POZNAN UNIVERSITY OF TECHNOLOGY ACADEMIC JOURNALS
No 60 Electrical Engineering 2009

Jerzy R. TCHÓRZEWSKI*

THE DEVELOPMENT PROCESS OF ELECTRICAL POWER SYSTEM FROM THE POINT OF VIEW OF EFFICIENCY

The paper concerns the research on the electrical power market development from the point of view of efficiency. As a result of identification a model in the form of th matrix and in the form of state equations and input for selected input and output variables were obtained. Identification was conducted for IEEE RST testing data obtaining the matrix and matrices **A**, **B**, **C** and **D**. Subsequently, changes both in degrees and the values of individual elements of matrices. In order to define the notion development efficiency, development efficiency for each development stage was examined both for one aggregated model of SEE system development model (Part I) and for the models from each stage of development (Part II).

1. BASIC DEVELOPMENT MODELS BASED ON IEEE RST TESTING DATA

So far, in order to define the behaviour of an electrical power system (SEE) in the future, various methods of forecasting, planning or even programming development were used for various time periods [1,5,6,9,13,14,17,21,30,31]. These methods prove to be insufficient when it comes to a bigger and more distributed electrical power system with various forms of ownership and more and more complex electrical power market [13,14,21-26,29]. Present methods used for research concerning electrical power systems may be supplemented by development design methods, well known for their use in electrical power systems design [10,11,13-18,28,29]. A basic action while designing an electrical power system understood as a very complex electrical power system is determining a predicted load which conditions the number of subsystems as well as the kind, quantity and quality of elements used, in short, which conditions the structure and the parameters of individual subsystems.

However, development design is connected with the knowledge of both the so-far structural and parametric changes as well as the expected behaviour of the system following the new designed changes of the SEE system. Therefore, a current problem is, first and foremost, obtaining any development model, which is

* University of Podlasie.

possible using statistical data. When such a development model has been obtained, it is important to examine the SEE system behaviour i.a. from the point of view of efficiency and safety (including environment protection).

The method of examining regularities in the development from the point of view of the safety was discussed in the paper [27], in which the notion of development safety was defined, and, a method of development safety level assessment was shown using numerical example, obtaining, as a final result, critical points of development and safe development range.

This paper draws particular attention to the method of development examination from the point of view of development efficiency. It should be mentioned that this approach does not aim at defining the criterion of development efficiency as we do not deal with optimization problems but we deal with development assessment problems for the purpose of the design of future development states.

1.1. Development efficiency

Although there are a lot of definitions of the notion of efficiency [3,9,6,18,20,28] the concept of development efficiency has not been unequivocally defined yet as regards electrical power. It is convenient to measure the efficiency Λ of the development system using generalized characteristics that have the following form [25-27]:

$$\Lambda(K,\theta) = \frac{F(K,\theta)}{R(K,\theta)} \tag{1}$$

where: F(K,θ) – usefulness outlay variable (FI) or usefulness income (FD), R(K,θ) – protection potential variable (RI) operational potential (RD).

It is, therefore, possible to talk about two indexes of SEE system efficiency:

1) income efficiency:

$$\Lambda_{DI}(K,\theta) = \frac{FD(K,\theta)}{RI(K,\theta)}, \tag{2}$$

2) outlay efficiency (fig. 1):

$$\Lambda_{ID}(K,\theta) = \frac{FI(K,\theta)}{RD(K,\theta)}, \tag{3}$$

and also about four indexes of dynamic efficiency which is discussed in paper [27].

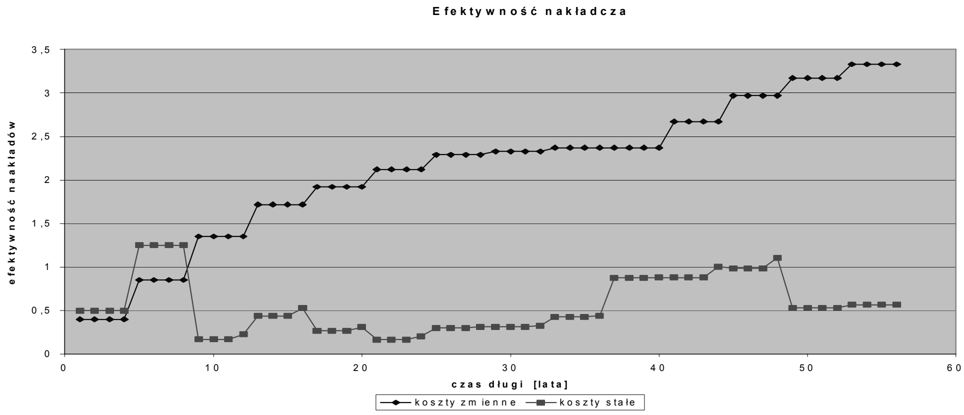

Fig. 1. SEE outlay efficiency changes runs

1.2. Development model

Testing data IEEE RST 1996 are assumed, modified for the development conditions of SEE development as presented in table 1 [4,12,18,25,26]. Arx model was used for the purpose of identification [30]:

$$A(q)y(\theta) = B(q)u(\theta) + e(\theta) \tag{4}$$

obtaining SEE development model according to IEEE RST of arx365 type for the output y_1 (generators power, model accuracy 90,75%):

$$\begin{aligned}
A(q) &= 1 - 0.2684q^{-1} + 0.0681q^{-2} - 0.09727q^{-3} \\
B1(q) &= -1.242q^{-5} + 2.121q^{-6} - 1.419q^{-7} + 0.3434q^{-8} + \\
&\quad -0.4248q^{-9} + 1.003q^{-10} \\
B2(q) &= -0.3073q^{-5} + 0.1444q^{-6} + 0.4468q^{-7} - 1.203q^{-8} + \\
&\quad -0.9924q^{-9} - 0.9051q^{-10} \\
B3(q) &= 0.3591q^{-5} + 0.08519q^{-6} + 0.235q^{-7} - 0.7524q^{-8} + \\
&\quad +0.6681q^{-9} - 0.4691q^{-10} \\
B4(q) &= -150.8q^{-5} + 303.3q^{-6} + 23.82q^{-7} - 5.247q^{-8} + \\
&\quad -400.8q^{-9} + 53.38q^{-10} \\
B5(q) &= 7.883q^{-5} - 2.957q^{-6} - 3.208q^{-7} - 7.613q^{-8} + \\
&\quad +5.98q^{-9} - 5.041q^{-10}
\end{aligned} \tag{5}$$

$$B6(q) = 456.4q^{-5} - 167.6q^{-6} + 112.6q^{-7} - 55.74q^{-8} + \\ +105.9q^{-9} - 77.5q^{-10}$$

and as a final result a model in states space was obtained for the output y_1 in the form of the following state equations:

$$\begin{aligned}
\dot{x}_1 &= 0.2684x_1 + x_2 - 1.2419x_{10} - 0.3073x_{14} + 0.3591x_{18} - 150.8208x_{22} + 7.8831x_{26} + 456.378x_{30} \\
\dot{x}_2 &= -0.0681x_1 + x_3 + 2.1213x_{10} + 0.1444x_{14} + 0.0852x_{18} + 303.3459x_{22} - 2.9569x_{26} - 167.5974x_{30} \\
\dot{x}_3 &= -0.0973x_1 + x_4 - 1.4185x_{10} + 0.4468x_{14} - 0.2350x_{18} + 23.8203x_{22} - 3.2077x_{26} + 112.6062x_{30} \\
\dot{x}_4 &= x_5 + 0.3434x_{10} - 1.2033x_{14} - 0.7524x_{18} - 5.2468x_{22} - 7.6125x_{26} - 55.7384x_{30} \\
\dot{x}_5 &= x_6 - 0.2448x_{10} - 0.9924x_{14} + 0.6681x_{18} - 400.7828x_{22} + 5.979x_{24} + 5x_{26} + 105.8891x_{30} \\
\dot{x}_6 &= 1.0035x_{10} - 0.9051x_{14} - 0.4691x_{18} + 53.3839x_{22} - 5.0409x_{26} - 77.5027x_{30}
\end{aligned}$$

$$\dot{x}_7 = u_1,\ \dot{x}_8 = x_7,\ \dot{x}_9 = x_8,\ \dot{x}_{11} = u_2,\ \dot{x}_{12} = x_{11},\ \dot{x}_{13} = x_{12}, \tag{6}$$

$$\dot{x}_{14} = x_{13},\ \dot{x}_{15} = u_3,\ \dot{x}_{16} = x_{15},\ \dot{x}_{17} = x_{16},\ \dot{x}_{18} = x_{17},\ \dot{x}_{19} = u_4,$$

$$\dot{x}_{20} = x_{19},\ \dot{x}_{21} = x_{20},\ \dot{x}_{22} = x_{21},\ \dot{x}_{23} = u_5,\ \dot{x}_{24} = x_{23},\ \dot{x}_{25} = x_{24},$$

$$\dot{x}_{26} = x_{25},\ \dot{x}_{27} = u_6,\ \dot{x}_{28} = x_{27},\ \dot{x}_{29} = x_{28},\ \dot{x}_{30} = x_{29},$$

and output equation:

$$y_1 = x_1. \tag{7}$$

The obtained models may be used in predicting SEE development system for complex conditions of IEEE RST model, with an assumption of maintaining, or even improving the conditions of outlay and income efficiency expressed by the formula (2) and (3).

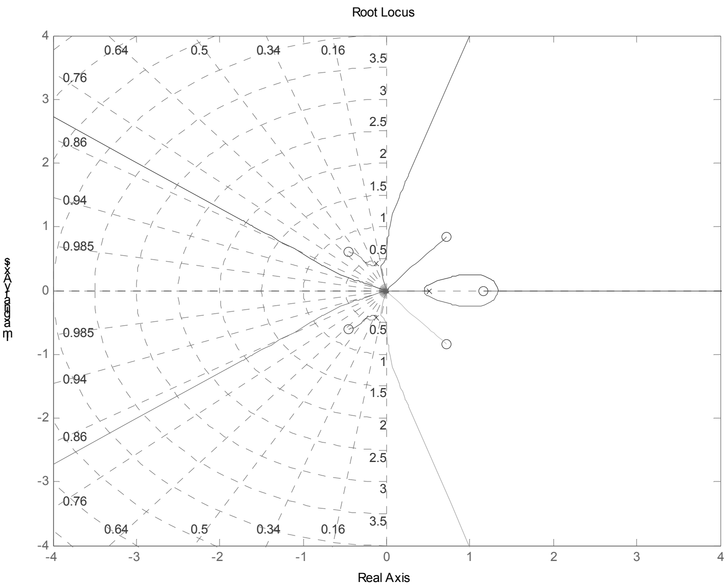

Fig. 2 Evans Roots Line – □ossible□ties of parametric and structural changes

2. DYNAMIC DEVELOPMENT MODELS

The model of SEE development obtained in part 1 has a lot of similarities with the models used so far in the prediction practice and theory [13,14,21-28]. In may well be used for predicting future states of SEE system development a few years ahead [25-26]. However, from the point of view of longer time periods this type of models, which take into account only parametric changes are not adapted for predicting structural changes [20].

In the meantime, we fitness structural changes as regards ownership changes and the structure of production, transfer, distribution and consumption of electrical power and energy. Due to these facts, both theory and practice of electrical power systems development wait for new solutions, which may prove developing systems.

In order to obtain a model of SEE system as a developing system it is necessary to conduct identification of SEE system development for many (a dozen or so, or even several dozen) development periods in order to obtain proper development models, and then conduct the identification of the model once again to obtain a developing model that reflects the development of the SEE system, where information about successive models of SEE development are data for identification [25-26]. For the purpose of such models of SEE development as a developing system, efficiency criterion should become a dynamic criterion.

2.1. Dynamic efficiency of development

In a general case, the model of system's development assessment contains: the information about the development system (inputs, outputs, state variables), criterion or a group of criteria of quality assessment, as well as an algorithm defining the value of development quality assessment criterion [20,22-27].

The quality of electrical power system development process may be presented as a difference between an assumed Δy_0(K,θ) and a real output characteristic Δy(K,θ) of SEE system, which for the discussed multi-dimensional case formulated in paper [20] may be written down as follows:

$$\overline{\Delta y}(\theta) = \left| \overline{\Delta y_0} - \overline{\Delta y} \right| \tag{8}$$

which leads to four dynamic efficiency indexes, i.e.:

1) supply efficiency:

$$\Lambda_I(K,\theta) = \frac{FI(K,\theta)}{RI(K,\theta)}, \tag{9}$$

2) operational efficiency:

$$\Lambda_D(K,\theta) = \frac{RD(K,\theta)}{FD(K,\theta)}, \tag{10}$$

3) financial efficiency:

$$\Lambda_F(K,\theta) = \frac{FI(K,\theta)}{FD(K,\theta)}, \tag{11}$$

4) technological efficiency:

$$\Lambda_R(K,\theta) = \frac{RD(K,\theta)}{RI(K,\theta)}. \tag{12}$$

Moreover, it is □ossible to distinguish Rother kinds of developing systems efficiency such as technical-economic efficiency, internal efficiency, etc. Which his paper does not discuss.

2.2. Dynamic model of development

Testing data IEEE RST 1996 are assumed modified for the conditions of SEE development as presented in paper [3] and the measurement period equal 25 years with the step of Δθ=1. (1 year). In this case identification for 32 periods of development was conducted and 28 th models as well as 28 models in states space were obtained (table 2).

Table 1. Data based on testing data IEEE RST concerning the see system development

Long time	Short time	Joint existing active power (Pmax)	Forecast concerning demand for active power increase (P)	Joint installed active power (P)	Jointly installed generators	Joint existing fixed cost	Existing unit gloating charges	Forecast generators power	Additional forecast fixed cost	Additional forecast floating charges
θ	t	u_1	u_2	u_3	u_4	u_5	u_6	y_1	y_2	y_3
[year]	[quarte]	[kW]	[kW]	[kW]	[unit]	[$]	[$/MW year]	[kW]	[$]	[$/MW year]
1 ... 14	1 ... 3	49.9 ... 6042.43	60.51 ... 18.55	60 ... 3305	1 ... 14	20 ... 198.5	0.4 ... 3.33	40 ... 350	30 ... 13	0.45 ... 0.16

Table 2. Example data for identification of the SEE model development

θ		B1(q)	B2(q)	A(q)
1	arx414	0.004574 q^-4	-0.567 q^-4	1 - 0.4204q^-1 - 0.0008252q^-2 + 0.002647q^-3 + 1.163q^4
2	arx414	0.004574 q^-4	-0.567 q^-4	1 - 0.4204q^-1 - 0.0008252q^-2 + 0.002647q^-3 + 1.163q^4
3	arx114	-0.1268 q^-4	-0.8978 q^-4	1 - 0.707 q^-1
...	....	....	....	....
25	arx114	-0.04534 q^-4	0.5382 q^-4	1 - 0.5538 q^-1
26	arx214	-0.05215 q^-4	0.5396 q^-4	1 - 0.6126 q^-1 + 0.09865 q^-2
27	arx111	-0.06659 q^-1	-0.03003 q^-1	1 - 0.3661q^-1
28	arx311	-0.07288 q^-1	-0.02269 q^-1	1 - 0.2558 q^-1 - 0.006983 q^-2 - 0.1034 q^-3

Then, a_i parameters from th models were used as inputs and b_i parameters were used as outputs of the models and identification of the development model was conducted which resulted in obtaining a dynamic model od SEE system development as a developing system, which for the output y_1 and for the term

B2(q) of the th model (table 1) and A(q) has the following form in the states space. A model obtained in his way is a development model and contains information both about parametric and structural changes.

$$\begin{aligned}
\dot{x}_1 &= x_2 + 1.2u_1 + u_3 - u_4, \\
\dot{x}_2 &= x_3 + 3u_1 + 2u_2 + 2u_3 + 7u_4, \\
\dot{x}_3 &= x_4 - 3u_1 - 2u_2 - 2u_3 + u_4, \\
\dot{x}_4 &= -0.586x_1 + 2u_1 + 3u_2 + 3u_3 + 8.6434u_4, \\
y_1 &= x_1.
\end{aligned} \tag{13}$$

If we make an attempt at interpreting 4 obtained state variables for the continouos linear model it turns out that [2,7,8,10,25-27]:

x_1 – state variable defining the influence of the situation one year ago has the value of the term A(q-1) as a term that is connected with $y_1(K,\theta)$ i.e. forecast power of generators,

x_2 – derivative of state variable defining the influence of the situation 1 year ago on the value of the term A(q-1) as a term that is connected with $y_1(K,\theta)$ i.e. forecast power of generators, i.e. specific speed of changes of the term A(q-1) in the period of 1 year,

x_3 – second derivative of state variable defining the influence of the situation one year ago on the value of the term A(q-1) as a term that is connected with $y_1(K,\theta)$ i.e. forecast power of generators, i.e. specific speed of changes of the term A(q-1) in the period of 1 year,

x_4 – integral of the state variable defining the influence of the situation one year ago on the value of the term A(q-1) as a term that is connected with $y_1(K,\theta)$ i.e. forecast power of generators, i.e. specific yearly mean value of the term A(q-1).

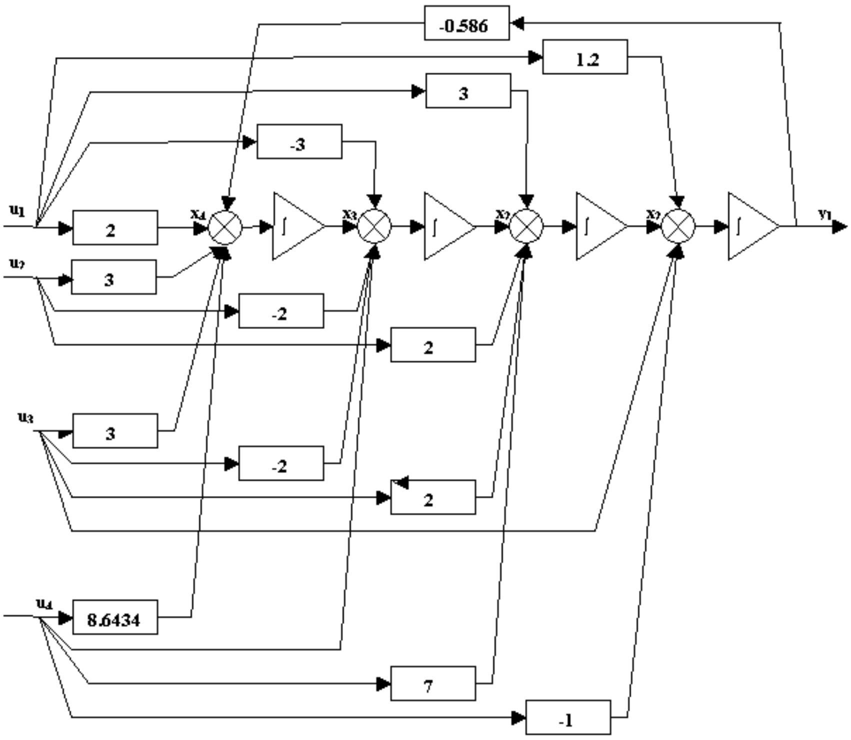

Fig. 3. Flowchart of state variable for equation (13)

Models for the remaining outputs may be obtained in a similar way, i.e. for the remaining elements of the term A(q), i.e. in the discussed example A(q-2), A(q-3), A(q-4), A(q-5), A(q-6).

Defining the efficiency of the SEE system as a developing system we obtain the efficiency run e.g. one presented in fig. 1 (operational efficiency) i.e. :

$$\Lambda_D(K,\theta)=\frac{y_1(K,\theta)}{u_2(K,\theta)}=\frac{B2(K,q)}{A(K,q)}, \tag{14}$$

where: $y_1(K,\theta)$ – forecast Power of generators [kW], $u_2(K,\theta)$ – forecast demand for the increase of active power P [kW], A(K,q) – the term connected with $y_1(K,\theta)$ defining the degree of the influence of situations from previous years on the current value of the index, B2(K,q) – the term connected with the input variable $u_2(\theta)$ expressing forecast demand for the increase in the active power P [kW].

Thus:

$$\Lambda_D(K,\theta)=\Lambda(q-1)+\Lambda(q-2)+\Lambda(q-3)+\Lambda(q-4)+\Lambda(q-5)+\Lambda(q-6) \tag{15}$$

where e.g.:

$$\Lambda(q-1)=\frac{y_1(K,q-1)}{u_2(K,q-1)}=\frac{B2(K,q-1)}{A(K,q-1)}, \tag{16}$$

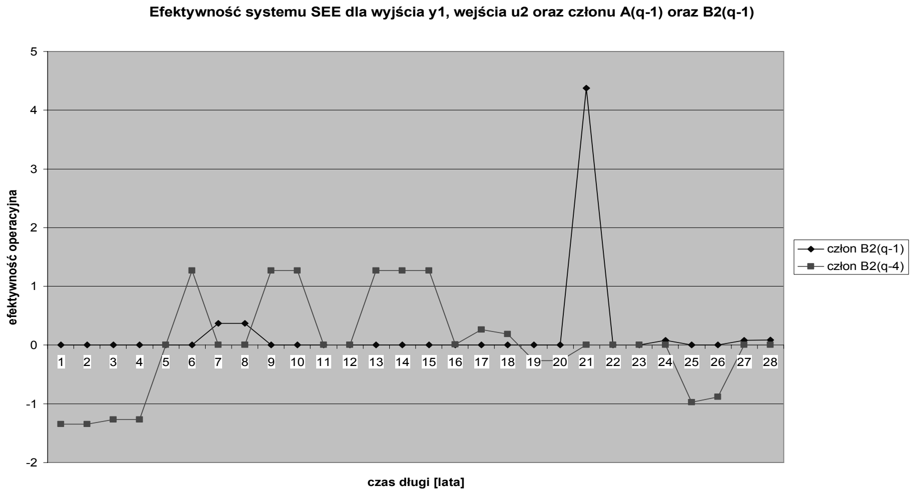

Fig. 4. Operational efficiency of the SEE system for the output y_1 (forecast power of generators) and for the input u_2

3. FINAL REMARKS AND DIRECTIONS FOR FUTURE RESEARCH

Using testing numerical data IEEE RST [4,12,18,25,26] it is possible to design statistical models of electrical power system (SEE) development in the form of th matrices or models in the states space [2,7,8,17,20,25,26]. However, such a model is still a statistical model, being, on the other hand, possible for making predictions concerning development, but not meeting the requirements and conditions of dynamic models in the full meaning of this word – developing systems [20]. The second part of this paper (Part II) shows a method and research results of obtaining the dynamic models of SEE system development and a method of development assessment of developing electrical power systems development from the point of view of efficiency.

Obtaining a model of state variables for development processes of huge systems like The Electrical Power System (EPS) seen as self-evolving system such as deserted factories (without people) is connected with the identification of the system using statistical data [19]. In the case considered, arx method was used for the purpose of identification and the following: arx654 model, transmittance tf model and finally state variables model: A, B, C, D matrices were obtained successively as relation (6) and (13) [25,26].

Then, it is convenient to present radical lines e.g. Evans' radical lines, which show structural changes and parametric changes in the development (fig. 2). First, changes for discrete models were examined; then the same was done for continuous models. Each change in the structure results in a new radical line (or its absence), and parametric changes mean selecting new radicals situated on the existing lines. Furthermore, it is possible to conduct research concerning regularities in the development for the remaining EPS system outputs, and examine the control system for various periods of the EPS system functioning and in greater or smaller detail, which this paper does not include.

REFERENCES

[1] Assis T.M.L., Falcao D.M.: Dynamic Transmission Capability Calculation Using Integrated Analysis Tools and Intelligent Systems. IEEE Transactions on Power Systems, Vol. 22, No 4, Nov. 2007, pp. 1760-1770.

[2] Bolkowska B.: Planowanie systemu elektroenergetycznego w ujęciu teorii sterowania. Archiwum Energetyki nr 4/1974.

[3] Boogert A.: When Supply Meets Demand: The Case of Hourly Spot Electricity Proces. IEEE Transactions on Power Systems. Vol. 23, No. 2, May 2008, pp.389-398.

[4] Brzóska M.: Algorytm ewolucyjny rozwoju systemu elektroenergetycznego na przykładzie systemu testowego IEEE. Praca dyplomowa pod kierunkiem dr J. Tchórzewskiego. Instytut Informatyki AP. Siedlce 2001.

[5] Bubnicki Z.: Identification of control objects (polish: Identyfikacja obiektów sterowania). PWN, Warszawa, 1974.

[6] Crandall J., Cummings M. L.: Identifying Predictive Metrics for Supervisory Control of Multiple Robots. IEEE Transaction on Robotics. Vol. 23, Issue 5, Oct. 2007, pp. 942-951.

[7] Kaczorek T., Dzieliński A., Dąbrowski W., Łopatka R.: Podstawy teorii sterowania. WNT, Warszawa 2005.

[8] Kozłowski K., Dutkiewicz P., Wróblewski W.: Modelowanie i sterowanie robotów. PWN. Warszawa 2003.

[9] Kowalik J.: Sterowanie statystycznie optymalne w ekonometrycznych modelach wzrostu. Zeszyty Naukowe-Seria II. Prace Habilitacyjne. Zeszyt 129, Poznań 1003.

[10] Kremens Z., Sobierajski M.: Analiza systemów elektroenergetycznych. WNT. Warszawa 1996.

[11] Kulczycki J.: Optymalizacja struktur sieci elektroenergetycznych. Warszawa. WNT 1990, s. 191.

[12] Macan E.: Peak-Load Transmission Pricing for the IEEE Relibility Test System. Dept. of Elrctrical Engineering and Computer Science. Copyright 1997 Edo Macan, p. 112.
[13] Malko J., Otręba L., Skorupski W.: Identyfikacja modelu autoregresji-średniej ruchomej krótkoterminowej predykcji procesu zapotrzebowania mocy. Archiwum Energetyki, Nr 1-2 1990, s. 101-108.
[14] Malko J.: Wybrane zagadnienia prognozowaia w elektroenergetyce.OW PW. Wrocław 1995. s. 84.
[15] Marzecki J.: Stan obecny oraz kierunki modernizacji i rozwoju elektrociepłowni przemysłowych. Gospodarka Paliwami i Energią 5/1990.
[16] Marzecki J., Parol M.: Komputerowa analiza pracy elektroenergetycznych sieci rozdzielczych. PWN. Warszawa 2001.
[17] Nazarko J.: Estymacja stanów pracy elektroenergetycznych sieci rozdzielczych. Rozprawy Naukowe Nr. 9. PB. Białystok 1991.
[18] Paska J.: Niezawodność systemów elektroenergetycznych. OW PW, Warszawa 2005.
[19] Statistic of Polish Electro-Energetic (polish: Statystyka Elektroenergetyki Polskiej). Wydawnictwo Zjednoczenia Energetyków, Centrum Informatyki Energetyki, Agencja Rynku Energii S. A., Warszawa 1952-2007.
[20] Staniszewski R.: Sterowanie procesem eksploatacji. WNT. Warszawa 1990.
[21] Tadeusiewicz R.: Badanie właściwości układów samodzielnych współpracujących ze stochastycznie zmiennym środowiskiem. Postępy Cybernetyki. 4/1976.
[22] Tchórzewski J.: The identification proces of power system as self-evolving technical object. Procedeengs of XIII Conference Computer Applications in Electrical Engineering. IEEP PP. EEC PAN. IEEE Poland Section. Poznań 2008, pp. 67-68.
[23] Tchórzewski J.: The development process of power system as unmanned factory. Procedeengs of XIII Conference Computer Applications in Electrical Engineering. IEEP PP. EEC PAN. IEEE Poland Section. Poznań 2008, pp.69-70.
[24] Tchórzewski J.: Rozwijajacy się system elektroenergetyczny jako fabryka bezludna. Materiały V Konferencji Naukowej pt. „Modelowanie i Symulacja" (MiS-5). OW PTETiS. Wydz. Elektryczny PW. Warszawa 2008, str. 165-168.
[25] Tchórzewski J.: Rozwój systemu elektroenergetycznego z punktu widzenia efektywności. Cz. 1. Postawowe modele rozwoju na przykładzie danych liczbowych IEEE RST. Materiały Konferencyjne ZKwE. Poznań 2009.
[26] Tchórzewski J.: Rozwój systemu elektroenergetycznego z punktu widzenia efektywności. Cz. 2. Dynamiczne modele rozwoju na przykładzie danych liczbowych IEEE RST. Materiały Konferencyjne ZKwE. Poznań 2009.
[27] Tchórzewski J.: Development of Electrical Power System fom Point of Viev of Safetly. Preccedings of 2008 IEEE 25-th Convention of Electrical and Electronics Engineers in Izrael. IEEE Xplore 2009.
[28] Trzaska Z.: A Modelowanie i symulacja układów dynamicznych. Wyd. PW. Warszawa 1993.
[29] Wilkosz K., Sobierajski M.: Sieci elektroenergetyczne a rynki energii elektrycznej. Problemy i perpektywy. PN IE PWr. Wrocław 2000.

[30] Zimmer A., Englot A.: Identyfikacja obiektów i sygnałów. Teoria i praktyka dla użytkowników MATLABA, Politechnika Krakowska, 2005.
[31] Zhou N., Trudnowski D. J., Pierre J. W., and Mittelstadt W. A.: Electromechanical Mode Online Estimation Using Regularized Robust RLS Methods. IEEE Transactions on Power Systems. Vol. 23. No 4. Nov 2008, pp. 1670-1680.