

# Improving flexible grid management methods to increase the sustainability of energy supply to mining industries

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## Abstract

Recent years have been characterized by a steady increase in the consumption of electric energy in areas of mining and mineral processing, driven by the growth and development of industrial production. At the same time, the development of the electric grid complex in a number of regions lags behind the growth of electricity consumption. Therefore, any failure of network equipment can lead to both local and systemic problems, including possible disconnection of consumers and the shutdown of the mining and processing of minerals. This situation requires advanced development of the electric grid, as equipment failures can lead to system failures. The growth in capacity from renewable energy sources (RES) power plants is driven by trends in the development of ecological energy. However, the growth of installed renewable energy capacity has created problems in both planning and managing the electric power modes of the energy system. This is due to the difficulty of predicting the dependence of energy production by solar and wind power plants on the time of day and weather conditions. At the same time, a sudden reset of the generation leads to a false alarm of emergency automation (EA) and disconnection of power lines.

Similar problems appear when network equipment is being repaired. Based on analysis of the EA operation across various repair schemes of the power system, problems with automation object devices that fail to perform their functions in the event of electrical network accidents, including power line and power grid equipment shutdowns, have been identified. A solution to the voiced problem is proposed, consisting of equipping the automation device with an additional resistance organ to prevent equipment overload. To identify the nature of the overload of the protected network element and the issuance of effective control actions (CA), the CA efficiency for unloading the network element was linked to the resistance applied at the installation point of the automation device. This approach made it possible to achieve adaptability of the automation device while maintaining the simplicity of its design.

Based on an analytical review of trends in the development of renewable energy sources and their integration into the energy system, approaches to upgrading existing emergency automation devices in complex networks with a high proportion of renewable energy generation to increase network capacity are substantiated. The proposed methods for flexible management of electric grids enable increased stability of energy supply in regions associated with the mining and processing of minerals.

## Keywords

Energy system management; solar power plants; repair schemes; emergency automation; regulatory authority; adaptive networks.



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## Introduction

A significant proportion of renewable energy sources in modern power systems, and a variety of configurations of electrical networks, when operating in modes that reduce the range of reactive power regulation and the moment of inertia of the equivalent generator of the system, increase errors in planning the power system's balance of power. All this leads to the introduction of excessive system restrictions to maintain the reliability and stability of the energy system. System restrictions are understood as the permissible values of the maximum active power overflows in controlled sections of the electrical network, the provision of reserves of active power for regulating frequency and overflows, as well as increased requirements for voltage levels at network control points. Therefore, the study of energy supply processes, including the problems of increasing the capacity of transport channels and methods of adaptation and self-repair of electric networks, is relevant.

Studies have shown the need to take into account the emergency power imbalance caused by a decrease in the active capacity of solar power plants located in one power plant within 10 minutes due to changes in weather conditions associated with a decrease in solar activity (Order of the Ministry of Energy; Sitnikov et al., 2022).

In addition, with maximum renewable energy generation in 110 kV distribution networks, high-voltage levels occur during normal operation. However, in the post-emergency mode, when switching off renewable energy sources, the opposite situation may occur, in which it is necessary to limit the permissible flow of active power in a cross-section - in a set of elements of one or more electrical connections, the simultaneous disconnection of which leads or does not lead to the separation of the power system into two isolated operating parts. At the same time, it is problematic to provide for the real value of renewable energy generation in the calculations of established regimes, which imposes unnecessary restrictions on the management of the electric power regime.

Another important aspect of the operation of renewable energy sources in parallel with the energy system is their impact on the energy system's stability (Klačková et al., 2022). Firstly, a large proportion of renewable energy sources, combined with stations powered by traditional energy sources with synchronous generators, reduces the equivalent moment of inertia of the power system. This factor increases the likelihood of a violation of the dynamic stability of the power system in certain modes.

Secondly, due to the lack of regulation of reactive power by RES, the limit of transmitted power at power system connections is reduced, which results in greater influence of RES on voltage regulation (Yakimovich et al., 2017). This problem leads to a decrease in static aperiodic stability in an energy system with a high proportion of renewable energy generation (Yakimovich et al., 2017; Kucherov et al., 2015; Kramskoy et al., 2017).

The lack of regulation of the reactive power of renewable energy sources is a consequence of a purposeful narrowing of the range of changes in  $\cos \varphi$ . The purpose of such manipulation by the owner is to maximize the production of paid active power, as opposed to reactive power. Expanding the range of regulation for the reactive power of renewable energy sources and proper adjustment of renewable energy regulators can increase the stability of the energy system (Kucherov et al., 2015; Nikiforov et al., 2015; Krankovský et al., 2020).

The issues of stability and reliability of the electric power system are effectively addressed through the introduction of new controlled AC transmission systems (FACTS devices) and microprocessor-based emergency automation systems. All the measures mentioned above are aimed at creating the structure of an active adaptive electric grid. The distinctive features of such a system will be high reliability, stability, manageability, and economic efficiency (Sitnikov et al., 2021; Astashev et al., 2016; Zhmurov et al., 2010; Kovanič, 2013).

Recent trends in modern energy indicate the need to develop high-speed automated devices for system-mode control. Currently, all existing automation systems and complexes operate based on the results of online analysis of incoming data, as their logic already includes solutions derived from preliminary analytical work on the calculation of the energy system's dynamic modes.

Currently, with the growth of digitalization, there is a growing demand to increase the automation and efficiency of existing devices and complexes through the development of active, adaptive systems and the introduction of new logical connections and algorithms (Yasko et al., 2017; Kovanič et al., 2021).

The development of global energy towards alternative energy sources, due to their unstable operation mode, requires additional solutions to increase the capacity of electric networks. This goal can be achieved by modernizing and building an electric grid and generating complex systems, as well as by building devices and systems for emergency response and automation (Sitnikov et al., 2021).

Most of the tasks of preventing emergency modes are intended to be handled by local emergency automation systems, which, by their purpose and design principles, are simple and reliable devices. (Voropai 2020; Sitnikov et al., 2022)

However, the existing automation cannot fully and correctly assess the circuit-mode state of the power system. Difficulties in choosing the right algorithm for configuring an automation facility arise from the inconsistent generation of renewable energy facilities, changes in the electrical network topology due to emergency shutdowns and equipment repairs, and uneven load schedules (Klačková, I. (2025)). The voiced problem is clearly expressed in the existing automation devices for limiting equipment overload (ADLEO). As you know, the ADLEO, being an object-based one, cannot solve complex tasks that require an analysis of the electrical network

mode. Often, such devices implement a limited number of operating algorithms selected by the system operators on duty when changing the network layout and the composition of the generating equipment (STO 59012820.29.020.002).

The aim of the study is to increase the stability and reliability of the electric power system by introducing new control algorithms and modernizing existing automatic control systems (Kuric et al., 2022). To achieve this goal, it is necessary to conduct an analytical review of network development trends, consider the features of managing a power system with a high proportion of renewable energy generation, and justify the directions for upgrading existing emergency automation devices when changing the network configuration due to a false, emergency, or planned shutdown during equipment repair (Kaczmarczyk and Dobrzaniecki, 2023)

## Material and Methods

### The impact of solar generation on the management of the energy system

An increase in the share of renewable energy generation in the energy system leads to an increase in the percentage of generated active capacity that defies precise planning. This leads to the need to take into account the emergency power imbalance caused by a decrease in the active capacity of solar power plants located in one power plant within 10 minutes due to changes in weather conditions associated with a decrease in solar activity (Order of the Ministry of Energy).

In the Crimean energy system, the total installed capacity of solar power plants (SPP) reaches about 300 MW. The largest power plants on the Crimean Peninsula are: SPP "Perovo" (106 MW), SPP "Okhotnikovo" (80 MW), SPP "Nikolaevka" (70 MW) (Guryev et al., 2020; Sitnikov et al., 2021). Another feature of the SPP of the Crimean Peninsula is its close proximity to each other, both geographically and within the energy system. All power plants are located within a 23-kilometer radius in the western part of the peninsula. In other words, the studies conducted for a group of power plants will be fair, since the SPP are in the same meteorological conditions (Kakushina et al., 2025).

However, it is impossible to achieve the generation value of the installed SPP capacity, even at noon, due to various factors (Guryev et al., 2020; Guryev et al., 2018). The main limiting factors for generating maximum SPP power are: illumination, cloud cover, and daylight duration (Guryev et al., 2017; Kakushina et al., 2018). Such meteorological factors are typical for certain seasons of the year (Morozov et al., 2016; Morozova et al., 2017; Tukfatullin, 2016).

In order to determine the real range of reactive power regulation, during the study, a sample was made of the values of the generation of active power by the SPP of the power system during the day, according to the characteristic seasons. The results are presented as daily generation graphs.

To determine the total average daily generation schedules for the SPP of the energy system, 2020 data were used with a 30-minute interval. Based on this, a generation profile was obtained based on the average half-hour values for each month of the year. As a result, the two most contrasting generation profiles were identified for the winter and summer seasons; this separation is due to meteorological factors characteristic of the Crimean Peninsula's energy system. Figure 1 shows graphs of the total generation of the Crimean SPP in the summer and winter seasons (Ságová et al., 2022). The main differences are in the amount of active power generation and the length of daylight hours.

The daily schedule of SPP generation in the summer season of the Crimean energy system is typical for eight months of the year, from March to October. The winter season lasts four months, from November to February, and is the most cloudy period, with short days. This seasonal division is typical for solar generation on the Crimean Peninsula.

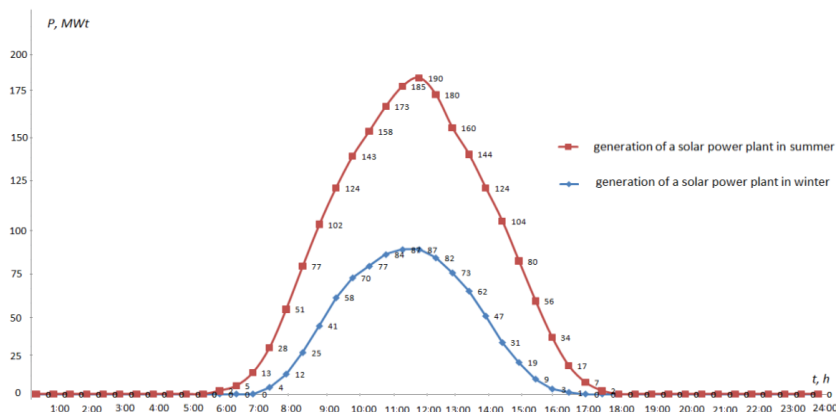


Fig. 1. Graphs of daily SPP generation for typical seasons of the year

Based on the results of calculations of the graphs of the total generation of the active power of the SPP, the graphs of the upper and lower limits of the control range of the reactive power of the SPP of the power system are determined, as shown in Figure 2.

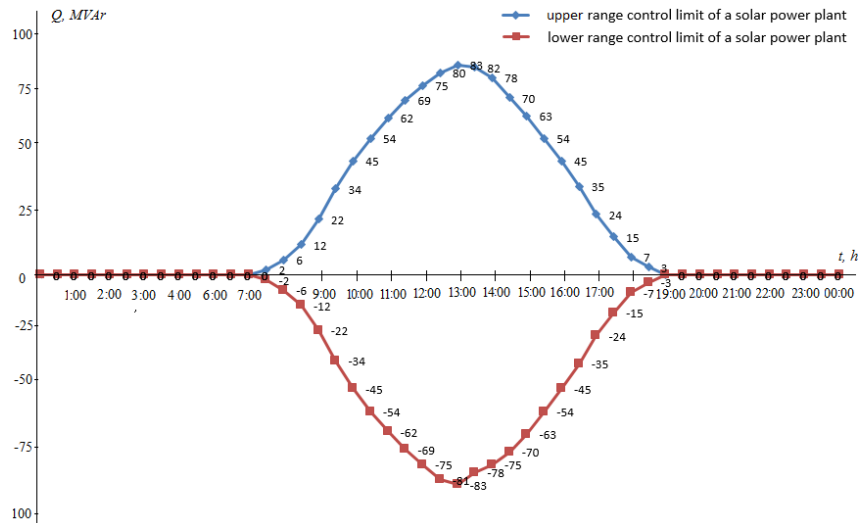


Fig. 2. Total adjustment range of reactive power of the SPP of the Crimean energy system in the summer season

The extreme limits of the range are calculated based on the nominal parameters of the inverters used at the SPP. For example, the nominal data for the Protect PV.250 inverter are used, as the most common on the SPP of the Crimean energy system. The inverter manufacturer has declared a  $\cos \varphi$  equal to the range of values within  $(-0.9; +0.9)$ .

From the graphs in Figure 2, it can be seen that the reactive power control range of more than  $\pm 20$  MVar is provided for about 11 hours during the summer season. In addition, during the summer season, a control range of more than  $\pm 70$  MVar is provided for 4 hours a day. Such values in the regulation of reactive power are comparable to the generation of a battery of static capacitors (STCs) and the consumption of a bypass reactor (BR), or with the control range of a modern thermal power plant up to 150 MW.

However, it is not beneficial for the owner to participate in regulating the SPP voltage, because when the generating equipment is loaded with reactive power, it is unloaded at active power, for which the owner receives payment.

The owner of the SPP deliberately reduces the  $\cos \varphi$  value to one in order to maximize the generation of active power equal to the full capacity of the station.

$$S_{SPP} = P_{SPP} \cdot \cos \varphi, \tag{1}$$

where,  $S_{SPP}$  is the total power generated by the SPP;

$P_{SPP}$  is the total active capacity generated by the SPP.

In this case, the station is not involved in voltage regulation. However, as mentioned earlier, voltage regulation plays an important role in maintaining power system stability.

For example, let's consider the impact of regulating the reactive power of the SPP in the summer season in an excess energy district (Figure 3). In this example, the generation of an excess energy district consists of SPP and thermal power plants (TPP), and the section connecting the energy district to the unified energy system (UES) is complete.

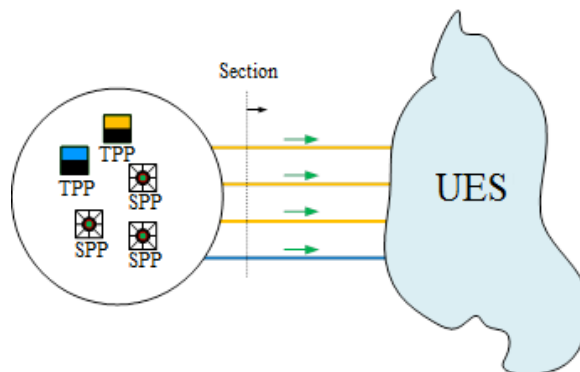


Fig. 3. The simplest scheme of the redundant area within the UES

In such a situation, it is quite possible that dynamic stability may be disrupted by a regulatory disturbance in a normal or repair scheme. As a result, it is necessary to regulate the flow in the cross-section by limiting thermal power plant generation to prevent the consequences of a severe short circuit (Kucherov et al., 2015; Sitnikov et al., 2021; Sitnikov et al., 2024).

However, by using the full range of SPP for reactive power regulation, it is possible to dampen disturbances in the power system (Balog et al., 2016). For a detailed consideration of the SPP control operation, let us turn to the angular characteristic of the transmitted power shown in Figure 4 and determined by formula (2).

Here (Figure 4), I is the characteristic of the limit of transmitted power in pre-emergency mode, II is during a short circuit, III is after disconnecting the damaged network element,  $\delta_{sc}$  is the angle at which a short circuit occurred (equilibrium point),  $\delta_{discon}$  is the angle at which the network element was disconnected,  $\delta_{kp}$  is the angle at which the communication stability is disrupted,  $f_{ac}$  is the acceleration site,  $f_{br}$  is the braking site,  $P_{br}$  is the active power generated at the power plants of the energy district.

$$P_c = \frac{U_1 \cdot U_2}{Z_c} \cdot \sin \delta, \tag{2}$$

where:  $P_c$  is the active power transmitted across the section (Figure 3);

$U_1, U_2$  are the voltages at the ends of the section;

$Z_c$  is the total resistance of the lines included in the section;

$\delta$  is the angle between the voltage vectors at the ends of the section.

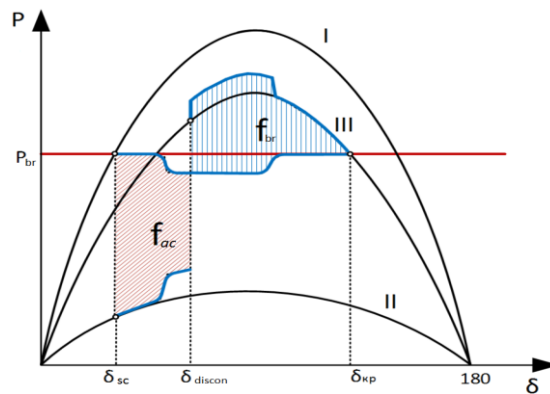


Fig. 4. Angular characteristic of the transmitted power while maintaining the remote control

As can be seen from Figure 4, in the event of a severe short circuit close to the cross-section, as well as with the mode of operation of the energy distribution area, the instantaneous reaction of the SPP regulators will reduce the acceleration area and increase the braking area due to unloading at active power and additional loading at reactive power. Such an SPP operation will reduce excess power in the energy district, thereby preventing the rotors of TPP generators from accelerating during short-circuit current, and will, in addition, increase the limit of transmitted power in pre-emergency and post-emergency modes by increasing network voltage.

### Features of power system management during shutdowns and equipment repairs

In the context of the intensive development of the country's economy, which requires a qualitatively new approach to the creation of intelligent electric power systems, the question arises of improving and modernizing existing energy systems and complexes (Knapčiková et al., 2017). Currently, with the growth of digitalization, there is a growing demand to increase the automation and efficiency of existing devices and complexes through the development of active, adaptive systems and the introduction of new logical connections and algorithms (Yasko et al., 2017).

The development of global energy towards alternative energy sources, due to their unstable operation mode, requires additional solutions to increase the capacity of electric networks. This goal can be achieved by modernizing and building an electric grid and generating complex systems, as well as by building devices and systems for emergency response and automation (Sitnikov et al., 2021; Shaitor et al., 2023).

With the growing share of renewable energy generation complexes owned by energy companies, there are currently several problems associated with the possible emergence of new emergency electric power systems. Most of the tasks to prevent such modes are designed to be handled by local emergency automation systems, which are simple and reliable devices that follow their purpose and design principles (Voropai, 2020).

However, the existing automation is unable to fully and correctly assess the circuit-mode situation in the power system (Majko et al., 2022; Sága et al., 2011). Difficulties in choosing the right algorithm for configuring an automation facility arise from the inconsistent generation of renewable energy facilities, changes in the electrical network topology due to emergency shutdowns and equipment repairs, and uneven load schedules. Due to these factors, the EA requires a large number of embedded algorithms, which complicates its construction and operational maintenance and increases the risk of incorrect operation. It is considered that the EA device did not function correctly if the implemented control actions (CA) did not result in unloading the protected network element. Often, such impacts lead to an aggravation of the regime and the development of an accident (Order of the Ministry of Energy, Rules, 2018).

The voiced problem is clearly expressed in the existing automation devices for limiting equipment overload (ADLEO). As you know, the ADLEO, being an object-based one, cannot solve complex problems that require an analysis of the electrical network mode. Often, such devices implement several algorithms for working with a large number of sets of CA, which are selected promptly when changing the network layout and the composition of the generating equipment (STO 59012820.29.020.002). Such an implementation of automation requires dispatching personnel who manage the elimination of an accident to continuously analyze the existing network scheme and the speed of decision-making.

Figure 5 shows a diagram of a substation (SS A), with the autotransformer (AT-1 330/110 kV) protected by an ADLEO. This automation is a simple and reliable device, given its purpose and construction principle (Kopas, P. et al., 2017). The automation terminal receives measurements of the electric current through the protected network element, the voltage, and the outdoor temperature from sensors installed on an open switchgear. Using the received data, the automation device calculates the direction of power flow through the protected element of the network. When the current setpoint is exceeded, taking into account the power direction and the set shutter speed is reached, the ADLEO issues control actions aimed at unloading the network element (AT-1 330/110 kV). Such CA can be: prolonged unloading of the turbine (PUT) of a steam turbine or gas turbine unit of a power plant, shutting off the generator (exhaust) at a thermal power plant or hydroelectric power station, automatic loading of generators (ALG), disconnecting the load (DL), changing the network topology (CNT), changing the operating mode and operational condition of the controlled elements of the electrical network, disconnecting the protected network element (STO 59012820.29.020.004).

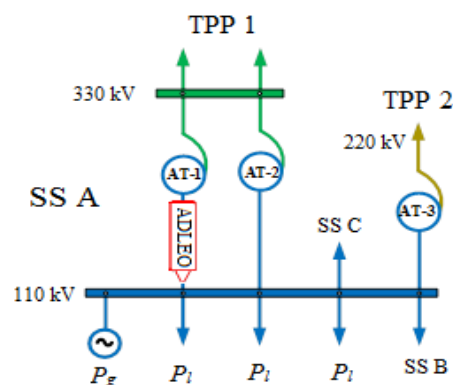


Fig. 5. Substation diagram with ADLEO device

An ADLEO kit with the same direction of active power flow and the same current and time settings must implement different CA in different repair circuits of the same network, with different emergency shutdowns. However, modern ADLEO does not solve this problem.

For the correct selection of control actions, it is necessary that automation assess the mode of the adjacent network and the circuit modification using other parameters of the electric power regime to select CA, in addition to the amount of electric current and the direction of active power flow. Under the operating mode of the adjacent network, this paper considers the operational conditions of the equipment of power transmission lines, power stations, and substations that affect the electrical current loading of the network element in question (AT-1 330/110 kV SS A autotransformer).

A solution to the problem is required that makes it possible to unambiguously determine the cause of the overload of the protected network element using measurements of the parameters of the electric power regime from the installation site of the emergency automation device.

Using simplification, substitution, and equivalence, we will bring the scheme (Figure 5) to the required form (Figure 6). Figure 6 below shows the resistances of the connections of TPP 1 and SS A with the power system ( $Z_b$ ,  $Z_c$ ), as well as the connection between the objects ( $Z_a$ ), which is a protected network element. Also, an important element of the circuit is the consumption of the active load power of the SS A node ( $Z_d$ ).

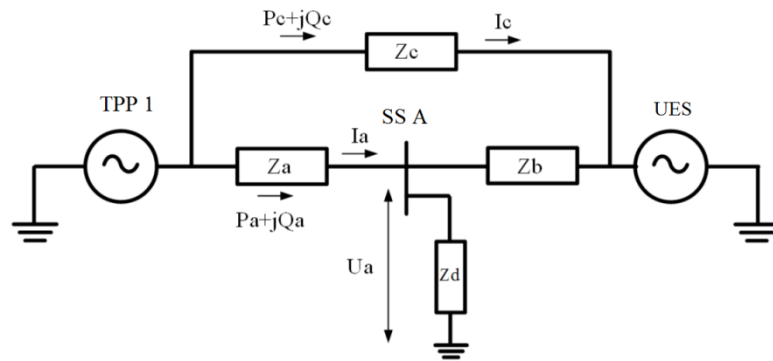


Fig. 6. Simplified network replacement scheme

Now let's define the inherently extreme modes: the first is when there is a dead-end load behind the SS A tires ( $Z_b = \infty$ ), and the second is when the thermal power plant outputs its power only to the SS A tires ( $Z_c = \infty$ ). The marked schemes are shown below (Figures 7 and 8). In Figure 7,  $Z_e$  is the equivalent resistance of a 110 kV deficit network behind the protected network element.

The remaining possible modes will be characterized by multiple sets of circuits with different resistance ratios  $Z_b$  and  $Z_c$ . Also, an important factor affecting the loading of the protected element will be the ratio of the value of the generated active power of TPP 1 and the consumed power of the SS A node ( $P_{load}$ ).

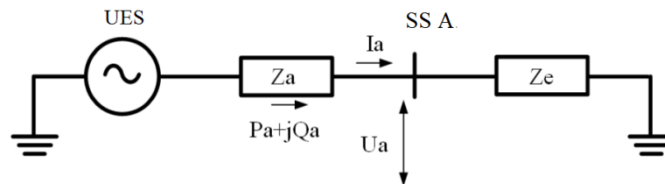


Fig. 7. Network replacement scheme with  $Z_a = \infty$

Using the values of the parameters of the electric power regime obtained by measuring at the substation (the flow of active and reactive power, the amount of electric current and voltage), it is possible to calculate the equivalent network resistance behind the substation buses (for Figure 7 -  $Z_e$ , for Figure 8, the equivalent of the resistances  $Z_b$  and  $Z_d$ ). The amount of resistance, along with its active and reactive components, will characterize the network mode in different circuit configurations.

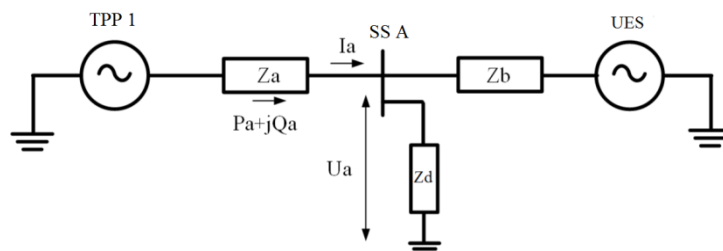


Fig. 8. Network replacement scheme at  $Z_c = \infty$

Total resistance behind the protected network element:

$$Z = \frac{U_a}{\sqrt{3} \times I_a}, \text{ Ohm} \quad (3)$$

Active resistance behind the protected network element:

$$R = \frac{Z \times P_a}{\sqrt{P_a^2 + Q_a^2}}, \text{ Ohm} \quad (4)$$

Inductive resistance behind the protected network element:

$$X = \frac{Z \times Q_a}{\sqrt{P_a^2 + Q_a^2}}, \text{ Ohm} \quad (5)$$

The method described above for calculating network resistance must be used to configure the resistance control on the automation device to limit equipment overload. To do this, it is necessary to include an additional resistance element with specified zones in the device's logic.

To adjust the resistance organ, the modes were calculated using a mathematical model of the Crimean power system in the RastrWin3 software package. Figure 9 shows a diagram for calculating the resistance of the ADLEO protecting the autotransformer (AT) on the SS A. To determine the resistance (X, R) applied to the AT on the SS A, the calculated parameters for the mode on the 110 kV side were used: voltage (U), phase on the substation buses, and electric current (I) through the AT.

Three characteristic network schemes have been selected to determine the effectiveness of control actions:

- excess capacity of energy district 1 in the absence of bypass connections; lines № 1 and № 2 are disconnected;
- dead-end load with interruption of transit on lines between energy district 2 and energy district 3; lines № 3, № 4, and № 5 are disconnected;
- a mixed mode with an excess of power in energy district 1, combined with a decrease in the number of bypass connections in the network and a deficit in energy district 2 (a variety of circuit conditions under which it is impossible to clearly identify the cause of AT overload).

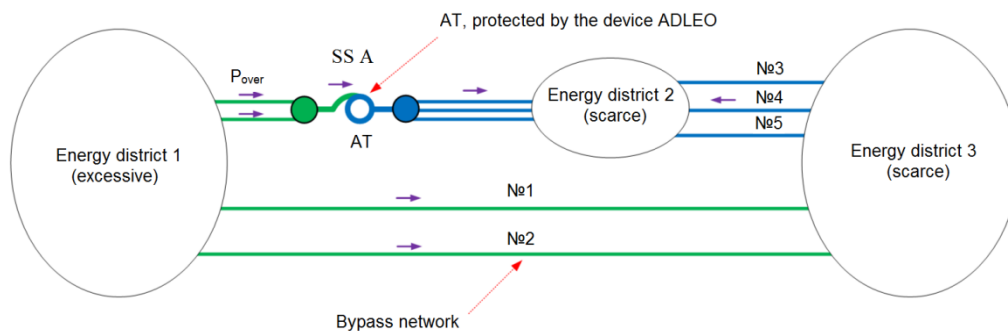


Fig. 9. Network diagram for calculating modes associated with AT overload

The calculation results are shown in Table 1. Depending on the circuit conditions, three groups of modes can be distinguished:

- with green markers – maximum efficiency of AT unloading is achieved by switching off the load in energy district 2;
- with blue markers, the highest efficiency of AT unloading is achieved by turning off generation in energy district 1;
- with orange markers, the highest efficiency of AT unloading is achieved by implementing balanced control actions: turning off the load in energy district 2 and turning off generation in energy district 1.

Tab 1. Results of the calculation of the resistance behind the protected network element

№	Circuit description / excess power of energy district 1 / consumption of energy district 2	U		P [MW]	Q [Mvar]	I [A]	Z [Ohm]	R [Ohm]	X [Ohm]
		Module [kV]	Phase [el.degree]						
1	Lines № 1, № 2 / 220 MW / 1400 MW are disconnected	111,1	-38,61	210,7	24,8	1102	58,22	57,82	6,81
2	Lines № 1, № 2 / 220 MW / 1600 MW are disconnected	108,4	-58,57	209,9	49,3	1148	54,5	53,06	12,46
3	Lines № 1, № 2 / 220 MW / 1600 MW are disconnected	106,6	-20,78	429,5	22,8	2327	26,44	26,4	1,4
4	Lines are disconnected №3, №4, №5 / 450 MW / 1100 MW	111,84	2,66	239,6	52,7	1268	50,92	49,73	10,94
5	Lines are disconnected №3, №4, №5 / 450 MW / 1600 MW	105,2	-43,06	352,8	87	1998	30,4	29,51	7,28
6	Lines № 1, № 3 / 220 MW / 1600 MW are disconnected	102,4	-72,75	249,7	104,8	1533	38,55	35,55	14,92
7	Lines № 1, № 3 / 380 MW / 700 MW are disconnected	116,8	45,42	225,6	-17,6	1117	60,37	60,18	-4,7
8	Lines № 1, № 3 / 450 MW / 1600 MW are disconnected	107,2	-37,22	332,9	61,1	1824	33,93	33,37	6,12

To analyze all the data obtained, we combine the resistance characteristics of all calculated modes on one plane (Figure 10).

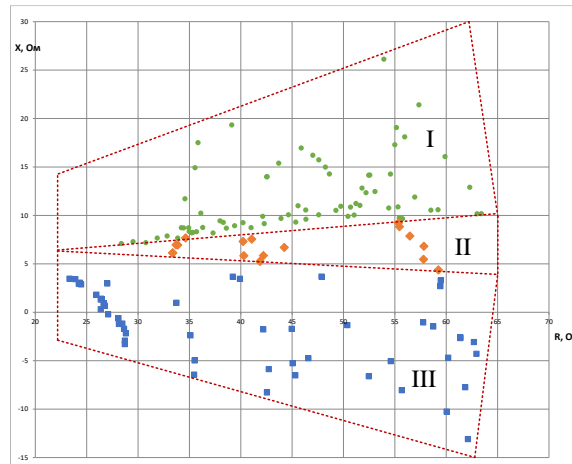


Fig. 10. Resistance characteristics for various mode parameters

The final characteristic is divided into resistance areas:

- the first area of resistance is the modes in which it is effective to turn off the load in energy district 2 in order to unload the protected network element (AT SS A);
- the second area of resistance is the modes in which balanced control actions are effective for unloading the protected network element (switching off the load in energy district 2 and switching off the generation in energy district 1);
- the third area of resistance is the modes in which, in order to unload the protected network element, it is effective to turn off generation in energy district 1.

The obtained characteristic is used to adjust the resistance control during automated limiting of AT equipment overload to SS A. Such an organ should include three resistance zones, each of which, when actuated, determines the set of necessary control actions.

When implementing CA and unloading the protected network element, it is possible to change the mode parameters (voltage and current loading AT) and, as a result, shift the equivalent resistance, for example, from the balanced CA (II) zone to the load disconnection (III) zone. In this case, automation in the process of eliminating current overload AT will correct and issue new CA having greater efficiency, taking into account previously implemented CA. This principle of operation enables the automation device to adapt to various circuit conditions during accident elimination (Sitnikov et al., 2022; Yasko et al., 2017).

## Results and Discussions

An analytical review of the trends in the development of renewable energy sources and their integration into the structure of the energy system revealed problems associated with the growing share of renewable energy generation in the grid structure. Statistics on maximum unbalances of active power, in particular in the Crimea, provide opportunities to calculate the discharge rate and power set characteristics of solar power plants in the regional energy system for typical seasons of the year. Based on these characteristics, it is possible to determine the reliable magnitude of irregular oscillations and take them into account when setting the alarm thresholds for the dynamics over the 20-second interval. This opens the possibility of estimating the volumes and characteristics of reserves for normalized primary frequency control, as well as for automatic secondary frequency control and active power overflows, by comparing them with the dynamics of renewable energy sources over intervals of 1, 5, and 10 minutes. In addition, conditions are being created to assess the volume and characteristics of tertiary capacity reserves by comparing them with the characteristics of the rate and volume of RES load relief for intervals of 20 and 60 minutes.

The analysis of the operation of emergency automation in regional power systems revealed the problems of the automation devices of the networks. As a result of a number of unaccounted-for factors, they do not perform their functions due to incorrect activation settings. Difficulties in choosing the right algorithm for configuring automation facilities arise not only from the variability in the generation of renewable energy facilities but also from changes in electrical network topology during emergency shutdowns and scheduled equipment repairs, as well as from uneven load schedules.

A solution to the voiced problem is proposed, which consists of equipping automation to prevent equipment overload with an additional resistance organ. To identify the nature of the overload on the protected network element and to formulate effective control actions, the unloading of the network element is linked to the resistance

applied at the installation point of the automation device. This approach makes it possible to achieve adaptability of the automation device while maintaining the simplicity of its design.

### Conclusion

Currently, there is no general approach to modeling and accounting for renewable energy regulation systems in computational models. Therefore, the accounting for the modes of operation of renewable energy sources in ensuring power system reserves is not sufficiently accurate and requires more precise execution. Further development of an automated system for accurate forecasting of renewable energy capacity imbalances in combination with stability reserve monitoring systems and a centralized emergency automation system will create additional technical capabilities to increase the share of renewable energy in the energy system.

The use of an additional resistance element in the automation device to prevent equipment overload enables the determination of the nature of the overload, whether excess power or a deficiency in the load node. Based on the overload causes, the device provides effective control actions under current circuit conditions to turn off loads or generation sources. The adjustment of the implemented control actions in the process of overload elimination makes it possible to reduce their redundancy by sequentially triggering different zones on the resistance characteristic. Thus, the automation device for preventing equipment overload has received new functions that increase its efficiency and ensure the sustainability of energy supply to mining regions.

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