POWER SYSTEMS AND ELECTRIC NETWORKS

TECHNICAL SOLUTIONS FOR AUTOMATING SELECTION IN A BALANCED POWER REGION OF A THERMAL POWER PLANT CROSS-LINKED BY STEAM

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Approaches to organizing a system for automatic selection in a balanced power region when there are deep frequency reductions in a thermal power station, cross-linked by steam, are considered, using the example of the Omsk thermal power plant TÉTs-4 (Omsk TÉTs-4). Modes of operation of the power plant and of the power system for parallel operation with the United Power System, and also when there is a loss of connection at a junction substation, are analyzed. The results of modeling of the characteristic winter/summer modes of operation are presented, and the effectiveness of using automation of the selection of the power plant in a balanced power region based on a model of the power system is shown.

Keywords: relay protection and automation of power units; antiemergency control of power systems and power interconnections; electric power plants; emergency reduction in frequency and voltage.

The power systems of Russia are at present undergoing modernization with the replacement of ageing equipment, including automatic control systems, and devices for regulation, protection and automation based on electronic and semiconductor components. They are being replaced by various digital microprocessors. Nevertheless, the occurrence of large-scale systems emergencies remains a serious problem. Thus, on October 7, 2003, part of the Central and Black Earth regions of Russia were without electricity supplies (in the Vladimir Oblast' 970 populated areas were without light, 580 in the Lipetsk and Smolensk Oblast's, and 200 in the Tambov and Belgorod Oblast's, and due to breakdowns of the contact network, electric trains were brought to a halt). On May 25, 2005, due to an emergency in the power network of Central Russia, Moscow, and the Tula, Moscow, Kaluga, and Ryazan' Oblast's suffered. During the last decades several breakdowns of the largest power systems have occurred causing considerable damage. This situation imposes even newer requirements on the relay protection and automation devices, to increase their reliability.

When there are breakdowns in the unified power systems with a separation of the regional power systems from the unified power systems with a deficit of generating power, a considerable reduction in the frequency below the permissible limits is possible (and a reduction in the voltage at the junctions of the power system), which may cause damage to equipment, and a breakdown of normal operation both to consumers and sources of electric power situated in this region. The main problem in the automatic disconnection of a power plant in a balanced power region and, as a consequence, the natural needs (ADPP, according to the latest changes in the nomenclature this is now called a frequency-dividing automatic system, henceforth FDAS) consists in maintaining the stability of the thermal power plant for such major emergencies [1, 2].

As experience has shown, there are a number of factors which may lead to such a situation: loss of coupling with the system when there is a large internal deficit in a region, loss of power supply from the major power units or even complete power units etc. A sharp change in the balance between the generated and consumed power, particularly on the consumption side, leads to a change in frequency to try to reduce this, and hence the automation system is triggered towards reducing the frequency, and, if necessary, the voltage also, depending on the design. It is worth noting that the purpose of introducing an automatic system is not to rescue the power system, but to preserve the power system, and to preserve the power plant and the equipment of the automatic system.

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Such preservation enables damage to the plant equipment to be prevented at the price of cutting off normal supplies and thereby reducing the post-emergency period. Moreover, the power supply to consumers in the power region covered by the automatic system is maintained, which is also not unimportant since this region may be fairly large and power rich, and also can supply important groups of consumers with a continuous cycle of operation.

The frequency of the ac voltage is one of the main indicators of the electric power quality. The frequency of rotation of the electric motors, and consequently the output of the mechanisms rotated by them (lathes, pumps, ventilators etc.), depends on it, and hence if the frequency falls their output is reduced [3]. An increase in the frequency leads to overconsumption of electric power, and hence any variation of the frequency is detrimental to the consumer. The value of the frequency deviation is regulated by the State Standard [4]. As is well known, the economy of power plants is most sensitive to a reduction in the frequency for objective reasons.

The breakdown in the Moscow power system in the summer of 2005, during which there was a loss of supply to a considerable number of consumers, and an analysis of this breakdown showed that a number of Russian power stations lack a most important feature, namely, stability. The breakdown in the Moscow Power System sharply illustrated the problem of the need for technical reequipment and reconstruction of the main sections of the power system in order to ensure its stability. Moreover, it is worth noting that it took more than two weeks to repair this breakdown, and this once again confirmed the need to reactivate the automatic equipment for matching thermal power plants to the natural needs, the start of the practical introduction of which was in the first half of the twentieth century.

One of the main methods of increasing the stability of electric power plant is to install automatic equipment in them for selecting balanced power regions (henceforth ASDPP; we mean by a balanced region a power region of a power plant which assigns automatic equipment and hence a balance is produced between the generated and consumed power by delivering controlling actions), which operates when there is an unsafe emergency reduction of the frequency and voltage in the power system and isolates from the power system the turbogenerator of the thermal power station to operate into a balanced load to meet normal needs or a power region of the power plant together with dead-end lines, supplying the load. The introduction of the ASDPP was required according to the standards and directives of the United Power System of Russia.

As a result of separating power plants according to their operating parameters, a recalculation of the balance between the generated and consumed power is required at the power junctions and an equalization of this balance due to a deviation of the loads and the use of all existing standby power plants [5]. In fact, at the instant when a power region is selected by the automatic equipment, an analysis is carried out on the balance of power in the selected power region, namely:

if $P_{\Sigma g} < P_{\Sigma n} + P_{\Sigma l}$, where $P_{\Sigma g}$ is the power of the generators, $P_{\Sigma n}$ is the power consumed for normal needs, and $P_{\Sigma l}$ is the power of the load, the controlling actions of the automatic equipment are directed towards disconnecting the load when there is a specified value of the unbalance (an addition, which can be disconnected, specified by the operator of the power plant with the possibility of changing the real-time operating conditions);

if $P_{\Sigma g} > P_{\Sigma n} + P_{\Sigma l}$, the controlling actions of the automatic equipment are directed towards reducing the generation of electric power at a specified unbalance value.

It is also worth noting that this approach is universal and enables any separate power region of the plant to be balanced irrespective of the nature of the breakdown and its reasons, the configuration of the power region and the values of the generated and consumed power, and also any residual factors which may affect the working capability of the system as a whole.

The standard solution for selecting thermal power plants for extreme reductions in frequency has been the selection of a single generator supplying normal needs (in the case when the chosen generator is removed for repair, the automatic system is transferred to another working generator). However, the use of this form of “recovery” of a power plant from resting at zero depends on the structure of the cross linking by steam.

In this paper we discuss the problem of selecting a power plant in a balanced power region and ways of solving this problem as it applies to the Omsk TÉTs-4, where one generator on a balanced load supplying normal needs could not be selected due to cross linking by steam in the thermal part. It should be noted that in this thermal power plant there was no automatic system of the type considered and the problem could not be solved by increasing the stability of the power plant.

During the course of the operation, we developed and proposed a technical solution for selecting a power plant when there is a major reduction in the frequency in the balanced power region of the Omsk TÉTs-4 with typical loads of 110, 35, and 6 kV. This solution is not only technically but also economically justified, since when there is a breakdown, a considerable number of consumers are guaranteed power supplies.

Active power unbalance at a selected power junction of a thermal power plant is removed by the electrical part of the automation (ASDPP), called the ASDPP-E. Unbalance with respect to the steam power, which occurs in the thermal part, is removed by the thermal part of the ASDPP, called ASDPP-T. It should also be noted that the decisions taken in the Omsk TÉTs-4, individual and using other power plants, may be partially or even completely changed (but still maintaining the overall concept), because it is simply impossible to obtain two absolutely identical power plants as regards their equipment and the features of their modes of operation.

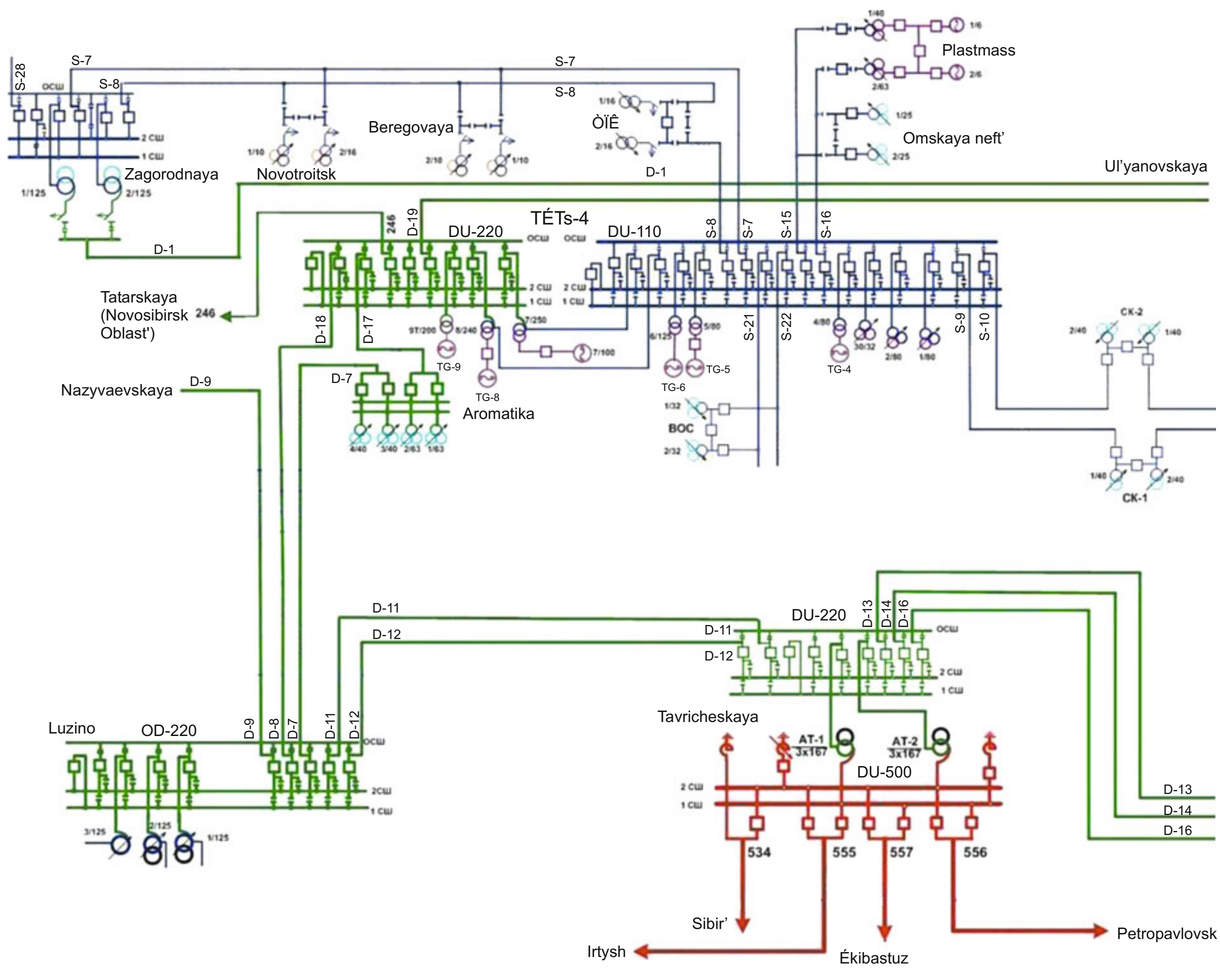

Fig. 1. The Omsk TÉTs-4 and its connections to the power system.

The ASDPP devices based on microprocessor technology enable the remaining load for normal supplies to be fairly accurately determined as well as the load of the thermogenerator of the power plant at the instant when it is isolated from the power system, and it also enables one to balance the generated and consumed active and reactive powers of the turbogenerators of the power plant and the normal load by discrete switchings in the main electrical and thermal equipment and thereby prevent any considerable increase in the rotation frequency of the turbogenerators.

We designed the automatic system for selecting the normal requirements of the Omsk TÉTs-4 with a transition to autonomous operation with a selection of the normal load and typical lines with the help of the JSC "Sibtekhénergo" based on a relay protection terminal, and automation and control of the EKRA 200 series designed by the EKRA Ltd. Company.

The Omsk power system is connected (Fig. 1) to the Kazakhstan united power system via the Ermak – Irtyshskaya – Tavricheskaya 500 kV lines (overhead line 555), the Ékibastuz – Tavricheskaya lines (overhead line 557), and with the Ural united power system via the Kurgan – Petropavlovsk – Tavricheskaya lines (overhead line 556). The parallel mode of operation of the Omsk power system with the Siberian united power system is provided at present over the 220 kV intersystem line (overhead line 246) from the Omsk power station TÉTs-4 to the Tatarskaya 220 kV substation and then to Novosibirsk, and also via the 110 kV lines (S-15 and S-16) from the Valerino substation to the Tatarskaya substation. There are 220 kV connecting lines with Barnaul, along which one can also achieve parallel operation of the Omsk power system and the Siberian united power system.

The most difficult mode of operation is chosen as the emergency theoretical mode of the Omsk power system (it is also considered in this paper, but in the design we also investigated the remaining probable modes of operation, which are not described here in view of the abundance of material), which leads to an emergency reduction in frequency to impermissible limits and the operation of the automatic plant selection of the Omsk thermal power plant. At the time when the problem was solved, there was no ASDPP device at the Omsk TÉTs-4.

The Omsk power system is deficient. In the summer of 2006 the active power of the generators of the Omsk power plant was P_g = 569 MW and the reactive power Q_g =

= 184.8 Mvar, whereas the load power P_l = 979.3 MW and Q_l = 586.6 Mvar. In the winter of 2007, P_g = 1079 MW, Q_g = 421 Mvar, P_l = 1519.1 MW, and Q_l = 668.9 Mvar. The existing power deficit of the Omsk power system is eliminated due to the fact that it has connections along the 500 kV lines to the Kazakhstan united power system (the Ermak power plant and the AES "Ékibastuz"), and the Ural united power system, along which the main return flows are obtained, and also along the 220 kV and 110 kV lines with the Siberian united power system (from the Novosibirsk and Barnaul power systems).

In Table 1 we show data on the return flows of active power along the 500 – 220 – 110 kV lines connecting the Omsk power system with the Kazakhstan united power system, the Ural united power system and the Siberian united power system in characteristic summer and winter modes of operation.

The factors considered are also the basis of the operation of the electrical part of the Omsk TÉTs-4 automatic selection system.

The main condition that triggers the ASDPP-E devices is a simultaneous drop in the frequency of the voltage in the first and in the second systems of 110 and 220 kV busbars to the following limits (three operating settings):

1) setting 1: operating frequency $f < 47$ Hz, with a time delay of 30 sec;

2) setting 2: operating frequency $f < 46.5$ Hz, with a time delay of 0.5 sec;

3) setting 3: depending on the rate of drop in frequency (for a rate of drop in frequency $df/dt > 1.5$ Hz/sec, reaching a value of the frequency of 47 Hz the automatic system operates with a time delay of 0.1 sec).

The ASDPP-E device acts on the disconnection of the line circuit breakers from the 110 kV power system and on the circuit breakers of the connection lines from the 220 kV power system. Standby of the controlling actions in disconnecting the lines is achieved by delivering, if necessary, a command to split the 220/110 kV autotransformer connection.

TABLE 1. Return flows of active and reactive power along the 500 – 220 – 110 kV lines

OL	Voltage, kV	*P*, MW	*Q*, MVar
Aksu SRPP – Irtysh	500	482/475	–98/–152
Mynkul' – Irtysh	220	11/9.8	5/67.3
Valikhanovo – Irtysh	220	11/9.1	–2/92.4
Ékibastuz SRPP – Tavricheskaya	500	321/316	34/–23
Avrora – Tavricheskaya	500	–439/–471	129/–74
Tatarskaya – Omsk TÉTs-4	220	–3/63	1/–12
Tatarskaya – Valerino	110	5.8/46.3	–8.9/19.2
Total return flow in the Omsk power system		388.8/448.2	77.9/–229.5

Notes. The numerator is the characteristic summer mode of operation for 2006, the denominator is the characteristic winter mode of operation for 2007.

Calculated data on the modes of operation of the Omsk power system, possible versions of the construction of the automatic system for selecting power plants (OTÉTs-4), including the selection of the plants in the balanced region, operating in parallel with the Novosibirsk power system, were considered starting from the summer 2006 – winter 2007 modes of operation, information on which existed at the instant when work on constructing the system had begun. The calculation was carried out beginning with the existence of the most difficult emergency situation in the Omsk power system, due to a loss of connection with the united power system at the Tavricheskaya substation, resulting from the disconnection of the autotransformer connection. When the autotransformer AT-2 at the Tavricheskaya substation was in repair, as a result of an emergency, the autotransformer AT-1 failed, and the Omsk power system lost its connection with the Kazakhstan united power system and the Ural united power system. As a result of the emergency, an active power deficit arose in the Omsk power system, leading to a hazardous reduction in frequency in the power system.

Antiemergency action was taken primarily by the AFS (automatic frequency shedding) device by disconnecting the load on the consumer substations, but their action was insufficient, since there was a large deficit of active power. Due to the difference in the frequencies, asynchronous behavior of the Omsk power system occurred with respect to the Siberian United Power System along the 220 kV line (overhead line 246) and the 110 kV lines connecting with the Novosibirsk power system, and also along the 220 kV lines connecting with the Barnaul power system. The Novosibirsk power system is connected to the Siberian United Power System along 220 and 500 kV lines at the Zarya 500/220 kV substation. When there is asynchronous behavior in the Omsk power system, the automatic system for eliminating asynchronous operation (ASEAO) disconnects two 110 kV lines at the Valerino substation and two lines at the Irtysh substation. Overhead line 246 should then be disconnected by the automatic system at the Omsk power plant (TÉTs-4) or at the Tatarskaya substation.

On the basis of data obtained from "Omskénergo" and also from "Novosibirskénergo" we set up a combined model of the Omsk and Novosibirsk power systems, matched with the unified despatcher system of Siberia, and modeled a theoretical emergency and specified the operation of the acting automatic system of the Omsk power system, and also the operation of the projected ASDPP-E automatic system, established at the Omsk TÉTs-4. We made the following assumptions in the calculations:

1) the Omsk power system is specified completely, according to the circuit obtained from "Omskénergo";

2) the Novosibirsk power system is specified by a simplified circuit (only the main substations, the power stations and the 220 and 500 kV connecting lines are taken into account);

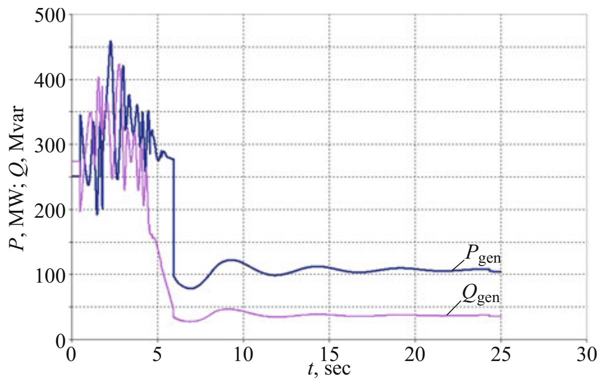

Fig. 2. Oscillations of the generated active power P_g and the reactive power Q_g in the Omsk TÉTs-4 (characteristic winter operation).

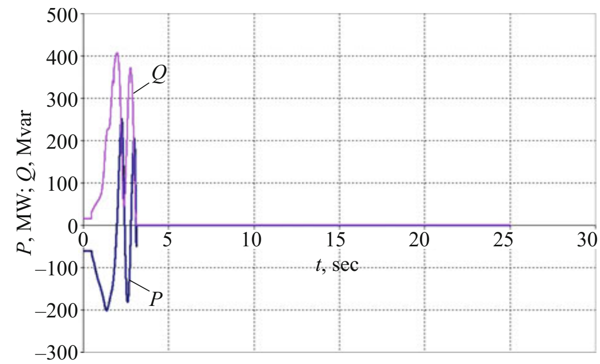

Fig. 3. Return flow of active and reactive power along overhead line OL 246 connected with the Novosibirsk Power System (characteristic winter operation).

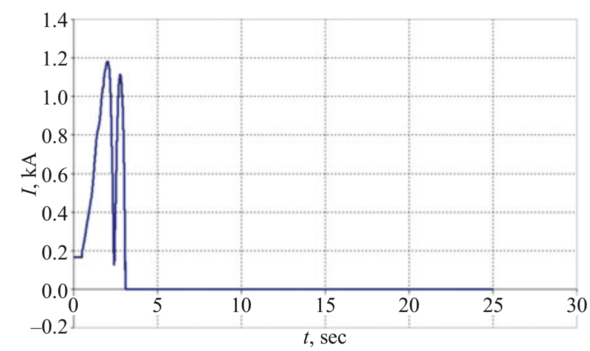

Fig. 4. Current in overhead line OL 246 connecting the Omsk TÉTs-4 with the Novosibirsk power system (characteristic winter operation).

3) we took the 500 kV busbars of the Zarya substation as the busbar of infinite power in the Siberian united power system;

4) automatic frequency shedding of the units of the Omsk power system is specified as a disconnection of part of the load on the 110 kV substations (in view of the lack of data on the 10 kV feeders, leaving these substations).

All the modes of operation of the power system were calculated taking into account the existing automatic system of the Omsk power system and the established ASDPP of the Omsk TÉTs-4. The Omsk and Novosibirsk power systems were connected along 220 kV lines (overhead lines 246) from the Omsk TÉTs-4 to the Tatarskaya substation and along the 110 kV lines from the Valerino substation to the Tatarskaya substation, while the Omsk and Barnaul power systems were connected along 220 kV lines from the Irtysh substation.

Emergency conditions in the Omsk power system were calculated taking into account an investigation of the possibility of converting the Omsk TÉTs-4 to parallel operation with the Novosibirsk power system. This solution was recognized to be impossible, in view of the disconnection of overhead line OL 246 while the automatic equipment for eliminating asynchronous operation (ASEAO) before the ASDPP operated under all conditions.

Calculations of the emergency modes of operation showed that, for specified initial conditions, the Omsk TÉTs-4 when a theoretical emergency occurrs will always be selected for isolated operation both in the summer and winter periods. Asynchronous behavior occurs in the overhead line OL 246 of the Omsk thermal power plant with the Novosibirsk power system, and it is always disconnected by the automatic equipment for eliminating asynchronous operation, connected in overhead line OL 246 at the Omsk TÉTs-4 or the similar apparatus at the Tatarskaya substation.

Calculations were carried out for typical winter – summer operation of the Omsk power system, and its isolated operation when there is a systems emergency and operation of the automatic system for disconnecting the power plant (ASDPP).

Results of a calculation of the emergency modes of operation for isolating the turbogenerators of the Omsk TÉTs-4 from the power system for operation into an isolated load and a balanced energy region **during the winter maximum**. As a result of an emergency drop in frequency in the power system, asynchronous behavior of the Omsk power system with respect to the Siberian united power system occurs along the overhead lines OL 246 and S-15, S-16, and overhead line OL 224 and overhead line OL 225, and they are disconnected by the automatic system for eliminating asynchronous operation.

As follows from the calculation, during the initial emergency period, when there is asynchronous behavior along overhead line OL 246 (for 2.8 sec), the voltage on the 220 kV busbars of the Omsk TÉTs-4 oscillates from 181 to 225 kV, and the voltage on the 110 kV busbars oscillates from 100 to 120 kV. The overall active and reactive power of the turbogenerators of the Omsk TÉTs-4 vary from 200 to 460 MW and from 195 to 420 Mvar, respectively (Fig. 2).

During the asynchronous operation, the active and reactive powers in overhead line OL 246 oscillate from –200 to +240 MW and from 40 to 420 Mvar, respectively (Fig. 3). The current in overhead line OL 246 then oscillates for 2.8 sec from 0.100 kA to 1.18 kA (Fig. 4).

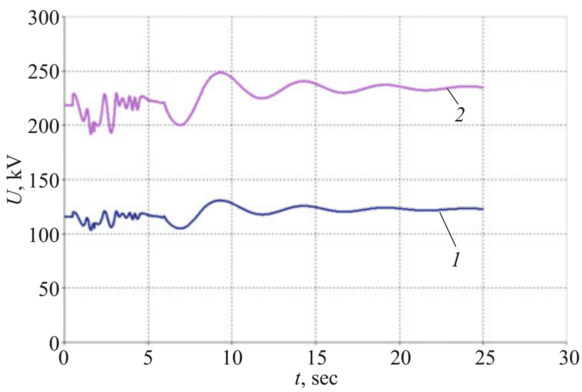

Fig. 5. Voltages on the 110 kV busbars (*1*) and the 220 kV busbars (*2*) of the Omsk TÉTs-4 (characteristic winter operation).

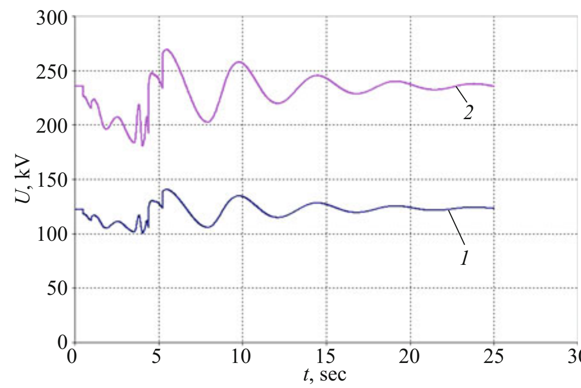

Fig. 6. Voltages on the 110 kV busbars (*1*) and the 220 kV busbars (*2*) of the Omsk TÉTs-4 (characteristic summer operation).

The reduction in the frequency in the Omsk power system leads to operation of the automatic frequency shedding system, and the frequency in the power system and on the 110 and 220 kV busbars of the Omsk TÉTs-4 is reduced in 5.5 sec from the initial value of 50 Hz to 46.5 Hz (at a rate of 0.56 Hz/sec). The automatic system for disconnecting the power plant (ASDPP-E) operates according to the second setting $f \leq 46.5$ Hz, $t = 0.5$ sec) and disconnects the line circuit breakers of the connecting lines with the 110 kV power system (S-7, S-8, S-21, and S-22) and the 220 kV connecting lines (D-17, D-18, and D-19). The Omsk TÉTs-4 is then released into isolated operation with the normal load and typical 110 – 35 – 6 kV lines (Fig. 1) and is called the Omsk TÉTs-4 power region.

As a result of the operation of the automatic system for disconnecting the power plant (ASDPP-E) of the Omsk thermal power plant (TÉTs-4), its turbogenerators are assigned to isolated operation with an excess of generated power (this is a necessary condition). When separated from the power system, the total generated active power of the turbogenerators is reduced to 100 MW (in accordance with the statism of the turbine speed regulators), and the total reactive power is reduced to 40 Mvar. The frequency on the 110 and 220 kV busbars of the Omsk TÉTs-4 reaches 51.8 Hz after 2.5 sec and, after some decaying oscillations (for 15 sec) is established at a level of 51.5 Hz with a maximum rate of change of the frequency of 2.6 Hz/sec. The voltage on the 110 kV busbars of the thermal power plant, after attenuation of the oscillations, is established after 15 sec at a level of 121 kV, 220 – 235 kV on the busbars, the minimum value of the voltage on the 110 kV busbars of the closed distributor is 105 kV, the maximum value is 135 kV, while on the busbars of the 220 kV closed distributor it is 181 and 250 kV, respectively (Fig. 5).

The voltage on the 220 kV busbars of the Tatarskaya substation under these conditions varied from 200 to 215 kV with asynchronous behavior along the overhead line OL 246 and was established at a nominal level after 4 sec from the time the emergency started.

The results of a calculation of the emergency modes of operation when the thermogenerators of the power plant are separated from the power system for operation into an isolated load and a balanced power region **in the minimum summer period**. As a result of the emergency reduction in frequency in the power system, asynchronous behavior occurs in the Omsk power system with respect to the Siberian united power system along the overhead line OL 246 and S-15 and S-16 and overhead lines OL 224 and OL 225, and they are disconnected by the automated elimination of asynchronous operation (ASEAO).

When there is an emergency reduction in frequency in the power system during the summer period, the frequency on the 110 kV busbars of the Omsk TÉTs-4 is reduced from the nominal value of 50 to 45.7 Hz, and the voltage on the 110 kV busbars of the Omsk TÉTs-4 is reduced from 122 to 100 kV (Fig. 6). The turbogenerators of the power plant in this mode of operation are supplied to eliminate the occurrence of a power deficit in the power system, and oscillations of the active and reactive power of the turbogenerators of the power plant are observed. After the overhead line OL 246 is disconnected by the automatic disconnection system and the transient dies away (Fig. 7), the total active power of the turbogenerators of the power plant is established.

The emergency reduction in frequency in the Omsk power system leads to the operation of the automatic frequency regulation, and the frequency in the power system and on the 110 and 220 kV busbars of the power plant is reduced in 3.0 sec from the initial value of 50 to 45.7 Hz (at a maximum rate of 2.4 Hz/sec) (Fig. 8). Automatic disconnection of the power plant operates at the third setting (f? 47 Hz, $df/dt > 1.5$ Hz/sec and $t = 0.1$ sec) and disconnects the line circuit breakers from the 110 kV power system (S-7, S-8, S-21, and S-22) and the 220 kV power system (D-17, D-18, and D-19). Then the Omsk TÉTs-4 is assigned to isolated operation with a load at the normal level and typical 110 – 35 – 6 kV lines.

As a result of the operation for automatically disconnecting the Omsk TÉTs-4, its turbogenerators are assigned to isolated operation with an excess of power. When separated

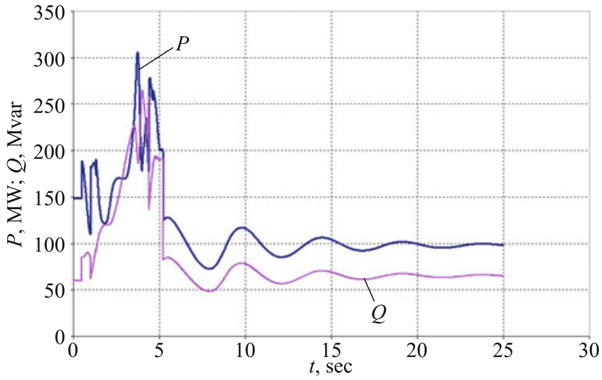

Fig. 7. Oscillations of the active power P and of the reactive power Q in the Omsk TÉTs-4 (the characteristic summer operation).

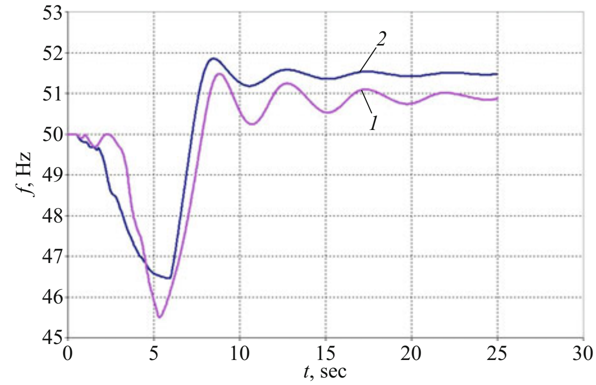

Fig. 8. Frequency of the voltage in the system of 110 kV busbars when an emergency develops and the automatic system for disconnecting the power plant operates: *1*, characteristic summer mode of operation; *2*, characteristic winter mode of operation.

from the power system, the total active power of the power plant turbogenerators is reduced to 98 MW (in accordance with the statism of the turbine speed regulators), and the total reactive power is reduced to 65 Mvar (Fig. 7).

As a result of the operation of the automatic disconnection system, the frequency on the 110 and 220 kV busbars of the Omsk TÉTs-4 reaches 51.5 Hz after 3 sec and, after several decaying oscillations (taking 15 sec) is established at a level of 51 Hz, and the maximum rate of change of the frequency is 2.6 Hz/sec. The voltage on the 110 and 220 kV busbars of the power plant, after the oscillations have attenuated, taking 15 sec, is established at a level of 122 and 238 kV, on the busbars of the closed distributor it is 110 – 102 kV (the maximum value of 140 kV), and on the busbars of the closed distributor it is 220 – 182 (270) kV.

The voltage on the 220 kV busbars of the Tatarskaya substation in this mode of operation changes from 100 to 140 kV with asynchronous behavior on the overhead line OL 246 and is established at the nominal value 9 sec from the beginning of the emergency.

The following measuring (displaying) instruments of the antiemergency automation system ASDPP-E of the Omsk TÉTs-4 operate:

— an instrument for monitoring the operation of the power plant, which chooses one of the possible versions of selecting the power plant by the automatic system, and determines the turbogenerators introduced into operation, and the system lines and lines connecting the power plant with the power system of the neighboring region (in fact, the presence of these for the Omsk TÉTs-4 is the overhead line OL 246 connecting the Omsk and Novosibirsk power systems);

— an instrument for monitoring the connections which displays the operation of all the system lines and transformers on them, and indicates whether they are connected or disconnected. The operation of the automatic system for disconnecting the power plant is only possible when a signal is received indicating reliable disconnection of all the system lines of the region;

— a frequency instrument, which monitors, in real time, the frequency of the voltage of the power plant buses. The frequency reacting instruments have operating settings indicating a reduction in the voltage frequency, and also the rate of this variation. The frequency instrument also acts to analyze the value of the frequency after the necessary disconnections have been carried out in the selected power unit for the purpose of extracting frequencies higher than 49.8 Hz (the upper frequency limit is determined by the static characteristics of the turbogenerators, connected in the power plant). Further, signaling operates in the established mode of operation indicating stable location of the frequency within permissible limits and issues a command in the thermal part of the automatic disconnection system for balancing the generated and consumed steam power in the technological part of the power plant, since, to preserve power balance, it is also necessary for the consumption of steam to correspond to that generated in the boilers. If the frequency in the power unit is less than 49.8 Hz, the automatic equipment produces controlling actions on further disconnection of typical lines by a calculated amount, which ensures an increase in frequency to the required limits (all the disconnected lines and their orders of disconnection are agreed with the customer). The automatic system for disconnecting the power plant is transferred into the expectation mode when there is a stable increase in the frequency of the voltage on the controlling systems of busbars above 49.8 Hz;

— a power unbalance unit, which carries out constant monitoring of the values of the generated and consumed powers in each connection. From this data a calculation is made of the disconnected load after the automatic system operates. In general form the active power of the dead-end load of the power plant, which is to be disconnected, is calculated as follows:

$$\Delta P_{\mathrm{d}} = \frac{1}{1.05}\sum P_{\mathrm{g}} - \sum P_{\mathrm{tn}}\left(1 + \frac{f_{\mathrm{nom}} - f_1}{f_{\mathrm{nom}}} K_{\mathrm{r}f}\right),$$

where ΣP_{g} is the total active power, generated by the turbogenerators of the power plant before the emergency, ΣP_{tn} is the total active power, consumed by the power plant for normal needs and the supply of dead-end loads before the emergency, f_1 is the frequency of the voltage on the busbars of the power plant and K_{rf} is the load regulating effect factor.

The automatic system for disconnecting the power plant continuously records the power of each connection, the total power of the generators, the total power consumed by the load for normal needs, the dead-end loads of the 6 – 35 – 110 kV lines, and determines the excess or deficit of active power in the power unit, separated from the Omsk power system up to the separation of the Omsk TÉTs-4 with the 110 and 220 kV lines of the Omsk power region. The automatic disconnection unit constantly monitors the direction of the return flows of power along the connections of the 110 and 220 kV busbars of the power plant, the frequency of the voltage of the power plant busbar systems and their rate of change.

In Fig. 8 we show the calculated change in the frequency in the winter and summer periods when an emergency develops, due to a deficit in the generation arising from a loss of connections with the power system. All the settings, by which the automatic disconnection system operates, are chosen and taken into account on the basis of these calculations. The disconnection of the power plant from operation in the balanced power region by the automatic system occurs correctly, and the necessary achievement of an excess of generated power occurs after a short time interval (it corresponds to all the operating requirements imposed on similar devices). The excess of generated power attained leads to an increase in the frequency by a permissible amount [2] and is removed by the operation of the turbine regulators (reduced to a nominal 50 Hz), together with the fact that the ASDPP-T enters into operation, leading to a balancing of the generated and consumed steam in the technological part.

The ASDPP-E device analyzes the analog signals of the current and voltage transformers of the turbogenerators, the medium voltage transformer and coupling transformers, the autotransformers, the 6 – 35 – 110 – 220 kV lines, and the closed distributor busbars. At the input of the ASDPP-E digital signals also arrive on the position of the circuit breakers of the turbogenerators, the medium voltage transformers and the coupling transformers, the autotransformers and the 6 – 35 – 110 – 220 kV lines. The ASDPP-E system supervises the processing of 55 currents and voltages, controlling 40 connections of 6, 35, 110 and 220 kV of the Omsk TÉTs-4 power region.

The logic controller processes the information obtained on the control power unit and, in accordance with the ASDPP-E algorithms, generates controlling signals via the output relay units to disconnect the circuit breakers of the 110 and 220 kV system lines and also to disconnect the circuit breakers of the dead-end lines of the 110 kV, 35 and 6 kV loads as necessary.

The minimum summer mode of operation of 2006 is characterized by the operation of three turbogenerators TG-4, TG-6 and TG-7. The overall power of the plant $P_{\Sigma tg}$ is 149 MW. Along system line 246 connecting with the Novosibirsk power system, the return flow amounts to 32.36 MW, along the two system lines of the Omsk power system D-18 and D-19 it is 42.7 MW, and along the system lines D-17, S-8, S-7, S-21, and S-22 it is 110.63 MW. The load of the dead-end lines from the Omsk TÉTs-4 and power of normal needs is $P_{\Sigma tn}$ = 113.43 MW (Table 2).

When there is a loss of connection between the Omsk power system and the united power system, an emergency begins to develop (this event will be assumed to have a reference point, i.e., a time of 0.0 sec). 1.0 sec after, due to a reduction in the frequency and the occurrence of asynchronous behavior, the ASEAO devices of the 110 – 220 kV lines of communication between the Omsk power system and neighboring regions operate. Disconnection of the 110 – 220 kV system connections continues for a time of 0.52 sec, and connection line 246 of the Novosibirsk power system and the Omsk TÉTs-4 is disconnected. 3.75 sec later the ASDPP operates according to the following setting: $f \leq 47$ Hz, $df/dt >$ > 1.5 Hz/sec and $t = 0.1$ sec, and, in accordance with the specified operating algorithm of the device, the circuit breakers of the lines with the 110 kV power system (S-7, S-8, S-21, and S-22) and the 220 kV power system (D-17, D-18, and D-19) are disconnected. Then the Omsk TÉTs-4 is converted to isolated operation with a normal load and 110 – 35 – 6 kV dead-end lines. Disconnection of the dead-end lines is not required since $P_{\Sigma tg} > P_{\Sigma tm}$ in the isolated unit of the TÉTs-4 (operational unbalance, preceding the emer-

TABLE 2. Operating Parameters of the Omsk TÉTs-4 (Characteristic Summer Mode)

Unit	*P*, MW	*Q*, Mvar	Note
TG-4	45	14.8	—
TG-5	Removed	—	
TG-6	57	26.8	—
TG-7	47	18.5	—
TG-8	Removed	—	
TG-9	Removed	—	
Total from turbogenerators	149	60.1	—
Systems lines D-246, D-18, D-19	75.06	38.1	Return flow to the Omsk TÉTs-4
Systems lines D-17, S-8, S-7, S-21, S-22	110.66	29.31	Return flow from the Omsk TÉTs-4
Total load of dead-end connections of Omsk TÉTs-4	113.4	68.88	110 – 35 – 6 kV dead-end lines

gency, 149 and 113.43 MW constitutes 35.53 MW excess generation).

The maximum winter mode of 2007 is characterized by greater generation at the power plant and greater consumption in the system, in accordance with the winter load graph. There are five turbogenerators in operation: TG-4, TG-5, TG-6, TG-7, and TG-9. The overall generated power amounts to 251 MW, and inflow along lines 246 and D-19 amounts to 94.96 MW. The power removed from the Omsk TÉTs-4 along system lines D-17, D-18, S-7, S-8, S-21, and S-22 amounts to 216.33 MW, the load of the dead-end lines from the Omsk TÉTs-4 and the load of normal requirements is 129.63 MW (Table 3).

When a loss of connection between the Omsk power system and the united power system occurs, an emergency begins to develop (this event will be assumed to have a reference point, i.e., a time of 0.0 sec). After 0.49 sec, due to the reduction in the frequency and the occurrence of asynchronous behavior, the ASEAO equipment of the 110 – 220 kV communication lines of the Omsk power system with the power system of neighboring regions operates. Disconnection continues up to the instant of time 0.89 sec (then line 246 of the Omsk TÉTs-4 with the Novosibirsk system is disconnected) At a time 8.55 sec the ASDPP operates with the following settings: $f \leq 46.5$ Hz and $t = 0.1$ sec, and the connecting lines with the 110 kV power system (S-7, S-8, S-21, and S-22) and the 220 kV power system (D-17, D-18, and D-19) are disconnected. The Omsk TÉTs-4 is assigned to isolated operation with the load of normal requirements and the 110 – 35 – 6 kV dead-end lines. Disconnection of the dead-end lines is not required since $P_{\Sigma tg} > P_{\Sigma tn}$ in the isolated unit of the Omsk TÉTs-4 (operational unbalance, preceding the emergency, 251 and 129.63 MW constitute 121.37 MW towards an increase in the generation). Generator TG-8 is introduced into operation at the discretion of the plant dispatcher, depending on the balance of the operation of the power system under normal operating conditions.

The ASDPP-E system provides for possible further development of the plant and the connection of additional attachments in the operating algorithm, namely the introduction of the TG-1 unit and new lines into the system.

We have shown in the examples considered above that the transfer of the TÉTs-4 to the isolated power unit occurs with an excess of production over consumption. However, situations are possible when a smaller number of turbogenerators will come into operation and a section of the plant will be left with a deficit of generated power. Then, to “spread” the frequency to the nominal value, the dead-end lines will be disconnected (in the case when $P_{\Sigma tg} > P_{\Sigma tn}$) at a specified value of the deficit. These controlling actions are determined by the internal algorithm of ASDPP-E and acts to disconnect the necessary number of connections [lines S-9, S-10, and S-15 (while on standby), S-16 (while on standby), S-45 and S-46, and also the load of the 6 kV distributor and the 35 kV closed distributor]. The mode of operation of the power plant which generates less power than the power consumable by the dead-end load lines connected to the Omsk TÉTs-4, is possible in the summer, when one or two turbogenerators are operating.

The reasons for this low generation may be the low consumption of thermal power (or generally no consumption at all), repair or reconstruction of the primary equipment, and other factors. Disconnections occur until the frequency no longer exceeds the setting of 49.8 Hz, and only then does the ASDPP-T come into operation; the upper limit of the frequency in the selected power unit is determined by the static characteristic of the power plant generators.

The balances of active power were calculated from the power return flows along the connections which preceded the emergency, which are important for the rapid achievement of power balance and frequency stabilization in the selected unit over a specified range of permissible deviations.

The ASDPP-E action algorithm provides for the possibility of changing the order in which the dead-end loads are disconnected, and also provides for the possibility of deleting specific positions from this list. The order and withdrawal of individual positions can be changed by the power plant operator or by the operational personnel using the list of operating and withdrawn connections.

This algorithm is based on antiemergency automatic systems and an EKRA 200 series terminal, which execute a protocol of events and transmit them through the communications channels on request to a personal computer. For each

TABLE 3. Operating Parameters of the Omsk TÉTs-4 (Characteristic Winter Operation)

Unit	*P*, MW	*Q*, Mvar	Note
TG-4	34	39.4	—
TG-5	48.0	40.5	—
TG-6	56.5	57.8	—
TG-7	56.5	61.9	—
TG-8	Removed	—	
TG-9	56.0	74.0	—
Total from turbogenerators	251.0	273.62	—
System lines D-246, D-19	94.96	20.8	Return flow into the Omsk TÉTs-4
System lines D-17, D-18, S-7, S-8, S-21, S-22	216.33	239.58	Return flow from the Omsk TÉTs-4
Total load of dead-end connections of the Omsk TÉTs-4	129.63	54.84	110 – 35 – 6 kV dead-end lines

event a date, time and the main parameters of the operation and specific information corresponding to this event are recorded. Data is transmitted on the state of the operation of the automatic system in the power plant. The ASDPP-E itself is not sufficient to balance and achieve normal operation of the power plant for systems emergencies. Operation with boiler equipment, the least maneuverable part of telemechanical equipment, is the most complex operation in a balanced load. The ASDPP-T is designed specially for this purpose.

Similarly, unbalance of the active and reactive power in the electrical part of the system occurs when a power plant is removed and also unbalance in the generated and consumed steam power, which is eliminated by the ASDPP-T automatic system. The technological part of the ASDPP automatic equipment is integrated into combined operation with the ASDPP-E (Fig. 9). It is precisely this combination which enables the desired result to be obtained in autonomous operation of the power plant.

The thermal part analyzes the operation of the boilers, both acting and on standby, takes into account in their algorithms the nominal and actual load of the boilers and their regulated ranges, the forms of fuel and its parameters (including possible changes in the parameters of one form of the fuel), determines the steam requirements of the turbines and manages the input/output of new powers. Physically, the electrotechnical and thermotechnical parts of the ASDPP are distributed between different devices, since the first part is essentially a system for controlling the mode of operation of the power region with a selection of the power plants, while the other is a group regulator of the thermal apparatus when selecting the power plants, which operates more slowly and using quite different control algorithms (controlling the technological processes of the power plant).

The method of organizing the thermal parts of the ASDPP-T, which must be used and its operating principles will be discussed in a separate paper.

CONCLUSIONS

1. We have described a method of obtaining stability in thermal power plants with transverse connections by steam, where, in the majority of cases such an automatic system is

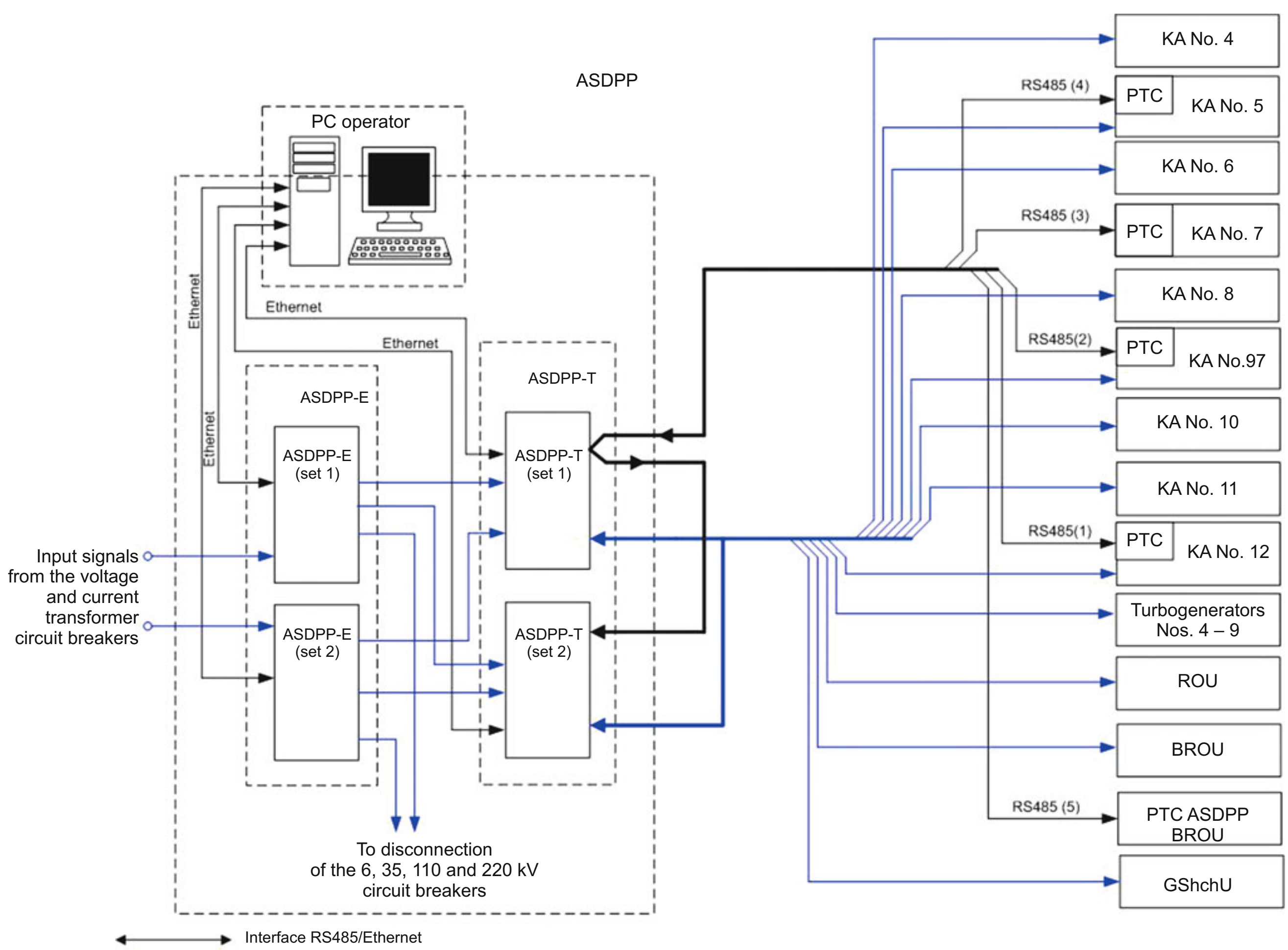

Fig. 9. Sketch of the arrangement of the ASDPP system (ASDPP-E and ASDPP-T) and its interaction with the electrical and technical equipment of the power plant.

not used at the present time in view of the impossibility of selecting the generator unit.

2. The basic principles for selecting a power plant have been described, and a mathematical model of the Omsk and Novosibirsk power systems with their connections to the United Power System, has been set up for the calculations, and an automatic system for selecting the Omsk TÉTs-4 has been described, and calculations of all the characteristic modes of operation of the power plant have been carried out.

3. We have proved by calculations using a digital model of the power system, that the electrical part of the ASDPP system (ASDPP-E) operates correctly in all probable working states of the power plant, taking into account the equipment that exists in them, which ensures prolonged autonomous operation starting from any preemergency states, which, as a whole, enables the stability of the power plant to be increased by selecting it in a balanced power region.

4. Based on the results obtained, we have constructed the electrical part of the ASDPP-E automatic system and the technological part (ASDPP-T) for the Omsk TÉTs-4, which were also set up in the system.

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