Development of a model for diagnosing rotor conditions in the parallel connection of synchronous generators with the network

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Abstract. This article introduces a model for diagnosing rotor angular changes in generators when integrating synchronous generators into the grid. The model addresses issues like leakage currents, reverse moments, and stator bushing short circuits caused by rotor angle changes during parallel addition of large-capacity synchronous generators. Its unique approach simplifies precise synchronization during parallel connection and enables continuous graphical monitoring of rotor angle changes through computer programs. Experimental results from 110 MW synchronous generators at "Navoi Thermal Power Plant" JSC validate the model's effectiveness. It is designed to resolve rotor angle change challenges when integrating synchronous generators of varying capacities into existing power plants, ensuring uninterrupted electricity supply and optimizing technical and economic performance. The model aims to enhance operational efficiency and reduce costs for electricity consumers.

1 Introduction

Today, thermal power plants play an important role in providing electricity consumers in industrial enterprises, production zones, mining and agriculture in our country with continuous electricity. Therefore, 78.6% of the total electricity produced in our republic corresponds to thermal power plants. (Figure 1). Synchronous generators are the main element in the production of electricity in thermal power stations. Currently, 110 MW synchronous generators located at "Navoi Thermal Power Station" JSC are in service [1, 2].

When connecting these generators in parallel with another generator or with a large power network, the change of the rotor rotation angle of the generator is one of the main problems [3,4].

Due to such problems, the temperature of the rotor increases sharply, as a result, the speed of the magnetic field in the stator has a great effect on the rotor until it reaches synchronous speed, which has a large negative effect when connecting the generator in parallel with the network [4,5].

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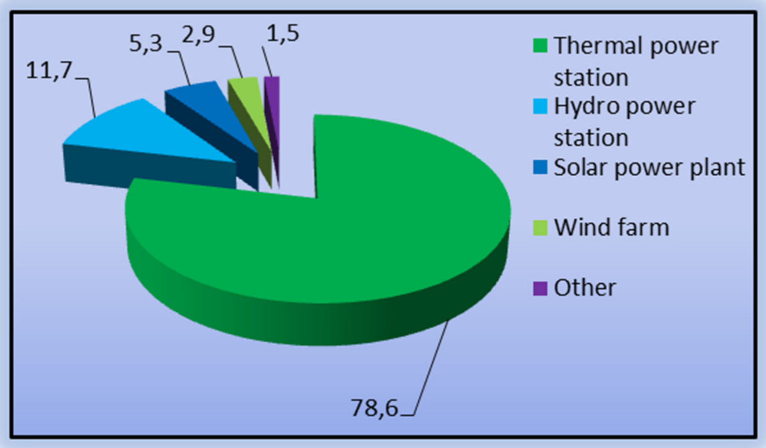

Fig. 1. The share of electricity generation in power plants.

Therefore, it is necessary to regularly diagnose generators in order to avoid such problems that arise when connecting generators in parallel. As a result, when connecting generators in parallel, changes in the technical condition of the generator and accidents can be detected early and prevented [6, 7].

2 Materials and methods

Synchronous generators consist of equalizing the vector of voltages generated when connecting parallel generators with another large power source (thermal, hydro, solar, wind power plants) or a network of different power. For this, the following conditions must be met:

- The three-phase voltage produced by the generator must be equal to the amplitudes of the synchronized voltages of the same phases as the network $U_1 = U_2$;
- The frequency generated in the generator and the frequency of the network should be equal to each other $\omega_1 = \omega_2$;
- The difference of the vectors between the voltage phases in the network and the voltages of the generator should be equal to 0. $\Delta\phi = \phi_2 - \phi_1 = 0$.

These three conditions are the conditions of the exact synchronization method, and if these conditions are not exactly met, it is not allowed to add the generator in parallel. In practice, to fulfill the third condition, the synchronized voltage vector is given a certain relative velocity, thus causing the violation of the second condition of exact synchronization [8, 9]. As a result, the generator creates a voltage difference between the generated voltage and the grid. This creates a force opposite to the rotation of the rotor of the generator. This situation limits the control of the speed control system of the generator rotor rotation and the possibility of correcting the change in the angle of rotation of the rotor is lost. Thus, after correcting the phase shift angle of the synchronized voltage to ensure all the conditions of parallel operation of the generator, a switch is added that connects the generator to the network when the rotor of the generator is brought to zero relative speed [10].

3 Results and discussion

Without violating the condition of equality of synchronized voltage frequencies, it is possible to indicate the condition of the rotor angle change through the speed control panel of the rotor of the synchronous generator. During synchronization, the task of the generator rotor position control system is to change the position of the rotor to the desired angle equal to the angle between the synchronized voltage vectors and prevent it from turning to another position. The principle diagram of the synchronous generator rotor angle change located at the research facility is shown in Figure 2.

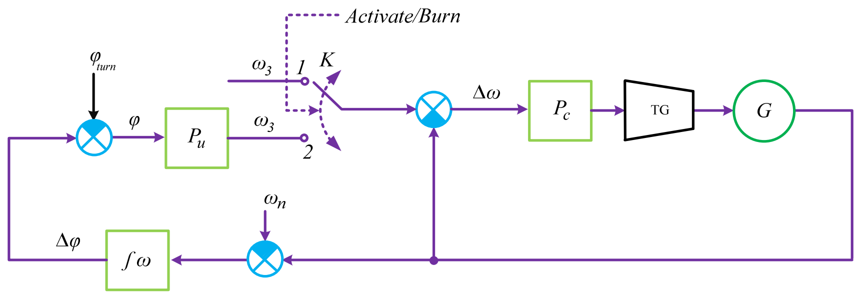

Fig. 2. The principal scheme of the automatic control system of the rotor rotation angle of the generator under investigation.

In the above figure, when controlling the angular change of the generator rotor, the switch K is switched to position "2" after the amplitude and frequency of the generated voltage are synchronized. The turning angle φ of the generator rotor is compared with the rotor turning angle Δφ after the switch is switched. The comparison error signal φ is fed to the controller Pu and the signal ωu is generated which defines this speed. The given signal ωu is compared with the current speed ω of the generator rotor, and the result of the comparison comes to the controller Dω, Pc, and it forms the signals needed for the control system of the steam coming to the turbine of the turbogenerator. After turning the rotor of the generator to the desired angle, the signal at the input of the regulator takes a zero value, the control system comes to a stable state, and the K switch automatically switches to the "1" position. After that, it is allowed to connect the synchronous generator under investigation to the grid [11,12].

In order to study the dynamic transient processes during the parallel operation of the synchronous generator, we developed a mathematical model that allows simulation of the object under study using the MATLAB/Simulink virtual program. This developed mathematical model is shown in Figure 3.

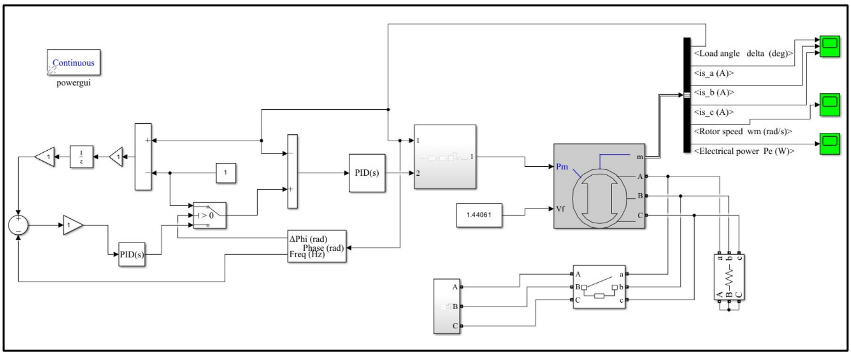

Fig. 3. The diagram of the mathematical model of diagnosing the condition of the rotor angle change of the synchronous generator, made in the Matlab/Simulik virtual program.

As a synchronous generator model, a standard three-phase model of Block shape using the SimPowerSystems element library was used. The parameters of the synchronous generator are also based on the parameters of the 110 MW open-pole synchronous generator installed in the existing facility, and their values are shown in Figure 4.

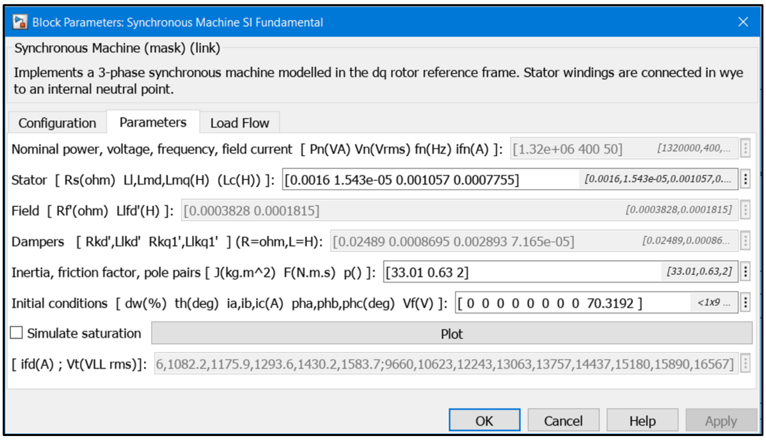

Fig. 4. Synchronous generator parameters.

The transmission mechanism (1) of the control system of the steam coming to the turbine of the turbogenerator is represented by the following function:

$$W_A(s) = \frac{K(1+T_1 s)}{s(1+T_2 s)(1+T_3 s)} \quad (1)$$

The turbogenerator's turbine drive time and the generator's operating time are shown in the following figures [13].

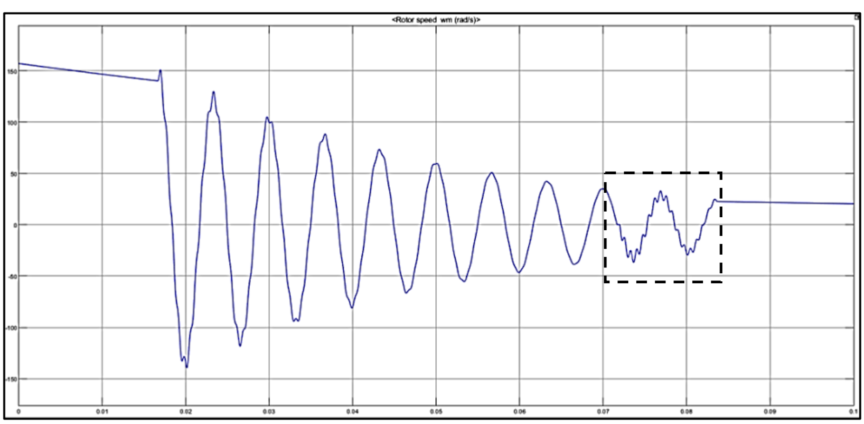

Fig. 5. Phase current generated in the stator coils of a synchronous generator.

Figure 5 shows the currents in the stator windings of the synchronous generator, in which the currents of the phases in the cases "A", "B", "C" are shown and change between 0.07 seconds and 0.085 seconds. is observed. As a result, when connecting the generator in parallel with the network, the change in currents causes forces opposite to the rotation of the rotor. The graph of the variation of the generated electric energy of the generator is shown in Figure 6.

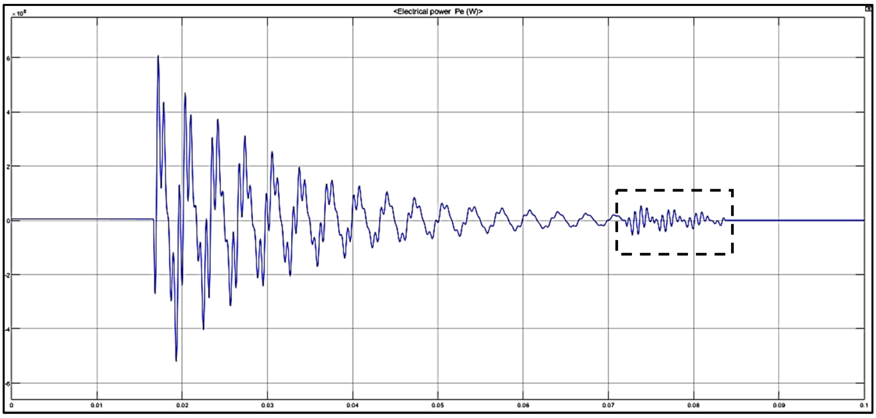

Fig. 6. Change in the electricity produced by the synchronous generator.

The figure above shows the variation in the electricity produced by the synchronous generator located at the research facility. It was observed that the generated energy of the generator varies between 0.07 seconds and 0.085 seconds, as a result, the rotor of the generator heats up and causes the generation of torques opposite to the direction of movement (Figure 7).

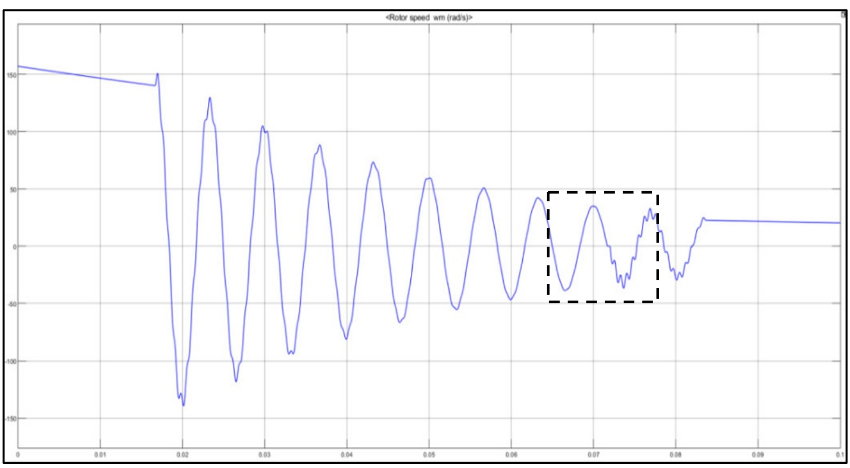

Fig. 7. The graph of the rotor angle change of the generator when connecting the synchronous generator in parallel with the network.

As can be seen from the results of the above-mentioned exemplary research, when connecting synchronous generators in parallel with the network, the rotor angle change affects the electromechanical and electrical parts of the generator. As a result, it has a negative effect on the operating cycle of the generator and connecting it in parallel with the network [10, 11, 12].

4 Conclusion

In conclusion, it can be said that when adding synchronous generators in parallel with the network, a diagnostic analysis of the rotor angular change state was considered. During the investigation, virtual programs were used. A model of a synchronous generator was constructed using the Matlab/Simulink vital environment. The model made it possible to view all parameters of the synchronous generator in a virtual state. Based on the analysis of the electrical parameters of the synchronous generator, it was possible to eliminate the accidents that occur in it by detecting them in advance. We can see the states of the electrical parameters of the synchronous generator from the pictures above. The state of the change in the electromagnetic converter moment of the generators was monitored. In this case, a decrease in the rotor rotation speed of the generator occurs. For these reasons, the temperature of the rotor blades exceeds the normal temperature. The rotor of the generator is formed by the decay of the insulation of the grooves. Due to these factors, accidents that occur when adding generators with a generator or a large power grid are obtained.

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