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Experimental wind power and photovoltaic plants as a basis for researching to use renewable energy sources in the power supply systems for non-traction consumers

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Експериментальні вітро- та фотоелектричні установки як база для дослідження використання відновлювальних джерел енергії в системах живлення нетягових споживачів залізничного транспорту

Мета. *Описати засоби, які використовуються авторами для експериментальних досліджень щодо можливостей використання відновлювальних джерел енергії в системах живлення нетягових споживачів залізничного транспорту. Методика дослідження ґрунтується на сучасних методах обчислювальної математики, статистики та аналізу інформації з використанням сучасних комп'ютерних технологій.* ***Результати дослідження.*** *На сьогодні немає комплексного підходу та конкретних обґрунтованих заходів до впровадження відновлювальних джерел енергії в енергозабезпечення нетягових споживачів. У статті наведено приклади впровадження відновлюваних джерел енергії в системи електропостачання залізниць закордоном. Зазначено, що при використанні різних відновлюваних джерел енергії в системах живлення нетягових споживачів, необхідно мати обсяг статистичної інформації для визначення їх техніко-економічних показників. Наведено класифікацію вітроенергетичних установок з горизонтальною віссю. Надано принципову схему та загальний вигляд розробленої експериментальної вітроенергетичної установки. Надано принципову схему та загальний вигляд розробленої експериментальної фотоелектричної установки. Розглянуто обладнання, яке використовується для досліджень вітрового потоку та інтенсивності сонячного випромінювання у місцях можливого знаходження вітроенергетичних чи фотоелектричних установок. Приведені експериментальні вітро- та фотоелектричні установки, які слугують для комплексного вивчення можливостей використання вітрових та сонячних джерел в системах живлення нетягових споживачів, мають узагальнений характер і дають можливість уточнювати необхідні для прийняття рішень данні.*

Наукова новизна *полягає у впровадженні відновлюваних джерел енергії в систему електропостачання нетягових споживачів залізничного транспорту.*

Практичне значення*. Використання додаткових відновлюваних джерел енергії для живлення нетягових споживачів призводить до мінімізації витрат електроенергії.*

Ключові слова: відновлювані джерела енергії, якість електричної енергії, вітроенергетична установка, фотоелектрична установка, мережі електропостачання залізничного транспорту, тягові і нетягові споживачі, виробництво електроенергії.

Purpose*. Describe the tools used by the authors for experimental research on the possibilities of using renewable energy sources in the power supply systems of non-traction consumers of railway transport.*

The methodology of research is based on modern methods of computational mathematics, statistics and information analysis using modern computer technology.

Findings. *To date, there is no comprehensive approach and specific reasonable measures for the introduction of renewable energy sources in the energy supply of non-traction consumers. The article presents examples of the introduction of renewable energy sources in the power supply systems of railways abroad. It is noted that when using different renewable energy sources in the power supply systems of non-traction consumers, it is necessary to have a volume of statistical information to determine their technical and economic indicators. The classification of wind power plants with a horizontal axis is given. The schematic diagram and general view of the developed experimental wind power plant are given. The schematic diagram and general view of the developed experimental photovoltaic plant are given. The equipment used for research of wind flow and intensity of solar radiation in places of possible location of wind power or photovoltaic installations is considered. The presented experimental wind power and photovoltaic plants, which serve for a comprehensive study of the possibilities of using wind and solar sources in the power supply systems of non-traction consumers, are generalized and allow to clarify the necessary data for decision making.*

The originality *is the introduction of renewable energy sources in the power supply system of non-traction consumers of railway transport.*

Practical implications*. The use of additional renewable energy sources to supply non-traction consumers minimizes electricity consumption.*

Keywords: renewable energy sources, quality of electric energy, wind power plant, photovoltaic plant, power supply networks of railway transport, traction and non-traction consumers, electricity production

Introduction

As is known [1] in Ukraine at present 9926 kilometers of railways are electrified. The total length of railways and today is 19.790 kilometers, which is almost half of all railway lines [2]. Electrified railways receive electricity from power systems, which are formed by a set of large power plants connected by power lines and jointly supplying consumers with electric and thermal energy [3]. Since at present the railway is energy deficient, recently the issue of energy supply to its individual objects, namely non-traction consumers, with the possibility of using renewable energy sources is being considered [3].

Analysis of literature sources and problem statement

At present, the priority is the development of own

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generation of electricity for the supply of non-traction consumers through the use of renewable energy sources in order to reduce the cost of energy supply of railway transport [4].

The solution to this problem is proposed by the authors [5], who assess the potential of distributed solar generation using a geographic information system consisting of layers: solar radiation, railways, power lines, power plants, reservoirs, land strips, alienated for infrastructure in Russia. In [6] it is considered how solar power plants can be integrated into the railway power supply system. Renewable energy sources in the power supply systems of railway transport have been introduced in foreign countries, such as Belgium [7], Germany [8] and Great Britain [9].

Thus, the use of renewable energy sources in rail transport is an urgent need today from the standpoint of energy efficiency. Improving the efficiency of the use of renewable energy sources opens up great prospects for the railway [10].

The purpose and objectives of research

It is understood that to make decisions as for the use of some renewable energy source in the power supply systems for non-traction consumers it is required to have enough information for determining their technical and economic indices. Taking into account the random nature of input of energy resources, corresponding to the case, the specifications of equipment to be used should be either clarified or even identified independently. Thus, adequate experimental base should be available.

While orienting only to wind and solar radiation, analyze the possibilities of the development of experimental plants simulating the operation of corresponding equipment.

Research results

It is known that wind is formed as a result of nonuniform heating of the Earth's surface by the sun. The air circulates as a result of its rotation around its axis as well. In this context, in the northern hemisphere it moves counterwise, while in the southern hemisphere it moves clockwise. According to the expert estimation [11], Ukraine has great resources of wind energy which annual technical potential is almost 30 bln kW·h. Unfortunately, regional distribution of that resource is not uniform.

Depending on the generator capacity, the available wind plants are divided into the classes, which parameters are represented in Table 1. Nowadays, plants with horizontal axis (Fig.1) are the most popular ones. Their main elements are as follows: wind-receiving device (blade), electric generator and reducer to transmit torque to it (located in a nacelle), and tower.

Table 1

Classification of wind power plants

Plant class	Capacity, kW	Wheel diameter, m	Number of blades	Purpose
Low capacity	15 – 50	3 – 10	3 – 2	Battery charging, power supply for pumps, household needs etc.
Medium capacity	100 – 600	25 – 44	3 – 2	Power generation
High capacity	1000 – 4000	> 45	2	Power generation

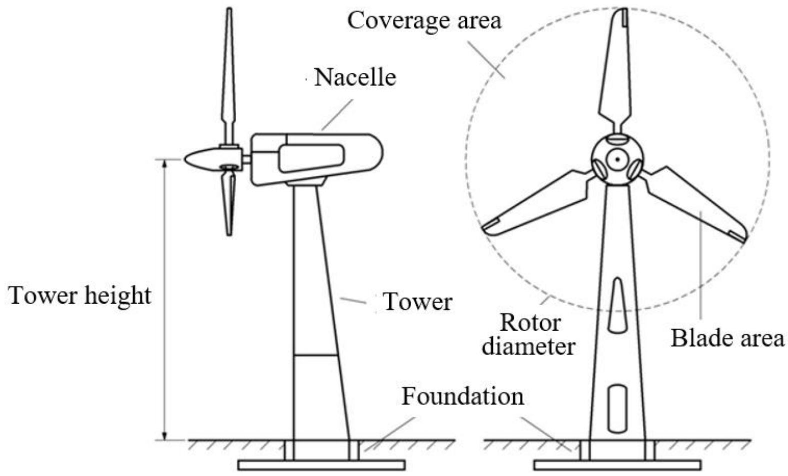

Fig. 1. Principle diagram of a wind power plant

A wind-receiving device together with the reducer form so-called wind motor, which torque is generated owing to the specially selected blade configuration. It is clear that to use wind power plant (WPP) analyzed in the paper only low-capacity plants may be suitable (not more than 50 kW).

Gear set together with a wind turbine form so called wind engine which torque originates owing to specially selected configuration of blades. It is understood that only low power installations are acceptable for WPP, considered by the research (i.e. no more than 50 kW).

Experimental plant to study WPP, which scheme is represented in Fig. 2, includes following basic components:

– nacelle of the analyzed WPP;

– asynchronous motor driving the generator;

– frequency converter (FC) ПЧ-2000 which helps control AM rotating velocity simulating the wind flow action;

– continuous power supply source (CPSS) ДБЖ–1.5/3С-ВГ which produces in output the stabilized constant and sinusoidal voltages with their digital indication;

– personal computer with software for corresponding processing of the obtained data and SCPS and FC matching; and

– storage battery with the voltage of 24 V.

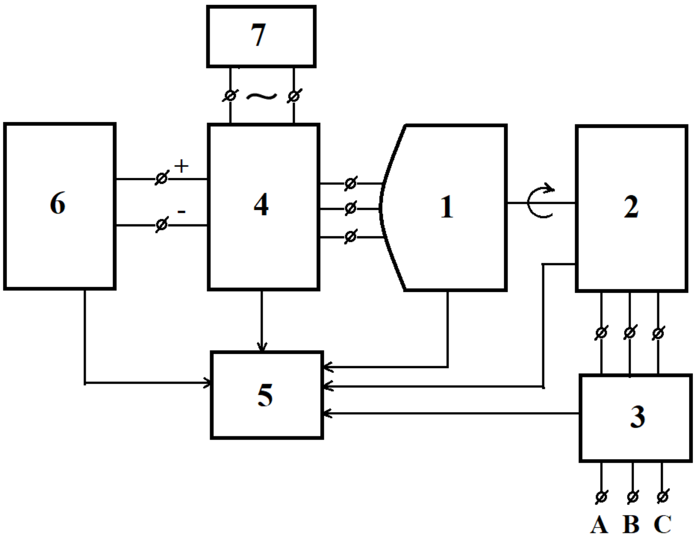

Fig. 2 Principle diagram of the experimental wind power plant: 1 – nacelle with generator; 2 – AM with belt drive; 3 – frequency converter (FC) FC-2000; 4 – continuous power supply source (CPSS) ДБЖ – 1.5/3С-ВГ; 5 – personal computer; 6 – storage battery (SB); 7 – alternating current loading.

In the process of analysis, following data are obtained and transferred to the PC for their processing:
– magnitude of currents in circuits of the generator and the one coming in the inverter;
– voltage value on the SB terminals;
– degree of SB charge;
– temperature of FC radiator;
– state of regulator of the current entering from WPP;
– state of CPSS switches and voltage availability on CPSS; and
– rotating frequency of the generator shaft.
Fig 3 shows general view of the developed experimental wind power plant.

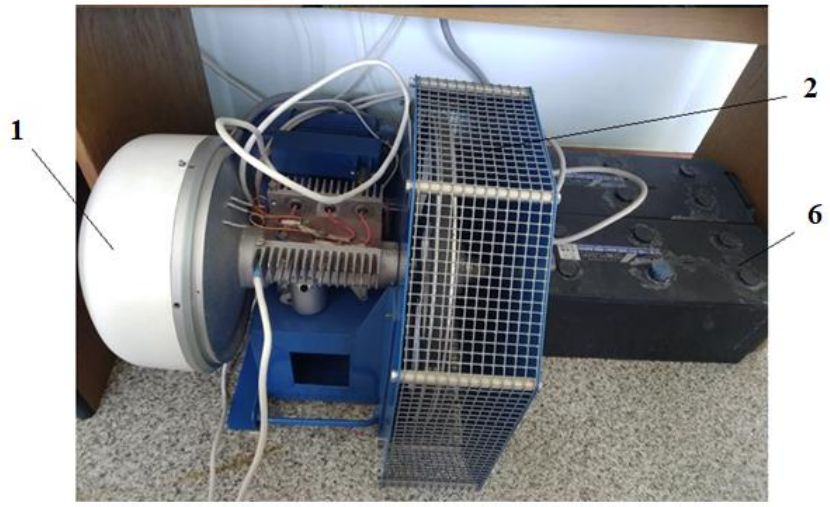

Fig. 3. General view of the experimental wind power plant 1 – nacelle with generator; 2 – AM with belt drive; 3 – frequency converter (FC) ПЧ-2000; 4 – continuous power supply source (CPSS) БЖД– 1.5/3С-ВГ; 5 – personal computer; 6 – storage battery; 7 – alternating current loading.

Moving on to the analysis of the experimental solar plant, it should be remembered that solar energy is converted into electric one mostly by direct photovoltaic conversion with the use of semiconducting elements. First, photovoltaic plants (PVP) were used as the power source for space equipment as it was the only way to provide electric energy for that kind of facilities. Thus, high specific cost of that production did not prevent from application of that technology.

Use of photovoltaic converters to generate great amount of electric energy on the Earth is still problematic not only due to its expensiveness but also due to the necessity to cover huge areas for their location. However, rational use of photovoltaic plants to supply power for the consumers being scattered over the large territories or located far from the centralized power grids, may be the only (in some cases) expedient way for their power supply.

Principle of the photovoltaic converter work is based on the phenomenon of internal photoeffect in semiconductors and effect of division of charge carriers (electrons, holes) by electron-hole transfer or potential barrier of the metal – dielectric – semiconductor (MDS) type. Nowadays, silicon is the most promising material for that use; it is characterized by high mobility of charge carriers, producibility, and sufficient amounts in the earth's interior.

The simplest device to collect a lot of solar energy is a flat battery with many photo elements connected in the successive and parallel groups for reaching the required output capacity and voltage. Despite the fact that it differs with spectral selectivity, the battery does not react to the infrared band of spectrum which results in its considerable heating and distinct decrease in the conversion efficiency.

Experimental plant to study PVP is developed on the basis of the principle diagram represented in Fig. 4. It consists of solar panel 1, simulator of solar radiation 2, sensor of the radiation density 3, unit of energy conversions and accumulation of the necessary information 4, storage battery 5, and personal computer 6. During the study, following information is recorded and collected in unit 4: voltage on the photopanel output, $U_{f.p.}, V$; loading current of a photopanel, $I_{f.p.}, A$; radiation density $G, W/m^2$; and panel temperature $T_{f.p.}, {}^0C$.

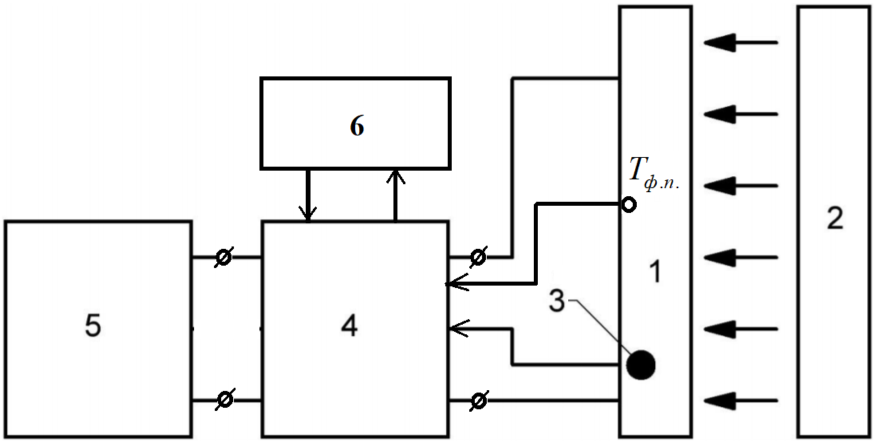

Fig.4. Principle diagram of the experimental photovoltaic plant: 1 – solar electric panel; 2 – simulator of solar radiation; 3 – sensor of radiation flow density; 4 – unit of energy and information conversions; 5 – storage battery; 6 – PC.

Simulator of solar radiation is made in the form of a mobile panel with specially selected electric bulbs mounted on it; the bulb light is close to the one of solar spectrum (PHILIPS crypton bulbs). The simulator capacity may be varied by regulator; it also moves towards or backwards from the photovoltaic panel by means of a mechanical device. Fig. 5 shows general view of the experimental plant based on the represented principle diagram.

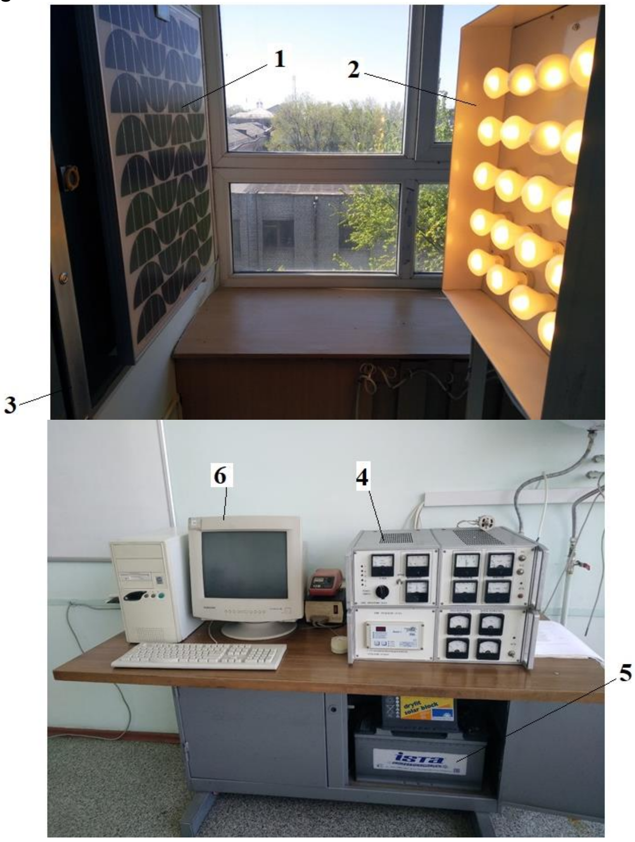

Fig. 5 General view of the experimental photovoltaic plant: 1 – photopanel; 2 – simulator of solar radiation; 3 – sensor of radiation flow density; 4 – unit of energy and information conversions; 5 – storage battery; 6 – PC.

Finally, consider the equipment for studying wind flow or solar radiation intensity within the places of possible location of WPP or PVP. In terms of the first case, today there are a lot of compact converters used for construction, production, operating wind power plants – everywhere where it is necessary to record accurate meteorological data to meet the specified conditions. Our research involves compact sensor of wind velocity made by “Micro-Step-MIS” Ltd (Russia), which general view is given in Fig. 6.

Fig. 6 General view of the applied device to measure wind velocity made by “Micro-Step-MIS” Ltd (Russia)

The device is easy to mount on any available supports (posts, roofs of buildings etc.) after its raising at the required level by the additional pipe. It has following technical characteristics:

– measuring range is from 0.5 to 50 m/s;

– accuracy is $\pm 3\%$ of real value;

– dimensions are: 135×225 mm; and

– weight is 0.75 kg.

The obtained values of wind velocity are recorded and shown digitally. More details about the device can be found on the company site. The number of the product we use is 4.3518.00.700.

To measure solar radiation intensity, pyranometer SMP made by KIPP&ZONEN was used. The device is specially designed to record the solar energy flow falling on a flat surface from the sun and horizon within the wavelength range from 300 to 3000 nanometers (Nm). The device has intellectual interface; it is made in two modifications: with voltage analogue output (from 0 to 1 V) and with signal current (from 4 to 20 mA). We have used the first variant.

Fig. 7 demonstrates general view and scheme of signal passing in the pyranometer. It involves two-conductor successive interface RS-485. All the technical characteristics of the applied device as well as other modifications can be found on the site of company representative in Ukraine: http://data-luff.com, e-mail:luff@ukr.net.

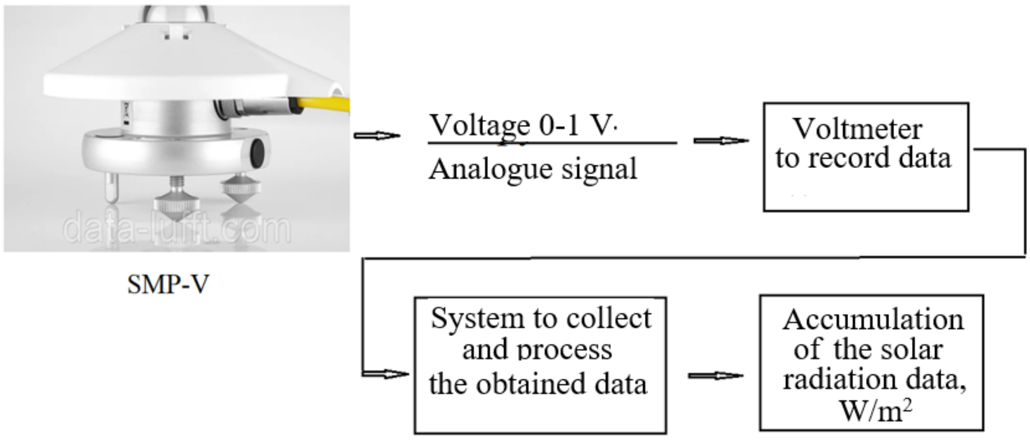

Fig. 7. General view and sequence of the information passing in the pyrometer SMP-V

Conclusions

The experimental plants, designed for the integrated analysis of use of wind sources and solar sources within the power supply systems for non-traction consumers are of multipurpose nature. Moreover, they make it possible to specify the required values and dependences as for their engineering and power parameters to make correct decisions.

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