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АНАЛІЗ І МОДЕЛЮВАННЯ ЕЛЕКТРОННИХ КІЛ ТА СИСТЕМ

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DIGITAL REGULATOR OF EXCITEMENT FOR THE POWER SYNCHRONOUS GENERATOR

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In the work the transfer functions of synchronous generator (SG) in discrete z-transformations as well for open-loop, as closed-loop of voltage control system are obtained. Using logartithmical pseudofrequency characters are established optimal transfer functions and parametres of excitiment regulator of SG. The transient processes of the voltage of SG are simulated in MatLab.

Key words: digital control system, synchronous generator, transient processes.

It is well known that future trends for power synchronous generators of power stations are mainly connected with advances of the digital control systems [1]. To determine of the optimal digital regulator of excitiment SG, at first, we define the transfer functions of the control system according to the structural scheme presented on fig.1.

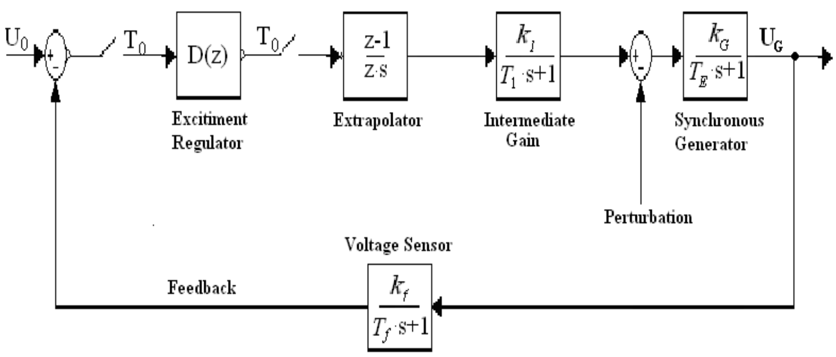

Fig.1

On the scheme are used following notations: U_0 denotes input signal of the system; T_0 - discretization period (in our case T_0 =0.01 sec.); $z = e^{T_0 s}$ - discrete operator of a digital system (z^{-1}-discrete integrator); $s = d/dt$ -so called Karson-Heaviside operator (s^{-1} - integration operator of an analogous system); k_1 - and T_1 –gain coefficient of voltage and time constant of intermediate gain (k_1 =200, T_1=0.05 sec.); k_G и T_E -gain coefficient of generator and time constant its field coil (k_G=25, T_E=0.75 sec.); k_f и T_f -transfer coefficient of the network's feedback and its time constant (k_f=0.001, T_f =0.12 sec.).

General transfer function of the object of considerable control system may be expressed as follows:

$$\mathrm{W}_0(s) = \frac{k_1 k_G k_f}{(T_1 s+1)(T_E s+1)(T_f s+1)} = \frac{1111.11}{(s+20)(s+1.33)(s+8.33)}. \qquad (1)$$

To represent in a z-transformation form the transfer function (1) it is necessary to rewrite it as fractional-rational summ, in particular:

$$W_0(s) = \sum_{i=1}^{3} \frac{\mathrm{A}_i}{s+\alpha_i}, \qquad (2)$$

where $\mathrm{A}_1 = 5.1$; $\mathrm{A}_2 = 8.5$ and $\mathrm{A}_3 = -13.6$; $\alpha_1 = 20$; $\alpha_2 = 1.33$ and $\alpha_3 = 8.33$.

Consequently, we have:

$$W_0(s) = \frac{5.1}{s+20} + \frac{8.5}{s+1.33} + \frac{13.6}{s+8.33}. \qquad (3)$$

Discrete form of transfer function with zero order predictor (without dead time element) of control object corresponding to the expression (3) could be given as following [1,2] :

$$W_0(z) = \sum_{i=1}^{3} \frac{\mathrm{A}_i(1-d_i)}{z-d_i}, \qquad (4)$$

where $d_i = e^{-\alpha_i T_0}$, $i = \overline{1;3}$; $d_1 = 0.83$; $d_2 = 0.987$; $d_3 = 0.923$.

Appropriate substitutions in (4) easily gives the discrete transfer function of the object of voltage control system of SG :

$$\mathrm{W}_0(z) = \frac{0.00017z^2 + 0.00064z + 0.0001483}{z^3 - 2.74z^2 + 2.49z - 0.75} \qquad (5)$$

To define parameters of an exciteiment's regulator of the system under consideration, we apply the method of pseudo-frequency characters [3,4].

Using conformal transformation [1]:

$$Z = \frac{1 + j\lambda \, T_0/2}{1 - j\lambda \, T_0/2}, \tag{6}$$

from (5) we get transfer function in pseudo-frequency form of the system of object SG

$$W_0(j\lambda) = \frac{7.33(1 + j0.3\lambda T_0)(1 - j0.4\lambda T_0)(1 - j0.5\lambda T_0)}{j\lambda(1 + j5.4\lambda T_0)(1 + j12.47\lambda T_0)}, \tag{7}$$

where λ denotes pseudo-frequency of the system; $j = \sqrt{-1}$.

To plotting the amplitude and phase characteristics of the system we need to express module and argument of the transfer function (7). Below we give their values, respectively:

$$\begin{aligned} A_0(\lambda) = &\left\{7.33\left[1+(0.3\lambda T_0)^2\right]^{0.5}\left[1+(0.4\lambda T_0)^2\right]^{0.5}\left[1+(0.5\lambda T_0)^2\right]\right\}\times \\ &\times\left\{\lambda\left[1+(5.4\lambda T_0)^2\right]^{0.5}\left[1+(12.47\lambda T_0)^2\right]\right\}^{-1}; \end{aligned} \tag{8}$$

$$\begin{aligned} \phi_0(\lambda) = -\frac{\pi}{2} + \mathrm{arctg}(0.3\lambda T_0) - arctg(0.4\lambda T_0) - arctg(0.5\lambda T_0) - \\ - arctg(5.4\lambda T_0) - arctg(12.47\lambda T_0). \end{aligned} \tag{9}$$

According to the expressions (8) and (9) on fig.2 are plotted logarithm-frequency character-istics of the object of the voltage control system SG, where (L_0)-amplitude and (φ_0)-phase characteristics, respectively.

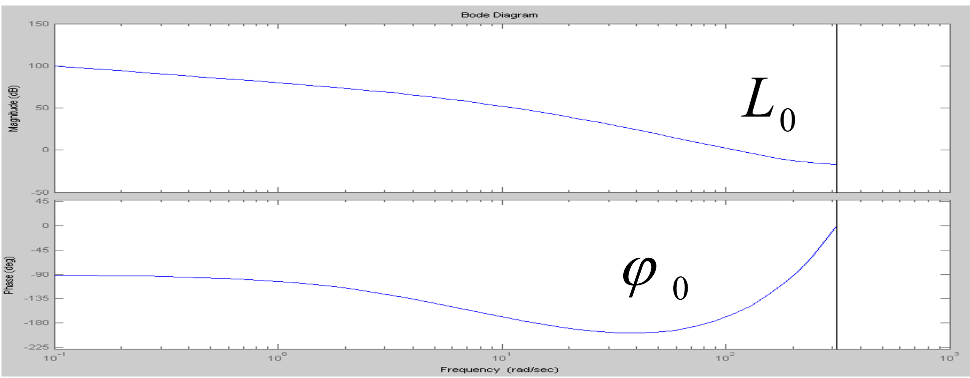

Fig.2

On the base of frequency analysis and synthesis of (7) was defined regulator of excitiment with the frequency transfer function

$$D(j\lambda) = \frac{1.1(1+1.25\lambda T_0)}{1+j\lambda 0.5T_0}. \tag{10}$$

Frequency characteristics presented on fig.3 are obtained via (10)

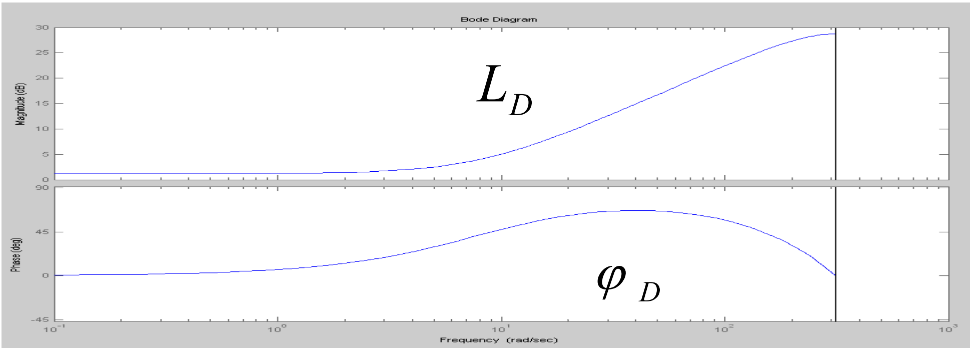

Fig.3

Because from (6) we have

$$j\lambda = \frac{2}{T_0} \cdot \frac{z-1}{z+1}\ , \tag{11}$$

then the transfer function (10) in z-transformation form expressed as follows:

$$D(z) = 14.3(z-0.92)/z = 14.37 - 13.156z^{-1}\ . \tag{12}$$

It must to notice that obtained discrete regulator is differential and for its realization it is sufficient one discrete integrator and two operational amplifiers. On the fig.4 are presented frequency characteristics (L_1, φ_1) of open-loop network, which establishes dynamical effeciency of the considered system.

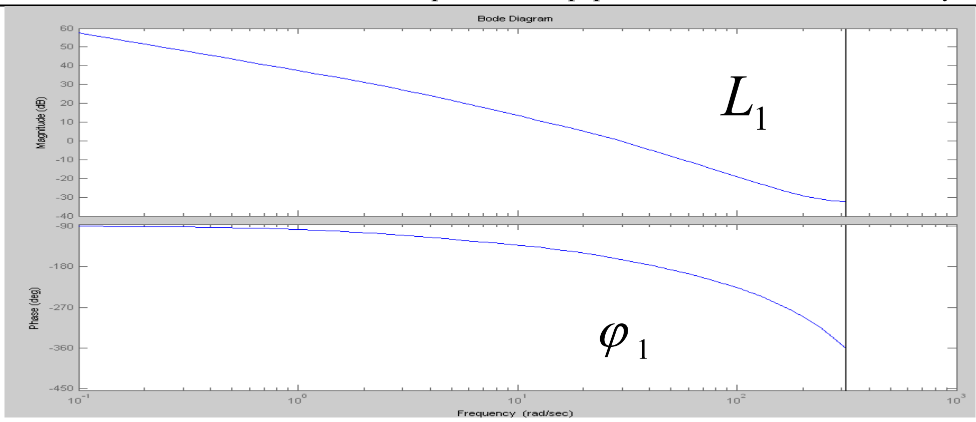

Fig.4

General transfer function (in discrete form) of closed-loop control system of SG looks like:

$$W_C(z) = \frac{D(z)\cdot W_0(z)}{1+D(z)W_0(z)} = \frac{0.0024z^3+0.007z^2-0.006z-0.002}{z^4-2.7374z^3+2.495z^2-0.7535z-0.002} \tag{13}$$

The roots of characteristic equation (13) are: $z_1 = 0.8,\quad z_2 = -0.0026,$ $z_{3,4} = 0.97 \pm i0.096\ \left(\left|z_{3,4}\right| = 0.972 < 1\right)$. They have sufficient resources for stability (all lie in the unit disk) of the system. Hence obtained control system indicates on efficiency of it.

Response of the control system of SG on unit step signal may be analytically obtained with the help following expression:

$$\mathrm{R}[z] = W_C(z)\frac{z}{z-1}. \tag{14}$$

To find original of the function (14) it is well known (see e.g. [1]) following expression:

$$R[n\mathrm{T}_0] = \frac{1}{2\pi j}\oint\limits_{|z|<1} z^{n\text{-}1}R(z)dz,\ n\in N \tag{15}$$

Apply to (15) Cauchy integral formula we calculate:

$$\begin{aligned}\mathrm{R}[\mathrm{n}T_0] &= \frac{1}{2\pi j}\oint\limits_{|z|<1} z^n\left[\frac{0.6657}{z-1}-\frac{0.08425}{z+0.003}-\frac{0.037}{z-0.8}-\frac{0.4586-0.503j}{z-(0.97+0.095j)}-\frac{0.4586+0.503j}{z-(0.97-0.095j)}\right]dz = \\ &0.6657-0.08425(-0.003)^n-0.038(0.8)^n-(0.4586-0.503j)(0.97+0.095j)^n-(0.4586+0.503j)\times \\ &\times(0.97-0.095j)^n = 0.6657-0.08425(0.003)^n-0.038(0.8)^n-2(0.9786+0.095)^{0.5n}\times \\ &\times(0.4586\cos n\phi+0.503\sin n\phi)\end{aligned} \tag{16}$$

where $\varphi = arctg(0.095/0.97) = 5^{\circ},36^{/}$.

Transient-process curve (presented on fig.5) of the output voltage SG obtained on the base (16) and with the help simulation in MatLab.

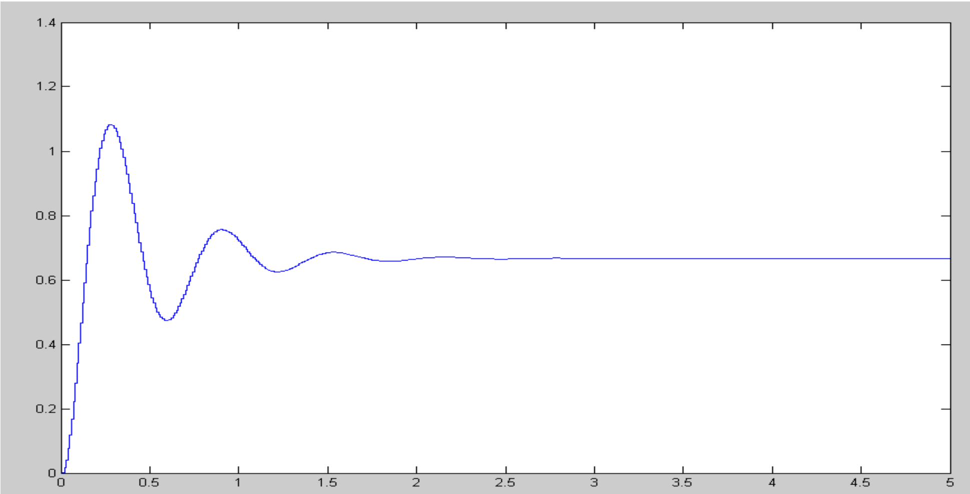

Fig.5

As on fig.5 is shown transient-process time of the control system is $t_T = 1.5 \div 2$ sec. with acceptably number of oscillations of the voltage SG.

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ЦИФРОВОЙ РЕГУЛЯТОР ВОЗБУЖДЕНИЯ ДЛЯ МОЩНЫХ СИНХРОННЫХ ГЕНЕРАТОРОВ

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Получены передаточные функции в z-преобразованном виде как разомкнутой, так и замкнутой системы управления напряжением синхронного генератора (СГ). С помощью логарифмических псевдочастотных характеристик определены оптимальные передаточная функция и параметры регулятора возбуждения СГ. Получены кривые переходных процессов напряжения СГ, как при управляющем, так и при возмущающем воздействиях.

Ключевые слова: система цифрового управления, синхронный генератор, переходный процесс.

ЦИФРОВИЙ РЕГУЛЯТОР ЗБУДЖЕННЯ ДЛЯ ПОТУЖНИХ СИНХРОННИХ ГЕНЕРАТОРІВ

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Отримано передавальні функції в z-перетвореному вигляді як разімкнутої, так і замкнутої системи керування напругою синхронного генератора (СГ). За допомогою логарифмічних псевдочастотних характеристик визначені оптимальні передавальна функція та параметри регулятора збудження СГ. Отримано залежності перехідних процесів напруги СГ, як при керуючому, так і при збурюючих впливах.

Ключові слова: система цифрового управління, синхронний генератор, перехідний процес.

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