*Journal of mining institute.* 2021. Vol. 249. P. 408-416
Boris N. Abramovich, Ivan A. Bogdanov
DOI: 10.31897/PMI.2021.3.10

UDC 621.311

# Improving the efficiency of autonomous electrical complexes of oil and gas enterprises

**Boris N. ABRAMOVICH, Ivan A. BOGDANOV** ✉
*Saint Petersburg Mining University, Saint Petersburg, Russia*

***How to cite this article*:** Abramovich B.N., Bogdanov I.A. Improving the efficiency of autonomous electrical complexes of oil and gas enterprises. Journal of Mining Institute. 2021. Vol. 249, p. 408-416. DOI: 10.31897/PMI.2021.3.10

***Abstract.*** In accordance with the Energy Strategy until 2035, the possibility of increasing the efficiency of energy use of secondary energy resources in the form of associated oil and waste gases has been substantiated by increasing the energy efficiency of the primary energy carrier to 90-95 % by means of cogeneration plants with a binary cycle of electricity generation and trigeneration systems with using the energy of the waste gas to cool the air flow at the inlet of gas turbine plants. The conditions for maintaining the rated power of the main generator with variations in the ambient temperature are shown. An effective topology of electrical complexes in a multi-connected power supply system of oil and gas enterprises according to the reliability condition is presented, which allows increasing the availability factor by 0.6 %, mean time between failures by 33 %, the probability of failure-free operation by 15 % and reducing the mean time of system recovery by 40 %. The article considers the use of parallel active filters to improve the quality of electricity and reduce voltage drops to 0.1 s when used in autonomous electrical complexes of oil and gas enterprises. The possibility of providing uninterrupted power supply when using thyristor systems for automatic reserve input has been proven. A comparative analysis was carried out to assess the effect of parallel active filters and thyristor systems of automatic transfer of reserve on the main indicators of the reliability of power supply systems of oil and gas enterprises.

***Key words*:** autonomous power supply systems; secondary resources; trigeneration mode; bridge topology of power supply systems; power quality; reliability of power supply; parallel active filters

**Introducton.** The production processes of oil and gas enterprises (OGE) are carried out with a high consumption of electricity, the payment for which can be 0.5-0.6 of the total costs of enterprises. Electricity consumers of OGE technological units mainly belong to the first and second categories in terms of power supply reliability. Installed capacity of electrical receivers ranges from hundreds of kilowatts to tens of megawatts, input voltage – 6(10) kV [6]. In accordance with the Energy Strategy of the Russian Federation, through the use of secondary energy resources, the use of the primary energy carrier in the production of electricity for the own needs of industrial enterprises should be reduced [14, 21].

Under the conditions of oil and gas production, secondary energy resources are associated oil and waste gases of gas turbine plants (GTP), which cause significant increases in the energy efficiency of the processes of oil and gas production, transportation and processing by generating electricity by autonomous power plants in cogeneration, binary cycle and trigeneration modes, as well as by improving the technological and electrical facilities of OGE.

Modern power generating plants have an efficiency not exceeding 42 %. The utilization factor of the potential of the primary energy carrier with such work is 0.4 [16]. The efficiency of using secondary energy resources can be increased in the cogeneration mode. However, in the conditions of oil and gas production, as a rule, there are no significant consumers of heat energy. The process of generating electricity in a binary mode can proceed with a coefficient of utilization of secondary energy resources up to 70 % [33]. In such installations, there must be a main and a secondary, dissimilar in physical properties, generating sets, which prevents the organization of their stable parallel operation [32].

**Formulation of the problem.** Energy efficiency of electricity generation in trigeneration mode is achieved by using the energy of secondary energy resources to cool the ambient air and supply it to the input of the turbine generator set. This will make it possible, with appropriate

DOI: 10.31897/PMI.2021.3.10

automatic control, to reduce the installed power of the turbine generator, ensuring a constant power at the generator output when the ambient temperature varies from –40 to 40 °C.

Technological installations for oil production are highly sensitive to the quality of electricity. Voltage dips of 0.15 s can lead to shutdown of mining electric motors and disruption of technological processes, the restoration of which will require 30 min or more. Due to the unjustified application of the simplified topology of switchgears with voltage of 6(10) kV and 0.4 kV, up to 10 failures per year occur under OGE conditions, which leads to significant economic damage. Reducing the duration of power supply interruptions can be achieved by introducing into the power supply system the devices for high-speed automatic transfer and sectioning of sections of electrical networks using power electronics and electrical grid automation. However, there are no recommendations on the substantiation and selection of circuit solutions and parameters of a multi-level power supply system using these means. The choice of the topology of electrical complexes with different voltage levels and multi-connected power supply systems should be made subject to ensuring uninterrupted power supply to consumers and achieving technically and economically sound reliability indicators. To optimize technological processes and energy saving, frequency converters are widely introduced, which complicates the task of ensuring the quality of electricity in accordance with GOST 32144-2013.

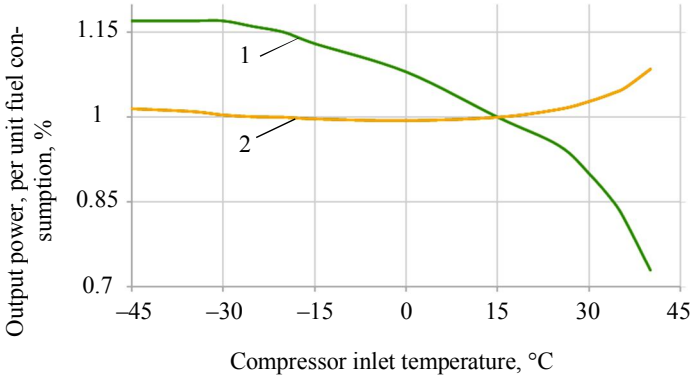



Fig.1. Dependence of indicators of output power (1) and specific fuel consumption (2) from the ambient temperature

**Methodology.** *Trigeneration mode as an effective means of maintaining the power at the outlet of the turbine generator regardless of the ambient temperature*. In the article, the most important considered consumer of cold energy is a gas turbine unit. According to the technical characteristics of the GTP operation, the power at the generator output can vary depending on the ambient air temperature within 40 % (Fig.1): when the temperature rises from 15 to 40 °C, the output power of the GTU decreases by 25-28 % [2], and the per unit fuel consumption rises to 8 %.

The use of the trigeneration mode of power supply allows achieving the utilization rate of the primary energy carrier up to 90-95 % and at the same time effectively using the generated thermal energy [4, 11, 24].

The ambient air temperature can vary by more than 20 % during the day. For the effective operation of the trigeneration system, it is necessary to maintain a constant temperature at the inlet to the gas turbine unit by promptly regulating heat exchange processes in the compressor air cleaning unit [29]. The residual potential of the secondary resources energy at the outlet of the gas turbine plant can provide production processes and household needs of the oil and gas industry with high-temperature energy and cold energy. Using the transfer function of the heat transfer process [3] and models of the automatic control system of the air cooler [20, 31] the possibility of maintaining the power at the outlet of the turbogenerator, when the ambient temperature $T_1$ changes from 10 to 40 °C (Fig.2, *a*) and relative humidity from 0 to 100 % according to a sinusoidal dependence on time, is assessed. As a result of the research [9] the time dependence of the temperature $T_2$ of the turbo generator air supply system entering the inlet was obtained, confirming the possibility of maintaining the temperature $T_2$ = 15 °C at the gas turbine inlet with variations in the environmental parameters within the above limits and, as a consequence, the possibility of reducing the installed power by 25 %. Without cooling the turbine generator supplied to the input, the installed power of the gas turbine should be taken equal to 1.25 of the rated power of the generator.

DOI: 10.31897/PMI.2021.3.10

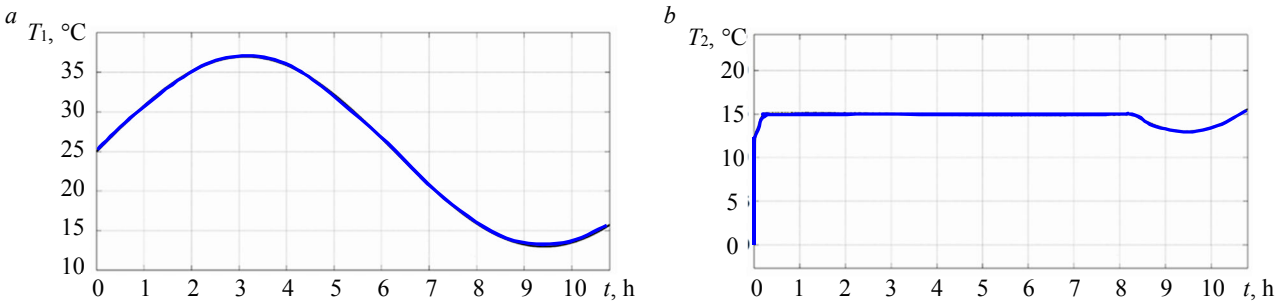



Fig.2. Dependences of the temperatures of ambient air (*a*) and air at the inlet to the gas turbine unit (*b*) on time

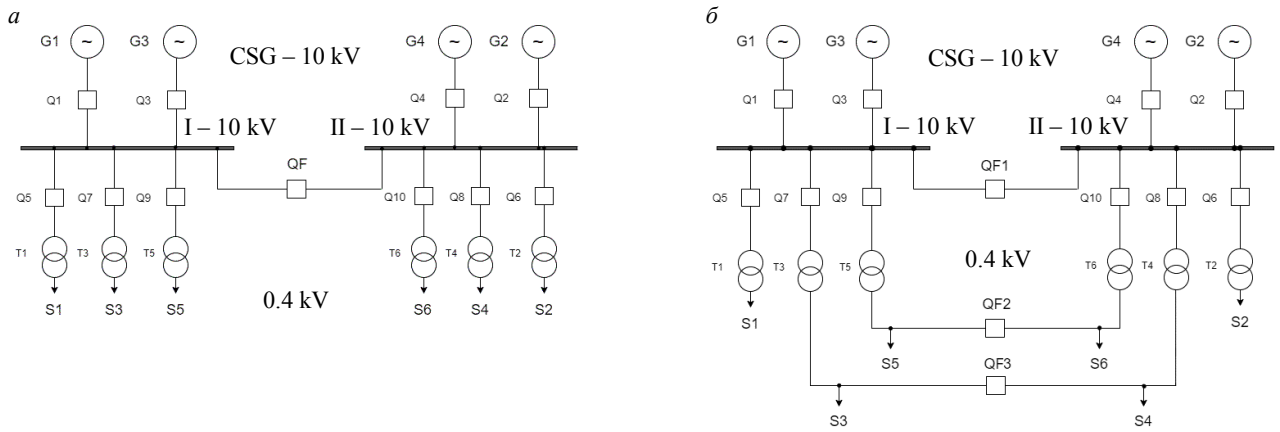



Fig.3. Divided (*a*) and bridged (*b*) power structures

G1, G2 – generators of the independent electrical engineering complex of OGE; QF1, QF2, QF3 – sectional switches of high voltage sections, PTS of the compressor workshop and PTS for auxiliary needs, respectively; Q1-Q10 – high-voltage switches 10 kV in indoor switchgear 10 kV; T1-T6 – transformers 10/0.4 kV

*Justification of the effective topology of electrical complexes in a multi-connected power supply system of OGE according to the reability condition*. In the power supply systems of OGE, the topology of power distribution is applied using single and separate busbars [13]. Taking into account the results of data collection at the facilities of the oil and gas production department (OGPD), the MTBF of such a topology can be estimated at 15000-16000 h, and the recovery time – 16 h or more [22, 26]. To select a more optimal topology, a comparative assessment of the reliability of the divided and bridged power structures was carried out (Fig.3) [28].

The use of a bridge structure increases the reliability of the backup power supply of the low-voltage load in the event of a breaker failure on the 10 kV side or insufficient speed of the relay protection. In traditional structures (Fig.3, *a*), automatic sectioning of especially critical low-voltage consumers is not always provided.

For a comparative assessment of the reliability indicators of the CS power supply system topology, the influence of individual constituent components on the resulting structure reliability indicators was simulated, a logical-probabilistic method was used, and a functional integrity scheme (FIS) was built. Logical-probabilistic method is a method for calculating the reliability of complex technical systems, in which their structural model is described by means of mathematical logic, and a quantitative assessment of reliability is performed using the theory of probability. To enter the modeling program, the FISs were compiled in accordance with the real topology of the structure of the electrical complex of the OGE. Reliability indicators of structures with recoverable elements were determined on the assumption of an exponential distribution of MTBF and system recovery time using the ARBITR software package [15]. A diagram of functional integrity with an indication of the parameters of the constituent components presented in the table, a structure with a single separated busbar system is shown in Fig.4, *a*, and a bridge structure in Fig.4, *b*.

**Composition of PSS elements and parameters of their reliability**

| Element number | Element type | $T_{sf}$, year | $T_{sr}$, h |
|---|---|---|---|
| 1, 5 | Generators | 0.214 | 0.5 |
| 2, 6-12 | Switches | 45.5 | 11 |
| 3, 4 | Busbar sections | 33 | 7 |
| 13-18 | Transformers | 71.4 | 70 |
| 19-24 | Circuit breakers | 20 | 4 |
| 25 | Sectional switches 10 kV | 45.5 | 11 |
| 27, 28 | Sectional switches 0.4 kV | 20 | 4 |

In Fig.4, *a* and *b*, the arrows indicate the connections of the elements corresponding to the logical "OR" indicating the direction of the flow of electricity. Element 26 denotes the function of the system, which consists in the simultaneous power supply of all electrical receivers of the OGE, which has connections with the rest of the elements corresponding to the logical "AND".

When using a bridge structure, the system availability factor ($K_{saf}$) increases by 0.6 % (from 0.9989 to 0.9995), the average system recovery time ($T_{sr}$) decreases by 40 % (from 15.5 to 9.41 h), mean time between failures ($T_{sf}$) increases by 33 % (from 15170 (1.732) to 20.250 (2.312) h), the probability of no-failure operation ($R_{sr}$) increases by 15 % (from 0.5612 to 0.6488). The results obtained allowed us to recommend for use in autonomous ETC of OGE topology with bridge structures on the 6(10) and 0.4 kV side.

Now, in the event of an emergency shutdown of the power plant, the technological equipment continued to work without a power outage, and the rest of the load was stepwise transferred to the 0.4 kV unit that remained in operation with a short-term loss of power.

*Ensuring the quality of electricity and uninterrupted power supply in the ETC of OGE. Parallel active filter as a means of improving the quality of electrical energy on the buses of electrical complexes of OGE.* In addition to long-term voltage dips due to generator shutdowns, it is necessary to exclude the influence of short-term voltage dips and distortions associated in the oil and gas industry, as a rule, with a sharp increase in load when starting powerful synchronous electric motors of drilling or pumping units of pressure maintenance systems for carbon raw materials, as well as in emergency modes, especially in the event of short circuits [17, 18].

Figure 5, *a* shows the structure of an autonomous power supply system based on distributed generation sources, in which a parallel active filter (PAF) is integrated, which implements several functions for high-quality and uninterrupted power supply to the most responsible technological consumers of the mineral resource complex.

The most responsible technological consumers receive power from two autonomous sources G1 and G2, the electrical complex of each of which is equipped with power converters SP1 and SP2

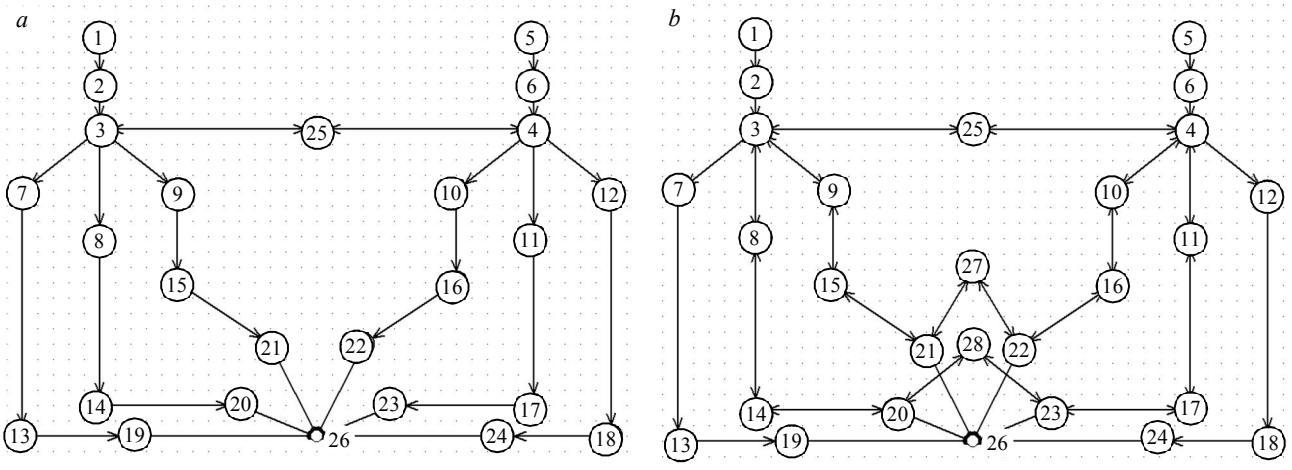



Fig.4. SPC and parameters of the components of the structure with separated sections of the busbars (*a*) and the bridge structure (*b*)

DOI: 10.31897/PMI.2021.3.10

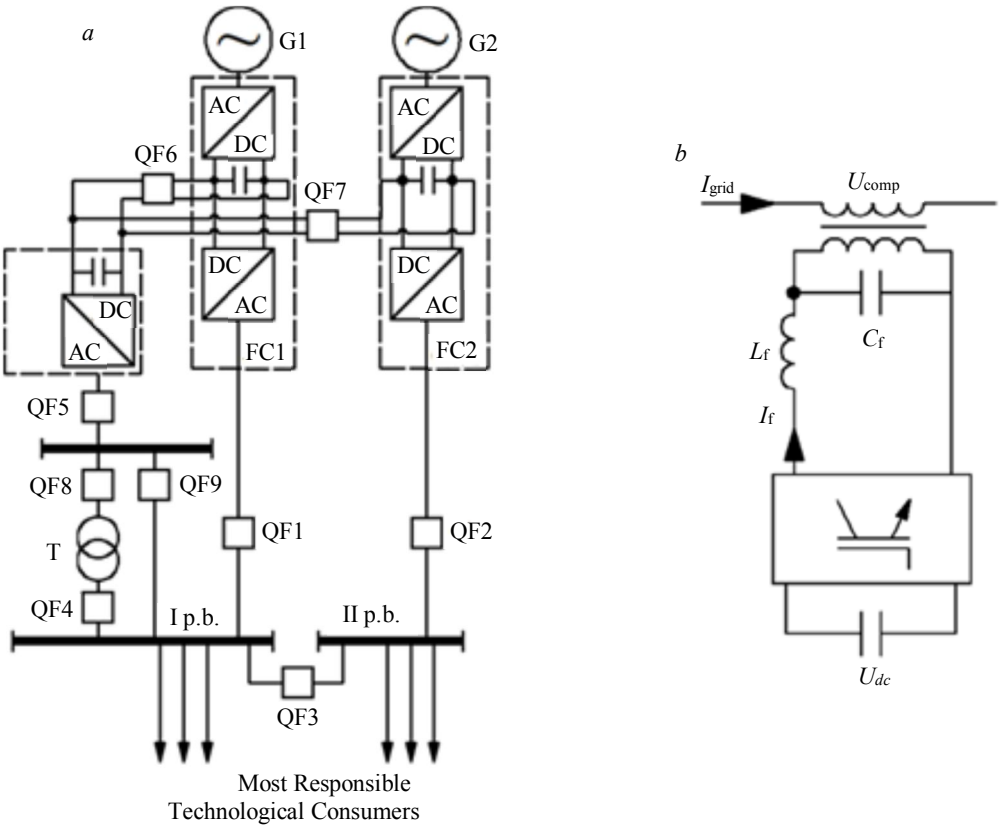



Fig.5. Structure of an autonomous power supply system based on distributed generation sources with PAF (*a*) and structure of PAF (*b*)

with rectifiers and inverters Fig.5, *a*. Sources G1 and G2 are connected to two sections of buses supplying responsible consumers through automatic switches QF1 and QF2. Both bus sections are interconnected by a sectional switch QF3, which is normally open. In the event of a failure in either of the two sources, the QF3 sectional breaker is tripped. In this case, the entire critical load is connected to one autonomous source, which causes significant voltage deviations on the buses (the deviation level may not correspond to the standards of GOST 32144-2013). In the conditions of autonomous power systems of limited capacity, any load shedding or surge has a significant impact on the voltage regime. There are studies [1, 23] showing that among the technological consumers of the mineral resource complex there is a load that is extremely sensitive to voltage dips and deviations. For these reasons, the structure shown in Fig.5, a contains a PAF, which implements the following functions: suppression of higher harmonics of current and voltage, compensation of voltage dips and deviations, uninterrupted power supply to responsible consumers for the period of trouble-free completion of the technological process. In this case, the PAF structure has the form shown in Fig.5, *b*. The operation of an active filter is described by the following basic equations:

$$U_{\text{comp}} = kI_{\text{grid}}; \quad k_{\text{tr}} = \frac{U_{\text{comp}}}{U_{C_{\text{f}}}}; \quad U_{\text{inv}} = L_{\text{f}} \frac{dI_{\text{f}}}{dt} + U_{C_{\text{f}}}; \quad U_{\text{inv}} = k_i U_{dc},$$

where $U_{\text{comp}}$ – compensaition voltage; $k$ – coefficient depending on the power of the output transformer; $I_{\text{grid}}$ – compensated current of circuit; $k_{\text{tr}}$ – transformation ratio of the output transformer; $U_{C_{\text{f}}}$ – voltage across the capacitance of the output passive filter; $L_{\text{f}}$, $C_{\text{f}}$ – parameters of the passive filter at the inverter output; $dI_{\text{f}}$ – current increment of the passive filter at the inverter output; $k_i$ – function of the state of the power switches of the inverter; $U_{\text{inv}}$ – inverter output voltage; $U_{dc}$ – voltage across the storage capacitor of the inverter.

When the QF3 circuit breaker is triggered, the QF4 and QF5 switches and PAF are simultaneously turned on, by means of a booster transformer T, which maintains the voltage on the buses in accordance with the standards of GOST 32144-2013, as well as based on the level of resistance of certain types of electrical equipment to voltage dips and deviations. The storage capacitor PAF charges in two ways: with direct compensation of higher harmonics of current and voltage [25, 30], as well as with the help of direct current links of electrical complexes of G1 and G2 sources when the QF6 and QF7 circuit breakers are turned on. The principle of combining DC links of active filters with other elements at a short distance from each other is also described and justified [25, 34]. Considering the rather high cost of the active filter, it is advisable to use it primarily as a multifunctional device, especially in the conditions of autonomous power systems of distributed generation.

When the QF5, QF8 circuit breakers are turned on and the QF4 breaker is turned off, the PAF performs the function of compensating for the higher harmonics of current and voltage. When you turn off the QF8 switch and turn on QF4 and QF9, the PAF implements the function of an uninterruptible power supply or a dynamic compensator for deviations and voltage dips during the trouble-free completion of the technological process or the transition of power supply from one autonomous source to another.

In accordance with Fig.5, *a* simulation model is built in the MATLAB Simulink environment [7, 8, 10]. Based on the simulation results, an oscillogram of the voltage on the buses of responsible consumers was obtained when the second source was put into operation due to the failure of the original source, with the active filter implementing the function of a dynamic compensator for voltage dips and deviations (Fig.6).

The results of simulation showed the ability of the PAF to compensate for short-term voltage deviations arising from the sectioning of power supplies in emergency modes [30]. When the voltage deviation passes into a dip in case of unsuccessful or long-term sectioning, it is necessary to use devices for a dynamic voltage distortion compensator (DVDC), which include booster transformers that can compensate for voltage drops of a given depth and duration, in contrast to PAF, the main purpose of which is to compensate for higher harmonics current and voltage [19]. Thus, depending on the level of power quality and the mode of sectioning power supplies in emergency modes, the proposed structure of an autonomous power supply system based on distributed generation sources may contain PAF or DVDC [1]. At the same time, according to the results of research, it was found that when using PAF in the DVDC mode, no-current pauses of up to 0.1 s are possible.

With all their advantages, DVDCs do not allow to completely exclude no-current pauses due to the fixed time of maintaining a given voltage level in the line, for which certain DVDC modifications are designed. Upon expiration of this time, a recharge of the storage elements of the DVDC is required, which entails voltage dips in case of unsuccessful sectioning of the sources. The limitation of power supply interruptions in 6(10) kV networks and the elimination of a no-current pause can be carried out using thyristor high-speed automatic transfer switches (HSATS), in which the sectional switch is shunted by counter-parallel connected thyristors to accelerate the transfer of the reserve, which allows exclude a no-current pause.

HSATS consists of two main parts: a thyristor switch and a control module. The thyristor switch is connected in parallel with the sectional switch and, due to its speed, contributes to the accelerated connection of bus sections. The control module detects emergency situations in the operation of the switchgear and generates commands to control the thyristor switch with input and sectional switches.

Fundamental features of HSATS: time of faulty input detection – 0.034 s after input disconnection; practically synchronous switching of electric motors of a faulty section of the busbars to a serviceable section with a phase mismatch angle of less than 19° el.; voltage drop on the faulty section of the busbars up to 0.85 of the nominal; absence of a transient process in switched electric motors; preservation of the excitation field in synchronous electric motors.

DOI: 10.31897/PMI.2021.3.10

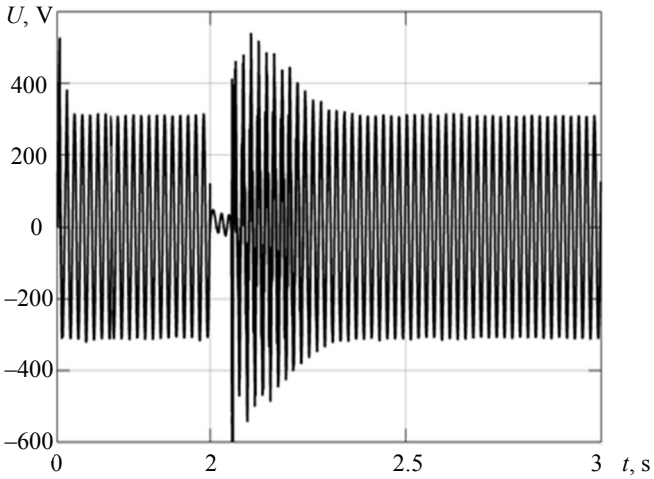



Fig.6. Oscillogram of the voltage on the buses of the responsible customers

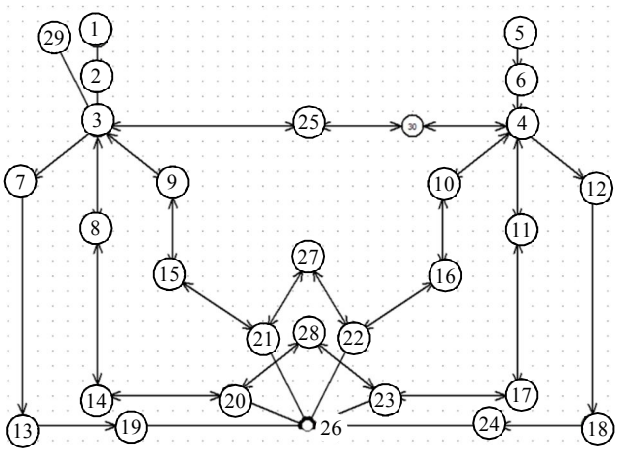



Fig.7. SFC of bridge structure using PAF and HSATS

Currently, there are no other devices of this type capable of switching electric motors from a faulty section of the busbars to a serviceable one with similar HSATS parameters [5, 12, 27].

*Modeling and calculation of reliability in the SFC of the power supply system with the use of PAF and HSATS in the ARBITR software*. An assessment of the reliability of the bridge structure of autonomous electrical engineering complexes of OGE with the inclusion of PAF and HSATS in their composition was carried out by a logical-probabilistic method. A diagram of the structural and functional integrity of autonomous electrical complexes with PAF and HSATS is shown in Fig.7.

In the scheme, PAF and HSATS are designated as elements 29 and 30, respectively. Based on the results of logical-probabilistic modeling using the ARBITR software, the following indicators of the reliability of the power supply system were obtained.

In the scheme, PAF and HSATS are designated as elements 29 and 30, respectively. Based on the results of logical-probabilistic modeling using the ARBITR software, the following indicators of the reliability of the power supply system were obtained: $K_{saf} = 0.9995$; $T_{sr} = 9.41$ h; $T_{sf} = 20250$ h (2.31 year); $R_{sr}$, by one year – 0.6488. As a result of a comparative analysis, it was found that the introduction of PAF and HSATS into the power supply system does not lead to a significant change in the reliability indicators of the OGE autonomous electrical complex.

**Discussion.** The conducted studies have shown the possibility of efficient use of the primary energy carrier through the use of secondary energy resources, which corresponds to modern energy problems. This can be achieved by using a trigeneration mode with a cooling cycle of the turbine generator to maintain nominal operating conditions under high ambient temperature operating conditions and locations above 1000 m above sea level. In this case, it is possible to use a cogeneration mode of operation with a binary cycle, however, this method has a number of disadvantages, including the need to create a synchronization system for dissimilar generators of the main and auxiliary electrical installations.

To improve the reliability and ensure uninterrupted operation of oil and gas industry facilities belonging to 1-2 categories of reliability, according to studies, it is advisable to use a bridge structure of power supply with the introduction of a multifunctional active filter, with the possibility of functioning in the modes of dynamic compensation of voltage dips and distortions, and also compensation of current harmonics in conjunction with HSATS, which ensures uninterrupted power supply between bus sections.

The results of the studies carried out on the example of a specific structure of the power supply system have shown the possibility of using an active filter as a multifunctional device for controlling power quality indicators and power supply mode. In many domestic and foreign scientific publications, active filters are considered mainly as a device for improving the quality of electricity. Within the framework of combined power supply systems operating on the basis of parallel operation of centralized and autonomous sources, active filters should be considered precisely as multifunctional devices.

**Conclusion.** The possibility of increasing the efficiency of using the energy of secondary energy resources in the form of associated oil and waste gases by means of cogeneration units with a binary cycle of electricity generation and trigeneration systems using waste gas energy to cool the air flow at the gas turbine inlet has been substantiated. The possibility of stabilizing the temperature at the inlet of the trigeneration system at the level of 15 °C, regardless of the environmental parameters, has been proven, which makes it possible to reduce the installed capacity of the turbine generator set to 25 % when used at the power facilities of the oil and gas industry in almost all climatic zones of the Russian Federation.

It has been proved that in multi-connected power supply systems of the OGE, for the condition of increasing reliability on the 6(10) kV side, it is advisable to use bridge switching circuits for equipment. Bridge structures increase availability by 0.6 %, mean time between failures by 33 %, probability of uptime by 15 %, and reduce mean time to recovery by 40 %.

The possibility of using PAF as a technical means of improving the quality of electricity by the level of higher harmonics in an autonomous power supply system based on distributed generation sources is shown. Also, PAF can be used to compensate for small voltage deviations arising from the backup of power supply sources, with a duration of up to 0.1 s. The limitation of power supply interruptions in 6(10) kV networks and the elimination of a no-current pause can be carried out using HSATS, in which the sectional switch is shunted by counter-parallel connected thyristors to accelerate the action of the reserve input and minimize the no-current pause. As a result of a comparative analysis, it was found that the introduction of PAF and HSATS into the power supply system does not lead to a decrease in the reliability indicators of an autonomous electrotechnical complex of OGE in comparison with traditional topologies**.**

## REFERENCES

1. Abramovich B.N. Uninterruptible power supply system for mining enterprises. *Journal of Mining Institute*. 2018. Vol. 229, p. 31-40. DOI: 10.25515/PMI.2018.1.31 (in Russian).

2. Aleksikov A.I. Air cooling systems at the inlet to gas turbine units. *Almanakh nauchnykh rabot molodykh uchenykh Universiteta ITMO*. St. Petersburg: Universitet ITMO, 2015. Vol. 1, p. 19-25 (in Russian).

3. Alimov S.V., Migacheva L.A., Titov A.R. Transfer functions of the heat exchange process in the oil air cooler. *Vestnik Samarskogo gosudarstvennogo tekhnicheskogo universiteta. Seriya* "*Tekhnicheskie nauki*". 2012. N 4 (36), p. 198-205 (in Russian).

4. Anisimov S.N., Krugovykh D.E., Molodkin D.S. Increasing the performance of the GTU at high ambient temperatures. *Turbiny i dizeli*. 2013. N 6 (51), p. 34-41 (in Russian).

5. Aptekar D.I., Muratbakeev E.Kh. Emergency management to reduce oil production losses. *Neftyanoe khozyaistvo*. 2010. N 5, p. 124-126 (in Russian).

6. Ustinov D.A., Konovalov Yu.V., Plotnikov I.G., Turysheva A.V. Probabilistic characteristics of energy consumption of oil and gas production enterprises. *Nauchno-tekhnicheskie vedomosti Sankt-Peterburgskogo gosudarstvennogo politekhnicheskogo universiteta. Estestvennye i inzhenernye nauki*. 2011. N 4 (135), p. 90-94 (in Russian).

7. German-Galkin S. Virtual laboratories of power electronics devices in the MATLAB-Simulink environment. Lesson 19. Transients in a parallel active filter. *Silovaya elektronika*. 2015. Vol. 2. N 53, p. 90-95 (in Russian).

8. German-Galkin S. MATLAB school. Virtual laboratories of power electronics devices in the MATLAB-Simulink environment. Lesson 16. Investigation of an electrical circuit with a three-phase active filter. *Silovaya elektronika*. 2013. Vol. 1. N 40, p. 80-86 (in Russian).

9. Malarev V.I., Bogdanov I.A., Turysheva A.V. Trigeneration system as a means of increasing the efficiency of binary complexes for the production of electrical and thermal energy. *Promyshlennaya energetika*. 2020. N 3, p. 21-27. DOI: 10.34831/EP.2020.66.67.001 (in Russian).

10. Portnyagin N.N., Ershov M.S., Barbasov P.Yu., Chernev M.Yu. Modeling the influence of the magnitude of the nonlinear load on the quality of electricity of industrial electrical systems. *Izvestiya vysshikh uchebnykh zavedenii. Elektromekhanika*. 2017. Vol. 60. N 1, p. 61-66. DOI: 10.17213/0136-3360-2017-1-61-66 (in Russian).

11. Morenov V.A. Improving the efficiency of energy supply to oil and gas production facilities using associated petroleum gas as an energy carrier: Avtoref. dis. … kand. tekhn. nauk. St. Petersburg: Saint Petersburg Mining University, 2016, p. 22 (in Russian).

12. Muratbakeev E.Kh. Substantiation of the structure and parameters of a multi-level power supply system for oil production facilities with sectioning of sections of the electrical network: Avtoref. dis. … kand. tekhn. nauk. St. Petersburg: Saint Petersburg Mining University, 2009, p. 21 (in Russian).

13. Belousenko I.V., Shvarts G.R., Velikii S.N. et al. New technologies and modern equipment in the electric power industry of the gas industry. Moscow: Nedra, 2007, p. 478 (in Russian).

14. Pashkevich N.V., Iseeva L.I., Fedchenko A.A. Russia in the world markets of mineral raw materials: reserves, production, export. *Journal of Mining Institute*. 2014. Vol. 208, p. 60-64 (in Russian).

15. Petrov S.P., Baburin S.V., Ustinov D.A. Application of a logical-probabilistic modeling method for calculating the reliability of power supply systems. *Nauka i tekhnika v gazovoi promyshlennosti*. 2011. N 3 (47), p. 47-51 (in Russian).

16. Polishchuk V.V., Morenov V.A., Kasyanova A.N. Cogeneration unit with a binary cycle for power supply of objects of oil and gas enterprises. *Estestvennye i tekhnicheskie*. 2015. N 5 (83), p. 102-105 (in Russian).
17. Sychev Yu.A., Kuznetsov P.A., Zimin R.Yu., Soloveva Ya.A. Problems of compensation of higher harmonics of current and voltage in conditions of distributed generation. *Vestnik Moskovskogo aviatsionnogo instituta.* 2018. Vol. 25. N 4, p. 216-228 (in Russian).
18. Rozanov Yu.K., Lepanov M.G., Kiselev M.G. Multifunctional power quality regulator based on a power electronic converter. *Elektrotekhnika*. 2014. N 8, p. 51-59 (in Russian).
19. Ryabinin I.A. Reliability and safety of structurally complex systems. St. Petersburg: Politekhnika, 2012, p. 248 (in Russian).
20. Abramovich B.N., Bogdanov I.A., Malarev V.I. Certificate of official registration of the computer program N 2018616011 RF. A simulation model of a binary-cycle trigeneration system to improve the efficiency of using the primary energy carrier. Zayav. 26.03.2018. Publ. 21.05.2018 (in Russian).
21. Averyanov V.K., Davydov O.A., Blinov A.N., Anisimov S.M. Trends in the development of energy systems of gas distribution stations. *Vestnik grazhdanskikh inzhenerov.* 2019. N 2 (73), p. 122-130. DOI: 10.23968/1999-5571-2018-16-2-122-130 (in Russian).
22. Tokarev I.S., Khrushchev Yu.V. Ensuring the stability of the operation of autonomous power supply systems of gas compressor stations. Elektrotekhnika. Elektrotekhnologiya. Energetika: Sb. nauch. trudov VII Mezhdunarodnoi nauchnoi konferentsii molodykh uchenykh, 9-12 iyunya, 2015, Novosibirsk, Rossiya. Novosibirsk: Novosibirskii gosudarstvennyi tekhnicheskii universitet, 2015, p. 177-181 (in Russian).
23. Fedorov A.V., Makhalin A.N., Baburin S.V. The use of UPS in power plants of technological facilities in the oil and gas industry. *Nauka i tekhnika v gazovoi promyshlennosti*. 2014. N 2 (58), p. 69-73 (in Russian).
24. Firsova E.V., Chichirova N.D., Sokolov V.Yu. Trigeneration energy sources of low and medium power. *Promyshlennaya energetika*. 2017. N 4, p. 17-24 (in Russian).
25. Khabibullin M.M., Meshcheryakov V.N. Active power filter with a common DC link and a control system based on a relay current regulator. *Pribory i sistemy. Upravlenie, kontrol, diagnostika.* 2014. N 7, p. 26-33 (in Russian).
26. Khrushchev Yu.V., Tokarev I.S. Development of technical solutions to improve the stability and reliability of the power plant for auxiliary needs of the head gas compressor station "Sakhalin". *Elektrotekhnicheskie kompleksy i sistemy upravleniya.* 2014. N 3, p. 77-82 (in Russian).
27. Baburin S.V., Zyrin V.O., Kovalchuk M.S. Dependence of power supply systems reliability on the type of redundancy. International Scientific Electric Power Conference 2019 (ISEPC 2019), 23-24 May, 2019, St. Petersburg, Russian Federation. IOP Conference Series: Materials Science and Engineering, 2019. Vol. 643. N 012134. DOI: 10.1088/1757-899X/643/1/012134/
28. Costabeber A., Tenti P., Caldognetto T., Verri Liberado E. Selective compensation of reactive, unbalance, and distortion power in smart grids by synergistic control of distributed switching power interfaces. 15th European Conference on Power Electronics and Applications (EPE 2013), 2-6 September, 2013, Lille, France. IEEE, 2013. Vol. 1, p. 1-9.
29. Lokurlu A., Saidi K. Solar Trigeneration: Electricity, Cooling and Steam from the Sun. Towards 100 % Renewable Energy. Springer Proceedings in Energy. 2017, p. 87-94. DOI: 10.1007/978-3-319-45659-1_8
30. Sychev Y., Zimin R., Aladin M. The assessment of the series active filter efficiency in power supply systems of oil production enterprises. International Scientific Conference on Energy, Environmental and Construction Engineering (EECE-2019), 19-20 November, 2019, St. Petersburg, Russian Federation. E3S Web of Conferences, 2019. Vol. 140. N 04003. DOI: 10.1051/e3sconf/201914004003
31. Abramovich B.N., Bogdanov I.A., Kopteva A.V., Malarev V.I. The system of trigeneration with binary cycle for use as an energy source for gas fuel. International Scientific Electric Power Conference 2019 (ISEPC 2019), 23-24 May, 2019, St. Petersburg, Russian Federation. IOP Conference Series: Materials Science and Engineering, 2019. Vol. 643. N 012092. DOI: 10.1088/1757-899X/643/1/012092
32. Tokarev I.S., Bogdanov I.A., Serikov V.A. Solutions to Improving the Self-Contained Power Supply to the Gas Industry Facilities when Operating Gas Turbine Power Plants in the Binary Cycle and Trigeneration Modes. 2020 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon), 6-9 October, 2020, Vladivostok, Russian Federation. IEEE, 2020. N 20256187. DOI: 10.1109/FarEastCon50210.2020.9271596
33. Turysheva A.V., Gulkov Y.V., Krivenko A.V. Improving energy performance of the oil and gas industry by applying technologies for the use of associated petroleum gas. Topical Issues of Rational Use of Natural Resources. CRC Press, 2019, p. 442-447 DOI: 10.1201/9781003014577-56
34. Veprikov A.A., Glukhov A.A. Problems of operating industrial DC power sources in parallel connection. 2020 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), 27-30 January, 2020, St. Petersburg and Moscow, Russian Federation. IEEE, 2020. N 19472016, p. 1339-1343. DOI: 10.1109/EIConRus49466.2020.9038928

***Authors:*** **Boris N. Abramovich,** *Doctor of Engineering Sciences*, *Professor* (*Saint Petersburg Mining University*, *Saint Petersburg*, *Russia*), **Ivan A. Bogdanov,** *Postgraduate Student*, *s175106@stud.spmi.ru, https://orcid.org/0000-0001-8847-3352* (*Saint Petersburg Mining University*, *Saint Petersburg*, *Russia*).

*The authors declare no conflict of interests.*

*The paper was received on 30 March, 2021.*
*The paper was accepted for publication on 26 May, 2021.*