Modelling the synchronization process of generators on gas-turbine power plant

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Abstract. The article is about modelling the process of synchronization generators on autonomous gas-turbine power plant. The paper presents the system of automatic speed control (ASC) and the synchronization algorithm for the gas turbine unit, developed in the Matlab Simulink. The proposed synchronization model makes it possible to reduce the time of input of the synchronous generator into operation.

1. Introduction
The problem of synchronization of generators has been considered since the beginning of the appearance of the energy industry and it has received enough attention to solve it [1]-[3]. But, it should be noted that this issue was considered for the united power utility systems, which differ from isolated systems both qualitatively and quantitatively. In addition, the market of the production of distributed generation facilities was occupied by aviation factories and ship-building yards, which don’t have complete information about the operating modes of the generator in the power utility system. This leads to unpredictable results during the operation of such installations. Based on the foregoing, the development of automatic control systems for autonomous power plants of the oil and gas producing industry and transient simulation when turning on sources for parallel operation is an vital task for efficiency gain of designing and operating distributed generation facilities.

In the oil and gas industry, gas turbine systems are most in demand [4]-[9]. It serves for electric and heat supply of facilities. Such systems have a high efficiency factor due to the conversion of the exhaust gas energy into heat energy. Associated gas can be used as fuel. It allows to reduce the electricity production cost. Conversion of mechanical power into electrical power in gas turbine systems occurs by a synchronous generator.

During isolated operation of the power station, the shortage of generated power leads to a decrease in the generated voltage frequency. This in turn leads to a decrease in the rotational speed of the pump electric motors and, as a result, leads to a disruption of the technological process. As a rule, additional capacity is put into operation to compensate for this shortage. This process is accompanied by the turbine start-up, excitation of the generator and synchronization with units which is in operation

2. Paralleling of generators and synchronization
Typically, three synchronization methods are distinguished: coarse synchronization, self-synchronization, and precision automatic synchronization [10]-[11]. However, for the operating
conditions of the isolated power system, the first two methods are unsuitable, due to the fact that they are accompanied by large equalizing currents. Precision automatic synchronization is most appropriate for switching on a gas turbine unit to parallel operation with an autonomous gas turbine power plant. The necessary conditions for successful precision synchronization are: equal voltage amplitudes of the generator and buses, equal voltage frequencies of the generator and buses, no phase shift between the voltages of the generator and buses. The first two conditions are fulfilled by the ASC and AEC systems, the third condition is achieved by issuing control pulses to the generator drive by means of ASC and adjusting the generator phase to the grid phase, but the phase adjustment time is unpredictable, and this negatively affects the generator commissioning time. Schematic structure of the synchronization process is shown in Figure 1.

![Figure 1. Structural scheme of the generator synchronization in an isolated power system.](image)

Figure 1 shows the synchronized generator G1, the equivalent generator G2, automatic excitation control AEC and speed control ASC. The voltage signals on the buses of the synchronized generator and generating capacity are taken from the voltage transformers VT. Next, the signals go to the value calculator VC. After some transformations, the discriminant of control parameters is sent to the control pulse calculation unit CPCU. CPCU generates control signals that act on AEC and ASC.

3. Simulation and results
The model is research in Matlab Simulink. In the designed synchronization model, an improved ASC system was proposed, which affects both the synchronized generator and operating generators, which allows accelerating the process of equalizing the phase angle of synchronized objects.

The modelling of gas turbine is discussed in many works: [12]-[14]. In this article simplified Rowen’s model is used [15]. Full review of this model is given in [16].

The mathematical model of a synchronous machine is described by a system of differential equations of the 5th order [17]. The parameters for the equivalent circuit of the synchronous machine under research are of the following values:

| Parameter                          | Symbol | Unit | Value |
|------------------------------------|--------|------|-------|
| Nominal apparent power             | \( S_n \) | MV-A | 15    |
| Nominal phase-to-phase voltage,    | \( U_n \) | kV   | 6.3   |
| Nominal frequency                  | \( f_n \) | Hz   | 50    |
| Synchronous inductive resistance along the direct axis | \( x_d \) | r.u. | 0.99 |
| Transient inductive resistance along the direct axis | \( x_{d}^{'}\) | r.u. | 0.155 |
| Subtransient inductive resistance along the direct axis | \( x_{d}^{''}\) | r.u. | 0.121 |
### Table

| Parameter                                              | Symbol | Unit | Value  |
|--------------------------------------------------------|--------|------|--------|
| Synchronous inductive resistance along the quadrature axis | \( x_q \) | r.u. | 0.931  |
| Transient inductive resistance along the quadrature axis | \( x'_{q} \) | r.u. | 0.150  |
| Subtransient inductive resistance along the quadrature axis | \( x''_{q} \) | r.u. | 0.181  |
| Dissipation resistance                                 | \( x_l \) | r.u. | 0.096  |
| Transient time constant along the direct axis          | \( T'_d \) | sec  | 0.756  |
| Subtransient time constant along the direct axis       | \( T''_d \) | sec  | 0.095  |
| Transient time constant along the quadrature axis      | \( T'_q \) | sec  | 0.3371 |
| Subtransient time constant along the quadrature axis   | \( T''_q \) | sec  | 0.0295 |
| Stator winding active resistance                       | \( R_s \) | r.u. | 0.003  |
| Mechanical inertia constant of the generator           | \( T_j \) | sec  | 4.344  |
| Number of pairs of poles                               | \( p \) | -    | 1      |

In the model is used the synchronous machine excitation unit "Excitation System" from the Simulink library. The target voltage value at the terminals of the synchronous generator and the actually effective value of the generator voltage are applied to the input of the unit. The output signal of the system is the excitation voltage of the synchronous machine.

The presented model makes it possible to analyze the operation of automatic speed control, automatic excitation control and synchronization algorithm for the gas-turbine installation. The research results of the designed model are shown in Figure 2 and Figure 3. Figure 2 shows the rotational speeds of an equivalent and synchronized generator as a function of time. Figure 3, in turn, shows the phase angles of similar phases of an equivalent and synchronized generator as a function of time.

![Figure 2. Rotational speeds of G1 and G2.](image)

At time \( t_1 \), on the power plant buses occurred load rise, and rotational speed of the equivalent generator is dropped. After a time delay, which is necessary to avoid a short-term power shortage, the ASC system of the equivalent generator increased its speed to the nominal and, at the same time, the generator G1 started up for its subsequent synchronization with the equivalent generator G2. After the speed and voltage at the terminals of the generator put into operation reach their nominal values, the...
CPCU is activated (Figure 1). The CPCU equalized the phase angles of the voltages of the synchronized and equivalent generator (Figure 3).

![Voltage phase angles of G1 and G2 and their algebraic difference in control implementation.](image)

**Figure 3.** Voltage phase angles of G1 and G2 and their algebraic difference in control implementation.

In accordance with what sign the phases of the synchronized signals have, the generators ASC system receives impulses of negative or positive polarity from the synchronizer unit, slowing down or accelerating the generator turbine. After the voltage phase difference of the synchronized and equivalent generators takes a steady-state minimum value, the synchronizer unit sends a control pulse to turn on the generator switch (Figure 1).

4. Conclusions
The designed model has shown that the improved ASC system allows reducing the time of generator start-up in conditions of power shortage by controlling the speed of rotation of both the synchronized generator and the generators in operation. Using the obtained synchronization model allows us to conclude about the efficiency of the synchronization algorithm used.

5. References
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