UDC: 621.4
DOI: 10.15587/1729-4061.2023.280740

DEVISING A CALCULATION METHOD FOR DETERMINING THE IMPACT OF DESIGN FEATURES OF SOLAR PANELS ON PERFORMANCE

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An actual scientific and practical task related to the sustainable development of the country's energy sector is to forecast parameters and predict the conditions of operation of solar cells and solar batteries in regular and non-regular situations. It is emphasized that this makes it possible to provide solar energy with high efficiency indicators, in particular, the indicator of profitability on invested capital in the construction of solar panels.

The main specific research method is regression analysis – to build a forecast model of the total amount of generated energy of solar panels in ground installations under variable conditions of operation.

An analysis of the distribution of the output data of the model by the number of solar battery modules was carried out using the example of terrestrial solar installations. To obtain empirical data, 31 objects in the Dnipropetrovsk and Zaporizhia oblasts, which have functioning solar batteries with different numbers of modules, were selected. This makes it possible to calculate the weighted average amount of generated energy during operation under variable conditions. 10 intervals of frequency values were separated with the largest range of values within the interval of 10,000–20,000 pieces of solar modules.

A model of the dependence of the total amount of generated energy on the number of solar battery modules and the weighted average amount of generated energy was built based on regression analysis. It was determined that the influencing factor of the model «number of solar modules» has a positive influence on the resulting factor (productivity of solar panels), while the influencing factor «weighted average amount of generated energy» has a negative influence. However, the «number of solar modules» influence factor is more significant. The obtained results give grounds for asserting the possibility of their implementation in the energy sector

Keywords: solar battery, photovoltaic cell, generated energy, hot spot, reliability

Received date 06.03.2023
Accepted date 29.05.2023
Published date 30.06.2023

How to Cite: *Hilorme, T., Nakashydze, L., Tonkoshkur, A., Kolbunov, V., Gomilko, I., Mazurik, S., Ponomarov, O. (2023). Devising a calculation method for determining the impact of design features of solar panels on performance. Eastern-European Journal of Enterprise Technologies, 3 (8 (123)), 30–36. doi: https://doi.org/10.15587/1729-4061.2023.280740*

1. Introduction

Forecasting the parameters and predicting the conditions of operation of solar cells (SCs) and solar batteries (SBs) is one of the main tasks in the formation of energy supply systems; the energy of solar radiation is used as the main energy resource.

But at the same time, it is very important to take into account the errors of the influence of natural conditions, the human factor, and other important factors that appear during the operation of solar batteries, under the conditions of space and ground operation.

A number of natural factors affect the performance and efficiency of solar cells and solar batteries when operating in terrestrial operating languages. Among the main ones, the following can be distinguished: weather and climatic conditions: rain, snow, hail, cloudiness, fog, heat, cold; change of day and night; uneven lighting: local pollution; temperature increase; pollution: dust, snow; irreversible losses, etc. If the totality of these factors corresponds to the normal conditions of SB functioning, this is a full-time working situation. There are deviations from the norm – this is an extraordinary situation.

The cost of SBs is relatively constantly decreasing and solar energy has high indicators of the weighted average cost of generated electricity (LCOE). This indicator reflects a fixed tariff for electricity, which reflects the cost of its generation and in which the total discounted revenue from the sale of electricity to the final consumer is equal to the total discounted costs throughout the entire life cycle of the power-generating facility. This is the minimum price at which the electricity generated during the entire life of the power plant must be sold to reach its break-even point (NPV=0). If the electricity price is higher than LCOE, it will give a higher return on invested capital (NPV > 0) than the adopted discount rate, while a lower price will not allow the project to pay for itself at the given discount rate (NPV < 0).

The insufficient level of development of the scientific basis for choosing the optimal parameters for the operation of solar batteries remains an unsolved problem of the energy development of the technological platform in many countries of the world. Fragmentation in the choice of project solutions for determining the necessary generated energy depending on the design of SB leads to the emergence of various activity risks, primarily environmental risks.

Therefore, the complex of issues related to the determination of the specifics of the implementation of project solutions for the construction of SB requires an in-depth analysis and methodical clarification. It is becoming more and more difficult for companies in the energy sector to determine the set of indicators of the effectiveness of project decision tools, which is necessary to create long-term relationships in the market and achieve satisfaction of consumer needs.

Thus, the further development of the principles of designing efficient solar batteries is an important scientific and practical task. For the development of the energy industry in the world, this is an actual scientific and practical issue that needs further refinement and solution.

2. Literature review and problem statement

In works [1–3], the peculiarities of the operation of solar batteries in cloudy weather are considered. It is outlined that their highest efficiency can be achieved in sunny weather at a heating temperature of photovoltaic elements of no more than 85 °C [1]. When the sky is overcast, the efficiency of operation and productivity of SB is significantly reduced, but the generation does not stop. In the darkest weather, the output power is only 5–20 % of maximally possible [2]. This is due to the fact that clouds block the access of the sun's rays to the panels, leaving only diffused light. It is emphasized that the use of a rotary mechanism for SB is effective in cloudy weather [3]. In fact, even in the absence of sunlight, turning the photovoltaic cells towards the cloud-obscured sun makes a difference. This is due to the fact that even diffused light has higher insolation. And therefore, to increase the efficiency of the solar power plant in cloudy weather, it is recommended to install panels that rotate with the movement of the sun. But the cited works do not clearly outline the level of influence of these factors, and the error that must be taken into account when designing such installations.

In works [4–6], the presence of influence on the effectiveness of the operation of local contamination of SB surface was analyzed. If the solar element included in the SB is illuminated less intensively than the neighboring one, it becomes a parasitic load and reduces the total energy output [4]. If part of the panels is in the shade, it will negatively affect the production of all modules, even those under the Sun. They partially function, but only partially from the real potential [5]. This not only reduces efficiency but also affects the panels themselves: silicon cells heat up, wear of current-carrying parts increases [6]. If the solar power plant (SPP) operates under this mode for several days, there is a slight decrease in productivity, but with regular partial shading, the basic efficiency decreases due to the weakening of the contacts between the elements, and, as a result, the failure of certain areas of the solar power plant.

Partial shading affects the performance and reliability of thin-film and crystalline silicon SBs. It was noted in [7] that experiments show that solar panels based on thin-film technologies and SBs based on crystalline silicon SCs behave differently under the same shading schemes [8]. In thin-film solar modules with partial shading, the power is reduced mainly due to a decrease in the total current generated by the module, and in the case of solar modules based on crystalline silicon photovoltaic cells, the power is reduced due to a simultaneous decrease in the current and voltage generated by the module. In addition, thermographic studies of shaded modules showed the appearance of hot spots, and the temperature of hot spots in the case of solar modules based on crystalline silicon CEs reached a temperature of 86 °C [9]. Experiments have shown that partial shading has a greater impact on solar modules based on crystalline silicon CEs [10]. However, the cited paper does not define the negative limiting physical and technical parameters of the influence of the level of shading of SB.

In work [11], the problem of the appearance of hot spots is considered, which can cause accelerated aging and a decrease in the reliability of SB module in general. The formation of recommendations to eliminate this problem by using bypass diodes or intelligent switches is positive. The disadvantage of these recommendations is that their implementation does not make it possible to completely avoid problems with hot spots. A promising solution to prevent the appearance of hot spots is the correct adjustment of the operating point of photovoltaic elements in the plane of the dependence of current on voltage [12]. Correctly selected operating points make it possible to find a suitable compromise between the maximization of the extracted power and the minimization of the thermal stress arising in SB modules. But the disadvantage is the insufficient level of consideration of the need to model the level of generation change when solving the problem of hot spots. The aspect of the quantitative composition of the power generation system (that is, the dependence on the number of modules) has not been considered.

A change in the structural technical solutions for the construction of SB can lead to a change in the energy-generating capacity of the installation. At the same time, it is necessary to forecast and anticipate changes in technological parameters.

All this gives reason to assert that it is expedient to conduct a study to substantiate the determination of the influence of the quantitative composition of the structure on the performance of solar batteries with the use of modern scientific tools.

3. The aim and objectives of the study

The purpose of this work is to devise a calculation method for determining the influence of the design features of the construction of solar panels on productivity under various variable operating conditions. This will make it possible to increase the efficiency of SB in terms of its productivity and increase energy generation reserves.

To accomplish the aim, the following tasks have been set:

– to analyze the distribution of the output data of the model by the number of SB modules using the example of terrestrial solar installations;

– to determine the regression model of the dependence of the total level of generated energy on the number of SB modules and the weighted average amount of generated energy.

4. The study materials and methods

4. 1. The object and hypothesis of the study

The object of our study is the decision-making process regarding the selection of the number of SB modules in order to obtain the amount of energy required by the consumer. The subject of the study is the theoretical-methodological, scientific-methodical, and applied foundations of SB productivity management.

The main hypothesis of the study assumes that the selected variant of the number of SB modules is effective. This variant will ensure obtaining the necessary amount of energy of SB, reducing losses, and maintaining operational characteristics. This justifies the provision of uninterrupted operation of solar batteries in power plants in non-standard situations.

The criterion for choosing the best SPP option is a set of requirements that must be met by technical and economic indicators. Two main forms of criteria are used in the technical and economic substantiation of the feasibility of developing new energy systems. The first involves achieving the maximum useful effect at the specified costs (principle of maximizing the effect), the second – minimizing costs in order to ensure the necessary useful effect (principle of saving resources). These two forms of criteria are equivalent to each other, and each of them can be used to find the best solution.

The main obstacle to the widespread development of semiconductor solar energy is the high cost of solar cells, solar radiation concentration and orientation systems, and other structural elements of the installation. The choice of the structure and parameters of the energy system is influenced by external and internal factors. The set of external factors includes needs for electrical energy (amount of energy), program of its use, etc.

Thus, parameters characterizing internal factors can be conditionally separated into two groups. The first group of factors is characterized by the ability to influence SB parameters. The second group is the parameters whose nature of change is considered discrete, in particular, the number of solar cells and modules on the basis of which the energy system can be composed.

For SPP, internal factors are the efficiency of solar energy concentration systems, orientation, coordination of output parameters with consumers, energy efficiency of the solar cell, etc.

A change in the structure of the constituent components of SPP, related to internal factors, can lead to a change in the energy-generating capacity and appearance of the entire energy-generating installation – it is necessary to forecast and predict changes in technological parameters.

4. 2. Methods

The study considered a model with two regressors. To describe the dependence of y on two variables, the linear model takes the form [13]:

$$Y = a_0 + a_1 X_1 + a_2 X_2 + c, \tag{1}$$

where Y is the output variable; a_0, a_1, a_2 – model parameters; X_1, X_2 – independent input variables; c is a random error.

Estimates of model parameters (a_0, a_1, a_2) were calculated by the method of least squares (LSM) [14].

The significance of the regression was checked by calculating the p-value. The random variable F was calculated, taking the value $F0$ (this is the p-value), then the p-value was compared with the given level of significance u [15–18]. If the p-value is greater than the significance level, then there is no reason to reject the null hypothesis, and the regression is insignificant.

Regression coefficients were calculated using the MS Excel package.

4. 3. Materials

31 objects in the Dnipropetrovsk and Zaporizhia oblasts were selected as the initial data for constructing the dependence of the total amount of generated energy on the number of SB modules and the weighted average amount of generated energy. They have functioning SBs with different number of modules and the ability to calculate the weighted average amount of generated energy. The following assumptions were used: the actual service life of SB is 15–20 years; the number of modules is approximately the same in the design; average level of insolation, etc.

The task of choosing the number of intervals for grouping empirical data for their statistical processing can be stated as the task of optimal filtering of random deviations of the histogram of the distribution of the empirical sample from the smooth curve of the density of the distribution of the general population. As a rule, intervals of equal width or equal probability are used [19]. It can be proved that there is an optimal number of intervals of a certain type for a given sample.

5. Results of research on the construction of a calculation method for determining the influence of the design features of the structure of solar batteries

5. 1. Analysis of the distribution of model output data by the number of solar battery modules

The subjective criterion of the correctness of the choice of the number of classes is the accuracy of the display of the nature of the distribution of empirical (actual frequencies) frequencies of the studied population. This makes it possible to carry out an analysis of the distribution of model output data by the number of SB modules using the example of terrestrial solar installations (Table 1).

Based on the result of the analysis of the distribution of model data in frequency intervals (Table 1), the following conclusions can be drawn. 10 intervals of values are separated, while the number of objects corresponds to the following ranges: 0–100 – 0 objects; 100–200 – 0 objects; 200–500 – 0 objects; 500–1000 – 0 objects; 1000–2000 – 0 objects; 2000–5000 – 2 objects; 5,000–10,000 – 5 objects; 10,000–20,000 – 13 objects; 20,000–50,000 – 10 objects; 50,000–100,000 – 1 object. The value of the share of the actual distribution of the general sampling model is 100 %, while the share of the normal distribution of the general sampling model is 82 %. As can be seen, the original population of 31 SBs is divided into 5 intervals. In each interval, the following are calculated: frequency, accumulated frequency, percentage of the total frequency, accumulated percentage of the total frequency, percentage of the total number of observations, accumulated percentage of the total number of observations, theoretical frequency, accumulated theoretical frequency.

For continuous distributions, it is advisable to display the plot of absolute frequencies as a bar chart, and for discrete ones – as a histogram, dot or line graph.

Fig. 1 shows a histogram of the distribution of model output data in frequency intervals.

The series of output data of the number of SB modules has a normal distribution, skewed to the left. After the logarithm of the intervals of values, the data acquired the appearance of a normal distribution, suitable for further statistical processing and modeling. To confirm this statement, the frequency accumulation of the output data of the model was built (Fig. 2).

Table 1

Distribution of model output data in frequency ranges

No. of entry	Range of values, pcs			Number of objects	Share		Share accumulated	
	from (included in range)	to (out of range)	from – to		Actual distribution	Normal distribution	Actual distribution	Normal distribution
1	0	100	0–100	0	0.0 %	0.2 %	0.0 %	0.2 %
2	100	200	100–200	0	0.0 %	0.2 %	0.0 %	0.5 %
3	200	500	200–500	0	0.0 %	0.7 %	0.0 %	1.2 %
4	500	1000	500–1000	0	0.0 %	1.3 %	0.0 %	2.5 %
5	1000	2000	1000–2000	0	0.0 %	2.7 %	0.0 %	5.1 %
6	2000	5000	2000–5000	2	6.5 %	9.1 %	6.5 %	14.2 %
7	5000	10000	5000–10000	5	16.1 %	17.6 %	22.6 %	31.8 %
8	10000	20000	10000–20000	13	41.9 %	32.2 %	64.5 %	64.0 %
9	20000	50000	20000–50000	10	32.3 %	18.4 %	96.8 %	82.4 %
10	50000	100000	50000–100000	1	3.2 %	0.0 %	100.0 %	82.4 %
Total, sampling model	X	X	X	31	100 %	82 %	–	–

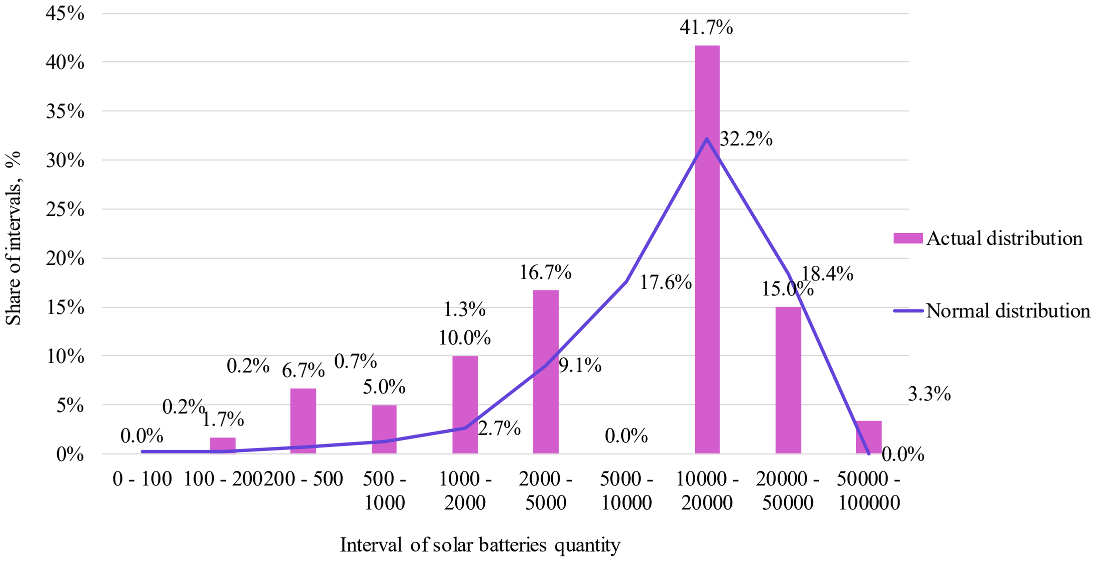


Fig. 1. Histogram of the distribution of model output data in frequency intervals

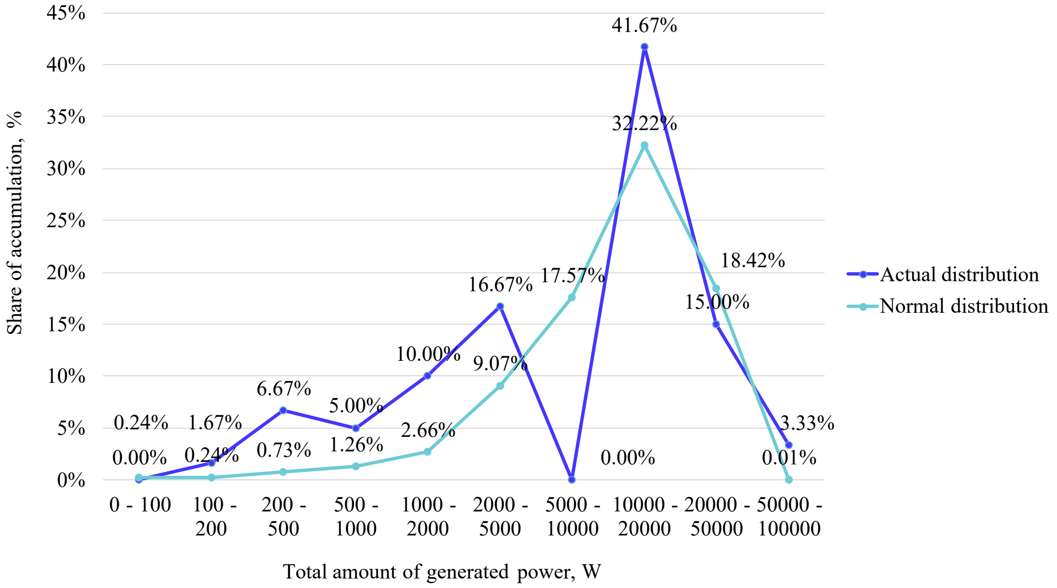


Fig. 2. Accumulation of frequencies of model output data

The comparison of actual (empirical) and theoretical frequencies and accumulated empirical and theoretical frequencies shown in Fig. 2 allow us to draw conclusions about compliance with the normal law of distribution and to determine the frequency discrepancy in each of the studied intervals.

5. 2. Determining the regression model of the influence of the design features of the structure of solar panels on productivity

When constructing a regression model of the dependence of the total amount of generated energy on the number of SB modules and the weighted average amount of generated energy, the initial data were determined (Table 2).

Table 2

Output data of the regression model of the dependence of the total amount of generated energy on the number of SB modules and the weighted average amount of generated energy

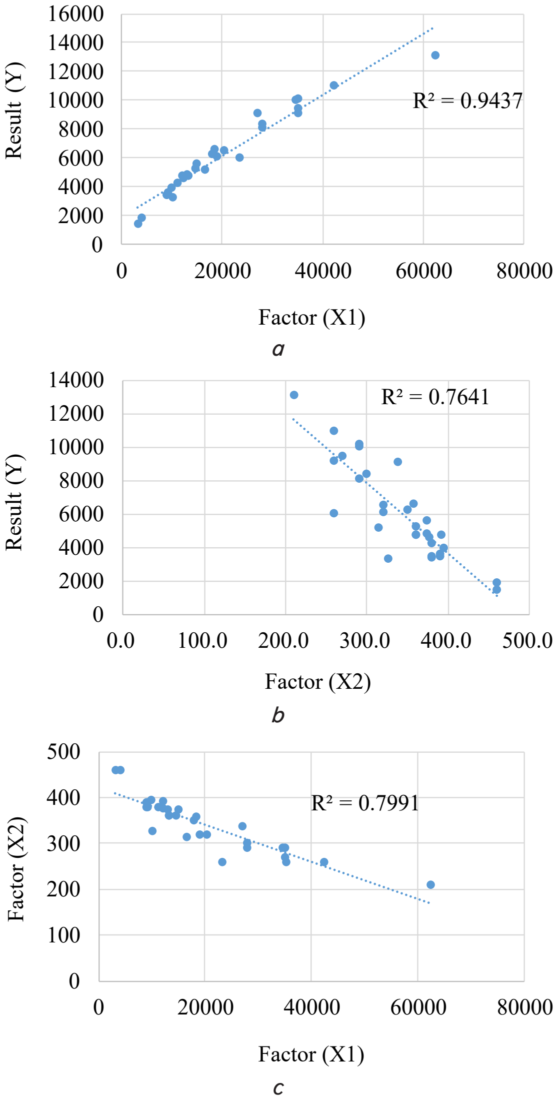
No. of entry	Number of SB modules, pcs ($X1$)	Weighted average amount of generated energy from SB modules, W/pcs ($X2$)	Total amount of generated energy, W (Y)
1	42 300	260	10998000
2	27 911	300	8373300
3	20 427	320	6536640
4	35 000	290	10150000
5	17 962	350	6286700
6	13 321	360	4795560
7	13 000	373	4849000
8	62 300	210	13083000
9	16 465	314	5170010
10	15 000	373	5595000
11	19 021	320	6086720
12	12 228	377	4609956
13	18 459	357	6589863
14	9 000	380	3420000
15	10 121	326	3299446
16	13 236	360	4764960
17	8 900	390	3471000
18	23 354	260	6072040
19	9 293	390	3624270
20	10 000	395	3950000
21	12 180	391	4762380
22	14 655	360	5275800
23	27 000	338	9126000
24	11 200	380	4256000
25	9 200	380	3496000
26	28 000	290	8120000
27	35 000	270	9450000
28	34 624	290	10040960
29	4 100	460	1886000
30	35 200	260	9152000
31	3 200	460	1472000

Partial correlograms of influencing factors on the resulting feature are shown in Fig. 3.

Fig. 3 shows that all three partial correlograms have a close relationship – the linear correlation coefficient is greater than 0.7.

Based on the direct calculation of the regression coefficients, the analytical form of the model is determined; the equation is divided by 1000 to convert into kW:

$$Y = 2113.528 + 0.2063X1 - 0.2757X2. \qquad (2)$$



a

b

c

Fig. 3. Partial correlograms (matrix scatter diagrams): *a* – $Y(X1)$; *b* – $Y(X2)$; *c* – $X1(X2)$

With an increase in the total amount of generated energy by more than 1 kW, the number of SB modules increases by an average of 0.2063 kW, and with an increase in Y by 1 kW, the weighted average amount of generated energy decreases by an average of 0.2757 kW.

Checking the significance of the coefficients showed that the paired regression of the dependence of the total amount of generated energy on the number of SB modules is the most statistically significant, reliable, and that it does not need to be improved by including the additional factor $X2$.

Based on the direct calculation of the regression coefficients, the analytical form of the model is determined; the equation is divided by 1000 to convert into kW:

$$Y = 6088.9045 + 0.2118X1. \qquad (3)$$

Fig. 4 shows the distribution of residuals (absolute errors) of the regression model.

Confirmation of the expediency of activating energy production is the results of the above regression analysis. Namely, the weighted average amount of generated energy has the greatest influence on the volume of the total amount of generated energy.

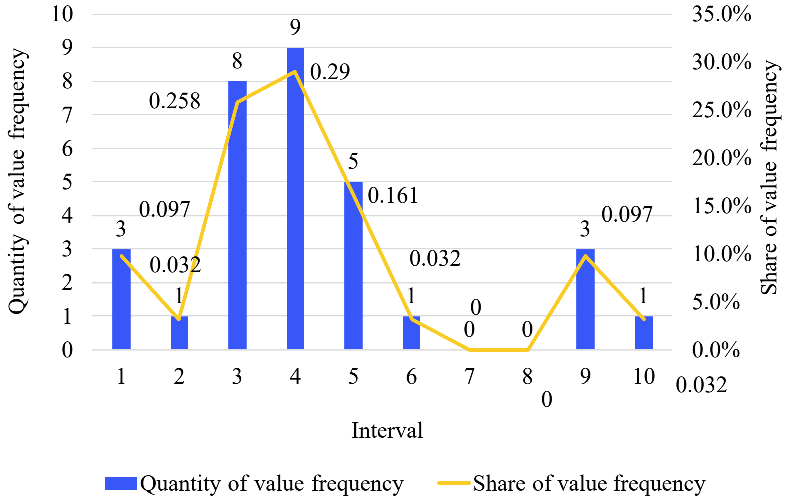


Fig. 4. Histogram of the distribution of the residuals (absolute errors) of the regression model

6. Discussion of results of the construction of a model of the influence of the design features of the structure of solar panels on productivity

In contrast to [1–12], where the scientific principles of choosing the optimal parameters for the operation of solar batteries are considered in a fragmentary manner, our result of the selection of parameters allows determining the plane of forecasts of the performance of solar panels depending on the design. This becomes possible thanks to the use of the method of regression analysis with the possibility of multi-criteria analysis of parameters of electrothermal protection of solar batteries. Fragmentation involves a single choice, without comparison, of the functioning parameters of solar batteries in power plants.

Conducting an analysis of the distribution of the output data of the model by the number of SB modules using the example of terrestrial solar installations, it is possible to determine the frequency intervals accordingly (Table 1). The constructed histogram of the distribution of the output data of the model in frequency intervals (Fig. 1) has a normal distribution. Logarithmization of intervals of values makes it possible to build the frequency accumulation of the output data of the model (Fig. 2).

A fragment of the output data of the regression model of the dependence of the total amount of generated energy on the number of SB modules and the weighted average amount of generated energy is provided (Table 2). The constructed partial correlograms (matrix scatter diagrams) allow us to determine that the spread of points relative to the regression plane is not at all large and therefore, most likely, the constructed model is useful (Fig. 3). The histogram of the distribution of the residuals (absolute errors) of the regression model (Fig. 4) show that the defined analytical model (3) meets the conditions for applying regression analysis.

The results can be used in the design of optimal options for electrothermal protection of solar batteries in power plants of space vehicles. Also, taking into account the specifics of the operating conditions of solar batteries during the operation of mobile vehicles of defense importance, which use SB technology.

The results of the study are limited by the range of variation of the input variables. In addition, there is a reserve for increasing the accuracy of the model by taking into account non-linear influencing factors, for example, leaving the core of the plan unchanged and implementing the procedure for building a central orthogonal composite plan. But at the same time, it should be possible to conduct an active experiment in the star points of the plan.

The simplification of the proposed study is based on the principle of ceteris paribus. Namely, SB functions under the same conditions. Conditions are determined by groups of factors: technical, economic, political, social, etc.

The advancement of this research involves the development of scenarios for the operation of solar batteries based on the change and interaction of factors (concepts) with the use of impulse and agent modeling. This will make it possible to develop the implementation of the necessary prevention, protection, and control mechanisms in emergency access situations at the appropriate levels of the energy infrastructure.

7. Conclusions

1. An analysis of the distribution of the output data of the model by the number of solar battery modules was carried out using the example of terrestrial solar installations. 10 intervals with the corresponding ranges of the number of modules in the corresponding design of SB are separated. The output data from the number of SB modules has a normal distribution, skewed to the left. This makes it possible to determine the sample as representative – its parameters coincide with the parameters of the general population within the specified permissible error.

2. A regression model of the dependence of the total amount of generated energy on the number of SB modules and the weighted average amount of generated energy was built. But the histogram of the residuals is slightly different from the normal law. The partial correlation plots indicate a good approximation to a linear relationship for all independent variables. With an increase in the total amount of generated energy by more than 1 kW, the number of SB modules increases by an average of 0.2063 kW, and with an increase in Y by 1 kW, the weighted average amount of generated energy decreases by an average of 0.2757 kW.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

The data will be provided upon reasonable request.

References

1. Abdmouleh, Z., Gastli, A., Ben-Brahim, L., Haouari, M., Al-Emadi, N. A. (2017). Review of optimization techniques applied for the integration of distributed generation from renewable energy sources. Renewable Energy, 113, 266–280. doi: https://doi.org/10.1016/j.renene.2017.05.087
2. Chang, R.-D., Zuo, J., Zhao, Z.-Y., Zillante, G., Gan, X.-L., Soebarto, V. (2017). Evolving theories of sustainability and firms: History, future directions and implications for renewable energy research. Renewable and Sustainable Energy Reviews, 72, 48–56. doi: https://doi.org/10.1016/j.rser.2017.01.029
3. Xu, X., Wei, Z., Ji, Q., Wang, C., Gao, G. (2019). Global renewable energy development: Influencing factors, trend predictions and countermeasures. Resources Policy, 63, 101470. doi: https://doi.org/10.1016/j.resourpol.2019.101470
4. Ibidunni, A. S., Ogunnaike, O. O., Abiodun, A. J. (2017). Extending the knowledge strategy concept: linking organizational knowledge with strategic orientations. Academy of Strategic Management Journal, 16 (3). Available at: https://core.ac.uk/download/pdf/162043788.pdf
5. Che, L., Zhang, X., Shahidehpour, M., Alabdulwahab, A., Abusorrah, A. (2017). Optimal Interconnection Planning of Community Microgrids With Renewable Energy Sources. IEEE Transactions on Smart Grid, 8 (3), 1054–1063. doi: https://doi.org/10.1109/tsg.2015.2456834
6. Kumar, A., Sah, B., Singh, A. R., Deng, Y., He, X., Kumar, P., Bansal, R. C. (2017). A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renewable and Sustainable Energy Reviews, 69, 596–609. doi: https://doi.org/10.1016/j.rser.2016.11.191
7. Chen, H. H., Lee, A. H. I., Kang, H.-Y. (2017). The fuzzy conceptual model for selecting energy sources. Energy Sources, Part B: Economics, Planning, and Policy, 12 (4), 297–304. doi: https://doi.org/10.1080/15567249.2011.652339
8. Karabegović, I., Doleček, V. (2015). Development and implementation of renewable energy sources in the world and European Union. Contemporary Materials, 6 (2), 130–148. doi: https://doi.org/10.7251/comen1502130k
9. Ghimire, L. P., Kim, Y. (2018). An analysis on barriers to renewable energy development in the context of Nepal using AHP. Renewable Energy, 129, 446–456. doi: https://doi.org/10.1016/j.renene.2018.06.011
10. Dubey, R., Gunasekaran, A., Papadopoulos, T., Childe, S. J., Shibin, K. T., Wamba, S. F. (2017). Sustainable supply chain management: framework and further research directions. Journal of Cleaner Production, 142, 1119–1130. doi: https://doi.org/10.1016/j.jclepro.2016.03.117
11. Dreidy, M., Mokhlis, H., Mekhilef, S. (2017). Inertia response and frequency control techniques for renewable energy sources: A review. Renewable and Sustainable Energy Reviews, 69, 144–155. doi: https://doi.org/10.1016/j.rser.2016.11.170
12. Nakashydze, L., Hilorme, T., Nakashydze, I. (2020). Substantiating the criteria of choosing project solutions for climate control systems based on renewable energy sources. Eastern-European Journal of Enterprise Technologies, 3 (3 (105)), 42–50. doi: https://doi.org/10.15587/1729-4061.2020.201527
13. Nakashydze, L., Gabrinets, V., Mitikov, Y., Alekseyenko, S., Liashenko, I. (2021). Determination of features of formation of energy supply systems with the use of renewable energy sources in the transition period. Eastern-European Journal of Enterprise Technologies, 5 (8 (113)), 23–29. doi: https://doi.org/10.15587/1729-4061.2021.243112
14. Zhou, Y., Cao, S., Hensen, J. L. M., Hasan, A. (2020). Heuristic battery-protective strategy for energy management of an interactive renewables – buildings – vehicles energy sharing network with high energy flexibility. Energy Conversion and Management, 214, 112891. doi: https://doi.org/10.1016/j.enconman.2020.112891
15. Kalair, A., Abas, N., Saleem, M. S., Kalair, A. R., Khan, N. (2020). Role of energy storage systems in energy transition from fossil fuels to renewables. Energy Storage, 3 (1). doi: https://doi.org/10.1002/est2.135
16. Anvari, A. (2019). Application of plasma technology in aerospace vehicles: A review. Journal of Engineering and Technology Research, 11 (2), 12–28. doi: https://doi.org/10.5897/jetr2018.0654
17. Hilorme, T., Perevozova, I., Sakun, A., Reznik, O., Khaustova, Ye. (2020). (2020). Accounting model of human capital assessment within the information space of the enterprise. Academy of Accounting and Financial Studies Journal, 24 (3). Available at: https://www.abacademies.org/articles/Accounting-Model-of-Human-Capital-Assessment-Within-the-Information-1528-2635-24-3-540.pdf
18. Hilorme, T., Nakashydze, L., Mazurik, S., Gabrinets, V., Kolbunov, V., Gomilko, I. (2022). Substantiation for the selection of parameters for ensuring electrothermal protection of solar batteries in spacecraft power systems. Eastern-European Journal of Enterprise Technologies, 3 (8 (117)), 17–24. doi: https://doi.org/10.15587/1729-4061.2022.258480
19. Tonkoshkur, A., Ivanchenko, A., Nakashydze, L., Lyashkov, A., Gomilko, I. (2021). Application of polymer posistor nanocomposites in systems for protecting photovoltaic components of solar arrays from electrical overloads. Boston. doi: https://doi.org/10.46299/978-1-63972-054-5