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ASSESSMENT OF THE DEGRADATION PROCESS OF SOLAR PHOTOVOLTAIC PLANTS IN THE CLIMATIC CONDITIONS OF UZBEKISTAN

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Abstract: The article researches the degradation processes of PV panels at the 130 kW Namangan-Pop Solar photovoltaic plant (SPVP) as a result of seasonal climate effects. All PV panels installed in the SPVP are HSL 250, JSMM 2501, SM250 PC 8 and TS-S 400 polycrystalline solar panels manufactured by South Korean companies HANHWA, JSPV, S-ENERGY and TOPSUN. Among them, degradation processes were observed in HANHWA HSL 250 type solar panels. These degradation processes have been determined based on experimental researches based on the requirements of the International Standard. The comparison of the volt-ampere characteristics and power-voltage graphs of HANHWA's defective and new unused HSL 250 solar panels are presented. In Namangan-Pop Solar photovoltaic plant, reference (Y_r) and final (Y_f) production during the study period are averaged 4.12 hours and 3.67 hours per year, respectively and the production ratio (PR) varies between 87.24% - 93.58% and the average annual production ratio (PR) is 87.28% and the rate of degradation of SPVP between 2015-2021 was determined to be 0.224% per year on average.

Keywords: solar cell, solar panel, solar photovoltaic plant, degradation process, EVA film, reference (Y_r) and final (Y_f) production, production coefficient (PR).

Introduction. Currently, only 10.2% of all energy produced in the world is accounted for by renewable energy sources (RES). In particular, in the last five years, the share of renewable energy sources in providing global energy demand has exceeded 20 percent, and it is expected that by the end of 2023, the global production rate will be 12.4 percent [1,2,3]. Currently, renewable energy sources produce approximately 100 times less energy than conventional energy sources [3,5]. However, in the following years, the production of electricity with the help of solar photovoltaic power plants (SPVP) is increasing in the world. Overall growth in solar PV has increased by 50% between 2013-2019 and 2020-2022, which means the construction of many solar photovoltaic power plants and the production of solar panels, which are the main part of them, increase their efficiency and performance resource and requires reducing degradation processes under the influence of external and internal factors that negatively affect the efficient operation of solar photovoltaic power plants [5].

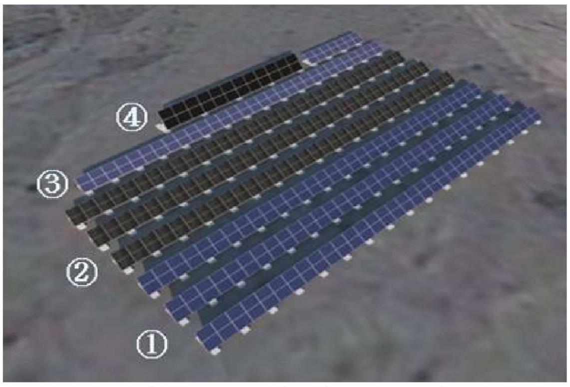
The beginning of the construction of many solar photovoltaic power plants in Uzbekistan leads to an increase in the demand for analysis and research of solar panels, which are the main part of them. Because, as a result of their operation in real climatic conditions for a certain period of time, changes in their output parameters and degradation processes are observed over time. In recent years, scientists around the world have been conducting a lot of research on the degradation of solar panels, studies [6,7] tried to determine the degradation process of solar panels during their operation in real conditions [8,9].

Thus, studying the process of degradation of solar panels and determining the causes of their occurrence and finding ways to prevent and eliminate them is one of the urgent issues of modern science.

This article presents research on the degradation process of polycrystalline silicon-based solar panels at the Namangan-Pop solar photovoltaic power plant in the climatic conditions of Uzbekistan after 7 years of operation.

The object of the study. The research object is a 130 kW solar photovoltaic power plant built for a test experiment in Pop district of Namangan region in 2015. All solar panels installed in the solar photovoltaic power plant are HSL 250, JSMM 2501, SM250 PC 8 and TS-S 400 polycrystalline solar panels manufactured by South Korean companies HANHWA, JSPV, S-ENERGY and TOPSUN, and "KASO" and "DASS TECH" inverters manufactured in Germany [10,11]. The Namangan-Pop solar photovoltaic power plant is designed to produce an average of 500-600 kWh of electricity per day.

An overview of the location of the Namangan-Pop solar photovoltaic power plant and rows of installed solar panels, as well as the technical project of the location of the solar panels relative to the horizon are presented in Figures 1.a,b,). The solar panels in the 1st, 2nd and 3rd rows are fixed at an angle of 30^0 to the horizon, the solar panels of the 4th row are installed in such a way that they can be changed in the range of angles from 15^0 to 45^0 depending on the seasons.



a) Rows of solar panels

b) General view of Namangan-Pop solar photovoltaic power plant

Figure 1. Technical project and general view of the arrangement of solar panels relative to the horizon

The solar photovoltaic plant is connected in parallel to the power grid. Each company's solar panels are equipped with separate inverters and electricity meters.

Research method and device. During the years 2015-2021, a total of 830739 kWh of electricity was supplied to the electric grid by the solar photovoltaic plant. In particular, the solar photovoltaic plant produced 141556 kWh of electricity in 2015, and 7 years later, and 138448 kWh of electricity in 2021. From these figures, it follows that the production efficiency of the solar photovoltaic power plant has decreased by 2.2% during these years. In order to investigate the reason for this, when inspecting the outer surface of all the solar panels installed in the solar photovoltaic plant, a number of defects appeared in the HSL 250 type solar panels of HANHWA (Figure 2).

Figure 2. HSL250 defective solar panels from HANHWA

As the temperature of the solar panel exceeds the norm, air bubbles have appeared between the EVA film layer on the surface of the solar panels and the solar panel in some parts of the solar panel. As a result, some of the sunlight falling on the solar cell is scattered in these bubbles and does not reach the solar cell, resulting in a decrease in the efficiency of the solar panel.

In order to determine the efficiency of solar panels with such defects, one defective HANHWA solar panel was removed from a solar photovoltaic power plant. In order to compare the results obtained from measuring the output characteristics of this selected solar panel, a brand new solar panel from the same HANHWA company in stock, which has not yet been used, was also selected. The output characteristics of this solar panel were brought to the laboratory for experimental measurement and research purposes. The laboratory is equipped with a special "EESFC" device that studies solar panels in the "SCADA" system of the "EDIBON" company.

This device allows for computer control of the study of the electric energy production of the solar panels and to carry out studies on all the characteristics and parameters of the solar panels [12]. The general view and connection diagram of the special "EESFC" device for studying solar panels in the "SCADA" system of the "EDIBON" company is presented in Fig. 3.

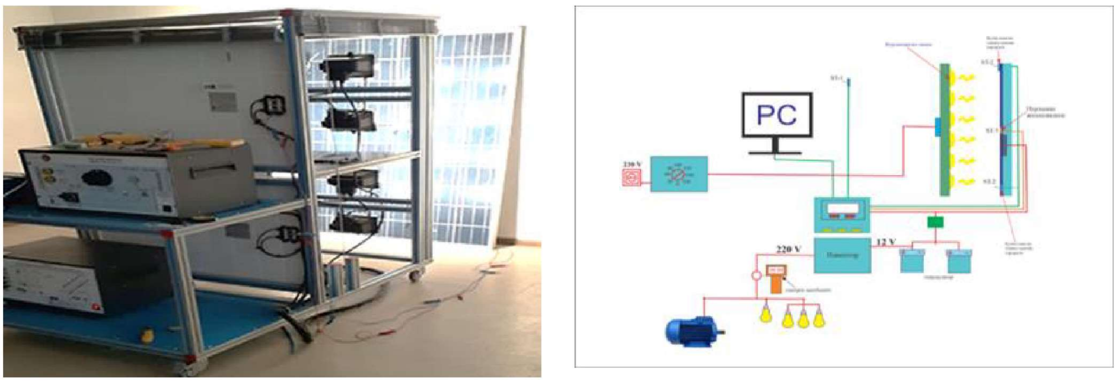


Figure 3. Experimental research device overview and connection diagram

Using this device, the intensity of the light falling on the solar panel J(W/m^2), the produced current I(A), the voltage U(V) and the power P(W) were measured. In addition, room temperature T_{rt} (^{0}C) and solar panel temperature T_{pt} (^{0}C) were measured each time the radiation intensity was increased. These measurements were taken separately for a new non-operational solar panel and separately for a solar panel operated for 7 years under real climate conditions.

Measurement results. Table 1 shows the results of the influence of the temperature of the solar panel on the output parameters for the case where the intensity of the light falling on the new non-operational solar panel is J=750W/m^2.

Parameter indicators of the non-exploited solar panel

Energy parameters	The temperature of the solar panel is ^{0}C									
	31	35	39	43	47	51	55	57	59	61
U (V)	32,9	32,2	31,9	31,5	31,1	30,9	30,5	30,3	30,2	30,1
I (A)	6,71	6,84	6,85	6,87	6,88	6,89	6,95	6,98	7,00	7,01
P (W)	220,8	220,3	218,5	216,4	214,0	213,0	212,0	211,5	211,4	211,0

Table 2 shows the experimental results obtained on the effect of the defective solar panel temperature on the output parameters.

Table 2

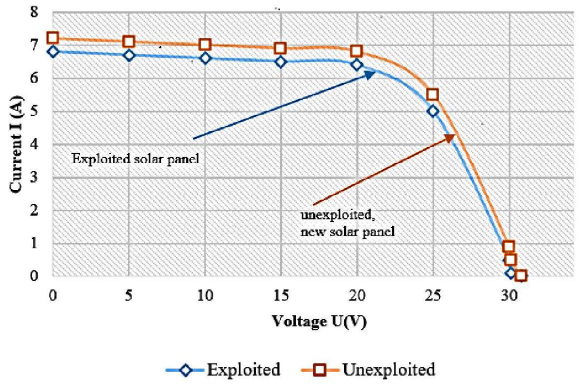
Parameter indicators of a solar panel operated for 7 years

Energy parameters	The temperature of the solar panel is ^{0}C									
	31	35	39	43	47	51	55	57	59	61
U (V)	30,8	30,7	30,7	30,6	30,5	29,8	29,2	28,8	28,5	28,1
I (A)	6,58	6,58	6,59	6,59	6,61	6,62	6,63	6,64	6,65	6,66
P (W)	202,7	200,6	202,3	201,7	201,6	197,3	193,6	191,2	189,5	187,2

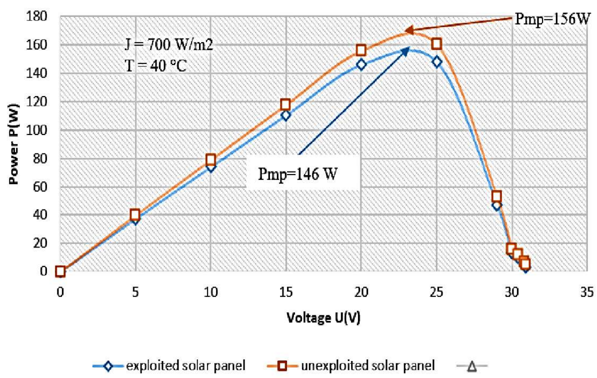
The volt-ampere characteristics (VAX) and power-voltage graphs of HANHWA HSL 250 defective and new unused solar panels are shown in Figures 4a) and b). The maximum voltage of the defective solar panel of HANHWA company HSL 250 type solar panel operated in real climate conditions for 7 years $U_{max(def.SP)}$=24.8V, the maximum voltage of the new unused solar panel $U_{max(new.SP)}$=25.9 V It was found to be equal to V. So, the generated voltage U(V) and current I(A) decreased by a certain value, i.e. 1.1%.

In order to determine the dependence of the power on the voltage, measurements were made when the temperature of the solar panels was T=40^{0}C. The obtained experimental results showed that the maximum power of a new, unused solar panel is P_{mp}=156W, and the maximum power of a defective, i.e., operated solar panel is P_{mp}=146W.

Similarly, short-circuit current I_{SC}(A) and direct voltage U_{oc}(V), i.e., volt-ampere characteristics, were studied for values of 550 W/m^2, 650 W/m^2 and 750 W/m^2 irradiance intensity on the solar panel. As the radiation intensity J(W/m^2) falling on the solar panel increased, the direct voltage U_{OC}(V) decreased significantly, and the short-circuit current I_{sc}(A) increased slightly. When the radiation intensity was 750 W/m^2, the no-load voltage U_{OC} =35.1V and the short-circuit current I_{SC} =7.2A. If the intensity of the light falling on the solar panel is J = 750W/m^2: P_{new}(W) is the effect of temperature on the output power of a new unused solar panel and an analysis of the effect of temperature on the output power $P_{def.}$(W) of a defective solar panel operated for 7 years showed that, indeed, for both solar panels, the increase in solar panel temperature T(^{0}C) decreases the output power P(W), it was found that the output characteristics of the solar panels changed and the degradation processes started in the defective solar panels.



a) Volt-ampere characteristic of solar panel.



b) Power and voltage dependence of the solar panel

Figure 4.-a) and b) show the volt-ampere characteristics and power-voltage dependence of the HSL 250 type defective and new unused solar panel

Research results. International standard IEC-61724 requirements and authors' previous articles [13,14,15,16,17] were used to determine the speed of degradation processes in solar photovoltaic power plant. It is shown in Figure 5 that the average values of reference (Y_r) and final (Y_f) production for the research period are 4.12 hours and 3.67 hours, respectively. Similarly, the variation of the efficiency coefficient of the Namangan-Pop solar photovoltaic power plant over the years is presented in Figure 6.

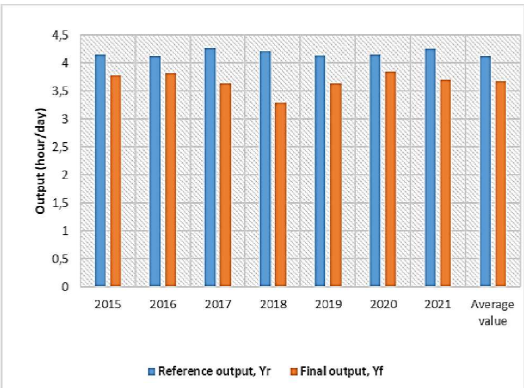


Figure 5. Hours of annual change in reference (Y_r) and final (Y_f) production over the study period

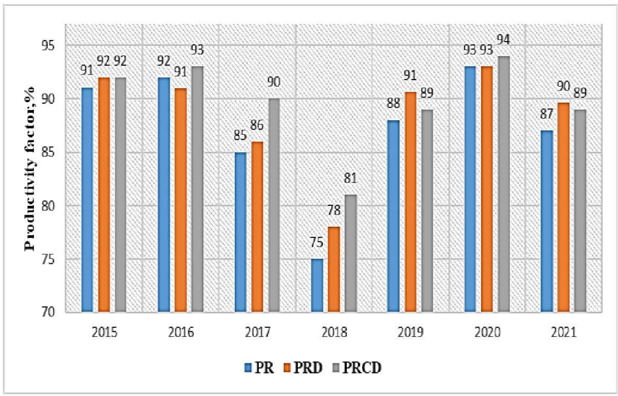


Figure 6. Annual changes in solar PV efficiency over the study period

The average annual efficiency ratios of the solar photovoltaic power plant were 80.74% - 87.25%. The difference-adjusted productivity rate was determined using the odds ratio (PR_D), and the productivity rate for 2020 was 93%. The production ratios (PR) and operating hours of the Namangan Pop solar photovoltaic power plant are compared with the operation of solar photovoltaic power plants in Europe and Asia in Table 3.

Table 3

Solar PV production coefficients in Europe and Asia

Country	Research period (years) / maximum capacity	Technology	*PR* (%)	Range of values for PR (%).	Reference (Y_r) production (day/hour)	Final (Y_f) production (day/hour)	Application
Sardinia, Italy	1 year 300 kW	p-Si	83.20	74.81 to 89.93	-----	-----	(Ghiani et al., 2013))
Spain II	3 years 4.6 MW	p-Si	85.09	83.56 to 87.12	7.25	6.16	(Martín-Martínez et al., 2019)
Spain III	3 years 370 kW	p-Si	80.96	80.39 to 81.43	5.46	4.42	(Martín-Martínez et al., 2019)
Surdun, France	7 years 4.5 MW	p-Si	87.18	84.12 to 90.54	3.92	3.33	Mohamed El Hacen et al., 2018)
Pop-Namangan Uzbekistan	7 years 130 kW	p-Si	87,02	75.85 to 93.28	4.12	3.67	Results of research

From Table 3, it is known that in Italy (Sardinia) the annual production coefficient (PR) of solar photovoltaic power plants was 83.20%, and in Spain II and Spain III the production coefficients (PR) of solar photovoltaic power plants were 85.08% and 80%. It was determined to be 96%. In this, in Spain II reference (Y_r) and final (Y_f) production hours changed from 7.25 to 6.12, a difference of 1.09 hours. In Spain III, reference (Y_r) and final (Y_f) production hours changed from 5.46 to 4.42, a difference of 1.04 hours. Hence, the reference (Y_r) and final (Y_f) production hours in Spain II and Spain III differed by about 1.06 hours. Similarly, the production coefficient (PR) in France (Surdun) was found to be 87.18%. In this case, the reference (Y_r) and final (Y_f) production hours differed by 0.89 hours. Therefore, the production energy efficiency of solar photovoltaic power plants in France is higher than in Spain. According to the results of scientific studies of the Namangan-Pop solar photovoltaic power plant for 7 years, the production coefficient (PR) was found to be 87.02%. In this case, reference (Y_r) and final (Y_f) production hours changed from 4.12 to 3.67, a difference of 0.45 hours.

So, it was determined that the production energy efficiency of solar photovoltaic power plants in the climatic conditions of Uzbekistan is higher than that of Spain and France. A comparison diagram of the degradation level of Namangan-Pop solar photovoltaic power plant with solar photovoltaic power plants in other European and Asian countries is presented in Figure 7. Degradation rates, determined from the slope of the efficiency decline, ranged from 0.18% to 0.209% per year for Spain III and 0.721% for Spain II during 3 years or more of operation of solar PV plants in Spain.

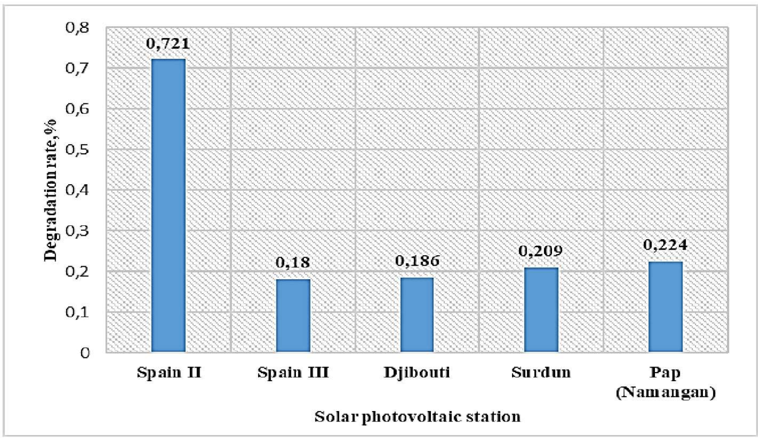


Figure 7. Comparison diagram of solar photovoltaic power plants in Asia and Europe with the degradation rate of Namangan-Pop Solar PV (Uzbekistan)

In Djibouti, despite having a tropical desert-marine climate, the degradation rate was 0.186% per year. In another study in a temperate climate, the degradation rate of Solar PV in France (Surdun) was 0.209% per year.

Thus, it was found that the degradation rate of Namangan-Pop Solar PV in the period 2015-2021 is 0.224% per year on average.

Conclusions. Based on the results of a study of the degradation process of solar panels based on polycrystalline silicon in the climatic conditions of Uzbekistan after 7 years of operation, the following were obtained:

1. As a result of the increase in the temperature of the solar panels during the hot days in the climatic conditions of Uzbekistan, defects appeared on the surface of the solar panels of the HANHWA company, and it was found that this is a degradation process.

2. It was determined that the maximum electric energy produced in Namangan-Pop QFES in 2020 was 143871kWh, and the minimum electric energy was 127468kWh in 2018, and its production efficiency decreased by 2.2% during 2015-2021.

3. In experimental studies, due to changing the intensity of light falling on the solar panel, it was determined that its output power, voltage and current change depending on the temperature.

4. In Namangan-Pop QFES, the reference (Y_r) and final (Y_f) production during the study period averaged 4.12 hours and 3.67 hours per year, respectively, and the production ratio (PR) varied between 87.24% - 93.58% and average annual production rate (PR) was found to be 87.28%.

5. It was determined that the degradation rate of Namangan-Pop solar photovoltaic power plant between 2015 and 2021 is 0.224% per year on average.

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CONTENTS