Magazine of Civil Engineering. 2026. 19(1). Article No. 14101

Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

Research article

UDC 004.02

DOI: 10.34910/MCE.141.1

Electric power system functioning in conditions of extreme weather events in the presence of distributed generation based on renewable energy sources

A.O. Feshin[1], ***M.A. Polyukhovich***[1], ***Yu.V. Logvinova***[1], ***V.G. Burlov***[1] ✉, ***V.V. Barskov***[1], ***J. Arzola-Ruiz***[2], ***M. Castro Fernandez***[2]

[1] *Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russian Federation*

[2] *Technological University of Havana "José Antonio Echeverría", Havana, Cuba*

✉ *burlov_vg@spbstu.ru*

Keywords: energy efficiency, optimal mode, machine learning, genetic algorithm, objective function, optimal allocation, extreme weather event

Abstract. Significant number of accidents in electric power systems are caused by the effects of extreme weather events. In such conditions, providing consumers with electric energy is especially important. This study is devoted to solving this problem, in which a decision-making model has been developed that takes into account distributed generation based on renewable energy sources. The proposed model is a procedure for optimizing the established electric power mode. Optimization is performed using a genetic algorithm. The regulated parameters are the active capacities of electric power plants, the voltage on the busbars of generators of these stations, and the transformation coefficients. The values of these parameters are determined in case of disconnection of one and two overhead power lines using the example of a modified IEEE-39 circuit. The results show that distributed generation makes it possible to provide full power supply to consumers in a larger number of these emergencies (by 13.2 % and 27.2 %, respectively). With the most optimal location and generation capacity based on renewable energy sources, full power supply to consumers is achieved in 100 % and 98.3 % of emergency situations, respectively. The proposed decision-making model has a high potential to expand its functionality.

Funding: This research was supported by the Ministry of Science and Higher Education of the Russian Federation (agreement № 075-15-2025-673 dated August 20, 2025).

Citation: Feshin, A.O., Polyukhovich, M.A., Logvinova, Yu.V., Burlov, V.G., Barskov, V.V., Arzola-Ruiz, J., Castro Fernandez, M. Electric power system functioning in conditions of extreme weather events in the presence of distributed generation based on renewable energy sources. Magazine of Civil Engineering. 2026. 19(1). Article no. 14101. DOI: 10.34910/MCE.141.1

1. Introduction

Electric power industry occupies a special place in human economic activity, since the supply of electric energy is critically necessary in all areas of the economy: industry, agriculture, transport, healthcare, etc. In addition, a significant part of the total consumption of electric energy is occupied by household consumers.

Extreme weather events have an impact on all areas of human activity [1]. Electric power facilities are also affected by these phenomena [2–4]. Since the main task of the complex is to supply consumers with electric energy, the issue of ensuring reliable and uninterrupted power supply becomes even more urgent in conditions of extreme events.

Electric power systems (EPS) contain many elements, one of which is overhead power lines (OHPL). Due to the significant length of overhead lines, more than other elements of the EPS are adversely affected by extreme weather events. The impact of these phenomena can lead to an emergency shutdown of one or more overhead lines, which, in turn, may be accompanied by a disruption in the supply of electrical energy to consumers.

Centralized restoration of power supply requires repair of damaged network infrastructure, which, in some cases, may take a long time. Therefore, a common method is the temporary use of backup power circuits and backup sources of electrical energy, which makes it possible to fully or partially restore supply to consumers. At the same time, an important circumstance should be noted: even in an emergency state, the parameters of the electric power mode, as a rule, must be within strictly defined limits.

Based on the information and statistics available to the author's team on the EPS of the Republic of Cuba, an analysis of the threats of power supply disruption was performed. As a result, risk factors have been identified that can lead to emergency disturbances in the operation of the EPS. Extreme weather events are among these factors:

- hurricanes and severe storms; high probability of damage to the electric grid infrastructure, massive power outages, long-term repairs of the EPS infrastructure;
- high ambient temperature; overheating of equipment, increased electrical loads of equipment, damage to OHPL supports due to thermal expansion of materials and reduced structural strength; increased boom sag of OHPL wires;
- heavy rains, which can lead, among other things, to floods and landslides; falling OHPL poles due to soil erosion, damage to underground utilities, flooding of power grid infrastructure, power outages.

From 1980 to 2024, 112 major accidents occurred in the EPS of the Republic of Cuba, disabling more than half of consumers and causing significant economic and technological damage. At the same time, in 97 cases, the interruption in the electricity supply to consumers was more than a day. The causes of these accidents were:

- high ambient temperature – 23 cases (20.5 %);
- thunderstorm events – 19 cases (17 %);
- floods – 9 cases (8 %);
- complex of adverse events (hurricanes/storms and floods) – 34 cases (30.4 %);
- complex of adverse events (thunderstorms and floods) – 2 cases (1.8 %);
- hurricanes/storms – 1 case (0.9 %);
- other reasons (equipment wear, personnel error during repair work, etc.) – 24 cases (21.4 %).

Presented results show that 78.6 % of accidents in the EPS of the Republic of Cuba occurred as a result of exposure to extreme weather events. This resulted in broken wires and falling OHPL supports, flooding of substations, overload of the electrical network due to abnormally high temperatures, and short circuits.

Functioning of EPS in conditions of extreme weather events is characterized by the concept of resilience, which is defined as the ability of EPS to withstand extreme events and recover quickly after these events [5]. Resilience measures can be divided into short-term or operational, which are applied in a relatively short time interval (several days or weeks), including an extreme weather event, and long-term, which are aimed at reducing the vulnerability of EPS to future events [5, 6]. The optimal functioning of EPS in conditions of exposure to extreme weather events is possible if a high level of resilience is ensured and the volume of disconnected electrical energy is reduced among consumers. This issue is of interest among researchers and is considered by them as an optimization problem.

In [7], the solution of the noted problem is performed by determining the optimal composition, capacity, and location of virtual power plants. The virtual station includes generating sources based on renewable energy sources (RES), energy storage systems based on rechargeable batteries and electric vehicles (it is assumed that the latter will operate in the power supply mode in the event of an accident). The problem is solved using the IEEE-118 distribution scheme using the "black widow" optimization algorithm. The determination of the optimal composition, capacity, and location of virtual power plants is also discussed in [8–11]. The following optimization algorithms are used in these works, the effectiveness of which is tested in IEEE test distribution schemes: the spotted hyena algorithm, IEEE-34 scheme [8]; a hybrid algorithm based on the algorithms "herd of krill" and "pack of gray wolves", IEEE-33 scheme [9]; the hunting prey algorithm, IEEE-85 scheme [10]; hybrid algorithm based on the "krill herd" and "sine-cosine" algorithms, IEEE-69 scheme [11].

Method for increasing the resilience of an electric distribution network, which is formulated as a multi-criteria optimization model, was proposed in [12]. The paper describes in detail the mathematical part of the model, in which the nonlinear components are linearized, and the penalty components are introduced into the objective function. Optimization is performed using the GUROBI software product. The efficiency check was performed in the IEEE-123 test distribution circuit. The developed method is proposed as an assistant to dispatching personnel when making decisions in conditions of extreme weather events.

In [13], it was proposed to optimize the location of charging stations for electric vehicles. A joint solution algorithm is used that combines the Voronoi diagram and the particle swarm optimization algorithm. Testing of the developed algorithm is carried out in the IEEE-39 distribution scheme.

Solution to the optimization problem, taking into account energy storage systems and the individual characteristics of consumer load schedules, is presented in [14]. The particle swarm optimization algorithm is used, testing is performed in the IEEE-33 distribution scheme.

The articles [15, 16] consider the issue of increasing resilience by determining the optimal topology of the electrical network. In [17], in order to increase resilience, it is proposed to determine the optimal composition of power transmission lines that should be laid underground. In these studies, optimization is performed using a genetic algorithm [15], the "Column & Constraint Generation" algorithm based on decomposition [17], and the HiGHS software product [16].

In order to increase resilience in operation [18], a solution is proposed, in which OHPL supports are reinforced and distributed and mobile energy sources are placed. In [19], RES-based sources and battery-based energy storage systems are considered for this purpose. In these studies, the CPLEX software product is used to find the optimal solution. The approaches presented in the papers were tested in IEEE-33 distribution schemes [18, 19] and modified IEEE-118 [19].

In [20], measures such as strengthening OHPL supports and placing distributed energy sources and energy storage systems are considered to solve the optimization problem. The problem is solved using a genetic algorithm. The article [21] uses a particle swarm optimization algorithm and examines the reinforcement of OHPL supports. It is worth noting that [21] additionally takes into account the influence of the state of wind turbines, and in the study [22], when solving the optimization problem, the random nature of power generation by RES-based generating sources is taken into account. The solutions proposed in [20, 21] were tested in the IEEE-69 distribution scheme (a modified scheme is used in [21]).

In the work cycle [23, 24], attention was paid to strengthening and modernizing OHPL supports, pruning bushes and trees, and commissioning backup generating sources. These studies use, among other things, the greedy search algorithm [23] and the "Progressive Hedging" decomposition algorithm [24]. The operation of the proposed models is shown on the test schemes EPRI [23], IEEE-34 [24], and IEEE-123 [24].

It is important to note that the solution of the noted optimization problem is also performed using machine learning algorithms. Increasing the resilience of systems and distribution networks is considered in [25–27]. In [28], a decision support system is presented for managing the demand for electrical energy in distribution networks. In [29], it is predicted that wind power plants will generate power, which has a serious impact on the resilience of the system and the reliability of electricity supply to consumers.

The result of the optimization algorithm is the values of the variables, at which the best value of the objective function is achieved. Based on the analysis of the literature and [30], it can be concluded that researchers use as such variables: reduction or restoration of the load volume (i.e., forced disconnection of electrical energy from some consumers or restoration of their power supply); the capacity of distributed energy sources (including RES-based ones); location and capacity of mobile energy sources, energy storage systems, reactive power compensation systems; the location of electric vehicles and the capacity of their batteries; the condition of devices that change the topology of the electrical network (on or off); variables that characterize the condition of operational repair teams; and some others.

Statistics on accidents in the EPS of the Republic of Cuba and a number of countries (for example, [1–4] and others), as well as the interest of researchers in increasing the resilience of EPS, emphasize the urgency of the problem of optimal functioning of EPS in conditions of extreme weather events. The results obtained in this work are new and complement the above studies. These results include the following. Firstly, the paper considers the EPS scheme, rather than the scheme of the distribution network, that is, the study was carried out on a larger scale. Secondly, since the EPS scheme is being considered, the work uses a new set of variables for which the best value of the objective function is achieved. Thirdly, the implemented model makes it possible to determine the values of these variables practically for the current electric power mode.

The task of optimizing the current electric power mode can be formulated as follows. It is necessary to determine the values of regulated (independent or optimized) operating and circuit parameters, which will ensure the fullest possible supply of electric energy to consumers. The optimization problem is conditional because it contains constraints in the form of equalities and inequalities.

The noted task was solved by the team of authors, who developed a decision-making model for the optimal functioning of EPS under the influence of extreme weather events. This paper is devoted to the development of this model, which will allow taking into account the availability of distributed energy sources based on RES when making decisions.

Thus, the purpose of this study is to evaluate the effectiveness of integration into EPS of distributed generation based on RES to fully provide consumers with electric energy under the influence of extreme weather events. Such phenomena include high ambient temperature and phenomena that lead to OHPL shutdown (hurricanes, storms, and others). In accordance with the purpose of the study, the following tasks are formulated:

- perform accounting in a distributed generation decision-making model based on RES;
- in the EPS test scheme, determine the optimal RES-based generation capacity and location for various emergency scenarios;
- in the EPS test scheme, consider the uniform distribution of RES-based generation for various emergency scenarios;
- to evaluate the effectiveness of the solutions obtained for the full provision of electric energy to consumers.

2. Methods

The developed decision-making model is a procedure for optimizing the steady-state electric power mode, which makes it possible to determine the values of regulated operating and circuit parameters, at which the minimum value of the objective function is achieved.

The following parameters are accepted as regulated parameters: active capacities of centralized power supply stations, voltage modules on the busbars of generators of these stations, transformation coefficients of step-down transformers.

Optimization task is solved taking into account two types of constraints. Constraints in the form of equalities represent a system of nonlinear equations of the steady-state electric power mode, the solution of which is performed by the Newton method. These equations relate all the operating and circuit parameters of EPS to each other. Restrictions in the form of inequalities are imposed on the regulated variables, as well as on the currents flowing in the OHPL and on the voltages in the EPS nodes.

The dependence of the form is considered as an objective function:

$$F = \sum_{k=1}^{K} I_k + \sum_{m=1}^{M} U_m - \frac{\sum_{n=1}^{N} P_n}{N} \rightarrow \min,$$

where K is the number of OHPL that take into account restrictions on the amount of current flowing; M is the number of EPS nodes that take into account restrictions on the amount of voltage; N is the number of EPS nodes that require a full supply of electrical energy to consumers; I_k is the amount of OHPL current exceeding the maximum limit number k; U_m is the amount of if the voltage in the node with the number m exceeds the minimum or maximum limit; P_n is the relative value of the current value of the consumed active power in the node with the number n.

Thus, the objective function takes into account both the current power consumption values and limitations in the form of inequalities. In the optimal mode, OHPL currents and EPS node voltages should be within the specified limits, so the first two components of the objective function will be zero. When consumers are fully supplied with electric energy, $P_n = 1$. Therefore, in this case, the minimum value of the objective function, regardless of the EPS scheme and the set of optimized parameters, is a constant value and is –1.

Distributed generation based on RES is taken into account in the model when forming a system of nonlinear equations of the steady-state electric power mode. The paper considers two accounting methods. The first one is focused on determining the optimal location (among the consumption nodes) and generation capacity during the current emergency event. In this case, it is assumed that each consumption node has generation capacity (the maximum value of which is 50% of the load capacity), which is included in the list of adjustable parameters. The second method considers the uniform distribution of generation in the consumption nodes.

Let us make an important remark about the above. The lists of regulated parameters and constraints in the form of inequalities adopted in the work are not strictly defined and can be expanded. The lists selected in the work are designed and allow us to show the fundamental possibility of solving the optimization problem. Taking into account additional parameters and restrictions in the algorithm will not lead to significant difficulties.

Optimization of the mode in the developed decision-making model is performed using a genetic algorithm. This algorithm, as follows from the literature review, is used by researchers to solve such problems, since, due to its stochastic nature, it supports a variety of possible solutions and allows for various constraints. This article does not compare the effectiveness of solving the optimization problem using different methods, as this study addresses a different goal. Such a comparison could be performed as part of a continuation and development of this research.

Let us note one more fact. Earlier it was said that the objective function has a known minimum value –1. However, the set of values of the regulated parameters, at which this minimum is achieved, is not the only one. In other words, the minimum of the objective function is not a point, but a certain surface. Due to the stochastic nature of the genetic algorithm, solving the same problem generally leads to different sets of values of the regulated parameters. Thus, among the many solutions, you should choose the one that best suits the current properties and technical characteristics of the equipment. Another possible method, which does not require the marked choice, is to take into account additional components in the expression of the objective function, which will change the form of the function so that it will have obvious extremum points (for example, such a component may be the loss of active power in an electrical network). In this paper, these features are not considered – as noted earlier, the fundamental possibility of solving the optimization problem is shown.

3. Results and Discussion

Testing of the new version of the decision-making model was performed in a modified IEEE-39 scheme, in which the structure and values of the parameters were changed. The structural changes are as follows: three transformers that are not connected to generating sources have been replaced by OHPL; a step-down transformer has been added to each consumption node. The EPS diagram obtained in this way is shown in Fig. 1.

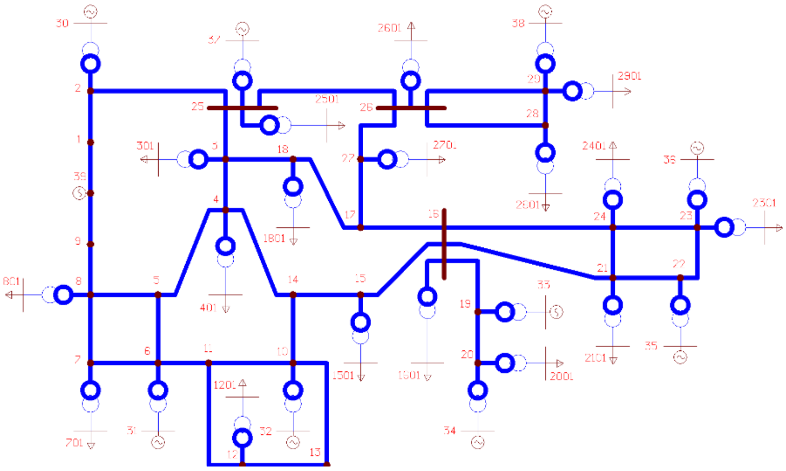

Figure 1. EPS schematic diagram.

This circuit contains 56 nodes, of which 17 are load-bearing (represented as a ZIP model), 9 are generating (represented as a PU model), and 29 are intermediate. The number of branches in the circuit is 64, of which 38 are OHPL, 17 are transformers connected to consumption nodes (LT), and 9 are transformers connected to generating sources (GT). The parameters of the same type of nodes and branches are the same and are presented in Table 1 (U_{nom}, P_{nom}, Q_{nom} are the nominal values of voltage, active power, and reactive power, respectively) and Table 2 (R, X, G, B are active and inductive resistance, active and reactive conductivity, respectively; k_t is the transformation coefficient; Δk_t is the limits of change in the transformation coefficient).

Table 1. Node parameters.

Node	Parameters			
	U_{nom}, kV	P_{nom}, MW	Q_{nom}, Mvar	ZIP model
Loading	10	100	50	$K_{PZ} = 0.47$; $K_{PI} = -0.3$; $K_{PP} = 0.83$; $K_{QZ} = 6.2$; $K_{QI} = -10.1$; $K_{QP} = 4.9$
Generating	10.5	200	–	–
Intermediate	220	–	–	–

Table 2. Branch parameters.

Branch	Parameters					
	R, Ω	X, Ω	G, μS	B, μS	k_t	Δk_t
OHPL	7.5	42	–	270	–	–
LT	2	50.3	3.1	20.4	0.047826	±8x1.5 %
GT	0.7	26	4.6	21.3	0.043388	–

In the accepted formulation of the optimization problem, constraints in the form of inequalities are imposed on the currents flowing in the OHPL. The high ambient temperature leads to a decrease in the permissible OHPL current load, which is expressed in terms of a correction factor, the minimum value of which is 0.67, which corresponds to a temperature of +50 °C. Assuming these most severe conditions, we obtain that the maximum OHPL current limit is 536 A. The minimum and maximum limits for regulated parameters and voltages in EPS nodes are presented in Table 3.

Table 3. Limits of variable variation.

Variable	min	max
Active power, MW	50	200
Generator voltage, kV	10	11
Voltage in the intermediate nodes, kV	198	242
Voltage in the consumption nodes, kV	9	11

So, the effect of high ambient temperature is taken into account in the decision-making model by reducing the permissible OHPL current load. The effects of other extreme weather events that cause OHPL wires to break or supports to fall are taken into account in the model by disabling the corresponding OHPL. In this study, only two possible combinations are considered: disabling one OHPL (38 possible options) and disabling two OHPL (703 possible options). Disabling more OHPLS was not considered due to the increased computational and time costs incurred in sorting through all possible options (for example, when disabling three OHPL, there are 8436 possible options). Nevertheless, for the specific case of disabling several OHPL, the developed decision-making model allows us to determine the values of the regulated parameters corresponding to the most optimal mode of EPS operation. However, in the received mode, some of the electric energy consumers may be turned off.

Let's make an important point. In some of the considered variants, disabling OHPL leads to the separation of the EPS circuit into two independent subcircuits. In this case, the optimal mode is determined for the part of the circuit that contains node No 39, which is the basic balancing node.

Results for the case of disabling one OHPL are shown in Table 4. This table shows the number of shutdown options, in which consumers are fully supplied with electrical energy. In the case of optimal distribution of RES generation, the model solves the problem of determining the optimal location and power of generating sources in a given emergency situation. The uniform distribution of RES generation is taken into account by the presence of generation power consumption in the nodes, which ranges from 5 % to 20 % of the load capacity. The values shown in the columns with the distribution of RES generation take into account the number of options, in which the power supply to consumers is provided without RES.

Table 4. Calculation results when one OHPL is turned off.

Without RES	Optimal distribution of RES generation	Uniform distribution of RES generation			
		5 %	10 %	15 %	20 %
32 (84.2 %)	38 (100 %)	34 (89.5 %)	36 (94.7 %)	37 (97.4 %)	37 (97.4 %)

The data obtained show that the availability of RES-based generation contributes to a more complete supply of electric energy to consumers. With optimal distribution, full power supply to consumers is achieved in all emergency situations. However, such a solution is not universal, since the location and power of the generating source are determined for a specific emergency situation, with another emergency disturbance, the result will not be optimal. Therefore, in this formulation of the problem, the uniform distribution of RES generation is a more universal solution.

Similar results for the case of disabling two OHPL are presented in Table 5. These data also confirm the noted positive impact of RES generation on the power supply to consumers. However, in the case of disabling two OHPL, there is a decrease in the relative number of options, which indicates that there is no required minimum value of the objective function due to the concomitant aggravation of the EPS operating mode.

Table 5. Calculation results when two OHPL are disabled.

Without RES	Optimal distribution of RES generation	Uniform distribution of RES generation			
		5 %	10 %	15 %	20 %
450 (64 %)	691 (98.3 %)	517 (73.5 %)	585 (83.2 %)	625 (88.9 %)	641 (91.2 %)

With a uniform distribution of RES generation (10 %), three calculations were performed for the case of disconnection of one OHPL (3–4) and two OHPL (3–4 and 10–14). The average number of generations (iterations) required to obtain the minimum value of the objective function was 7 in the first case and 12 in the second. The convergence process for all cases is shown in Fig. 2 when one overhead line is disconnected and in Fig. 3 when two OHPL are disconnected. The results obtained demonstrate slower convergence to the solution in the case of disconnection of the two OHPL, which also indicates a more severe mode of EPS operation.

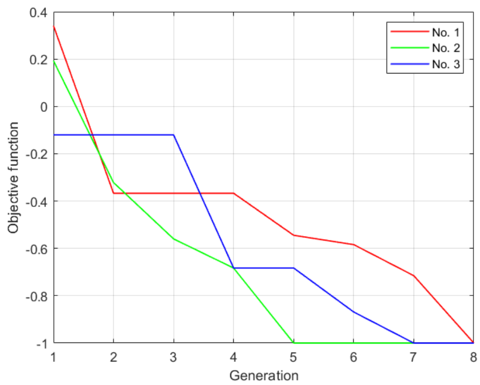

Figure 2. The process of convergence to the minimum of the objective function when one OHPL is turned off.

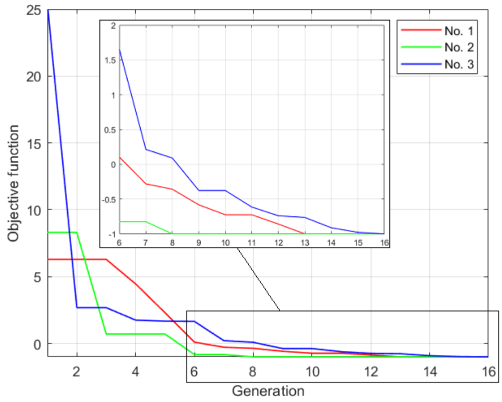

Figure 3. The process of convergence to the minimum of the objective function when two OHPL are disabled.

In the EPS scheme under consideration, the number of adjustable parameters is 35 (in the case of optimal RES generation distribution, the number of parameters is 52). Table 6 shows the values of some of these parameters for the above cases of disconnection of one OHPL (3–4) and two OHPL (3–4 and 10–14). The presented results confirm that the minimum of the objective function is generally achieved with different sets of values of the controlled parameters.

Table 6. Values of the regulated parameters.

Parameter	Disabling one OHPL (3–4)			Disabling two OHPL (3–4 и 10–14)		
	Calculation No 1	Calculation No 2	Calculation No 3	Calculation No 1	Calculation No 2	Calculation No 3
P_{G31}, MW	163.51	173.49	149.2	153.90	106.65	138.46
P_{G34}, MW	127.24	161.07	158.13	93.96	115.38	83.6
P_{G37}, MW	197.68	155.58	196.19	186.45	196.09	196.4
U_{G32}, kV	10.792	10.75	10.846	10.209	10.649	10.455
U_{G35}, kV	10.599	10.939	10.503	10.734	10.822	10.732
U_{G38}, kV	10.348	10.88	10.817	10.851	10.46	10.89
$k_{t(4-401)}$	0.053437	0.043281	0.050879	0.051704	0.049305	0.048554
$k_{t(20-2001)}$	0.05008	0.047826	0.046433	0.044489	0.045767	0.045767
$k_{t(26-2601)}$	0.046433	0.044489	0.045119	0.045767	0.051704	0.043877

Results shown in Table 4 and Table 5 were obtained by iterating through all possible options for disabling one OHPL and two OHPL. Consider the case of disabling three (3–4, 10–14, 28–29), four (3–4, 10–14, 28–29, 14–15), and five (3–4, 10–14, 28–29, 14–15, 16–24) OHPL in a scheme with uniform distribution of generating sources based on RES (10 %). We will perform three calculations for each case. The average number of generations required to achieve the minimum value of the objective function was 21, 25, and 31, respectively. The process of convergence to the solution, which is defined in each case for the calculation with the largest number of generations, is shown in Fig. 4. The results show that each addition of a disabled OHPL leads to a heavier EPS mode.

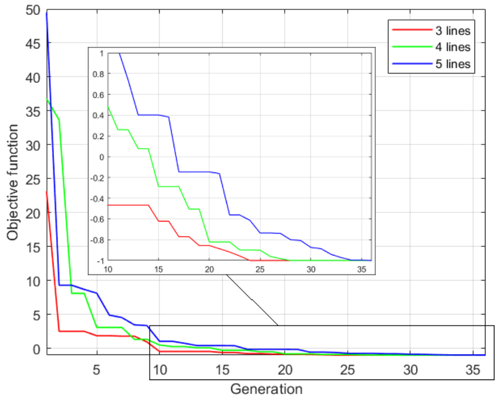

Figure 4. The process of convergence to the solution.

Thus, the calculations performed confirm that in conditions of exposure to extreme weather events, distributed generation based on RES makes it possible in some cases to fully provide consumers with electric energy. The cases of disconnection of one and two OHPL were considered in the most detail. It follows from the results obtained that even a small distributed generation (5 % of the consumption capacity) can save the power supply to consumers in case of 2 additional accidents in the first case and 67 accidents in the second case. Solutions with optimal distribution of sources based on RES have the greatest efficiency in fully providing electric energy, but each such solution is designed for a specific emergency situation. For this reason, this result is generally not acceptable.

The results of this study are consistent with the results obtained by other authors (for example, [7, 9, 10]). These studies note that the optimal implementation of distributed energy sources, including those based on RES, significantly increases the resilience of the system and reduces the amount of electric energy that is not supplied to consumers.

4. Conclusions

The performed research allows us to conclude the following:

- a decision-making model is proposed for the optimal functioning of EPS under the influence of extreme weather events, taking into account the availability of distributed energy sources based on RES;
- the algorithms implemented in the model make it possible to account for various regulated variables, constraints and functions without significant difficulties, which determines the flexibility of the model and the possibility of obtaining scalable solutions (both for large EPS schemes and for electric distribution network schemes);
- the application of the developed model to the modified IEEE-39 scheme made it possible to determine for a number of emergency situations the values of controlled variables, in which the full or maximum supply of electric energy to consumers is achieved;
- uniform (or proportional to the volume of load power) distribution of RES generation in the consumption nodes is preferable to optimal, since it allows to preserve the power supply to consumers in a larger number of emergency situations;
- an algorithm for solving the problem of optimal distribution of RES generation in consumption nodes in the event of a specific emergency can be used to develop an algorithm for solving a similar problem, but in the case of several emergencies.

References

1. Jufri, F.H., Widiputra, V., Jung, J. State-of-the-art review on power grid resilience to extreme weather events: Definitions, frameworks, quantitative assessment methodologies, and enhancement strategies. Applied Energy. 2019. 239. Pp. 1049–1065. DOI: 10.1016/j.apenergy.2019.02.017
2. Bao, M., Ding, Y., Sang, M., Daqing, Li., Shao, C., Yan, J. Modeling and evaluating nodal resilience of multi-energy systems under windstorms. Applied Energy. 2020. 270. Article no. 115136. DOI: 10.1016/j.apenergy.2020.115736
3. Salman, A.M., Li, Y., Stewart, M.G. Evaluating system reliability and targeted hardening strategies of power distribution systems subjected to hurricanes. Reliability Engineering & System Safety. 2015. 144. Pp. 319–333. DOI: 10.1016/j.ress.2015.07.028

4. Wang, C., Ju, P., Wu, F., Pan, X., Wang, Z. A systematic review on power system resilience from the perspective of generation, network, and load. Renewable and Sustainable Energy Reviews. 2022. 167. Article no. 112567. DOI: 10.1016/j.rser.2022.112567
5. Panteli, M., Mancarella, P. Influence of extreme weather and climate change on the resilience of power systems: Impacts and possible mitigation strategies. Electric Power Systems Research. 2015. 127. Pp. 259–270. DOI: 10.1016/j.epsr.2015.06.012
6. Tari, A.N., Sepasian, M.S., Kenari, M.T. Resilience assessment and improvement of distribution networks against extreme weather events. International Journal of Electrical Power & Energy Systems. 2021. 125. Article no. 106414. DOI: 10.1016/j.ijepes.2020.106414
7. Suresh, T.D., Thirumalai, M., Hemalatha, R., Bajaj, M., Blazek, V., Prokop, L. Resilient VPP cost optimization in DER-driven microgrids for large distribution systems considering uncertainty during extreme events. Energy Conversion and Management: X. 2025. 27. Article no. 101176. DOI: 10.1016/j.ecmx.2025.101176
8. Babu, C.H., Raju, H., Thangaraj, Y., Thanikanti, S.B., Nastasi, B. Optimizing power and energy loss reduction in distribution systems with RDGs, DSVCs and EVCS under different weather scenarios. Sustainable Energy Technologies and Assessments. 2025. 75. Article no. 104219. DOI: 10.1016/j.seta.2025.104219
9. Dehghan, M., Zadehbagheri, M., Kiani, M.J., Nejatian, S. Virtual power plants planning in the distribution network constrained to system resiliency under extreme weather events. Energy Reports. 2023. 9. Pp. 4243–4256. DOI: 10.1016/j.egyr.2023.03.080
10. Yuvaraj, T., Krishnamoorthy, R., Arun, S., Thanikanti, S.B., Nwulu, N. Optimizing virtual power plant allocation for enhanced resilience in smart microgrids under severe fault conditions using the hunting prey optimization algorithm. Energy Reports. 2024. 11. Pp. 6094–6108. DOI: 10.1016/j.egyr.2024.05.043
11. Piltan, G., Pirouzi, S., Azarhooshang, A., Jordehi, A.R., Paeizi, A., Ghadamyari, M. Storage-integrated virtual power plants for resiliency enhancement of smart distribution systems. Journal of Energy Storage. 2022. 55(B). Article no. 105563. DOI: 10.1016/j.est.2022.105563
12. Zeng, Y., Qin, C., Liu, J., Xu, X. Coordinating multiple resources for enhancing distribution system resilience against extreme weather events considering multi-stage coupling. International Journal of Electrical Power & Energy Systems. 2022. 138. Article no. 107901. DOI: 10.1016/j.ijepes.2021.107901
13. Mei, H., Wu, Q., Ren, H., Zhang, J., Li, Q. Optimization of electric vehicle charging station layout considering the improvement of distribution network resilience under extreme disasters. Energy. 2025. 323. Article no. 135831. DOI: 10.1016/j.energy.2025.135831
14. Yang, X., Xu, L. Optimal Distribution Grid Scheduling Strategy in the Context of Insufficient Power Supply During Extreme Weather Events. 2024 6th International Conference on Power and Energy Technology (ICPET). Beijing, 2024. Pp. 747–752. DOI: 10.1109/ICPET62369.2024.10940646
15. Widiputra, V., Jung, J. Optimal Grid Reconfiguration Algorithm for Improving System Resilience under Extreme Weather Events. 2020 4th International Conference on Green Energy and Applications (ICGEA). Singapore. 2020. Pp. 12–16. DOI: 10.1109/ICGEA49367.2020.239685
16. Velini, A., Cometa, R., Lorusso, F., La Scala, M., Bruno, S. Optimal Network Reconfiguration for Mitigating the Impact of Adverse Weather Events on Distribution Networks. 2024 IEEE International Humanitarian Technologies Conference (IHTC). Bari, 2024. Pp. 1–7. DOI: 10.1109/IHTC61819.2024.10855123
17. Trakas, D.N., Hatziargyriou, N.D. Strengthening Transmission System Resilience Against Extreme Weather Events by Undergrounding Selected Lines. IEEE Transactions on Power Systems. 2022. 37(4). Pp. 2808–2820. DOI: 10.1109/TPWRS.2021.3128020
18. Ghasemi, M., Kazemi, A., Bompard, E., Aminifar, F. A two-stage resilience improvement planning for power distribution systems against hurricanes. International Journal of Electrical Power & Energy Systems. 2021. 132. Article no. 107214. DOI: 10.1016/j.ijepes.2021.107214
19. Serrano-Fontova, A., Liao, Z., Li, H., Booth, C. A novel resilience assessment for active distribution networks including a DER voltage regulation scheme considering windstorms. International Journal of Electrical Power & Energy Systems. 2023. 153. Article no. 109310. DOI: 10.1016/j.ijepes.2023.109310
20. Ghosh, P., De, M. A stochastic investment decision making method for distribution system resilience enhancement considering automation, hardening and distributed energy resources. Reliability Engineering & System Safety. 2023. 237. Article no. 109395. DOI: 10.1016/j.ress.2023.109395
21. Shabani, A., Nafar, M., Niknam, T. Four-level framework for enhancing active distribution network resilience to wind storms. Electric Power Systems Research. 2025. 249. Article no. 112027. DOI: 10.1016/j.epsr.2025.112027
22. Ren, H., Jiang, Z., Wu, Q., Li, Q., Lv, H. Optimal planning of an economic and resilient district integrated energy system considering renewable energy uncertainty and demand response under natural disasters. Energy. 2023. 277. Article no. 127644. DOI: 10.1016/j.energy.2023.127644
23. Ma, S., Chen, B., Wang, Z. Resilience enhancement strategy for distribution systems under extreme weather events. IEEE Transactions on Smart Grid. 2018. 9(2). Pp. 1442–1451. DOI: 10.1109/TSG.2016.2591885
24. Ma, S., Su, L., Wang, Z., Qiu, F., Guo, G. Resilience Enhancement of Distribution Grids Against Extreme Weather Events. IEEE Transactions on Power Systems. 2018. 33(5). Pp. 4842–4853. DOI: 10.1109/TPWRS.2018.2822295
25. Moradi-Sepahvand, M., Amraee, T., Gougheri, S.S. Deep Learning Based Hurricane Resilient Coplanning of Transmission Lines, Battery Energy Storages, and Wind Farms. IEEE Transactions on Industrial Informatics. 2021. 18(3). Pp. 2120–2131. DOI: 10.1109/TII.2021.3074397
26. Das, A., Ni, Z., Zhong, X. Microgrid energy scheduling under uncertain extreme weather: Adaptation from parallelized reinforcement learning agents. International Journal of Electrical Power & Energy Systems. 2023. 152. Article no. 109210. DOI: 10.1016/j.ijepes.2023.109210
27. Zhou, Z., Wu, Z., Jin, T. Deep reinforcement learning framework for resilience enhancement of distribution systems under extreme weather events. International Journal of Electrical Power & Energy Systems. 2021. 128. Article no. 106676. DOI: 10.1016/j.ijepes.2020.106676
28. Tettey, A., Pham, H., Chen, H., Wu, D., Wooley, A. A decision support framework for electric demand planning in distribution systems during extreme minimum temperatures. Energy Reports. 2025. 14. Pp. 1137–1148. DOI: 10.1016/j.egyr.2025.06.020

29. Liu, Y., Wang, J., Liu, L. Physics-informed reinforcement learning for probabilistic wind power forecasting under extreme events. Applied Energy. 2024. 376(A). Article no. 124068. DOI: 10.1016/j.apenergy.2024.124068
30. Shi, Q., Liu, W., Zeng, B., Hui, H., Li, F. Enhancing distribution system resilience against extreme weather events: Concept review, algorithm summary, and future vision. International Journal of Electrical Power & Energy Systems. 2022. 138. Article no. 107860. DOI: 10.1016/j.ijepes.2021.107860

Contacts:

Aleksandr Feshin,
ORCID: https://orcid.org/0000-0002-4149-4348
E-mail: feshin_ao@spbstu.ru

Maxim Polyukhovich,
ORCID: https://orcid.org/0000-0003-2722-5552
E-mail: polyuhovich_ma@spbstu.ru

Yulia Logvinova,
ORCID: https://orcid.org/0000-0002-8392-1790
E-mail: logvinova_yuv@spbstu.ru

Vyacheslav Burlov,
ORCID: https://orcid.org/0000-0001-7603-9786
E-mail: burlov_vg@spbstu.ru

Viktor Barskov,
ORCID: https://orcid.org/0000-0001-6914-8212
E-mail: barskov_vv@spbstu.ru

Jose Arzola-Ruiz,
ORCID: https://orcid.org/0000-0002-4101-878X
E-mail: josearzolaruiz1945@gmail.com

Miguel Castro Fernandez,
ORCID: https://orcid.org/0000-0002-3983-469X
E-mail: mcastro@electrica.cujae.edu.cu

Received 04.12.2025. Approved after reviewing . Accepted .