A Model of Electric Power System from the Point of View of its Growth

Development of the internal organization and control level on the basis of numerical data for the years 1999-2008

Jerzy Tchorzewski
Institute of Computer Science
University of Podlasie
Siedlce, Poland
Jerzy.Tchorzewski@ap.siedlce.pl

Abstract - The paper proposes a model of the domestic electrical power system from the point of view of parametric development and structural development. A catalogue of models obtained for numerical data for the years 1946-2007 was used to create the model of development. The problem of development was linked with the movement of roots on the complex variable plane s. The paper presents selected research results for the output representing the total power achievable in power plants [24-30]. Attention was paid to the changes in the state variable matrices, especially to the transition matrix (A), responsible for the internal organization of the system and matrix B, responsible for the process of controlling the development.

Keywords: modern electric power system, unmanned manufactory, self-developing system, control theory, state space, identification of development, MATLAB and Simulink

I. INTRODUCTION

The research on the regularities of the domestic electrical power system (KSE) may be brought down to examining structural changes and parametric changes in long time θ [22]. In order to achieve it, the problem of KSE development may be linked with the movement of roots on the complex variable plane s and use the method of Evans' root lines [6, 24-30,32].

Parametric changes are connected with movement of roots along the existing root lines, and structural changes are connected with the appearance of new lines or disappearance of the existing ones. In case of the examined KSE system e.g. for the output y_1 concerning total achievable power, it turned out that the appearance of new values of coefficients (or roots) was characteristic of parametric changes while structural changes were connected with the appearance of a higher order polynomial or the reduction of the order of the polynomial, e.g. the appearance of new coefficients of polynomials or new roots. It is very imported when we want to obtain model of system KSE as unmanned manufactory [3.16,19.24-30].

Due to the fact that the technique of programming the development not only looks for the model of development but also for the rules of development in long time θ, an attempt was made to generalize the phenomenon of structural changes and parametric changes in the development of KSE system characterizing individual 30-year long periods of development in the years 1946-2007, with the step equal 1 year. The results of the research were published in papers [24-30]. Appropriate th models, obtained as a result of identification, their counterparts in the form of state and output equations, or in the form of a transmittance matrix as well as characteristics of changes of the matrix elements, were presented in the papers. Then, the problem of the KSE system development was linked to the movement of roots on the complex variable plane s [32].

II. DEFINING THE PROBLEM OF KSE DEVELOPMENT

A number of characteristics of Evans' root lines was obtained. Selected results generated for the output y_1, representing the total power achievable in power plants, were presented in table 1. In the studied case, the model of development was e.g. a model of state variables described by the state equation and the output equation, with the parametric changes being connected with the changes in the values of the elements of matrices **A, B, C, D** present in state and output equations. Due to the fact that the elements of matrix **A** are responsible for the internal organization of the KSE system, the elements of matrix **B** are responsible for the connections between the KSE system and the external surroundings by means of inputs, the elements of matrix **C** are responsible for the connections between the SEE system with the external surroundings by means of outputs, it was convenient to observe parametric and structural changes by observing the changes occurring in each state matrix [2,5,6,8-14,22].

In case of structural changes both the quantities and their number change as well as the ranks of matrices **A, B, C and D**, which results from including in the model new state variables, new inputs or outputs of the system (or resignation from the existing ones) as a result e.g. technological, organizational, etc. changes. Therefore, the structural changes of the KSE system result both from the change in the number of elements and the change of the relations between the elements.

On the other hand, the analysis of the KSE system resulting from the changes of the elements of matrices **A, B, C and D** in the state variable equations indicates that the KSE system as a developing system is characterized by the changeable structure, depends on long time θ and is susceptible (sensitive) to changes of the parameters of development.

It turned out that parametric changes do not disturb the state of safe development of the KSE system and the development of the electric power system. However, structural changes introduce the unsafe state of development both with respect to the model as well as the electric power system, the occurrence of which may result in sudden change in quantity characteristics and the values of state variable quantities as well as inputs and outputs [2,4,7,12,15,22,24].

Examining the stability of linear continuous or impulse-based systems may be brought down to studying the positions of the roots of characteristic equation by means of appropriate criteria of stability. It showed that some of the models, both arx models and the corresponding models in state space ss, obtained as a result of identification process, were unstable (some roots of characteristic equation were not located in the left semi-plane of the complex variable). Therefore, it is important to analyze the changes to avoid unstable development of the KSE system.

Due to the fact that in some models of development that were obtained, some real parts of the eigenvalues (characteristic values) the were positive, these models needed to be improved by introducing parametric and structural alterations. Stability of closed systems is examined most often. Therefore, the paper assesses the stability of the domestic electrical power system as a closed system, with the denominator's roots being the poles and the numerator's roots being zeros.

Then, the problem of the KSE system development was linked to the movement of roots on the complex variable plane s using the Evans' root lines method, and making the amplification coefficient k changeable. Movement of roots along the existing root lines was observed as the system's parameters changed (k - as a cumulated amplification parameter) and the appearance or gradual disappearance of root lines in case of structural changes (disintegration or integration of the existing zeros and poles of the transmittance) 5,17,21,31,33].

We may say, after Robert Staniszewski [21], that one-dimensional linear model of development of an electric power system is stable only when the values of parameters and the relations between them (structure) do not belong to the critical state of values of elements and relations, which is directly connected with the concept of development safety. In other words, a system of development i.e. an electric power system as a one-dimensional, linear system is unstable when critical states may occur in the system that are defined by the physical nature of the processes undergoing in the electrical power system. The interpretation of this instability may be conducted by means of the analysis of the nature of the electric power system development [2,8,14,21,23].

The causes of the unstable development may be the physical nature of the KSE system development itself (some physical processes in the system of development may have a tendency to unstable development, e.g. imposed emission restrictions), construction errors in the systems and elements of the KSE system as a technical system, technological errors, especially resulting from the cooperation of new technologies concerning renewable energy with the existing KSE system [18,28].

Therefore, in order to eliminate the occurrence of unstable state of development of the domestic electric power system, the causes of unstable development have to be identified [24-30,24]. It makes it possible to design the development of the KSE in such a way so as to eliminate potential states of unstable development in the future. Thus, when unstable systems of development and unstable models of development occur, the efficient method to eliminate them is to design the system in such a way that no unstable states occur. This additionally proves the usefulness of this paper as it is necessary to study the systems and their models prior to the introduction of the development solutions.

Also, it must be emphasized that parametric changes only in some cases allow for a change in the distribution of zeros and poles on the complex variable plane s so as they are all located in the left semi-plane of the complex variable. However, the efficient method involves controlled structural changes, which, by means of the introduction of new zeros and/or poles, result in a different distribution of the existing zeros and poles, thus resulting in a new distribution of Evans' root lines [32].

Thus, the elimination of the instability of the system of the domestic electric power system is connected with the necessity to introduce parametric changes, and if this proves ineffective, with the need to introduce structural changes or even perform a system transformation, where it is especially important to eliminate the costs of the unstable work of the domestic electric power system and similarly unstable development of the domestic electric power system.

In the discussed experiment, the cause of the instability of the development were structural changes connected, i.a. with the technological changes, e.g. the introduction of new powers to the KSE system, the introduction of new power lines, as well as economic changes such as denomination of the Polish currency. It must be added that in the discussed case, we deal with the instability of the development of the KSE system and the instability of the model of development of the KSE system. Positive feedback (not negative one) is responsible for the development. Therefore, a temporary instability of the development should only be treated as a warning for the designers of the development.

III. ANALYSIS OF THE KSE SYSTEM DEVELOPMENT

Analysis of the KSE development may be conducted from different points of view. Due to extremely fast process of automation of the domestic electric power system, KSE, it is significant to conduct the analysis of development from the point of view of the growth of the internal organization of the KSE system and in order to develop a higher level of control, including the control of development. Evans' root lines method proved very useful in this respect [32].

A model of a subsystem was used as an example, which has an input u_1 - employment in power plants in total, and an output y_1- total power achievable in power plants. It turned out that in the studied period three models were present, i.e. the following model occurring in the periods of development 1946-1975 and 1950-1979:

$$C_1(s) = s - 0.5109, \tag{1}$$

which, as a result of structural changes and parametric changes transformed into the following model in the years 1955-1984:

$$C_2(s) = s^2 - 1.8934 \cdot s, \tag{2}$$

and, which, during the periods 1961-1990 and 1966-1995, 1971-2000, 1976-2005 changed back into the model described by the dependence (1), and then in the years 1978-2007 it assumed the following form, i.e.:

$$C_2(s) = s^5 - 1.2399 \cdot s^4. \tag{3}$$

Therefore, assuming that higher level of development is characterized by a higher level of complexity of the internal organization of the KSE system, we may talk about periods of faster and slower development of the KSE system, in the discussed case, especially from the point of view of the total achievable power (y_1) and changes concerning employment (u_1) [24-30].

Hence, in the discussed case, there is the following characteristic polynomial in the highest order:

$$C_2(s) = a_5 \cdot s^5 + a_4 \cdot s^4 + a_3 \cdot s^3 + a_2 \cdot s^2 + a_1 \cdot s + a_0, \tag{4}$$

in which respective coefficients in individual periods of development assumed values equal zero.

If we further write it down in the radical form, taking into account the possibility of making structural and parametric changes in the development, we obtain the following:

$$M_1(s) = (m_1 s - 0.5109), \tag{5}$$

which indicates that the only changes which might have taken place were connected with the coefficient m_1, responsible for parametric changes in the period.

Taking into account the fact that, the growth (expansion) of the system is connected with the appearance of another root, the following may be obtained:

$$M_1(s) = (m_1 \cdot s - 0.5109) \cdot (m_2 \cdot s - k_2), \tag{6}$$

and, after the transformation, the following is obtained:

$$M_1(s) = m_1 \cdot m_2 \cdot s^2 - (0.5109 \cdot m_2 + m_1 \cdot k_2) \cdot s + 0.5109 \cdot k_2. \tag{7}$$

Comparing coefficients from (2) and (7), we obtain the following:

$$\begin{aligned} & m_1 \cdot m_2 = 1, \\ & 0.5109 \cdot m_2 + m_1 \cdot k_2 = 1.8934, \\ & 0.5109 \cdot k_2 = 0. \end{aligned} \tag{8}$$

Thus, parametric and structural development was connected with the following parametric changes (k_2=0):

$$\begin{aligned} & k_2 = 0, \\ & m_2 = \frac{1.8934}{0.5109} \\ & m_1 = \frac{1}{m_2} = \frac{0.5109}{1.8934}. \end{aligned} \tag{9}$$

As a result of next structural changes, we obtain a polynomial which has the same form as the one before first changes took place, which means that the development is negative. The transition from (2) to (1) took place. Thus, the polynomial (1) might take the following form:

$$M_2(s) = (m_1 s - k_1) \cdot (m_2 s - 1.8934), \tag{10}$$

and, after the transformations, the following is obtained:

$$M_2(s) = m_1 \cdot m_2 \cdot s^2 - (1.8934 \cdot m_1 + m_2 \cdot k_1) \cdot s + 1.8934 \cdot k_1, \tag{11}$$

As a result of appropriate comparisons of coefficients in equation (1) and in equation (2) we obtain:

$$\begin{aligned} & m_2 = 0 \quad \text{lub} \quad m_1 = 0, \\ & k_1 = -\frac{0.5109}{1.8934}, \\ & m_1 = \frac{1}{1.8934} \quad \text{lub} \quad m_2 = -\frac{1}{k_1} = -\frac{1.8934}{0.5109}. \end{aligned} \tag{12}$$

Finally, as a result of next structural changes, the polynomial (5) was obtained, which was connected with other structural and parametric adjustments, i.e.:

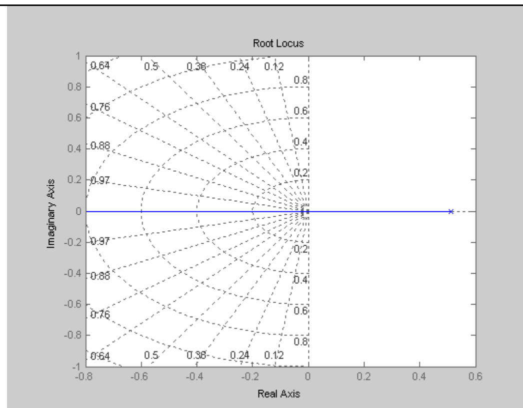
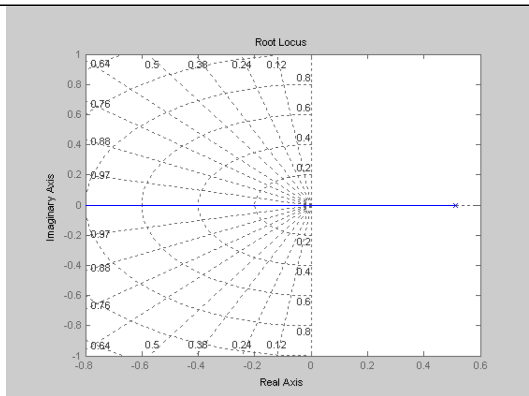
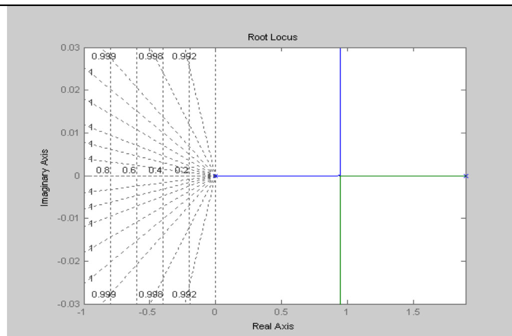
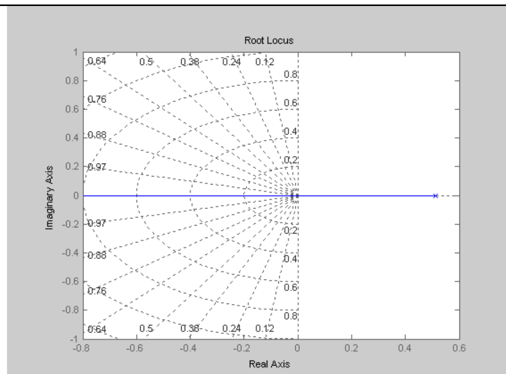
$$\begin{aligned} M_3(s) = & (m_1 \cdot s - 0.5109) \cdot (m_2 \cdot s - k_2) \cdot (m_3 \cdot s - k_3) \cdot \\ & (m_4 \cdot s - k_3) \cdot (m_5 \cdot s - k_5) \end{aligned} \tag{13}$$

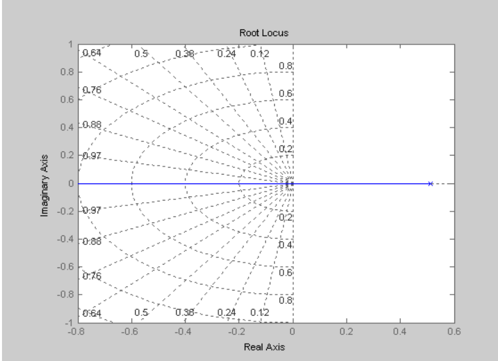
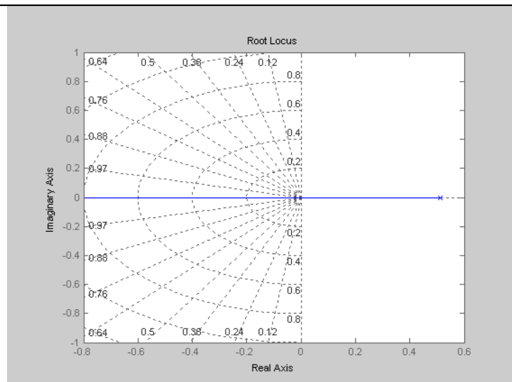
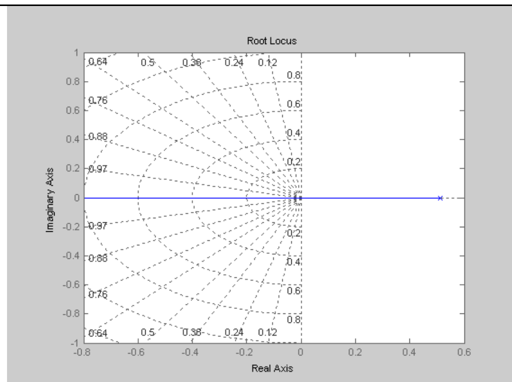
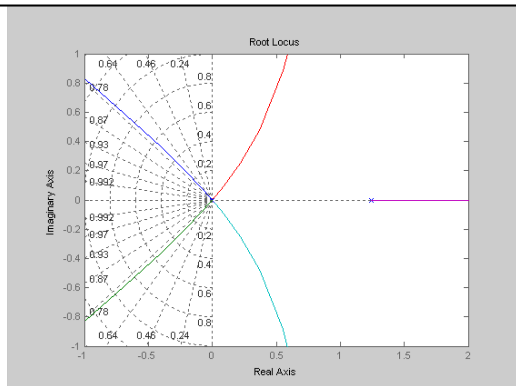
which indicates that structural development took place (4 new roots appeared) and that parametric changes accompanying structural changes also took place.

IV. SUMMARY AND DIRECTIONS OF FURTHER RESEARCH PODSUMOWANIE I KIERUNKI DALSZYCH BADAŃ

The results of development may also be analysed by studying the changes in positions of both the roots as well as Evans' root lines on the complex variable plane s (table 1).

An illustration of the relationship between the development and the course of Evans' root lines for the outpuy $y_1(K,\theta)$ - total achievable power (taking into account 14 inputs) Table 1

No.	years	Model	Characteristic	Evans' root lines
u1 y11	**1946-1975**	**arx111**	**(83.7845%)** KSE development in the 50s was a result of growing demand for electric power, mainly caused by power-consuming heavy industry, which, in turn, resulted in increasing the installed power to 6316 MW in 1960. The length of power lines with the voltage 220V was 1660 kilometres, and the system network with voltage 110 V was 9140 km long. The first international connection with the voltage 220 kV was finished in 1960 and in 1964 the first line with the voltage 400kV was completed, It was 317 km long. At the same time, a system generating power was expanded by two new units: 120 MW and 200 MW. This changes is reflected by the appearance of a new Evans' root line, along which parametric changes take place in this period of time. $C_{E1} = \frac{0.1566}{s-0.5109}$	
u5 y15	1950-1979	arx111	83.7845% In the period of 1975-1979, there were no structural changes, and the existing lines did not undergo any changes as well. In this period, parametric changes along one Evans' root line took place. In the 1970s, KSE system developed very fast, which was connected with the expansion of transmission power network 400kV, system network 100kV, introduction of transformer-based connections 400 kV/220 kV, 400 kV/110 kV, 220 kV/110 kV, the installation of 200 MW units, the introduction of 500 MW units and completion of the pumped storage power plant, which was a continuation of so far adopted direction of development. $C_{E5} = \frac{0.1566}{s-0.5109}$	
u10 y110	1955-1984	arx112	98.4917% The economic crisis in the years 1979-1985 resulted in the decreased consumption of electric power. As a consequence, the decision not to expand the transmission network 220 kV was made. Instead it was decided to expand the transmission network 400 kV and build the line 750 kV (year 1985). A pumped storage power plant was built (1982), power plants in Połaniec, Bełchatów and Opole. Structural changes appeared, which is reflected in the appearance of new Evans' root lines. $C_{E1} = \frac{0.1958}{s(s-1.8934)}$	
u15 y115	1961-1990	arx111	83.9845% In the years1984-1990 structural changes took place, the indication of which are the disappearance of Evans' root lines as well as the changes in the course of the only remaining line, along which parametric changes occur in this period of time. In the 80s, first indications of economic decline could be noticed. It was also the time when first PCs were produced, and decentralization of computing took place. In 1990, CDC 3170 system (used for making analyses off-line) was stopped being used, and CDC 1700 and 1774 systems were replaced by the DYSTER system (it started to be used in 1996). A new generation of remote control engineering together with optic fibre network with the throughput of 2.4 Gb/s were introduced. $C_{E1} = \frac{0.1566}{s-0.5109}$	

<table>
<tr><td rowspan="2">u20
y120</td><td>1966-1995</td><td>arx111</td><td>83.7845%</td><td rowspan="2">
</td></tr>
<tr><td colspan="3">In the years 1990-1995, parametric changes occur along one Evans' root line. Energy Law act comes into force, the market of electric power is created, the Electrical power Stock Exchange (GEE), distribution companies, turnover companies (PO), technical operators (OT), technical-trade operators (OT-H)[1] , etc. are created. However, these changes do not result in the restructuring of employment and do not change the relation in terms of the degree of automation of the KSE system. According to the forecasts concerning the energy consumption in Poland, domestic consumption is going to increase 80-93% by 2025[2].
$C_{E20} = \frac{0.1566}{s-0.5109}$</td></tr>
<tr><td rowspan="2">u25
y125</td><td>1971-2000</td><td>arx111</td><td>83.7845%</td><td rowspan="2">
</td></tr>
<tr><td colspan="3">In the years 1995-2000 further parametric changes occur along one Evans' root line, and there are still problems as regards privatization of electrical power engineering industry, which makes effective investment policy more difficult, as regards the development of KSE system.
$C_{E25} = \frac{0.1566}{s-0.5109}$</td></tr>
<tr><td rowspan="2">u30
y130</td><td>1976-2005</td><td>arx111</td><td>83.7845%</td><td rowspan="2">
</td></tr>
<tr><td colspan="3">In the period of 2000-2005 there were no structural changes, which is indicated by the fact that the number of Evans' root lines did not change and the there were no changes in the course of the only existing Evans' root line. In this period, parametric changes occur along one Evans' root line.
$C_{E30} = \frac{0.1566}{s-0.5109}$</td></tr>
<tr><td rowspan="2">u33
y133</td><td>1978-2007</td><td>arx115</td><td>97.5939%)</td><td rowspan="2">
</td></tr>
<tr><td colspan="3">In the years 2005-2007, further structural changes occurred, which is indicated by the appearance of four new root lines and the changes in the course of the existing line. In this period parametric changes occur along five Evans' root lines.
Moreover, cogeneration technologies used so far, often have low index of association i.e. proportion of electrical power production to heat production. The cause of insufficient development of cogeneration technologies are economic (financial), legal, administrative and social barriers. Taking into account the level of development of technologies currently used in the field of electrical power engineering, technical barriers are of little importance.
$C_{E33} = \frac{-0.0043}{s^4(s-1.2399)}$</td></tr>
</table>

[1] According to the Energy Law, the target model of the electric power market is based on access of third parties to electric power networks (TPA). Moreover, the Polish model of the market allows to make bilateral deals, transactions on the stock exchange and the balance market, managed by the Transmission System Operator (OSP). PSE S.A. acts as the Transmission System Operator. This solution conforms to the European Union directive 96/92/EC

[2]Announcement by the Minister of Economy and Labour of 1 July 2005 concerning domestic energy policy by 2025 (M.P. of 22 July 2005)

The paper presents selected results of research concerning the development of the domestic electric power system. The paper is one of a series of papers devoted to finding a model of the KSE system. Thus, the results of identification, obtained in previous papers, were used in this paper. They were in the form of appropriate models of development, which were then used to link the problem of development to the movement of roots on the complex variable semiplane s [24-30].

Visualization of the development was obtained, and the analysis of development was conducted using as the example the output representing total achievable power. The research is continued as regards thorough analysis concerning internal organization of the KSE system as well as its higher level of development.

It was noticed that it is also possible to conduct analytical research using characteristic polynomials obtained for each period of development. The change in the number of roots and their values indicated structural changes and parametric changes.

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