**Energy efficiency of using solar panels for backup and alternative power supply of railway transport devices**

Saulesh Minazhova 1, Elena Iksar 2, Malika Tuychieva2, a)

*1* *Satbayev University, Almaty, Kazakhstan*

*2 Tashkent State Transport University, Tashkent, Uzbekistan*

a) Corresponding author*:* [*ismalika8689@gmail.com*](mailto:ismalika8689@gmail.com)

**Abstract.** The article explores the most promising methods for utilizing solar panels as backup and alternative energy sources for railway automation devices. The climatic and geographical conditions in Uzbekistan are conducive to harnessing solar energy for large-scale electricity generation. A key objective in developing rail transport is to establish high-speed railways that can serve as a viable alternative to automobile and air travel for short distances. In addition to the well-known technologies for alternative energy, renewable energy sources can also be employed in rail transport applications, such as in heat pump systems for heating switch points, utilizing heat from hump complex compressors, and providing heating for electrical centralization posts and traction substation transformers for their internal needs.

**INTRODUCTION**

The global environmental protection strategy aims to increase the utilization of renewable energy sources, with solar energy being one of them.

Today, the economic potential of renewable energy sources (RES) in Uzbekistan is estimated at 13 million tons of conventional fuel, which accounts for approximately 30% of the country's total consumption of fuel and energy resources. The development of modern rail transport in Uzbekistan is closely linked to the efficient use of energy resources. To achieve this, the electrification of the entire transport system is continually being updated, with an emphasis on energy-saving technologies. Initially, direct current technologies were prioritized; however, advancements in converter technology have allowed for the modernization of control systems. As a result, there's a growing focus on technologies that utilize alternating current. At present, there is significant attention paid to implementing the most efficient "green" technologies. For rail transport, solar energy can be harnessed for train traction, backup power for automation systems, electricity supply for control systems and auxiliary equipment circuits. The energy efficiency strategy for rail transport is structured around two main categories: traction and non-traction indicators [7,8,12].

Traction indicators include:

• increasing the energy efficiency of the transportation process;

• improving the methods of train traffic control;

• improving the indicators of energy efficient use of locomotives;

• improving the indicators of traction power supply.

Non-traction indicators are:

• improving the technical condition of rolling stock and track facilities;

• improving the level of energy recovery in electric traction;

• increasing the energy efficiency of train traction:

• optimizing the power supply of auxiliary equipment.

**EXPERIMENTAL RESEARCH**

Uzbekistan has a vast potential for solar energy, estimated at over 525 billion kWh to 760 billion kWh per year. This amount significantly surpasses the energy potential of all the country's explored hydrocarbon reserves. The annual solar radiation ranges from 4800 MJ/m² in the north to 6500 MJ/m² in the south, occurring over a span of 7 to 10 hours each day.

The annual solar radiation that reaches Uzbekistan exceeds the energy potential of the country’s proven carbon reserves. However, to date, only 0.6 million tons of oil equivalent in solar energy has been harnessed, representing just 0.3% of the total technical potential. The use of solar energy in rail transport presents significant opportunities for development.

**Table 1.** Solar radiation indicators by region Amount of solar heat energy in Uzbekistan by city

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| City | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII | MJ/m2  per year | KWh of heat  per year |
| Kyzylcha | 289 | 377 | 530 | 545 | 662 | 812 | 850 | 796 | 599 | 404 | 297 | 247 | 6408 | 1780,0 |
| Samarkand | 222 | 263 | 373 | 524 | 708 | 825 | 854 | 784 | 620 | 423 | 243 | 189 | 6028 | 1674,4 |
| Takhiatash | 205 | 283 | 425 | 582 | 771 | 838 | 834 | 754 | 654 | 456 | 264 | 163 | 6088 | 1691,1 |
| Tashkent | 191 | 247 | 383 | 526 | 714 | 802 | 836 | 735 | 574 | 373 | 222 | 153 | 5773 | 1604,7 |
| Termez | 245 | 312 | 457 | 601 | 783 | 867 | 865 | 787 | 643 | 463 | 300 | 220 | 6543 | 1817,5 |
| Fergana | 193 | 266 | 387 | 517 | 706 | 792 | 808 | 739 | 578 | 383 | 238 | 151 | 5748 | 1596,7 |

The study utilizes regional meteorological data on solar irradiance, alongside technical specifications of photovoltaic and energy storage systems. For energy yield estimation, the annual solar insolation for Termez city (1815 kWh/m²/year) was taken with a correction factor of 1.10. The energy output for a 10 kW photovoltaic system was calculated based on standardized methods, taking into account efficiency coefficients of panels, inverters, and battery storage. Analytical comparison was performed between monocrystalline, polycrystalline, and thin-film technologies regarding cost, efficiency, durability, and adaptability to railway operating conditions.

E = 1 815 [kW·h/(m² ·year)] × 1.1 × 10 [kW] × 0.9 / 1 [kW·h/m²] = 1799.8 [kW·h/year]

This calculation of solar panels allows us to estimate the average annual energy generation of a photovoltaic station. In Uzbekistan, solar heat energy intensity exceeds 800 MJ/m² in the summer months and is about 200 MJ/m² in the winter months. On average, the amount of solar heat energy received on a horizontal area of 1 m² per year is 1603.6 kW∙h in Tashkent and 1817.5 kW∙h in Termez. Uzbekistan's current energy system generates 66.4 billion kW∙h of electricity, but it requires 69.14 billion kW∙h to meet consumption needs. With the country's industrial development, electricity demand is projected to rise to 117 billion kW∙h in the future. By 2030, the share of alternative energy sources in the total electricity production of the republic is expected to increase to 30%. To address these energy challenges, a new energy policy has been developed in recent years that focuses on utilizing Hybrid Renewable Energy Systems (HRES). These systems combine traditional electricity sources with photovoltaic modules, promoting a more sustainable energy framework [11,12].

The innovative development of modern solar panels significantly reduces the cost of solar energy, making it a viable option for railway transport. The natural conditions across all regions of the Republic of Uzbekistan enable the maximum capture of solar radiation. The duration of sunshine varies between 2,200 to 3,000 hours per year, with an average solar radiation energy of 1,200 kW/m² annually. In the southern regions, the duration of solar radiation ranges from 2,000 to 3,000 hours per year, yielding a solar heat energy potential of 1,280 to 1,870 kW/h per 1 m². During the sunniest month, energy production can reach between 6.4 to 7.5 kW/h per day per square meter. Independent power supply from the general power supply network or special converters, batteries can be used as alternative independent sources; switching to a backup source occurs automatically. Railway automation devices can be powered by direct current, single-phase alternating current, or three-phase alternating current. Standardized voltages in the power supply system of railway automation devices correspond to the following series of voltages [4, 5]:

− nominal voltages of direct current (in volts): U = 5, 6, 12.24, 36, 48, 60, 110, 120, 136, 220;

− nominal voltages of alternating single-phase current (in volts): U = 12, 24, 55, 60, 110, 115, 130, 145, 220, 230;

- nominal voltages of three-phase current (phase/in volts): U == 115, 127, 220, 230, 380, 550, 1000.

Solar panels can be used as the main power supply units of railway automation, connected to the industrial network, or as a backup source, connected to an autonomous power plant.

For economic reasons, monocrystalline solar cells are used as functional solar modules in railway transport [3]. The use of monocrystalline cells can increase losses in devices for converting and storing electrical energy (batteries, inverters, distributors, etc.), which leads to the fact that the actual values ​​of power produced by the photocells of the installation are significantly less than the potentially possible ones.

For innovative photovoltaic systems for converting solar energy, the main element is monocrystalline and polycrystalline silicon (tape, sheet, layered, amorphous), as well as cadmium telluride and gallium arsenide, and converters with an *AlGaAs-GaAs* structure. The productivity of these elements reaches 22% (silicon elements provide only 12-17%); the elements are labor-intensive to manufacture and have a high cost, which increases the cost of solar panels [10].

In world production, silicon accounts for approximately 75% of global semiconductor production. Choosing silicon as the primary material for photovoltaic cells minimizes reflection losses. Additionally, silicon photovoltaic cells are less sensitive to temperature fluctuations, which is crucial for railway transport conditions.

The dimensions of trains allow the use of the roofs of rolling stock for the installation of photovoltaic modules; the battery can be recharged during stops. It is proposed to install monocrystalline solar panels from three to ten square meters in size, with a storage device based on a lithium-iron-phosphate battery (LiFePO4, LFP) with an average daily consumption of up to 30 kW·h. In addition, the panels can be mounted on the power support structure or the frame near the turnout.

To reduce the cost of silicon, which is essential for making photovoltaic energy competitive with other energy sources, two approaches can be considered:

1. Producing monocrystalline silicon that meets semiconductor standards.

2. Producing lower-cost monocrystalline silicon that is less effective for photovoltaic converters.

The electric power generated by photoelectric converters should not be viewed as a replacement for traditional electric power. Instead, it represents an opportunity to provide electricity to consumers who are far from the power grid or to serve as a backup source in case the main power supply fails. These systems can be low-power installations that include a battery to supply power during the night.

The transition to thin-film elements will significantly reduce the cost of the installed power. The energy generated by solar panels can be used to operate the engine, auxiliary equipment fan motors, brake compressor motors, and lighting circuits. During the generation process, energy is simultaneously accumulated in batteries for further use for the needs of auxiliary equipment [6, 10].

The use of solar power plants in rail transport has the following advantages:

- environmentally friendly electricity generation, no greenhouse gas emissions;

- universal application;

- simple design and light weight;

- silent operation;

- modular power gain principle;

- high reliability.

Solar energy is becoming an important energy resource for the railway industry. The introduction of solar panels in railway transport is conducted in two main directions:

1. Additional power supply for trains by installing batteries directly on the roof of the rolling stock (power supply for auxiliary equipment).

2. Power supply from solar panels for infrastructure and signaling devices (operation of auxiliary units, lighting, air conditioning systems, etc.).

Efficiency and reliability of power supply for railways, the use of new energy sources, resource-saving technologies, and decentralization of power supply for railways will provide significant energy savings and increase traffic safety. It will be an additional source of electricity to back up critical devices of railway automation.

**RESEARCH RESULTS**

The estimated output from a 10 kW PVS installed in Termez amounts to 1799.8 kWh/year. This confirms the practical viability of integrating solar panels into railway infrastructure, especially in southern regions of Uzbekistan. Monocrystalline silicon modules demonstrated superior performance under high temperature and solar exposure, making them suitable for on-board and stationary applications. Energy storage based on LiFePO4 batteries ensures reliable autonomous operation during night-time or power outages. Moreover, thin-film solar cells provide a cost-effective alternative for non-critical systems, offering flexibility in installation. The proposed configurations allow for modular scaling, facilitating decentralized energy supply for automation posts, switch heating systems, and control circuits. Despite the relatively high initial capital cost, the long-term savings and energy independence justify the investment.

**CONCLUSIONS**

The role of alternative energy sources in rail transport is continually increasing, with new technical solutions and technologies being developed in this field. The effectiveness of utilizing alternative energy sources relies on a scientific approach that draws on existing experience or successful innovations from related industries. This approach helps to identify the appropriate time, location, and scale for their implementation, while considering the specific technical and technological characteristics of production processes. Among the innovative technical solutions in rail transport, the development of high-speed railways, recuperation systems, and heat pump technologies are currently prioritized.

Photovoltaic systems offer a promising solution to enhance the resilience and energy independence of railway transport infrastructure. Their deployment, tailored to Uzbekistan’s climatic conditions, supports sustainable energy transition goals. Scientific modeling and engineering validation confirm the technical feasibility of integrating solar energy for powering signaling systems, auxiliary train functions, and heating units. Future work will focus on developing hybrid schemes, combining PVS with conventional and renewable energy sources for optimal efficiency and cost performance.

**REFERENCES**

1. Allaev K. R., “Energy needs a strategy,” *Economic Review*, No. 6 (2018).
2. Allaev K. R., “Energy efficiency and renewable energy sources,” in *Problems of Energy and Resource Saving*, Special issue, Proc. Int. Conf. “Modern Scientific and Technical Solutions for the Efficient Use of Renewable Energy Sources” (Tashkent State Technical University, Tashkent, 2011).
3. Yanson R. A., *Wind Turbines*, teaching aid for the courses “Wind Power” and “Power Engineering of Non-Traditional and Renewable Energy Sources,” ed. M. I. Osipov (Bauman Moscow State Technical University Press, Moscow, 2007), 36 p.
4. Sulaymonov U., Jelutkevich A., Nabiyevna M., Sayfullayev O., and Berdiyorov U., “Research of energy-saving composite materials for electric motors,” *E3S Web of Conferences* **461**, 01054 (2024).
5. Burkhankhodjaev A., Tuychieva M., Iksar E., Kholbutayeva K., and Nurmatov B., “Investigation of the energy performance of electric locomotives in asymmetric modes,” *AIP Conference Proceedings* **2552**, 030018 (2023).
6. Bezrukikh P. P., *Scientific, Technical and Methodological Substantiation of Resources and Directions of Use of Renewable Energy Sources*, D.Sc. dissertation (Moscow, 2003), 268 p.
7. Golubenko N. S. *et al.*, “On the dependence of wind speed on altitude taking into account the terrain,” electronic resource (2005), available at. http://wind.dp.ua/download/ozavisimosti-skorosti-vetra-ot-vysoty.doc (accessed June 15, 2017).
8. Meytin M., “Photovoltaics: materials, technologies, prospects,” *Electronics: Science, Technology, Business*, No. 6, 40–46 (2010).
9. Vissarionov V. I., *Solar Energy: A Textbook for Universities* (MPEI Publishing House, Moscow, 2008), 317 p.
10. Butuzov V. V., “Calculated values of solar radiation intensity for the design of solar power plants,” *Alternative Energy and Ecology*, No. 11 (79), 75 (2016).
11. Pirmatov N., Tuychiyeva M. N., Usmonov K. K., and Nazirkhonov T. M., “Device for measuring the resultant magnetic field of the stator winding of a traction asynchronous motor of an electric rolling stock,” *AIP Conference Proceedings* **3152**(1), 050014 (2024).
12. Berdiyev U. T., Kolesnikov I. K., and Tuychiyeva M. N., *Functional Diagnostics of the Control Circuit in Non-Standard Situations in the Traction Mode of Electric Locomotives* (Ziyo Nashr-Matbaa, Tashkent, 2023), 148 p.
13. Iksar E. V. and Kayumov S. N., “Innovative application of solar panels for backup power supply in railway transport,” in *Proc. Int. Sci. and Tech. Conf. “Innovative Technologies in Water, Municipal Utilities and Water Transport”* (October 17–18, 2024).