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Research Paper

PRACTICAL EVALUATION OF POLYCRYSTALLINE PHOTOVOLTAIC MODULE EFFICIENCY UNDER KARAGANDA CONDITIONS

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Abstract

Nowadays, seven major projects aiming at solar power plants development with total capacity of 300 MW have been introduced in Kazakhstan, which advances the use of non-conventional renewable energy sources and develops the technologies to promote the solar energy. The paper reports on the research focused on the design and construction of 60 MW solar power plant in the city of Saran. An experimental solar power plant has been built at Karaganda State Technical University to study technical parameters of photovoltaic modules under operational conditions and their adjustment to climatic conditions of Karaganda located in Central Kazakhstan. The statistical analysis of data was performed, and the distribution parameters with the criteria for processing experimental results were evaluated. It was found out that the monitoring system and the change in the values of Azimuth and Zenith angles of solar modules will be effective for Karaganda. The results of observations have shown that the amount of electrical energy produced in 2014 exceeded the amount generated in 2015 in the range of 10 %, depending on the month of the year. A temperature increase by 1 °C from 25 °C reduces the solar panel capacity by approximately 0.51 %.

Key words: green technologies, solar power plants, Kazakhstan, solar modules, electric power.

1. Introduction

The concept of transition to the production of clean energy implemented in Kazakhstan will ensure a new level of it in accordance with the global trend towards renewable power engineering. Fundamentally new approaches are required to make advances in the expansion of new green technologies. Kazakhstan is actively involved in the design of renewable energy sources since industry 4.0 cannot be developed without energy-efficient technologies. Total amount of electricity generated in the country is expected to reach 30 % by 2030. Kazakhstan is a self-sufficient country to realize this concept in transition to renewable sources and green technologies of energy production in an environmentally friendly way. According to the forecasts of the leading foreign analysts, the global production level of clean energy will reach 80 % by 2050 [1–6]. Kazakhstan is rich not only in minerals, but also in energy resources that can be effectively used. In the southern regions of the country, there are more than 300 sunny days a year and the daily amount of solar radiation is 4.8–5.1 kWh/m^2, which will make it possible to build large photovoltaic plants capable of producing green energy for the whole country. Kazakhstan is rich in oil, gas and coal. For example, its considerable coal reserves will suffice for more than 300 years.

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However, this energy system causes appreciable damage to the environment and the consequences of carelessness and waste will be more evident in the near future throughout the world. We can see the first signs of future environmental problems, which may be dangerous for the life of people in many countries of the world and turn them into ecological refugees.

Today, the developed countries actively implement the policy on renewable sources and a unified system of generated energy distribution. The hydrocarbon epoch is declining; new environmentally friendly sources are in demand. Fifty-five facilities for the production of renewable energy with a total capacity of 336 MW were put into operation to produce about 1.1 billion kWh of clean energy in 2017 [7–11]. The world community appreciated the contribution and aspiration of Kazakhstan to develop green technologies for energy production. As a result, Kazakhstan became a platform for the International Specialized Exhibition EXPO which showed the rapid pace of technological progress and high technological level in the field of alternative energy. The exhibition was devoted to the «Energy of the future», that is the energy produced by renewable sources, which are being actively developed in Kazakhstan.

Kazakhstan is at its initial stage to explore nonconventional renewable energy sources (NRES) as compared to the EU countries. The country develops its own technologies to promote the solar energy. However, there are certain challenges associated primarily with high cost of initial investments and unresolved problems related to the connection of the electric power sources with a capacity of less than 1 MW to the network of the national operator of the Kazakhstan Electricity Grid Operating Company (KEGOC JSC). The KEGOC JSC monopoly restricts the connection of solar power plants of small capacity since it puts forward technical requirements that cannot be fulfilled due to significant financial expenses required for the power and switching electric equipment, when the payback period can exceed 20 years depending on conditions. As a result, small solar power plants lack financial support since they cannot be connected to the General power system and sell energy at an inflated rate with state subsidies. They are engaged in power supply of remote facilities or storage devices in private residencies. Therefore, the cost of the energy produced by the solar power plant (SPP) is 3 times higher than that of conventionally produced one, which makes healthy competition impossible. The only way out is the state support of low capacity SPP to be used for small distributed loads in rural areas. In Kazakhstan, the potential of solar energy is approximately 2.5 billion kWh per year, the annual amount of solar radiation arriving to its territory is not less than 19×1017 kcal, which is the equivalent to 270 billion TOE. This enables creation of general power system of SPP with a capacity of about 50,000 MW per year. This corresponds to the capacity of 50 nuclear reactors, which is slightly less than that in France and exceeds that in Japan [12–17].

Seven major projects for the development of solar power plants with a total capacity of 300 MW have been introduced in Kazakhstan, mainly in the southern regions. The largest 100 MW plant is in the South Kazakhstan region, that with less capacity is located in Dzhambul, the Almaty region, and two power plants with a total capacity of 80 MW each are located in Sairam and Ordabas areas. In 2013, the 7 MW power plant Otar was commissioned in the Zhambyl region and that with a capacity of 2 MW directly connected to the electric grid was put into operation in Kopchegai. Two 50 MW SPPs were put into operation in Kyzylorda and Zhambyl regions. In Kazakhstan, the sunshine duration is 2.200–3.000 hours per year, the solar energy is 1.100–1.800 kW/m^2 per year, and the average power is 130–180 W/m^2. The total solar radiation varies from 4.100 to 5.300 MJ/m from South to North. The proportion of effective radiation ranges from 1.600 to 2.000 MJ/m. In winter, the reflected solar radiation is 70–80 %, which reduces to 20–30 % in summer. A large number of sunny days (especially in summer), high air temperature and little precipitation during the year are very typical. The Kyzylorda region that borders Uzbekistan has a huge potential. The number of sunny hours reaches 3.100 hours here, and solar energy is equal to about 2.000 kW/m^2 per year. Currently, the share of renewable energy sources is 0.3 % of the total electricity generation, of which more than 90 % accrue to small hydropower plants. In accordance with the Strategic Development Plan of the Republic of Kazakhstan until 2020 the share of the alternative energy sources in the total volume of electricity consumption is expected to be more than 3 % (for comparison, in the EU, it is 20 % and in Russia it attains 4.5 %). Considerable world reserves of silicon in the amount of 24 % in Kazakhstan create great opportunities for the production of solar modules.

In Kazakhstan, about 72 % of electricity is produced from coal, 12.3 % is obtained from hydraulic resources, 10.6 % is generated from gas and 4.9 % is produced from oil. Considering the current rates with no progressive growth taken into account, these reserves will be sufficient: oil – for 50 years; natural gas – for 80 years, coal – for 200–250 years, and brown coal – for 450–500 years. The power industry in Kazakhstan is determined by electricity production at thermal power plants. More than 40 % of all energy is produced in the North in Pavlodar region, where large area and the length of power lines of about 370 thousand kilometers cause annual losses from 20 to 40 % of the generated capacity. Therefore, it is more profitable to produce electricity at the place of its consumption with no transport losses; hence, solar power plants built in the southern regions of the country can be of great help. The energy system Kazakhstan is connected to the EEU of Russia and Central Asia from where the missing capacities have to be purchased.

In Astana, Kazatomprom's subsidiary plant for assembly of photovoltaic modules Astana Solar LLP was launched in 2013. It provides a full cycle of production: from the extraction of raw materials, silicon smelting to the production of photovoltaic plates with 100 % Kazakhstan content of products, which work according to the French technology of enterprises with a plate efficiency of 16.5 % [9]. The full capacity of the enterprise for production of these panels will be 60 MW with an extension to 100 MW in the future. Astana Solar LLP produces two main types of photovoltaic plates KZPV 230 M60 (215–245 Watts) and KZPV 270 M72 (250–300 Watts). Within the state support of the domestic manufacturer and subsidies, the manufacturer's price for solar cells ranges from 140 to 190 US dollars depending on the capacity. The government offers various support mechanisms and 50 % recovery of expenses to farmers; however, healthy competition in the market is out of the question due to a great number of manufacturers from China. A rather high cost of production is determined by a considerably high cost of silicon wafers.

2. Studies of Astana Solar photovoltaic module of KZ PV 270 M72 type

The studies conducted are necessary to design and construct the SPP with a capacity of 60 MW in the town of Saran. The contractors of Photovolt Kosice from Slovakia are involved in the construction. The representatives of this company asked Karaganda State Technical University (KarSTU) for cooperation in working with KZ PV 270 M72 photovoltaic modules produced by Astana Solar LLP to assess their efficiency for energy supply of the future power plant. Such large-scale studies have not been performed before, and the data to rely upon was the generalized data obtained on the Internet. In KarSTU, an experimental SPP was constructed to study technical parameters of photovoltaic modules under operational conditions and their adjustment to the climatic conditions of the city of Karaganda in Central Kazakhstan with sharply continental climate and geographical position of 49°48' N, 73°07'E.

The length of a solar day is 2.300 hours per year, the average amount of solar energy is 1.300 kW/m^2 per year, and the average power is 130 W/m^2. SPP is a metal structure with rotating platform with an actuator and an orientation system. The rotation is performed around the polar axis. The rotary system is equipped with the biaxial orientation system with four photovoltaic modules of KZ PV 270 M72 type produced by Astana Solar LLP. The basic technical data are as follows: 270 Watt installed capacity; 24 V rated voltage; 7.5 A rated current; polycrystalline 6'' (156×156 mm) silicon wafers, 6 columns of 12 cells; 1.967×992×40 mm in dimension, 0/+5W permissible deviation; 16 % efficiency.

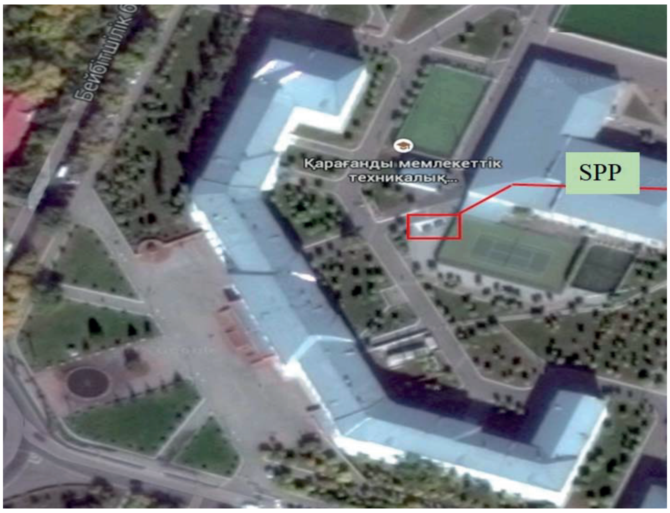

Fig. 1. *Location of SPP in the courtyard of KarSTU campus*

Fig. 2. *The external view of SPP*

SPP is made according to the classical circuitry. The only difference is the load sharing powered from AC and DC separately. The load sharing is required to reduce the load on the inverter.

This circuitry has certain advantages; however, we do not consider them in this paper.

3. Materials and methods

The 100 W incandescent bulbs symmetrically distributed by 5 pieces per unit for each type of voltage were used as a load. The orientation system combined in one unit with the monitoring system and

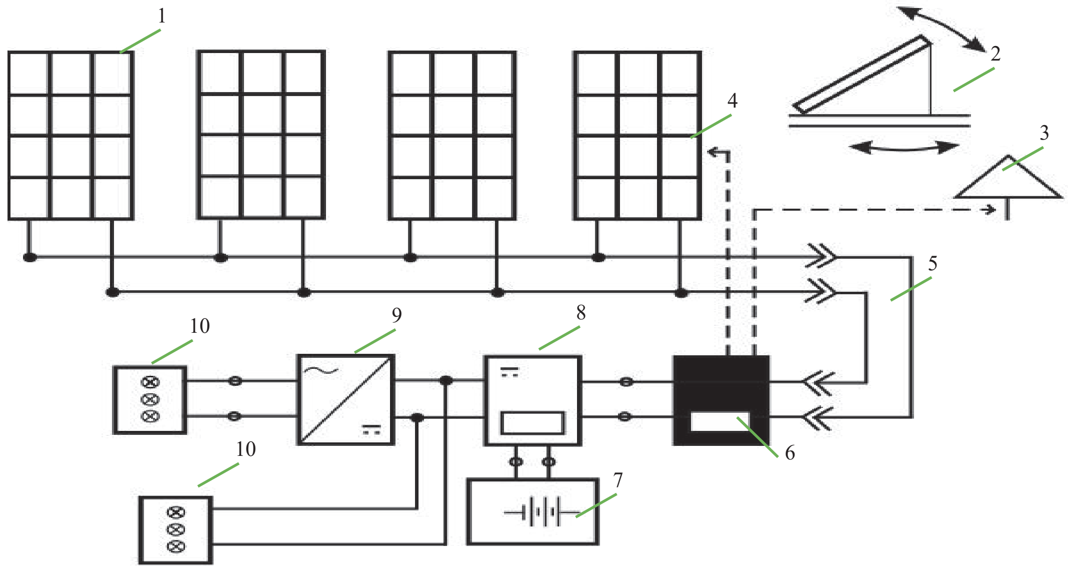

Fig. 3. *Solar power station circuitry:*
1 – four photovoltaic modules of KZ PV 270 M72 type; 2 – positions of the module orientation in space; 3 – orientation system sensor; 4 – control communication with the actuator of rotary orientation system; 5 – 24 V DC connecting line; 6 – orientation, monitoring and measuring system; 7 – storage battery; 8 – battery charg

electrical generation metering is located directly on the SPP site. Some of the results of the studies performed in 2014–2015 are presented in Figs. 4–6.

The statistical analysis of data, evaluation of distribution parameters with criteria for processing experimental results, as well as the correlation and regression analysis were carried out. The least square method (coefficient calculation) was used in data processing. The descriptive statistics and mathematical methods were performed using MS Excel spreadsheet. The theoretical values of the amount of energy produced in kWh/day were obtained with the help of the developed mathematical model, and practical measurements were performed in situ using the system of measuring. The difference between the theoretically calculated energy yield and the one obtained experimentally is due to a high value of annual solar radiation in the pilot area.

4. Results and discussion

The analysis showed that the mathematical model does not take into account the impact of some external factors affecting the generation of electrical energy, such as solar activity, solar battery contamination, atmosphere transparency, reflection of sunlight by snow cover, the number of sunny days per year u.a.m. [19–21]. Since too many factors complicate theoretical calculation, it was performed using simplified models without taking into account these factors. The amount of the energy produced by SPP at the end of 2014 exceeded that in 2015 by 10 %, Fig. 5. The result was primarily influenced by weath-

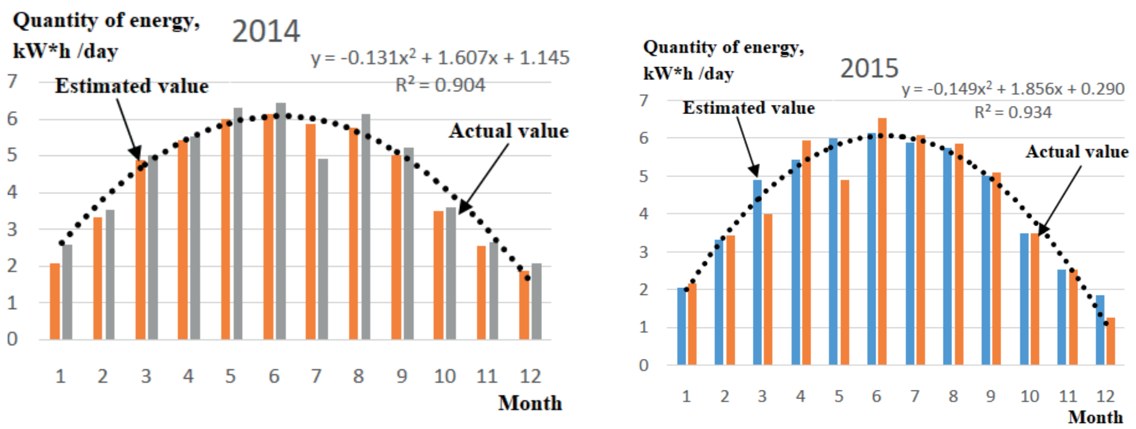

Fig. 4. *Amount of electrical energy generated by SPP in 2014 and 2015 taking into account calculated and actual value*

er conditions in Karaganda, as well as some other factors mentioned above.

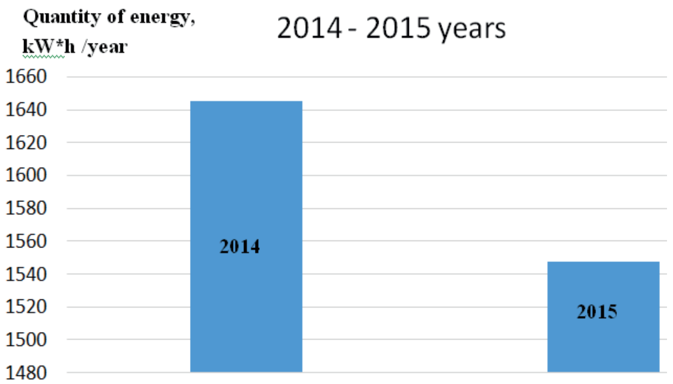

Fig. 5. *Total amount of electrical energy generated in 2014 and 2015*

We have found out that the system of monitoring and the change in the Azimuth and Zenith angles of solar modules will be effective for Karaganda. The application of the uniaxial system will bring an additional increase by 28 % per year (full-axis rotation and change in the value of the Azimuth angle), and the biaxial monitoring system will increase the generated capacity of photovoltaic modules up to 49 %. This is especially important for winter and autumn periods; however, the problems with the system operation under the conditions of Karaganda should be considered. In addition, the cost of the SPP installation is about 2.1–2.2 times more than that without the orientation system. High structural strength is required to withstand the wind gusts up to 30–40 m/s, as well as snow cover up to 1.3 meters or more. The features of the use of trackers in Kazakhstan are significant investments in their bearing capacity due to a large wind load as well as the impact of snow. It is also necessary to protect against lightning and overloads.

It is not recommend to use the orientation and positioning system in SPP, as the costs do not meet the expected profit under conditions of the city of Karaganda.

5. Conclusion

The results of the observations show that the amount of the electrical energy produced in 2014 exceeded the amount of energy generated in 2015 in the range of 10 % depending on the month of the year. Weather conditions, the level of solar activity and the state of the atmosphere over the city of Karaganda affected the energy generation. The efficiency of solar modules depends on temperature, which varies at different times of the year. A temperature increase by 1 °C from 25 °C reduces the solar panel capacity by approximately 0.51 %. When the panels are blown by wind, their temperature may decrease, which positively affects their efficiency. Cleaning should be performed at least once a week due to high dustiness, otherwise the SPP productivity will decrease from 10 to 90 % depending on the surface contamination; the panels are less contaminated in the vertical position. In winter, the snow cover can reach from 0.7 to over 1.3 m, but even if the panels are arranged at 65° angle at a height of a panel installation of 0.7 m above the ground, they need periodical cleaning after prolonged snowfalls and blizzards. In winter, the productivity of solar power plants falls sharply; therefore, the orientation system (tracker) can provide their effective operation. Its use is recommended only for micro SPP with peak capacity up to 1–5 kW, this packaging arrangement is more suitable for private stand-alone objects. Under the conditions of our environment, the effect of reflection by snow cover will be employed for efficient operation of SPP to improve its performance in the period of February–April. The solar power plant will be built in the steppe area away from Saran city and 30 kilometers above Karaganda, where the level of contamination of snow cover is minimal, that is it remains «white» almost throughout the winter. The study results were reported to Photovolt Kosice representatives. One of the recommendations was to use a KZ PV 270 M72 photovoltaic module, since this product is state supported and state subsidies.

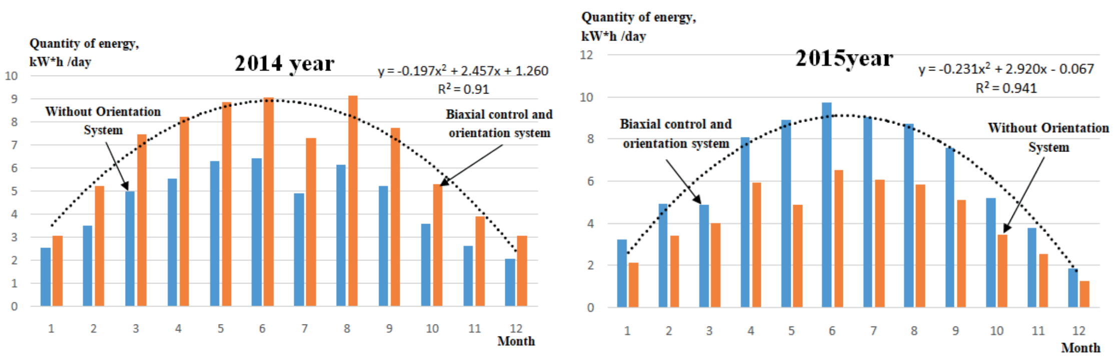

Fig. 6. *Amount of the generated electrical energy using the orientation system and without it for 2014 and 2015*

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