comparative study of the efficiency, effectiveness and robustness of the TGE S.A. Day-Ahead Market model and system

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Abstract. The article contains selected results of comparative research on the quality of the parametric model, corrected in selected situations with the use of ANN and the Day-Ahead Market system of TGE S.A. carried out in MATLAB and Simulink. The System Identification Toolbox library was used for identification tests and Simulink for simulation and comparative tests. The comparative studies used such measures of model and system quality as: efficiency, effectiveness and robustness. Their waveforms as well as their average values and absolute errors and relative errors between the identification model or the identification-neural model and the system were obtained. The results of general tests were shown for the hours: 6:00, 12:00, 18:00 and 24:00 in 2019, and the detailed tests for 6:00. The sensitivity of the waveforms obtained in terms of model quality and the Day-Ahead Market system was also tested, depending on the assumed values of such parameters as e.g. electricity volume or volume-weighted average price of electricity.

Keywords. Comparative study, Day Ahead Market System, efficiency, effectiveness, MATLAB and Simulink, robustness.

1. Introduction

Information and communication technologies make the use of electronic marketplaces for services more and more common, which also applies to e.g. Polish Power Exchange and other subsystems of the Electricity Market in Poland and in the world [1, 5, 14, 33]. The flow of information accelerated in this way makes management more and more professional due to the fact of computer support, despite the emergence of new barriers and technical difficulties, especially in the field of forecasting [2-4, 7-9, 19]. The new situation gives rise to new challenges, which in times of economic war and energy crisis [20] relate in particular to the search for new possibilities to assess the effectiveness or to assess the effectiveness of models and systems [7, 10, 18, 22].

To meet this type of demand, i.a. in the original works [11-14, 27, 29], a definition and mutual relations between the efficiency Λ_s (K,θ,t), the efficiency Γ_ms (K,t) and the robustness Λ_s (K,θ,t) of the Day Market model and system were proposed of the next TGE S.A., including the important definition of robustness as a specific balance between efficiency (so-called execution efficiency) and efficiency, which can be written as follows for:

1) Implementation efficiency:

$$\Lambda_S(K,\theta,t) = \frac{DF_S(K,\theta,t)}{IF_S(K,\theta,t)}, \tag{1}$$

where:

$DF_s(K,\theta,t)$ – implementation effect (output variable from the system), i.e. the stream of decision-making potential being a function of the decision-making utility of the type of decision-making effort, expressed as the volume-weighted average price for delivered and sold on the DAM on a given day (θ) at a given hour of the day (time t), characterized by function of the effort put into the DAM management system, representing the economic side of the DAM operation and development process [PLN/MWh],

$IF_s(K,\theta,t)$ – implementation effort (input variable), i.e. the stream of information potential of securing the DAM system of the information income type, characterizing the management process in terms of information from the technical point of view and determining the technical

(energy) value of the functioning and development of the DAM system in an informative way, i.e. delivered and sold on a given day (θ) and at a given specific hour of the day (time t) electricity [MWh],

K – model/system parameters,

θ – long time as an independent variable of the process of parametric and/or structural changes of the system and model [week, month, quarter, half-year, year, etc.].

t – short time as an independent variable of the dynamics of parametric and/or structural changes of the system and model [hour, day];

2) implementation effectiveness:

$$\Gamma_{ms}(K, t) = \frac{DF_m(K,\theta,t)}{DF_s(K,\theta,t)}, \tag{2}$$

where moreover:

$DF_m(K,\theta,t)$ – the implementation effect of the system model (output variable from the DAM system model), i.e. the volume-weighted average price for delivered and sold ee obtained at a given hour of the day on a given day;

2) implementation robustness:

$$\Xi_{ms} = \Lambda_s \Gamma_{ms} = \frac{DF_s(K,\theta,t)}{IF_s(K,\theta,t)} \cdot \frac{DF_m(K,\theta,t)}{DF_s(K,\theta,t)} = \frac{DF_m(K,\theta,t)}{IF_s(K,\theta,t)}. \tag{3}$$

On the other hand, papers [14-15, 29] include a simulation model of the TGE S.A. Day-Ahead Market system implemented in the MATLAB and Simulink environments, which was also used to determine the efficiency, effectiveness and robustness of the model and the system and to conduct appropriate comparative studies. This model generally consists of 17 subsystems of the following eight types:

– ee volume separator of hourly data of the DAM system (one subsystem),
– hourly efficiency generator of the DAM system (one subsystem),
– meter of hourly effectiveness of the DAM system (one subsystem),
– measure of the relative error of robustness between the model and the DAM system (four subsystems),
– ee price separator of hourly DAM system data (one subsystem),

– measure of the relative efficiency error between the model and the DAM system (four subsystems),

– generator of model quality assessment indicators for the DAM system (effectiveness, effectiveness, robustness, etc.) (four subsystems),

– the hourly model of the DAM system (one subsystem).

In addition, the simulation model includes, among others, From Workspace blocks used to enter data on ee volume listed on the DAM in the relevant year and To Workspace blocks used to output results to the MATLAB workspace. Each of the above-mentioned subsystems is built of an appropriate number of subsequent appropriate subsystems and other accompanying elements, creating a hierarchical model of the DAM system.

2. The results of the study of effectiveness, efficiency and robustness of the DAM system

Currently, the research focused mainly on two types of models of the TGE S.A. Day-Ahead Market system, including []:

– forecast models developed using the results of the analysis of time series of prices quoted on the DAM,

– identification models, including neural models obtained on the basis of various input and output values, both regarding the volume of EE, as well as the average volume-weighted price of electricity delivered and sold on the DAM, as well as other factors (especially those used as input values), including: economic , climate, social, etc. [11-15].

In the light of the literature studies carried out, it should be stated that there are no research results on the identification metamodeling of systems leading to obtaining metamodels in general, and in particular to obtaining RDN metamodels, apart from works being the results of own research in which the author of the dissertation participated [11, 13] Moreover, the results of the analysis of the existing state of knowledge in the field of identifying the Day-Ahead Market system indicate that the research conducted so far concerns obtaining identification models using hourly, daily, weekly, monthly and quarterly data. There are also attempts to obtain the above-mentioned identification models using half-yearly and annual data, but there are no published research results sufficiently confirming the accuracy of the obtained DAM system models. There is therefore a natural need to conduct this type of research, using hourly data over a six-month and annual period, which will fill the identified gap. Moreover, existing

identification methods, especially those enhanced with neural and simulation modeling, also create great theoretical and implementation opportunities for using them to model the RDN system.

Creating models of the Day-Ahead Market system of TGE S.A. it is possible e.g. by building analytical, identification and neural models supported by evolution, and even inspired by quantum, where the modeling method is usually always selected depending on the modeled system, such as ar, arx, armax, garch, etc. [16-17, 21, 23, 25-28, 30-32]. In the considered case, the parametric identification arx was used, and the obtained models were implemented in Simulink in order to carry out appropriate simulation, comparative and sensitivity tests [11-15, 29]. Also with the use of a simulation model, both the courses of individual quantities regarding efficiency, effectiveness and robustness, as well as their average values, were determined. The results of research on selected waveforms of the above-mentioned size for hours 6:00 for both the system and the DAM system model are shown in Fig. 1-5, and the average values of efficiency, effectiveness and vigor for the hours: 6:00, 12:00, 18:00 and 24:00 for 2019. summarized in the table 1.

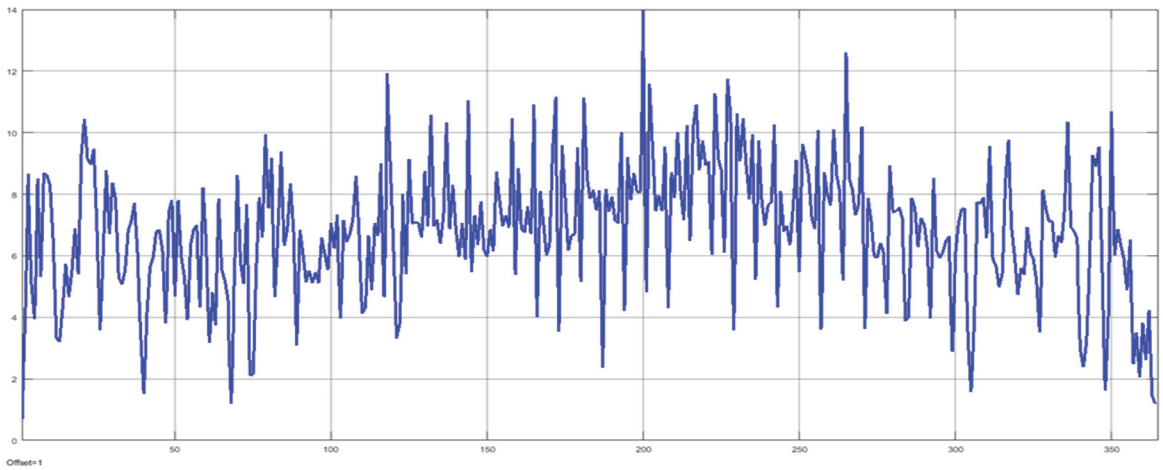

Figure 1. The course of the efficiency of the DAM system model for 6:00 am for 2019. Source: Own study in the MATLAB and Simulink environment [6, 15, 24, 29].

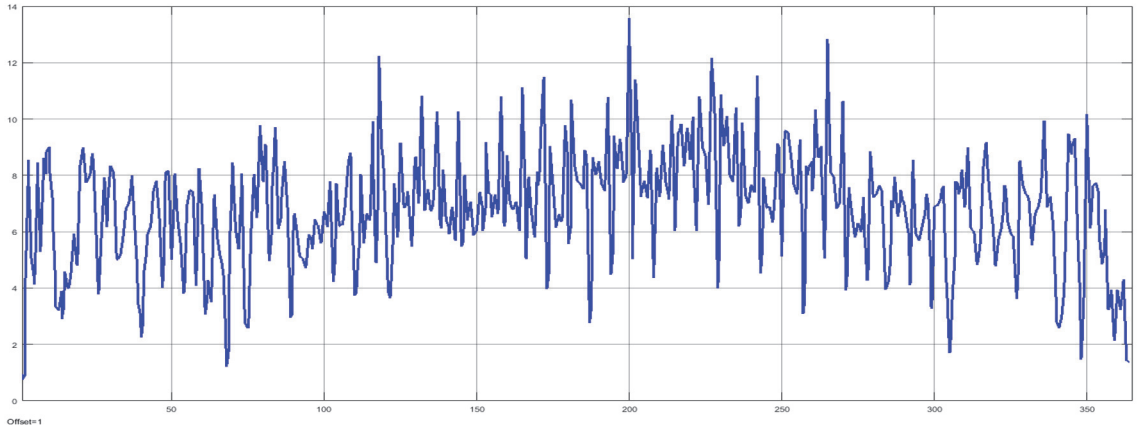

Figure 2. The course of the efficiency of the DAM system for 6:00 am for 2019. Source: Own study in the MATLAB and Simulink environment [6, 15, 24, 29].

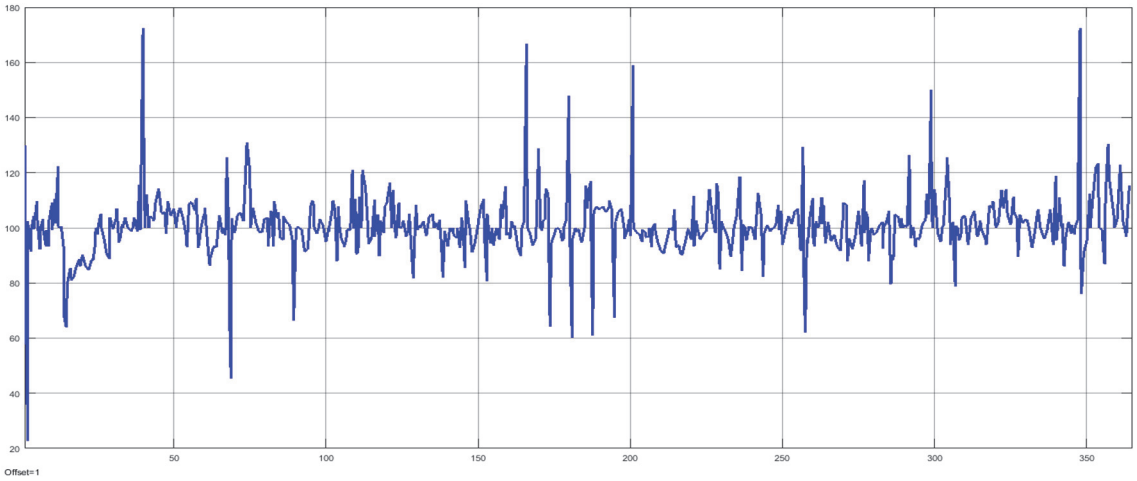

Figure 3. The course of the effectiveness of the DAM system model for 6:00 am for 2019. Source: Own study in the MATLAB and Simulink environment [6, 15, 24, 29].

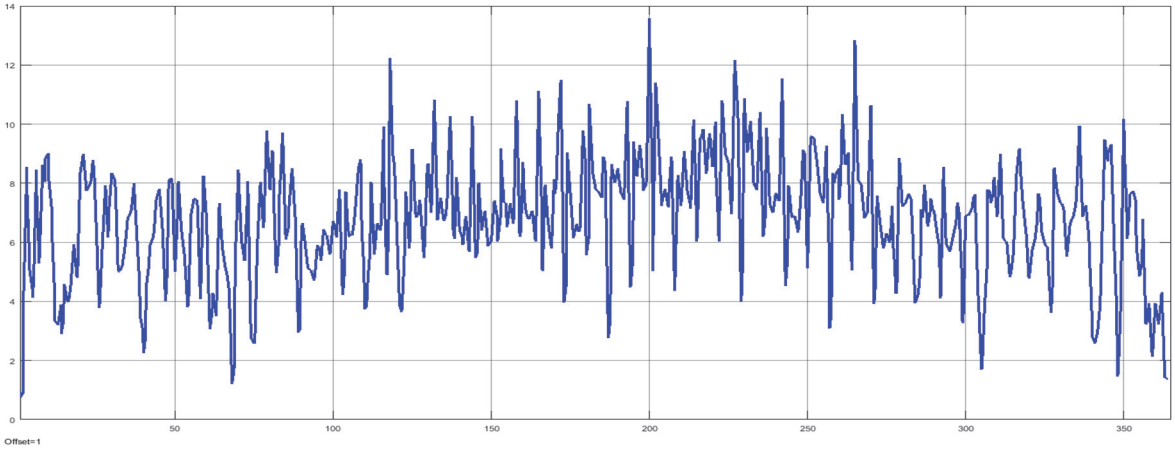

Figure 4. Course of robustness of the DAM system at 6:00 for 2019. Source: Own elaboration in MATLAB and Simulink environment [6, 15, 24, 29].

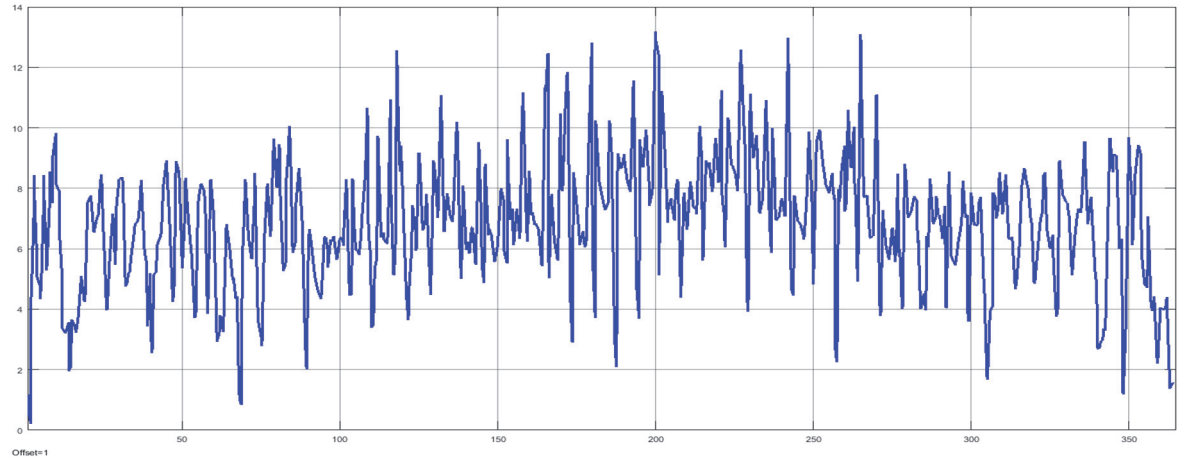

Figure 5. Course of robustness of the DAM system model at 6:00 for 2019. Source: Own elaboration in MATLAB and Simulink environment [6, 15, 24, 29].

Relative errors concerning the efficiency, effectiveness and robustness of the model and system were also determined, the average values of which are also presented in Table 1, and their courses for 6:00 am in Fig. 6-8, respectively. In addition, Fig. 9-11 shows the efficiency, effectiveness and robustness curves of the model and the DAM system for 6:00 a.m. in 2019.

Table 1. Summary of average values and relative errors of efficiency, effectiveness and robustness of the model and system for the hours: 6:00, 12:00, 18:00, 24:00 in 2019. Source: Own study in MATLAB and Simulink [6, 15, 24, 29].

Itemization	Implementation efficiency		Effectiveness	robustness	
	system	model		system	model
Values for h6	6.81	6.82	99.03	6.82	6.86
Relative error for h6	4.81		5.39	4.87	
Values for h12	7.91	8.01	97.36	8.15	8.62
Relative error for h12	9.6291		10.2842	13.2027	
Values for h18	7.87	7.51	95.79	7.52	7.35
Relative error for h18	11.72		12.47	11.38	
Values for h24	7.27	7.19	99.50	7.40	7.31
Relative error for h24	6.045		6.96	6.68	

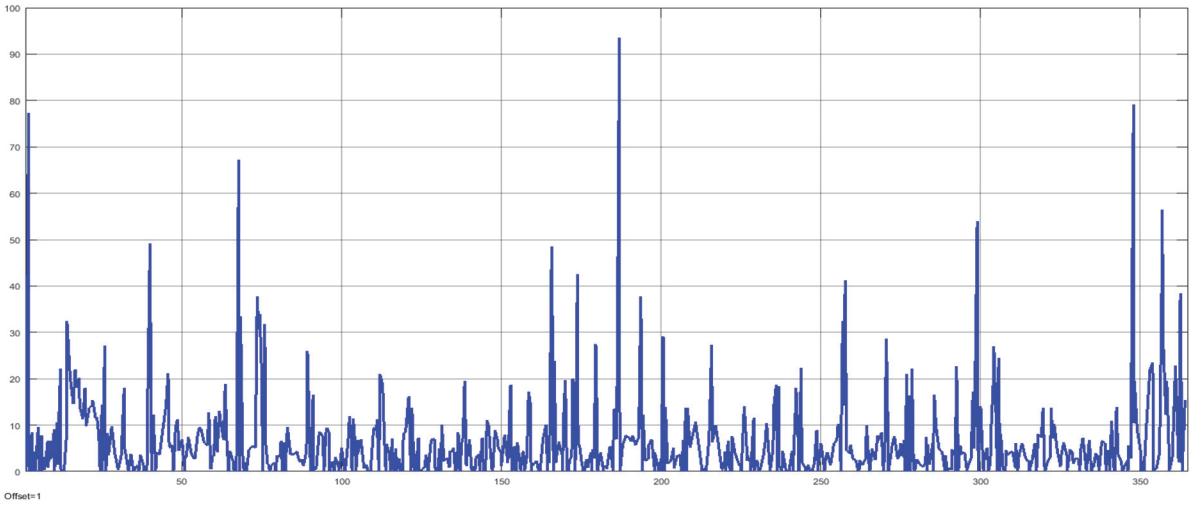

Figure 6. Course of the relative efficiency error between the model and the DAM system for h6. Source: Own elaboration in MATLAB and Simulink [6, 15, 24, 29].

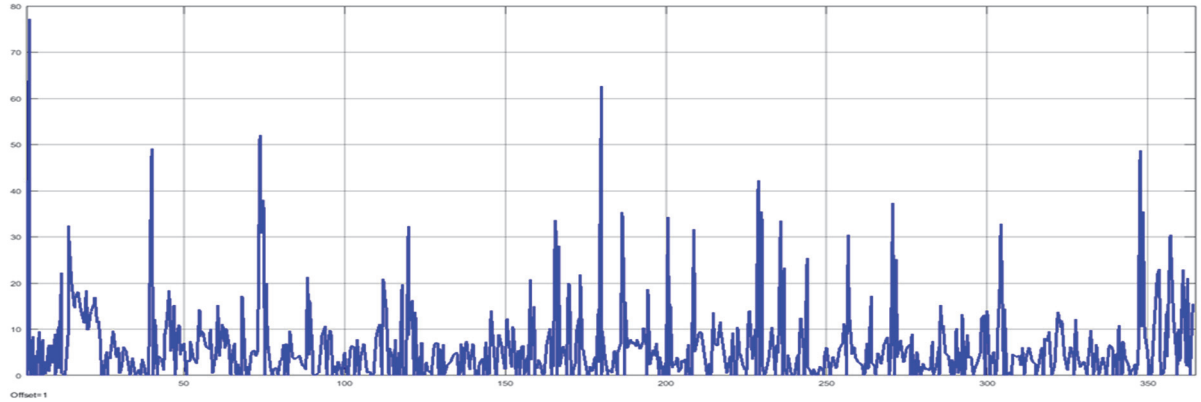

Figure 7. The course of the relative error of effectiveness between the model and the DAM system for h6. Source: Own elaboration in MATLAB and Simulink [6, 15, 24, 29].

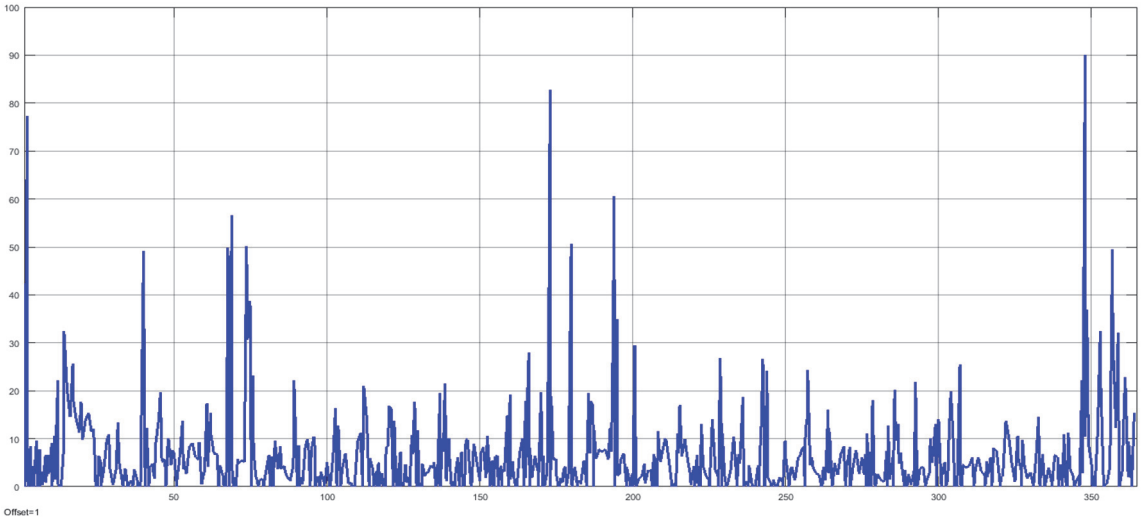

Figure 8. The course of the relative error of robustness between the model and the DAM system for h6. Source: Own elaboration in MATLAB and Simulink [6, 15, 24, 29].

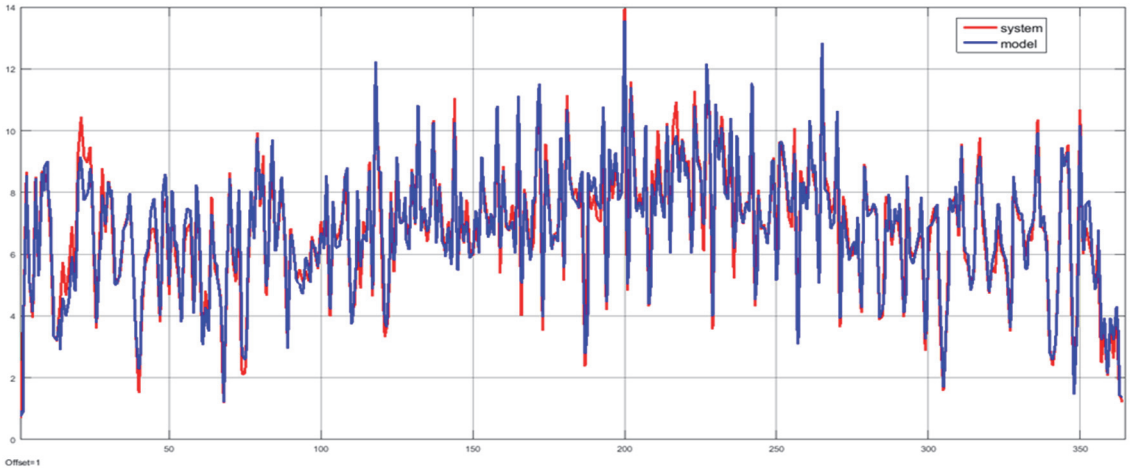

Figure 9. Comparative analysis of efficiency curves of the models and the DAM system for 6:00 in 2019. Source: Own study in MATLAB and Simulink environment [6, 15, 24, 29].

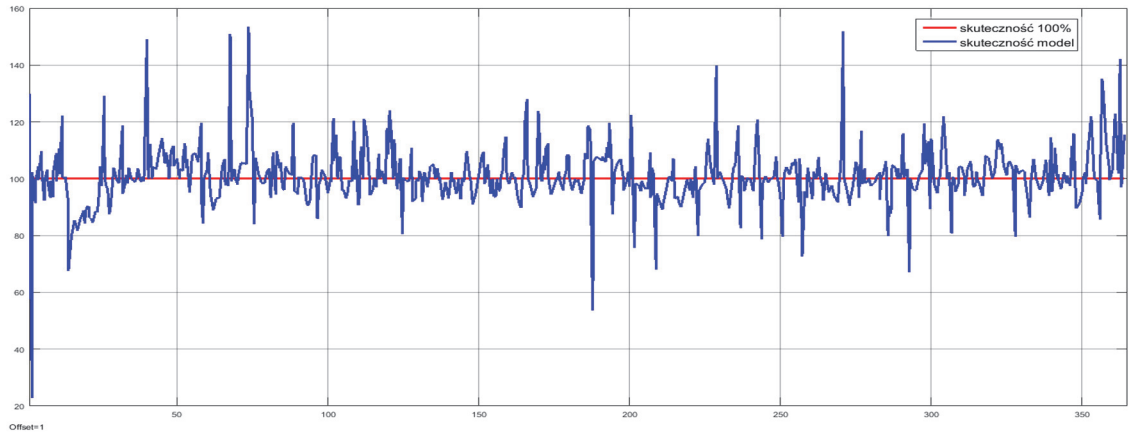

Figure 10. Comparative analysis of the efficiency curves of the models and the DAM system for 6:00 am in 2019 Source: Own study in MATLAB and Simulink [6, 15, 24, 29].

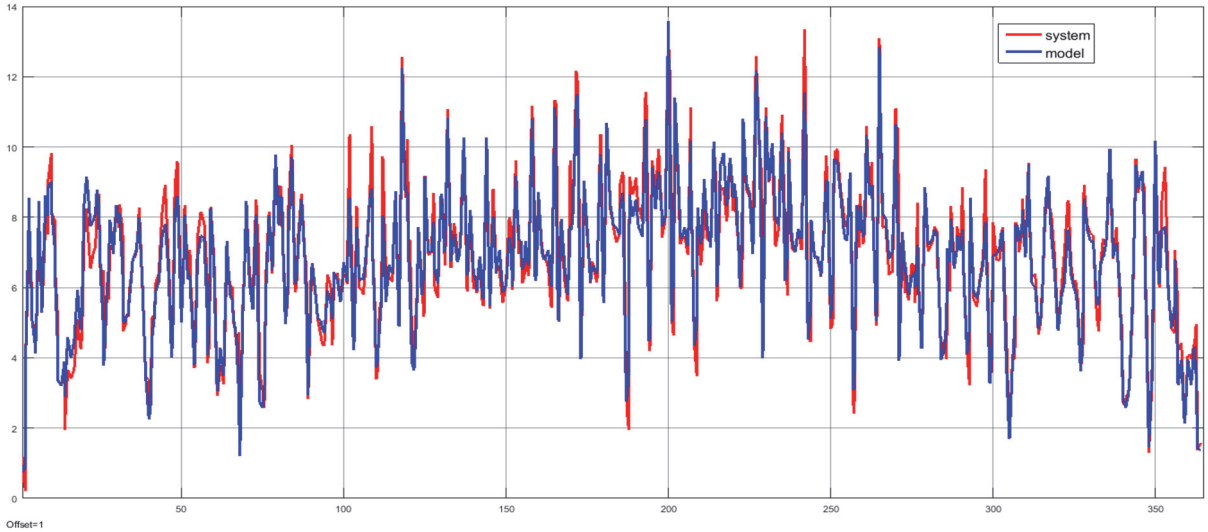

Figure 11. Comparative analysis of model and DAM system robustness at 6:00 a.m. in 2019. Source: Own study in MATLAB and Simulink [6, 15, 24, 29].

Determined relative errors in the case of correcting the TGE S.A. Day-Ahead Market system model using the Artificial Neural Network (ANN) for individual four hours, i.e. for the hours: 6:00, 12:00, 18:00 and 24:00 for 2019 amounted to:

- efficiency of the DAM system model within the range of 4.81% for 6:00 a.m. to 11.72% for 6:00 p.m.,
- effectiveness of the DAM system model ranged from 5.39% for 6:00 a.m. to 12.47% for 6:00 p.m.,
- robustness of the DAM system model ranged from 4.87% at 6:00 to 13.20% at 12:00.

3. Model and system quality assessment

In the case of data used in the identification from 1 January 2016 to 31 December 2019, 24 models of the DAM system of discrete and continuous type were obtained as a result of identification, followed by 24 continuous models in the state space, respectively for the following years: 2016, 2017 , 2018 and 2019.

For a detailed analysis, four models were used for each year, i.e. for the following hours: 6:00, 12:00, 18:00, 24:00, determining for them, among others, relative errors, MAPE errors and the effectiveness, efficiency and robustness of the models and DAM systems using appropriate simulation and comparative models.

The relative errors ranged from 5.39% at 6:00 a.m. in 2019 to 10.54% at 12:00 a.m. in 2019. Moreover, errors were determined for selected months of 2019, which amounted to 3.46% at 6:00 a.m. in December 2019 for the adjusted DAM system model to the value of 13.69% at 12:00 in December 2019 for the DAM system model.

In addition, errors were determined for selected weeks (the first full week of December) of 2019, which ranged from 0.71% at 6:00 in December 2019 for the corrected DAM system model to 14.91% at 12:00 in December 2019 for the DAM system model. Taking into account only working days, they ranged from 2.5209% to 13.92% in a month and from 1.26% to 11.42% in a week.

MAPE errors ranged from 5.39% at 6:00 a.m. in 2019 to 9.55% at 12:00 a.m. 2019. In addition, errors were determined for selected months of 2019, which amounted to 6.57% at 6 a.m. in December 2019, respectively for the DAM system model to the value of 12.21% for 12:00 in December 2019 for the adjusted DAM system model.

Errors were also determined for selected weeks (the first full week of December) of 2019, which ranged from 3.01% at 6:00 a.m. in December 2019 to 11.24% at 12:00 a.m. in December 2019 for the DAM system model . Taking into account only working days, they ranged from 6.15% to 12.49% in a month and from 2.85% to 13.91% in a week.

The determined system and model efficiency values ranged from 6.81% and 6.82%, respectively, for 6:00 a.m. 2019 to 7.91% and 8.01% for 12:00 p.m. 2019, and the model-to-system performance values ranged from 95.79% for 18:00 2019 to 99.50% at 24:00 2019 and system and model robustness values ranged from 6.82% and 6.86% at 6:00 2019 respectively to 8.15% and 8.62% at12:00 2019. Relative errors were also determined for individual four hours, i.e. for the hours: 6:00, 12:00, 18:00 and 24:00 for 2019, which for:

- the effectiveness of the DAM system model adjusted with ANN ranged from 4.81% for 6:00 a.m. to 11.72% for 6:00 p.m.,
- the effectiveness of the DAM system model corrected by ANN was shaped
- within the range of 5.39% for 6:00 a.m. to 12.47% for 6:00 p.m.,
- the robustness of the DAM system model corrected by ANN ranged from 4.87% for 6:00 a.m. to 13.20%. for an hour 12:00.

4. Efficiency testing depending on the volume of electricity

In addition, it was investigated efficiency curves depending on electricity volume for 6:00, 12:00, 18:00 and 24:00 for 2019. The curves obtained are presented in Fig. 12-15.

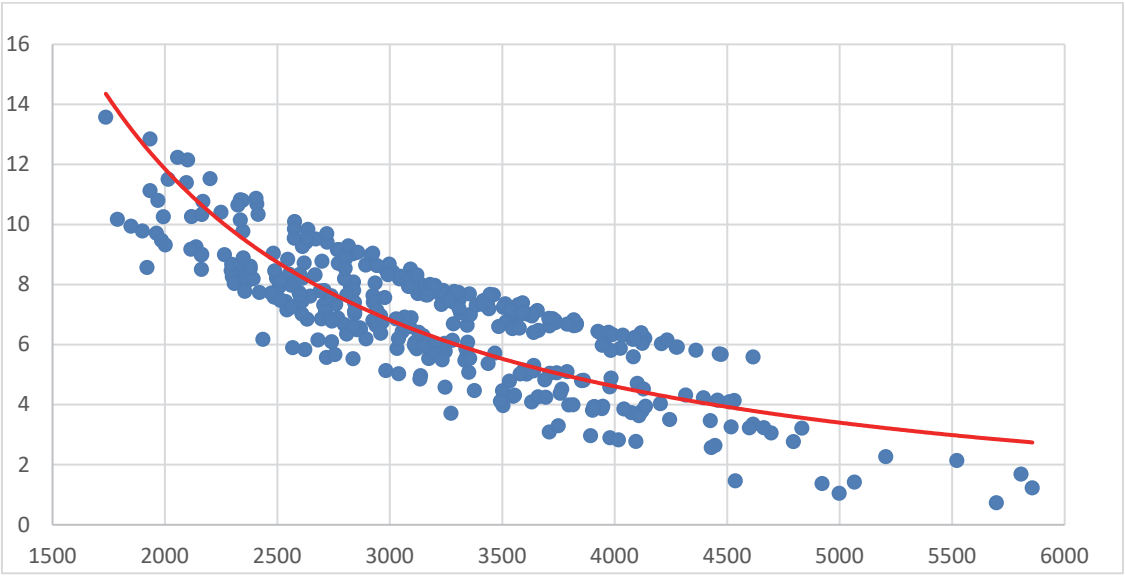

Figure 12. Efficiency depending on ee volume for 6:00 am 2019. Source: Own study in MATLAB and Simulink environment [6, 15, 24, 29].

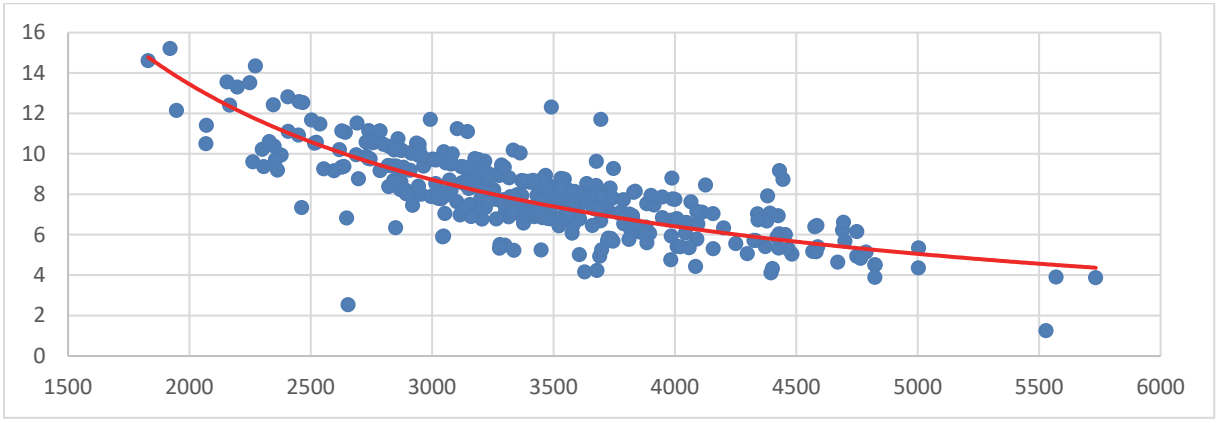

Figure 13. Efficiency depending on electricity volume for 12:00 2019. Source: Own study in MATLAB and Simulink environment [6, 15, 24, 29].

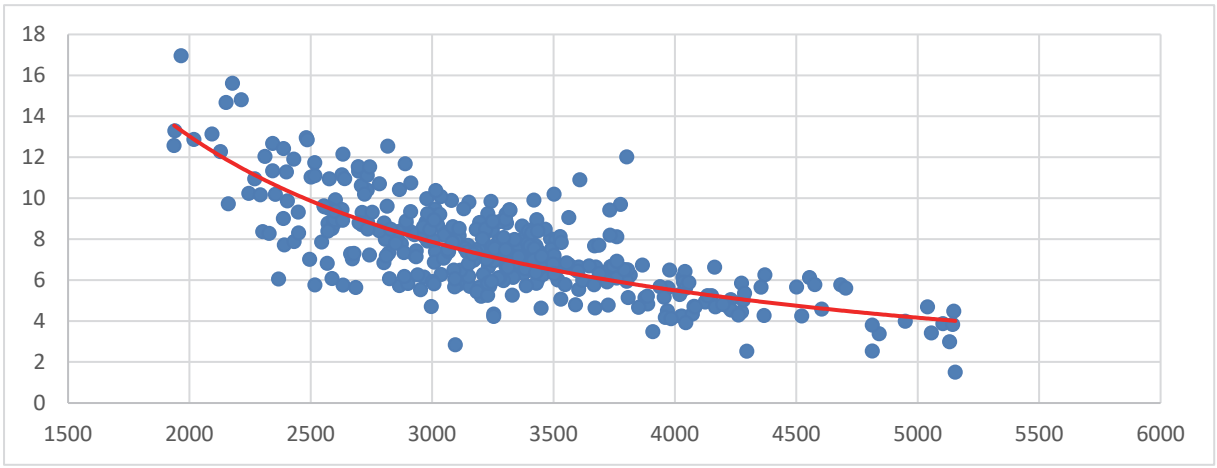

Figure 14. Efficiency depending on ee volume for hours 182:00 2019. Source: Own study in MATLAB and Simulink environment [6, 15, 24, 29].

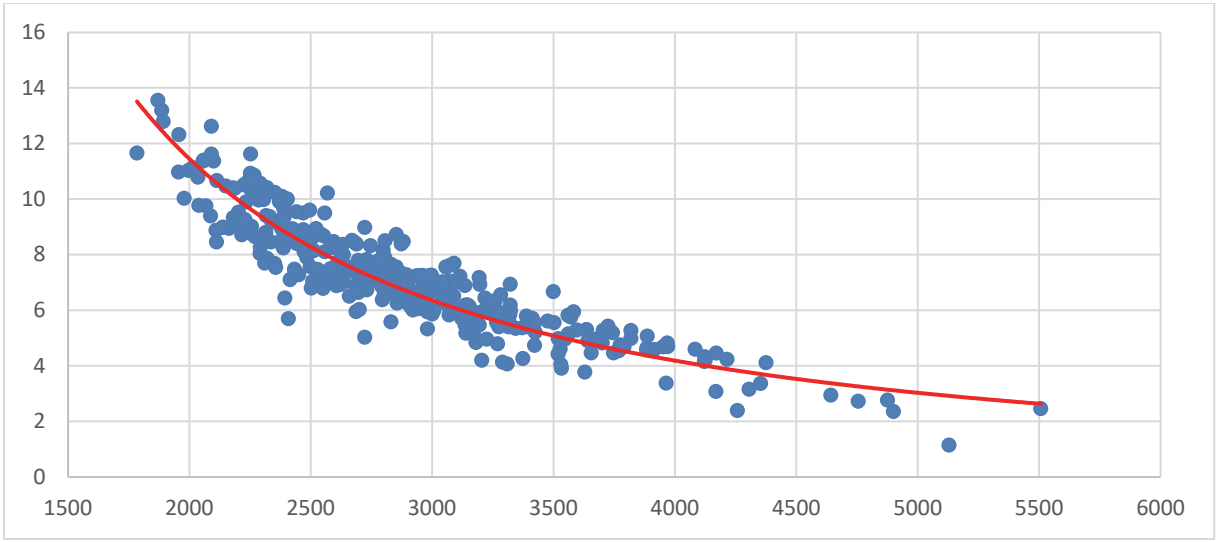

Figure 15. Efficiency depending on ee volume for hours 18:00 2019. Source: Own study in MATLAB and Simulink environment [6, 15, 24, 29].

It can be seen that the increase in the volume of supplied and sold electricity was accompanied by a decrease in the effectiveness of the DAM system model, for the assumed values of the obtained price for supplied and sold electricity and the effectiveness of the system model. The summary of efficiency depending on the electricity volume for the hours: 6:00, 12:00, 18:00 and 24:00 in 2019 is shown in the figure 16.

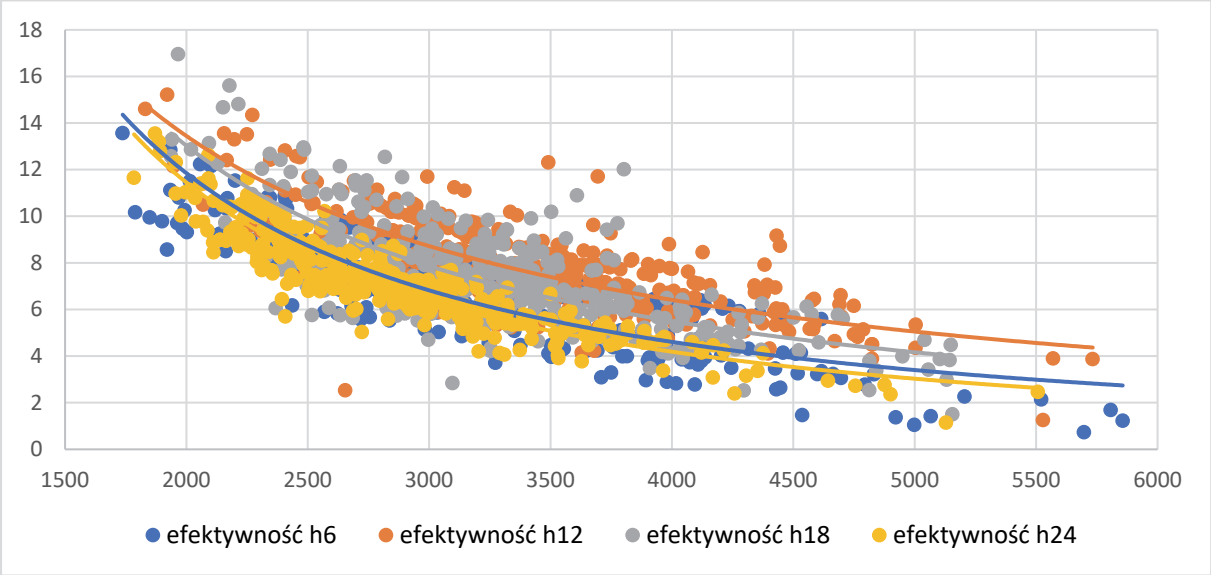

Figure 16. List of efficiency depending on the ee volume for 6:00, 12:00, 18:00, 24:00 in 2019. Source: Own study in MATLAB and Simulink environment [6, 15, 24, 29].

The analysis of power trend lines for the above-mentioned four hours shows, among other things, that the greatest decrease in efficiency occurred at 24:00 and the lowest at 6:00. Individual trend lines of implementation effectiveness are expressed in the following relationships:

$$\Lambda_6 = 373026\ u_6^{-1,363},$$

$$\Lambda_{12} = 45265\ u_{12}^{-1,069}, \tag{4}$$

$$\Lambda_{18} = 167964\ u_{18}^{-1,245},$$

$$\Lambda_{24} = 707966\ u_{24}^{-1,451},$$

which show that the execution efficiency of the DAM system model is inversely proportional to the volume of electricity supplied and sold for the assumed values of the price obtained for the electricity delivered and sold and the effectiveness of the model to the system.

5. Conclusions and directions of further research

The article contains selected results of comparative research on the quality of the TGE S.A. Day-Ahead Market model and system. The research used such quality measures as efficiency, effectiveness and robustness regarding the model and the system, built as part of the simulation model of the TGE S.A. Day-Ahead Market system.

Both the courses of individual quantities, i.e. efficiency, effectiveness and robustness, as well as their average values and absolute and erroneous errors between the model and the system were obtained. The results of general tests on the courses of effectiveness, efficiency and cohesiveness obtained for the hours of 6:00, 12:00, 18:00 and 24:00 are shown, including the results of detailed tests for 6:00 in 2019.

The sensitivity of the obtained waveforms of quality measures of the TGE S.A. Day-Ahead Market and system was also tested. on selected parameters of 2019. The sensitivity of the obtained waveforms of model quality measures and the Day-Ahead Market system to selected parameters was also tested. In this respect, the Simulink library turned out to be a very good implementation tool, especially in the case of the need to constantly expand the hierarchical simulation model to meet new research needs. The presented method of assessing the quality of the model and system on the example of assessing the Day Ahead Market can be used at TGE S.A. to evaluate the functioning of quotations on the Stock Exchange, it can also be used to evaluate other electronic service markets, especially smart city or smart village markets, etc.

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