Radosław MARLĘGA[1]

[1] PhD Student at Computer Science Institute
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 Identification Methods of the Management System of the Day-Ahead Market of Polish Energy Market S.A.

DOI: 10.34739/si.2021.25.04

Abstract. Nowadays, identification and neural methods are used more and more often in modeling IT forecasting systems in addition to analytical methods. Six characteristic models used to forecast the Day-Ahead Market system functioning as a transaction management system at the Polish Power Exchange (POLPX) and the Nord Pool Spot market have been selected for comparative analysis. The research was preceded by a detailed discussion of modern criteria used to assess the quality of model fitting to the system, namely: effectiveness, efficiency, and robustness. In the literature, there are two main groups of system modeling methods, namely time series modeling methods and identification modeling methods, including neural modeling methods. Modeling usually results in such models as parametric models and artificial neural networks learned neural models of the Day-Ahead Market, as well as time series models, among others. In the comparative analysis, special attention was paid to the accuracy of the obtained models concerning the system. It has been pointed out that the studied solutions used to measure the accuracy of modeling criteria such as accuracy of fit or efficiency, and did not use the modeling efficiency, which is very important in IT forecasting systems for such large markets as the Day-Ahead Market of POLPX. The search for the best market models, including identification models of the Day-Ahead Market operation that can be used in electricity price forecasting is a very important issue both from the point of view of algorithmic solutions and economical solutions.

Keywords. Artificial Neural Network, Business Intelligence, Day Ahead Market, Identification Methods, Information System in Management, Parametrical Models, Polish Energy Market

1. Introduction

In the process of system testing, the system model, including the Day-Ahead Market (DAM) system model as a management system, which operates at the Polish Power Exchange (POLPX), is increasingly used. (TGE S.A.) [31], conducting research experiments on it instead of conducting them on the real system. The primary reasons for using the model rather than the system include the rationale of looking for cost reduction or obtaining research results in situations that are impossible to perform on the real system [21-23].

Nowadays, there are many modeling methods that can be used, including analytical modeling methods, identification modeling methods, as well as modeling methods using artificial neural networks (neural modeling methods), and time series modeling methods. Moreover, there should be underlined that up to now most widely used is the fourth group of methods, the so-called analytical modeling methods, which are methods that use the laws that govern systems, physical laws, economic laws, biological laws, etc. [23].

Unfortunately, it is not always possible to describe a system with a model constructed using analytical models, especially in the conditions of designing and implementing not only a numerical database but also a document database [2, 23].

This was the reason for the search for new methods possible on the basis of data that can be measured in an active or passive experiment conducted on a real system such as the Day-Ahead Market system. On this basis, over time a new group of modeling methods emerged, which were called identification modeling methods (or simply the identification of systems, processes, objects) [21-23].

Nowadays, in addition, the third group of modeling methods called neural modeling is used, which are created using artificial neural networks taught to the system model (so-called neural methods) [21-25].

Thus, following the work [23], the above-mentioned three basic groups of system modeling methods are distinguished, namely: analytical modeling, identification modeling (identification of systems, processes, objects, etc.), and neural modeling (design of artificial neural networks).

From the point of view of the obtained results, which are the models of DAM systems, identification of systems is a branch of modeling of systems, including dynamic systems, in which the system model is created based on knowledge of experimental data, whereas, among others, in the work [21] identification of systems is included as a branch of modeling of dynamic systems distinguishing two ways of construction of system models: mathematical modeling as an analytical approach and identification of systems as an experimental approach.

Identification modeling is used when analytical modeling is not feasible or the resulting models are too complex [21-23]. In the case of searching for a model of the Day-Ahead Market system as a management system operating at the POLPX, the accepted way to obtain a model of the system is through various parametric identification methods, using methods such as ar, arx, armax, arima [4, 21] and even this type such as GARCH [29].

Therefore, searching for the best market models, including identification models of the Day-Ahead Market operation which can be used in electricity price forecasting is a very important issue both from the point of view of algorithmic solutions and economical solutions. However, this requires the development of a new criterion which is the criterion of robustness that combines a specific balance between effectiveness and efficiency.

For the reasons mentioned above, this paper pays particular attention to the discussion of the essence of the solidity criterion and its relations with the effectiveness and efficiency criteria as well as to the concept of resources, which in the case of the Day-Ahead Market system are the resources of electricity delivered for sale.

Moreover, the literature review shows that the solidity criterion is not used in the evaluation of the Day-Ahead Market system models used for forecasting.

2. Effectiveness and efficiency criteria in systems modeling

2.1. Effectiveness models

On the one hand, the literature lacks generally accepted criteria for measuring the degree of model-system fit, such as the criterion of systems effectiveness, among others. Nevertheless, on the other hand, the following models are distinguished [9, 23-25]:

– **system-resource model**, which should focus on the extent to which the management system is able to provide and influence the DAM management system with the needed resources, which in the considered experiment is the volume of electricity delivered for sale in particular hours of the day,

– **a model concerning the internal organization of the management system, i.e. it's functioning from the point of view of internal processes**, which takes into account internal organization subsystem, management subsystem, and executive subsystem, of which the DAM TGE S.A. system is composed as a management system,

– **system-target model**, which concentrates on the degree, to which the DAM system of the POLPX will achieve the assumed goals, and so it will achieve the result in form of appropriate average price weighted by volume of electricity delivered and sold on the DAM in each separate hour of the day.

Each of the previously mentioned models focuses on different aspects of the operation of the management system, with the appropriate approach for the system models identified in this thesis being the solution of the objective approach, which focuses basically on the outcome, that is, the volume-weighted average electricity price achieved.

In doing so, it is assumed that there is a close relationship between efficiency and effectiveness in any model of the DAM system, e.g., as shown behind the work [9, 25] in Fig. 1.

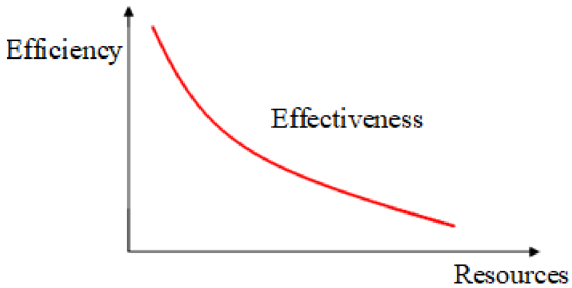

Figure 1. Effectiveness is the relationship between efficiency and system resources, that is, information on the volume of electricity delivered and sold in each hour of the day [MWh]. Source: [9, 25].

2.2. DAM system performance model

It has been assumed that we are dealing with the realization effectiveness of the system [23] reduced, following the work of K. Halicka [7] to the ratio of the effect, which is the average volume-weighted price of delivered and sold electricity, obtained separately at each hour of the day on a given day, retrieved from the DAM system model concerning the corresponding average electricity price obtained from the DAM system of the POLPX, expressed as follows:

$$\Gamma_{ms}(K,t) = \frac{DF_m(K,\theta,t)}{DF_s(K,\theta,t)}, \quad (1)$$

where:

$DF_m(K,\theta,t)$ – modelling result as an average price obtained in given hour of the day for delivered and sold electricity obtained from the DAM management system model,

$DF_s(K,\theta,t)$ – assumed target, that is average price obtained during given hour of the day for electricity delivered and sold, obtained during the quotation process by the right of real transactions entered into on the DAM as the management system.

In such an approach the modeling effectiveness is reduced to the degree of the approach of the output from the model to the output from the DAM management system, and so - in the experiment under consideration - to the average price quoted at a given hour of the day on a given day, and so the effectiveness is such thing, what is specified degree and precision leads to the effect intended as the goal, that is the measure of effectiveness is the degree and precision of approaching the goal, what finally means that in this criterion the cost of functioning of the DAM management system is not taken into consideration, but the predictable effects obtained from the management system model.

In the considered Day-Ahead Market system of POLPX, there is the realization effectiveness indicator, called also the technological (e.g. power) effectiveness indicator, which can be written after Robert Staniszewski [21] as a quotient of $DFs(K,\theta,t)$ and $IFs(K,\theta,t)$ functions, which determines technical and economic effectiveness of the process of operation and development of the DAM management system [MWh/PLN] in the following form [23]:

$$\Lambda_s(K,\theta,t) = \frac{DF_s(K,\theta,t)}{IF_s(K,\theta,t)}, \tag{2}$$

where:

$DF_s(K,\theta,t)$ – output variable as a stream of decision-making potential (decision-making input utility function) expressed as a volume-weighted average price for delivered and sold on the DAM on a given day (θ) in a given hour of the day (t), characterizing the effort function of the DAM system as a management system, representing the economic side of the process of DAM operation and development [PLN/MWh],

$IF_s(K,\theta,t)$ – the input variable as a stream of information potential of the management system collateral type: information income characterizing the management process from the technical point of view and determining in the informative way the technical (energetic) value of functioning and development of the DAM management system, that is delivered and sold on given day (θ) and in given hour of the day (t) electricity [MWh].

The notion of execution efficiency, recognized also as technological (e.g. power) efficiency of operations and development of the DAM management system of the POLPX, despite many definitions of the very notion of efficiency in the literature of the subject, has not lived to see an unambiguous definition in the theory of systems, including in the scope of management issues. One of its definitions has been proposed in the work of J. Tchórzewski [23] as technological (energy) effectiveness, the concept of which has been used to define the technological effectiveness of the DAM system as a management system.

Thus, it has been further assumed that technological effectiveness is a ratio of a measured effect (achieved value of the volume-weighted average price obtained for electricity delivered and sold in a given hour of the day) to a measured input, i.e. delivered and sold ee to consumers as incurred by the DAM management system (output from the DAM system model) [23].

2.3. Concepts of efficiency, effectiveness and cohesiveness

Besides the notion of effectiveness introduced in item 2.2. it is also possible to speak about execution effectiveness during the whole period of the experiment being tested, that is about the ratio of the difference between the value obtained from the ee volume sold in a given hour of the day on the last day of the tested period (average price times the volume) and in a given hour of the day on the first day of the tested period in relation to the inputs, that is in relation to the delivered and sold ee volume during the aforementioned period of the experiment conducted on the DAM.

Because of the accepted settlements on the DAM, the electricity sold is the electricity delivered for sale. Therefore the statement that firstly the effectiveness of realization of the obtained model should be researched in relation to the system as the function of resources, which in the considered case is the information about electricity delivered and sold at each hour of the day, and then the effectiveness of realization of the management system, which - after determination of the DFs variable from formula (1) and after substitution into formula (2) can be reduced to the following form [25]:

$$\Lambda_s(K,\theta,t) = \frac{1}{\Gamma_{ms}(K,\theta,t)} \cdot \frac{DF_m(K,\theta,t)}{IF_s(K,\theta,t)}. \tag{3}$$

Thus, in the case of an increase in the volume of electricity delivered in a given hour of the day in the DAM, and thus in the case of an increase in the value resulting from the variable IFs(K,θ,t), maintaining the weighted average price for electricity delivered and sold in the DAM (DFs(K,θ,t) = const) is associated with a decrease in realization efficiency under the assumption that the realization efficiency of the model to the DAM system is kept constant, i.e. $\Gamma_{ms}(K,\theta,t) = \text{const}$.

At the same time, it should be pointed out that the execution effectiveness is highly dependent on the management system models, and therefore modeling of those systems is extremely important in case of conducting transactions on the DAM [7, 25].

Assuming further that:

$$\Lambda_s \Gamma_{ms} = \frac{DF_m(K,\theta,t)}{IF_s(K,\theta,t)}, \tag{4}$$

shall be obtained:

$$DF_m = \Lambda_s \Gamma_{ms} IF_s(K,\theta,t), \tag{5}$$

and denoting that:

$$\Xi_{ms} = \Lambda_s \Gamma_{ms} \tag{6}$$

is cohesiveness in the sense of a specific balance between efficiency and effectiveness [24], one can obtain a catalog of runs of the solidification index as a function of information about the volume of electricity delivered and sold in the DAM IFs(K,θ,t) for different values of the decision DFm(K,θ,t) expressed as a volume-weighted average of the price of electricity delivered and sold in individual hours of the day.

Thus, ultimately, the cohesiveness index (shorter: cohesiveness) can be expressed as follows after the work [25]:

$$\Xi_{ms} = \Lambda_s \Gamma_{ms} = \frac{DF_s(K,\theta,t)}{IF_s(K,\theta,t)} \cdot \frac{DF_m(K,\theta,t)}{DF_s(K,\theta,t)} = \frac{DF_m(K,\theta,t)}{IF_s(K,\theta,t)}, \tag{7}$$

and so as the ratio of the average price decision, obtained on the grounds of the model, weighted by the volume of electricity delivered and sold on the DAM TGE S.A. during each hour of the day regarding the information about the volume of electricity delivered and sold during each hour of the day, recorded in the actual management system on the DAM TGE S.A. or - in case of price forecast - the forecast price.

3. Comparison of selected price forecasting methods

For the comparative study of the Day-Ahead Market system models, there has been made a purposeful selection of six works which are the most adequate to the essence of the investigated issue of the DAM system modeling, chosen from the available and not very rich literature on the subject [1, 4, 5-8, 11-15, 18-20, 27-28, 30].

In the comparative studies, the criteria cited in sections 2 and 3 were used, first of all, that is, the criteria of efficiency, effectiveness, and robustness, in addition to the general criterion of model fit to real data or the system. The results are summarized in Table 1 [6-7, 19-20, 30].

The comparative analysis of the six modeled systems (Day-Ahead Market and the Nord Pool Spot) shows, among other things, that the modeling is characterized by the following regularities:

1) there are two main groups of modeling methods, one using time series of prices, that is: multiplicative Holt-Winters model developed by J. Ejdys, K. Halicka and J. Godlewska [6], Winters, Holt and creeping trend models with harmonic weights proposed by T. Poplawski and M. Wężgowiec [18], models, among others: SARIMA, SARIMA and GARCH proposed by S. Voronin [30], and the second using identification modeling, including neural modeling, that is, obtained neural models based on Perceptron Artificial Neural Network with different number of input neurons proposed by K. Halicka [7] and D. Rucinski [19-20],
2) different length and detail of data used in modeling is assumed, including time measured in hours, days, weeks (full or excluding weekends and holidays), etc. [6-7, 18-20, 30] due to the need for the modeling to take into account the relationship between the length of the study period and the forecasting period,
3) the length and detail of data used in modeling is assumed to vary, including time measured in hours, days, weeks (full or excluding weekends and holidays), etc. [6-7, 18-20, 30],
4) different forecasting horizons (in hours) are assumed, including day, week, month [6-7, 18-20, 30],
5) the metrics used to measure the fit of the model to the system (to real data): fit accuracy (quality) and effectiveness [6-7, 18-20, 30],
6) the forecasting errors obtained, including Mean Error (ME), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), Median Absolute Percentage Error (MdAPE),
7) modeling support environment used: Statistica, MATLAB, and Simulink as well as custom programs used in modeling, etc.

Thus, from the point of view of the modeling method used, various types of models of the POLPX Day Ahead Market system were obtained, including among others:

– forecasting models obtained on the basis of time series concerning prices quoted on the DAM [3, 6, 18],

– identification modeling models, including neural modeling, obtained on the grounds of different input and output quantities, both concerning prices as well as the volume of electricity delivered and sold on the DAM, and also other factors (especially those used as input quantities), including economic, climatic, etc. [6-7, 18-20, 30].

As far as the selection of the Artificial Neural Network type (ANN) and the length of the modeled period are concerned, the relevant research has been carried out by D. Ruciński, who in his works [19-20] has presented the results of neural modeling of the Day-Ahead Market system of the Polish Power Exchange (POLPX) using the numerical data concerning the fixed time intervals from one month, through the quarter and half-year period to annual and multi-year periods and the whole period of POLPX S.A. functioning (years 2002-2020).

The neural modeling of the Day-Ahead Market has been carried out based on three models of artificial neural networks, i.e: Perceptron Artificial Neural Network (so-called Multi-Layer Perceptron), Recurrent ANN, and Radial ANN. As a result of neural modeling, 1,191 DAM models were obtained and evaluated according to the criterion of least error MSE and according to the determination index R2 [19-20].

It turned out that the best neural model of the Day-Ahead Market that can be used in forecasting studies is the Perceptron Artificial Neural Network, and the best neural modeling ranges in terms of value and variability were time intervals close to mid-year for the Perceptron ANN, in which the MSE error ranged from 0.006723 to 0.001065 and was slightly smaller for the same time intervals and ranged from 0.006723 to 0.00025243 for the Recurrent ANN, which supports the adoption of the Perceptron ANN for neural modeling of the POLPX DAM [19-20].

The obtained mean values of the MSE index were respectively for the model:

1) containing one factor i.e. demand: 2.691*10-5.
2) containing all factors i.e. energy demand, economic factors such as, inflation level, debt level, government expenditure balance, money supply and environmental factors such as temperature, humidity, cloud cover and wind strength: 2,200*10-5.
3) containing economic factors: 5,344*10-5.
4) containing weather factors: 5,018*10-5.
5) containing weather factors and selected economic factors i.e. balance of state spending: 1,909*10-5.

While the coefficient of determination R2 was respectively for the model:

1) containing one factor, i.e. demand: 0.789.

2) containing all factors, i.e. energy demand, economic factors such as inflation, debt level, balance of government expenditure, money supply and environmental factors such as temperature, humidity, cloud cover and wind power: 0.832.

3) containing economic factors: 0.493.

4) containing weather factors: 0.538.

5) containing weather factors and selected economic factors i.e. balance of government spending: 0.856.

Table 1. Results of a comparative modeling study of the Day-Ahead Market system. Labels in the text. Source: Own elaboration based on work [6-7, 18-20, 30].

Authors/ Title of book/ article	**Modeled system/object/system/process/etc.**	**Type of modeling, including identification/prediction methods used**	**Data used for modeling (input/output/periods, etc.)**	**Forecasting horizon**	**Fitting the model to the system (to real data)**	**Metrics used**	**Obtained forecasting results (including types of errors and their values)**	**Comments, including those regarding the computing environment**
1	2	3	4	5	6	7	8	9

1.	1. J. Ejdys, K. Halicka, J. Godlewska/ Forecasting electricity prices on the power exchange [38]
2.	Day-Ahead Market of POLPX
3.	The forecasting model consists of a multiplicative Holt-Winters model for the time series with a development trend and for seasonal fluctuations - Artificial Neural Network - Multilayer Perceptron
4.	The data for modelling were derived from the DAM quoted in the single price fixing system 1 From the period from January 1, 2012 to April 30, 2013. (16 months). Data for testing from 24.04.2013 to 30.04.2013(7 days), time series price data for electricity was used
5.	One day (1.05.2013)
6.	Quality (learning) 0.938556 Quality (testing) 0.950492 Error (learning) 87.0137 Error (testing) 88.9143[4]
7.	Accuracy of matching results to data
8.	For Holt-Winters model: ME -0.75 PLN, MAE 59.39 PLN, max AE 1004.35 PLN, MAPE 37.32%, RMSE 76.44 PLN, MdAPE 30.48%, max APE 282.12%, For Multilayer Perceptron: ME -0.02 PLN, MAE 7.93 PLN, max AE 300.05 PLN, MAPE 4.71%, RMSE 13.12 PLN, MdAPE 3.07%, max APE 50.03%,
9.	STATISTICA programming environment

[4] In the article, the units of measurement are not given. In the first case, it is a non-variable value, in the second case, the unit is [PLN].

1.	2. T. Popławski , M. Weżgowiec Short-term price forecasts on the Polish Power Exchange using the crawling trend model [109]
2.	Day-Ahead Market of POLPX
3.	Winters model, Holt model, Creeping trend model with harmonic weights
4.	Data from April, May and June 2012 (91) in hourly excluding weekends and holidays (61 days), Electricity price data collated into time series were used
5.	Five consecutive days hour after hour
6.	Mean APE error [%]: Winters model: Additive 10.33 Multiplicative 5.89 Holt model: Model1 5.10 Model2 4.93 Creeping trend for[5] : k = 3 4.74, k = 4 4,61 k = 5 4,53 k = 6 4,5
7.	Matching accuracy
8.	MAPE mean error [%]: Winters model: Additive 4.51 Multiplicative 7.01 Holt model: Model1 2.98 Model2 3.17 Creeping trend for: k = 3 3.07, k = 4 2,69 k = 5 2,4 k = 6 2,14
9.	The analysis shows that energy prices quoted on the Day-Ahead Market are highly variable, which makes their forecasting a difficult task. It is difficult to find methods referring to this problem in the literature. The research shows that the price distributions are not normal, but show the stationarity of their processes. Periodicities corresponding to 24 and 12 hours were detected. Based on the test for stationarity and the analysis of autocorrelation ACF and partial autocorrelation, PACF one may also try to apply to forecasting prices ARMA/ARIMA class models. The performed analyses are helpful to define appropriate parameters of the mentioned models. Thus, the authors leave an open path as to the application of ARMA/ARIMA class models in forecasting prices at POLPX.

[5] k - smoothing parameter (from value 3 to 6)

1.	3. K. Halicka The effectiveness of forecasting in energy exchange transaction management [46]
2.	Day-Ahead Market of POLPX Balancing Market
3.	Artificial Neural Network - Multilayer Perceptron (with one or two hidden layers), MISO models: model I (10 neurons input layer, 1 neuron output layer),), model II (7 neurons input layer, 1 neuron output layer
4.	The data used to build the models came from from the period from 01.01.2004 to 31.12.2004. (8,760 cases)
5.	Data from 01/01/05 to 31/01/05 (744 cases) were used to test the predictive ability of the model
6.	The average deviation of energy price forecasts from actual values in January 2005 is about 3.60 PLN, which is about 2.61% of the forecast variable. The maximum difference between the actual and forecast value was PLN 13.76
7.	Effectiveness[6] (purchase 0.91, sale 0.95)
8.	I ANN Model ME -0.57 PLN MAE 4.06 PLN maxAE 14.96 PLN RMSE 5.50 PLN MAPE 3.69% MdAPE 2.74% maxAPE 61.77% , II ANN Model ME -0.14 PLN, MAE 3.70 PLN, maxAE 17.90 PLN, RMSE 5.06 PLN, MAPE 3.35%, MdAPE 2.44%, maxAPE 44.23%, (detailed results in the text)[7]
9.	Statistica 6.0.

[6] The units are not given in the paper, these are the unmeasured values

[7] Results of evaluating model fit to real data in different MLP-type SSN architectures for Model II by K. Halicka [46]. MLP 7:168-7-1:1: ME -0.22 PLN, MAE 4.93 PLN, maxAE 18.85 PLN, RMSE 6.89 PLN, MAPE 4.50%, MdAPE 3.11%, maxAPE 63.69%,MLP 7:168-30-5-1:1: ME 0,21 PLN, MAE 2,72 PLN, maxAE 12,95 PLN, RMSE 3,75 PLN, MAPE 2,47%, MdAPE 1,83%, maxAPE 39,48%, MLP 7:168-30-6-1:1: ME -0,14 PLN, MAE 3,70 PLN, ,maxAE 17,90 PLN, RMSE 5,06 PLN, MAPE 3,35%, MdAPE 2,44%, maxAPE 44,23%.

1.	4. S. Voronin Price spike forecasting in a competitive day-ahead energy market [140]
2.	Nord Pool Spot, The Finnish day-ahead electricity market
3.	SARIMA model SARIMA+GARCH models, MR MR no seas, MR no r/s, ARMA(2,1), GARCH(1,1) no r/s, ARMA(2,1)+GARCH(1,1) SARIMA(1,1,1)(1,1,1) no seas, all models include 24 hours
4.	Real-time hourly electricity prices from 16/09/2009 to 21/11/2009. The entire data set is divided into training (60 days) and test (7 days) sets from November 15, 2009 to November 21, 2009
5.	2010
6.	Original SARIMA (1,1,1)((1,7),1,1) MAPE [%] 5.83, Original SARIMA(1,1,0)(7,1,1) + GARCH(1,1) MAPE [%] 4.62 Adjusted SARIMA(1,1,1)((1,7),1,1) MAPE [%] 4.05 Adjusted SARIMA(1,1,0)(7,1,1)+GARCH(1,1) MAPE [%] 3.65
7.	Accuracy of price matching, including price spikes
8.	MAPE[%], MR 15.57, MR no seas. 38.15, MR no r/s. 24.35, ARMA(2,1) 13.74, GARCH(1,1) no r/s. 16.17, ARMA(2,1)+GARCH(1,1) 12.84 SARIMA(1,1,1)(1,1,1)24 no seas. 17.81
9.	It was shown that Box-Jenkins models were unable to estimate the high volatility and clustering peaks presented in the original price series

1.	5. D. Ruciński: The Influence of the Artificial Neural Network type on the quality of learning on the Day-Ahead Market model at Polish Power Exchange joint-stock company [19]
2.	Day-Ahead Market of POLPX
3.	Perceptron Artificial Neural Network, Recurrent Artificial Neural Network, Radial Artificial Neural Network
4.	Years 2002-2020 (MIMO models, 24 x 24)
5.	The experiments involved different horizons from a month, to a quarter and a year, etc. Using a simulation model
6.	Note: The results obtained, which relate to a number of factors that influence the system model, are presented in the text
7.	Matching model to system t
8.	MSE and R^2 for different factors are given in the text
9.	MATLAB and Simulink environments

1.	6. R. Marlęga: State-space model and implementation Polish Power Exchange in MATLAB and Simulnk environments [12], R. Marlęga, J. Tchórzewski: Identification modeling of Polish electric power exchange [13]
2.	Day-Ahead Market of POLPX
3.	Arx model, neural model (Perceptron Artificial Neural Network)
4.	Data for identification from 2002-2020
5.	Month, quarter, half year, year
6.	Obtained model fit to the system (real data)
7.	Efficiency , Effectiveness, Cohesiveness
8.	MAPE [%], 2019 hour 6 - 0.75601, 12 - 1.082227, 18 - 0.62989, 24 - 0.895718
9.	MATLAB and Simulink environments using System Identification Toolbox and Neural Networks Toolbox

4. Final remarks

Nowadays, in the modeling of IT forecasting systems, apart from analytical methods, identification and neuronal methods are used more and more often. Four characteristic modeling methods used for modeling the Day-Ahead Market system functioning as a transaction management system at the Polish Power Exchange and the Nord Pool Spot market have been selected for comparative analysis.

The research has been preceded by a detailed discussion of modern criteria used for quality assessment of the model fitting to the system, namely: efficiency, effectiveness, and robustness criteria. There are two main methods of modeling systems in the literature, that is, time series modeling and identification modeling, including neural modeling. Modeling usually results in models such as parametric models and artificial neural networks learned neural models of the Day-Ahead Market, among others.

In the comparative analysis, special attention was paid to the accuracy of the obtained models to the system. It has been pointed out that in the investigated solutions the following criteria have been used to measure the modeling accuracy: accuracy of fit or efficiency, but the modeling efficiency which is very important in IT forecasting systems for such large markets as the Day-Ahead Market of POLPX has not been used.

A comparative analysis of models used in electricity price forecasting shows that the most frequently used criterion is the criterion of the accuracy of model fitting to the system, strengthened by the criterion of effectiveness or efficiency. Therefore, an attempt was made to develop a synthetic index combining all three above-mentioned criteria, which was called the solidity criterion. As the solidification criterion evaluates models well concerning the system, Table 1 also includes our research results, which are continued. An important algorithmic and economic issue already undertaken and to be solved is the need to obtain a family of solidification characteristics as a function of volume for different periods and hours.

References

1. Aggarwal S.K., Saini L.M., Kumar A. Electricity price forecasting in deregulated markets: A review and evaluation, International Journal of Electrical Power & Energy Systems, No. 31/2009, pp. 13-22.

2. Barczak A., Barczak M.: Projektowanie i implementacja bazy dokumentów (English: Design and implementation of a document database), Wydawnictwo Uczelniane, UPH, Siedlce 2020, pp. 126

3. Box G. E. P., Jenkins G. M.: Analiza szeregów czasowych. Prognozowanie i sterowanie (English: Time series analysis. Forecasting and control). PWN, Warszawa 1983.

4. Conejo A. J., Plazas M. A. , [et all]: Day-ahead electricity price forecasting using the wavelet transform and ARIMA models. IEEE Transaction on Power System, No. 20(2)/2005, pp.1035–1042.

5. Dash S.K., Dash K.P.: Short-term mixed electricity demand and price forecasting using adaptive autoregressive moving average and functional link neural network, Journal of Modern Power Systems and Clean Energy, No. 7(5)/2019, pp. 1241–1255.

6. Ejdys, Halicka K., Godlewska J.: Prognozowanie cen energii elektrycznej na giełdzie energii (English: Forecasting electricity prices on the power exchange). Zeszyty Naukowe Politechniki Śląskiej, Seria: Organizacja i Zarządzanie, Z. 77, Nr 1927, ss. 1-10.

7. Halicka K.: Skuteczność prognozowania w zarządzaniu transakcjami na giełdzie energii (English: Effectiveness of forecasting in managing transactions on the power exchange). Rozprawa doktorska pod kierunkiem (English: doctoral dissertation under the supervision of) prof. dr hab. inż. Joanicjusza Nazarko, Wydział Zarządzania UW, Warszawa 2007.

8. Jiang L.L., Hu G.: Day-Ahead Price Forcasting for Electricity Market using Long-Short Term Memory Recurent Neural Network. 2018 15th International Conference on Control, Automation, Robotics and Vision (ICARCV), Singapure, Nov. 19-21, IEEE Digital Library, pp. 949-954.

9. Kowal W.: Skuteczność i efektywność – zróżnicowane aspekty interpretacji (English: Effectiveness and efficiency - various aspects of interpretation). Kwartalnik Naukowy pt. Organizacja i Kierowanie. Nr 4(157), SGH, Warszawa 2013.

10. Labib N., Wadid E.: Comparative study of Intelligent Systems for Management of GIT Cancers, MATEC Web of Conferences 125, 02063 (2017, CSCC 2017, pp. 1-6, 2017.

11. Mandal P., Senyju T. [et all]: A Novel Approach to Forecast Electricity Price for PJM Using Neural Network and Similar Days Method, IEEE Transactions on Power Systems, 22(4)/2007, pp. 2058 – 2065.

12. Marlęga R.: State-space model and implementation Polish Power Exchange in MATLAB and Simulnk environments. Information Systems in Management. Vol. 6, No. 4/2017, pp. 294-308.

13. Marlęga R., Tchórzewski J.: Identification modeling of Polish electric power exchange, Information Systems in Management, No. 2, Vol. 5/2016, pp. 195-204.

14. Mandal P., Haque A.U., Meng J., Srivastava A.K., Martinez R.: A Novel Hybrid Approach Using Wavelet, Firefly Algorithm, and Fuzzy ARTMAP for Day-Ahead Electricity Price Forecasting, IEEE Transactions on Power Systems, Vol. 28. No. 2, pp. 1041-1051, May 2013.

15. Merayo D., Rodriguez-Prieto A., Camacho A.M.: Comparative analysis of artificial intelligence techniques for material selection applied to manufacturing in Industry 4.0, Procedia Manufacturing No. 41/2019, pp. 42-49.

16. Moghaddam R.K., Yazdan N. M.: A Comparative Analisis of Artificial Intelligence – Based Methods for Fault Diagnosis of Mechanical Systems, Mechanics and Mechanical Engineering, No. 23/2019, Sciendo, pp. 113-124.

17. Mynarski S.: Modelowanie rynku w ujęciu systemowym (English: System modeling of the market). PWN, Warszawa 1982, stron182.

18. Popławski T., Weżgowiec M.: Krótkoterminowe prognozy cen na Towarowej Giełdzie Energii z wykorzystaniem modelu trendu pełzającego (English: Short-term price forecasts on the Polish Power Exchange using the crawling trend model). Przegląd Elektrotechniczny, R. 91, Nr 12/2015, ss. 267-270.

19. Ruciński D.: The Influence of the Artificial Neural Network type on the quality of learning on the Day-Ahead Market model at Polish Power Exchange joint-stock company. Studia Informatica. Systems and Information Technology. No. 1-2 (23)2019, pp. 77-93.

20. Ruciński D.: Neural modeling of electricity prices quoted on the Day-Ahead Market of TGE S.A. shaped by environmental and economic factors. Studia Informatica. Systems and Information Technology. No. 1-2 (24)2020, pp. 25-36.

21. Staniszewski R.: Sterowanie procesem eksploatacji (English: Control of the operation process). WNT, Warszawa 1988, stron 475.

22. Tchórzewski J.: Cybernetyka życia i rozwoju systemów (English: Cybernetics of life and systems development). WSRP, Siedlce 1992, stron 408.

23. Tchórzewski J.: Rozwój system elektroenergetycznego w ujęciu teorii sterowania i systemów (English: Development of the power system in terms of control theory and systems). OW PWr, Wrocław 2013, stron 190.

24. Tchórzewski J.: Metody sztucznej inteligencji i informatyki kwantowej w ujęciu teorii sterowania i systemów (English: Methods of artificial intelligence and quantum computing in terms of control theory and system). Wydawnictwo Naukowe UPH, Siedlce 2021, stron 343.

25. Tchórzewski J. and Marlęga R.: The Day-Ahead Market System Simulation Model in the MATLAB and Simulink Environment, 2021 Progress in Applied Electrical Engineering (PAEE), 2021, pp. 1-8.

26. Tchórzewski J., Marlęga R.: Modeling and simulation of the control- and the systems-inspired of the Polish Electricity Exchange, 2017 Progress in Applied Electrical Engineering (PAEE), Kościelisko, IEEE Digital Library, pp. 1-6, 2017.

27. Tchórzewski J., Marlęga R., The Management System of the Polish Electricity Exchange from the Viewpoint of the Control and Systems Theory,16th International Conference on the European Energy Market (EEM), Ljubljana, Slovenia, IEEE Xplore Digital Library, 2019, pp. 1-5.

28. Tchórzewski J., Ruciński D.: Modeling and simulation inspired by quantum methods of the Polish Electricity Stock Exchange, Progress in Applied Electrical Engineering, Kościelisko, 2017, pp. 1-6.

29. Trusz M., Tserakh U.: GARCH(1,1) models with stable residuals. Studia Informatica. Systems and Information Technology. No. 1-2(22)2017, pp. 47-57.

30. Voronin S.: Price spike forecasting in a competitive day-ahead energy market. Acta Universitatis, Lappeenrantaensis 530, pp. 9-177.

31. www.tge.pl – the website of Towarowa Giełda Energii S.A. [access: 2016-2021].