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Operation mode selection algorithm development of a wind-diesel power plant supply complex

Yaroslav E. SHKLYARSKIY, Daria E. BATUEVA✉
Saint Petersburg Mining University, Saint Petersburg, Russia

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Abstract. The power supply system is affected by external disturbances, so it should be stable and operate normally in compliance with power quality standards. The power supply system goes into abnormal modes operation when, after a short-term failure or disturbance, it does not restore normal mode. The electrical complex, which includes a wind power plant, as well as a battery and a diesel generator connected in parallel, is able to provide reliable power supply to consumers which meets the power quality indicators. The article develops an algorithm that is implemented by an automatic control system to select the operating mode depending on climatic factors (wind) and the forecast of energy consumption for the day ahead. Forecast data is selected based on the choice of the methods, which will have the smallest forecast error. It is concluded that if the energy consumption forecast data is added to the automatic control system, then it will be possible to increase the efficiency of the power supply complex. In the developed algorithm the verification of normal and abnormal modes of operation is considered based on the stability theory. The criteria for assessing the normal mode of operation are identified, as well as the indicators of the object's load schedules for assessing the load of power supply sources and the quality standards for power supply to consumers for ranking the load by priority under critical operating conditions and restoring normal operation are considered.

***Keywords*:** wind diesel complex; normal operation; sustainability of the energy system; power balance; energy consumption forecast

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Introduction. In the Arctic zone of Russia [1], which makes up one fifth of the country's territory, there are many problems related to the efficiency of power plants and power supply in remote regions. The consumption of all types of primary energy resources is growing, the physical deterioration of the energy infrastructure is growing at an accelerated pace [2]. Therefore, against the background of the increasing limitation of the traditional energy resource base, the role of renewable energy and energy storage systems is critically important [3] in conjunction with smart energy and energy efficiency [4].

The Energy Strategy of Russia for the period up to 2035 [5] and the Strategy for the Economic Security of Russia for the period up to 2030 [6] reflect the importance of developing regional energy in the Arctic and the Far North, including renewable energy sources (RES), and improving living standards. The development of wind-diesel complexes is currently slow due to the long localization of international and European standards, and the promotion of the investments in projects is limited by excessive requirements for the design, construction and operation of facilities based on renewable energy.

The value of the technical potential of wind energy in the Arctic regions exceeds the technical and economic data of existing power plants, which makes it possible to fully cover the cost of the equivalent fuel for energy production [7]. When using the potential of wind energy, there is a significant saving of traditional organic energy resources [8], which, in turn, can be used in those regions where climatic conditions do not imply the generation of energy using renewable energy sources in the required quantity, in order to cover the needs of the region [9].

The main consumers of electricity in settlements that do not have industrial enterprises are boiler plants operating on oil or coal. The schedule of electrical load is determined by the village heating systems which leads to a significant unevenness of energy consumption depending on the season. The deviation of real energy consumption is 11-56 % of the planned load schedules. During the summer month there is a maximum deviation in power consumption. Stably low air temperatures are observed only in winter, the rest of the time the average temperature changes significantly every month, which entails a shift in the load curve [10].

Infrastructure is another barrier that characterizes isolated power supply areas. The Far North is distinguished by settlements quite remote from each other and complex and poor-quality transport routes [11]. The transport period for many northern regions is only two to three months and is carried out on temporary, unequipped routes. In these conditions, the delivery and unloading of large equipment is a difficult task.

An electrical complex, which includes a wind power plant (WPP) with a battery and a diesel generator plant (DGP) connected in parallel [12], is able to provide reliable power supply to consumers in accordance with power quality indicators [13, 14]. An analysis of literature showed that for guaranteed power supply to consumers in the North and North-East of the country in conditions of extreme annual temperature fluctuations from −60 to +40 °C, for autonomous complexes based on renewable energy sources, the horizontal-axial wind turbines with a permanent magnet synchronous generator are the most promising for implementation, due to theirs modular design and sufficiently high reliability with proper design and manufacture of installations [15-17].

At the same time, the construction of isolated power supply systems based on several types of energy sources using wind turbines and diesel generator plants connected by a common DC bus makes it possible to get rid of the 20 % limitation of the wind turbine power share, as well as to use diesel generator plants with a synchronous generator with inverter type permanent magnets, which have a smaller specific fuel consumption when working on a changing load [18, 19].

However, increased costs for fuel and its delivery determine the high cost of electricity for consumers, and emissions of pollutants into the atmosphere as well as volumes of waste from used fuel worsen the environmental situation in the region. [20]. Therefore, the implementation of projects related to the development of decentralized energy systems based on wind power plants, for which there is a significant wind potential, is a promising task [21, 22].

Formulation of problem. *Power supply complex operating modes.* The wind turbine operates in automatic mode, providing maximum output according to the current wind speed. A bidirectional current converter (BDCC) provides smoothing of energy generation from wind turbines and power balance by charging and discharging accumulator batteries (AB) with charging and consuming energy to/from the grid. Thus, BDCC and AB together form a network support – storage system.

The following operating modes are implemented in the automatic control system of the power supply complex of the object under study:

- State 1 – single operation of the DGP on load: when the power supply complex is switched on for the first time, it switches to state 1.

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- State 2 – operation of the DGP with BDCC in synchronous mode: after the successful switching on of the DGP, the BDCC is connected to the load and synchronized with the power supply complex.
- State 3 – wind turbine operation in slave mode is in parallel with BDCC and DGP: in this state, the wind turbine sends wind energy into the network, while for the DGP the load is reduced. With power fluctuations from the side of the wind turbine, first BDCC reacts (as an inertialess machine), compensating for power fluctuations for smooth operation of the DGP.
- State 4 – wind turbine operation in slave mode with BDCC as a reference source, DGP is stopped (maximum diesel fuel saving mode). The transition is possible when the output from wind turbines exceeds consumption.

This system considers only four power system operation states; therefore, it is necessary to consider the choice of operating modes and checking for the stability of normal modes, and also take into account the possibility of integrating energy consumption forecast into the automatic control system.

Energy consumption forecasting. At present, when operating a power supply complex with a wind-diesel power plant, the possibilities of improving the efficiency of the electrical complex by taking into account the forecast of energy consumption for the day ahead and the possible impact of changes in load schedules depending on the duration of daylight hours, seasonality, ambient temperature are not taken into account [23].

Forecasting energy consumption, on the one hand, will allow to prevent interruptions in the supply of electricity when the load increases more than planned, to plan operating modes providing electricity to consumers during sudden changes in wind speed, and, on the other hand, reducing electricity consumption due to forecasting will affect efficiency operation of the power supply complex, including DGP service life retrenchment and reducing fuel consumption [24]. Prediction of energy consumption, performed with sufficient accuracy, allows maintaining a balance of power, which is the main criterion in the operation of any power supply complex.

The results of using various forecasting methods may have different accuracy, since the study is closely related to changes in the process of power consumption by the object, the type of consumer load and external climatic changes. Therefore, not all forecasting methods can be used. Statistical methods do not provide sufficient accuracy [25-27], however, they are often used for facilities with a small installed capacity and domestic load. Multifactor methods require a large number of input parameters, and for each object the data set will be unique [28]. Common intelligent methods in many cases do not take into account the individual characteristics of the power consumption process [29, 30]. Increasingly, research has been carried out using hybrid methods [31], which combine structurally-simple methods and the advantages of intelligent methods, while the process of power consumption is taken into account in dynamics [32, 33].

The developed algorithm uses predictive data obtained by calculating by four methods: regressive, exponential smoothing, artificial neural networks and a combined method. The program allows to predict the daily consumption of electricity. As output, the user receives a load schedule for the next day. Since the analysis of the load curves of various energy supply complexes in different industries shows that the uniformity of electricity consumption is significantly different, the program considers several forecasting methods, and the user can choose a method for his system with the least forecasting error. Thus, in the developed algorithm, it is necessary to take into account the possibility of obtaining predictive data on the energy consumption of an object for effective planning of operating modes.

Energy supply complex stability. The object of the study is a wind-diesel complex in the Khabarovsk Territory, operating in an islanded (autonomous) mode and supplying a shift camp with electricity (heating and household load). At present, generating units operate in parallel – wind turbines with an installed capacity of 100 kW and three DGPs with an installed capacity of 58 kW (in summer),

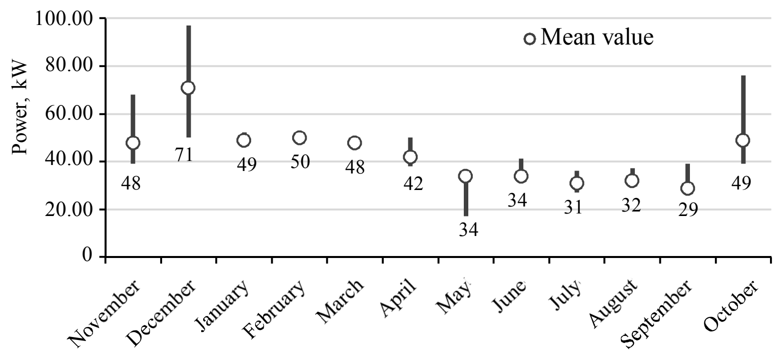

Fig.1. Electricity consumption chart

110 kW (in winter) and 120 kW (in reserve). When the wind flow is less than 2.5 m/s, the DGP operates at full load, and the wind turbine is turned off. At the same time, when the wind speed reaches 10-15 m/s, the wind turbine fully provides the facility with electricity, is able to recharge batteries with a capacity of 340 Ah, and if some operating parameters change, it can participate in water heating, reducing the load on hot water boilers. The wind turbine will save up to 53 tons of fuel per year and reduce emissions into the atmosphere.

The power consumption of the power supply complex is 377,046 kWh, while the total consumption of diesel fuel at the DGP is 123,800 liters. The specific fuel consumption is 269 g/kWh. The average annual power consumption is 43 kW, the peak power in a year is 97 kW (Fig.1). The average deviation of monthly power consumption is 14.5 %, which negatively affects the operating modes of the power supply complex without forecasting energy consumption, making a forecast of unstable operating modes and their duration. A characteristic feature is also the reduction of electrical load in the summer period. Compared to the warmest (July) and coldest (December) months, the difference in electricity consumption reaches 2.5 times.

One of the conditions for the sustainable operation of a local network is to maintain a balance of generated and consumed energy (power). The main source of energy supply is wind turbines. In the absence of a sufficient level of wind energy, the DGP is started. In this case, the output voltage of the bidirectional current converter is adjusted in frequency and amplitude to the DGP voltage. As the power generated by the wind turbine increases, the load on the DGP decreases up to its complete shutdown. The optimal load for a DGP is a load equal to 50-70 % of the rated power. With a further increase in the generation of wind turbines and a corresponding decrease in the power of the diesel generator set, it turns off, the battery compensates short-term power shortages or excesses through the BDCC.

In this regard, it is necessary to identify a number of criteria that will allow to evaluate the operating modes of the power supply system: stable operation of wind turbines; preventing the synchronous generator from falling out of synchronism; prevention of DGP transition to the motor mode; static stability of the load node and power quality indicators.

Thus, after selecting the operating mode, in order to ensure the normal mode in the developed algorithm, it is necessary to check the stability of the power system with a wind-diesel power plant. The normal mode of operation is such a mode when, in the event of external disturbances, the power system does not go into an abnormal mode of operation, stability is maintained, and the criteria for the quality of power supply to consumers do not decrease.

Methodology. The article develops an algorithm for selecting the operating mode depending on climatic factors (wind) and the forecast of energy consumption for the day ahead, which is implemented by the automatic control system. The thesis is considered that if the data of energy consumption forecast for the day ahead is added to the automatic control system, then it is possible to increase the efficiency of using the power supply complex, since an increase in the accuracy of forecasting and, accordingly, setting the parameters for selecting the operating mode allow maintaining a power balance.

Energy consumption forecasting methods (regressive, exponential smoothing, artificial neural networks and combined) are based on the methods of statistical data processing, mathematical forecasting, and artificial intelligence. At the output, forecast data is selected based on which of the methods will have the smallest forecast error.

In the developed algorithm, the verification of normal and abnormal modes of operation is considered on the basis of theories of stability, electric drive, mathematical statistics, and criteria for assessing the normal mode of operation are identified. The indicators of object load schedules for assessing the load of power supply sources and the quality standards of power supply to consumers for ranking the load by priority under critical operating conditions and restoring normal operation are discussed.

Discussion. *Development of an algorithm for the operation of the wind-diesel plant, taking into account the check according to the stability criteria.* The algorithm is built taking into account the operating modes of the object under study, stability criteria, the forecast of the object's energy consumption for the day ahead, and the calculation of the power balance in this autonomous power system (Fig.2).

The consumer parameters are pre-set – the length of the lines between the power supply sources and consumers l, the power of consumer installations P_{load} (set for a common load node), the load schedule. Since this study considers the possibility of improving the efficiency of the electrical complex by taking into account the forecast of energy consumption, the data of the planned hourly load, predicted a day ahead, should also be loaded into the parameter setting block.

Then the source data is determined – the type, quantity, power of power plants, the wind parameters and the battery charge level are set.

Further, based on the specified parameters, the operating mode of the power supply complex is set, which determines which installations the load is connected to, the current, voltage at the nodes, frequency, values of active and reactive power are calculated. The parameters of synchronous generators in the system are also fixed: moment on the generator shaft, angular velocities, excitation current, load angles, etc.

For the efficient operation of the battery, it is assumed that the battery cannot be discharged by more than 80 % (i.e. the battery is charged at least 20 % of the total capacity), since in wind diesel systems the battery life is to a greater extent limited by the number of deep discharge cycles it can withstand. At this facility, at least 1000 cycles are provided, and the battery can supply energy to the network when charged at least 80 %.

To check the stability of the system and the normal mode of operation, the power balance in the power system is calculated, a conclusion is made about the stability or instability of the mode of operation. If an abnormal operation mode is determined, the system is checked according to stability criteria, thus determining the cause and node of stability violation.

The modes of operation of the autonomous power supply system, presented in the algorithm, can be described as follows (power from the DGP differs in summer (58 kW) and winter (100 kW):

- mode 1 – power supply from the wind power plant and battery charge;
- mode 2 – power supply of the load from the wind power plant and storage battery;
- mode 3 – power supply of the load from the wind power plant;
- mode 4 – parallel operation of wind power and diesel generator sets and storage battery;
- mode 5 – parallel operation of wind power and diesel generator sets and battery charging;
- mode 6 – parallel operation of wind power and diesel generator sets;
- mode 7 – load power supply from diesel generator set and storage battery;
- mode 8 – load power supply from diesel generator set and battery charge;
- mode 9 – load power from diesel generator set.

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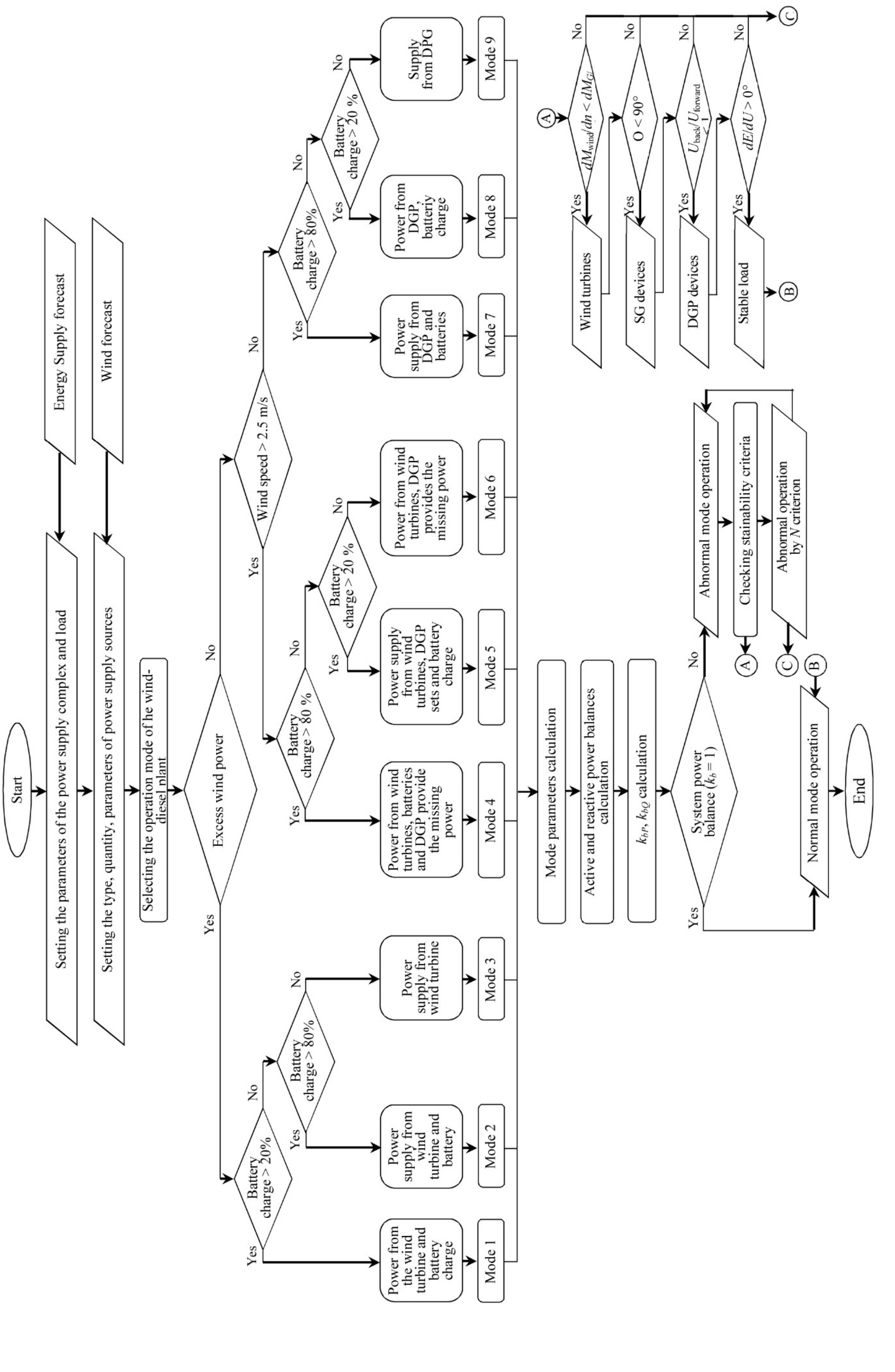

Fig.2. Algorithm for selecting and evaluating the operating mode of the power supply complex with wind-diesel plants

The calculation of power balances specified in the algorithm is carried out after selecting the mode and calculating its parameters:

- active power balance factor

$$k_{bP}=\frac{P_{\mathrm{WT}i}}{P_{\mathrm{load}i}}+\frac{P_{\mathrm{DGP}i}}{P_{\mathrm{load}i}}\pm\frac{P_{\mathrm{AB}i}}{P_{\mathrm{load}i}}-\frac{P_{\mathrm{bl}i}}{P_{\mathrm{load}i}}-\frac{\Delta P}{P_{\mathrm{load}i}};$$

- reactive power balance factor

$$k_{bQ}=\frac{Q_{\mathrm{WT}i}}{Q_{\mathrm{load}i}}+\frac{Q_{\mathrm{DGP}i}}{Q_{\mathrm{load}i}}-\frac{\Delta Q}{Q_{\mathrm{load}i}},$$

where P, Q – active (W) and reactive (var) power in the i-th mode, respectively; bl – ballast load; load – power of the load; Δ – system's power loss.

The power system operates in normal mode, when the coefficients k_{bP} and k_{bQ} are equal to 1. If the power balances do not converge, then it is necessary to identify the reasons for the violation of the operating mode. If at least one criterion is not met, then the mode is considered abnormal, the parameters are reconfigured, and the mode is calculated again.

Calculation of electrical load graphs indicators. The difference in the energy consumption of the facility in summer and winter reaches 2.5 times. Accordingly, it is necessary to consider the characteristic modes of operation during the period of the summer minimum and winter maximum loads. It is necessary to analyze such indicators of the electrical load graphs as the coefficients: the use of k_{use}, the inclusion of the consumer k_{on}, the load k_{load}. The calculation was made for July and December.

The utilization factor will show how efficiently the installations are used, and the calculation of the load distribution among the generators during parallel operation will show how loaded the generators are for a given period of time.

The utilization factor (the main indicator for calculating the load) is the ratio of the average active power of an individual receiver (or a group of them) to its nominal value:

$$k_{\mathrm{use}}=\frac{P_{\mathrm{av}}}{P_{\mathrm{nom}}}.$$

The consumer turn-on ratio is the ratio of the consumer turn-on time in the cycle t_{on} to the entire cycle time t_{c} (24 h):

$$k_{\mathrm{on}}=\frac{t_{\mathrm{on}}}{t_{\mathrm{c}}}.$$

The load factor is the ratio of the actual average active power consumed to the rated power of the receiver:

$$k_{\mathrm{load}}=\frac{P_{\mathrm{av}}}{P_{\mathrm{nom}}}=\frac{1}{P_{\mathrm{nom}}t_{\mathrm{on}}}\int_0^{t_{\mathrm{c}}}p(t)\,dt=\frac{P_{\mathrm{av}}}{P_{\mathrm{nom}}}\frac{t_{\mathrm{on}}}{t_{\mathrm{c}}}=\frac{k_{\mathrm{use}}}{k_{\mathrm{on}}}.$$

As a result of calculating these coefficients for July and December, the following conclusions were made:

- In July, the utilization factor when powered by a 58 kW DGP ranges from 0.10 (4 h of operation per day, the rest of the time – wind turbines) to 0.68 (24 h of operation per day); in December, when powered by a 110 kW DGP, the utilization factor ranges from 0.02 (2 h of operation per day, the rest of the time – wind turbines) to 0.45 (24 h of operation per day).
- The turn-on factor in July ranges from 0.17 (powered only by the wind turbine) to 1.0 (the wind turbine is out of order or under repair).

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• The load factor when powered in July by a 58 kW DGP ranges from 0.47 to 0.73; when powered in December by a 110 kW DGP, the load factor is in the range from 0.26 to 0.45.

Considering that the DGP operates in normal mode with a load of 50-75 %, in this electrical complex DGPs mainly operate with underload, which increases fuel consumption and reduces efficiency, especially in winter.

Stability criteria for the normal mode of the wind-diesel power plant operation. Normal modes of operation, first of all, are determined by compliance with the power balance condition, for which it is necessary to manage and control the magnitude of the currents of the power sources, the modes of charge/discharge of batteries and the magnitude of the ballast load current.

However, in addition to this, it is necessary to highlight a number of criteria proposed in the source [34], which will allow assessing the operating modes of the power supply system: stable operation of wind turbines; preventing the synchronous generator from falling out of synchronism; prevention of DGP transition to the motor mode; static stability of the load node and power quality indicators.

Sustainable operation of wind turbines. The system is statically stable under the condition that, under any perturbation, the resulting moment tends to return the system to its original position. Therefore, the increment of the electromagnetic moment of the generator must be greater than the change in the mechanical moment of the turbine. It follows that the stability condition for wind turbines is expressed as

$$\frac{dM_{\mathrm{WT}}}{dn} < \frac{dM_{\mathrm{G}}}{dn},$$

where M_{WT}, M_{G} – torque of the wind turbine and generator, respectively, N·m; n – rotation speed of the engine output shaft, rpm.

When applying the power $P_{\mathrm{on}} = f(n)$ and moment $M_{\mathrm{WT}} = f(n)$ characteristics of the wind turbine and generator, reduced to the rotation speed n of the same shaft, the operating points of the wind turbine are determined.

For the wind turbine under study, it follows from the above conditions that when using a gearless permanent magnet generator with a variable speed in the system, stability will be ensured if the sloping characteristic of the generator intersects with the right-hand sides of the turbine characteristic equation.

Preventing the synchronous generator from falling out of synchronism. Checking the DGP for stability is carried out on the basis of the angular characteristics of the generator, highlighting the areas of stable and unstable modes. An unstable mode of operation is considered to be such a mode when the load angle θ goes beyond 90° (Fig.3), i.e. when changing the external torque or braking torque M_{out} applied to the shaft of a synchronous machine, synchronous rotation is not preserved. The frequencies of synchronous rotation of the rotor n_2 and the resulting magnetic field n_1 become equal ($n_1 = n_2$):

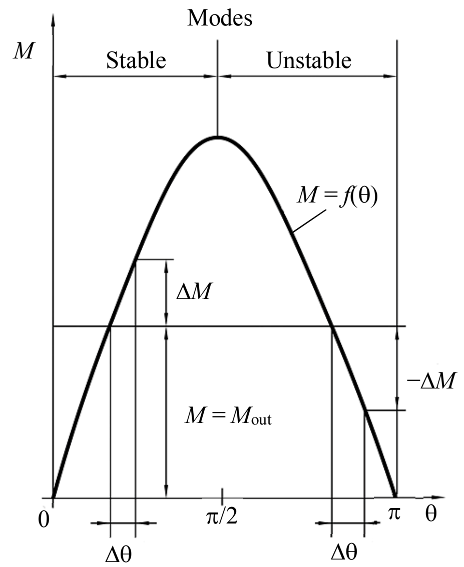

Fig.3. Angular response of synchronous generator

$$\theta < \frac{\pi}{2}.$$

Thus, the smaller the load angle, the greater the stability margin of the synchronous machine is, and the load angle decreases with increasing excitation current.

One of the reasons for the violation of stability can be a significant proportion of the active-capacitive load in the system. Then the generator will work in the underexcitation mode to maintain a stable voltage, the excitation current will decrease, and the load angle will increase. Also, with a decrease

decrease in wind speed, the torque of the wind turbine and the excitation current will decrease.

Then the question arises of precise synchronization of wind turbines and diesel generator sets, when the power produced by wind turbines is not enough, and it is necessary to turn on the diesel generator set. The self-synchronization method is used, while the exact synchronization method is very difficult due to the fact that the generator must be included in a working network without falling out of synchronism, and the current surge should not exceed the limit values. The self-synchronization method allows you to increase the limits of permissible slip values and does not require checking the switching phases when connecting the generator to the system.

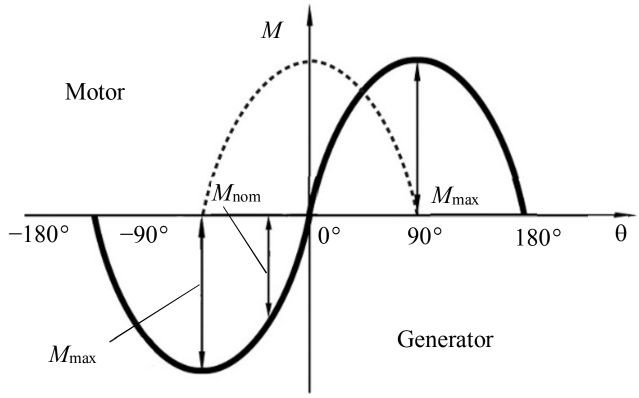

Fig.4. Operating modes of a synchronous machine

Prevention of DGP transition to motor mode. As noted, the generator operates in a stable mode when the load angle θ varies from 0 to 90°. In this case, if the load angle becomes less than 0°, then the synchronous machine will switch from generator to motor mode, i.e. in an abnormal mode of operation with a violation of the power supply to consumers (Fig.4).

One of the reasons for such a transition may be a breakdown of the rectifier. A breakdown of the rectifier diodes can occur when the voltage rises, overheating by the current passing through the diodes, or during mechanical damage. Then the resistance becomes equal to zero, and a short circuit of the phases of the stator winding may occur and, accordingly, a generator failure.

Condition, the fulfillment of which will exclude the breakdown of the rectifier:

$$\frac{U_{\text{back}}}{U_{\text{forward}}} < 1 ,$$

where U_{back}, U_{forward} – reverse voltage applied to the rectifier and breakdown voltage, respectively, V. If this condition is not observed, rectifier breakdown occurs and the generator switches to motor mode.

Statistic stability of the load node and the power quality indicators. As a rule, in autonomous isolated power systems, the power of power sources is selected approximately equal to the load power, therefore, a decrease in voltage at the load node can lead to braking of asynchronous motors at the consumer or to a voltage avalanche (GOST 32144-2013) when the voltage drops to a critical level. The stability of the load can be estimated through the voltage safety factor

$$K_U = \frac{U_0 - U_{\text{crit}}}{U_0} \cdot 100\ \%,$$

where U_0, U_{crit} – rated voltage of the network and critical voltage, i.e. the boundary of the static stability of the system, respectively, V.

If the voltage safety factor increases, then the stability of the load node also increases. The following practical criteria can be used to calculate sustainability:

$$\frac{d\Delta Q}{dU} < 0,$$

where ΔQ – unbalance in the node between the power generated by the generator $Q_G(U)$ and consumed load $Q_{\text{load}}(U)$, var; U – load node voltage, V.

Unbalance of reactive power ΔQ causes a change in the EMF of the generator E:

$$\frac{dE}{dU} > 0.$$

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Since the load of consumers at the facility has a rather low power (up to 100 kW), the facilities are located at short distances and represent a complex load connected through one node to the power supply network, it is possible to consider the whole node. Then the calculation of the static stability of the load node can be made for the total static characteristics (SLC) P(U) and Q(U) in terms of voltage.

The static characteristics of loads can be expressed analytically as polynomials of the n-th degree [35]:

$$P(U)=P_{\text{nom}}\left[\alpha_0+\alpha_1\frac{U}{U_{\text{nom}}}+\alpha_2\left(\frac{U}{U_{\text{nom}}}\right)^2+\dots+\alpha_n\left(\frac{U}{U_{\text{nom}}}\right)^n\right];$$

$$Q(U)=Q_{\text{nom}}\left[\beta_0+\beta_1\frac{U}{U_{\text{nom}}}+\beta_2\left(\frac{U}{U_{\text{nom}}}\right)^2+\dots+\beta_n\left(\frac{U}{U_{\text{nom}}}\right)^n\right],$$

where P_{nom}, Q_{nom} – active and reactive load power, respectively; U – current voltage value; α, β – coefficients of approximating polynomials.

With sufficient accuracy for practical calculations, SLC are reflected by polynomials of the second degree:

$$P(U)=P_{\text{nom}}\left(\alpha_0+\alpha_1U^*+\alpha_2U^{*2}\right);$$

$$Q(U)=Q_{\text{nom}}\left(\beta_0+\beta_1U^*+\beta_2U^{*2}\right),$$

where $U^*=U/U_{\text{nom}}$ – current relative voltage value.

In addition to the static stability of the load node, it is necessary to consider the requirements for power quality that satisfy various consumer groups in order to further assess the operating modes of the power supply complex in the event of critical operating conditions.

First, the main electricity consumers were divided into priority groups:

- Group 1 (cyclic intermittent operation, controlled by the control system) – electric water heater.
- Group 2 (low priority load) – clothes dryer, 20 kW; washing machine for clothes, 3 pcs. 1.5 kW each; electric heater 16 kW; iron.
- Group 3 (high priority load above 700 W) – electric cooker, 18 kW; electric frying pan, 12 kW; cooking oven, 18 kW; potter, 3 kW; refrigerated container, 2 pcs. 6 kW each; refrigerator, 2 pcs. of 0.25 W.
- Group 4 (high priority load below 700 W) – lighting; computer technology; TV.

According to the Rules for the installation of electrical installations, for consumers of the III category of reliability, a break in power supply is no more than a day – for the duration of emergency recovery work (Table). However, it is possible to rank consumers on the basis of an expert assessment by priority for switching off one by one in case of accidents or switching on after restoration work (taking into account the requirements for electricity quality standards, according to GOST 32144-2013).

Interruptions in the power supply of consumers

Permissible limits of electric energy quality indicators	Group 1	Group 2	Group 3	Group 4
Frequency deviation ±1 Hz Voltage fluctuations and flicker ±10 % of U_{nom} Non-sinusoidal voltage depending on the order of the harmonic component Voltage unbalance in three-phase systems 2 % Voltage interruptions 5 % of U_{ref} Voltage dips and surges up to 1 min	Up to 6 h	Up to 24 h	Up to 12 h	Up to 24 h

If random situations occur that lead to a change in voltage characteristics, as well as voltage deviation at various points of power transmission at a specific point in time, when part of the load must be turned off, one should be guided by the priority of the load to restore normal operation. High priority should be given to the first group, then to the third group and then to the second and fourth groups in equal proportion. In particular, the forecast of energy consumption for the day ahead during each hour will allow to evaluate which of the groups of loads can remain off for a long period of time. It is also necessary to take into account that all generators should operate with the same power factors, equal to the power factor of the network.

Results. In this study, an algorithm for selecting and evaluating the operating modes of a power supply complex with a wind-diesel power plant has been developed. At the first stage, the parameters of consumers are set, taking into account the forecast of energy consumption for the day ahead and generation data. The algorithm considers nine possible modes of operation for the object under study.

Since the possibility of improving the electrical complex efficiency by taking into account the forecast of energy consumption was investigated, the data of the planned hourly load, predicted a day ahead and selected by the method that has the smallest prediction error, should also be loaded into the parameter setting block.

The necessity of analyzing the stability of the power system according to the selected criteria was determined: stable operation of the wind turbine, prevention of the synchronous generator falling out of synchronism, prevention of the transition of the diesel generator set to the motor mode, static stability of the load node and power quality indicators. To check the stability of the system and normal operation, the power balance is calculated. If an abnormal operation mode is determined, the system is checked according to the stability criteria and the cause and node of the violation of stability are determined.

The algorithm is built taking into account the operating modes of the object under study, stability criteria, the planned forecast of the object's energy consumption for the day ahead, and taking into account the calculation of the power balance in this autonomous power system. Such a system will improve the efficiency of using the power supply complex, ensure reliable power supply to consumers, observing the standards for power quality.

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Authors**: Yaroslav E. Shklyarskiy,** *Doctor of Engineering Sciences, Professor, https://orcid.org/0000-0001-8803-9898 (Saint Petersburg Mining University, Saint Petersburg, Russia*), **Daria E. Batueva,** *Postgraduate Student, s175071@stud.spmi.ru, https://orcid.org/0000-0002-6945-2270 (Saint Petersburg Mining University, Saint Petersburg, Russia).*

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