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Development of a System for Automated Control of a Power Station with Transverse Links during Its Isolation from the Power System

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Abstract—We present the results of works aimed at developing a universal algorithm and constructing a system for automatically isolating a power station with transverse links to operate on unbalanced load when a shortage of generating capacities occurs in the power system.

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System failures that sometimes occur in power systems with a shortage of generating capacities usually entail a drop of frequency. The value of this drop is commonly limited through the use of automatic frequency load shedding. However, this measure may turn to be insufficient under the conditions of a severe accident. In this case, islanding a power station for an isolated area (in the limiting case, for in-house loads) remains the only means for keeping it in service. Apart from preventing full blackout in the area, this measure also allows the accident to be removed within a shorter period of time. The use of such technique for keeping power stations in service is stipulated by the relevant standards of the Central Dispatch Board's System Operator Department and by other directive documents [1–3].

The above-mentioned documents stipulate islanding power stations or parts of them from the power system for an approximately balanced load region or separating individual power units for supplying power to the in-house loads. However, attempts to fulfill these prescriptions encounter at least two difficulties:

—Separation of an approximately balanced area for a power station with variable modes of its operation involving deep changes of its load is an extremely difficult problem, which at the current state of engineering can hardly be solved with sufficient reliability.

—If the power system does not contain power stations containing single-boiler single-turbine power units, or if for some reasons power units cannot be shifted to operate for in-house loads, changing the operating modes of power stations with transverse links remains the only possibility for making maneuvers in the power system. With a single-boiler single-turbine power unit, the initial load of the transition or at least its final point, i.e., the load of power unit auxiliaries is known. For a power station with transverse links, neither the initial nor the final load of the transition is known due to a variable composition of the operating equipment.

Earlier, operations for shifting power units to operate for in-house loads were carried out [4, 5]. As was already pointed out, making a similar shift at power stations with transverse links is a more difficult task. These difficulties are stemming from control of heat-generating and mechanical equipment because the way in which a power station is disconnected from the power system by means of electrical equipment is almost independent on the power station structure. At the same time, islanding of a power station with keeping it connected to an area always seems to be a preferred solution. With such an approach, it becomes possible to reject the power station load by a smaller extent and retain part of consumers, which is sometimes even more important if these are loads relating to high categories.

The way in which these difficulties can be overcome is seen in implementing the idea of islanding a power station with transverse links for an unbalanced load. The load is balanced at the moment of carrying out the changeover. In this case, the power station is islanded together with its dead-end loads the capacities of which by the moment of changeover are not known in advance.

Specialists of OAO Sibtekhenergo have designed systems for automatically isolating power stations from the power system to operate on unbalanced load (UPSISs) for a few cogeneration stations (CSs) with transverse links operating in the Omsk and Kuzbass power systems.

One of such projects was implemented in 2009–2010 at the Omsk TETs-4 cogeneration station using the computerized automation system supplied by NPO EKRA. Along with being fitted with the automatic control system, the power station's thermal circuit was augmented with a device for damping steam into the atmosphere, known as a fast-acting reduction and cooling installation (FRCI). The throughput capacity of this device was calculated in designing the UPSIS.

The UPSIS thermal part (UPSIS-T) is intended to minimize pressure deviations in the power station's main steam header when it is isolated from the power system together with its dead-end loads. Large deviations of pressure in the main steam header may lead to unauthorized tripping of steam-generating capacities and, as a result, to loss of auxiliary power supply and full shutdown of the power station. The permissible range of pressure deviations is equal to half the difference between the nominal pressure and the pressure at which the safety valves come into action.

The UPSIS system serves to simultaneously perform the following three control functions:

—control of boiler equipment (the boilers that must be left in operation with the new loads in the emergency situation are selected, and the remaining boilers are shut down);

—control of the pilot-operated safety valves (PSVs) of boilers; and

—control of the additional fast-acting steam dump device ($FRCI_{UPSIS}$).

The greatest difficulties are encountered in setting up interaction of the UPSIS-T with the boiler equipment, which is the least maneuverable part of heat-generating and mechanical equipment.

The basic principles according to which the considered system operates are as follows.

The thermal part (UPSIS-T) begins to operate only when it receives the signal indicating that the UPSIS electrical part (UPSIS-E) has finished its operation. All boilers that do not have feed controllers switched into operation are disconnected when the UPSIS comes into action. When the UPSIS is in operation, the CS steam loads are covered by the boilers whose feed and combustion controllers operate in the automatic control mode. If there is a need to cover a steam load exceeding the capacities of the boilers the combustion controllers of which are switched into operation, boilers without combustion control may take part in covering this load. These boilers must have their feed controllers switched into operation, and they will not change their load during operation of the UPSIS.

The composition of boilers covering steam load during operation of the UPSIS must include a boiler maintaining the pressure in the main steam line. If none of the boilers maintains the pressure in the main steam line, the UPSIS will operate, but unsuccessful operation of the system will be more probable.

Of the boilers that can participate in covering loads, a composition is selected with which the sum of minimal boiler loads in their adjustment ranges is minimized.

The fast-acting reducing installation of the UPSIS ($FRCI_{UPSIS}$) for dumping excess steam into the atmosphere must be in serviceable state. The FRCI pressure controller maintaining the pressure in the live steam pipeline must be in the "automatic control" mode. The UPSIS' fast-acting reducing installation for discharging excess steam into the atmosphere receives the signal enabling its operation after the UPSIS thermal part is put in operation. The algorithm according to which the $FRCI_{UPSIS}$ operates is determined by the imbalances of steam occurring after the power station is disconnected from the power system. If any command has not been executed automatically due to a malfunction in the system, a request to the operator for its manual execution is generated. Depending on the kind of the command that has not been executed, the system either waits until the operator executes it or continues to run the algorithm. In the latter case, the system returns to execution of the interrupted chain of the algorithm after the operator has executed the command.

The exchange of signals between the UPSIS and controlled equipment is organized as follows.

(i) Exchange of signals with boilers whose control is performed using programmed controllers is implemented via digital communication channels.

(ii) Exchange of signals with boilers and turbines whose control is performed without using digital technologies is implemented by means of a unified signal or by means of a discrete signal in the form of a dry contact.

Operation of the $FRCI_{UPSIS}$ is enabled from the UPSIS-T by producing a dry-contact signal to the $FRCI_{UPSIS}$ automatic control circuit. The UPSIS thermal part produces commands to the pilot-operated safety valves of the boilers. The UPSIS system does not interact with the controllers of the regular reducing and cooling installations (RCIs) and regular FRCIs. Once the algorithm has been fully executed, the UPSIS thermal part stops its operation and restores the initial settings.

Cases are possible when the UPSIS-E repeatedly comes into action:

—when a dead-end consumer increased its load;

—when the boiler was tripped in an emergency manner, due to which the power output of the generators dropped; and

—when the turbine was tripped in an emergency manner, and the amount steam that remained available after the load had been distributed among the turbines left in operation turned to be insufficient for covering the needs of consumers, e.g., if the most efficient turbine was disconnected.

After the UPSIS has come into action once again, the signal for repeated actuation of the UPSIS-T is produced. In this case, the UPSIS-T operation algorithm will depend on whether this system has completed its operation after its previous actuation from the UPSIS-E.

Due to a considerable extent to which the electrical equipment used at existing CSs has been worn,

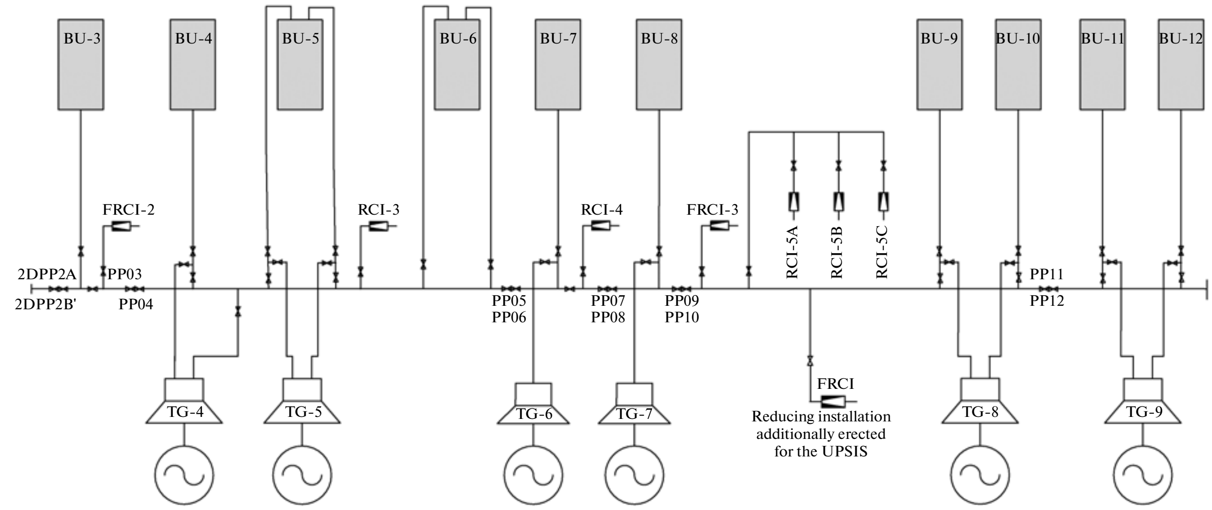

Fig. 1. Simplified scheme of connecting the main equipment to the live-steam line at the Omsk TETs-4 power station (only the sectionalizing electrically driven gate valves are shown in the scheme).

attempts to perform switching operations in their auxiliary power supply system are often not met with success, which is especially inadmissible when corrective actions must be performed within a short period of time to rectify an emergency situation. One of the most important advantages of the projects that have been developed is that they did not involve making any switching operations in the power station's auxiliary power supply systems during its disconnection from the power system.

The operating algorithm of the UPSIS-T system was elaborated on models that were constructed using the results from field tests carried out on operating equipment of the CSs for which this system was designed. Since the project has been implemented only at the Omsk TETs-4 cogeneration station, only this power station will be considered in the further discussion.

The dead-end consumers connected to the Omsk TETs-4 cogeneration station are enterprises with a continuous cycle of their production process; interruption of this cycle may entail a large loss of money and give rise to environmental problems.

The UPSIS-T system is constantly in a waiting mode; once the signal from the electrical part about isolation from the power system arrives, the system is activated and performs the necessary actions in a fully automatic manner, producing indications about its operation to the personnel. If any command in the system is not executed, a message with exhaustive information about continuation of work is produced to the operator, a feature due to which more reliable operation of the system is achieved.

The scheme according to which the main equipment is connected to the main steam line of the Omsk TETs-4 cogeneration station is shown in Fig. 1. The following steam boilers are installed at the power station:

(i) three BKZ E-320-140 boilers and six BKZ E-420-140 boilers;

(ii) type R-50-130/15 50-MW turbine generators TG-4 and TG-5 with controlled back pressure;

(iii) type T-100-130 100-MW turbine generators TG-6 and TG-7 with two controlled district-heating extractions;

(iv) the R-100-130/15 100-MW turbine generator TG-8 with controlled back pressure; and

(v) the PT-135/165-130/15 135-MW turbine generator TG-9 with two controlled production steam extractions and two controlled district-heating steam extractions.

The installed thermal capacity of the cogeneration station is 6300 GJ/h (1500 Gcal/h); its working thermal power output does not exceed 5900 GJ/h (1404 Gcal/h), and the installed electrical capacity is equal to 535 MW.

The CS uses coal as the main fuel and fuel oil as standby coal. The required level of pressure in the live steam line is maintained in the operating mode by a controller producing control outputs to one boiler.

Different versions of maximal and minimal loads during operation of the UPSIS under winter and summer conditions, as well as the version of isolating the CS to operate for only in-house loads, were analyzed, and it was found from that analysis that the range of required steam loads is from 60 to 750 t/h, and different compositions of boilers are required for covering this range in different versions. The configuration of boiler units with their steam loads obtained after the UPSIS comes into action is presented in Tables 1 and 2.

Thus, at least two boilers with a steam load of 420 t/h and one 320 t/h boiler must operate in winter,

Table 1. Summer versions of loads

Load	Version		
Electrical, MW	17–50	50–70	70–100
Steam, t/h	60–230	230–350	350–560
On boilers and $FRCI_{UPSIS}$	One BKZ-320 boiler with a load of 230 t/h (the steam flowrate through the FRCI is from 170 to 0 t/h)	One BKZ-420 boiler with a load of 350 t/h (the steam flowrate through the FRCI is from 120 to 0 t/h)	One BKZ-320 boiler with a load of 220 t/h and one BKZ-420 boiler with a load of 340 t/h (the steam flowrate through the FRCI is from 210 to 0 t/h)

Table 2. Winter versions of loads

Load	Version				
Electrical, MW	25–50	50–70	70–100	100–110	110–120
Steam, t/h	115–230	230–350	350–560	560–700	700–750
On boilers and $FRCI_{UPSIS}$	One BKZ-320 boiler with a load of 230 t/h (the steam flowrate through the FRCI is from 170 to 0 t/h)	One BKZ-420 boiler with a load of 350 t/h (the steam flowrate through the FRCI is from 120 to 0 t/h)	One BKZ-320 boiler with a load of 220 t/h and one BKZ-420 boiler with a load of 340 t/h (the steam flowrate through the FRCI is from 210 to 0 t/h)	Two BKZ-420 boilers with a load of 375 t/h each (the steam flowrate through the FRCI is from 140 to 0 t/h)	Two BKZ-420 boilers with a load of 340 t/h and one BKZ-320 boiler with a load of 220 t/h (the steam flowrate through the FRCI is from 200 to 150 t/h)

and one 420 t/h boiler and one 320 t/h boiler must operate in summer. Since some boilers may be taken for repair, no less than three 420 t/h boilers and two 320 t/h boilers must be fitted with devices for receiving signals from the UPSIS and with devices for automatic control of fuel combustion.

As was already pointed out, the work on designing the thermal part of the system involved simulation of the processes that take place in the thermal equipment (in the boilers, turbines, and main steam line) when the power station is isolated from the power system. The models were constructed based on the results obtained from field dynamic tests of the boilers, turbines, and main steam lines carried out at the power station. Simulation was carried out for different initial imbalances of steam. The term "imbalance of steam" is understood to mean the difference between the amount of steam generated by the boilers and the amount of steam required after isolation of the power station from the power system. The simulation results are shown in Fig. 2. Curve *1* represents the situation in which the UPSIS is not used. Since all boilers remain in operation, and the capacities of the boiler controlling the pressure in the steam line are quickly exhausted, the pressure shows a rapid growth (within 3 min) to the protection actuation setpoints (the dashed curve in Fig. 2), and all boilers are tripped. Curve *2* reflects the case in which noncompensated excess quantities of steam may appear due to the narrow adjustment ranges of coal-fired boilers and limitations imposed on decreasing their load, as a result of which a growth of pressure is observed. The growth of pressure (curve *3*) is caused by the same factors as in the preceding case; part of generated steam remains noncompensated. Curve *4* describes a situation in which the FRCI is controlled in accordance with a two-stage scheme. The logic part comes in operation first, which opens the FRCI valves to a certain position depending on the initial imbalance, after which the FRCI is switched to operate in the analog control mode in accordance with a PI control law. Thus, it can be seen from Fig. 2 that incorporation of an additional steam-discharging $FRCI_{UPSIS}$ into the thermal circuit and operations with the pilot-operated safety valves of the boilers are the necessary conditions for successful operation of the system whatever the power imbalance between the power station and consumers isolated together with the station.

At the same time, in view of a rather high cost of the additional steam-discharge high-pressure FRCI, a question arises if the system can operate without this installation.

For solving this question specifically for the Omsk TETs-4 cogeneration station, simulation was carried out to analyze how the pressure in the main steam line varies depending on the difference by which the amount of generated steam exceeds its consumption. The results of this simulation are shown in Fig. 3. It can be seen from the graphs that, taking into account the failure-free criterion mentioned above, according to which the growth of pressure in the main steam line must not be more than half the range to the level at which the safety valves come into action, the possible excess of generated steam during operation without the FRCI is no more than 100 t/h. Depending on the types of boilers remaining in operation, the actual

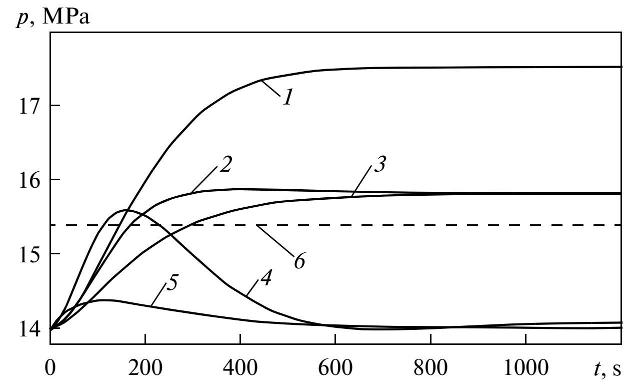

Fig. 2. Variation of pressure in the main steam line in the cases of using different methods for control of process equipment. (*1*) Without an UPSIS and with using the main controller at an initial steam imbalance of 500 t/h; (*2*) with the UPSIS, but without the PSVs and FRCI at an initial steam imbalance of 500 t/h; (*3*) with the UPSIS, but without the FRCI and with using the PSVs of the disconnected boilers at an initial steam imbalance of 500 t/h; (*4*) with the UPSIS and FRCI, the PSVs are not used, the initial imbalance of steam is 1220 t/h; (*5*) with the UPSIS, FRCI, and PSVs of the disconnected boilers, the initial imbalance of steam is 2300 t/h; and (*6*) the pressure at which the safety valves come into action.

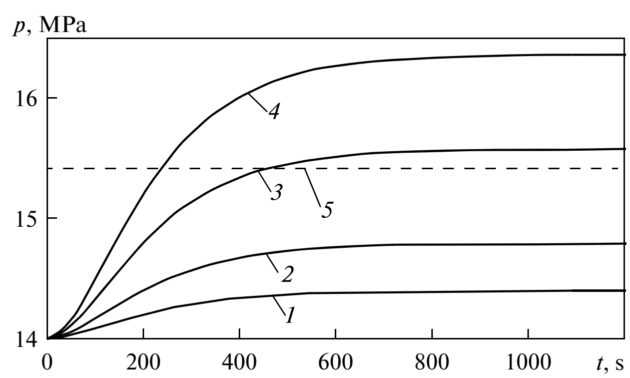

Fig. 3. Variation of pressure in the main steam line depending on the excess of steam. Excess of steam, t/h: (*1*) 50, (*2*) 100, (*3*) 200, (*4*) 300, and (*5*) the pressure at which the safety valves come into action.

excess of steam may reach 290 t/h. Hence, with the same probability of excess amounts of steam in the range 0–290 t/h, the operation of the system without a special steam-discharge FRCI will be unsuccessful in 65% of cases.

At present, the UPSIS system has passed detailed testing in accordance with special programs and has been put in trial operation. Testing of the system under field conditions is an important and self-contained work, which is carried out in several stages in accordance with a carefully elaborated program and requires numerous agreements for its execution.

Thus, the experience gained from the development and implementation of Sibtekhenergo's project testifies that it is really possible to keep a power station with transverse links and with the dead-end consumers connected to it (and in the limiting case only with its in-house loads) in a serviceable state when a system-wide failure occurs in the power system by isolating this power station from the power system and shifting it to operate on an unbalanced load. The balance between the generation and consumption is reached automatically through the use of the UPSIS-T control system immediately after the power station has been isolated from the power system.

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