COMBINED ENERGY SYSTEMS BASED ON RENEWABLE ENERGY SOURCES

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Ensuring the quality of energy supply to remote regions is relevant for grid companies and the state. One of the solutions to this problem is the use of renewable energy sources to generate electrical energy. Given this, the article considers an integrated approach to designing combined autonomous energy systems of an individual residential building based on renewable energy sources with the complete replacement of traditional energy carriers. In addition to the combined power system, the proposed solution implies using an insulated facade of the building, which will reduce heat loss by 1.5 times, compared with an un-insulated building. to increase the reliability of the energy supply, the project provides for a wind power plant, a backup diesel generator station and a battery pack with an inverter. Estimated calculations have shown that the probability of failure of the power system of this configuration is 3%. The conducted ecological and economic justification of the use of an autonomous combined power system allows us to conclude that 2.1 tons of conventional fuel per year is saved and the payback of the energy supply system for a period of up to 8 years.

KEYWORDS

Renewable energy, Photovoltaic array, P–V And I–V Curve, Wind power plant, Wind-Diesel system, Combined energy

1 INTRODUCTION

On the territory of the Crimean Peninsula, as in any other region of Russia, there are several problems with uninterrupted power supply to various facilities [Abd Ali 2019a, Cheboxarov 2019a,b, Vologdin 2019]. Taking into account the level of own generation and the presence of significant potential of renewable energy sources (RES) on the peninsula, it can be concluded that the lack of own production and power outages from the mainland, as well as the poor quality of electricity transmitted through obsolete internal networks, lead to a voltage drop in transmission lines below the permissible level, especially in winter, which negatively affects the end consumer [Ayang 2016, Abdel-Aty 2020, Abd Ali 2021]. The paper considers one of the solutions to this problem in the example of an individual residential building. The territory of Crimea is rich in its own natural energy resources, which can provide electricity generation without emissions of pollutants into the environment [Humar 2011, Waqas 2013, Kuvshinov 2019a, Abd Ali 2020]. Namely: wind, solar and geothermal energy.

2 MATERIALS AND METHODS

An individual residential building with an area of up to 300 m2, located outside the city limits, was chosen as an object for the development of a fully autonomous energy supply project based on renewable energy sources, due to the remoteness from centralized power supply networks. An autonomous combined power system with a complete replacement of traditional energy carriers was designed and calculated for the selected facility [Diao 2019]. During the development of the project, a phased solution of a number of tasks was envisaged, including an energy analysis of the territory for the selection of generating plants based on renewable energy, the design features of the building were considered, and its energy consumption was calculated [Abd Ali 2019b].

The conducted energy analysis of the construction site of the facility assumed the determination of the potential of renewable energy resources and the choice of generating plants. The potential of wind energy is considered, which makes it possible to convert the mechanical energy of a rotating rotor on a wind power plant (wind turbine) into electrical energy [Abdali 2022, Porte-Agel 2020]. The above paper accepts a similar solution [Wiecek 2019].

Solar energy is one of the most promising in this area. In cloudless weather, an average of 1 kW/m^2 of solar energy falls on the horizontal surface, it can be converted photothermal into thermal energy for hot water supply (HWS) and heating systems due to flat solar collectors (FSC). The thermal energy of the Earth, or as it is also called – geothermal energy, is used to supply thermal energy to a building using an underground heat pump (HP), which takes heat from the bowels of the earth and, after conversion, transfers it to heat the coolant in the heating system or HWS [Elbakian 2018, Saga 2019]. Based on the analysis, it is concluded that it is advisable to use a combined decentralized system based on renewable energy sources for uninterrupted power supply of the selected facility [Al-Rufaee 2021, Wu 2019]. Various new engineering solutions are used in the design and construction of modern buildings to improve the energy efficiency of the facility [Rojek 2021, Abd Ali 2019c]. Various types of thermal insulation are designed on the selected object (Figure 1).

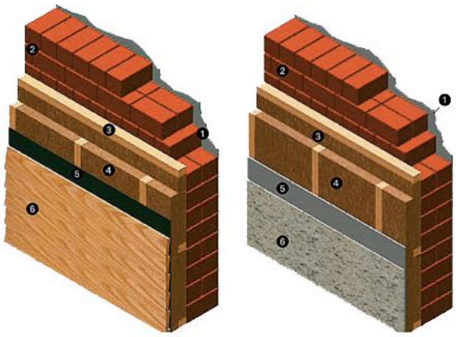

Figure 1. Options for insulation of the exterior walls of the building(1 – internal plaster; 2 – basic building material; 3 – "Thermo-Hanf" between the longitudinal details of the battens; 5 – base for plaster (for lathing); 6 – plaster (cladding)

The main advantage of heat-insulated facades is high strength, light resistance and frost resistance. The materials included in the insulation are heat- and fire-resistant, and the finishing finish provides protection from atmospheric influences. The calculations carried out for the insulation of the facade of the building showed a decrease in heat loss by 1.5 times in relation to the non-insulated object, which later became the basis for designing an autonomous power supply system for a residential building [Kuvshinov 2021]. Based on the analysis of the market of the presented equipment, an autonomous combined energy supply system of a residential building was designed on the basis of renewable energy sources. The proposed system includes two subsystems: autonomous electricity and heat supply. In order to increase reliability, each of the developed subsystems contains several generating sources [Kuvshinov 2019b, Chen 2023]. The type of use of a particular system for providing hot water and heat supply with the use of solar power plants is determined by the cost-effectiveness compared to traditional heat supply systems and depends mainly on the climatic conditions of the location area of the facility, investments in a combined system with the use of solar power plants and the cost of organic fuel in the region. The designed combined solar system of the facility is shown in Figure 2.

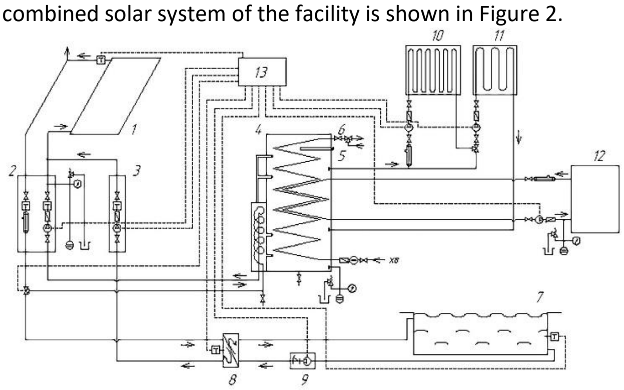

Figure 2. Scheme of the combined solar system of the object (1 – flat solar collector; 2 – pumping module of the FSC circuit; 3 – pumping module of the pool circuit; 4 – battery tank; 5 – electric heater; 6 – water collection points; 7 – swimming pool; 8 – heat exchanger; 9 – filtration unit; 10, 11 – underfloor heating system; 12 – heat pump; 13 – automatic control unit) [Kuvshinov 2019b, Kuric 2019]

According to the results of field tests of various types of solar collectors, in order to increase the efficiency of the combined solar system, a rational design of a solar collector operating with minimal losses to the environment was chosen, as well as the use of special rationally oriented structures of the FSC with a total area of 24 m^2 providing heating of a 1.5 m^3 battery tank (Fig. 3). The use of such structures makes it possible to increase the duration of operation of solar collectors during daylight hours, making them more independent of weather conditions and, accordingly, increasing the energy efficiency of the system itself [Guryev 2019, Shuravin 2022].

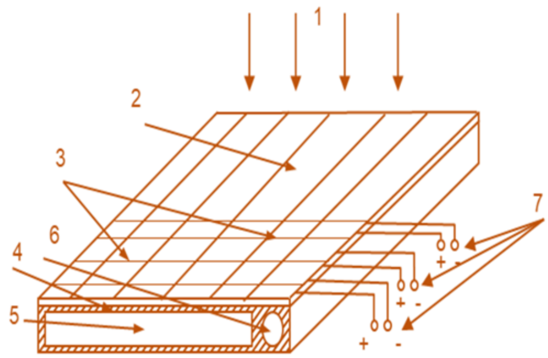

Figure 3. Combined thermal photoelectric helioprofile 1 - incident solar radiation; 2 - heat-absorbing surface; 3 - solar cells; 4 - walls of the absorbing surface of the helioprofile; 5 - air channel; 6 - channel for water; 7 – output electrical contacts of solar cells

At the same time, in order to increase the efficiency of using the solar radiation flux, it was proposed to use a thermo-photoelectric solar collector built into the roof of a building, which is a full-size industrial helioprofile intended directly for the installation of roofing in residential buildings. The profile is made of aluminum [Kopas 2017]. Inside the helioprofile, there are tubes for a liquid heat carrier and cavities (channels) for air or heat storage material. Such helioprofiles are capable of covering up to 7 m of roof height and an unlimited area in width. On the receiving surface of the helioprofile, there are solar cells that are attached to the receiving surface using a special heat-conducting paste with high resistance. The elements cover 1/3 to 1/2 of the bottom of the helioprofile. Due to the low temperature and the circulation of the coolant, the elements are cooled, which improves the quality of work. Because silicon solar cells convert a part of the spectrum other than a heat absorber, there is an overall increase in energy production [Kuznetsov 2020, Liu 2021].

3 RESULTS AND DISCUSSION

3.1 Experimental results

The paper presents full-scale tests of photovoltaic units of a combined thermo-photoelectric helioprofile. The electrical blocks were recruited from monosilicon elements; a chain of elements welded in series on the absorber has an output voltage of 17 V [Bozek 2013]. The experimental results are shown in the graphs (Fig. 4), which show the current-voltage and power characteristics obtained during the tests.

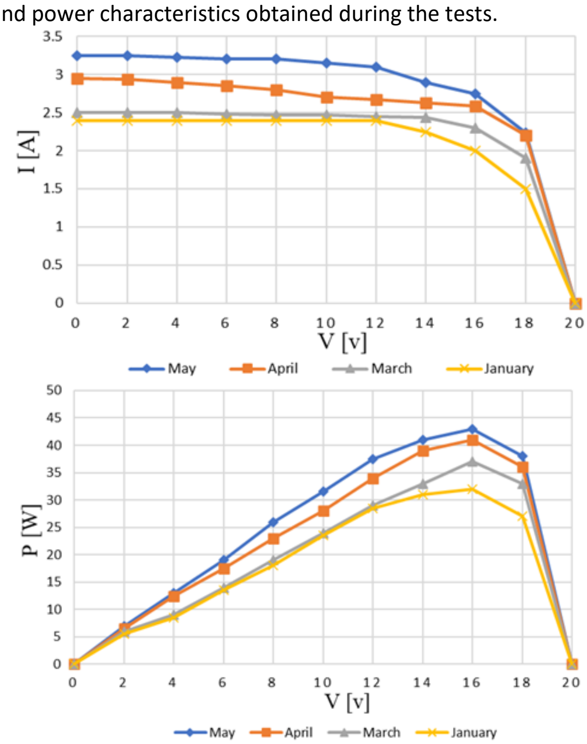

Figure 4. I-V and P-V characteristics of solar profile photoelectric converters for different months of the year

As clear from the graphs during field tests (the data were obtained at temperatures of about 15 °C and various illuminations), the voltage value of the module at the operating point decreases with an increase in illumination in the spring months (Fig. 4). The power characteristics are preserved, but the current values grow stronger than factory parameters.

The experimental values of the current-voltage characteristics of the elements were obtained at various temperature factors. In the Fig. 5, can be seen that at the same illumination values, the power of the module increases at low temperatures. The conversion factor of the module depends on the illumination, it increases in cold and clear weather and decreases with an increase in atmospheric temperature. The results show that the effective mode of operation of the module is observed at negative air temperatures. A cold temperature has the positive effect on the operation of the module. An increase in the conversion coefficient of the module is clearly visible.

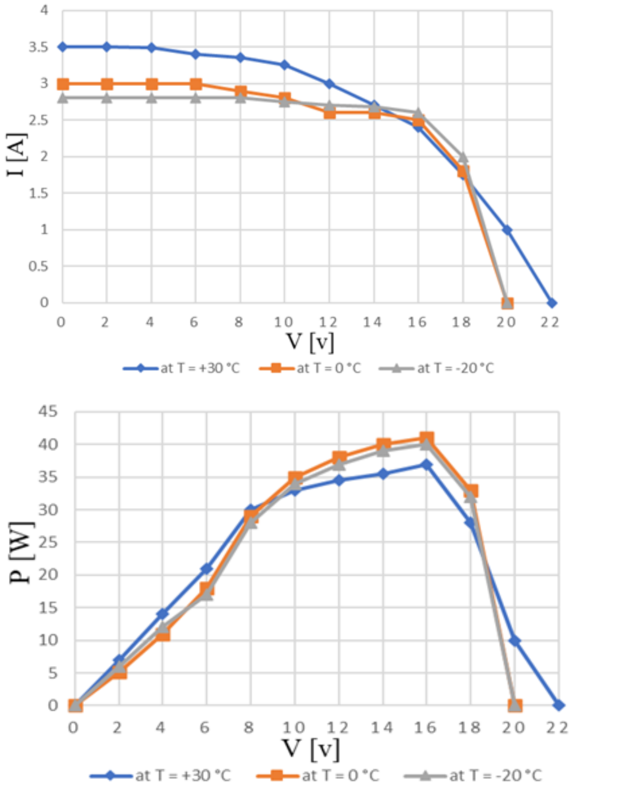

Figure 5. I-V and P-V characteristics obtained at different times of the year (illumination of about 800 W/m^2) dependence of Temperature

3.2 Combined system wind-diesel generator with battery

Optimization of the indoor heating system in winter is carried out through the use of low-temperature underfloor heating. Excess heat from the solar system in the summer is used to heat the water in the pool through a heat exchanger according to a counter-current scheme. If there is a lack of heat from the solar system, its heating is carried out by using a ground heat pump integrated into the heating circuit. The system is provided with a multi-circuit, the first closed circuit includes rationally oriented FSC filled with a non-freezing, non-toxic coolant, which allows not to drain it from the circuit in winter. The optimal connection scheme of the FSC in groups allows to reduce hydraulic losses in the circuit. The second open circuit provides the supply of tap water to the heat exchanger located in the accumulator tank, its heating, and water collection by the consumer. The third closed circuit provides heating of the building through the use of low-temperature underfloor heating, the circulation of the coolant which is provided by a circulation pump. The project provides a power supply system for a building with distributed generation (Figure 6), which, in order to increase reliability, includes three sources of electric energy: a wind turbine, a backup diesel generator station (DG) and a battery pack (battery) with an inverter. The general scheme is divided into two groups of electric energy receivers: the power group - HP of the hot water supply system and a group of household receivers in the building of the facility (lighting and outlet network, technological equipment), as well as the system of automatic regulation of the modes of operation of the power supply system [Drwiega 2023, Jasim 2023, Bediar 2023]. The calculation of the reliability assessment of the autonomous power supply system of an individual residential building based on RES showed that the probability of its failure is 3%. The result obtained satisfies the energy supply needs of the building with the use of combined power systems of this class (Fig. 7).

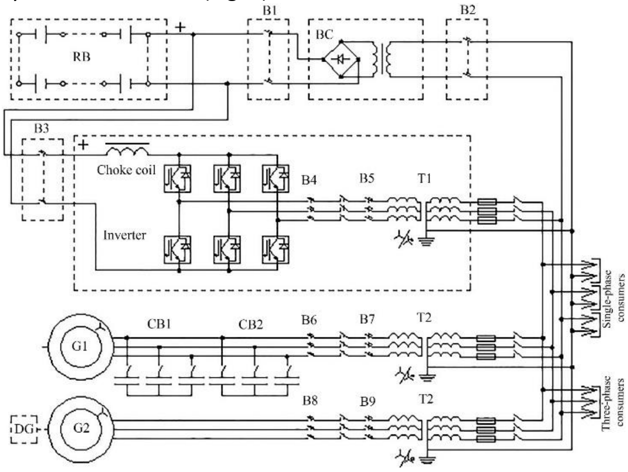

Figure 6. Scheme of the combined autonomous power supply system (RB – batteries; G1 – three-phase induction generator with reactive power compensation; G2 – three-phase synchronous generator with permanent magnets; DG – diesel generator; BC – charger; T – separation transformers; CB - capacitor banks; B – breakers

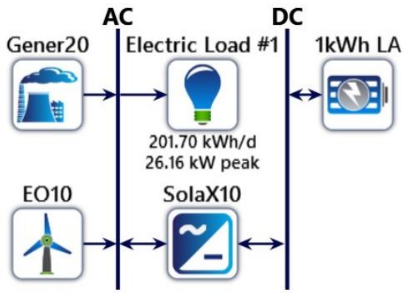

Figure 7. Combined system design

It observes the following based on the findings of the simulation: The 0% energy shortage shows that the suggested system is capable of meeting 100% of the necessary electrical load and prevents any electricity shortages at any time of year. Figure 8 illustrates the potential for electricity generation from diesel and wind turbines during various seasons and different conditions of the year. The annual contribution of different energy sources to the suggested system is shown in Table 1.

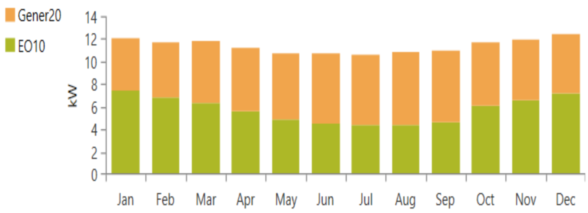

Figure 8. Average monthly electricity production by the combined system

Table 1. Annual energy production of the proposed combined system. Energy contribution of various energy sources

Production	EO10-Gen20	
	Electricity	Wood
Diesel generator (DG)	49.629	49.7
Wind Turbine	50.250	50.3
Total	99.879	100
AC Primary Load	73.613	
Excess electricity	26.269	26.3

Figure 8 and Table 1 show the results obtained. When the combined system consists of batteries and a wind-DG, it produces electricity, and as a result, it produces a 26.3% surplus of electrical energy, and 50.3% is the share of energy used from renewable energy. In rural areas isolated from the grid, renewable energy can have an important role in energy production, or through it, we can overcome the shortage of electric power in several different places. Emissions that negatively affect the environment, and the most important renewable energies are wind and solar energy. The conducted ecological and economic justification of the use of an autonomous combined energy system for the energy supply of a residential building at the expense of renewable energy sources allows us to determine the profitability of its construction, as well as to estimate the savings of traditional energy resources and, as a result, the reduction of emissions of pollutants into the environment, the savings of conventional fuel will amount to 2.1 tons per year. The payback of the autonomous power supply system, taking into account the specifics of the project, is 6 years, and the thermal part is in the range of 6 to 8 years at the current price of organic fuel. The calculated payback period of the project is relative and can be reduced by taking into account changes in energy prices.

4 CONCLUSION

It is clear from the results of the calculations of the simulated system and the experiments, that the following main conclusions can be drawn: The use of various types of installations in a combined system can significantly increase its efficiency of use and ensure uninterrupted operation to provide the consumption. The result of the calculations of the simulated systems shows that the use of combined systems is advisable and energy-efficient, but the amount of generated energy directly depends on weather conditions. In case of unfavorable weather conditions, it is necessary to use duplicate sources. DG and batteries are used as backup sources for the power supply system. From the results of the calculations of the simulated system and the experiments, the following main conclusions can be drawn: The use of several types of installations in a combined system can significantly increase its efficiency of use and ensure uninterrupted operation to provide the consumption. The result of the calculations of the simulated systems shows that the use of combined systems is advisable and energy-efficient, but the amount of generated energy directly depends on weather conditions. In case of unfavorable weather conditions, it is necessary to use duplicate sources. DG and batteries are used as backup sources for the power supply system. For heat supply, it is recommended to use an electric water heater or HP, which will preheat the coolant to the required temperature. The use of combined energy supply systems based on renewable energy sources can significantly reduce the use of traditional fuels and reduce air emissions.

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REFERENCES

[Abd Ali 2019a] Abd Ali, L.M., et al. Modeling and simulation of tidal energy, J. Eng. Appl.Sci., 2019, No. 14, pp. 3698-3706. https://doi.org/10.3923/jeasci.2019.3698.3706.

[Abd Ali 2019b] Abd Ali, L.M., et al. A novel design of 7-level diode clamped inverter. J. Eng. App. Sci., 2019, No. 14, pp. 3666-3673. doi.org/10.36478/jeasci.2019.3666.3673.

[Abd Ali 2019c] Abd Ali, L.M., Mohmmed, H.A., Wahhab, H.A. A novel design of 7-level diode clamped inverter. J. Eng. Appl. Sci., 2019, No. 14, p. 3666.

[Abd Ali 2020] Abd Ali, L.M., et al. Study of hybrid wind–solar systems for the Iraq energy complex. Appl. Sol. Energy, 2020, Vol. 56, No. 4, pp. 284-290. https://doi.org/10.3103/S0003701X20040027.

[Abd Ali 2021] Abd Ali, L.M., et al. Developing a thermal design for steam power plants by using concentrating solar power technologies for a clean environment. Acta Montanistica Slovaca, 2021, Vol. 26, No. 4, pp. 773-783. https://doi.org/10.46544/AMS.v26i4.14.

[Abdali 2022] Abdali, L.M., et al. Using hybrid wind-solar power systems for the Al-Najaf city in Iraq. Vestnik IzGTU M.T. Kalashnikova, 2022, Vol. 25, no. 3, pp. 82-91 (in Russian). DOI: 10.22213/2413-1172-2022-3-82-91.

[Abdel-Aty 2020] Abdel-Aty, et al. A quantum classification algorithm for classification incomplete patterns based on entanglement measure, Journal of Intelligent & Fuzzy Systems, 2020, Vol. 38, No. 3, pp. 2809-2816.

[Al-Rufaee 2021] Al-Rufaee, F.M., et al. Development of hybrid photo-wind power systems with a diesel generator to overcome energy shortages. E3S Web of Conferences, 2021, Vol. 270, pp.1-9.

[Ayang 2016] Ayang, A., et al. Power consumption: Base stations of telecommunication in sahel zone of cameroon: Typology based on the power consumption – model and energy savings. Journal of Energy, 2016, Art.ID 3161060. https://doi.org/10.1155/2016/3161060.

[Bediar 2023] Bediar, S., Harrouz, A., Belatrache, D. Feasibility analysis a hybrid system PV/Wind Turbine/Battery assisted by a diesel generator in southwest of Algeria. Algerian J. of Environ. Sci. and Technology, 2023, Vol. 9, No. 1.

[Blatnicky 2021] Blatnicky, M., et al. Design of a mechanical part of an automated platform for oblique manipulation. Applied Sciences, 2021, Vol. 10, Iss. 23. DOI: 10.3390/app10238467.

[Bozek 2013] Bozek, P. Robot path optimization for spot welding applications in automotive industry. Technical Gazette, 2013, Vol. 20, No. 5, pp. 913-917.

[Cheboxarov 2019a] Cheboxarov, V.V., et al. Some results of a study of wave energy converters at Sevastopol state university. Appl. Sol. Energy, 2019, Vol. 55, No. 4, pp. 256-259. doi.org/10.3103/S0003701X19040029.

[Cheboxarov 2019b] Cheboxarov, V.V., et al. An offshore wind-power-based water desalination complex as a response to an emergency in water supply to northern Crimea. Appl. Sol. Energy, 2019, Vol.55, no. 4, pp. 260-264.doi.org/10.3103/S0003701X19040030.

[Chen 2023] Chen, T.-C., et al. Modeling and Optimization of Combined Heating, Power, and Gas Production System Based on Renewable Energies. Sustainability 2023, Vol. 15, No. 10, p. 7888.

[Diao 2019] Diao, Y.H., et al. Numerical investigation of the thermal performance enhancement of latent heat thermal energy storage using longitudinal rectangular fins and flat micro-heat pipe arrays. Applied\Energy, 2019, Vol. 233, pp. 894-905.

[Drwiega 2023] Drwiega, A., et al. Maximization the latent heat storage unit (lhsu) energy saving using simulated annealing algorithm. MM Science Journal, 2023, No. June, pp. 6489-6494.

[Elbakian 2018] Elbakian, A, et al. Automated separation of basalt fiber and other earth resources by the means of acoustic vibrations. Acta Montanistica Slovaca, 2018, Vol. 23, No. 3, pp. 271-281.
[Guryev 2019] Guryev, V.V., Yakimovich, B. A., Abd Ali, L.M., Al Barmani, A.G. Improvement of methods for predicting the generation capacity of solar power plants: The case of the power systems in the Republic of Crimea and city of Sevastopol. Applied Solar Energy, 2019, Vol. 55, pp.242-246.
[Humar 2011] Humar, I., et al. Rethinking energy efficiency models of cellular networks with embodied energy. IEEE network, 2011, Vol. 25, No. 2, pp. 40-49.
[Jasim 2023] Jasim, A.M., Jasim, B.H., Baiceanu, F.-C., Neagu, B.-C. Optimized sizing of energy management system for off-grid hybrid solar/wind/battery/biogasifier/ diesel microgrid system. Mathematics, 2023, Vol. 11, No. 5, 1248.
[Kopas 2017] Kopas, P., et al. Identification of mechanical properties of weld joints of AlMgSi07.F25 aluminium alloy. Metalurgia, 2017, Vol. 56, Issue 1-2, pp. 99-102.
[Kuric 2019] Kuric, I., et al. Visual Product Inspection Based on Deep Learning Methods. Lecture Notes in Mechanical Engineering, 2019, pp. 148-156. doi.org/10.1007/978-3-030-40724-7_15.
[Kuvshinov 2019a] Kuvshinov, V.V., et al. Storage system for solar plants. Appl. Sol. Energy, 2019, Vol. 55, No. 3, pp. 153-158. doi.org/10.3103/S0003701X19030046W.
[Kuvshinov 2019b] Kuvshinov, V.V., et al. Studies of the PV array characteristics with changing array surface irradiance. Appl. Sol. Energy, 2019, Vol. 55, pp. 223-228.
[Kuvshinov 2021] Kuvshinov, V. V., et al. Experimental studies on receiving surfaces of flat solar collectors. Surface engineering and applied electrochemistry, 2021, Vol. 57, No. 6, pp. 715-720.
[Kuznetsov 2020] Kuznetsov, N.P., et al. Investigation of the losses of photovoltaic solar systems during operation under partial shading. J. of Applied Engineering Science, 2020, Vol. 18, No. 3, pp. 313-320.
[Liu 2021] Liu, Q. et al. An optimized quantum minimum searching algorithm with sure-success probability and its experiment simulation with Cirq. J Ambient Intell Human Comput., 2021, Vol. 12, pp. 10425-10434. https://doi.org/10.1007/s12652-020-02840-z.
[Porte-Agel 2020] Porte-Agel, F., Bastankhah, M., Shamsoddin, S. Wind-turbine and wind-farm flows: A review. Boundary-layer meteorology, 2020, Vol. 174, No. 1, pp. 1-59.
[Rojek 2021] Rojek, I., et al. Modern methods in the field of machine modelling and simulation as a research and practical issue related to Industry. Bulletin of the Polish Acad. of Sciences - Technical Sciences, 2021, Vol. 69, Iss. 2. DOI: 10.24425/bpasts.2021.136717.
[Saga 2019] Saga, M., et al. Contribution to random vibration numerical simulation and optimisation of nonlinear mechanical systems. Scientific J. of Silesian University of Technology - series Transport, 2019, Vol. 103, pp. 143-154. DOI: 10.20858/sjsutst. 2019.103.11, 2019.
[Shuravin 2022] Shuravin, A.P., et al. A study of the convergence of a genetic algorithm for solving the problem of temperature imbalance in heated rooms. Intelligent systems in manufacturing, 2022, Vol. 20. No. 1, pp. 106-114. (in Russian). DOI: 10.22213/2410-9304-2022-1-106-114.
[Vologdin 2019] Vologdin, S.V., et al. Analysis of various energy supply scenarios of Crimea with allowance for operating modes of solar power planta. Appl. Sol. Energy, 2019, Vol. 55, No. 4, pp. 229-234. https://doi.org/10.3103/S0003701X1904008X.
[Waqas 2013] Waqas, A., et al. Phase change material (PCM) storage for free cooling of buildings – review. Renewable and sustainable energy reviews, 2013, Vol. 18, pp. 607-625.
[Wiecek 2019] Wiecek, D., et al. The use of ANN in improving efficiency and ensuring the stability of the copper ore mining process. Acta Montanistica Slovaca, 2019, Vol. 24, Iss. 1, pp. 1-14.
[Wu 2019] Wu, W., et al. Form-stable and thermally induced flexible composite phase change material for thermal energy storage and thermal management applications. Applied Energy, 2019, Vol. 236, pp. 10-21.

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