# Searching of regularities in the development of electrical power system. Part I - Identification and evaluation

Jerzy Tchórzewski
Siedlce University of Natural Sciences and Humanities
08-110 Siedlce, ul. 3-Maja 54, e-mail: jtchorzewski@interia.pl

The paper contains selected results of research on identification of the development of the electrical power system, presented in the table in the form of development models th, matrices of state variables and characteristic polynomials. An algorithm of development was also presented along with assumptions concerning the evaluation and examination of regularities in development.

## 1. Introduction

Examination of regularities in the development of the Electrical Power System (hereinafter called the EPS system or EPS) comes down to the examination of structural changes and parametric changes of the system in long time θ [years]. For this purpose, it is necessary to begin with the identification of the development in order to obtain a model of development, and then, bind the problem of the system development with the movement of roots on the complex variable plane s using the Evans root locus method [35].

Parametric changes on the complex variable plane s are connected with movement of roots along the existing root loci, and structural changes are connected with the appearance of new loci or disappearance of the old ones [ 26-33]. Therefore, the goal of the programming development technique is to find not only the model of development [2-4, 22, 34] but also the rules governing its development in long time θ [23]. In the case examined in this paper, the model of development is a model expressed in the form of the arx model matrices or in the form of the state variable model, with the parametric changes being connected with the changes of values of coefficients in polynomials A(q) and B(q) or with changes of the elements of matrices ***A, B, C, D*** in state equations, and the structural changes being connected with the change of the degree of the polynomial or with the change of the dimensions of the matrices, especially matrix ***A***, which is responsible for internal organization of the EPS system. While examining changes in the control system, it is convenient to study elements of matrix **B**, which is responsible for the control effect expressed through it by the influence of control quantities on the EPS system development. Examination of changes in both matrices ***A and B*** is especially significant from the point of view of technological changes leading to more flexible functioning of systems and their robotization, as matrix ***A*** is a carrier of knowledge about the degree of internal organization of the EPS system development, and matrix $\boldsymbol{B}$ - is a carrier of knowledge about the level of the EPS system development control.

## 2. Identification of the EPS system development

To find a new model of the EPS system, identification of the EPS system development ought to be performed in a specified period of time to define so far used models of development. Then, appropriate assessment ought to be carried out in accordance with the theory of system development engineering [26-33]. The development of a mathematical model of the EPS for the purpose of studying regularities in the development, using modelling is not possible due to the fact that the EPS system is a great and highly complex system. Thus, the only way to obtain a model for the above mentioned purpose is by means of identification, e.g. by means of interval identification in the stepping system [37]. As a result of identification, ***th*** matrices are obtained, and, following their transformation into the state space in the MATLAB environment, state equations and output equations that describe the EPS for the studied periods of development are obtained. From this perspective, states of the EPS system are described by state vectors, which change their dimension and composition as well as values in each period of development.

As a result of identification, models of the EPS system development are obtained for appropriate periods of the EPS system development, which may then be used to generate a metamodel of development, which is a specific information code of the EPS system development - an artificial genetic code in the context of genetic algorithms (fig. 1). The operation of coding development results in obtaining the above mentioned development code, which, in fact, is a specific genetic model of development, and the operation of decoding the development of the system leads to obtaining a new state of the EPS system on the basis of the new artificial genetic code that has been obtained. In works [26-33], examples how to use the proposed system development engineering as regards the electrical power system were presented.

The developed conception of system development engineering was verified in practice. First, a series of processes of identification of the electrical power system and its sub-systems was performed. Then, the obtained model was used to study regularities in the development by performing a series of experimental tests in the MATLAB and Simulink environments using its toolboxes, especially the System Identification Toolbox and the Control system Toolbox.

Identification of the system is a fundamental issue as regards the theory of control and systems, especially in a situation, in which a model to be developed is a model of a great system, and such a model is the electrical power system. When developing a model of the system in the state space, a state vector that describes the state of the system is sought. A state of the system may change in long time $\theta$, and, in this situation, it is possible to speak about a state of the electrical power system

(EPS) development in the state space, expressed by the vector of state variables ***x(θ)***, which is the vector with the smallest set of elements $x_i(\theta)$, which fully define the results of past influences on the system. If the initial state and the input function in a certain interval of long time ($\Delta\theta$) is given, it is sufficient to define states of the system and its output in this interval of time, and the state of the system development may not be directly observed.

Systems of development, and similarly, dynamic systems, for which the state of the system development in long time θ is measured by the derivative of the state vector ***x(θ)***, may be described using a system of n linear differential equations. E.g. a system of such equations may be presented in the following general form for the SISO[1] object:

$$\frac{dx(K,\theta,t=const)}{d\theta} = f_1(x(K,\theta,t=const),u(K,\theta,t=const),z(K,\theta,t=const),\theta), \quad (1)$$

and supplement it with the output equation:

$$y(K,\theta,t=const) = f_2(x(K,\theta,t=const),u(K,\theta,t=const),z(K,\theta,t=const),\theta), \quad (2)$$

where: $x(K,\theta)$ – system development state variables, $u(K,\theta)$ – input variables (input signal, inputs, input functions), $z(K,\theta)$ – interference, K – a set of characteristic quantities for the electrical power system, which, in case of a developing system (development of the system) depend on long time θ, e.g. $K_1(\theta)$, $K_2(\theta)$, … , $K_n(\theta)$ - they occur in the form of e.g. components of vector K(θ) - a vector of electrical power system development state, which, i.a. indicates the dynamics of the electrical power system development. Thus, in dynamic systems as well as in the systems of development, the current value of the output variable depends not only on the current values of external stimulating signals but also on the state of the EPS system development.

In subsequent periods, the examined electrical power system undergoes changes as regards values $K_i(\theta)$ (i=1,2,…,n) in time θ as a result of external interactions caused e.g. by the inflow of new technical and technological information allowing for the upgrade of the EPS system, and, consequently, improvement of its safety; the inflow of new economic information allowing to increase the efficiency of the electrical power system and information about new requirements that allow to improve reliability supplied by electrical energy recipients who wish to be supplied with power that meets quality requirements and parameters on time. For these reasons, changes that the electrical power system undergoes may conveniently be measured using the derivative of the vector of the system development state.

A mathematical model may be obtained using modelling provided that it is possible to use e.g. physical laws related to circuits theory and electro engineering. In case of difficulties in obtaining a phenomenological model a process of experimental identification is applied when the inputs and outputs of the system are available for measuring.

[1] SISO – Single Input Single Output, i.e. a control system described using one input variable and one output variable.

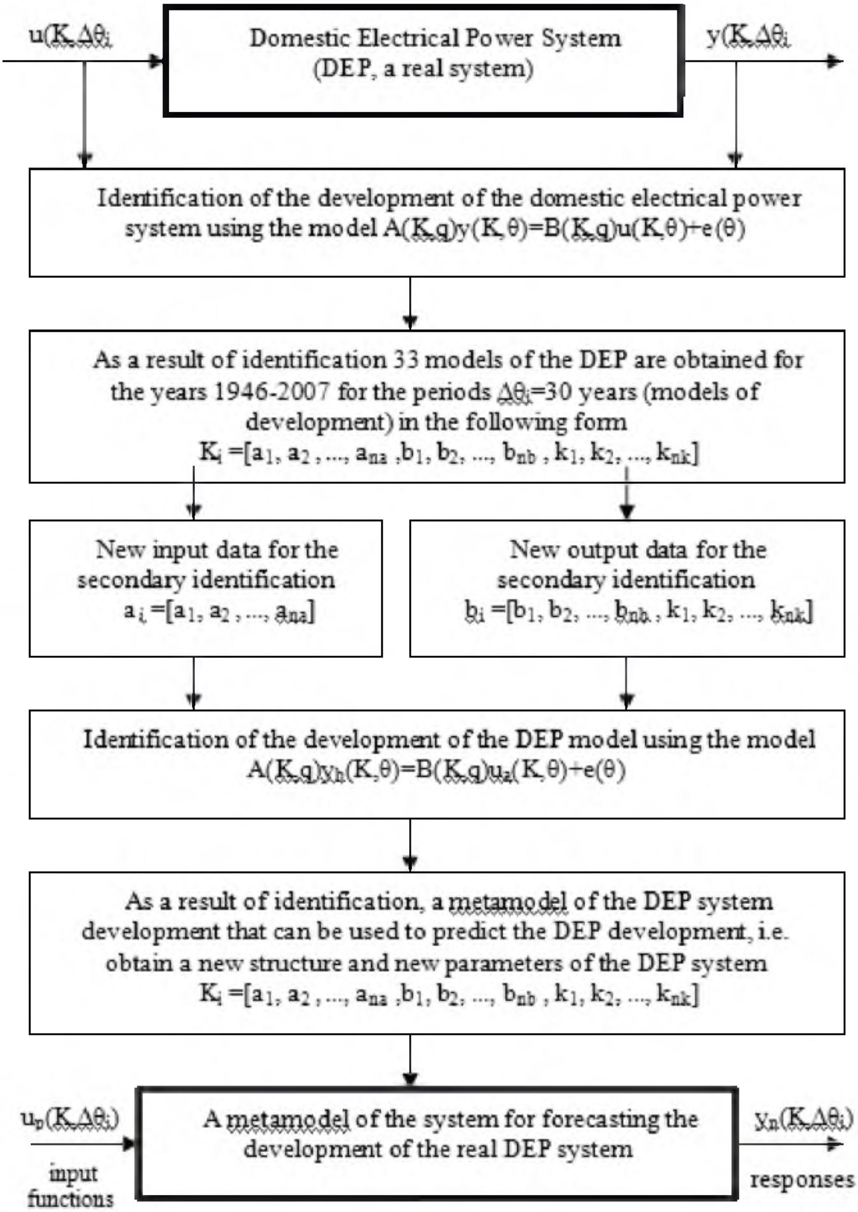


Fig. 1. A diagram showing how to obtain models of development and a metamodel of the DEP system development. Explanations in the text

Differential equations (or their discrete equivalents - difference equations) are used to describe dynamic phenomena in modelled real systems. There exists a finite number of parameters used in the models, and because of that such models are called *parametric models.* In the MATLAB's library named the *System Identification Toolbox* differences between individual parametric models result from the method of considering the influence of interference on the work of the system. One of these models used in this work is an autoregressive model with an exogenous input - ARX [37], described by the following equation:

$$A(q)\cdot y(\theta)=B(q)\cdot u(\theta-nk)+e(\theta), \qquad (3)$$

which may be written down in the following form of a difference equation:

$$y(\theta)=-a_1y(\theta-1)-a_2y(\theta-2)-...-a_{na}y(\theta-na)+b_1u(\theta-1)+...+b_{nb-nk}u(\theta-nb-nk)+e(\theta)$$
$$e(\theta)=\varepsilon(\theta)+a_1\varepsilon(\theta-1)+...+a_{na}\varepsilon(\theta-na), \qquad (4)$$

where: $u(\theta)$ - input of the system observed in a discrete instant of time $\theta$, $y(\theta)$ - output of the system observed in a discrete instant of time $\theta$, $v(\theta)$ - a replacement interference that occurs in a discrete instant of time $\theta$ (non-correlated randomly generated signal of the "white noise" type with a normal distribution and the average value equal zero and with constant variance), $\varepsilon$ - a random variable with the average value equal zero and constant variance, *na* - a number of factors connected with the output signal y, *nb* - a number of factors connected with the input signal u, nk - a number of factors connected with the lag between signal y and signal u, $A(q)=1+a_1q^{-1}+a_2q^{-2}+...+a_{na}q^{-na}$ - rational functions of the lag operator $q^{-i}$ of a polynomial connected with $y(\theta)$, which have constant coefficients representing parameters of the model, $B_i(q)=b_0+b_1q^{-1}+b_2q^{-2}+...+b_{nb-nk}q^{-(nb+nk)}$ - rational functions of the lag operator $q^{-i}$ of a polynomial connected with $u(\theta)$, which have constant coefficients representing parameters of the model.

ARX model (AutoRegressive with eXogenous input) is defined with the help of the model structure used for modelling technological object as in practice the ratio of noise to the signal is small. The function call has the following form: th=arx([y u],[na nb nk]), where: *y, u* - i/o column vectors, *[na nb nk]* - coefficients of the equation describing the model, 'na' specifies the number of poles (denominator's roots), 'nb-1' specifies the number of zeros (enumerator's roots), nk - number of factors connected with the lag between signal y and signal u, *th* - a matrix of identification factors with the THETA format. It contains the whole information about a model, its structure and estimators of parameters together with their estimation using covariance. This matrix has a strictly specified dimension. The elements of the first row contain in the following sequence: estimators of the variance of the parameters, sampling interval, the values of parameters na, nb, nk, etc. The second row contains: FPE (Final Prediction Error) index, year, month, day, minute, and numerical code of the command used to generate a specific model. The third row contains estimators of the model parameters in the alphabetical order: $a_1$, $a_2$, …, $b_0$, $b_1$, …(with zeros and ones at the beginning of the polynomial being disregarded). Rows 4 to 3+n contain estimations of the covariance matrix [37].

Therefore, the current value of the output signal depends on a certain number **na** of previous values of the output signal $y$ (autoregression), a certain number **nb** of successive values of the input signal $u$, on the time **nk** between the lag y and u and on the value of the interference signal (denoted by $\varepsilon$). The structure of the model is unequivocally specified by three parameters na, nb, nk. The arx model is stable when all its poles are inside the unit circle on the complex variable plane Z, and it is minimum phase if this condition is also satisfied by its zeros. It is also necessary to examine the roots lying on the unit circle. The parametric method used in the paper is the least squares method. In order to find a model that specifies the relations between the output signal $y$ and the input signal $u$, based on $N$ samples corresponding to successive instants of time $kT_P$ ($T_P$ – sampling period, $k=1,2,...,N$), coefficients of the model expressed as equation (4), which is only satisfied in approximation when the input signal, the output signal and the interference are intercorrelated, and estimator $\Theta$ for the least squares method is biased [37]. Due to the fact that the coefficients vector [na nb nk] specifying the rank of the enumerator and denominator of the transmittance and the lag is unknown, it is sought according to the criterion of minimization of the error determined during the verification of the model. In order to analyze a greater number of the structures of models in a relatively short time, a method which automatically generates the best results of verification performed on all possible structures with parameters [na, nb, nk] within the interval <1,10> was used. From all the structures, the system automatically selects parameters [na, nb, nk] so that the obtained arx model approximates the expected output signal to the real output in the best possible way.

## 3. Evaluation and examination of regularities in the development

A model for the evaluation of the system development contains, i.a.:

- information about the EPS system related to the structure, parameters and characteristics of the system,
- criterion or a set of criteria for the evaluation of the EPS system development quality, which contains information about energy and power as a product of the system,
- algorithm allowing to determine the value of the criterion, which contains information about the EPS system and about energy and power as a product of the system.

In the technique of programming development of systems there occur two groups of problems, namely: problems connected with the formulation of the model of development and problems connected with determination of laws governing the changes it undergoes in long time $\theta$ (examining regularities in the development of the system). This work deals with problems connected with working out models of development as well as problems connected with the specification of parametric and structural changes of the electrical power system in long time θ. In the control and systems theory, and especially in systems development engineering, evaluation involves working out a model of development on the basis of appropriate information about changes in the system. Evaluation criteria, the subject and the object of evaluation as well as the essence of the evaluation are elements connected by a certain relation, which make up evaluation, and the relation between the subject and the objects of evaluation is called a system of evaluation. Different evaluation criteria are adopted, and these criteria are always tightly connected with the value of the system. In his work, [21] Piotr Sienkiewicz emphasizes that evaluation applies to certain values due to specific needs of the system. In the studied case of the EPS system development, the value of the system is connected with the demand for power and electric energy, thus, in the evaluation phase it is possible to examine the difference between the demand for the system development usefulness and the obtained results as possibilities of the development of the system.

Therefore, evaluation of the development can be brought down to the evaluation of needs and evaluation of the development potential, and needs of the system of development as regards the security stream are equal to the financial outlay it can afford, and the capability of the system of development is equal to its operational potential as regards power and electrical energy production. Ultimately, the evaluation of needs connected with development may be reduced to the evaluation of the system inputs (usefulness income and the potential connected with securing development), and the evaluation of the development potential may be reduced to the evaluation of the system outputs (operational potential and outlay on usefulness) (4). The evaluation of needs and potential of development may be supplemented with the evaluation of development strength based on the theory of systems and control (evaluation of power- and information-related complex quantities). Assuming that the EPS system state is defined by the following formula:

$$s(K,\theta,t) = < Z(K,\theta,t,u(K,\theta,t) >, \tag{5}$$

and the function Z(K,θ,t) and the function u(K,θ,t) are called indexes of the system state, and the change of the system state is called system's movement, the sequence of system changes for the selected instants of time is called a system trajectory [6-7]. The subject of the study is the EPS system as a technical system or technical-economic system, in which, over the years, parameters and structure undergo changes[2]. An independent variable of the EPS system development is time *θ,* in the long aspect, measured in months, years and even decades. It was assumed that the

[2] Jacek Malko is of the opinion that "*apart from the complexity of the system itself and its relations with the neighbourhood it is also necessary to consider development dynamics while studying the problem of planning",* and he emphasizes that ..."a phenomenon of object structure change occurs in time, and is connected with the dynamics of increase in power demand (and with installing new power-generating units) and the process of ageing and taking operating objects out of active use"[100].

EPS system is a system with a developing structure, which evolves in time, at successive stages of development (1, 2,...,N), corresponding to individual states of the EPS system development, and each stage comprises the identification phase and development assessment phase. Successive stages of the EPS system development should show improvement in time, though it was not necessarily reflected in reality [18, 20, 22, 24, 26-33].

In order to describe a developing system at each stage of development $\theta$ we assume the theory of developing systems [23] after Robert Staniszewski, and in case of systems that belong to the same class as the EPS system, it is not possible to directly provide characteristic quantities because of the fact that a model of development obtainable using modelling development method is not available as well. However, a model of development may be obtained as a result of the identification of the EPS system development, and an artificial genetic code may be extracted from it, and written in the form of model (evolutionary model), whose genes are specific cumulated characteristic quantities describing the system.

If one is in possession of the artificial genetic code (evolutionary model), i.e. if one is in possession of a finite set of values of characteristic quantities of the EPS system expressed as the set $K(\theta)=\langle K_1(\theta), K_2(\theta), ..., K_n(\theta)\rangle$, one should seek a function of the system quality $J(K_1, K_2, ..., K_n)$ as a uniform criterion of evaluation of individual stages of the EPS system development. A set $K(\theta)$ may be expressed in the state space as a multi-dimensional vector of the EPS system development state in the following form [17, 26-33]:

$$\mathbf{K}_i(\theta) = [K_1(\theta) \quad K_2(\theta) \quad \ldots \quad K_n(\theta)]^T \tag{6}$$

and some components of the vector of the EPS system development state may constitute probability distributions.

The above formulation gives the possibility to use dynamics of systems development [1, 4, 6-20, 26-34], with the assumption that the researcher is not interested in the functioning of the system but in its development and, consequently, methods that allow to study and examine regularities in the development. Thus, as such, the EPS system and its subsystems are interesting from the point of view of the changes in the values of $K_i(\theta)$ (i=1-n) in long time $\theta$, which took place because of deliberate actions taken by the designers, producers, users, etc. of the system. These actions were taken in the form of control influences $s(\theta)$ as technical influences, economic influences or influences in the form of user requirements. Changes in the structure of the EPS system may be measured using the derivative of the state development vector $\boldsymbol{K}_i(\theta)$, i.e.

$$\frac{d\mathbf{K}_i(\theta)}{d\theta} = J[(K_1, K_2, ..., K_n), K_i(\theta) = C_i], \tag{7}$$

and: $C_i$ (i=1,2,...,n) specifies the initial state of the EPS system structure, $\theta$ – long time as an independent variable of the EPS system development process, $K_i(\theta)$ - components of the EPS system development state vector.

The development of the EPS system in the years 1946-2007 was multi-stage in nature. Thus, successive states of the EPS system were influenced by previous states, e.g. resulting from the stream of technical and economic information connected with various epochs. The pace of changes of the EPS system state vector also results from the multi-stage nature of changes, and it depends not only on the current state but also on the form of the system in the past, which may be expressed as follows:

$$\frac{dK_i(\theta)}{d\theta} = J[(K(\theta), K_1(\theta-\theta_1),..., K_n(\theta-\theta_1)), K_0(\theta) = C]. \tag{8}$$

It is necessary to emphasize that that the change of the transition process in time $\theta$, and not the course of the transition process as it is considered in the dynamics of systems functioning, is important for the processes of the EPS system development. In the EPS development, there occur two opposing processes, namely a process of the EPS system operation and a related process of ageing of the system as well as a process of improvement of the system and related process of modernization (a process of positive development of the system, modernization). Thus, if, as a result of the EPS system development, new states of the system characterized by transition processes gradually becoming gentler are obtained, the system seems to gradually improve[3]. Therefore, from the point of view of the development of the system, the functioning and development of the EPS system may be expressed jointly in the following way:

$$\frac{d\mathbf{K}_i(K,\theta,t)}{d\theta} = J[\mathbf{K}(K,\theta,t), \mathbf{K}_0(K,\theta,t) = C], \tag{9}$$

where: K – a set of parameters of the electrical power system development, θ – long time of the electrical power system development, t – short time of the electrical power system operation in one period of development $\theta_i$.

Thus, the vector of state development in (9) in relation to θ provides information about development, and in relation to t - information about dynamic properties connected with the system operation. Thus, there occurs one dynamic function **K**(K,θ,t), jointly comprising the dynamics and the development of the EPS system, and examination of the system was brought down in this work to states expressed in the following way:

$$\frac{dK_i(K,\theta,t=const)}{d\theta} = J[K(K,\theta,t=const), K_0(K,\theta,t=const) = C], \tag{10}$$

What seems interesting in this case is the change in the quality of successive states of the EPS system. And this work focuses on this case of the EPS system development, i.e. the case connected with its structural and parametric changes for the situation $t=0$ or $t=const$ seen from this perspective.

[3] In the theory of control and systems it is possible to speak about gentler processes when the shapes of characteristics become less steep and, consequently, the anticipated responses are more predictable. In the case of the SEE system operation, the quality of the system becomes worse as θ increases, which is reflected in the worse shape of the characteristics of the transition process (in short an ageing process occurs).

To show a clear-cut difference between the behaviour of characteristics of the EPS system in the function of operation time *t* and the behaviour of characteristics of the system in the function of time of the system structure development, it is possible to make a simple comparison of behaviour of such characteristics as deflection, time of the initial process establishment (transition process), or the number of pulsations in the initial process. It is also worth mentioning that characteristic quantities are not characteristics of the system operation, and which, in turn, are not characteristics of the EPS system development. Characteristic quantities of physical systems are quantities which assume appropriate values and shape the system, influence and decide about its weight, dimensions, physical properties, functional usefulness, etc.

In the process of operation (a course of physical process in short time t) these quantities change as a result of the operation of the system (its wear) and they change their values. As a result of development (long time $\theta$) the structure of machines, devices and systems changes, and sometimes, as a result of technology upgrade, physical process also changes, which results in the changes in the set of these quantities (the existing quantities disappear and new quantities appear, properties of the existing quantities change, etc.). Sets of these quantities are bounded from below and above, which may apply to certain external characteristics of the physical system (e.g. occurring capacities, inductance, energy characteristics, etc.) as well as certain characteristics of physical phenomena (e.g. maximum voltage, permissible frequency, etc.). Depending on the degree to which individual characteristic quantities influence the above mentioned characteristics, we may distinguish sensitive and insensitive characteristic quantities. Their positions may be marked on the characteristics. However, we may also speak about generalized characteristics, such as efficiency characteristics and characteristics of the safety of the EPS system development. It is also possible to speak about evaluation characteristics or ageing as well as characteristics of the electrical power systems development [23, 26-33].

Moreover, it is necessary to add that the EPS system, seen from this perspective, should only be treated as a technical object, and it should be used to study only working processes, i.e. material and energy flows, i.e. power and electrical energy transfer. One may also study it as an object of management and distinguish information-decision flows in it - e.g. functioning of the Energy Regulatory Office, etc. as a regulation system for the EPS system. Finally, it can be seen as a control system, in which it is possible to distinguish processes of energy flow and transfer services flow as well as processes connected with the flow of financial means.

It was assumed that the EPS system comprises control processes, i.e. takes into account processes connected with physical flow of energy and services (realization system) and oppositely directed processes connected with the flow of information and financial stream (control system), which allows to distinguish in the EPS development model energy and material processes as well as oppositely directed information and financial processes. The development of the EPS system presented in this way comes down to examining regularities in the development of the EPS system treated as a technical-economic system, where: $\bar{u} = \{u_1, u_2, ..., u_n\}$ - a set of quantities influencing the system e.g. a set of input quantities, $\bar{y} = \{y_1, y_2, ..., y_n\}$ - a set of external quantities of the system e.g. output quantities.

Thus, based on the theory of control and systems, the EPS system is composed of two sub-systems: a control system and the object of control, and in the object of control there occur working (technological) processes and in the control system - processes responsible for the organization of operation, i.e. processes that decide about the degree to which working (financial) processes are used.

When studying regularities in the EPS system development over years, i.e. taking historical data into account, it is significant to examine individual characteristic quantities as regards sensitivity to structural changes and parametric changes. It may turn out that small change in the value of the quantity $K_i(\theta)$ may result in significant improvement in the quality of the EPS system development, and, in another case, even a significant change of these quantities may not result in any changes at all, and even result in the deterioration of the quality of the system. Therefore, it is important to determine, which artificial genes, i.e. which values $K_i(\theta)$ are able to improve the quality of the system, and, to what extent. Among problems connected with the EPS system development, there is a problem connected with control of development using specified characteristic quantities, in this case using specified artificial genes. Mathematical description of the EPS system development control, as a technical-economic system, in accordance with information about technical, economic changes and about the change of the EPS system users requirements that appear in specified time is important. Hence, the following model of the EPS system development may be adopted in order to jointly present working and control processes:

$$\frac{dK}{d\theta} = J[K(\theta), s(\theta), r(\theta)] \tag{11}$$

where: $s(\theta)$ – control vector, $r(\theta)$ – vector containing technical and economic information, as well as information concerning users requirements (interference vector).

Examination of the EPS system development state changes in the state space expressed using (11) depends on the current value of the development state described by vector K(θ), the control vector (usually external input functions) s(θ) and the vector of technical, economic and functional information r(θ), which can be jointly written in the following form:

$$\frac{d\mathbf{K}(K,\theta)}{d\theta} = \mathbf{A}(K,\theta)\cdot\mathbf{K}(\theta) + \mathbf{D}(K,\theta)\cdot\mathbf{s}(\theta) + \mathbf{r}(\theta), \tag{12}$$

where: $A(K,\theta)$ – development process matrix, $D(K,\theta)$ – control matrix, $K(\theta)$ – state vector.

If the process is of n-th rank, then matrix $A$ is a square matrix n x n with constant coefficients, and the process is linear and non-stationary process. However, when the process and control matrices depend on time θ, the process is linear and the parameters are random.

It is worth noticing here that there occurs a special case for short time t=const (dependence 15), i.e. **A**(K,θ) is a square matrix n x n with constant coefficients, which ensure linearity (in relation to t - which results from the formula). It may be added that in relation to t, the process is a stationary process, with the parameters independent of short time t for a given stage of development $\theta_i$, but the process is a non-stationary process in long time θ (the matrix of process **A** and control matrix **B** depend on long time θ) or a process with random parameters if the above mentioned matrices depend on random values of process development parameters. If matrices **A** and **B** do not depend on time θ, the process is stationary in relation to long time θ.

Examination of regularities in the EPS system development is not about solving equation (15) with the set initial conditions but it is about defining the model on the basis of the process of system identification, and finding artificial genetic code based directly on the model of the system, as well as studying sensitivity of changes in the model quality depending on changes of individual parameters and the EPS system structure.

In case of the development of the EPS system, understood as an integrated automated system (a system that develops in the same way as unmanned factory) work quality may be determined e.g. by the degree of control error (deviation) during the whole period of the EPS system operation, i.e. in long time θ. However, due to random nature of interference, analytical determination of the real course of the control error is not possible. Thus, it is convenient to perform the evaluation of the system development quality based on the features and parameters of processes that occur as a result of certain typical input functions, such as unit step, sinusoidal function, or other typical input functions. The quality (goodness) of control systems is evaluated using appropriately adjusted indexes of quality expressing technological, economic and other requirements the system must meet (in the theory of control and systems they include, i.a. the following regulation quality criteria: stability margin, distribution of the characteristic equation roots, time, frequency and integral criteria).

## 4. Models of the DEP system development

It is convenient to bring down the examination of regularities in the electrical power system (EPS system or EPS) development to studying structural changes and parametric changes of the system in long time θ. For this purpose, a problem of the EPS development may be bound with movement of roots on the complex variable plane s using the method of Evans root loci [35].

Parametric changes do not undermine the state of safe development of the system and the EPS system model. However, structural changes introduce an unsafe state of the development, both as regards the EPS system and model, which may result in a sudden change of characteristics, in the number and value of the state variable quantities as well as system's inputs and outputs.

Examination of stability of linear continuous and pulse systems comes down to examining the positions of characteristic equation roots using appropriate criteria of stability [7, 23, 35-36], which showed that some of the models obtained as a result of the identification process using data for years 1946-2007 [24], both arx and corresponding models in the state space, were unstable. These models as models of the EPS system development and models of the EPS model of development (metamodels) were discussed in detail in works [26-33]. Therefore, in this work, the author will only discuss certain tendencies resulting from these models, obtained based on the examination of the behaviour of the course of Evans root loci.

Due to the fact that in the obtained models of the EPS development (table I) some proper values (eigenvalues) did not have negative real parts, these models are unstable. Usually, stability of closed models, and not open models is examined. Therefore, the stability of the EPS development as a closed system was assessed in the work, with denominator's roots being assumed poles and roots of the transmittance enumerator being assumed zeros. Then, the problem of the EPS system development was bound with the movement of roots on the complex variable plane s using Evans root loci method, and making amplification factor variable. Movement of roots along the existing root locus was obtained when the parameters of the system were changed (k as a cumulated amplification parameter) and appearance or disappearance of root loci in case of structural changes was observed.

Unstable development may be caused by the physical nature of the EPS development itself (some physical processes in the system may have a tendency towards unstable development, e.g. imposed emission restrictions, construction errors of the systems and elements of the EPS as a technical system, technological errors, especially those resulting from cooperation of new technologies connected with renewable power engineering with the existing elements of the EPS system, etc.

<table>
<tr><td colspan="2">Table I. Models of the EPS system development<br>FOR THE OUTPUT ELECTRICAL POWER CONSUMPTION AND 14 INPUTS<br>(YEARS 1946-2007)</td></tr>
<tr><td>arx111<br>90,1%<br>u1<br>y21<br>46-75</td><td>A(q) = 1 + 0.1786q^-1, B1(q) = 2.162q^-1, B2(q) = 5.626q^-1, B3(q )= 223.9q^-1, B4(q) = -2.289q^-1,bB5(q) = 1.255q^-1<br>B6(q) = 0.2639q^-1, B7(q) = -10.66q^-1, B8(q) = -0.003189q^-1, B9(q) = 1.261q^-1, B10(q) = -2.09q^-1, B11(q) = -1.822q^-1, B12(q) = -4.284q^-1, B13(q) = 27.43q^-1B14(q) = -18.55q^-1, $ans5 = [-0{,}1786]$</td></tr>
<tr><td colspan="2">$\mathbf{B1} = [2.162 \quad 5.626 \quad 223.8853 \quad -2.2886 \quad 1.2551 \quad 0.2639 \quad -10.6557 \quad -0.0032 \quad 1.2615 \quad -2.0896 \quad -1.8219 \quad -4.2842 \quad 27$<br><br>$\mathbf{A1} = [-0.1786]$ $\mathbf{C1} = [1]$, $\mathbf{D1} = [0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0]$, $C_{E1} = 2.162 \cdot \frac{1}{(s+0.1786)(s-2.1620)}$</td></tr>
<tr><td>arx113<br>98,7%<br>u5<br>y25<br>50-79</td><td>A(q) = 1 - 1.554q^-1, B1(q) = 0.0157q^-3, B2(q) = -1.113q^-3, B3(q) = -106.2q^-3, B4(q) = -78.44q^-3, B5(q) = -0.4607q^-3, B6(q) = 0.05317q^-3, B7(q) = 0.3395q^-3, B8(q) = 0.05702q^-3, B9(q) = -0.3424q^-3, B10(q) = -0.4439q^-3, B11(q) = -0.3456q^-3, B12(q) = -4.166q^-3, B13(q) = 6.395q^-3, B14(q) = -0.923q^-3, $ans5 = [1{,}5545 \quad 0 \quad 0]$</td></tr>
<tr><td colspan="2">$$\mathbf{B5} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0{,}9157 & -1{,}1125 & -106{,}2195 & -78{,}4388 & -0{,}4607 & 0{,}0532 & 0{,}3395 & 0{,}0570 & -0{,}3424 & -0{,}4439 & -0{,}3456 & -4{,}1656 & 6 \end{bmatrix}$$<br>$$\mathbf{A5} = \begin{bmatrix} 1{,}3345 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \; \mathbf{C5} = [1 \quad 0 \quad 0], \quad \mathbf{D5} = [0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0]$$<br>$$C_{E5} = 0{,}0157 \cdot \frac{1}{s^2(s+1{,}5545)}$$</td></tr>
<tr><td>rx112 98,6%<br>u10<br>y210<br>55-84</td><td>A(q) = 1 - 1.766q^-1, B1(q) = 0.03545q^-2, B2(q) = 0.06842q^-2, B3(q) = 83.57q^-2, B4(q) = -1.584q^-2, B5(q) = 0.1385q^-2,<br>B6(q) = -0.09277q^-2, B7(q) = -2.464q^-2, B8(q) = 0.02396q^-2, B9(q) = -0.2675q^-2, B10(q) = -2.324q^-2, B11(q) = -0.7672q^-2, B12(q) = 2.762q^-2, B13(q) = 17.04q^-2 , B14(q) = -4.71q^-2</td></tr>
<tr><td colspan="2">$$\mathbf{B10} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0{,}0354 & 0{,}0684 & 83{,}5675 & -1{,}5837 & 0{,}1385 & -0{,}0928 & -2{,}4637 & 0{,}0240 & -0{,}2675 & -2{,}3241 & -0{,}7672 & 2{,}7618 & 1 \end{bmatrix}$$<br>$$\mathbf{A10} = \begin{bmatrix} 1{,}7656 & 1 \\ 0 & 0 \end{bmatrix} \mathbf{C10} = [1 \quad 0], \mathbf{D10} = [0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0], C_{E1} = 0{,}0354 \cdot \frac{1}{s(s+1{,}7656)},$$<br>$ans1 = [1{,}7656 \quad 0]$</td></tr>
<tr><td>arx111<br>90,067% u15<br>y215<br>61-90</td><td>A(q) = 1 + 0.1786q^-1B1(q) = 2.162q^-1B2(q) = 5.626q^-1B3(q) = 223.9q^-1B4(q) = -2.289q^-1B5(q) = 1.255q^-1, B6(q) = 0.2639q^-1, B7(q) = -10.66q^-1, B8(q) = -0.003189q^-1, B9(q) = 1.261q^-1, B10(q) = -2.09q^-1, B11(q) = -1.822q^-1, B12(q) = -4.284q^-1, B13(q) = 27.43q^-1B14(q) = -18.55q^-1<br>$\mathbf{A15} = [-0{,}1786]$</td></tr>
<tr><td colspan="2">$\mathbf{B15} = [2{,}162 \quad 5{,}626 \quad 223{,}8853 \quad -2{,}2886 \quad 1{,}2551 \quad 0{,}2639 \quad -10{,}6557 \quad -0{,}0032 \quad 1{,}2615 \quad -2{,}0896 \quad -1{,}8219 \quad -4{,}2842 \quad 27{,}43$<br><br>$\mathbf{C15} = [1]$, $\mathbf{D15} = [0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0 \; 0]$,</td></tr>
</table>

<table>
<tr><td colspan="2">$C_{E15} = 2{,}1620 \cdot \dfrac{1}{(s - 0{,}1786)}$ $ans15 = [-0.1786]$</td></tr>
<tr><td>arx113<br>98,7166%u20<br>y220<br>66-95</td><td>A(q) = 1 - 1.554q^-1, B1(q) = 0.0157q^-3, B2(q) = -1.113q^-3, B3(q) = -106.2q^-3, B4(q) = -78.44q^-3,<br>B5(q) = -0.4607q^-3, B6(q) = 0.05317q^-3, B7(q) = 0.3395q^-3, B8(q) = 0.05702q^-3, B9(q) = -0.3424q^-3, B10(q)=0.4439q^-3, B11(q) = -0.3456 ^-3, B12(q) = -4.166q^-3, B13(q) = 6.395q^-3, B14(q) = -0.923q^-3</td></tr>
<tr><td colspan="2">$B20 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0{,}0157 & -1{,}1125 & -106{,}2195 & -78{,}4388 & -0{,}4607 & 0{,}0532 & 0{,}3395 & 0{,}057 & -0{,}3424 & -0{,}4439 & -0{,}3456 & -4{,}1656 \end{bmatrix}$<br>$\mathbf{A}20 = \begin{bmatrix} 1{,}5545 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}$ $\mathbf{C}20 = [1 \quad 0 \quad 0]$ $\mathbf{D}20 = [0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]$ $C_{E20} = 0{,}0157 \cdot \dfrac{1}{s^2(s + 1{,}5545)}$<br>$ans20 = [1{,}5545 \quad 0 \quad 0]$</td></tr>
<tr><td>arx111<br>90.1%<br>u25<br>y225<br>71-00</td><td>A(q) = 1 + 0.1786q^-1, B1(q) = 2.162q^-1, B2(q) = 5.626q^-1, B3(q) = 223.9q^-1, B4(q) = -2.289q^-1,<br>B5(q) = 1.255q^-1, B6(q) = 0.2639q^-1, B7(q) = -10.66q^-1, B8(q) = -0.003189q^-1, B9(q) = 1.261q^-1,<br>B10(q) = -2.09q^-1, B11(q) = -1.822q^-1, B12(q) = -4.284q^-1, B13(q) = 27.43q^-1B14(q) = -18.55q^-1</td></tr>
<tr><td colspan="2">$\mathbf{B}25 = [2{,}162 \quad 5{,}626 \quad 223{,}8853 \quad -2{,}2886 \quad 1{,}2551 \quad 0{,}2639 \quad -10{,}6557 \quad -0{,}0032 \quad 1{,}2615 \quad -2{,}0896 \quad -1{,}8219 \quad -4{,}2842$<br>$\mathbf{A}25 = [-0{,}1786]$, $\mathbf{C}25 = [1]$ $\mathbf{D}25 = [0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]$ $C_{E25} = 2{,}1620 \cdot \dfrac{1}{(s - 0{,}1786)}$<br>$ans25 = [-0.1786]$</td></tr>
<tr><td>arx111<br>90,067%<br>u30<br>y230<br>76-05</td><td>A(q) = 1 + 0.1786q^-1, B1(q) = 2.162q^-1, B2(q) = 5.626q^-1, B3(q) = 223.9q^-1, B4(q) = -2.289q^-1, B5(q) = 1.255q^-1, B6(q) = 0.2639q^-1, B7(q) = -10.66q^-1, B8(q) = -0.003189q^-1, B9(q) = 1.261q^-1, B10(q) = -2.09q^-1, B11(q) = -1.822q^-1, B12(q) = -4.284q^-1, B13(q) = 27.43q^-1B14(q) = -18.55q^-1</td></tr>
<tr><td colspan="2">$\mathbf{B}30 = [2{,}162 \quad 5{,}626 \quad 223{,}8853 \quad -2{,}2886 \quad 1{,}2551 \quad 0{,}2639 \quad -10{,}6557 \quad -0{,}0032 \quad 1{,}2615 \quad -2{,}0896 \quad -1{,}8219 \quad -4{,}2842 \quad 2$<br>$\mathbf{A}30 = [-0{,}1786]$, $\mathbf{C}30 = [1]$, $\mathbf{D}30 = [0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0 \ 0]$, $C_{E30} = 2{,}1620 \cdot \dfrac{1}{(s - 0{,}1786)}$,<br>$ans30 = [-0.1786]$</td></tr>
</table>

## 5. Summary and directions of further research

The work shows that it is possible to obtain a model of development of the domestic electrical power system using stepping identification, which is connected with the preparation of appropriate numeric input and output data of the system, initial processing of data, selection of the arx model and its structure (determination of na, nb, nk) for each stepping model, determination of parameters evaluation (selection of the appropriate estimation algorithm), performing the verification of the model e.g. by comparing the signal obtained from the model with the real signal and interpretation of the model obtained as a result of identification.

As a result of identification, 33 arx models were obtained in the stepping system, which were then transformed into state variable models. It is important to examine the rank of matrices in the models of state variables and changes of their elements while studying regularities and tendencies in the development. The second part entitled *"Part 2. Analysis and interpretation of development"* is a continuation of this work.

## References

[1] Bolkowska B.: Planowanie systemu elektroenergetycznego w ujęciu teorii sterowania. Archiwum Energetyki nr 4/1974.
[2] Brown M., Do Coutto Filho M., Cesar Stacchini de Souza J.: Forecasting-Aided State Estimation – Part I: Panorama, IEEE Transactions on Power Systems, Vol. 24, No. 4, Nov. 2009, pp. 1667-1677.
[3] BrownM., Do Coutto Filho M., Cesar Stacchini de Souza J., Sergio Freund R., Forecasting-Aided State Estimation – Part II: Implementation, IEEE Transactions on Power Systems, Vol. 24, No. 4, Nov. 2009, pp. 1678-1685.
[4] Cegielski M, Kremens Z., Soberajski M.: Systemy elektroenergetyczne – teraźniejszość i przyszłość. Archiwum Energetyki nr. 1-2/1997.
[5] 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.
[6] Kacejko P.: Analiza systemu elektroenergtycznego w ujęciu obiektowym. PN PW. Elektryka z. 104/1998.
[7] Kaczorek T., Dzieliński A., Dąbrowski W., Łopatka R.: Podstawy teorii sterowania. WNT, Warszawa 2005.
[8] Kłos A.: Planowanie rozwoju systemu elektroenergetycznego. Poradnik Inżyniera Elektryka. Tom IV. Elektroenergetyka. Warszawa 1975.
[9] Krawiec F.: Ewolucja planowania rozwoju elektroenergetyki w ramach deregulacji. Zeszyty Naukowe, Wyd. Adam Marszałek. Toruń Vol. 6, 1998.
[10] Kremens Z., Sobierajski M.: Analiza układów elektroenergetycznych. WNT. Warszawa 1996.
[11] Kulczycki J.: Optymalizacja struktur sieci elektroenergetycznych. Warszawa. WNT 1990, s. 191.
[12] Kulikowski R.: Sterowanie w wielkich systemach. WNT. Warszawa 1974.
[13] Kwaśnicki W.: Ewolucyjny model rozwoju przemysłu – perspektywy badawcze i dydaktyczne. Ekonomista 4, 2000.
[14] Machowski J., Bialik J.: Power System Dynamice and Stability. J. Wiley 1996.
[15] Malko J.: Planowanie systemów elektroenergetycznych. PWN. Warszawa 1976.
[16] 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.
[17] Mulawka J.: Systemy ekspertowe. WNT. Warszawa 1996.
[18] Niebrzydowski J.: Problemy rozwoju systemów elektroenergetycznych. Wyd. PB. Białystok 1989.
[19] Paska J.: Niezawodność systemów elektroenergetycznych. OW PW, Warszawa 2005

[20] Rebizant W.: Metody inteligentne w automatyce zabezpieczeniowej. Monografie Nr 29 (93). OW PWr, Wrocław 2004.
[21] Sienkiewicz P.: Cybernetyczna teoria systemów rozwijających się. [w:] Sztuczna Inteligencja i Rozwój Systemów. Tom 1. ZG PTC – AP. Warszawa – Siedlce 1988.
[22] Sobierajski M., Wikosz K.: Sieci elektroenergetyczne a rynki energii elektrycznej. Problemy i Perspektywy. Prace Naukowe Instytutu Energoelektryki Politechniki Wrocławskiej. OW PWr. Wroclaw 2000.
[23] Staniszewski R., Sterowanie procesem eksploatacji. WNT. Warszawa 1990.
[24] Statystyka Elektroenergetyki Polskiej. Wydawnictwo Zjednoczenia Energetyków, Centrum Informatyki Energetyki, ARE S.A., Warszawa 1952-2004.
[25] Tadeusiewicz R.: Badanie właściwości układów samodzielnych współpracujących ze stochastycznie zmiennym środowiskiem. Postępy Cybernetyki. 4/1976.
[26] Tchórzewski J.: A Model of Electric Power System from the Point of View of its Growght. Development of the internal organization and control level on the basis of numerical data for the years 1999-2008. IEEE Modern Electric Power System, MEPS'2010, paper 08.3, Wroclaw 2010.
[27] Tchórzewski J.: Identification of Electric Power System from the Point of View of Development. Polish Journal of Environmental Studies. Vol. 18, No. 4B/2009.
[28] Tchórzewski J.: The Development Process of Electrical Power System as Unmanned Factory. Electrical Engineering, Poznan University of Technology. Academic Journals, No 59/2009.
[29] Tchórzewski J.: Development models of electric power system as a in MATLAB environment using to System Identification Toolbox. Materiały XIV Międzynarodowej Konferencji Naukowej pt. „Aktualne Problemy w Elektroenergetyce". PG, Jurata 2009.
[30] Tchórzewski J.: Systemowe wspomaganie procesu badania prawidłowości rozwoju systemu sterowania na przykładzie elektroenergetycznej sieci przesyłowej. Rozprawa nr. 58. A.P. Siedlce 1999.
[31] Tchórzewski J.: Badanie prawidłowości rozwoju systemu elektroenergetycznego. Cz. I. Wybrane modele rozwoju. Computer Applications in Electrical Engineering. IEEE PP, EEC PAN, IEEE Poland Section, PP, Poznań 2011, pp. 71-72.
[32] Tchórzewski J.: Badanie prawidłowości rozwoju systemu elektroenergetycznego. Part 2. Interpretacja rozwoju z wykorzystaniem linii pierwiastkowych Evansa. Computer Applications in Electrical Engineering. IEEP PP, EEC PAN, IEEE Poland Section, PP, Poznań 2011, pp.73-74.
[33] Tchórzewski J.: Electric Power System from Point of View of Model Development. [in:] Computer Applications in Electrical Engineering [ed.] Nawrowski R., POLI-GRAF-JAK, Vol. 8, Ponan 2010.
[34] Trzaska Z.: A Modelowanie i symulacja układów dynamicznych. Wyd. PW. Warszawa 1993.
[35] Wajs K.: Linie pierwiastkowe Evansa w automatyce. PWN. Warszawa 1973.
[36] Zajczyk R.: Modele matematyczne systemu elektroenergetycznego do badania elektromechanicznych stanów nieustalonych i procesów regulacyjnych. Wyd. PG. Gdańsk 2003.
[37] Zimmer A., Englot A.: Identyfikacja obiektów i sygnałów. Teoria i praktyka dla użytkowników MATLABA, Politechnika Krakowska. Kraków 2005.