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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
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DEVELOPMENT OF A VARIABLE-STRUCTURE CONTROL SYSTEM FOR SERVO DRIVE OF SOLAR PHOTOVOLTAIC PLANT

Abstract. The dynamic properties of servo drive of solar photovoltaic plant are investigated in the article. Mathematical models for a single-circuit servo drive of solar photovoltaic plant have been developed.The variable structure system for the servo drivehas been developed, whichimproves the qualitative characteristics of the transient processes in servo driveand leads to a decrease in the sensitivity of the control system to a change in its parameters.A schematic diagram of the model is made in MATLABsoftware.

Key words: Servo drive, mathematical model, solar photovoltaic plant, single-circuitsystem, MATLABsoftware.

I. Introduction. One of the most important ways to improve the efficiency of solar power plants is to optimize the servo drives, operating in a continuous mode oftrackingforthe Sun, by energy indicators [1-4].

The analysis of energy indicators of various motors and power losses, depending on the generalized parameters of the electric drive, made it possible to determine the electric drives most adapted to the system load [5-7]. However, the electric drive control system does not provide the appropriate accuracy and quality of transient processes of the servo drives. In addition, it should be pointed out that the technical implementation of the servo drive control systems causes certain difficulties [8, 9].

The main disturbing effects on the solar plant drive were considered in works of scientists Ovsyannikov E.M. and Sorokin G.A. [8, 10]. But they did not consider in their works the matter related to the accuracy, speed of electric drive output coordinatedevelopment, and the effect of parameter changes on the transient processes of this electric drive.

Moreover, it should be noted that this servo drive of solar photovoltaic plant (SD SPVS) system does not take into account the decrease in the control system sensitivity to a change in its parameters in order to stabilize the system [11].

Purpose of this paper is to improve the energy indicators of servo drive, create a variable-structure control system that provides insensitivity to changes in control system parameters and reduces the electricity consumption for compensationof the disturbing effects.

Methods. To solve the tasks, the methods of mathematical analysis, theories of automatic control, mathematical and computer modeling were used.

II. Main body. The functional diagram (figure 1) is represented as a linearized schematic diagram, since the kinematic circuit of the servo drive of solarphotovoltaic station (SDSPVP) is a nonlinear element with a dead band.

Based on the transfer functions of the structural diagram (figure 1), the following differential equations can be written in the increments.

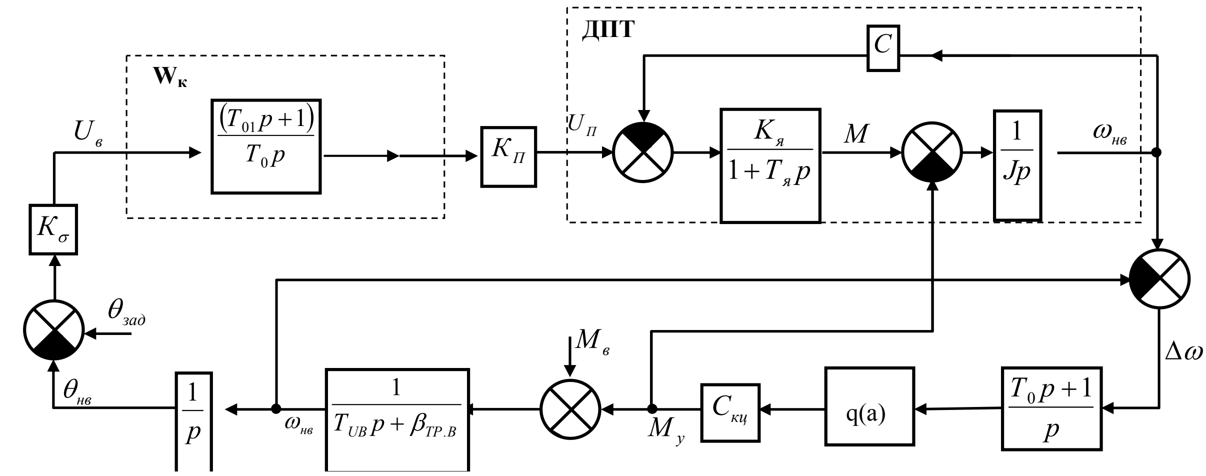

Figure 1 – SPVS SD schematic diagram

Technical and design parameters were used for ME215DC motor with the following parameters:
Magnet base - 4;
Purpose - antenna drive;
U Voltage - 12 V;
Power - 30 W;
Rotational speed - 2000 (rpm);
Weight - 1.4 kg.

For a DC motor with independent excitation (according to transfer functions), we represent two differential equations with well-known accepted assumptions [12]:

$$J\frac{\mathrm{d}\Delta\omega_{ДВ}}{\mathrm{dt}} = k_M \Delta I - \Delta M_У, \quad (1)$$

where $\Delta\omega_{дв}$ – armature speed; ΔI – armature current; ΔM_y – load torque increment; J – moment of inertia; k_M – coefficient of proportionality between the motor torque and armature current and the equation of electromotive force(emf) in the armature circuit.

$$T_Я\frac{\mathrm{d}\Delta I}{\mathrm{dt}} = k_Я(\Delta U_П - c\Delta\omega) - I, \quad (2)$$

where ΔU – voltage increment at converter output; $T_Я$ – armature electromagnetic constant; $k_я$– coefficient ($k_я = 1/r_я$); $r_я$ – resistance of the motor armature circuit; c – coefficient of proportionality between emfand ω.

Differential equation of the voltage converter will be as follows:

$$\mathrm{T}_0\frac{\mathrm{d}\Delta U_П}{\mathrm{dt}} = K_П \mathrm{K}_б \Delta\Theta_{зад} - K_П \mathrm{K}_б T_{01}\Delta\omega_M - K_П \mathrm{K}_б \Delta\Theta_{ИВ}, \quad (3)$$

where $K_п$ – converter transfer coefficient; $K_б$ – amplification coefficient; T_{01} – time constant of the compensating element; $\Theta_{зад}$ – preset angle of rotation of solar plant servo drive; $\Theta_{ив}$ – angle of actuator shaft.

In turn, the angle derivative ($\Theta_{ив}$) of the actuator shaft can be represented by the equation

$$\frac{d\Delta\Theta_{ИВ}}{dt} = \Delta\omega_{ИВ}, \quad (4)$$

where $\Delta\omega_{ив}$ – actuator shaft angular speed increment.

Differential equation for $\omega_{ив}$ will be as follows:

$$T_{ИВ}\frac{d\Delta\omega_{ИВ}}{dt}+\beta_{ТРВ}\Delta\omega_{ИВ}=\Delta M_{У}+\Delta M_{В}, \qquad (5)$$

where $\Delta M_У$ – rotation angle moment increment; $\Delta M_В$ – shaft rotation moment increment; $\beta_{ТР.В}$ – shaftfriction coefficient; $T_{ИВ}$ – time constant.

The differential equation of $\Delta M_У$moment taking into account the harmonic linearization for the actuating link with deadband [13, 14] and taking into account the coefficient $C_{К.Ц}$will be as follows:

$$\frac{d\Delta M_{У}}{dt}=C_{К.Ц}\cdot q(a)((T_0\frac{d\Delta\omega_{DB}}{dt}+\Delta\omega_{DB})-((T_0\frac{d\Delta\omega_{M}}{dt}+\Delta\omega_{DB})), \qquad (6)$$

where $C_{К.Ц}$ – elasticity coefficient.

$$q(a)=k-\frac{2k}{\pi}(\arcsin(\frac{b}{a})+\frac{b}{a}\sqrt{1-\frac{b^2}{a}}).$$

Thus, the system of linearized differential equations describing the processdynamicsin the solar plant servo drive will beasfollows [7]:

$$\frac{d\Delta\omega_{ДВ}}{dt}=\frac{1}{J}\Delta M-\frac{1}{J}\Delta M_{У},$$

$$\frac{d\Delta I_{Я}}{dt}=\frac{k_{Я}}{T_{Я}}\Delta U_{П}-\frac{k_{Я}\mathrm{k_e}}{T_{Я}}\Delta\omega-\frac{1}{T_{я}}\Delta I_{Я},$$

$$\frac{\mathrm{d}\Delta U_{П}}{\mathrm{dt}}=\frac{K_{П}\mathrm{K_б}}{T_0}\Delta\Theta_{\text{зад}}-\frac{T_{01}K_{П}\mathrm{K_б}}{T_0}\Delta\omega_{ив}-\frac{K_{П}\mathrm{K_б}}{T_0}\Delta\Theta_{\text{ИВ}}, \qquad (7)$$

$$\frac{d\Theta_{ИВ}}{dt}=\Delta\omega_{ИВ},$$

$$\frac{d\Delta\omega_{ИВ}}{dt}=\frac{1}{T_{ИВ}}(\Delta M_{У}+\Delta M_{В})-\frac{\beta_{ТР.В}}{T_{ИВ}}\Delta\omega_{ИВ},$$

$$\frac{d\Delta M_{У}}{dt}=C_{К.Ц}\cdot q(a)((T_0\frac{d\Delta\omega_{DB}}{dt}+\Delta\omega_{DB})-((T_0\frac{d\Delta\omega_{M}}{dt}+\Delta\omega_{DB})).$$

Based on the set of equations (7), a model is developed. The same schematic diagram of the model is shown in figure 2 as provided in MATLABsoftware.

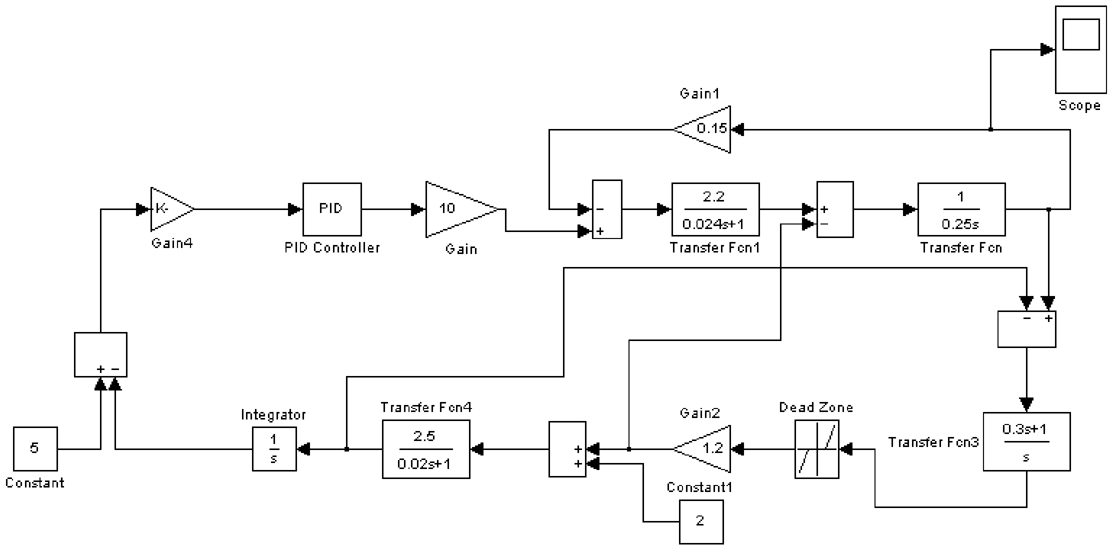

Figure 2 – Schematic diagram of SD SPVPmodel in MATLAB

The oscillogram $\Theta(t)$ obtained as a result of modelling is shown in figure 3.

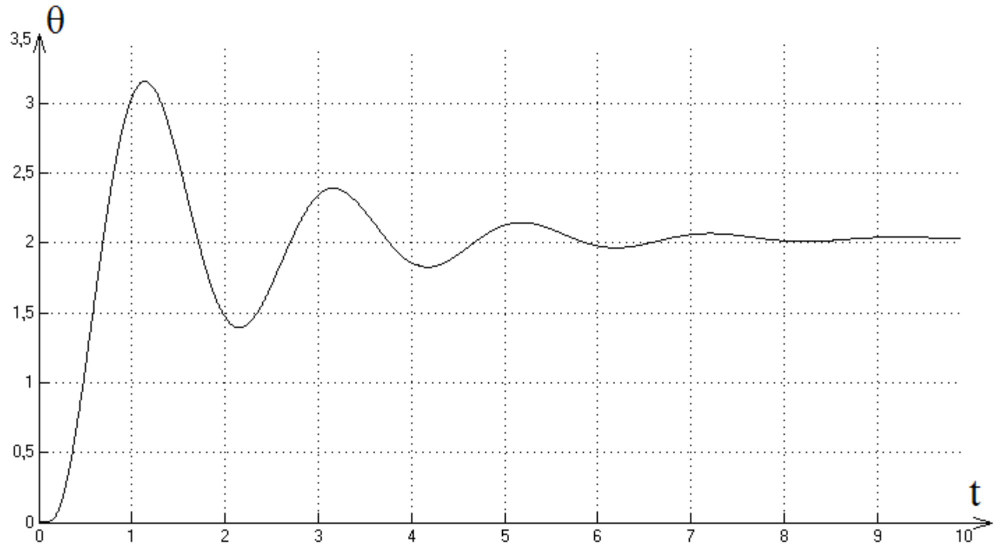

Figure 3 – Transient process of the angle ofrotation between reference and maintenance axesof actuator shift

As can be seen from figure 3, the overshoot value is 60%, the control time is 6s, and the number of oscillations is 3 that do not meet our requirements for accuracy and speed.

In this regard, a variable-structure system [11] was developed based on the single-circuit SDSPVP, which makes it possible to improve the quality of the transient processes and reduce the system sensitivity to changes in its parameters.Before considering the schematic diagram of a solar plant servo drive with a variable structure, let'sconsider the functional diagram in figure 4.

It should be noted that the functional scheme of SDSPVPin the variable-structure system (VSS)uses a relay element and a signalcomparison element by current and angular velocity rpm [17, 18].

Increase inaccuracy of tracking and quality of the transient processes intheservo drives (SD) of solar photovoltaic plant(SPVP)is one of the main tasks for designing a control system for this plant.

Figure 1 shows a schematic diagram of a single-circuit SDSPVP where DC motor, W_k – compensating element, M – motor torque and armature rotational speed.

This diagram ofSDSPVPuses a proportional-integral-differential control law to compensate external disturbances for the accuracy of task development.

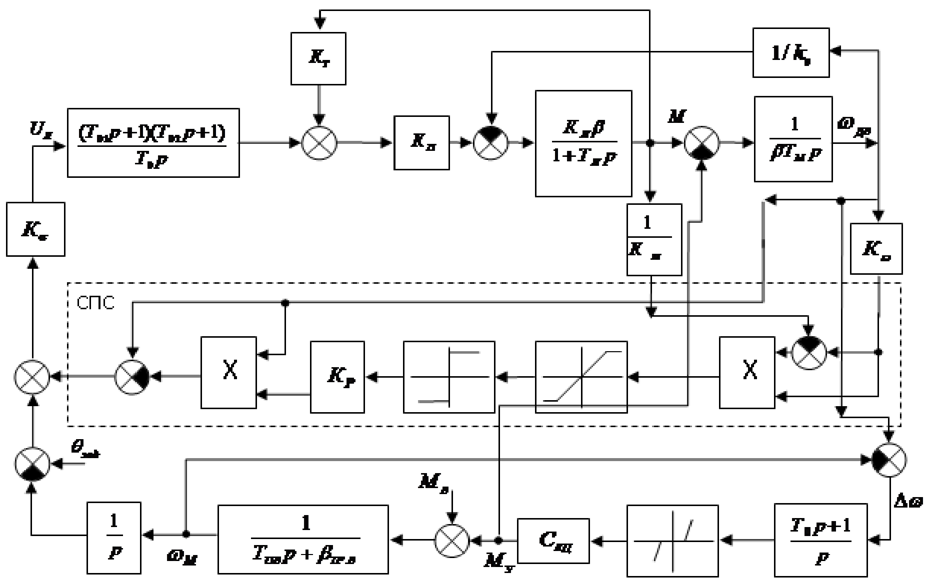

Figure 4 – Schematic diagram of single-circuit SDSPVS with VSS

However, this does not take into account the quality and sensitivity of the control system to changesinits parameters in order to stabilize the system. In this regard, based on the SDSPVPabove, a variable-structure system (VSS) is used, which makes it possible to improve the quality and sensitivity of the system.

The schematic diagram of single-circuit SDSPVPwith VSSis shown in figure 4.

The schematic diagram of SD SPVPmodel with VSSin MATLAB is shown in figure 5.

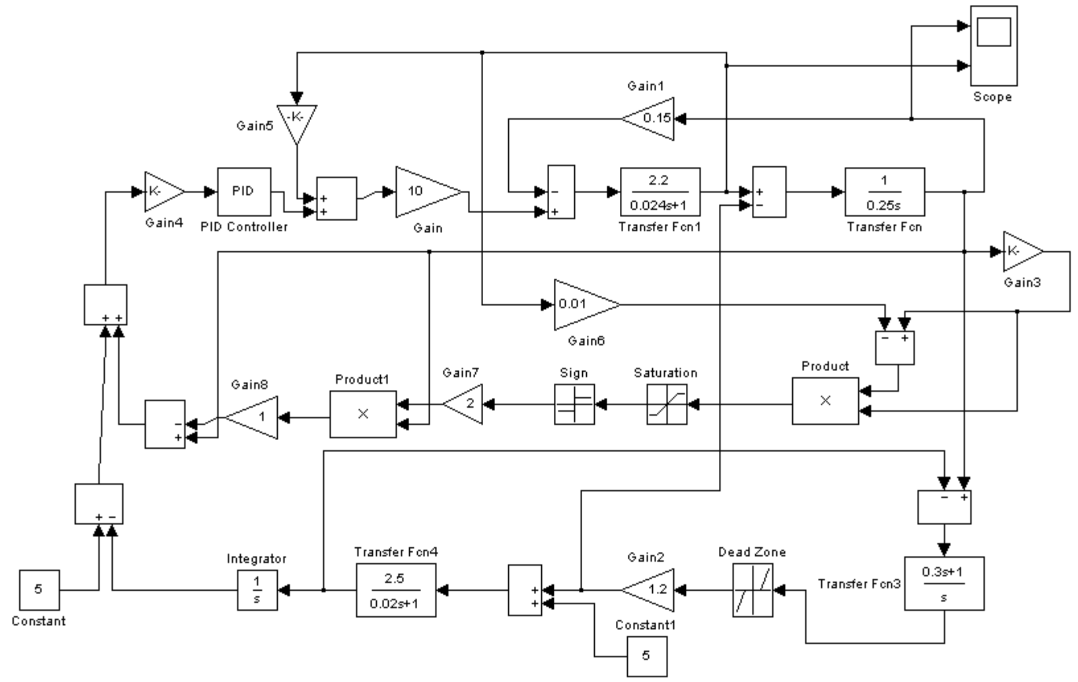

Figure 5 – Schematic diagram of SD SPVPmodel with VSS InMATLAB

The schematic diagram of VSS in figure 5 is represented by transfer functions of motor, gearbox and PIDelement (proportional-integral-differentiating element), two blocks of multiplication and three nonlinearities.

VSS operates according to the following principle: at some time, the feedback links are turned on in turn, and, therefore, the time of transient processes, overshoot value and number of oscillations reduce.

As a result of modelling, a transient process of the angle of rotation between reference and developing axes of SD SPVP model with VSShas been obtained.

As can be seen from figure 5, the overshoot value is zero, number of oscillations is zero, control time is 4s. Comparing the obtained curve of the transient process (figure 6) with the curve of the transient

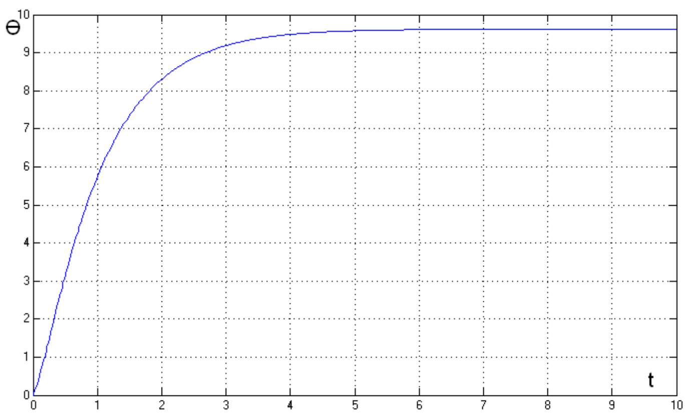

Figure 6 – Curve of transient process of the angle of rotation betweenreference and developing axes of SD SPVP with VSS

process in figures 7 and 6, we note that the qualitative characteristics of the transient process in figure 7 are much better than at the figuresabove. It should be noted that the obtained curve of the transient process in figure 7 coincides with the experimental one within 5%.

As a result of VSSapplication, we were able to ensure a minimum effect of disturbing effects on SD SPVP, improve the quality and reduce the sensitivity to changes in its parameters [17, 18].

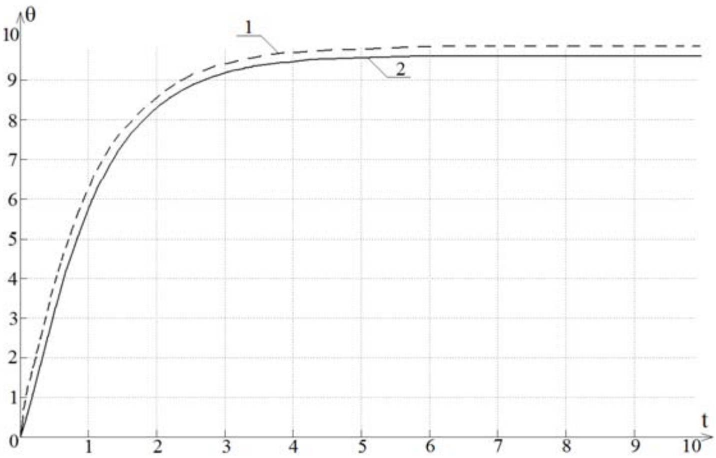

Figure 7 – Curve of transient process: 1 - experimental curve, 2 - curve obtained in the model

As a result, energy is spent less forcompensationof disturbing effects, i.e.the drive becomesoperating in the energy-saving mode [19, 20].

Comparing the nature of the transient processes in SD SPVPmodel (figure 3), it can be noted that the qualitative characteristics of transient processes of the armature rotation speed and the motor torque in SD SPVPwith VSS are much better, as the amplitude of their oscillation and the control time reduce. This circumstance makes it possible to significantly improve the tracking accuracy and quality of the transient processes in the servo drive of solar photovoltaic plant.

Conclusions.

1. Mathematical models for single-circuit SD SPVP have been developed.
2. Thevariable-structure system for servo drivehas been developed that improves the qualitative characteristics of SD transient processes and leads to a reduce in the control system sensitivity to changes in its parameters.
3. The variable-structure system provides high speed in development of preset angle of rotation of SD SPVP. As a result, less energy is spenton compensation of the disturbing effects, and the drive becomes operating in the energy-saving mode.
4. The modelled and experimental curves of transient process of the angle of rotation between the reference and developing axis of SD SPVP with VSShave been obtained.

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КҮН ФОТОЭЛЕКТР СТАНЦИЯСЫНЫҢ БАҒУШЫ ЭЛЕКТРЖЕТЕГІНІҢ ҚҰРЫЛЫМЫ АЙНЫМАЛЫ БАСҚАРУ ЖҮЙЕСІН ӘЗІРЛЕУ

Аннотация. Мақалада күн фотоэлектр станциясының бағушы электржетегінің динамикалық қасиеттері зерттелген. Күн фотоэлектр станциясының бір контурлы бағушы электржетегінің математикалық үлгілері әзірленген. Қадағалаушы электржетегінің құрылымы айнымалы жүйесі әзірленді, ол ЭҚЖ ауыспалы процес-терінің сапалық сипаттамаларын арттырады және басқару жүйесінің оның параметрлерінің өзгеруіне қатысты сезімталдығының төмендеуіне әкеледі. MATLAB программасында үлгінің құрылымдық сұлбасы әзірленді.

Түйін сөздер: бағушы электр жетегі, математикалық үлгі, күн фотоэлектр станциясы, бір контурлық жүйе, MATLAB программасы.

А. М. Дараев[1], С. Е. Ибекеев[1], Д. Г. Инсепов[2], А. Е. Куттыбаева[1], Г. М. Байкенова[1]

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РАЗРАБОТКА СИСТЕМЫ УПРАВЛЕНИЯ С ПЕРЕМЕННОЙ СТРУКТУРОЙ СЛЕДЯЩЕГО ЭЛЕКТРОПРИВОДА СОЛНЕЧНОЙ ФОТОЭЛЕКТРИЧЕСКОЙ СТАНЦИИ

Аннотация. В статье исследуются динамические свойства следящего электропривода солнечной фотоэлектрической станции. Разработаны математические модели для одноконтурного следящего электропривода солнечной фотоэлектрической станции. Разработана система с переменной структурой следящего электропривода, которая повышает качественные характеристики переходных процессов СЭП и приводит к уменьшению чувствительности системы управления к изменению её параметров. Построена структурная схема модели в программе MATLAB.

Ключевые слова: следящий электропривод, математическая модель, солнечная фотоэлектрическая станция, одноконтурная система, программе MATLAB.

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