# Mapping of Sakhalin Power Grid Vulnerability Based on Network Analysis

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**Abstract.** The vulnerability assessment methodology proposed for substations focuses on enhancing the conventional SVI index by incorporating a synthesized indicator to evaluate predisposition to high vulnerability in power transmission lines. This indicator amalgamates criteria such as operational time, transmission capacity, and line length, assigning weights based on their relative importance. Utilizing the Analytic Hierarchy Process (AHP), weight coefficients for each criterion are calculated to derive the overall vulnerability of power system elements. The assessment involves calculating SVI indicators for substations based on weighted shortest distances from energy sources, considering alternative energy supply routes. Additionally, the methodology evaluates the load on power lines using centrality measures, reflecting the lines' importance in transmitting electrical energy. Through simulation, cascading failures are modeled, highlighting critical points of failure and their impact on the power system. The results demonstrate the vulnerability of substations and power lines, particularly in coastal and central regions, emphasizing the need for network expansion and backup power supply routes to enhance system resilience. Zoning analysis identifies regions at risk of power outages, underscoring the importance of strategic planning and infrastructure development for ensuring reliable energy supply in the Sakhalin region. #CSOC1120.

**Keywords:** Vulnerability Assessment · Power System · Cascading Failures · Network Resilience · Energy Infrastructure · GIS

## 1 Introduction

In the majority of studies within the realm of transport geography, nomothetic models predicated on graph theory are employed to delineate the architecture of transportation networks [1]. Concomitant methodologies are adopted in research focused on the analysis and assessment of energy system vulnerability. Electrical power infrastructures are conceptualized as graphs, which include vertices connected by edges. Herein, the edges represent electric power lines, whereas vertices correspond to generation stations and substations [2]. The intrinsic structural vulnerability of the electric grid is quantified by the ratio of operational stations and substations to their respective counts following contingencies.


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Various strategies exist to evaluate the power system vulnerability. Not only does this attribute take into account the topology, but it also integrates additional parameters pertinent to the system's operation and external negative influences. A salient methodology for appraising the structural vulnerability of the electric grid is the selective elimination of network vertices [3], simulating assaults on power system nodes (substations), premised on the notion that spontaneous node failures are more probable. The approach encompasses determining the centrality metric of a graph predicated on shortest paths. Subsequent to each stochastic vertex exclusion, computations are performed anew to ascertain the shortest paths linking all substations to the nearest power plants, in addition counting such paths per substation. An overloading simulation for a substation is triggered if the resultant burden surpasses the original by a factor of two. System robustness within the study is gauged by the proportion of remaining vertices relative to the initial quantity. A shortcoming of these algorithms is their omission of variable transmission line capacities and diverse generation capacities of power plants.

The aforementioned vulnerability assessment method concentrates on unanticipated disruptions and on the topological configuration of energy nets but does not accommodate ancillary operating parameters, including, for instance, the inclusion or exclusion of local supplemental energy-generating facilities. In cases where the power architecture integrates auxiliary low-capacity generation plants, such as Distributed Energy Systems (DES), decentralized production at the distribution tier can supplant a portion of the centralized output at the transmission tier. This transition mitigates the electrical transmission distance, thereby amplifying the network's overall performance and resilience. Zhang and Chen [4] delineates two modes to appraise the vulnerability of electric grids incorporating analogous local energy sources, utilizing simulated cascade attacks. In the initial scenario, the resilience assessment draws on a comprehensive vulnerability metric – the efficiency index, which assesses the efficacy of electrical conveyance via each network line [5].

The Global Efficiency Index (GEI) serves as an indicator of network performance, premised on the postulate that the efficiency of electric power transmission between two nodes is inversely proportional to the spatial separation between them. This index encapsulates aggregated capacity of the electrical grid [6]. The energy system's susceptibility is evaluated based on this index; specifically, the magnitude of decrement in the global efficiency metric following a cascade failure provides a measure of vulnerability. Nevertheless, when considering the incorporation of local power generation nodes, the GEI may not suffice as a reliable metric for assessing the power system's stability. Consequently, in the second model of cascade failures, a reformed measure, termed the Modified Global Vulnerability Index, was utilized for vulnerability assessment [7]. This index accounts for the influence of individual node's generation capacity on the overall efficiency of the system.

Despite its limitations, the GEI has been extensively applied in the analysis of energy system vulnerability. The primary drawback of this efficiency measure is the underlying assumption that electrical transmission occurs exclusively along the shortest path, a scenario which often diverges from the actual network configuration where energy disperses through various conductive routes during transit from the generator to the consumer. Additionally, the power output of generators is not factored in. The Structural

Vulnerability Index (SVI) [8] builds upon the efficiency index but incorporates both the generator node's power and the maximal permissible load on the remaining nodes. Moreover, unlike earlier approaches, this formulation considers the actual impedance instead of the shortest path distance between nodes $i$ and $j$:

$$SVI = \frac{1}{n_g n_l} \sum_{i \in V_g j \in V_l} \frac{P_{gj}}{P_{li} \exp(Z_{ijeq})}, \quad (1)$$

here $P_{gj}$ denotes the allowable generation at the source node $j$, $P_{li}$ is the peak load at node $i$ and $Z_{ijeq}$ signifies the equivalent resistance (electrical distance) between nodes $i$ and $j$. Accordingly, this index captures not only the topological framework of the networks but also additional parameters pertinent to their structure and functionality, as previously discussed.

Analysis of the power system's robustness may also involve identifying its most fragile components, such as during simulations of transitory outages affecting certain generators or transmission lines. To appraise the criticality of such spontaneous failures the Continuity Vulnerability Index (CVI) could be used [8], which builds upon the aforementioned SVI. Given that a failure of one or more units results in an extended electrical transfer distance between nodes, SVI values diminish; the extent of this reduction is captured by the CVI.

Comparable method revolves around identifying the weakest links within the grid and is predicated on computing the variation in efficiency indices before and after network element severance [6]. The distinction with this approach is its consideration of severing all connections to the impacted node, rather than focusing solely on the node itself.

A narrowly tailored approach for pinpointing the least stable segments within a power grid involves the scrutiny of vulnerable transmission lines [9], which strives to formulate a comprehensive Line Vulnerability Index (LVI). The determination of the most critical transmission lines is contingent upon an examination of the network's complexity, as well as employing a risk index predicated on probabilistic power flow analyses to gauge the propensity for overloading each individual line. By leveraging the calculated composite index, a model of cascade failure within the electrical network is constructed that incorporates the magnitude of the energy flow to preclude overloads on specific lines.

Through an investigation of aggregated details regarding the physical, geographical, and climatic variables in the Sakhalin region, a hypothesis was posited that the power grids in this locale exhibit an intrinsic susceptibility to cascading failures, instigated by natural disasters such as ice storms and strong winds. It is paramount to note that the energy system is not only externally segregated, lacking access to reserve power from adjacent territories, but is also comprised of multiple disjointed energy nodes. Consequently, such an energy framework necessitates specialized scrutiny and stability analysis to forestall potential catastrophic repercussions.

## 2 Materials and Methods

The vulnerability assessment methodology for substations we are developing is based on the aforementioned SVI index, modifying the measure of distance between objects. Instead of using just the electrical resistance of the shortest path between the energy source and the substation or a single specific parameter, we propose to use a synthesized indicator of predisposition to high vulnerability for each line. This indicator is comprehensive and formed from three criteria of power line vulnerability: the degree of wear (operational time at the time of the study), transmission capacity in terms of the maximum allowable current, and the line length. The proposed synthesized indicator essentially acts as the weight of each line in graph theory and is used for further analysis of the vulnerability of power system elements. To calculate the resulting weight of the lines, the vulnerability criteria were ranked according to their presumed importance: the degree of wear has the greatest weight in the evaluation, while the line length has the least. A "1–2–3" ranking scale was chosen, where "1" signifies an equal importance of the compared criteria, which have the same significance for a higher-level element. "3" indicates a moderate superiority of one criterion over another, with preliminary evaluation suggesting slightly greater importance of one criterion compared to the other. The value "2" indicates an intermediate degree of one criterion's superiority over another. Let us state that the criterion for line age is three times more important than the criterion for line length, and the criterion for transmission capacity is twice as important as the length. Please note that in reverse situations, the line length criterion is 1/3 times more important than the line age criterion and 1/2 times more important than the transmission capacity. Then, using the Analytic Hierarchy Process (AHP), a weight coefficient for each criterion was calculated. This requires pairwise determining the degrees of superiority between criteria. The sums of the obtained values in each column are then calculated, followed by the normalized values of the criteria's degrees of superiority. The obtained values are averaged row by row and are the weight coefficients. All calculations and obtained coefficient values for vulnerability criteria are presented in Table 1.

**Table 1.** Calculation of weight coefficients for criteria of vulnerability of power transmission lines using AHP.

| | Length | Capacity | Age | Weight coefficient |
|---|---|---|---|---|
| Length | 1 | 0.5 | 0.333333 | 0.247691 |
| Capacity | 2 | 1 | 0.333333 | 0.479509 |
| Age | 3 | 3 | 1 | 0.893074 |
| Sum | 6 | 4.5 | 1.666667 | |
| **Normalized coefficients** | | | | |
| | Length/sum | Capacity/sum | Age/sum | |
| | 0.545455 | 0.15 | 0.047619 | |
| | 1.090909 | 0.3 | 0.047619 | |
| | 1.636364 | 0.9 | 0.142857 | |

The resulting weight for each line is calculated as the sum of the appropriately weighted parameters of wear, transmission capacity, and length. Thus, the greater the resulting cost value, the more important and, consequently, vulnerable the line is. The longer the service life of the wire or cable, and the longer the length of the line, the less stable it is. The greater the transmission capacity, the greater the damage that can be caused by the failure of the line itself or the associated nodes.

The vulnerability assessment of electrical substations in the network based on the modified SVI index consists of calculating the SVI indicator for each node using the formula:

$$SVI_{P_{li}} = \frac{P_{gj}}{P_{li}(Z_{ij})}, \tag{2}$$

where $P_{li}$ is the nominal power of substation $i$, $P_{gj}$ is the nominal power of the power source $j$, and $Z_{ij}$ is the shortest distance between the source and the substation, calculated based on the resulting weight of each line obtained above.

Since the same substation may not only be accessible from a single power station, i.e., in the event of a failure in the power flow path from one source to a node, there is an alternative possibility of energy supply from another source through other nodes, it is necessary to calculate for each substation the weighted shortest distance from all possible sources and sum the obtained values.

The numerical characteristics of substations obtained after calculation are interpreted as follows: the higher the value of the SVI index, the more stable it is and vice versa, i.e., a substation's vulnerability is inversely proportional to the sum of weighted distances between the substation and accessible energy sources.

In addition to calculating the vulnerability of substations, it is also necessary to determine the load on the power transmission lines, as the degree of their loading affects the resilience and consequences of failures at adjacent nodes of substations and power plants. The load on power lines is determined by the centrality measure of the graph based on the calculation of the shortest paths between power stations and substations (betweenness centrality), i.e., the number of shortest paths between the sources and consumers of energy passing through a given line is calculated for each line.

The calculated centrality measure is interpreted as follows: the higher the value, the greater the number of shortest paths that pass through the line, and therefore the more loaded it is. The higher the load on the line, the more important it is, as it is the most frequently used element in the path of transmitting electrical energy from sources to consumers. In the event of failures on the most loaded lines or adjacent nodes, the areas supplied with electricity are at risk of losing power.

In the event of failure of substations or power lines, it is necessary to assess the possibilities of redistributing transmitted electrical energy to other power lines to avoid blackouts. For this, it is necessary to simulate cascading failures in the Sakhalin region's power system.

Accident modeling is carried out according to the following scheme:

1. the most loaded power line is removed, i.e., the one with the highest centrality value;
2. for the remaining lines, the centrality measure is recalculated;
3. the SVI index for substations is recalculated (since the calculation of the shortest paths is only made for substations that are accessible from power sources, a de-energized substation will not have any values if adjacent lines that turned out to be the most loaded are removed);

4. if the recalculated centrality values are twice or more the original values on the lines, an accident is simulated on these lines;
5. if the centrality values have not changed or have decreased, the removal of lines with the highest initial centrality values continues;
6. the algorithm is repeated until the power system disintegrates into separate de-energized areas.

## 3 Results and Discussion

### 3.1 Implementation of the Vulnerability Assessment Methodology for Power System Elements

The vulnerability modeling of the Sakhalin region's power system is carried out using the NetworkX library of the Python programming language. This library allows working with an imported shapefile as a graph. To implement the algorithm for determining the stability of the nodes of the Sakhalin region's power system, three different graphs were obtained: a graph based on power transmission lines, a graph based on power substations, and a graph based on power plants. To calculate the distance from each source to each accessible substation, it is necessary to organize a loop of traversal through the elements of the power plant graph. Since each substation can be powered not just by one power plant but by several, it is necessary to add the calculated weighted shortest distances from each energy source to the accessible substations to the substation layer as separate attributes. To obtain the resulting SVI vulnerability index, it is necessary to sum up the individual indices calculated depending on the power of the power plant from which the shortest distance was calculated. To assess the load on transmission lines, it is also necessary to use the NetworkX library to calculate centrality metrics for each element.

### 3.2 Vulnerability Assessment of the Sakhalin Region's Power System Elements

The most vulnerable substations, whose SVI index $< 0.002$, are those that are farthest away from energy sources. These are mainly substations located along the coast or in the center of the island. The density of substations across the territory is uneven; it is important to note that in areas with a high concentration of substations, i.e., in places with the highest consumption, the most vulnerable are substations with high power (from 50 to 150 MVA) and correspondingly high voltage (up to 220 kV). Low-power substations (from 5 to 20 MVA) and low voltage (35/10 kV) have higher SVI values in cases where they are the only receivers of electricity in the territory. The most vulnerable substations with a voltage of 220 kV include substations in coastal major cities such as Korsakov, Nevelsk, Kholmsk, Tomari, Makarov, Shakhtersk, Uglegorsk, Smirnykh, and Tymovskoye. Substations of lower voltage but with high SVI values are those of such small settlements as Chekhov, Krasnogorsk, Krasnopole, Vakhrushev, Leonidovo, Lesogorskoye, Boshnyakov, Onor, Alexandrov-Sakhalinsky, Mgachi, and Dagi (Fig. 1).

The listed substations have adjacent power lines with high centrality values (centrality values greater than 60), i.e., those that are integral parts of the transport of electricity. Such lines are the most loaded due to their location—they connect remote parts of the island to the sources, for example, the southern part of the island (Tomari and Kholmsk)

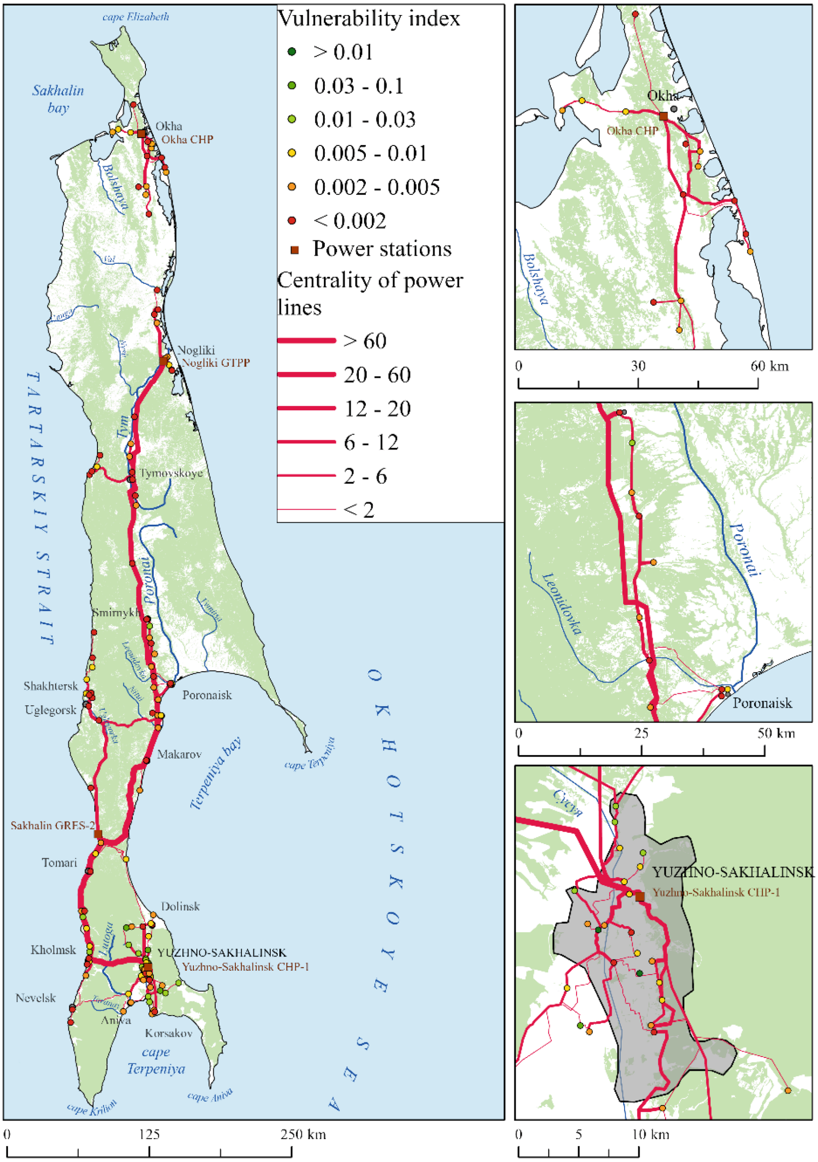


**Fig. 1.** Map of power grid elements vulnerability in Sakhalin

and the central part (Poronaysk, Makarov, Uglegorsk) to the southern energy sources Sakhalinskaya GRES-2 and Yuzhno-Sakhalinskaya TEC-1. Also, the most loaded lines adjacent to vulnerable high-voltage substations are lines connecting the central and northern (Tymovskoye, Nogliki) parts of the island with the northern Noglikskaya GES.

The above-mentioned vulnerable low-voltage substations have adjacent power lines with average or low centrality values, i.e., they have a relatively small load. This is because these substations are at a great distance from energy sources and are often end points, with only one power line extending to them. Thus, a substation is vulnerable due to a high value of weighted shortest distance (greater length of the path), but at the same time, the adjacent power lines are not loaded, since they carry between one to several shortest paths.

The most stable substations, with an SVI index $> 0.01$, are located within Yuzhno-Sakhalinsk and on its outskirts due to a large number of power transmission lines of equal weight (these lines are relatively short and new). Additionally, substations that are close to sources of electric power are also among the most stable. Stable substations have adjacent power lines with the lowest centrality metrics (centrality $< 6$) since there are often multiple paths to transmit energy to stable substations.

Separately, the vulnerability and congestion of the Okha energy district should be considered. This area is not centrally connected to the southern part of the power grid and exists in isolation. The entire Okha energy district has only one power station supplying individual substations. Most of these substations have low SVI index values, making them vulnerable. However, the power lines are not overloaded since, in most cases, they only supply a single substation on the edge of the network.

Thus, the most vulnerable substations are either the most remote ones or those with high power that lie on the route of power supply to remote areas. The most loaded power lines are those that connect the remote parts of the island and have high capacity since they carry the most optimal routes for power supply.

### 3.3 Modeling a Cascading Failure in the Power System

To fully assess the overall vulnerability of the Sakhalin region's power system and possible consequences, it is necessary to simulate a cascading failure in the system. As mentioned earlier, simulation involves the gradual removal of power transmission lines with high centrality metrics from operation.

The starting point of the cascading failure is the failure of the power line with the dispatch number T-232 (with the highest centrality metric, equal to 88) between the Sakhalin GRES-2 and the Ilinskaya substation. This line is the most loaded as it connects the most powerful source of electric power (455.25 MVA) with one of the elements on the power supply route to consumers.

As a result of the removal of this line, the load on the remaining elements evenly redistributed since there are alternative supply paths from Sakhalin GRES-2, and the overall load on the power system decreased. For the second removal, another one of the backup lines, specifically T-233, was taken out of service. After this iteration, there were no lines with low weights left on the power supply route from Sakhalin GRES-2, resulting in energy flow being redistributed through non-optimal routes, and the load on the adjacent lines to the source increased.

The load on the 220 kV power line with dispatch number D-8 increased the most. This line acts as a backup during the power supply to the Tomari district, as a result, when the main power flows are disconnected, the shortest paths to the substations are transferred to this line. After the removal of this line, the southern part of Sakhalin almost loses the possibility of power supply from Sakhalin GRES-2, as the only method of transferring electric power from this station remains the D-5 line, which is very long.

As a result, the main share of power supply falls on the Yuzhno-Sakhalinsk Central Heating Plant (CHP-1). Lines D-9 and D-12 are the main power supply routes for the western part of the island from the CHP, therefore, they are the most loaded. After their removal, the power flow is evenly redistributed to the backup 110 kV lines. Due to the removal of the lines through which the largest number of optimal routes pass, the overall load on the power system decreases, as it is evenly redistributed through the backup lines, thereby reducing the risk of the main power lines' failure. Subsequent failures are simulated on the main power supply routes from Yuzhno-Sakhalinsk CHP-1 with the highest centrality values, which are the 110 kV lines S-21, S-20, S-5, and S-14 with S-13. As these paths are removed, the transmitted electric power is redistributed to parallel lower voltage 35 kV lines, as a result of which the load on them increases insignificantly and failures are then simulated on these lines. As a result of the simulation, it is found that part of the power system in the southern part of the island disintegrates into separate de-energized districts, which can no longer receive energy from either Sakhalin GRES-2 or Yuzhno-Sakhalinsk CHP-1.

Meanwhile, the mentioned energy sources continue to supply the central and accessible northern parts of the island, however, power is only provided by the most extended and loaded 220 kV lines with dispatch numbers D-5, D-3, and D-6, which lack a backup power transmission capability.

Thus, with the removal of the main flows, the central and northern parts of the island lose power supply from the most powerful power stations. However, the northern Nogliki GTES continues to function and transmit energy. In this part of the island, the most loaded are the high-voltage lines D-13 and D-2 and the medium-voltage line S-55. If D-13 is removed, central Sakhalin completely loses power supply, as this line has no backup neighbors. If S-55 is removed, a large part of the northern settlements are de-energized.

It is also important to note that the S-53 and S-54 lines, which are the only connecting links between Nogliki GTES and consumers, are highly loaded. In case of failure on these lines, Nogliki GTES loses the rationale for power generation.

A separate part of the entire power system of the Sakhalin region is the northernmost part of the island, which has no possibility of power supply other than from the Okha CHP. Most of the settlements in this district are supplied directly from the CHP along a single power transmission line with multiple branches, and in rare cases, the power flow reaches consumers via two adjacent power lines. With such a network configuration, it is clear that if any power line fails, the consumer settlements are de-energized. When simulating a cascading failure, the power system disintegrated into separate de-energized districts upon the second removal of lines with high centrality metrics (Fig. 2).

Special attention needs to be paid to the changes in the vulnerability index SVI at the substations of the power system. As the load on the power lines adjacent to the substation nodes increased/decreased, the vulnerability index changed accordingly: it decreased, i.e., vulnerability increased due to the growth of the weighted shortest distance, and it increased, i.e., the stability of the node improved. As power lines were removed, the overall trend of substation vulnerability was characterized as increasing until the substations became unreachable and, accordingly, lost the ability to receive power supply.

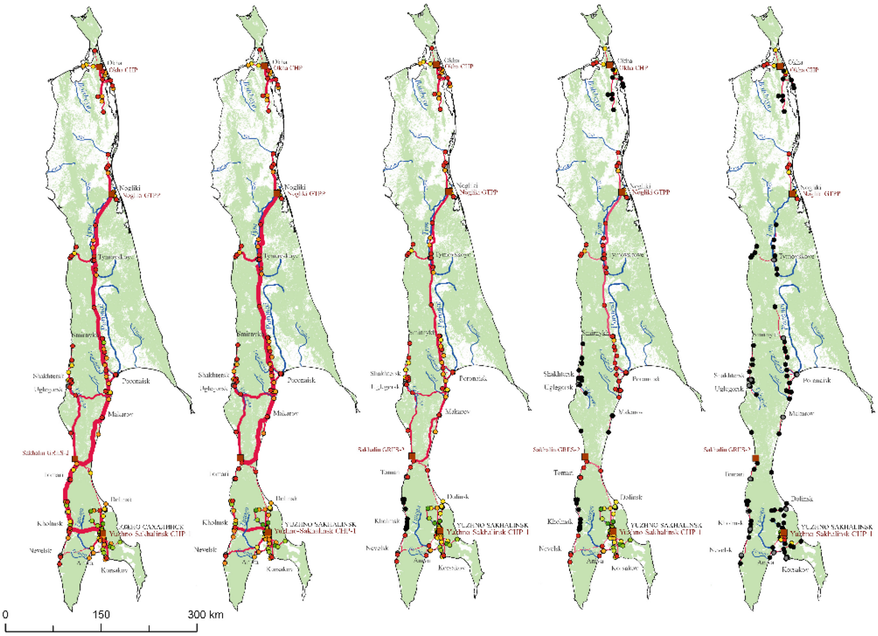

**Fig. 2.** Stages of cascading failure in Sakhalin power system.

### 3.4 Assessment of the Consequences of a Cascading Failure in the Power System for Populated Territories

As a result of the gradual failure of power transmission lines, the power system of the Sakhalin Region ceases to be intact and disintegrates into 11 parts, of which only two districts –Ногликsky and Yuzhno-Sakhalinsk – do not lose power supply. The probability of a blackout in these parts of the power system is extremely low because most of the substations are not vulnerable, and the load on the power lines is not high. The remaining districts and their substations are de-energized because the main routes of electricity transmission from the sources to the most powerful substations in the area are out of order, and the power lines within the districts were not removed during the simulation due to their low load.

### 3.5 Zoning of the Sakhalin Region According to the Degree of Power Supply Reliability

Based on the analysis of the obtained indicators of vulnerability and load on the elements of the power system, as well as based on the simulation of cascading failures, zoning of the populated part of Sakhalin was carried out according to the degree of vulnerability of the adjacent territories (see Fig. 3). The starting point for zoning is all populated localities of the Sakhalin Region obtained from the OSM. A Voronoi diagram was constructed based on these points: such surface division allows for determining the closest territories to each point in the context of their irregular spatial distribution.

After constructing the Voronoi diagram based on the points of populated localities, it is necessary to determine the stability of each cell of the obtained surface depending on the degree of vulnerability of the substation closest to the populated locality. The identification of the closest substations to the points was carried out taking into account the administrative-territorial division of the region. The degree of stability was determined by the average value of the SVI vulnerability index for all stages of the failures. Since a large part of the Sakhalin territory is not populated and occupied by small villages without electricity, and therefore does not require an assessment of the reliability of power supply, the obtained Voronoi polygons need to be edited, preserving the assessment of stability only in the populated areas.

It is also important to note that the most remote territories of the island, occupied by one or two small settlements, have their own local power supply like diesel power plants. Such regions do not make sense to assess the stability of power supply due to their dependence on a single source. A similar situation is typical for the islands of the Kuril chain, for this reason, this territory is also not subject to analysis.

Zoning of the Sakhalin Region by the degree of vulnerability of its elements allows identifying territories that are at risk of a blackout. The least stable territories are the coastal districts of the island and its central part. In the coastal regions, the greatest number of remote substations is concentrated, supplying electricity to no less remote localities. Often, such substations have only one possible way of supplying electricity, i.e., in case of a failure of one of the elements on the path from the source, the population of the district completely loses the possibility of supply. The central parts of Sakhalin are also most vulnerable due to the specific roles of power lines and substations – the former are links between sources and remote consumers, and the latter are transit points on the supply path. If such linking elements fail, the power system of the region disintegrates into several parts.

The most stable regions are those close to energy sources. However, it's interesting to note that, for example, areas around the Nogliki Thermal Power Plant (TPP), which are supplied directly from the source, are several times less stable than similar areas closest to the Yuzhno-Sakhalinsk Thermal Power Plant-1 (TPP-1). This is because the city of Yuzhno-Sakhalinsk and the surrounding areas have a large number of power lines that are a) less worn out, b) serve as backups for each other in terms of electricity transmission.

As a result, the power system in the Sakhalin region is quite vulnerable, with risks of power outages in remote populated areas. This is due to the following reasons:

1. The structure of the network: the network is highly extended from south to north, which necessitates the construction of extended power transmission lines,
2. Insufficient development of the power system at the time of the study: a large number of settlements can only be powered by one route, i.e., there is no backup power supply,
3. The terrain of the territory: most of the island is occupied by mountains, this factor complicates the possible expansion of the network, increasing the number of its components to reduce the load on the lines.

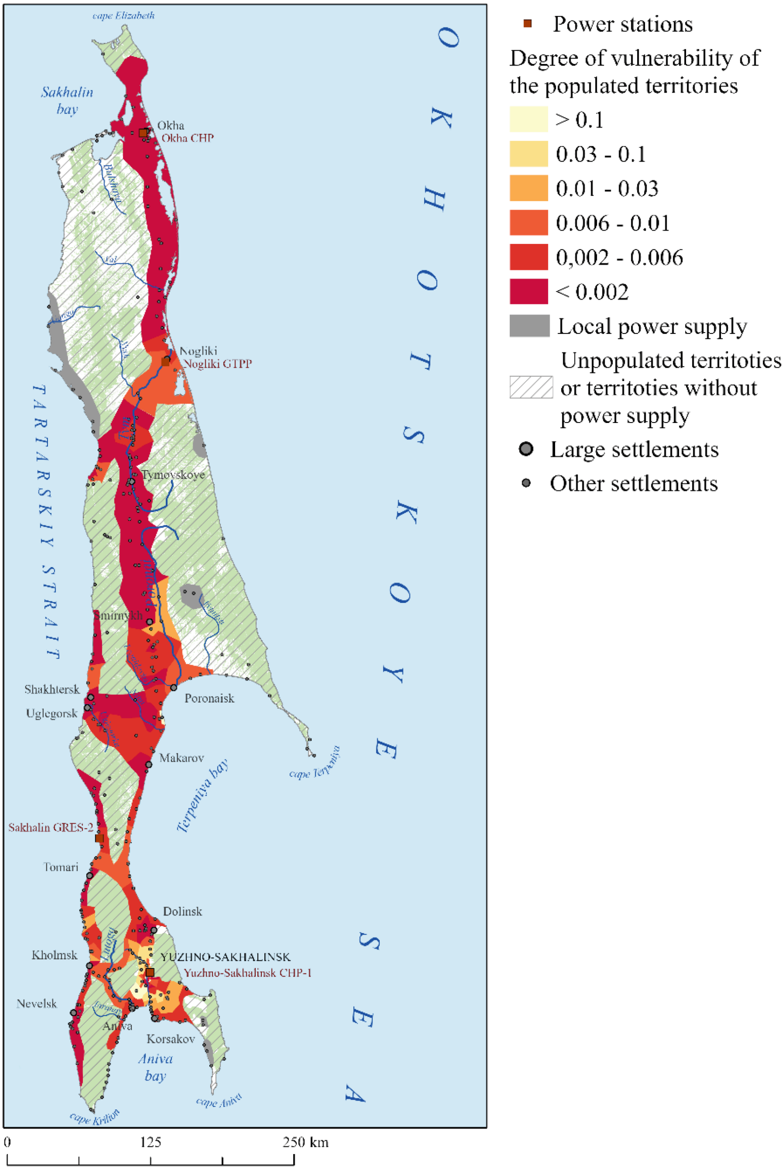


**Fig. 3.** Power supply stability in the Sakhalin Region

## 4 Conclusion

The energy system of the Sakhalin region is isolated and does not have the capability of backup power supply in case of serious accidents; moreover, it consists of separate energy districts. Both the external and internal isolation increase the risks of accidents related to the spatial configuration of the network and, consequently, contribute to the vulnerability of both individual elements and the entire energy system as a whole. This necessitates the analysis of the vulnerability of the region's energy system.

During the study, a current database of the energy system was developed, including all power transmission lines, electrical stations, and substations. Information on criteria affecting vulnerability was entered for each element. For the lines, these criteria are age, capacity, and length. These criteria were synthesized into a general weight indicator that was used in calculating the vulnerability of both the lines and the substations. For substations and power sources, the criteria are the nominal capacities.

As a result, maps of vulnerability assessment of substations and lines, stages of cascading failure, and the regions of Sakhalin that were de-energized as a result of the accident were obtained. The findings were summarized on a map of the regional zoning of Sakhalin's populated territory according to the degree of power supply resilience.

Accordingly, it was revealed that the Sakhalin region's energy system is quite vulnerable. The most vulnerable substations in the region are low-voltage substations in coastal areas, as well as high-voltage substations that act as "transition points" between sources and consumers. The most loaded and, consequently, most vulnerable, are lines adjacent to vulnerable high-voltage substations, because they are also the main elements of optimal power supply paths. Zoning the territory by the degree of resilience shows that much of the island is at risk of losing power supply in the event of accidents. This is due to the insufficient number of backup power supply routes, as well as the extended structure of the network due to the specific physical and geographical conditions.

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