

Modernization of the power supply system applying solar cells and batteries

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Abstract. In this paper, an assessment was made of the installation of solar panels as a backup power source for the Post of electric centralization. The advantages of using this system and an example of calculations for the Post of electric centralization were given. The norms of electricity consumption were analyzed.

1. Introduction

In an era marked by rapid industrialization, urbanization, and a growing demand for energy, the need for sustainable and efficient power supply systems has become more critical than ever before. Conventional energy sources, such as fossil fuels, have not only proven detrimental to the environment but also pose challenges of resource depletion. In response, the integration of renewable energy sources, specifically solar cells and advanced battery technologies, has emerged as a promising solution to modernize the power supply system and pave the way for a cleaner, greener future.

The modern world does not stand still and is constantly changing. Every day, new developments or improvements to existing systems or devices are introduced in various industries. The constant growth of humanity's needs for electricity forces them to either increase energy production resources or improve existing energy conversion technologies.

The railway industry is also developing day by day [1], [2]. The railway infrastructure contains many devices that require electricity, namely: electric rolling-stocks, lightings of interlocking systems, turnouts, automatics barriers, Posts of electric centralizations. They are consumers of first category for power supplying systems [3] – [5]. They are required supply from two independent sources [3], [4]. And therefore, part of them could be transferred to alternative power sources, which will save significant funds allocated for the operation of the railways. As an option for the source of electricity, you can consider solar panels and batteries [1], [2], [6].

Other aspect is climate change [7]. This process cannot be stopped, but we must take care of the environment. And now one of the main issues is to reduce carbon dioxide emissions into the atmosphere. The future belongs to "green" energy, which can be

achieved by installing solar panel farms using modern types of batteries. An urgent scientific challenge in terms of improving traction power supply systems is to develop and implement efficient, reliable, safe electrical systems. They can meet the growing demand for environmentally friendly and sustainable transport. At the same time, new and modernized railway electrification systems: power electronics components in these systems (substations and rectifiers, new electric rolling stock) must be highly efficient and reliable, and also create minimal electromagnetic emissions. Also it is needed to provide EMC of it with the operation of onboard train systems, railway automatics and communication devices.

As about batteries of railway automatics, substations: ABN-72, ABN-80 and open type SK-6 ... SK-12 are outdated and the system of backup power supply of it requires renovation [4], [5]. The installation of new types of batteries, especially at the using solar panels, will improve the working conditions of maintenance personnel, the quality parameters of electrical energy, efficiency and reliability of the backup power supply system, and give excess electrical energy to the external power supply system, which is especially relevant in those difficult conditions associated with unpredictable power outages in which Ukrainian Railways are located.

Since applying of electric traction, researchers have tried to increase the efficiency and quality of the traction power system (it was the first), to reduce its losses and the cost of the system itself, to provide their EMC with the railway automatics and telecommunication devices. So, the scientific topic deals with the renovation of reserve power supply system of railway automatics devices is actuality.

The main purpose of this paper is modernization of exists reserve supply system of railway automatics devices. The main tasks for the decision are:

- to analyze the advantages and disadvantages of the power supply system of traction substations, the EC post

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and railway automatics and EMC devices, possible sources of interference;

- to offer options for the modernization of the backup power supply system of railway automation and EMC devices;

- to calculate the batteries capacity of the EC post and number of solar cells and consider renovation options.

2. Power supply of the EC post

In modern railway automatics systems and their devices have very strict requirements regarding reliability, stability of drops of voltage and pulsations. Failure to comply with these requirements can lead to disruption of the operation of transport controls and affect the safety of trains. The modern EC system is characterized by centralized power supply of all objects: traffic lights, switch electric drives, track circuits, constructed in conjunction with the EC of station operational and technological communication devices, train communication and others. EC equipment is installed in separate buildings, which are called EC posts. Depending on the number of centralized arrows, stations are divided into small (up to 30 arrows), medium (from 30 to 100 arrows) and large (more than 100 arrows) [4]. For the normal functioning of the EC facilities located at the EC posts, electricity is needed, which is provided by electrical installations (EI).

The main elements of the EI are: power plants, power lines, transformer substations; own power plants that provide backup power; networks of electric power equipment and lighting, which provide energy to ventilation systems, heating, working rooms of industrial premises.

Power supply units must meet the following requirements: to provide reliable, uninterrupted power supply of the equipment with a voltage of the required stability, with an acceptable ripple value, to be economical during construction and operation, to have a sufficiently high value of efficiency and power factor, to be as automated as possible, to allow the possibility of developing an EC post without replacing the main power equipment [5].

The proposal discussed in this paper just carries such an essence, it is automated, in the event of a breakdown, it is necessary to replace the module, since the modular system, in comparison with existing backup power systems, has greater efficiency, does not take up much space, since it is possible to install an EC post on the lid, carries development due to the fact that it replaces outdated elements with modern ones.

For railway automatics devices, the accuracy of AC stabilization is 5 %, the permissible frequency change is not more than 2 %. The value of the nonlinear distortion coefficient is not higher than 10 %. The relative change in DC voltage should be no more than 10 % [8], [9], [10]. The magnitude of the pulsations is not normalized, but should be as small as possible.

The batteries at the EC post perform the following functions. It is the power source of the most critical devices of the EC post, when the main AC source is

disconnected. It provides continuity of power circuits when switching feeders and starting of automation diesel-generator (DGA). It follows additional smoothing of voltage pulsations at the output of rectifiers [4], [5].

3. Modernisation of power supply system of railway automatics

Solar energy, derived from the sun's inexhaustible rays, holds immense potential to revolutionize the power generation landscape. Solar cells, also known as photovoltaic cells, convert sunlight directly into electricity using the photovoltaic effect. As technology has advanced, solar cells have become increasingly efficient, affordable, and adaptable to various applications. The integration of solar panels into power supply systems does not only reduce greenhouse gas emissions, but also minimizes reliance on non-renewable resources.

One of the key advantages of solar energy is its decentralization potential. Unlike traditional power plants, solar installations can be deployed at various scales, from residential rooftops to massive solar farms. This distributed generation approach enhances energy security and reduces transmission losses, making power supply more resilient and reliable, particularly in remote or underserved areas.

A defining feature of solar energy is its capacity for decentralization. Traditional energy generation often relies on centralized power plants, necessitating extensive distribution networks and incurring transmission losses. Solar installations, however, can be deployed at various scales and integrated directly into existing infrastructure. Rooftop solar panels on homes, businesses, and public buildings can generate electricity at the point of consumption, reducing the need for long-distance energy transmission.

This decentralization has profound implications, particularly in remote or underserved areas. Off-grid communities, which previously struggled with limited or no access to electricity, can now leverage solar energy systems to meet their power needs independently. Additionally, microgrids powered by solar energy can enhance energy resilience in regions prone to natural disasters or grid disruptions, providing a stable source of electricity during challenging times.

Furthermore, solar energy generation requires minimal water usage compared to conventional power plants, which often rely on significant amounts of water for cooling and other processes. This water savings is particularly relevant in regions facing water scarcity and drought conditions.

To begin the analysis, it is necessary to find out what solar panels are and how they work.

Modern solar panels work according to the following principle. They consist of a circuit of photovoltaic cells that absorb solar energy and convert it into electrical energy. This process is called the photoelectric effect. The principle of operation is as follows: excess electrons of the n-layer leave their atoms and move to the p-layer, this effect is achieved only under the influence of

sunlight on the panel. In this way, it is possible to implement a cycle of transition of electrons from one layer to another, using a load. The load can be understood not only as a source of direct electricity consumption (traffic light, electric arrow motor), but also as a source of energy storage, such as a battery.

Solar panels or photovoltaic systems are divided into the following types: backup power systems; systems that are connected to the main power source; autonomous systems.

The scheme is shown in the Fig. 1 allows the use of electrical energy generated by solar panels without connecting the system to the main power supply. This scheme has the right to live on sections of the railway with low electricity needs and have a leading position in regulating the movement of trains [8], [9].

When designing the system, it is necessary to carefully select type of panels with the required electrical parameters and choose the method of connecting the panels to each other (serial, parallel or combined connection).

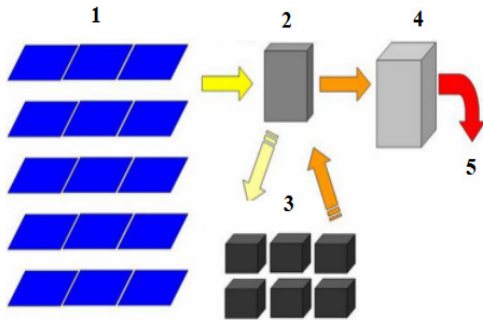


Fig. 1. Connection diagram of the consumer energy conversion system: 1-solar panels, 2-controller, 3-battery, 4-inverter, 5- consumer

In this paper, to provide backup power to the EC post, it is proposed to use a series-parallel connection of solar cells. Such a connection will provide a direct redundancy current of 28.28 A with a voltage of 24 V.

Initial data are down. Let's take the solar panel LG LG320N1C-G4 NeON2 G4 320W, which has the characteristics presented in the Table 1.

Table 1. Features of the LG LG320N1C-G4 NeON2 G4 320W solar panel

Parameters	Marking	Value
Maximum power	P1	320 W
Maximum voltage	Umax	33.6 V
Maximum current	Imax	9.53 A
Short circuit current	Ikz	10.5 A
Maximum system voltage	Umax	40.9 V
Weight	m	17 kg
Length	l	1.64 m
Width	b	1 m
Thickness	h	40 mm
Total area	S	1.64 m ²

It was chosen the series and parallels method of connection solar panels. This scheme allows you to adjust the input and output parameters to the parameters

of the electronics used in the circuit. The scheme is shown in the Fig. 2.

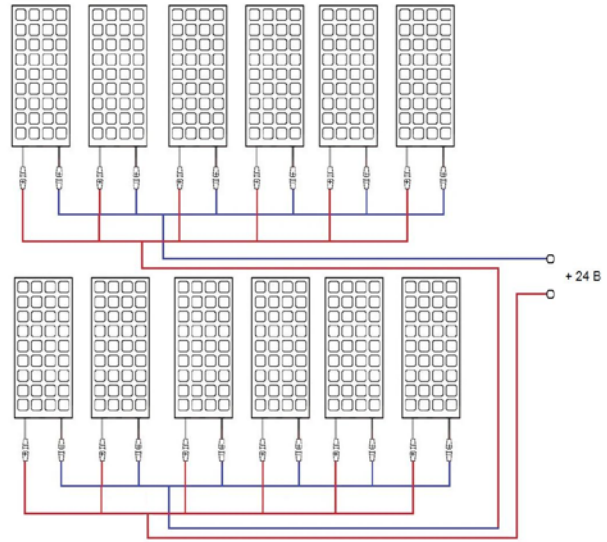


Fig. 2. Series-parallel connection of solar panels for aEC Post

For the calculation, we assume a system power of 1500 W, determine the required number of panels:

$$N = P / P_1, \quad (1)$$

where P is the power of the entire system, W; P_1 is power of one panel, W.

The number of solar panels connected in series is:

$$N_s = \frac{U_{in}}{U_{max}}, \quad (2)$$

where U_{in} is the input voltage of the installed inverter, V; U_{max} is solar panel voltage, V.

Power of serially connected panels:

$$P_s = N_s P_1. \quad (3)$$

The number of panels connected in parallel:

$$N_p = \frac{P_{max}}{P_s}, \quad (4)$$

where P_{max} is the power of the system, W.

The total number of panels in the system:

$$N = N_p N_s. \quad (5)$$

Total area of panels is:

$$S_i = SN. \quad (6)$$

Distance between rows of solar panels is:

$$L = h \sin(180 - (\theta + \beta) \frac{\pi}{180}) / \sin(\frac{\theta \pi}{180}), \quad (7)$$

where θ is the tilt angle of the solar panel; β is the optimal angle of inclination of the sun.

The results of calculation of quantity of solar panels for one Post of EC are given with the (1) – (7).

$$N = \frac{P}{P_1} = \frac{15000}{320} = 47, \quad N_s = \frac{U_{in}}{U_{max}} = \frac{230}{33.6} = 7,$$

$$P_s = N_s P_1 = 7 \cdot 320 = 2240W, \quad N_P = \frac{P_{max}}{P_s} = \frac{15000}{2240} = 7,$$

$$N = N_P N_s = 7 \cdot 7 = 49,$$

$$S_t = SN = 1.64 \cdot 49 = 80.36 \text{ m}^2,$$

$$L = 1.64 \cdot \sin(180^\circ - (15.5^\circ + 45^\circ)) \frac{\pi}{180} / \sin(\frac{15.5\pi}{180}) =$$

$$= 3.42 \text{ m}$$

One of the most remarkable achievements in solar technology has been the consistent increase in the efficiency of solar cells. Early solar panels had conversion efficiencies of around 6%, while modern

photovoltaic technologies have achieved efficiencies well above 20%. This substantial improvement means that a greater portion of sunlight can be converted into usable electricity, making solar energy an increasingly viable and competitive option for power generation.

Moreover, the mass production of solar panels has led to significant cost reductions. The concept of economies of scale has played a pivotal role in driving down the cost of solar energy systems, making them more accessible to a broader range of consumers, from individual homeowners to large-scale utility providers. This reduction in costs has been instrumental in promoting solar energy adoption and integration into existing power supply infrastructures.

4. Results of Simulation of the Annual Operation of the Accumulatory Battery

The layout of rows of solar panels is shown in the Fig. 3.



Fig. 3. Scheme of placement of solar panels

The diagram of the distribution of the intensity of solar radiation during the day for different months of the year for the region of Dnipro and Dnipropetrovsk region is shown in the Fig. 4. The Schedule of electricity production by the solar power plant by month is given in the Fig.5.

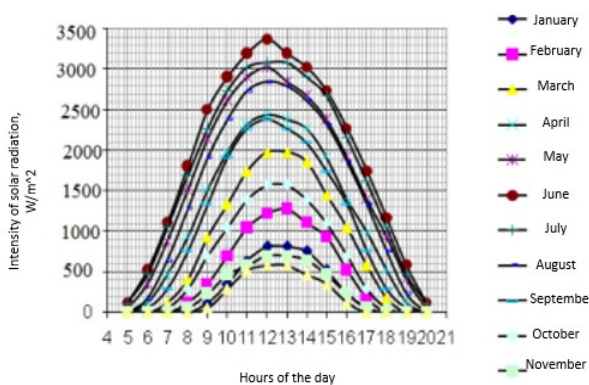


Fig. 4. Diagram of the distribution of the intensity of solar radiation during the day for different months of the year for the region of Dnipro

As can be seen from the diagram, the station with a capacity of 15 kW, which covers an area of 80.36 m², has an indicator of 15446.85 kWh.

This scheme can be installed on the roof of the EC post to provide backup power supply of a constant voltage of 24 V (Fig. 3). It should also be borne in mind that this indicator is calculated. The actual value of this system may be different, since the average annual value can be influenced by many factors, the angle of installation of the panels, the illumination of the terrain, temperature indicators, the cleanliness of the front side of the solar panel, the quality of equipment installation.

Currently, the issues of power supply of EC posts and other station premises (chipboard, relay booths), as well as SCB distillation devices are being resolved in accordance with the requirements of regulatory documents approved by the MSHS: instructions CE-462, CE-191, CE-881, VNTP-86. These documents are based basically on the requirements [3], [11]. At the same time, power is provided from combined or special complete transformer substations (KTP), and sometimes from its own feeders of 0.4 kV [5]. Mainly the railway station automatics devices are electrified and it are operated by the electric or dispatching centralization. They receive electricity from three-phase transformer substations with a secondary voltage of 380/220 V and a deaf-grounded neutral. The design of power supply and grounding devices is carried out in accordance with the approved regulatory documents and current state standards [11].

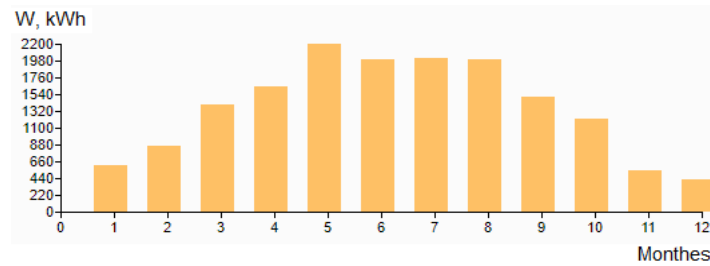


Fig. 5. Schedule of electricity production by the solar power plant by month

While solar energy offers a clean and abundant source of power during daylight hours, energy storage solutions are essential to ensure a continuous and reliable electricity supply, regardless of weather conditions or time of day. This is where advanced battery technologies come into play. Energy storage systems, often paired with solar installations, enable excess energy generated during sunny periods to be stored for later use.

Lithium-ion batteries, for instance, have witnessed remarkable advancements, becoming the preferred choice for energy storage due to their high energy density, efficiency, and cycle life. When integrated into the power supply system, these batteries can help stabilize the grid, manage peak demand, and provide backup power during outages. Furthermore, they support the integration of intermittent renewable sources into the grid by smoothing out fluctuations in energy generation.

While the modernization of the power supply system through solar cells and batteries offers promising solutions, several challenges need to be addressed for widespread adoption. These include the intermittency of renewable energy sources, the environmental impact of battery production and disposal, and the need for robust grid infrastructure upgrades.

Research and development efforts are ongoing to enhance energy storage technologies, improve battery recycling methods, and develop innovative grid management strategies. As advancements continue, the cost-effectiveness and efficiency of integrating solar cells and batteries into power supply systems are expected to improve significantly.

Backup power supply with a battery-free power supply system of the EC post (when two feeders are disconnected) is carried out from the battery. Currently, acid-lead batteries such as SK-6, SK-8, SK-10 or ABN-72, ABN-80 are used for backup power supply of station and distillation devices of railway automation. These batteries can provide a discharge current of up to 185 A, and therefore for a very long time they had no alternative as a backup power to arrows and traffic lights, especially at large stations with a number of arrows from 30 to 100 and above, however, these batteries are outdated, need constant maintenance and are harmful to staff [11].

For this system, it is proposed to use lithium-iron phosphate batteries with a nominal voltage of 3.2...3.3 V per cell as an alternative source of direct current.

These batteries have a number of advantages over lead-acid batteries, namely:

- the specific density of batteries is 3...5 times higher than lead-acid batteries;

- they provide a high discharge rate with a current of up to 10°C;
- they have a long service life, more than 2000 "charge-discharge" cycles;
- high level of security;
- wide range of operating temperatures from -10 to +60°C;
- no toxic production [9].

However, there are disadvantages, namely incompatibility with lithium-ion battery chargers, slightly inferior in energy density to lithium-polymer batteries.

The modernization of the power supply system goes beyond the adoption of solar cells and batteries. It also involves the implementation of smart grid technologies and advanced energy management systems. Smart grids enable bidirectional communication between power producers and consumers, optimizing energy distribution and consumption patterns. This two-way interaction allows consumers to become prosumers, producing their own energy and feeding excess energy back into the grid.

Sophisticated energy management systems, powered by artificial intelligence and machine learning, can forecast energy demand, optimize charging and discharging cycles of batteries, and make real-time adjustments to energy distribution. These systems contribute to the efficient utilization of renewable energy sources, reduce energy waste, and enhance overall grid resilience.

5. Conclusions

The introduction and use of solar panels in the power supply system as an additional or backup power source will save money that is allocated for the power supply of railway nodes. The modernization of the power supply system through the integration of solar cells and advanced battery technologies represents a significant step toward achieving a more sustainable and resilient energy future. By reducing reliance on fossil fuels, mitigating environmental impact, and enabling decentralized energy generation and storage, this transformation holds the potential to reshape the global energy landscape. As technology continues to evolve and innovations emerge, the transition to a cleaner and more efficient power supply system powered by solar energy and advanced batteries will play a crucial role in ensuring a brighter, greener tomorrow.

Also, thanks to the combination of solar panels and batteries, it is possible to adjust the necessary parameters

for consumers. Also, this scheme will allow operations to change the scheme without drastic changes to this scheme, parameter calculations are carried out in a short time, and the replacement of individual components is carried out modularly. In other words, if the solar panel or battery breaks down, or if another system component fails, the module can be replaced in a short time without major system adjustments. The use of lithium batteries in SCB devices will improve the working conditions of electromechanics (staff) by eliminating such a harmful factor.

Also, the advantage of this proposal is that it is "green energy", which is clean, does not pollute the environment. Also, when using such a structure at EC posts with the need for a small amount of electricity, it is possible to return excess electrical energy to the general system of the main power source. This saves money allocated for the provision of electricity to railway nodes.

Solar energy's journey from a niche technology to a mainstream power source has been characterized by relentless innovation and dedicated research efforts. Continued advancements in materials science, efficiency enhancement, and manufacturing techniques promise to make solar energy even more cost-effective and efficient in the coming years.

As governments, businesses, and individuals increasingly recognize the urgency of transitioning to sustainable energy sources, solar energy's role in modernizing the power supply system becomes ever more crucial. By harnessing the sun's energy, we are not only unlocking a clean and abundant source of power but also paving the way for a brighter and more sustainable future for generations to come.

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