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Development of the electrical power system from the point of view of unmanned factories

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Fundamentals of systems and control theory as well as systems development identification theory were used for the purpose of the DPS identification, which allowed to generate models of development, including models of development in the form of matrix **th** and the equations in the states space (ss). This served as the basis to develop the systemic model of the DPS system development, which was implemented in Simulink, by defining successive blocks of the model as characteristics of individual subsystems of the DPS, identified in the MATLAB environment using the System Identification Toolbox, and transformed into the models in the state space using the Control System Toolbox. As a result of solving a set of equations of state variables using an m-file in the MATLAB environment three state variables were obtained. Based on the obtained solution, responses of the DPS system (output variable y_1) to the following types of input functions: unit step $1(\theta)$, Dirac impulse $\delta(\theta)$ and $\sin(\theta)$ function were obtained. The results of experiments were interpreted. An attempt to design a system that corrects and adjusts the functioning of the model of the DPS was made using state regulator and state observer as an example.

KEYWORDS: unmanned factories, identification, models of development, states space, electrical power system development, MATLAB and Simulink

1. DPS as an unmanned factory

1.1. Unmanned factories

Studies on unmanned factories have been initiated towards the end of the 20th century in Japan and Taiwan, followed by China and South Korea. At the beginning of the 21st century, EU countries, which have taken interest in unmanned factories mainly due to the problem of ageing society and the necessity to make mass production cheaper, started to catch up with the highly integrated, automated and robotized flexible production of Asian countries [9, 17-25].

The related literature, the term super infrastructure has been used for a long time. The above mentioned infrastructure consists of electrical power system (EPS or EP system) that is highly integrated with teleinformatics (PCC - Power Communication and Computer), which results in, i.a., increased reliability, effectiveness and security of power and energy deliveries [4, 17-25].

As regards reliability increase of the EP system in terms of technical systems development oriented at unmanned factories, the main goal is, i.a. studying the resistance of systems to catastrophic failures and methods to prevent such failures, which requires the implementation of flexible control systems in electrical power networks (FACTS).

Within this study, an attempt was made to contribute to this new direction of science, by developing the model of the EPS development with view to using it to search for regularities in structural changes and parametric changes in terms of unmanned factories. Consequently, using the data base of the domestic electrical power system (DPS), a new method of studying the EP system development directed at unmanned factory was proposed, which method distinguished parametric and structural changes in the development [1, 10, 14-15, 17-25].

Following the development of the EPS system development using changes of the elements of the polynomials of the arx model (polynomials: A(q) and B(q)) or the elements of matrices occurring in the control model in the states space (matrices A, B, C and D) as an example, indicates the developmental tendency of the EP system, particularly the changes of its aggregated parameters and changes of structure [2, 4, 16-25].

1.2. The essence of controlling the development

The development of the EPS system, understood as the development of the devices and machines it consists of, comprises a catalogue of actions aimed at rational use and handling of the EPS system according to the plan of demand for energy and power in long time (θ) [15-25]. Control of the operation process comprises alternating actions such as use control and handling control. Control of the EPS system development is a separate issue. Its task is to introduce changes of the parameters of the system, and, if this fails to produce the desired results, introduce changes in the structure of the system.

Control of use is aimed at such start up and functioning within the EPS system, which, in certain interference situation leads to control of the functioning of the EPS system according with the anticipated plan of consumption of power and energy by the recipients. Control of handling is the second component of the process of control of operation of the EPS system, which process consists of diagnostic inspections, repairs, functional tests, periodic overhauls, etc.

It has two aspects, the optimal setting of individual actions in time and linking them to the schedule of use and effective control within the realization of each handling activity. The basis for the development of the plan of control of handling is the characteristic of operation wear and tear and natural ageing of the EPS system $h(t)$ [15, 17-25]. Subsystems, systems, devices, machines, elements, which make up the EPS system also have the same characteristic.

Control of the development of the EP system is extremely difficult due to the lack of adequate models, which, at present, may only be obtained by means of identification modelling (identification). In the related literature on control of large systems development, attempts have been made to develop models of development since the end of the 20th century. The work by R. Kulikowski "Control in large systems" (in Polish: "Sterowanie w wielkich systemach") [6], R. Staniszewski "Control of the process of operation" (in Polish: Sterowanie procesem eksploatacji" [15] and publications by the author of this paper [17-25].

Characteristic features of the EP system include: vastness and territorial distribution, continuous increase in demanded power, large investment and operational costs (that condition the use of methods dedicated to large systems for control of operation and development of the EP system). The assets of the system is real property, with its value doubling every 10 years [7, 13]. The EPS, in the control and systems theory, is a large system - multi input-multi output (MIMO), or isolated (dissipative), and increasingly self-tuning, controlled by a hybrid technical-personal system.

Electrical power parameters are: voltage, frequency, phase symmetry of voltages, content of linear distortions in the voltage curve, continuity of energy supply, etc., which, in the obtained model of the EPS system, find its place among aggregated parameters of the EPS.

1.3. Identification of the DPS as a developing system

An example of the model of the DPS obtained based on the experimental data for the years 1946-2007 for 14 output variables and one output y_1 representing total power that can be generated in power plants [MW] (MISO model)[1] in the states space, may be expressed by the following state and output equations [2, 4-5, 17-26]:

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0,13 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} +$$

$$+ \begin{bmatrix} 0,34 & -0,2 & -5,19 & -14,5 & 0,16 & 0,01 & -0,05 & -0,003 & 0,03 & 0,09 & 0,13 & 0,02 & -0,03 & -0,02 \\ -0,05 & -0,78 & 0,37 & 9,72 & -0,05 & -0,03 & -0,28 & -0,01 & 0,11 & 0,3 & 0,06 & -0,01 & -0.13 & 0,32 \\ -0,14 & 0,33 & 29,52 & 14,17 & 0,07 & 0,01 & -0,61 & 0,03 & -0,03 & 0,15 & -0,05 & -0,01 & 0,23 & 0,03 \end{bmatrix} \cdot \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \\ u_7 \\ u_8 \\ u_9 \\ u_{10} \\ u_{11} \\ u_{12} \\ u_{13} \\ u_{14} \end{bmatrix} + \quad (1)$$

$$+ \begin{bmatrix} 0,1342 \\ 0 \\ 0 \end{bmatrix},$$

$$y_1 = [1 \quad 0 \quad 0],$$

[1] MISO – Multi Input Single Output

where: x_1 – state variable that can be interpreted as electrical power that can be generated in power plants (total) [kWh], x_2 - state variable that can be interpreted as maximum power of generators [MW], x_3 – state variable that can be interpreted as the rate of changes in the maximum power of generators during a year [MW/year].

A detailed flowchart of state variables developed based on the state and output equations (1) is shown in Fig. 1.

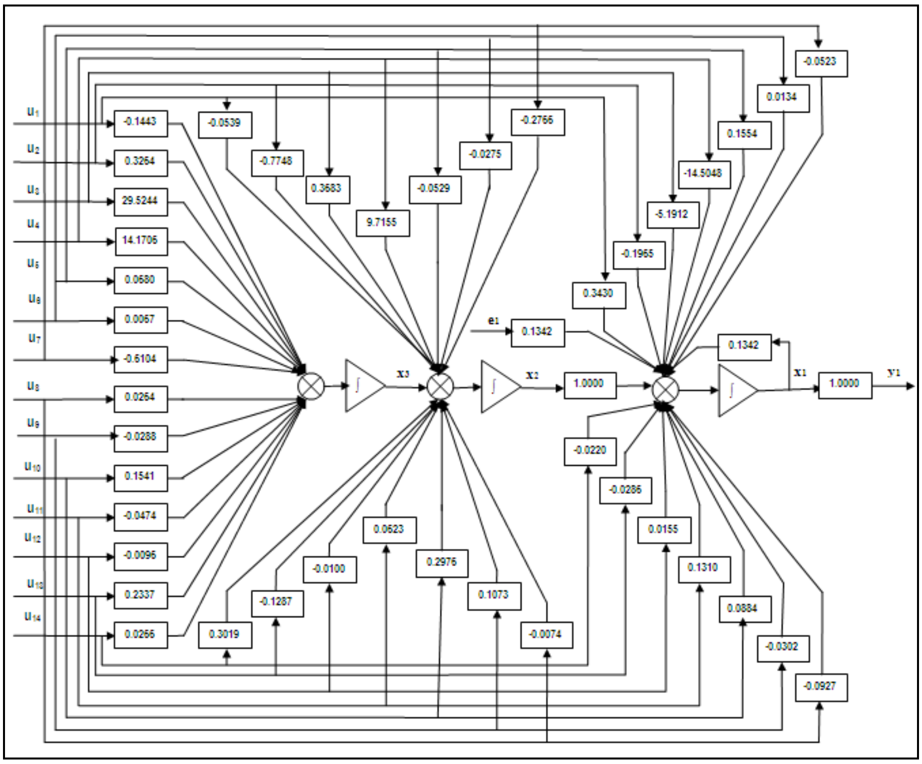

Fig. 1. Flowchart of state variables of the DPS model development for the years 1946-2007. Denotations in the text. Author's own compilation

The solution of the set of state and output equations (1) requires the determination of two components [1, 2, 4-5, 10, 15, 17]:

- free component dependent on the initial conditions:

$$x_s = e^{\mathbf{A}\theta} \cdot x(0), \tag{2}$$

- forced component:

$$x_w = \int_0^{\theta} e^{\mathbf{A}(\theta-\tau)} \cdot \mathbf{B} \cdot u(\tau) \cdot d\tau, \tag{3}$$

which requires, in the beginning, the determination of the elementary matrix (transition matrix) using the inverse Laplace transform.

$$e^{\mathbf{A}\cdot\theta} = \mathsf{L}^{-1}([s\cdot\mathbf{1}-\mathbf{A}]^{-1}), \tag{4}$$

with:

$$[s\cdot\mathbf{1}-\mathbf{A}] = \begin{bmatrix} s-0.13 & -1 & 0 \\ 0 & s & -1 \\ 0 & 0 & s \end{bmatrix}, \tag{5}$$

whose the determinant equals:

$$\det(s\mathbf{1}-\mathbf{A}) = s^2\cdot(s-0.13), \tag{6}$$

hence:

$$\left[s\cdot\mathbf{1}-\mathbf{A}\right]^{-1} = \frac{1}{\det(s\cdot\mathbf{1}-\mathbf{A})}\cdot\mathbf{A}_{\mathbf{D}}^{\mathbf{T}}, \tag{7}$$

where: $\mathbf{A_D}^{\mathbf{T}}$ is a transposed matrix of complements.

As a result of transformations the following was obtained:

$$[s\cdot\mathbf{1}-\mathbf{A}]^{-1} = \frac{1}{s^2(s-0.13)}\cdot\begin{bmatrix} s^2 & s & 1 \\ 0 & s(s-0.13) & s-0.13 \\ 0 & 0 & s(s-0.13) \end{bmatrix}, \tag{8}$$

and

$$e^{\mathbf{A}\cdot\theta} = \mathsf{L}^{-1}([s\cdot\mathbf{1}-\mathbf{A}]^{-1}) = \begin{bmatrix} e^{0.13\cdot\theta} & \frac{1}{0.13}(e^{0.13\cdot\theta}-1(\theta)) & \frac{1}{0.13}(\frac{1}{0.13}e^{0.13\cdot\theta}-\theta) \\ 0 & 1(\theta) & \theta \\ 0 & 0 & 1(\theta) \end{bmatrix}, \tag{9}$$

thus:

$$\mathbf{X}kse = e^{\mathbf{A}\cdot\theta}\cdot\mathbf{B}\cdot u(\theta) = \begin{bmatrix} e^{0.13\cdot\theta} & \frac{1}{0.13}(e^{0.13\cdot\theta)}-1(\theta)) & \frac{1}{0.13}(\frac{1}{0.13}e^{0.13\cdot\theta)}-\theta) \\ 0 & 1(\theta) & \theta \\ 0 & 0 & 1(\theta) \end{bmatrix} *$$

$$* \begin{bmatrix} 0{,}34 & -0{,}20 & -5{,}19 & -14{,}51 & 0{,}16 & 0{,}01 & -0{,}05 & -0{,}01 & 0{,}03 & 0{,}09 & 0{,}13 & 0{,}06 & -0{,}03 & -0{,}02 \\ -0{,}05 & -0{,}78 & 0{,}37 & 9{,}72 & -0{,}05 & -0{,}03 & -0{,}28 & -0{,}01 & 0{,}11 & 0{,}30 & 0{,}06 & -0{,}01 & -0.13 & 0{,}30 \\ -0{,}14 & 0{,}33 & 29{,}52 & 14{,}17 & 0{,}07 & 0{,}01 & -0{,}61 & 0{,}03 & -0{,}03 & 0{,}15 & -0{,}05 & -0{,}01 & 0{,}23 & 0{,}03 \end{bmatrix} \cdot \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \\ u_7 \\ u_8 \\ u_9 \\ u_{10} \\ u_{11} \\ u_{12} \\ u_{13} \\ u_{14} \end{bmatrix} \cdot (10)$$

and

$$\mathbf{Ykse}_1 = \mathbf{C} \cdot \mathbf{X}kse = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \cdot \mathbf{X}kse. \tag{11}$$

The results of responses of the DPS system (output variable y_1) on the following input functions: unit step 1(θ), Dirac impulse δ(θ), and the sin(θ) [4, 15, 17] obtained in Simulink are shown in table 1, with the solution of the set of equations of state variables being state variables expressed as follows:

$$\begin{aligned} x_1 = {} & (7.6736 \cdot e^{0.1342 \cdot \theta} + 1.0753 \cdot \theta - 0.4024 \cdot 1(\theta)) \cdot u_1 + (12.1333 \cdot e^{0.1342 \cdot \theta} - 2.4322 \cdot \theta + 5.7735 \cdot 1(\theta)) \cdot u_2 + \\ & + (1637.7976 \cdot e^{0.1342 \cdot \theta} + 220.003 \cdot \theta - 2.7444 \cdot 1(\theta)) \cdot u_3 + (845.1465 \cdot e^{0.1342 \cdot \theta} - 105.5932 \cdot \theta - 72.3957 \cdot 1(\theta)) \cdot u_4 + \\ & + (3.5398 \cdot e^{0.1342 \cdot \theta} - 0.5067 \cdot \theta + 0.3994 \cdot 1(\theta)) \cdot u_5 + (0.4358 \cdot e^{0.1342 \cdot \theta} - 0.0499 \cdot \theta - 0{,}0499 \cdot 1(\theta)) \cdot u_6 + \\ & + (-36.0245 \cdot e^{0.1342 \cdot \theta} - 4.5485 \cdot \theta - 0.0523 \cdot 1(\theta)) \cdot u_7 + (0.0889 \cdot e^{0.1342 \cdot \theta} - 0.1967 \cdot \theta - 0.0551 \cdot 1(\theta)) \cdot u_8 + \\ & + (2.4298 \cdot e^{0.1342 \cdot \theta} - 0.2147 \cdot \theta - 0.7996 \cdot 1(\theta)) \cdot u_9 + (10.8674 \cdot e^{0.1342 \cdot \theta} - 1.1483 \cdot \theta - 2.2179 \cdot 1(\theta)) \cdot u_{10} + \\ & + (-2.0381 \cdot e^{0.1342 \cdot \theta} + 0.3532 \cdot \theta + 0{,}4642 \cdot 1(\theta)) \cdot u_{11} + (-0.5923 \cdot e^{0.1342 \cdot \theta} + 0{,}715 \cdot \theta - 0.0745 \cdot 1(\theta)) \cdot u_{12} + \\ & + (1{,}2001 \cdot e^{0.1342 \cdot \theta} - 0.0745 \cdot \theta + 0.0715 \cdot 1(\theta)) \cdot u_{13} + (1.5974 \cdot e^{0.1342 \cdot \theta} + 0{,}1982 \cdot \theta - 0.1416 \cdot 1(\theta)) \cdot u_{14} + 0.1342, \end{aligned} \tag{12}$$

$$\begin{aligned} x_2 = {} & (-0.1443 \cdot \theta - 0.0539 \cdot 1(\theta)) \cdot u_1 + (0.3264 \cdot \theta - 0.7748 \cdot 1(\theta)) \cdot u_2 + 29.5244 \cdot \theta + 0.3683 \cdot 1(\theta)) \cdot u_3 + \\ & + (14.1706 \cdot \theta + 9.7155 \cdot 1(\theta)) \cdot u_4 + (0.068 \cdot \theta - 0.0528 \cdot 1(\theta)) \cdot u_5 + (0.0067 \cdot \theta - 0.0275 \cdot 1(\theta)) \cdot u_6 + \\ & + (-0.6104 \cdot \theta - 0.2766 \cdot 1(\theta)) \cdot u_7 + (0.0264 \cdot \theta - 0.0074 \cdot 1(\theta)) \cdot u_8 + (-0.0288 \cdot \theta + 0.1073 \cdot 1(\theta)) \cdot u_9 + \\ & + (0.1541 \cdot \theta - 0.2976 \cdot 1(\theta)) \cdot u_{10} + (-0.0474 \cdot \theta + 0.0623 \cdot 1(\theta)) \cdot u_{11} + (-0.0096 \cdot \theta - 0.01 \cdot 1(\theta)) \cdot u_{12} + \\ & + (0.2337 \cdot \theta - 0.1287 \cdot 1(\theta)) \cdot u_{13} + (0.0266 \cdot \theta + 0.3011 \cdot 1(\theta)) \cdot u_{14}, \end{aligned} \tag{13}$$

$$\begin{aligned} x_3 = {} & 1(\theta) \cdot (-0.1443 \cdot u_1 + 0.3264 \cdot u_2 + 29.5244 \cdot u_3 + 14.1706 \cdot u_4 + 0.068 \cdot u_5 + 0.0067 \cdot u_6 - 0.6104 \cdot u_7 + \\ & 0.0264 \cdot u_8 - 0.0288 \cdot u_9 + 0.1541 \cdot u_{10} - 0.0474 \cdot u_{11} - 0.0096 \cdot u_{12} + 0.2337 \cdot u_{13} + 0.0266 \cdot u_{14}), \end{aligned} \tag{14}$$

and the output variable:

$$\begin{aligned} y_1 = c_{11} \cdot x_1 = {} & (7.6736 \cdot e^{0.1342 \cdot \theta} + 1.0753 \cdot \theta - 0.4024 \cdot 1(\theta)) \cdot u_1 + (12.1333 \cdot e^{0.1342 \cdot \theta} - 2.4322 \cdot \theta + 5.7735 \cdot 1(\theta)) \cdot u_2 + \\ & + (1637.7976 \cdot e^{0.1342 \cdot \theta} + 220.003 \cdot \theta - 2.7444 \cdot 1(\theta)) \cdot u_3 + (845.1465 \cdot e^{0.1342 \cdot \theta} - 105.5932 \cdot \theta - 72.3957 \cdot 1(\theta)) \cdot u_4 + \\ & + (3.5398 \cdot e^{0.1342 \cdot \theta} - 0.5067 \cdot \theta + 0.3994 \cdot 1(\theta)) \cdot u_5 + (0.4358 \cdot e^{0.1342 \cdot \theta} - 0.0499 \cdot \theta - 0{,}0499 \cdot 1(\theta)) \cdot u_6 + \\ & + (-36.0245 \cdot e^{0.1342 \cdot \theta} - 4.5485 \cdot \theta - 0.0523 \cdot 1(\theta)) \cdot u_7 + (0.0889 \cdot e^{0.1342 \cdot \theta} - 0.1967 \cdot \theta - 0.0551 \cdot 1(\theta)) \cdot u_8 + \\ & + (2.4298 \cdot e^{0.1342 \cdot \theta} - 0.2147 \cdot \theta - 0.7996 \cdot 1(\theta)) \cdot u_9 + (10.8674 \cdot e^{0.1342 \cdot \theta} - 1.1483 \cdot \theta - 2.2179 \cdot 1(\theta)) \cdot u_{10} + \\ & + (-2.0381 \cdot e^{0.1342 \cdot \theta} + 0.3532 \cdot \theta + 0{,}4642 \cdot 1(\theta)) \cdot u_{11} + (-0.5923 \cdot e^{0.1342 \cdot \theta} + 0{,}715 \cdot \theta - 0.0745 \cdot 1(\theta)) \cdot u_{12} + \\ & + (1{,}2001 \cdot e^{0.1342 \cdot \theta} - 0.0745 \cdot \theta + 0.0715 \cdot 1(\theta)) \cdot u_{13} + (1.5974 \cdot e^{0.1342 \cdot \theta} + 0{,}1982 \cdot \theta - 0.1416 \cdot 1(\theta)) \cdot u_{14} + 0.1342. \end{aligned} \tag{15}$$

2. The development of the DPS

In case of the EP system development as an integrated automated system (a system that develops as an unmanned factory) the quality of work may be defined e.g. using the control deviation during the whole working period of the EPS, i.e. in the long time θ. However, due to the random nature of interferences, it is not possible to analytically determine the correct real course of the control error of the of the development system. Therefore, it is convenient to assess the quality of the development of the system based on the features and parameters of the processes that occur given certain typical input functions such as unit step, sinusoidal function or other typical input functions. Quality (goodness) of control systems can be assessed by means of properly selected quality indexes that express technological, economic and other requirements the system must meet. In the control and systems theory they include, i.a. the following regulation quality criteria: stability reserve, the distribution of the roots of the characteristic equation, time, frequency and integral criteria.

2.1. Evaluation of the quality of development of the DPS

If the input function [4, 15, 17] is:

1) sinusoidal, i.e. when u_1-u_{14}=sin(θ) (for ω=1) state variables may be expressed as follows:

$$\begin{aligned} x_1 &= (k_{11} \cdot e^{s_3 \cdot \theta} + k_{12} \cdot \theta + k_{13} \cdot 1(\theta)) \cdot \sin(\theta) + 0.1342, \\ x_2 &= (k_{22} \cdot \theta + k_{23} \cdot 1(\theta)) \cdot \sin(\theta), \\ x_3 &= k_{33} \cdot 1(\theta)) \cdot \sin(\theta), \end{aligned} \tag{16}$$

and: s_3 = 0.1342, k_{11} = 2 484,2353, k_{12} = 107,58, k_{13} = -72,2246, k_{22} = k_{33} = 43,6964, k_{23} = 8,9252, i.e. state variable x_1, i.e. output variable y_1 have the courses that result from 3 components: expotential component ($k_{11} \cdot e^{s3 \cdot \theta}$), rectilinear component $k_{12} \cdot \theta$ and unit step component with the value of k_{13} (state variables: x_2 and x_3, respectively),

2) unit step, i.e. when u_1-u_{14}=1(θ) state variables are equal:

$$\begin{aligned} x_1 &= (k_{11} \cdot e^{s_3 \cdot \theta} + k_{12} \cdot \theta + k_{13} \cdot 1(\theta)) \cdot 1(\theta), \\ x_2 &= (k_{22} \cdot \theta + k_{23} \cdot 1(\theta)) \cdot 1(\theta), \\ x_1 &= (k_{33} \cdot 1(\theta)) \cdot 1(\theta), \end{aligned} \tag{17}$$

3) Dirac impulse, i.e. when u_1-u_{14}=δ(θ) state variables are equal:

$$\begin{aligned} x_1 &= (k_{11} \cdot e^{s_3 \cdot \theta} + k_{12} \cdot \theta + k_{13} \cdot 1(\theta)) \cdot \delta(\theta), \\ x_2 &= (k_{22} \cdot \theta + k_{23} \cdot 1(\theta)) \cdot \delta(\theta), \\ x_1 &= (k_{33} \cdot 1(\theta)) \cdot \delta(\theta). \end{aligned} \tag{18}$$

Courses of state variables: x_1, x_2 and x_3 that occur in the DPS model (6.16), obtained in MATLAB environment as a result of solving a set of equations of state variables in time θ^2 are presented in Fig. 2 [17].

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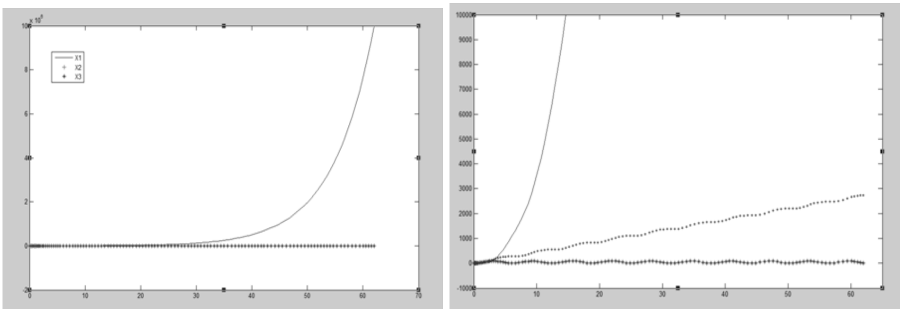
[2] Solving in time a set of equations of state variables in MATLAB using the ode45 function:

```
function xprim=kse1(tkse,xkse)
u=[sin(tkse);sin(tkse);sin(tkse);sin(tkse);sin(tkse);sin(tkse);sin(tkse);sin(tkse);sin(tkse);sin(tkse);sin(tkse);sin(tkse);sin(tkse);
sin(tkse);];
A=[0.1342 1 0; 0 0 1; 0 0 0];
B=[0.343013563367551, -0.196466073063211, -5.19121774603053,-14.5048469093668, 0.155364926402085,
0.0133508185876721, 0.0523419760633733, -0.00271779072167615, -0.0301527090971463, 0.0884092203462071,
0.130991507592293, 0.0154625644988539, -0.0285731557112965, -0.0219814655744797;
-0.0538712635106949, -0.774791061746606, 0.368263066405472, 9.71549145728839, -0.0529259182073755,
0.0275476833477622, -0.276563635485946, -0.00740840299183130, 0.107301367048242, 0.297567075473233,
0.0623074556509041, -0.00996107830542531, -0.128658322480848, 0.301927808385236;
```



a) b)

Fig. 2. Courses of state variables of the continuous model (ss133) of the DPS system described by the equations of state variables (1) for the input function sin(t): a) results for θ = 0 - 62 years, b) results for θ = 0 - 30 years. Denotations: axis y: x_1 – electrical power that can be generated during a year [kWh], x_2 – forecast power of generators during a year [MW], x_3 – rate of changes of the forecast power of generators during a year [MW/year], axis x – long time (θ) [years]. Author's own compilation in MATLAB

Detailed courses of individual state variables for the input function sin(t) are shown in Figs. 3-5.

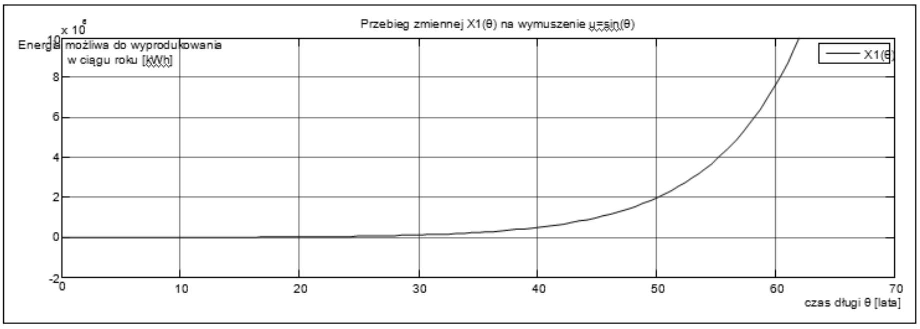


Fig. 3. The course of state variable x_1 (electrical power that can be generated during a year) that occurs in the continuous model (ss133) of the DPS system for the input function u = sin(θ) - results for θ = 0 - 62 years. Denotations: axis y: x_1 – electrical power that can be generated during a year [kWh], axis x – long time (θ) [years]. Author's own compilation in MATLAB

```
-0.144334900395375, 0.326373209014219, 29.5243564724218, 14.1705518163727, 0.0680336110776643,
0.00673903539076534, -0.610373279646815, 0.0263927369801369, -0.0288269565794885, 0.154056578872873, -
0.0473553534880257,-0.00960802128595807, 0.233658739059553, 0.0265544975310566;];
xprim=A*xkse+B*u;
end
Xkse0=[0;0;0;0];tkse0=0; tksee=61; [tkse,xkse]=ode45('kse1',[tkse0,tkkse],Xkse0); plot(tkse,xkse(:,1),'-', tkse,xkse(:,2),'.',
tkse,xkse(:,3),'*'); plot(tkse,xkse(:,1));
```

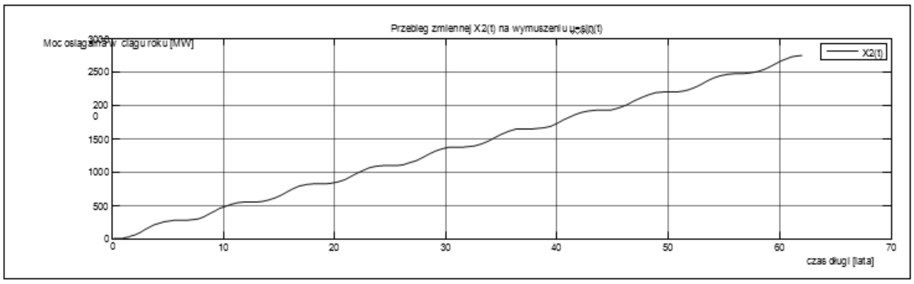


Fig. 4. The course of state variable x_2 (forecast power of generators during a year [MW]) that occurs in the continuous model (ss133) of the DPS system for the input function u = sin(θ) Denotations: axis y: x_1 – forecast power of generators during a year [MW], axis x – long time (θ) [years]. Author's own compilation in MATLAB

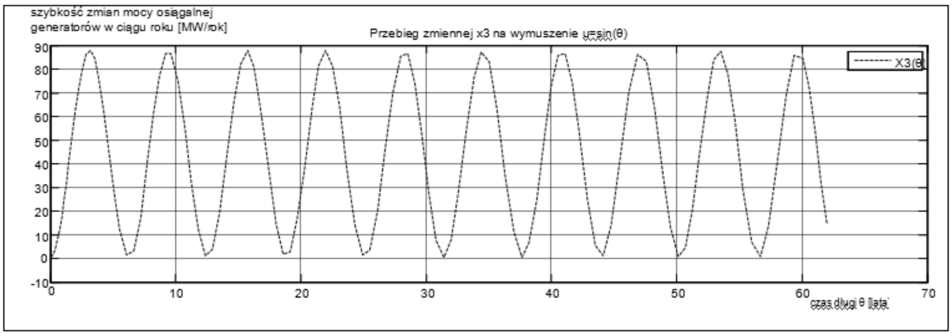


Fig. 5. The course of state variable x_3 (rate of changes of forecast power that can be generated during a year) that occurs in the continuous model (ss133) of the DPS system for the input function u=sin(θ) - results for θ = 0 - 62 years. Denotations: axis y: x_3 –rate of changes of power that can be generated by generators during a year [kWh], axis x – long time (θ) [years]. Author's own compilation in MATLAB

3. Correction systems related to the DPS model

Studying roots of the characteristic equation, i.e. i.a. elements of matrix **A** is significant from the point of view of the increase in the degree of the internal organization of the DPS, while studying i.a. elements of matrix **B** are significant as regards the change in the level of control. These problems were discussed i.a. in papers [17-25]. Research of this kind involve the support of the development of the EPS using methods provided by artificial intelligence, such as, i.a., expert systems, artificial neural networks and genetic algorithms [3, 12, 17-25], which is connected with the systemic view of control processes, functioning and development of the DPS, i.a., as regards the effectiveness and security, on the one hand, and the level of control and the internal organization of the DPS getting higher, on the other hand [4-6, 15-25]. Viewing development of the

DPS, taking the above mentioned criteria of control into account, leads to the following conclusions:

- the development of the DPS system that results from the course of variable x_1 (electrical power that can be generated during a year) is on the verge of stability, as two roots of the characteristic equation $s_{1,2}$ are equal 0,
- three components have an influence on the course of the state variable x_1, namely: the expotential ($k_{11}\cdot e^{\theta/T}$), linear $k_{12}\cdot\theta$ and step $k_{13}\cdot 1(\theta)$ course,
- time constant that occurs in the exponential characteristic of state variable x_1 (T_1) is negative and equals T_1= -1/0.1342= -7.4516,
- it may be observed that using the sinusoidal input function results in state variable:

a) x_1 returning to the state of balance of the expotential growth after a relatively short transitional state, induced by the sinusoidal input function (lasting 1.8 years in the long time of the system development, with the period of development equal 61 years - 2. 95%), i.e. state variable x_1 (power that can be generated during a year) with the sinusoidal input function has the course resulting from the expotentially damped sinusoidal vibrations ($k_{11}\cdot e^{s3\cdot\theta}$, attenuation rate is defined by s_3=0.1342), exponentially damped sinusoidal vibrations within the intervals of variability of the sinusoid along the straight line ($k_{12}\cdot\theta$) and sinusoidal vibrations along the straight line parallel to axis of time θ with the value k_{13} in the right semi-plane,

b) x_2 retaining the direction of changes as a result of the sinusoidal input function, with the changes being undamped oscillatorily ones (vibrations resulting from the course of sin(θ) appeared),

c) x_3 as a result of the sinusoidal input function had a sinusoidal course with undamped vibrations resulting from sin (θ).

3.1. Regulator of the state of the DPS development model

A dynamic set described in the state space by the state and output equations may be controlled using state vector, which is measured for the purpose of control. However, it is not always possible to measure the state vector, due to, i.a. technical reasons (measurements of certain physical elements cannot be performed), physical reasons (state vector may contain non-physical elements impossible to measure), and systemic reasons (state vector may contain historical, statistical elements, etc.) [11, 15].

In the case of the obtained model of the DPS development described by e.g. equations (1) state vector contains three components (state variables), two of which are generally possible to obtain (known), i.e. $x_1(\theta)$ – state variable that represents electrical power that can be generated in power plants (in total) [kWh] and $x_2(\theta)$ – state variable that represents maximum power of generators [MW] and one that cannot be obtained directly (directly from statistical, historical observation, etc.) i.e.

$x_3(\theta)$ – state variable representing the rate of changes of the power of generators that can be generated during a year [MW/year].

Difficulties resulting from measuring state variable $x_3(\theta)$ may justify the introduction of state observer $\hat{x}$, whose task is to reconstruct state vector **x** of the electrical power system (EPS or EP system) being observed[3] [4, 11, 15].

State observer $\hat{x}$ uses input signals to the EP system being observed $u(\theta)$ and output signals from the electrical power system being observed $y(\theta)$ to reconstruct the state vector **x**. State observer $\hat{x}$ may be used to determine the full state vector or its selected elements. In the first case, state observer $\hat{x}$ is and observer of the full order, in the second case, it is a reduced observer. System described in the state space may be controlled from the state vector and observed by the state observer provided that it meets the requirements of observability and controllability.

Asymptotic state observers, based on the structure of the system being observed, are used for the purpose of on-line reconstruction of state. State observer may easily be determined when matrices (**A**, **B**, **C**) of the EP system being observed are known, and state matrix **A** is asymptotically stable. Such an observer is realized by simulating a model of the EP system being observed.

The main problem that may occur for such an observer, is unfamiliarity of the initial conditions of the state vector **x**. An additional constraint is the dynamics of the observation error, which depends on the eigenvalues (proper values) of the state matrix **A**. Guaranteeing the asymptotic stability of the state matrix **A** of the observer, it requires modification by taking output signals from the EP system being observed into account.

3.2. State observer of the DPS development model

Using the available knowledge of the EP system, and specifically based on the knowledge of the EP system parameters described by matrices **A**, **B**, **C** and **D**, it is necessary to find a linear system, which, based on the known values of **u**(t) and **y**(t) will provide approximate value of $\hat{x}(t)$, state estimate **x**(t).

Assuming that in the case of the EP system being analyzed, it is worth determining full state vector x, using the Luenberger observer.

The basic idea behind the Luenberger observer involves adding to the considered stationary linear system, a stationary linear system whose inputs are

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[3] State observer $\hat{x}(t)$, also called state estimator in the control theory (state reconstructor) can be determined from the model of the real system, based on the knowledge of input variables and output variables. In most practical cases, it is not possible to determine the physical state of the system by direct observation. Instead, at the output of the system, one can observe direct effects caused by the internal state of the system. In such cases, it is necessary to use the systems that allow to estimate the state vector based on the output and control signals of the system. Systems that realize the above mentioned tasks are called state observers.

fed with signals u(t) and y(t) and which must generate the approximate value $\widehat{x}(t)$ of state x(t) at its output [11].

It results from these equations that both the current outputs of the system and their future state are defined by the current state of the system and current inputs of the system. If this system is observable, then the output of object y(t) may be used to steer the state of the state observer.

Model of the state observer for the physical system is usually derived from the above equations. They may contain additional expressions to ensure the convergence of the state model to the physical state of the system, following successive measured values of inputs and outputs of the objects.

In particular, the output of the observer may be subtracted from the output of the system and then multiply by the gain matrix of the convergence error **L**, this expression then being added to the observer state equations.

As a result, the so called **Luenberger observer** is obtained, defined by the equations below (in case of the linear system continuous time):

$$\begin{aligned}
\dot{\hat{\mathbf{x}}} &= \mathbf{A}\cdot\hat{\mathbf{x}}+\mathbf{B}\cdot\mathbf{u}+\mathbf{L}\cdot[\mathbf{y}-\hat{\mathbf{y}}],\\
\hat{\mathbf{y}} &= \mathbf{C}\cdot\hat{\mathbf{x}},\\
\hat{\mathbf{x}}(0) &= \hat{\mathbf{x}}_{\mathbf{0}}.
\end{aligned} \tag{19}$$

where, **L** - matrix of gains of the observer with the dimensions n x q, thus:

$$\dot{\hat{\mathbf{x}}} = \mathbf{A}\cdot\hat{\mathbf{x}}+\mathbf{B}\cdot\mathbf{u}+\mathbf{L}(\mathbf{y}-\mathbf{C}\cdot\hat{\mathbf{x}}), \tag{20}$$

and for the considered EP system(disregarding interferences):

$$\begin{bmatrix}\dot{\hat{x}}_1\\ \dot{\hat{x}}_2\\ \dot{\hat{x}}_3\end{bmatrix} = \begin{bmatrix}0{,}1342 & 1 & 0\\ 0 & 0 & 1\\ 0 & 0 & 0\end{bmatrix}\begin{bmatrix}\hat{x}_1\\ \hat{x}_2\\ \hat{x}_3\end{bmatrix} +$$

$$+\begin{bmatrix}0{,}343 & -0{,}1965 & -5{,}1912 & -14{,}5048 & 0{,}1554 & 0{,}0134 & -0{,}0523 & -0{,}0027 & 0{,}0302 & 0{,}0884 & 0{,}1310 & 0{,}0155 & -0{,}0286 & -0{,}022\\ -0{,}0539 & -0{,}7748 & 0{,}3683 & 9{,}7155 & -0{,}0528 & -0{,}0275 & -0{,}2766 & -0{,}0074 & 0{,}1073 & 0{,}2976 & 0{,}0623 & -0{,}01 & -0.1287 & 0{,}3019\\ -0{,}1443 & 0{,}3264 & 29{,}5244 & 14{,}1706 & 0{,}068 & 0{,}0067 & -0{,}6104 & 0{,}0264 & -0{,}0288 & 0{,}1541 & -0{,}0474 & -0{,}0096 & 0{,}2337 & 0{,}0266\end{bmatrix}\cdot\begin{bmatrix}u_1\\ u_2\\ u_3\\ u_4\\ u_5\\ u_6\\ u_7\\ u_8\\ u_9\\ u_{10}\\ u_{11}\\ u_{12}\\ u_{13}\\ u_{14}\end{bmatrix}+$$

$$+\begin{bmatrix}l_1\\ l_2\\ l_3\end{bmatrix}\cdot(y_1(\theta)-\hat{y}_1(\theta)). \tag{21}$$

Luenberger observer error $\mathbf{e} = \hat{\mathbf{x}} - \mathbf{x}$ satisfies the equation:

$$\dot{\mathbf{e}} = (\mathbf{A}-\mathbf{L}\cdot\mathbf{C})\cdot\mathbf{e}.$$

Expression

$$\mathbf{L}\cdot[y(\theta)-\hat{y}(\theta)]$$

is called the correction part of the state observer, and matrix **L** - matrix of gain of the convergence error. The observer is asymptotically stable when the observer error

$$\mathbf{e}=\hat{\mathbf{x}}-\mathbf{x}$$

which approaches zero, when k → ∞.

Luenberger observer for the considered discrete system is asymptotically stable if matrix

$$[\mathbf{A}-\mathbf{L}\cdot\mathbf{C}]$$

has all the eigenvalues inside the circle. For the purpose of control, the output of the observer of the EP system is fed back to the input of both the observer and the system through the so called gains matrix **K**:

$$\mathbf{u}(\theta)=-\mathbf{K}\cdot\hat{\mathbf{x}}(\theta). \tag{22}$$

The observer equations then assume the following form[4]:

$$\begin{aligned}\dot{\hat{\mathbf{x}}}(\theta)&=\mathbf{A}\cdot\hat{\mathbf{x}}(\theta)+\mathbf{L}(\mathbf{y}(\theta)-\hat{\mathbf{y}}(\theta))-\mathbf{B}\cdot\mathbf{K}\cdot\hat{\mathbf{x}}(\theta),\\ \hat{\mathbf{y}}(\theta)&=\mathbf{C}\cdot\hat{\mathbf{x}}(\theta).\end{aligned} \tag{23}$$

and finally:

$$\begin{aligned}\dot{\hat{\mathbf{x}}}(\theta)&=(\mathbf{A}-\mathbf{B}\cdot\mathbf{K})\cdot\hat{\mathbf{x}}(\theta)+\mathbf{L}(\mathbf{y}(\theta)-\hat{\mathbf{y}}(\theta)),\\ \hat{\mathbf{y}}(\theta)&=\mathbf{C}\cdot\hat{\mathbf{x}}(\theta).\end{aligned} \tag{24}$$

Due to the separation principle, matrices **K** and **L** may be chosen independently, without the negative impact on the overall stability of the EP system development. In practice, the poles of the observer [**A-L C**] are chosen to converge several times faster than the poles of the system **A-B K**.

Observer gain **L** is selected so as the error is asymptotically convergent to the zero (i.e. assuming that matrix [**A-L C**] is Hurwitz matrix). Eigenvalues of matrix [**A-L C**] may be selected by appropriate selection of observer **L** gain, assuming that the pair [**A**, **C**] is observable, i.e. the condition of observability is maintained[5]:

$$\begin{bmatrix}\mathbf{C}\\ \mathbf{C}\cdot\mathbf{A}\\ \mathbf{C}\cdot\mathbf{A}^2\end{bmatrix}, \tag{25}$$

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[4] Matrix **D** in the considered case is zero (null) matrix.

[5] prior to designing the observer, it is necessary to check whether the system is controllable and observable.

which, in the considered case is satisfied, as for the considered model of the EP system development, the observability matrix[6] **O** is as follows:

$$\mathbf{O} = \begin{bmatrix} 1 & 0 & 0 \\ 0{,}1342 & 1 & 0 \\ (0{,}1342)^2 & 0{,}1342 & 1 \end{bmatrix}. \tag{26}$$

The rank of the observability matrix **O** equals 3, and is equal to the number of elements of state vector[7].

Determination of the state observer requires checking whether the EP system development is stable. The considered system has three poles, two of which are equal zero ($s_1 = s_2 = 0$) and the third one is positive and equals $s_3 = 0.1342$. As the considered EP system development is instable, it is possible to introduce in the feedback path a regulator described by matrix **K**.

Dynamic properties of regulator K may be changed by appropriate selection of matrix **K.** The above mentioned regulator **K** needs to be determined prior to constructing the observer, as the regulator ensures stability of the EP system development as a closed system, i.e. it may be assumed that the state vector is fully available.

Matrix **K** of the regulator may be determined in the MATLAB environment using the Control System Toolbox e.g. in the following way:

$$K = place(A, B, [b_1 \quad b_2 \quad b_3]), \tag{27}$$

that allows to generate matrix **K** for p_1=-0,1342, p_2=-1, p_3=-1, e.g. of the form:

$$K = \begin{bmatrix} 0{,}017 & -210{,}0344 & 0{,}1771 \\ -0{,}0743 & 936{,}7111 & -0{,}7866 \\ 0{,}0044 & 11{,}8619 & 0{,}0309 \\ -0{,}0089 & -27{,}9706 & 0{,}0088 \\ 0{,}0068 & -82{,}8298 & 0{,}701 \\ -0{,}0013 & 16{,}9962 & -0{,}0142 \\ -0{,}0333 & 416{,}2478 & -0{,}3508 \\ -0{,}0005 & 6{,}5598 & -0.0055 \\ 0{,}0066 & -84{,}0773 & 0{,}705 \\ 0{,}0324 & -407{,}7325 & 0{,}3429 \\ 0{,}0135 & -168{,}5652 & 0{,}1418 \\ 0{,}0001 & -1{,}1189 & 0{,}0010 \\ -0{,}0101 & 128{,}2892 & -0.1074 \\ 0{,}0240 & -303{,}3198 & 0{,}2547 \end{bmatrix} \tag{28}$$

[6] Using the Control System Toolbox it is convenient to use function obsv(**A**,**C**), which returns elements of the above mentioned observability matrix, and then determine the rank using function rank(), which is extremely helpful for determination of higher orders of matrices **A** and **C**.

[7] The system is also controllable when the rank of controllability matrix **S**=[**B AB** $\mathbf{A}^2\mathbf{B}$ …$\mathbf{A}^{n-1}\mathbf{B}$] is also equal 3. Function CST ctrb(A,B) and rank() was used for the above mentioned purpose.

After placing regulator **K** in the feedback path from the state vector, the closed system may be described by the equation:

$$\mathbf{FR} = \mathbf{A} - \mathbf{B} \cdot \mathbf{K} \tag{29}$$

i.e.:

$$\mathbf{FR} = \begin{bmatrix} 0{,}1342 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} - \begin{bmatrix} 0{,}343 & -0{,}1965 & -5{,}1912 & -14{,}5048 & 0{,}1554 & 0{,}0134 & -0{,}0523 & -0{,}0027 & 0{,}0302 & 0{,}0884 & 0{,}1310 & 0{,}0155 & -0{,}0286 & -0{,}022 \\ -0{,}0539 & -0{,}7748 & 0{,}3683 & 9{,}7155 & -0{,}0528 & -0{,}0275 & -0{,}2766 & -0{,}0074 & 0{,}1073 & 0{,}2976 & 0{,}0623 & -0{,}01 & -0.1287 & 0{,}3019 \\ -0{,}1443 & 0{,}3264 & 29{,}5244 & 14{,}1706 & 0{,}068 & 0{,}0067 & -0{,}6104 & 0{,}0264 & -0{,}0288 & 0{,}1541 & -0{,}0474 & -0{,}0096 & 0{,}2337 & 0{,}0266 \end{bmatrix} \cdot \mathbf{K}$$

and finally:

$$\mathbf{FR} = 10^3 \cdot \begin{bmatrix} 0{,}001 & -0{,}0001 & 0{,}0001 \\ 0{,}0001 & 1{,}342 & 0{,}0001 \\ -0{,}0001 & 0{,}0001 & -0{,}0010 \end{bmatrix} \tag{30}$$

Further, eigenvalues of the new system of development may be found (considering the above mentioned regulator **K**[8]).

Due to the fact that the EP system is controllable and observable, state matrix of the state observer may be determined, which matrix is equal:

$$\mathbf{FO} = \mathbf{A} - \mathbf{L} \cdot \mathbf{C}, \tag{31}$$

i.e. in case of the considered case of the EP system development:

$$\mathbf{FO} = \begin{bmatrix} 0{,}1342 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} - \begin{bmatrix} l_1 \\ l_2 \\ l_3 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0{,}1342 - l_1 & 1 & 0 \\ -l_2 & 0 & 1 \\ -l_3 & 0 & 0 \end{bmatrix} \tag{32}$$

Next, characteristics of the state observer are also determined:

$$\det(s\mathbf{1} - \mathbf{FO}) = s^3 + s^2(l_2 - 0{,}1342) + s l_2 + l_3, \tag{33}$$

Assuming that the state observer has three poles, the following is obtained:

$$C(s) = s^3 + s^2(-p_1 - p_2 - p_3) + s(p_1p_2 + p_1p_2 + p_2p_3) - p_1p_2p_3 \tag{34}$$

By comparing the coefficients of the characteristic equation of the observer (32) with the assumed equation (33), the coefficients of matrix **L**: $l_1 = -p_1 - p_2 - p_3 + 0{,}1342$, $l_2 = p_1p_2 + p_1p_3 + p_2p_3$, $l_3 = p_1p_2p_3$ are obtained.

The following rules ought to be followed while selecting the eigenvalues of the state observer:

1) eigenvalues of the observer ought to ensure stability of observer's work (poles should have negative real parts),
2) poles of the observer should be selected so as the real parts of the observer poles are much smaller than the real parts of the system being observed ,
3) observer may only be designed for the observable and stable system.

Following the above mentioned rules allows to design the state observer for the considered EP system, described in the state space by the equations (9) that a new state matrix **FR**, input matrix **B** as well as matrices **C** and **D** have.

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[8] Correction systems with adjustable parameters are called regulators, and those with non-adjustable parameters are called correctors.

When the observer gain L is high, the linear Luenberger observer converges to the system state very quickly. However, high observer gain leads to a peak phenomenon, in which the initial error of the estimator becomes prohibitively large (i.e. impractical or unsafe to use). Kalman filter theory develops the theory of the (closed) Luenberger observer.

Kalman filter is an optimal state observer of the system as it allows to determine the optimal observer gain. Other, nonlinear methods of observers with large gains were also developed, e.g. sliding model control (SMC) may be used to design observers, which make the error of the estimate state variable reach zero in finite time, even in the presence of measurement errors; other state variables have an error that behaves in a similar way to the error in the Luenberger observer, when the peaking stops. Sliding mode observers also have the desired noise resilience properties, similar to the Kalman filter.

4. Conclusions

1. Fundamentals of systems and control theory as well as systems development identification theory allowed to generate DPS development models, including models of DPS development in the form of matrix **th** and equations in the states space (ss).
2. A systemic model of the DPS development was developed and implemented in Simulink, defining successive blocks of the model as characteristics of individual DPS subsystems, identified in MATLAB environment using the System Identification Toolbox and transformed into the form of models in the states space using Control System Toolbox.
3. As a result of solving a set of state equations using an m-file in the MATLAB environment three state variables were obtained. Based on the obtained solution of the state equations, responses of the DPS system (output variable y_1) were obtained in Simulink to the following types of input functions: unit step $1(\theta)$, Dirac impulse $\delta(\theta)$ and $\sin(\theta)$, and were interpreted.
4. An attempt to design a system that corrects and adjusts the functioning of the model of the DPS was made.

References

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

[2] Cichocki A., Osowski S., Siwek K.: MATLAB w zastosowaniu do obliczeń obwodowych i przetwarzania sygnałów. OW PW. Warszawa 2006.

[3] Helt P., Parol M., Piotrowski P.: Metody sztucznej inteligencji w elektroenergetyce. Wyd. PW. Warszawa 2000.

[4] Kaczorek T.: Teoria sterowania i systemów. PWN. Warszawa. 1996.

[5] Kremens Z., Sobierajski M.: Analiza układów elektroenergetycznych. WNT. Warszawa 1996.
[6] Kulikowski R.: Sterowanie w wielkich systemach. PWN, Warszawa.
[7] Malko J.: Planowanie systemów elektroenergetycznych. PWN. Warszawa 1976
[8] Mielczarski W.: Rynki energii elektrycznej. Wybrane aspekty techniczne i ekonomiczne. ARE S.A. Warszawa 2000.
[9] Olszewski M.: Manipulatory i roboty przemysłowe. WNT, Warszawa 1985.
[10] Osowski S.: Modelowanie i symulacja układów i procesów dynamicznych. OW PW. Warszawa 2007.
[11] Orłowska T.: Zastosowanie teorii obserwatorów w napędzie elektrycznym. Prace Naukowe Instytutu Maszyn, Napędów i Pomiarów Elektrycznych Politechniki Wrocławskiej Nr 58. Studia i materiały nr 25/2005, OW PWr., Wrocław 2009.
[12] Rebizant W.: Metody inteligentne w automatyce zabezpieczeniowej. PN IE Seria; Monografie Nr 29 (93). OW PWr., Wrocław 2004.
[13] Statystyka Elektroenergetyki Polskiej. ARE.Warszawa 1947-2008.
[14] Sienkiewicz P.: Teoria efektywności systemów. Ossolineum. Wrocław 1987.
[15] Staniszewski R.: Sterowanie procesem eksploatacji. WNT. Warszawa 1990.
[16] Tadeusiewicz R.: Badanie właściwości układów samodzielnych współpracujących ze stochastycznie zmiennym środowiskiem. Postępy Cybernetyki. 4/1976.
[17] Tchórzewski J.: The Development of the Power System in Terms of Control Theory and Systems (Polish: Rozwój system elektroenergetycznego w ujęciu teorii sterowania i systemów). OW PWR. Wrocław 2013.
[18] Tchórzewski J.: Development of Electrical Power System from the Point of View of Efficiency. Part 1. Basic development models based on IEEE IRS testing data. Computer Applications in Electrical Engineering. IEEP PP, EEC PAN, IEEE Poland Section, PP, Poznan 2009.
[19] Tchórzewski J.: Development of Electrical Power System from the Point of View of Efficiency. Part 2. Dynamic development models based on IEEE TRS testing data. Computer Applications in Electrical Engineering. IEEP PP, EEC PAN, IEEE Poland Section, PP, Poznan 2009.
[20] Tchórzewski J.: Development Models of Electric Power System in MATLAB Environment Using to System Identification Toolbox, XIV International Conference on. "Current Problems in Electrical Power" (Polish: "Międzynarodowa Konferencja Naukowa pt. „Aktualne Problemy w Elektroenergetyce"). PG, Jurata-Gdańsk, 2009.
[21] Tchórzewski J.: Identification of Electric Power System from Point of View of Development, Polish Journal of Environmental Studies, Vol. 18, No. 4B, HARD Publishing Company, Olsztyn, 2009.
[22] Tchórzewski J.: Development of Electrical Power System from Point of View of Safetly, Proc. of 2008 IEEEI 25-th Convention of Electrical and Electronics Engineers in Israel, IEEE Xplore, 2009.
[23] Tchórzewski J.: The development process of Electrical Power System as Unmanned Factory. Poznan University of Technology. Academic Journals. Electrical Engineering. OW PP, Poznan 2009.
[24] Tchórzewski J.: Cybernetics life and systems development (Polish: Cybernetyka życia i rozwoju systemów). Monografie nr 22, Wydawnictwa Uczelniane WSR-P w Siedlcach, Siedlce, 1992.

[25] Tchórzewski J.: Engineering of development systems (Polish: Inżynieria rozwoju systemów). Monografie nr 18. Wyd. Uczelniane WSR-P w Siedlcach. Siedlce 1990.
[26] Zajczyk R.: Modele matematyczne systemu elektroenergetycznego do badania elektromechanicznych stanów nieustalonych i procesów regulacyjnych. Wyd. PG. Gdańsk 2003.