SYNCHRONOUS GENERATOR MACROMODEL

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Abstract **– The regularised method of macromodel identification, based on the splitting of the signal spectrum and to select such basic functions of approximation, are described on the example of synchronous generator macromodel.**

I. SHORT THEORETICAL SUBSTANTIATION

We designate as macromodels the mathematical models of arrangements and systems which can be more simple than original but represent enough exactly the appreciable external peculiarities of modeling objects behavior.

On the whole the task of model construction is composed in: selection of the valid macromodels structures in the form of system of differential equations of the define class; normalized identification of the macromodels.

The equivalent by input-output system is that one, which consists of linear stationary dynamic and non-linear non-stationary non-dynamic subsystems according to equations [1]

$$a(\lambda)\bar{y} = D(\lambda)\bar{\chi}(\bar{y},\bar{y}^{(1)},...,\bar{y}^{(k-1)},\bar{v},\bar{v}^{(1)},...,\bar{v}^{(k-2)},\bar{u},\dot{\bar{u}},t). \quad (1)$$

The matrix of the transfer functions $W(\lambda)=D(\lambda)/a(\lambda)$ describes the linear subsystem with output vectors $\bar{y},...,\bar{y}^{(k-1)},\bar{v},...,\bar{v}^{(k-2)}$ and input vector $\bar{v}$, and the non-linear vector-function $\bar{\chi}(.)$ responds to the non-linear subsystem with input vector $\bar{y},...,\bar{y}^{(k-1)},\bar{v},...,\bar{v}^{(k-2)},\bar{u},\dot{\bar{u}}$ and output vector $\bar{v}$.

The system (1) responses to the block diagram on Fig.1

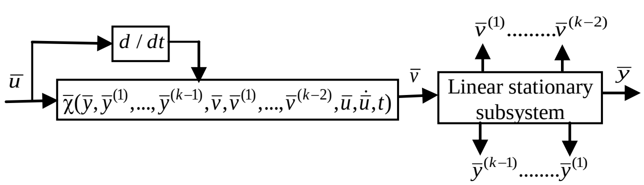

Fig.1. The structure of non-linear system

So the goal of the macromodeling after the structure (1) comes to the approximation of the linear dynamic system (more simple task) and non-linear vector function of many arguments $\bar{\chi}(.)$ (the task is significantly complicate).

For the second approximation the choice of the basic functions is very important. The multidimensional power polynomials are spread:

$$\chi(\bar{\xi}) \approx \sum_{i=0}^{r}\sum_{j=0}^{r}\cdots\sum_{k=0}^{r} c_{ij...k}\xi_1^i\xi_2^j...\xi_n^k, \quad i+j+...+k \le r . \quad (2)$$

However the approximation (2) reveals the incorrectness from the viewpoint of Hadamard for sufficiently large r. There exist the methods of incorrectness elimination which are based on the theory of regularization of incorrect tasks [2]. In particular the author elaborated the methods of regularization based on the splitting of the signal spectrum [1], reduction of approximating polynomial [1], use of the Lyapunov second method [3].

The efficient method to avoid the incorrectnesses events is to select such basic functions of approximation, different from degree polynomials and represent some essential peculiarities of the approximated function. The general theory of such approximation is not enough developed. Only the study of every concrete case gives the possibility to select the basic functions, what essentially facilitate the approximation task. In particular it makes the sense to attract the specific functions of the object to the basic functions.

For the systems which enable the measuring of the static characteristic, it is expedient to use the static characteristic as the basic function of the approximation.

II. EXAMPLES OF THE MACROMODELLING

Let us describe the regularization using the static characteristic as one of the basic functions by the example of cross-field synchronous generator macromodel. Let us synthesize the macromodel of the ship synchronous generator of TMB2-2 model with the following main parameters: S=2500кВН, U=400V, $I_ф$=3609A, f=50Hz, cosφ=0.8, $R_{Nном}$=0.8 Ohm. The object is described with the system of algebro-differential equations of Park-Gorev mode:

$$\begin{aligned}
&\psi'_f = 0.24U_f - 0.22i_f;\\
&i'_d = 523(U_d - R_N i_d) - 314 i_q;\\
&i'_q = 523(U_q - R_N i_q) + 314 i_d;\\
&i'_D = -42.7\psi'_f - 0.71 i'_d - 11.3 i_D;\\
&i'_Q = -0.8 i'_q - 0.82 i_Q;\\
&i_f = 1.59\psi_f - 0.47 i_d - 0.473 i_D;\\
&U_d = 0.18 R_N i_d - 1.29 i_d + 0.0026 i_D - 0.0036\psi'_f - 1.32 i_Q;\\
&U_q = 0.19 R_N i_q + 1.27 i_d + 0.0034 i_Q + 2.61 i_f + 1.3 i_D;\\
&U_N = \sqrt{U_d^2 + U_q^2};
\end{aligned} \quad (3)$$

were i_f, i_d, i_q, i_D, i_Q are correspondingly the root-mean-square values of excitation circuits currents, stator in d,q-directions, dampers in d,q - directions; U_f, ψ_f, U_d, U_q, are

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the root-mean-square values of the voltages and interlinkages of these circuits.

The control (input) variables of the object are the voltage of the exiting circuit U_f and the load resistance R_N, and the controlled (output) variable is the voltage U_N. The input variables are limited: $0 \le U_f \le 10$; $0.8 \le R_N \le 100$.

The initial conditions of the transient states calculation are the following: $\psi_f(0)=0.282$; $i_d(0)=-1.36$; $i_q(0)=0.47$; $i_D(0)=0$; $i_Q(0)=0$.

The goal of macromodeling is the decrease of the degree and of the rigidity of differential equations saving the sufficient behavior of the model at the set multitude of the input signals.

The identification process indicates that the success choice of the approximation basis variables is of the decisive importance.

The macromodel was identified for the step input functions U_f та R_N, which are shown in Fig. 2.

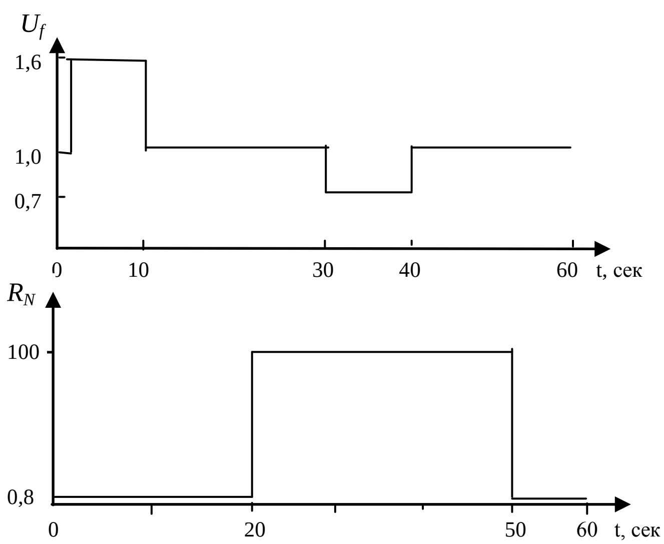

Fig.2. The input functions of the object

First the macromodel was synthesized after the recursive structure in Fig. 3.2 using the approximation of non-linear functions with multidimensional degree polynomials from the defined input and output variables with minimization of root-mean-square deviates during discrete time moments. But the trials to receive the acceptable macromodels in this way were unsuccessful because of the efficient ill-defined task which could not be eliminated with traditional methods.

The task was successfully solved only due to transfer to the other approximation basis which took in account the object peculiarities.

Approximation of the object static characteristic is determined by non-linear minimization of the rms error in accordance with the task

$$\min_{\bar{c}} \sum_{i=0}^{100} (U_{Ni} - (c_1 + c_2 \exp(c_3 (R_{Ni} - R_{Nnom}))))^2; \qquad (4)$$

where $R_{Ni}=0.8+i$; U_{Ni} – the corresponding to R_{Ni} value of U_N as the solution of the system (3) at $U_f=1$, $\psi'_f=i'_d=i'_q=i'_D=i'_Q=0$; $R_{Nnom}=0.8$; $\bar{c}=(c_1,c_2,c_3)$.

The approximation of the static characteristic with maximum ratio error 8% is the following

$$U_N \approx F_{UR}(U_f, R_N) = U_f (3.54 - 2.1\exp(-0.37(R_N - 0.8))). \qquad (5)$$

The function F_{UR} was used as the basic one in further approximations.

Because the transition processes in the object are enough complicated the regularization decomposition of the output signal to slow and fast components in the temporary realm was used.

The macromodeling was executed separately for slow U_{NN} and for fast U_{NV} components of the output signal U_N, assigned by linear filters of the first order with time constant 0.1 s.

The low frequency model was identified on the discrete time readings multitudes of variables U_{NN}, U'_{NN}, F_{UR}, F_{UR}/U_f, at this the approximated multidimensional power polynomials were developed relative to these variables. The corresponding linear approximation task looks like

$$\min_{\bar{a}} \sum_{i=0}^{600} ((U'_{NN})^i - (a_1 U^i_{NN} + a_2 F^i_{UR} + a_3 U^i_{NN} F^i_{UR} / U^i_f + a_4 (F^i_{UR})^2 / U^i_f))^2 \qquad (6)$$

where the upper index i designates the reading of the corresponding variable in the time moment $(0.1 * i)$ s.

The maximum ratio error of the reaction 5% was achieved already in the macromodel of the first order at $a_1=-a_2$ та $a_3=-a_4$:

$$U'_{MN} = (-0.7348 + 0.1415 \cdot F_{UR} / U_f)(U_{MN} - F_{UR}). \qquad (7)$$

The structure of the macromodel (7) meets completely the structure (1) for the input signal F_{UR} and for the output signal U_{MN}.

Similarly the approximation task is formulated for high frequency macromodel for variables U_{NV}, U'_{NV} and $F'_{UR}=dF_{UR}/dt$ near time moments 1, 10, 20, 30, 40 and 50 s:

$$\min_{\bar{b}} \sum_{i=in}^{in+100} ((U'_{NV})^i - (b_1 U^i_{NV} + b_2 U^i_{NV} {F'_{UR}}^i + b_3 ({F'_{UR}}^i)^2))^2, \qquad (8)$$

where in=100,1000,2000,3000,4000,5000, and the upper index i designates the reading of the correspondent variable in the tome $(0.01 * i)$ s.

For the high frequency macromodel the maximum ratio error of the reaction in the defined sections of the approximation is equal to 12%:

$$U'_{MV} = -395.3 U_{MV} + 0.2341 U_{MV} F'_{UR} + 0.3254 F'_{UR} - 0.0003196 (F'_{UR})^2. \qquad (9)$$

The structure of macromodel (9) also answers the macromodel common structure (1) for the input signal F'_{UR} and output signal U_{MV}. The complete macromodel is created with grouping of (7), (8) and (9) after the block diagram shown in fig.3.

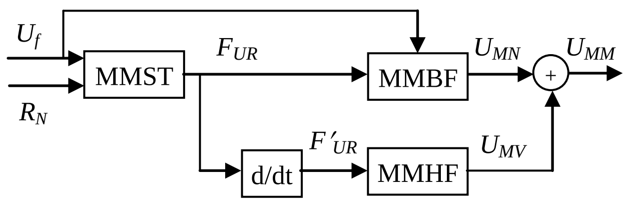

Fig.3. Block diagram of synchronous generator macromodel MMST – static macromodel (7); MMBF – macromodel with slow moving (8); MMHF – macromodel with fast moving (9).

The comparative calculation of the obtained macromodel and the system (3) indicated efficiently lesser rigidity of the macromodel. The maximum integration step after Runge-Cutt method for the macromodel shown in Fig.3 is 40times more then for the system (3) with equal value of the local error.

The quantity of the macromodel differential equations is three, what is two equation less than for the modelling object.

The transition processes in the object and in macromodel are shown in fig.4. The time dependencies of variables U_F, U_N, U_{MM}, R_N are shown in the plot. The input variables coincide with represented in fig.2, only the variable R_N is shown reduced in 25 times. As we see the plots of variables U_N and U_{MM} coincide practically. The ratio error of the signal U_N reproduction is not more 4%.

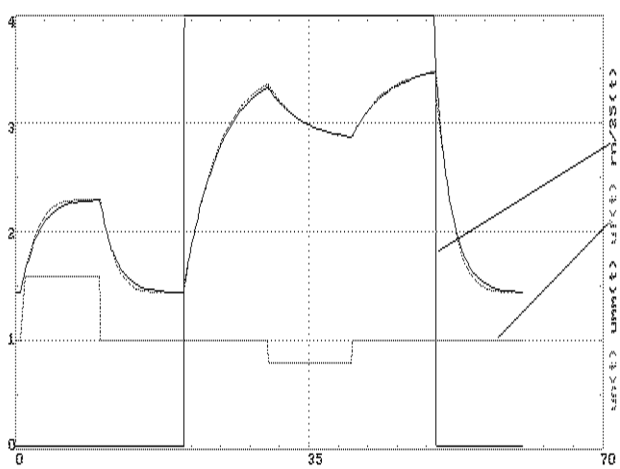

Fig.4. The transient processes in the object (cross-field generator) and of its macromodel.

The fast movements in the object and in macromodel near time moment 20 s are shown in fig. 5 on a large scale.

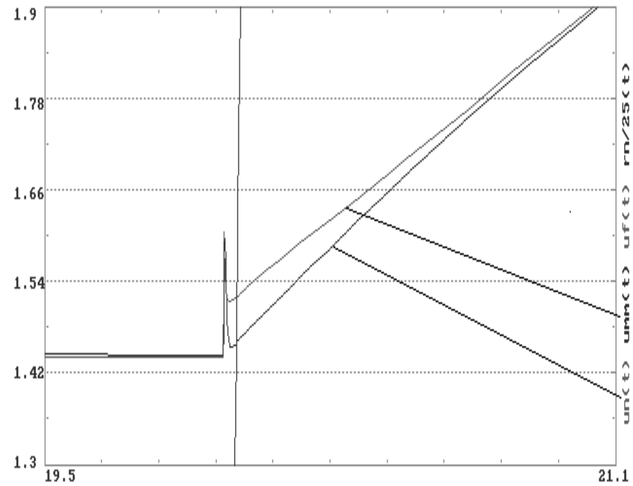

Fig.5. The fragment of fast movements in the object U_N and macromodel U_{MM}.

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