1. Vadim MANUSOV[1], 2. Alifbek KIRGIZOV[2], 3. Murodbek SAFARALIEV [3], 4. Inga ZICMANE[4], 5. Svetlana BERYOZKINA[5], 6. Sherkhon SULTONOV[2]

Novosibirsk State Technical University (1), Tajik Technical University (2), Ural Federal University (3), Riga Technical University (4), College of Engineering and Technology, American University of the Middle East, Kuwait (5)
ORCID: 2. 0000-0001-6603-1393; 3. 0000-0003-3433-9742; 4. 0000-0002-3378-0731. 5. 0000-0003-1593-129X; 6. 0000-0003-2322-5272;

doi:10.15199/48.2024.02.23

Stochastic Method for Predicting the Output of Electrical Energy Received from a Solar Panel

***Abstract**. One of the most important and promising types of non-traditional (renewable) energy sources is solar energy. Solar energy has two important advantages: first, its quantity is huge, and it is almost inexhaustible, and second, its use does not hurt the environment. However, the practical use of solar energy is difficult due to the low surface density of solar radiation. In addition, there are problems associated with the solar radiation fluctuations varying during daytime and period of the year. This work aimed to develop a method that allows predicting the output power of the solar panel based on a stochastic model. The proposed stochastic approach considers the following factors: fluctuations (random deviations) of solar radiation at different time intervals, the variable nature of the consumers' load, and the temperature mode of solar photovoltaic panels leading to assess their efficiency. The study presents a theoretical model with the future practical implementation.*

***Streszczenie.** Jednym z najważniejszych i najbardziej obiecujących rodzajów nietradycyjnych (odnawialnych) źródeł energii jest energia słoneczna. Energia słoneczna ma dwie ważne zalety: po pierwsze jej ilość jest ogromna i jest prawie niewyczerpalna, a po drugie jej wykorzystanie nie szkodzi środowisku. Jednak praktyczne wykorzystanie energii słonecznej jest trudne ze względu na małą gęstość powierzchniową promieniowania słonecznego. Ponadto występują problemy związane ze zmiennymi wahaniami promieniowania słonecznego w ciągu dnia i pory roku. Praca ta miała na celu opracowanie metody pozwalającej przewidywać moc wyjściową panelu fotowoltaicznego na podstawie modelu stochastycznego. Proponowane podejście stochastyczne uwzględnia następujące czynniki: fluktuacje (losowe odchylenia) promieniowania słonecznego w różnych przedziałach czasowych, zmienny charakter obciążenia odbiorców oraz tryb temperaturowy paneli fotowoltaicznych prowadzący do oceny ich wydajności. W opracowaniu przedstawiono model teoretyczny wraz z przyszłą praktyczną implementacją.(**Stochastyczna metoda przewidywania wydajności energii elektrycznej odbieranej z panelu słonecznego**)*

Keywords: Photovoltaic panels, renewable energy, stochastic method, solar energy, solar radiation
Słowa kluczowe: Panele fotowoltaiczne, energia odnawialna, metoda stochastyczna, energia słoneczna, promieniowanie słoneczne

Introduction

The development of the economies of rapidly developing countries and an increase in the standard of living of the population, as a rule, leads to an increase in the electricity demand. At the same time, the reserves of hydrocarbon fuel are decreasing every year, in addition, own sources of minerals are distributed extremely unevenly throughout the world. Environmental problems forcing scientists and researchers to increase the usage of alternative energy sources. Moreover, the adopted convention on the reduction of greenhouse gas emissions into the earth's atmosphere also drives the more active use of renewable energy sources (RES). Solar energy is considered the most acceptable source of electricity generation since it is the most affordable, free, and abundant for many regions of the world [1-6].

The main unit of a solar photovoltaic cell is a solar cell. Solar panels can only produce a small amount of energy. The power generated by a solar cell depends on its efficiency. Depending on the efficiency of the element, the power generated per unit area varies in the range of 10–25 W/cm2, which corresponds to 10–25% of the cell efficiency [7]. The typical area of one solar cell is 225 cm^2. With a cell efficiency of 10%, the maximum generated power is 2.25 W. To meet high power requirements, these cells are connected series/parallel to form modules. Solar photovoltaic modules are currently available with a power range from 3 W to 200 W.

Photovoltaic converters work during the day, and in the morning and evening twilight (with less efficiency). Moreover, the peak of power consumption occurs precisely in the evening hours. The produced electricity can fluctuate dramatically and unexpectedly due to weather changes. To overcome these disadvantages, solar power plants use efficient electric batteries. Nowadays, this problem is being solved by creating unified energy systems that combine various energy sources by redistributing the generated and consumed power [2, 8-12].

As known, the price of solar panels is relatively high, but with the development of technology and the rise in fossil fuel prices, this disadvantage will be gradually overcome. The surface of photovoltaic (PV) panels and mirrors (for heating machines) is cleaned from dust and other contaminants. The efficiency of the PV panels decreases when they are heated (this mainly concerns systems with concentrators), therefore, it becomes necessary to install cooling systems, usually water. In the PV panels, the conversion of thermal radiation into radiation is used for cooling most consistently with the absorbing material of the PV cell (the so-called up-conversion) [1, 5].

High variability of the energy supply to the generation unit could be considered one of the main issues related to the integration of the renewable energy sources, mainly, the solar, wind, and hydropower plants because of their operating nature. As result, the quality of the power supply reduces as well as problems occur due to new renewable units' integration into the unified power system.

As known, the variability of energy production could be divided into both deterministic and random components. The deterministic component includes stable cyclical processes, which are characterized by time dependences: seasonal, daily, etc. Deterministic solutions operate with fully established information. The random component considers various stochastic processes, which are extremely difficult to predict, for instance, strong deviations from average long-term observations. In the general case, the solution of such problems is based on deterministic methods solved under conditions of information incompleteness and essentially stochastic ones.

Solar PV panels have non-linear characteristics, and the produced electricity obeys a probabilistic model. The generated output power of the solar panel varies depending on meteorological factors and environmental conditions. To solve the problem of defining the PV panel generated power, the methods of deterministic and stochastic factor modeling are applied. For example, the two new stochastic forecasting models of the solar photovoltaic have been proposed in [13], where authors used the measurement data of the solar radiation and PV power to schedule a short-term probabilistic behavior of solar. Another study utilizes a novel artificial intelligent algorithm to predict solar irradiance in an adaptive and precise way, where forecasting is realized in real-time based on learning of data from discrete to continuous [14]. The prediction of the PV array power production based on the static model has been described in [15], where authors integrated both manufacturers and online data, for instance, solar irradiance, the PV array temperature data, and model parameters. The proposed mathematical model of a prediction of the PV panel output power has been proposed in [16], where authors examined the PV performance under different environmental conditions (collected data) lasting for two years in the State of Qatar.

This paper aims to analyze the issue of the admissibility of combining both deterministic and stochastic approaches to improve the accuracy of calculating the output power of solar panels. The formulation and solution of such statistical problems are carried out based on the probabilistic criteria, which, unlike deterministic ones, most often contain an additional operation of the statistical averaging and therefore are more complicated. The presented study considers a mathematical description of a new stochastic method to define the output power of the solar PV panel considering the variability of the solar radiation, consumption load, and PV panel temperature providing the possibility to access the solar panel efficiency. The proposed method considers a theoretical approach to the electrical energy prediction of the solar panel with the future practical implementation.

This paper is organized as follows: Section 2 describes the theoretical concept of the proposed stochastic method. Section 3 presents conclusions.

The Proposed Stochastic Method

Problem Statement

Forecasting the electricity demand for the energy units made of solar panels is an urgent task. To achieve the required accuracy of the computation, it is customary to use various deterministic methods based on the available changing and slightly changing data about the research object. Moreover, the statistical data can be used in the analysis by applying stochastic methods.

When solving the problem related to prediction and technological processes, the main concern is to determine the optimal parameters. From a mathematical point of view, this leads to the solution of the parameters' optimization problem. One of the main difficulties encountered in solving such problems is the presence of mathematical uncertainty when the output parameters of solar panels must be determined. The nature of the uncertainty can be different, thus, without considering all the uncertainties, the obtained solution to the stated problem may differ from the experimental approach.

The issues related to the prediction of the electricity generation at facilities operating under various types of renewable energy sources are associated with the problem of the stochastic nature of their generation. Such a task is multifactorial with a large number of poorly formalized and linguistic data since it is based on meteorological and climatological data, the aggregated nature of which also has a strong influence on the generation forecasting of the electrical energy.

Among other factors affecting generation power by the solar panels, there are many difficult-to-formalize heterogeneous parameters, for example, losses in inverters and transformers, in AC and DC lines, also the solar panel degradation, and other factors considered in the model. The key stage in predicting the generation of the appropriate authorities is to determine the main energy characteristic - solar panels, which depends on many hard-to-predict factors of a meteorological nature, Fig. 1.

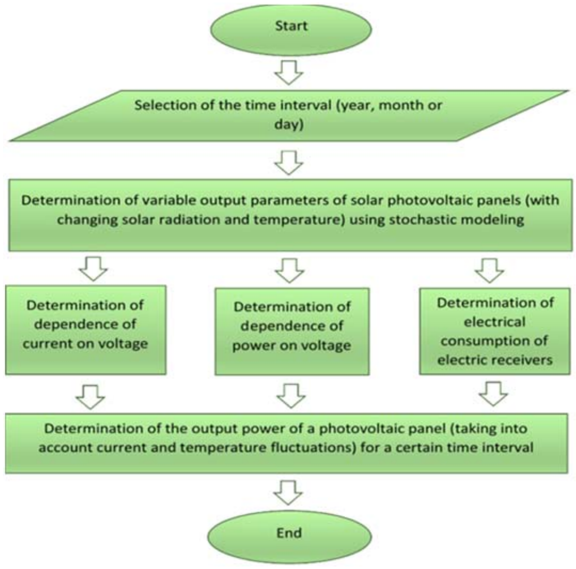

Fig. 1. Algorithm of determination of the output power of a photovoltaic panel

Parameters Selection

The output parameters of solar PV panels, offered by the manufacturers, are taken with the constancy of various factors affecting their output power. Fig. 2 and Fig. 3 show the characteristics of the dependence of current on voltage, and power on the voltage at constant solar radiation and temperature accordantly [10]. Fig. 4 shows the dependence of power on voltage with constant solar radiation and varying temperature. As the temperature rises, the panel's output power decreases.

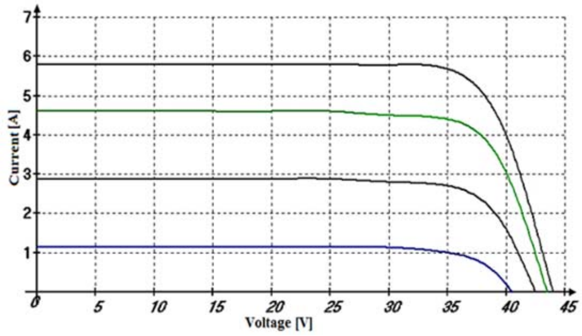

Fig. 2. Dependences on the current of the PV panel voltage at constant solar radiation

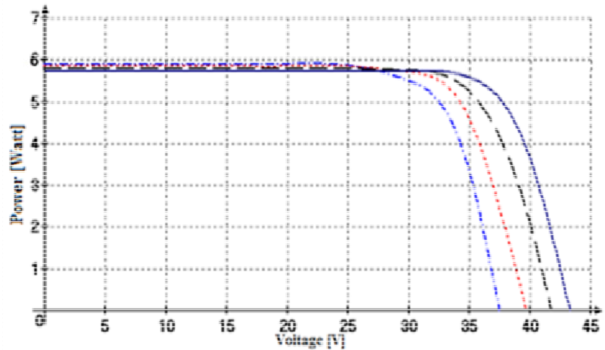

Fig. 3. Dependences on the power of the PV panel voltage at constant solar radiation

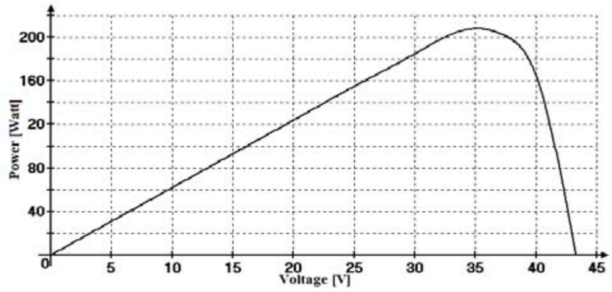

Fig. 4. Dependences on the power of the PV panel voltage at different ambient temperatures

In real conditions, these parameters cannot be constant, therefore, the output power of the PV panel will depend on all parameters at the same time.

Moreover, there are also technical inconsistencies in the manufacture of solar panels that can affect the output power too. In solar PV modules, solar cells are connected in series or in parallel on the assumption that all parameters of the connected solar cells are identical.

In practice, inconsistency can occur for the following reasons:

• Elements or modules have the same characteristics, but are manufactured in different ways;

• Cells are processed differently;

• External conditions, namely, conditions of partial shading, are different;

• Glass overs, etc. may be broken.

Connection mismatch can be caused by electrical parameters, but the most common mismatch occurs in two parameters, i.e. open-circuit voltage (V_{oc}) and short-circuits current (I_{SC}). Among these two parameters, I_{SC} mismatch is of concern, especially when solar cells are connected in series, which is a common way.

Inconsistency in V_{oc} is a problem when solar cells/modules are connected in parallel. Fig. 5 shows an analysis of the impact of I_{SC} mismatch when two solar cells are connected in series and their I_{SC} does not match. *T Cell 1* has a higher I_{SC} compared to cell 2. By convention, the I_{SC} flowing through the external circuit will be equal to the lower I_{SC} value, namely, cell 2 in this case. If the combination operates in a short-circuit condition, the sum of the voltage across both cells is zero, that is, on the Y-axis (where the dotted line intersects). At this current value, a solar cell with a lower I_{SC} value is forced to operate in reverse-bias mode. Due to this effect, there will be significant power losses.

Power conversion efficiency is measured by dividing the output electric power by the incident light power. Factors affecting output include spectral distribution, spatial power distribution, temperature, and resistive loading. The IEC 61215 standard [17] is used to compare cell performance and is designed considering standard (terrestrial, moderate) temperature and conditions (STC): illumination 1 kW/m^2, spectral distribution close to solar radiation through AM (air mass) 1.5 and cell temperature of 25°C. The resistive load changes until the peak or maximum power (MPP) is reached. The power at this point is recorded as peak watt (W_p). The same standard is used to measure the power and efficiency of PV modules and the efficiency of solar cells.

Since solar radiation has a probabilistic nature, the output power of the PV panel is also subject to this law. A probabilistic model is proposed for determining the power generated by PV systems due to solar insolation. The uncertainty of the model is associated with the uncertainty of the intensity of solar radiation, as well as with the probabilistic nature of the power consumption of electrical receivers [18-20].

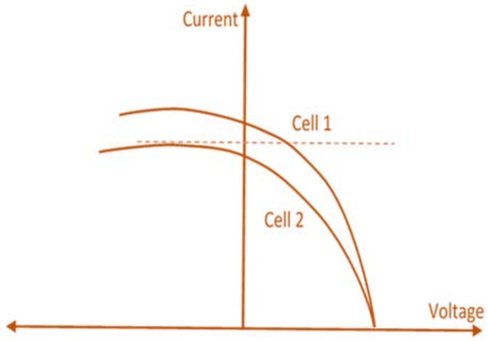

Fig. 5 The cell parameters of the I-V characteristic curve do not match

A simple way to determine the output power of a solar panel is through deterministic modeling, which considers only one factor. The deterministic model can be described as follows. The output power of a PV panel and power generation is related not only to the intensity of solar exposure but also to uncertainties such as temperature. On this basis, the deterministic model can be formulated as follows:

(1) $$\mathrm{P}_{det.SPP} = (1 - \alpha\eta_{SPP})\mathrm{P}_{instSPP},$$

(2) $$a = a_{ref}\left(\frac{T}{T_{ref}}\right),$$

where ***a*** - the ideality coefficient; a_{ref} - temperature coefficient; ηSPP - efficiency factor of a solar PV panel; $P_{instSPP}$ - installed power of the solar PV panel, *W; T* - set temperature, ^{0}C; T_{ref} - PV panel reference temperature for standard conditions, ^{0}C.

The temperature coefficient of resistivity can be determined as follows:

(3) $$\alpha_{ref} = \frac{1}{R}\cdot\frac{dR}{dT},$$

where *R* - the electrical resistance of the solar panel, Ω.

This value defines the relationship between the electrical resistance of the solar converter (panel) and temperature.

For most metals, the temperature coefficient αref is assumed constant in the temperature range from 0 to 25^0 C. For pure metals, the temperature coefficient of resistance is assumed to be as follows:

(4) $$\alpha_{ref} \approx \frac{1}{273} \approx K^{-1}.$$

Thus, the efficiency of the solar PV installation in % will be defined as:

(5) $$\eta SPP = \eta_0\,(1 - 0{,}0045\cdot(T_{panel} - 25)),$$

where η_0 - solar panel efficiency at 25 ^{0}C, %; *Tpanel* - solar panel surface temperature, ^{0}C.

Since the efficiency of solar panels depends on the radiation parameters and operating temperature, their variability of them must be considered. For instance, due to cloudiness and different time of the day the solar radiation changes, the same applies to ambient temperatures leading to the efficiency changes. As result, these changes must be considered, when calculating the electricity generated by solar panels in real ground conditions.

In this case, the surface temperature of the panel at ^{0}C is determined as follows [7, 21-26]:

(6) $$T_{panel} = T_{air} + E_i/800\,(T_{n.expl} - 20^0C),$$

where T_{air} – the ambient temperature at the design point, ^{0}C; E_i - solar radiation, W/m^2; $T_{n.expl}$ - solar panel surface temperature for a specific solar day for a specific month in operation, ^{0}C [26, 27].

In reality, the deterministic above-presented model does not take into account the active power loss in the resistance of the solar energy conversion device. If we assume that the solar battery generates only active power, which corresponds to reality, then the active power of the electric consumer P is equal to:

(7) $$P = U \cdot I,$$

where U - the voltage of the generation source, *V; I* - the current of the electric consumer, *A*.

Since the voltage of the source is maintained *constant U = const*, the deviation of the power of the electric consumer from the nominal value, for example, on a daily time interval, leads to a change in the current [28].

The solar module can operate at any voltage and current parameter located on its current-voltage characteristic (VAC), but in reality, the module works at one point at a given time. This point is not selected by the module, but by the electrical characteristics of the circuit to which this module is connected.

One of the negative properties of solar panels is the fact that the maximum power take-off from the solar battery takes place when the resistance of the external load satisfies the following condition:

(8) $$R_l = \frac{0.85 \cdot U_{xx}}{0.85 \cdot I_{sc}} \approx \frac{U_{xx}}{I_{sc}},$$

where R_l - the load resistance, Ω; U_{xx} – no-load voltage, V; I_{sc} – short-circuit current, A.

Since with a constant external load, this condition is continuously violated depending on the illumination and temperature, this circumstance must be considered when developing solar electrical installations.

The output power of a solar panel depends on many factors and their interrelationship, and stochastic modeling is suitable for determining it. Stochastic methods are based on the probabilistic nature of predicting which is a more convenient way predicting energy production from renewable sources. The probability of calculating the exact output power of RES installations is determined by the amount of input data used in predicting [26, 29, 30].

It can be assumed that random deviations of the power of the electric consumption in the time interval and, therefore, the current obey the normal law of the probability distribution, this is especially well consistent in the modes of maximum power consumption (peak hours). Then the output power of a solar device – PV panel is determined by a more accurate stochastic formula such as:

(9) $$P_{sto.SPP} = \left(1 - \alpha \cdot \left(1 - \frac{\Delta P_{Det\Sigma}}{P}\right)\right) \mathrm{P}_{instSPP},$$

where $\Delta P_{Det\Sigma}$ - total losses of active power in the electrical resistance of the solar panel, Joule losses, W; P - consumed active power, W.

In the probabilistic formulation of the problem, with a stochastic variation of the load current, the active power losses increase considering additional losses from the current variation (dispersion) and are equal to:

(10) $$\Delta P_{\Sigma sto} = M[I^2]R + D_I R = \left(\overline{I^2} + D_I\right)R \ ,$$

where $M[I] = \bar{I}$ is the mathematical expectation of the load current; $D_I = \sigma^2$ is the dispersion of the load current, $D_I\ squared\ is = \sigma^2$ is the standard deviation of the current [31-33].

As a result, the stochastic model of the output power of a solar PV panel can be written in the following form [34]:

(11) $$\mathrm{P_{sto.SPP}} = \left[1\text{-}\alpha \cdot \left(1\text{-}\frac{\Delta \mathrm{P}_\Sigma}{\mathrm{P}}\right)\right] \cdot \mathrm{P_{instSPP}} = \left[1\text{-}\alpha \cdot \left(1\text{-}\frac{(\overline{\mathrm{I}^2}+\mathrm{D_I})\mathrm{R}}{\mathrm{P}}\right)\right] \cdot \mathrm{P_{instSPP}} \ .$$

The resulting expression makes it possible to clarify the output power of the solar PV panel, taking into account both the current and temperature fluctuations at any time interval. The decrease inefficiency is caused by a linear drop in the open-circuit voltage due to a sharp exponential rise in the reverse saturation current and a corresponding decrease in the duty cycle.

Conclusions

Analysing the developed mathematical model from the theoretical point of view, the following could be concluded:

The real efficiency of a solar installation considering load fluctuations is somewhat lower than it is assumed in an idealized technical system: a load current fluctuation characterized by the magnitude of the current dispersion increases the losses in a resistor circuit.

The value of solar radiation (insolation) is a random variable that obeys the beta distribution law of probabilities of the third kind, which makes the model even more reliable, at the same time more complicated. To solve predicting problems in the field of solar energy, not only the average values of the sums of solar energy fluxes are important, but also their changes from year to year, which are primarily characterized by long-term standard deviations of these values. The total annual prediction of solar energy is more stable from year to year than monthly, and even more than daily, which is quite explainable by a significant amount of statistical data in the first case.

It is shown that the deterministic model is a special case of a more general stochastic model. The disadvantage of this approach is that it does not fully cover the fact that there are many possible outcomes, some more likely and some less likely.

The use of the proposed stochastic model to predict the output power of the solar PV panel could be considered reliable. Deterministic simulations with different scenarios do not provide accurate information on the guaranteed power from the solar panel because deterministic modelling does not consider all the factors that can affect the final power received from the solar PV panel. Stochastic modelling builds all variations (randomness) while performing the simulations, and therefore provides a better definition of the solar panel's output power taking into account all external factors impacting it over time.

An assessment of the accuracy influence of generation forecasting of the solar panels on the volume of active power reserves must be determined in the short-term planning of consumer operating modes. According to the existing practice of operational dispatch control, at the stages of short-term planning of electrical modes to compensate the stochastic decrease in power output by power plants based on renewable energy sources, the volume of reserves significantly increases.

Conflict of Interest. The authors declare no conflict of interest.

Acknowledgment
This research received no external funding.

Authors
D.Sc Manusov Vadim Zinovievich, Department of Industrial power supply systems, Novosibirsk State Technical University, Prospekt K. Marksa, 20, Novosibirsk, 630073, Russian Federation, e-mail: manusov36@mail.ru; PhD Kirgizov Alifbek Kirgizovich, Department of Electric stations, academicians Rajabov's avenue 10, 734042, Dushanbe, Republic of Tajikistan, e-mail: alifbek@mail.ru; PhD Murodbek Kholnazarovich Safaraliev , Department of Automated Electrical Systems, Ural Federal University, 19, Mira Street, Yekaterinburg, 620002, Russian Federation, e-mail: murodbek_03@mail.ru; D.Sc Inga Zicmane, Faculty of Electrical and Environmental Engineering, Riga Technical University, LV-1048 Riga, Latvia, e-mail: Inga.Zicmane@rtu.lv; PhD Svetlana Beryozkina, College of Engineering and Technology, American University of the Middle East, Egalia 54200, Kuwait, e-mail: Svetlana.Berjozkina@aum.edu.kw; PhD Sultonov Sherkhon Murtazoqulovich, Department of Electric stations, academicians Rajabov's avenue 10, 734042, Dushanbe, Republic of Tajikistan, e-mail: sultonzoda.sh@mail.ru;

REFERENCES

[1] Qazi, A., Fayaz, H, Wadi, A., Raj, R.G., Rahim, N.A., Khan, W.A. The Artificial Neural Network for Solar Radiation Prediction and Designing Solar Systems. A Systematic Literature Review, *Journal of Cleaner Production*, (2015), 1-12.
[2] Safaraliev M. Kh., Odinaev I. N., Ahyoev J. S., Rasulzoda Kh. N., Otashbekov R. A. Energy Potential Estimation of the Region's Solar Radiation Using a Solar Tracker, *Applied Solar Energy 56* (2020)., 270-275.
[3] Malinowski M., Leon J.I., Abu-Rub H. Photovoltaic Energy Systems. In Power Electronics in Renewable Energy Systems and Smart Grid: Technology and Applications, *Wiley*, (2019), 347-389.
[4] Padiyar K.R., Kulkarni A.M.Solar Power Generation and Energy Storage in Dynamics and Control of Electric Transmission and Microgrids, *Wiley*, (2019), 391-414.
[5] Singh G.K. Solar power generation by PV (photovoltaic) technology: A review, *Energy 53* (2013), 1-13.
[6] Katiraei F., Aguero J.R. Solar PV integration challenges, *IEEE Power and Energy Magazine 9* (2011), 62-71.
[7] Denholm P., Margolis R.M. Evaluating the limits of solar photovoltaics (PV) in traditional electric power systems, *Energy policy 35* (2007)., 2852-2861.
[8] Kirgizov A.K., Sultonov Sh.M. Mathematical Simulation of Energy Transformation Processes in an Energy Center, *Applied Solar Energy, 54* (2018), 314-317.
[9] Mukhammadiev M.M., Mamadiyarov E.K., Urishev B.U., et al. Technological model of micro power facilities based on renewable energy sources with the energy storage, *Applied Solar Energy, 48* (2012), 152-156.
[10] Adinoyi M.J., Said S.A. Effect of dust accumulation on the power outputs of solar photovoltaic modules, *Renewable energy, 60* (2013), 633-636.
[11] K. Berzina K., Zicmane I., Kasperuks K. Assessment of the Use of PV Panels with Energy Accumulation Option for Riga City Office Building, International Journal of Photoenergy, (2019), 1-11.
[12] Veremiichuk, Y., Yarmoliuk, O., Pustovyi, A., Mahnitko, A., Zicmane, I., Lomane, T. Features of Electricity Distribution Using Energy Storage in Solar Photovoltaic Structure, *Latvian Journal of Physics and Technical Sciences*, 57 (2020), no.5, 18-29.
[13] Dong J., Olama M.M., Kuruganti T., Melin A.M., Djouadi S.M., Zhang Y., Xue Y. Novel stochastic methods to predict short-term solar radiation and photovoltaic power, *Renewable Energy, 145* (2020), 333-346.
[14] Puah B.K., Chong L.W., Wong Y.W., Begam K.M., Khan N., Juman M.A., Rajkumar R.K. A regression unsupervised incremental learning algorithm for solar irradiance prediction, *Renewable Energy 164* (2021), 908-925.
[15] Gulin M., Pavlović T., Vašak M. Photovoltaic panel and array static models for power production prediction: Integration of manufacturers' and on-line data, *Renewable Energy 97* (2016), 399-413.
[16] Touati F., Chowdhury N.A., Benhmed K., A. J.R. San Pedro Gonzales A. J.R, Al-Hitmi M.A., M. Benammar M., A. Gastli A., Ben-Brahim L. Long-term performance analysis and power prediction of PV technology in the State of Qatar, *Renewable Energy 113* (2017), 952-965.
[17] International standard IEC 61215:2021 RLV – Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements, 96 p. Online:
[18] Sharma V., Chandel S.S. Performance and degradation analysis for long term reliability of solar photovoltaic systems: a review, *Renewable and Sustainable Energy Reviews 27* (2013), 753-767.
[19] Tonui, J.K., Tripanagnostopoulos Y. Performance improvement of PV/T solar collectors with natural air flow operation, *Solar Energy 82* (2008), 1-12.
[20] Powers L., Newmiller J., Townsend T. Measuring and modeling the effect of snow on photovoltaic system performance. *in 35th IEEE Photovoltaic Specialists Conference (PVSC), Honolulu*, (2010), 000973-000978.
[21] Manusov V.Z., Kirgizov A.K., Sultonov S.M. Optimization of the Operating Mode of a Hybrid Power Complex Consisting of Renewable Energy Sources, *in XIV International Scientific-Technical Conference on Actual Problems of Electronics Instrument Engineering (APEIE), IEEE, Novosibirsk*, (2018), 286-289.
[22] Asanova S.M., et. al. Optimization of the structure of autonomous distributed hybrid power complexes and energy balance management in them, *International Journal of Hydrogen Energy* 46.70 (2021), 34542-34549.
[23] Asanov M.S. et al., Algorithm for calculation and selection of micro hydropower plant taking into account hydrological parameters of small watercourses mountain rivers of Central Asia, *Int. J. Hydrogen Energy*, 46 (2021), № 75, 37109-37119.
[24] Kim S.K., Jeon J.H., Cho C.H., Kim E.S., Ahn J.B. Modeling and simulation of a grid-connected PV generation system for electromagnetic transient analysis, *Solar Energy 83* (2009), 664-678.
[25] Tyukhov I., Schakhramanyan M., Strebkov D., Tikhonov A., Vignola F. Modelling of solar irradiance using satellite images and direct terrestrial measurements with PV modules, *in Proc. of SPIE, the International Society for Optical Engineering. Optical Modeling and Measurements for Solar Energy Systems III, San Diego*. 7410 (2009), 48-56
[26] Arnold M., Negenborn R.R., Andersson G., Schutter B.D. Model-Based Predictive Control Applied to Multi-Carrier Energy Systems, *in Proc. of the IEEE PES General Meeting, Calgary*, (2009), 1-8
[27] Lukutin B.V., Surzhikova O.A., Shandarova E.B. (2012). Renewable energy in decentralized power supply, *Moscow: Energoatomizdat,* 231 p. (In Russian)
[28] Masih A., et al. Application of Dual Axis Solar Tracking System in Qurghonteppa, Tajikistan, *in IEEE 7th International Conference on Smart Energy Grid Engineering (SEGE),* (2019), 250-254.
[29] Khasanzoda, N., Safaraliev, M., Zicmane, I., Beryozkina, S., Rahimov, J., Ahyoev, J. Use of smart grid based wind resources in isolated power systems. *Energy 253*, (2022), 124188.
[30] Khasanzoda, N., Zicmane, I., Beryozkina, S., Safaraliev, M., Sultonov, S., Kirgizov, A. Regression model for predicting the speed of wind flows for energy needs based on fuzzy logic. *Renewable Energy 191,* (2022),723-731.
[31] Manusov V.Z., Beryozkina S., Nazarov M.H., M. Safaraliev, I. Zicmane, P.V. Matrenin, A.H. Ghulomzoda, Optimal management of energy consumption in an autonomous power system considering alternative energy sources. *Mathematics 10 (3), (2022)*, 525
[32] International Renewable Energy Agency (IRENA). Concentrating Solar Power. Renewable Energy Technologies: Cost analysis series. Volume 1, Power Sector, Issue 2/5, https://www.irena.org//media/Files/IRENA/Agency/Publication/2012/RE_Technologies_Cost_Analysis-CSP.pdf. (accessed 27 September 2021).
[33] Wang X., Kurdgelashvili L., Byrne J., Barnett A. The value of module efficiency in lowering the levelized cost of energy of photovoltaic systems, *Renewable and Sustainable Energy Reviews 15* (2011), 48-54.