

IDENTIFICATION MODELING OF POLISH ELECTRIC POWER EXCHANGE

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This paper contains selected results of identification modeling of Polish Electric Power Exchange (EPE). In order to obtain EPE system model it was performed identification based on figures of EPE's Day-Ahead Market. During performing identification process, parametric arx model in System Identification Toolbox environment was utilized. Generated EPE parametric model has been further used for performing simulation tests and realization of susceptibility testing. Suitable models were implemented in Simulink software. As a result of simulation and susceptibility testing, many interesting findings has been delivered.

Keywords: Parametrical Model, Identification Modeling, MATLAB and Simulink Environment, Simulation Research, Susceptibility Testing

1. Introduction

The concept of identification modeling is best defined by the theory of control systems, where identification is understood as creation of a mathematical model of the system based on the static and dynamic elements as well as on structures appearing in system. Based on this definition, it is assumed that identification of Polish Electric Power Exchange (EPE) system indicates finding a relationship between input and output system based on experimental data.

Thus, EPE system model is more convenient to receive by finding dependencies and relationships between measured data of Day-Ahead Market (DAM) without a phenomenological knowledge of the real system or process occurring in the system, i.e. without a detailed study of physical phenomena occurring in the system or process. Resulting EPE system model may be further used in process of the control system synthesis or in performing simulation studies for the purpose of determining system behavior in the future. Algorithms commonly used for identification systems and processes are among others following: LMS method, method of least squares (OLS), recursive least squares (RMNK), instrumental variable method, Fast Fourier transform, and many others.

Most commonly used method to identify the control system is method of least squares, which is a standard method for approximating solutions of overdetermined systems i.e. a set of equations in which there is more equations than variables. Identification methods are using it to estimate and determine the trend line based on a set of data in the form of input and output pairs of numbers. In this study, method is for creating parametrical model using ARX method based on EPE data. EPE data were represented by DAM as 12 input variables and one variable output with the progress of one hour. Inputs were representing volumes of electricity supplied in different hours of the day (kWh), while outputs were representing prices achieved on EPE for particular hours of the day (zł/kWh). This approach ensured delivery of 24 MISO type models in total. Numerical data used in modelling related to period from 30.06.2013 to 31.12.2013 (precisely 183 days) and were gathered for the EPE's DAM. Process of identification was performed in MATLAB and Simulink supported by System Identification Toolbox (SIT).

2. Problem formulation

Organization subject to modeling is Polish Power Exchange in scope of business processes related to the Day-Ahead Market. As input data, study used 24 variables (parameters) relating to the volume of electricity delivered for sale on stock exchange on EPE [kWh] during certain hours during a trade window, and as an output data, respectively obtained average prices for electricity [zł/kWh]. All data refer to six months period that is 183 days used for modelling (starting from 30.06.2013 up to 31.12.2013).

Experiment was performed for 12 input variables and one output (MISO models) in progressive system where single step was represented as one hour in a analyzed day (e.g. input data values for the periods 1-12, 2-13, 3-14, etc., and for each of given periods individual value as an output data). Such approach enabled receiving a 12 periods of the input data and for each of them 12 ARX models, and thus a total of 144 MISO models for further analysis. This paper presents test results for data input periods 1-12 (volume of electricity) and data values for the

first hour (the average price of electricity for period 0-1). Data values used for analysis represent real data downloaded from the website of TGE S.A. for the trading of electricity on DAM. Sample of changes of the input quantity ($u1EPE$) and output ($y1EPE$) for time period 0-1 is given in Fig. 1 (volume of electricity [kWh] for time period 0-1) and Fig. 2 (the average price of electricity for time period 0-1 [zł/kWh]).

3. Polish Electric Power Exchange

Polish Electric Power Exchange (EPE, polish: Towarowa Giełda Energii Elektrycznej, TGEE) is an entity running commodity exchange market, with particular distinction of Day Ahead Market (electricity spot market). EPE was established through the initiative of Treasury as an essential element of the liberalization of the electricity market. Organization and official launch of Polish Power Exchange was carried out by Elektrim S.A., which on 7 December 1999 launched business operations of commodity exchange market. The legal basis enabling operation of this commodity exchange was the Act of 10 April 1997 (Energy Law). EPE system is a subsystem of the Electricity Power Market (EPM) functioning is based on document: "Principles of the electricity market in Poland in 2000 and beyond", adopted and approved by the Economic Committee of the Council of Ministers.

Initially, exchange market has operated only spot trading and subsequently introduced a trading on Day Ahead – Intraday Market, Futures Market for Electricity Property Rights Market, Gas Market, as well as the CO₂ Emission Allowances Market.

Electricity exchange market operates as a wholesale market, which engages electricity producers and wholesale buyers as well as the retail market, where energy suppliers offer consumers energy supply, competing among themselves with price and delivery terms [5-6, 9]. While modeling EPE, that is functioning as a subsystem of the electricity market, it should be taken into account at least some circumstances, such as: the specificity of the electricity market resulting from the physical features of the system EE, including the need of ensuring continuous balancing of supply and demand side at any given period without energy storage options; separation of energy in terms of separation of a product side from its supplying network services (transmission and distribution); annual, weekly and daily seasonality, which includes periodically repeated price trends observed over period of days, weeks, months, years and even decades; tendency of returning prices of electricity to the average price level after passing trends, seasonality, random fluctuations, disturbances, etc.; unexpected, sudden price spikes that are caused by unforeseen events such as faults in power plants and transmission networks, sudden

weather changes, etc.; energy prices: oil, coal, gas, greenhouse gas emissions prices, and many others [1-3, 5-7, 9-13]. Identification modeling can therefore be based on DAM electricity quotations, i.e. on quotations of sold energy and price obtained for it. Therefore, development of models as a system models can be based on process of identification of the above mentioned conditions present on EPE.

Identification process is currently using different powerful computing environments such as i.e. MATLAB, Mathematica STATISTICA, SAS or SAP. Having regard to the technical characteristics and economic considerations, MATLAB solution was used for performing EPE identification process. This solution is characterized by large capabilities for research supporting by means of such libraries as System Identification Toolbox (SIT), Control System Toolbox (CST), Optimization Toolbox (OPT), Simulink (SIM), etc. Quotations on DAM market held daily, enabling market participants purchase of supply contract either 24 or 48 hours prior to its delivery. Each hour of delivery represents a separate contract for power (electricity) supply. Quotations on this exchange market are held according to a strict schedule. Each participant EPE has its own account and may submit any amount of orders. Each order specifies, among others, designation (ID) of the commodity that was the object of the transaction, designation (ID) of the exchange member entering into the transaction, type of transaction (sale or purchase), volume (the amount of energy purchased or sold), etc.

Detailed guidance on stock exchange transactions have been defined in documents “Trading Rules for the Commodities Market of the Towarowa Giełda Energii S.A. (Polish Power Exchange)”, “The Trading Terms for Weekly Electricity Forward Instruments”, “Day-Ahead Market Detailed Rules of Electricity Trading and Settlement”. The first price quotes on the DAM (on the websites TGE) appeared on 01.07.2000. Due to the adopted method for analyzing market data in hourly steps for purpose of this study, analyzed data relate to two months’ period, i.e. to all measured volumes and prices for each day starting from 30.06.2013 up to 31.12.2013 (for timeframe 0-1).

4. Parametric identification of EPE

For several years, Polish Electric Power Exchange is subject of an active and comprehensive interest, not only in area of technical but also in area of social and economic studies. However, until this moment, it was not yet elaborated generally acceptable definition of electricity exchanges as a system. Concept of market, simple and understandable in practical considerations, delivers a huge theoretical and interpretational difficulties, especially in area of strict definition of a model deter-

mining average price of electricity quoted on the basis of delivered energy volume, assuming that the model implicitly includes many different types of models determining energy prices, which have led to specific practical relationships. Formulation of the electricity market as a system followed by definition of power exchange as a subsystem requires a definition of the electricity market in terms of control theory and systems.

Parametric identification of EPE was performed in Matlab Simulink environment with support of System Identification Toolbox having capabilities of possibility of tasking a developed model ($na=1-10$, $nb=1-10$, $nk=1-10$) and therefore to define a degree of polynomials $A(q)$ and $B(q)$. Identification algorithm is as follows [1-4, 9-15]:

Step 1. Determine n volume of input values that are sold on the electricity stock exchange in different hours of the day and n being the size of the output electricity prices in the different hours of the day. Get numerical values containing volume and average prices for MATLAB workspace, where they are stored in the form of two matrixes of size 183×12 (for input) and 183×1 (for output).

Step 2. Import input data to the System Identification Toolbox by using the GUI while determining the parameters of import and validating imported data.

Step 3. Initial processing of data imported to the SIT, e.g. removing the constant (fixed) components (Remove means).

Step 4. Selecting a parametric identification method, e.g. ARX algorithm and performing of estimation.

Step 5. Analysis of the resulting model structure (its accuracy in relation to the system EPE) and analysis of the identification method (if adopted identification algorithm generates the correct parameters and structure of the EPE model).

Step 6. Decision regarding adoption of a model or a repetition of identification process using same or a new method for identification.

Step 7. Analysis of the correctness of the identification based on delivered model (e.g. model stability analysis).

Step 8. Export of delivered EPE model to Workspace.

Step 9. Decision of changing a period of identification (e.g. in order to adopt more than half a year period) in order to create a EPE system model and thus repeating a calculation process for the new (longer) period of measurement data.

Step 10. Establishing a new conditions for identification, e.g. measurement period, numbers of inputs and outputs, identification model (SISO, MISO, SIMO, MIMO), etc.

Step 11. Printout of EPE model as a result of identification process (or models catalogue).

5. MISO type EPE parametric models

Finally, as a result of performed experiments for 12 input variables (electricity volume type), where changes for timeframe 0-1 are given in Fig. 1, and one variable output, where changes for timeframe 12-13 are given in Fig. 2) yielded 144 ARX discrete parametric models (called AutoRegressive with exogenous input - autoregressive model with an external input) MISO type in the form of a matrix of **th** [4, 9-15] having the following structure:

$$A_j(z) \cdot y_j(t) = \sum_{i=1}^{12} B_i(z) \cdot u_i(t) + e_i(t), \quad (1)$$

where $A_j(z)$ and $B_i(z)$ are polynomials in the form:

$$A_j(z) = 1 + a_{j1} \cdot z^{-1} + a_{j2} \cdot z^{-2} + \dots + a_{jna} \cdot z^{-na},$$

$$B_i(z) = b_{i0} + b_{i1} \cdot z^{-1} + b_{i2} \cdot z^{-2} + \dots + b_{inb} \cdot z^{-inb-ink}, \quad (2)$$

wherein:

- $y_j(t)$ – output variable of price [PLN],
- $u_i(t)$ – input variable of electric energy [kWh],
- $e_i(t)$ – white noise,
- z – operator of time delay,

na , nb , nk – identification parameters, adequate: na – polynomial degree of $A_j(z)$, nb – polynomial degree of $B_i(z)$, nk – time delay of output in relation to the input.

System models EPE as matrices **th** has been obtained by parametric identification for 183 pairs of inputs and outputs on consecutive days from the first half of 2013. Example of MISO type parametric model obtained in the process of identification, e.g. for output related to one variable representing the average price for energy electricity obtained on EPE for timeframe 0-1 and up to 12 input variables on the stock exchange providing volume of electricity is as follows (model arx431 - Fig. 3):

$$A1(z) \cdot y_1(t) = \sum_{i=1}^{24} B_i(z) \cdot u_i(t) + e_i(t) \quad (3)$$

where:

$$A(z) = 1 - 0.4326 z^{-1} - 0.09115 z^{-2} - 0.109 z^{-3} - 0.1482 z^{-4},$$

$$B1(z) = -0.004636 - 0.009596 z^{-1} + 0.01161 z^{-2} + 0.006804 z^{-3},$$

$$B2(z) = -0.01674 - 0.01316 z^{-1} + 0.0003487 z^{-2} + 0.0001118 z^{-3},$$

$$B3(z) = 0.001692 + 0.008312 z^{-1} - 0.01295 z^{-2} + 0.001776 z^{-3},$$

$$B4(z) = 0.01043 + 0.009707 z^{-1} - 0.0002095 z^{-2} - 0.0153 z^{-3}$$

$$B5(z) = 0.01327 + 0.003071 z^{-1} - 0.001562 z^{-2} - 0.0004529 z^{-3}$$

$$B6(z) = 0.01299 z^{-1} + 0.003899 z^{-2} - 0.006581 z^{-3} - 0.0003308 z^{-4}$$

$$B7(z) = 0.002658 - 0.005702 z^{-1} - 0.007111 z^{-2} + 0.01386 z^{-3}$$

$$\begin{aligned}
B_8(z) &= -0.002058 + 0.009209 z^{-1} + 0.009561 z^{-2} - 0.008056 z^{-3} \\
B_9(z) &= 0.003635 + 0.003928 z^{-1} - 0.01141 z^{-2} + 0.02382 z^{-3} \\
B_{10}(z) &= 0.008453 - 0.01594 z^{-1} - 0.004618 z^{-2} - 0.02212 z^{-3} \\
B_{11}(z) &= -0.002638 - 0.003918 z^{-1} - 0.003695 z^{-2} + 0.00428 z^{-3} \\
B_{12}(z) &= -0.0007324 + 0.01391 z^{-1} + 0.007164 z^{-2} - 0.002329 z^{-3}
\end{aligned}$$

Therefore, the polynomial $A(x)$ degree equals $na = 4$, polynomials $B_i(z)$ degree equals $nb = 3$, and time delay of output relative to the input equals $nk = 1$.

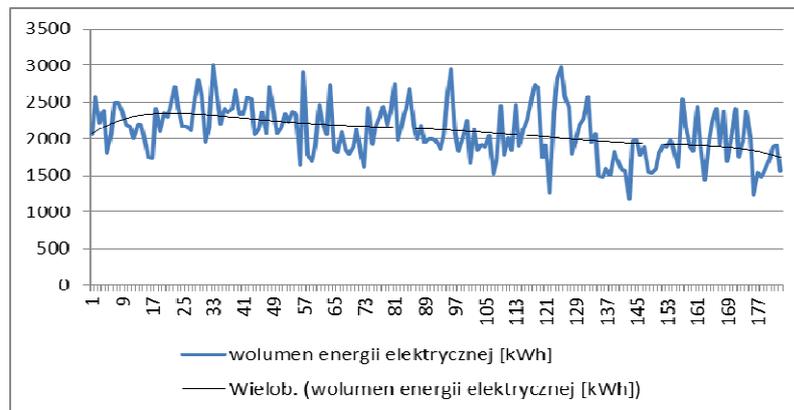


Figure 1. Example of input variable $u_1(t)$ - volume of electricity delivered for timeframe 0-1 [kWh]. *Source:* Independent work of the author on MATLAB and Simulink environment using the SIT

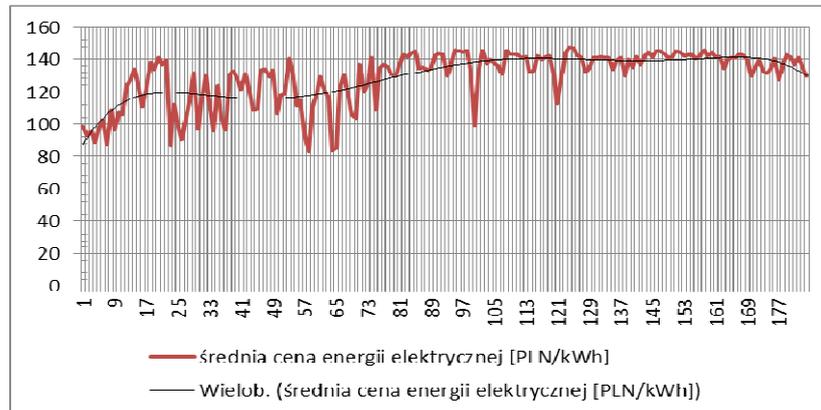


Figure 2. Example of the output variable $Y_1(t)$ - the average electricity price achieved in timeframe 0-1 [zł / kWh]. *Source:* Independent work of the author on MATLAB and Simulink environment using the SIT

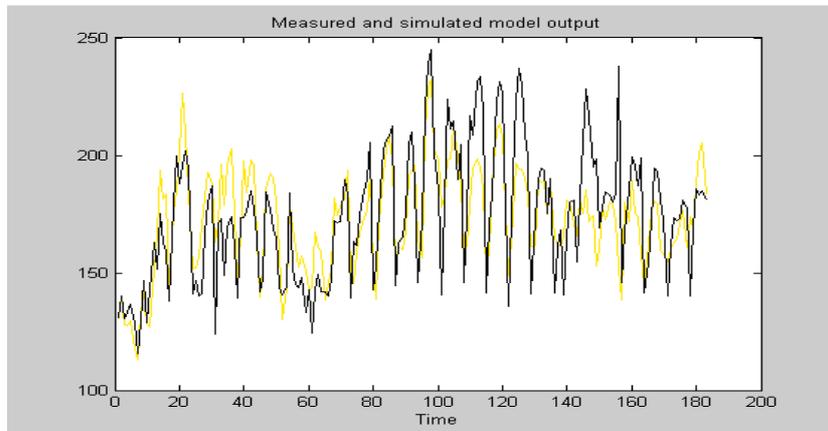


Figure 3. Comparative model and system EPE for timeframe 0-1 hours for the MISO type model . Symbols: X axis (Time) - the number of days of data were used to identify, Y-axis - measured and simulated at the output of the model [PLN / kWh].
Source: Independent work of the author on MATLAB and SIT environments

Analysis of input variables represented as on Fig. 1 shows downward trend in the total volume of electricity delivered for sold on the stock exchange, and the output variable presented on Fig. 2 shows the declining trend in the average price for sold electricity EPE for DAM quotations.

The resulting model shows that there is a fairly high accuracy of the resulting model in relation to the EPE system, especially in terms of tendencies of model output in relations to real system output (Fig. 3).

6. Summary and directions for further research of EPE

There is a possibility to perform parametric identification in order to generate the system model Polish Power Exchange. As a result of identification, 24 models of MISO type were obtained for up to 12 input variables representing the volume of electricity delivered to the energy stock exchange and for one output representing the average price obtained for sold electric energy, with the progress of one hour, while output was adopted, for the next hour after 12 hours of measurement.

Identification process is illustrated based on the MISO model, i.e. a model for timeframe 0-12 (input data represents volume of electricity delivered on EPE) and for timeframe 12-13 (output data represents average price of electricity registered on EPE).

Further studies should cover development of safety limits for trading turnovers for electricity trading at EPE for all 24 models MISO EPE. Such development may be based on rolling action identification. Developed models could be further

used for simulation modeling by virtue of Simulink and for model sensitivity testing as well as to improve development models of EPE system DAM.

It has been identified need and possibilities for Polish Power Exchange system modeling in order to get the system model EPE for Day-Ahead Market (DAM). One of the modeling methods leading to a system model modeling is EPE identification. In order to obtain an EPE identification system model, values for particular timeframes (particular hour of day) were collected posted on DAM and used in the identification process of EPE system model.

Emerging identification system model (EPE) is to be used in further research, especially in area of field testing simulations regarding to practicable directions of EPE development as well as on sensitivity testing of EPE in the event of unusual circumstances that may occur in crisis situations. Modeling method can also be used to build a model of identifying safety control of the development of the electricity market in Poland.

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