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Development of a computer simulation model of the SD-630 synchronous motor with excitation from a mini photovoltaic station

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ABSTRACT: This article is devoted to the development of a simulation model of the SD-630 synchronous motor with excitation from a mini photovoltaic station using the MATLAB (Simulink) program. Oscillograms of the rotor speed and electromagnetic torque of the synchronous motor were obtained when the excitation winding of the synchronous motor was powered from a solar panel.

KEY WORDS: Synchronous motor, solar panel, excitations, simulation, model, angular frequency, electromagnetic moment, winding, energy, winding, direct current power, solar radiation.

I. INTRODUCTION

The excitation winding of the synchronous machine is supplied with direct current power, which is from 0.3 to 3% of the useful power of the synchronous machine [1]. Excitation is a term used by electrical engineers, meaning the creation of a magnetic field on the windings of electrical machines [2].

To develop a simulation model of a synchronous motor SD-630 with excitation from a mini photovoltaic station in the Simulink package, we are based on the parameters of the synchronous motor Table-1. To study the characteristics of the rotational speed and electromagnetic torque, the parameters of the engine were measured with excitation from a mini photovoltaic station. The measurements were carried out on a post-repair test stand for the operation of the SD-630 engine in idle mode with excitation from a mini photovoltaic station.

II. SIGNIFICANCE OF THE SYSTEM

The direct excitation method has received the greatest distribution in synchronous machines. However, in cases where the excitation system is expected to work with powerful synchronous electric machines, independent excitation generators are used, the winding of which is supplied with direct current from another source, called under the exciter. Despite all the bulkiness, this system allows you to achieve greater stability in operation, as well as finer tuning of characteristics.

Excitation systems are divided into two types - direct and indirect. In direct excitation systems, the exciter armature is connected to the shaft of the synchronous machine. In indirect excitation systems, a motor that is fed drives the exciter from the auxiliary bus bars of the power plant or an auxiliary generator. The auxiliary generator can be connected to the shaft of the synchronous machine or operate independently. Direct systems are more reliable, since in case of emergencies in the power system, the exciter rotor continues to rotate together with the rotor of the synchronous machine, and the field winding does not immediately de-energize. Excitation of autonomous synchronous machines from solar energy is an urgent task.

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III. METHODOLOGY

The electric motor SD-630 is installed on a test stand without a load on the shaft, an alternating three-phase voltage of 6 kV is supplied to the stator winding, and direct current is supplied to the excitation winding (rotor) from a mini photovoltaic station. Table-1 shows the parameters of the synchronous motor SD-630.

Parameters of the synchronous motor SD-630
Table 1

1	Type of synchronous motor	Designation	SD-630	Unit
2	Synchronous motor power	P	630	kW
3	Stator voltages	Uc	6000	V
4	Stator current	Ic	72	A
5	Excitation voltage	U	36	V
6	Excitation current	I	247	A
7	Power factor	cosφ	0.9	-

As you know, the power received from a solar panel depends on the illumination, the intensity of solar radiation falling on its surface and, of course, depends on the time of day and year. The simulation takes into account the values of the solar station for a given region and the seasonal factor.

To develop the model, we used the MATLAB 6.5 program. The model is built in the following sequence. The following elements were selected from the Simulink library: a block of a synchronous machine with external excitation, a solar battery and a battery, a current, voltage and speed meter on the load, oscilloscopes, as well as blocks that set the values of the excitation current and torque [3]. To study the characteristics of the electromagnetic torque and rotational speed, the Park-Gorev equation (1) was used, taking into account the parameters of the rotor windings, stator and flux linkage [4].

$$\begin{cases} -e_d = \dfrac{d\psi_d}{dt} - \omega\psi_q + R_1 \cdot i_d; \\ -e_q = \omega\psi_d + \dfrac{d\psi_q}{dt} + R_1 \cdot i_q; \\ e_f = \dfrac{d\psi_f}{dt} + R_f \cdot i_f; \\ -e_0 = \dfrac{d\psi_0}{dt} + R_0 \cdot i_0; \\ 0 = \dfrac{d\psi_{Vd}}{dt} + R_{kd} \cdot i_{kd}; \\ 0 = \dfrac{d\psi_{Vq}}{dt} + R_{kq} \cdot i_{kq}. \end{cases} \quad (1)$$

The values of solar radiation in summer and winter months differ by 3.3 times. If we take winter radiation for calculations, then a photovoltaic plant will require a solar panel with a very large area. If summer, then the solar panel area will not provide daily power supply in the winter months [3].

If, for simplicity, the damper winding of a synchronous motor is ignored, then the last three equations can be omitted in this equation:
Formulas (2) for transformation have the form:

To move from a fixed to a rotating coordinate system, the transformation of the Park-Gorev equation is necessary, which makes it possible to orient the control system along the flux linkage vector [4].

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$$\begin{cases} \omega\psi_d - \omega\psi_q + R_1 \cdot i_d = U_d; \\ \omega\psi_d + \dfrac{\omega\psi_q}{dt} + R_1 \cdot i_q = U_q; \\ \dfrac{\omega\psi_f}{dt} + R_f \cdot i_f = U_f, \end{cases} \quad (2)$$

U_d and U_q are the mains voltage in the "d_q" coordinate system, supplied to the SM stator winding;
Ψ_d and Ψ_q are flux linkages along the d and q axes, respectively: $\Psi_d = L_d \cdot i_d + L_{fd} \cdot i_f$;
$\Psi_q = L_q \cdot i_q$;
Ψ_f – flux linkage of the excitation winding (EF): $\Psi_f = L_f \cdot i_f + L_{fd} \cdot i_d$;
L_d and L_q are self-inductances along the d and q axes;
L_f - is the inductance of the excitation winding;
L_{fd} - is the mutual inductance of the rotor and stator windings along the d axis;
R_1 - active resistance of the stator winding;
ω is the relative angular frequency of rotation of the rotor, i.e. the difference between the synchronous angular frequency of rotation ($\omega_c = 2\pi \cdot f$) and the angular frequency of rotation of the rotor ω_p;
R_f is the active resistance of the OF; Uf and if are the voltage and current of the excitation winding.

To equation (2) we add the equation of moments:

$$M = \psi_d \cdot i_q - \psi_q \cdot i_d$$
$$M = M_c + j\frac{d\omega_p}{dt} \quad (3)$$

Then we write an equation that is convenient for compiling a model in Matlab:
The input parameters of this model are the following quantities:

- stator voltage along the d and q axes U_d and U_q, in volts; rotor winding voltage U_f, in volts:

$$\begin{cases} p\psi_d = U_d - R_1 \cdot i_d - L_{fd} \cdot pi_f + (\omega_c - p_f \cdot \omega_p) \cdot \psi_q; \\ p\psi_q = U_q - R_1 \cdot i_q - (\omega_c - p_f \cdot \omega_p) \cdot (\omega_d + \psi_q); \\ p\psi_f = U_f - R_1 \cdot i_f - L_{fd} \cdot pi_d; \\ p\omega_p = \frac{M - M_c}{j} = \frac{p_j - (\psi_d \cdot i_q - \psi_q \cdot i_d) - M_c}{j}. \end{cases} \quad (4)$$

Active resistances of the stator and rotor windings R_1 and R_f, in ohms; inductance along the longitudinal and transverse axes L_d and L_q, in v henry; inductance L_{fd}, in henry;
Supply voltage frequency f, in hertz;
Moment of inertia of the rotor J, in kg·m^2;
Number of pairs of poles p;
Moment on the shaft of the synchronous motor Ms, in N·m;
Required daily amount of energy to excite a synchronous motor;
P_v kV seasonal coefficient (0.55 in summer, 0.7 in winter, 0.63 in spring and autumn); the value of solar radiation for this region [4].

The output parameters of the model are:
Rotor speed n_2, in rev. /min; electromagnetic moment SD.
By double - clicking on the oscilloscope block, we obtain oscillograms of variables in Figure-1.

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IV. RESULTS OF THE STUDY

Instead of a software implementation of a computer model of the system under study, in one of the universal programming languages, Simulink uses ready-made graphic blocks, which make up the structural systems (block systems) of the system under study. Then, the ongoing process in the system is simulated and the data obtained are analyzed [1].

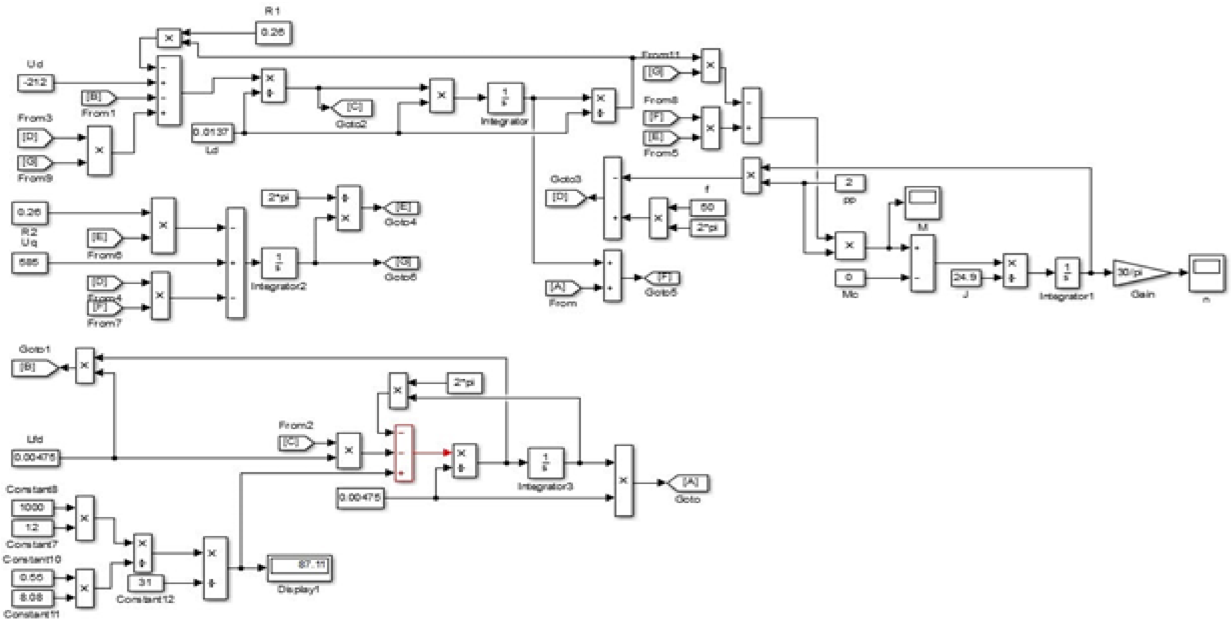

Fig-1. The structure of the simulation model of the SD-630 synchronous motor with excitation from a mini photovoltaic station.

The block diagram of the simulation model consists of 3 adders, the 1st winding parameters along the d axis, the 2nd parameters along the q axis, the 3rd parameters of the excitation winding.

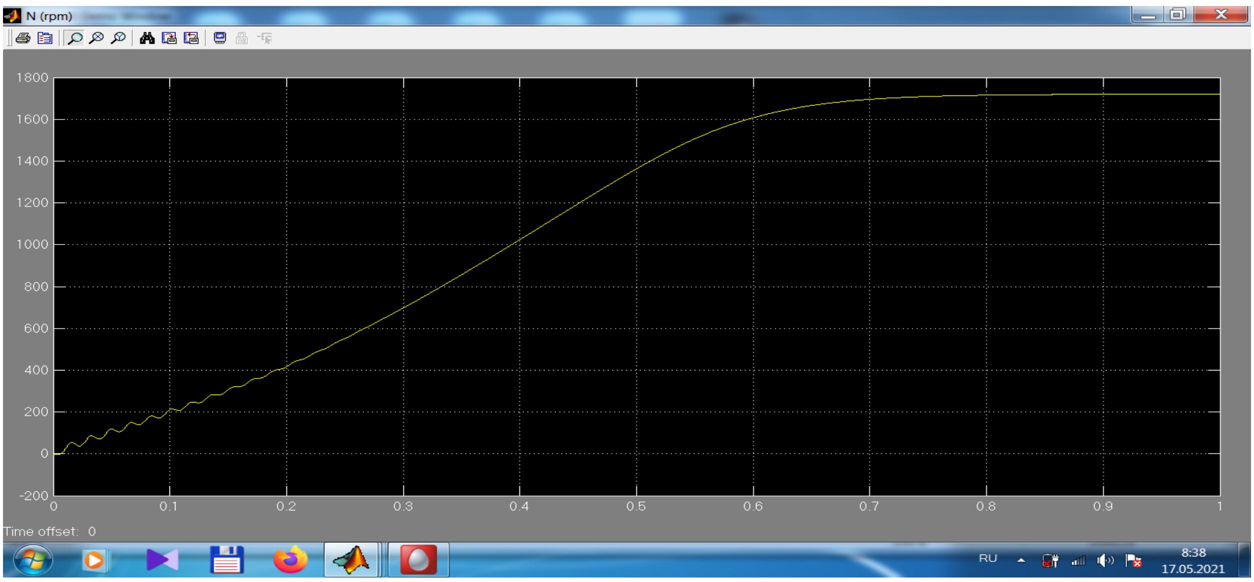

Fig-2.3. Oscillogram of the rotational speed of a synchronous motor during start-up with excitation from a solar panel.

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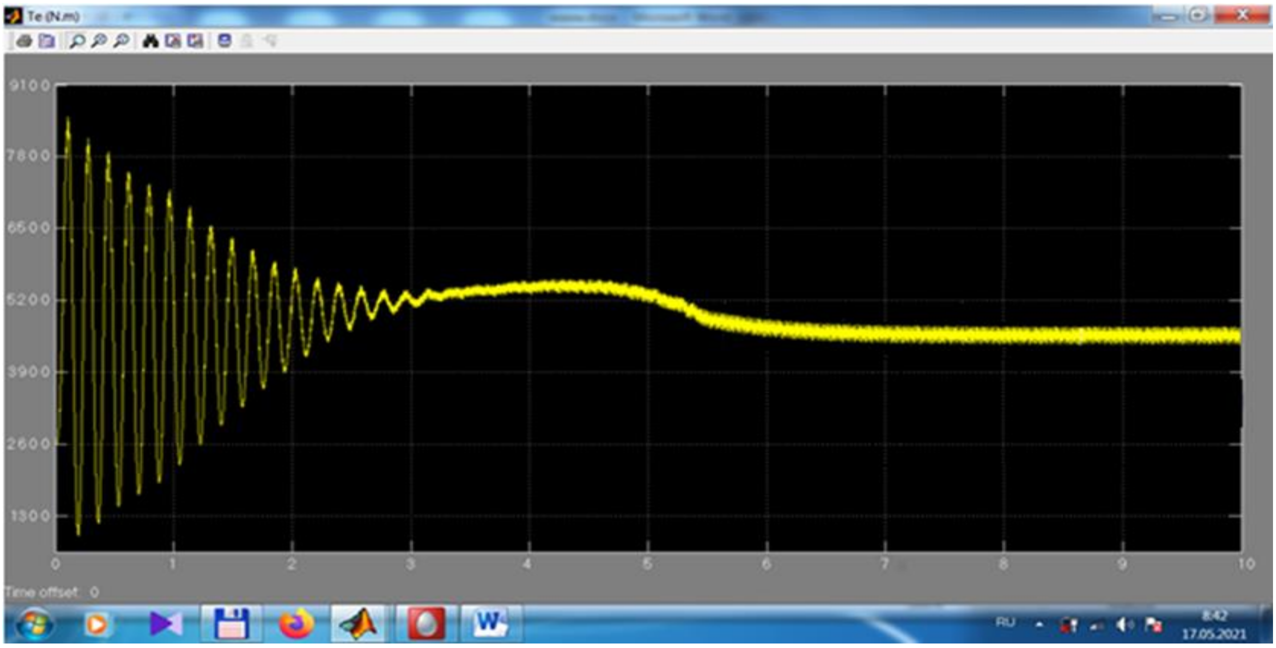

Fig-3. Oscillogram of the electromagnetic torque of a synchronous motor during start-up with excitation from a solar panel.

V. LITERARY STUDY

To conduct experiments on a computer model, we first set the value of the excitation current and load resistance. To run the model, click on the Simulink toolbar buttons. At the same time, the model is launched, and the displays show the values of the generator parameters.

When choosing mini photovoltaic stations, the following parameters were taken into account:

Solar radiation, seasonal coefficient by years, heat and electrical losses, required power of solar cells for the excitation system, ambient temperature for battery operation [1].

The main elements of a mini photovoltaic station are: a solar panel, batteries, an inverter and a battery charge and discharge controller.

As you know, the excitation system of synchronous machines consumes direct current, so when choosing a mini photovoltaic station, the choice of an inverter does not take into account excitation.

Thus, our studies have shown that the proposed method for excitation of synchronous machines of autonomous power plants from solar batteries develops and deepens theoretical ideas about the methodology for analyzing the excitation systems of electric generators of low and medium power of their parametric synthesis [5].

The article presents solutions to the problem of scientific and methodological foundations for the development of new power systems for the excitation winding of autonomous synchronous machines of medium power operated in conditions accessible to solar energy sources. The developed system can be used as a backup power supply for the excitation winding [6].

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VI. EXPERIMENTAL RESULTS

The SD-630 synchronous motor with excitation from a mini photovoltaic station has been studied. The results show that the oscillograms of the rotational speed and electromagnetic torque do not differ from the oscillograms when the engine is excited by existing methods. In operated synchronous motors SD-630, a thyristor self-excitation system is used.

The developed computer simulation model can be used to study medium power synchronous machines with excitation from solar energy.

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