Optimal egilish burchagini aniqlash uchun fotoelektrik batareyarning energetik ko‘rsatkichlari tahlili

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Dolzarblik: fotoelektrik batareyalarning (PV modullar) optimal egilish burchagi energiya ishlab chiqarishda muhum rol o'ynaydi. Ko'pincha PV modullarini quyosh nurlaridan maksimal darajada foydalanish uchun optimal burchakka e'tibor bermasdan, tomning tabiiy qiyaliklariga mos ravishda joylashtirilishi kuzatilmoqda. Noto‘g‘ri burchakda o‘rnatilgan PV modellarining samaradorligi pasayadi bu esa energiya ishlab chiqarish hajmini kamaytiradi. Shuning uchun PV modullarini ayniqsa fotoelektrik stansiyalarni optimal burchakda o‘rnatish PV tizimlari uchun muhum hisoblanadi. Ushbu maqolada 100kW quyosh fotoelektrik stansiyasi (FES) o‘rnatishdan oldin 550W quvvatli PV modulining statsiyonar holatda har xil egilish burchaglarida o‘lchangan elektr parametrlarining tahlili keltirilgan.

Maqsad: respublikaning janubiy mintaqasi bo‘lgan Termiz shahrida PV modularini optimal egilish burchagini va real sharoitdagi energetik ko‘rsatgichlarini aniqlash.

Usullar: fotoelektrik statnsiyalar “statsionar” o‘rnatilganligi sababli, tajribada ham FEB larning elektr parametrlarini o‘lchashning “statsionar” holati qo‘llanilgan.

Natijalar: respublikaning janubiy mintaqasida PV modullarining optimal egilish burchagini aniqlash uchun har xil egilish burchaklari sinab ko‘rildi. Bunda Termiz shahri uchun PV modulini doimiy (statsionar) burchakda o‘rnatish uchun eng yaxshi burchak 34^0 dan 38^0 gacha ekanligi aniqlandi. Mavsumiy o‘rnatish burchaklariga kelsak, qish fasli uchun tavsiya etilgan burchakga (34^0 dan 38^0 gacha) nisbatan 10^0-12^0 gradusga orttirish, yoz fasli uchun esa xuddi shuncha gradusga kamaytirish tavsiya etiladi. Quyosh panelining optimal egilish burchagi va yo'nalishi yilning oyi va o'rganilayotgan joyning geografik koordinatlariga bog'liq ekan.

Kalit so‘zlar: fotoelektrik batareya, statsiyonar holat, egilish burchagi, qisqa tutashuv toki, quyosh radiyatsiyasi, elektr quvvat.

Анализ энергетических характеристик фотоэлектрической батареи для определения оптимального угла наклона

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Актуальность: оптимальность угла наклона фотоэлектрических элементов (фотоэлектрических модулей) играет важную роль для эффективности производства энергии. Часто можно наблюдать, как фотоэлектрические модули размещаются в соответствии с естественными наклонами крыш, не принимая во внимание оптимальность угла для максимального использования солнечного света. Установленные под неправильным углом фотоэлектрические модули имеют меньшую эффективность, что приводит к снижению выработки энергии. Поэтому важно устанавливать фотоэлектрические модули, особенно фотоэлектрические установки, под оптимальным углом к излучению солнца. В статье представлен анализ электрических параметров, измеренных при различных углах наклона фотоэлектрического модуля мощностью 550 Вт, перед установкой солнечной фотоэлектрической электростанции (СФЭС) мощностью 100 кВт.

Цель: определение оптимального угла наклона фотоэлектрических модулей (ФЭМ) и их энергетических показателей в реальных условиях в городе Термез, южном регионе республики.

Методы: поскольку фотоэлектрические станции установлены «стационарно», в эксперименте также использовался «стационарный» метод измерения электрических параметров ФЭМ.

Результаты: для определения оптимального угла наклона фотоэлектрических модулей в южном регионе республики были протестированы различные углы наклона. В данном случае оптимальным углом

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установки фотоэлектрического модуля под постоянным (стационарным) углом для города Термез оказались углы от 34^0 до 38^0. Что касается сезонных углов установки, то рекомендуется увеличить рекомендуемый угол для зимнего сезона на 10^0–12^0 градусов (с 34^0 до 38^0), а для летнего сезона уменьшить на такое же количество градусов. Оказывается, что оптимальный угол наклона и ориентация солнечной панели зависят от месяца года и географических координат исследуемого места.
Ключевые слова: фотоэлектрические модули, стационарное состояние, угол наклона, ток короткого замыкания, солнечное излучение, электроэнергия.

Analysis of energy performance of a photoelectric battery to determine the optimal tilting angle

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Relevance: the optimal tilt angle of photovoltaic cells (PV modules) plays an important role in energy production. It is often observed that PV modules are installed in accordance with the natural slopes of roofs, without paying attention to the optimal angle to maximize the use of sunlight. The efficiency of PV models installed at the wrong angle decreases, which reduces the amount of energy production. Therefore, installing PV modules, especially photovoltaic stations, at the optimal angle is important for PV systems. This article presents an analysis of the electrical parameters of a 550W PV module at various tilt angles in a stationary state before installing a 100kW solar photovoltaic station (SPS).
Aim: determining the optimal tilt angle of PV modules and their energy performance in real conditions in the city of Termez, a southern region of the republic.
Methods: since the photovoltaic stations are installed "stationary", the "stationary" method of measuring the electrical parameters of the PVs was also used in the experiment.
Results: various tilt angles were tested to determine the optimal tilt angle of PV modules in the southern region of the republic. In this case, the best angle for installing a PV module at a constant (stationary) angle for the city of Termez was angles from 34^0 to 38^0. As for seasonal installation angles, it is recommended to increase the recommended angle for the winter season by 10^0-12^0 degrees compared to the angle (from 34^0 to 38^0) and reduce it by the same number of degrees for the summer season. The optimal tilt angle and direction of the solar panel depend on the month of the year and the geographical coordinates of the studied location.
Keywords: photovoltaic modules, stationary state, tilt angle, short-circuit current, solar radiation, electric power.

1. Introduction

As a major source of renewable energy, solar energy is becoming increasingly popular due to the increasing demand for energy and the gradual depletion of traditional energy sources [1-2].
Today, the demand for energy in the world is increasing day by day. The use of solar energy among renewable energy sources not only improves this problem, but also supports the green world policy. In recent years, the country has been carrying out a number of reforms to increase energy efficiency, including attracting private investment. In order to encourage the use of renewable energy sources, subsidies are being allocated to the population and specific measures are being taken to transition to a competitive energy market. In order to further comprehensively develop the energy sector, a legislative framework is being developed and measures are being introduced in our country to support renewable energy sources, including solar and wind energy. Photovoltaic (PV) panels are a system consisting of a p-n junction solar cell that directly converts light energy from the sun into electricity [3].

The photon energy incident on the PV surface creates electron-hole pairs, resulting in a short-circuit current and voltage [4]. When photovoltaic cells are exposed to photons (light particles) from the sun, these photons energize the p-n junction of the semiconductor. If the photon energy overcomes the potential barrier of the semiconductor, electrons migrate from the p-type to the n-type [5]. The efficiency of the p-n junction determines the overall efficiency of the PV. The quality of the junction design and the choice of materials affect the energy generation capacity of the cells. The power generated by a PV module depends on its temperature and the radiation incident on its front surface [6]. The data provided by the PV module manufacturers are usually limited to the short-circuit current Isc, the on-load voltage Voc, the maximum power Pmax and the temperature coefficients. Although these data are useful in analyzing the performance of the PV module, they are not sufficient to predict the energy generated in real-world conditions [7-9].

There are many studies on determining the optimal tilt angle of the PV module to maximize power [10]. For example, Khahro et al. evaluated solar energy sources by determining the optimal tilt angle and predicting diffuse solar radiation for a location in Sindh, Pakistan [11]. A study on the optimization of tilt angle in Basra, Iraq was conducted by calculating the energy received from a flat plate collector at different tilt angle positions. It was concluded that the amount of energy received by daily adjustment by adjusting the tilt angles eight times a year was the same [12]. The optimal tilt angle of solar collectors in Belgrade, Serbia was evaluated by determining the slope and orientation values that provide the maximum total radiation over a certain period of time [13]. The optimal tilt angles of PV panels were studied for different cities in the Kingdom of Saudi Arabia. According to the results of the study, adjusting the tilt angles six times a year yielded 99.5% of the solar radiation [14]. To find the optimal tilt angle, researchers used different solar radiation models of direct, diffuse and reflected components of radiation [15]. In addition, there are studies that simulated and optimized the tilt angle using MATLAB programming [16-18].

In the literature analyzed above, experiments aimed at determining the optimal tilt angle of the PV module have been conducted in different regions of the world. However, given the different geographical latitudes and longitudes of different countries, directly using the results of experiments conducted there will lead to errors. Therefore, conducting experiments aimed at finding the optimal tilt angle of PV modules in the city of Termez, located in the south of Uzbekistan, is an important task.

This article presents a preliminary study of the installation of a 100kWh solar photovoltaic power plant (SPP) on the roof of the Termez State University of Engineering and Agrotechnology. The aim is to determine the optimal angle with the highest energy efficiency by testing the electrical parameters of the solar panels planned for use in the SPP at different tilt angles.

2. Methods and materials

The experimental results were conducted on the roof of the Termez State University of Engineering and Agrotechnology, located in the city of Termez at 37°13'57" north latitude and 67°17'8" east longitude, 304 meters above sea level. For the test results, three RENEPV PV modules with a power of 550W each were tested at tilt angles of 22^0, 30^0, and 34^0 without changing their position under AM 1.5 conditions (Fig. 1).


Fig.1. Measuring PV module parameters in natural conditions

Table 1. Electrical and mechanical characteristics of the PVs

Module Type: ZY550M10PH-144	Electrical specifications	Solar Cell: P-Mono	Mechanical Specifications
Nominal Peak Power (Pmax)	550W	Front Glass	3,2mm tempered glass
Maximum Power Voltage (Vmp)	40,83V	Frame	Anodized aluminium alloy
Maximum Power Current (Imp)	13,48A	Junction Box	IP68,3 diodes
Open-circuit Voltage (Voc)	49,60V	Cables and connectors	4.0mm^2 PV-CXLH0601
Short-circuit Current (Isc)	14,04A	Maximum Load Capacity	5400Pa/2400Pa
Module Efficiency	21,3%	Safty Rate	Class II (IEC)
Maximum System Voltage	1500V	Fire rate	Class C (TUV)
Maximum Series Fuse Rating	25A	Dimensions	2278*1134*33mm
Temperature Coeffcient (P_{max})	-0,35%/C	Weight	28,0 kg (±3%)

Termez city is one of the cities with the highest number of sunny days and the largest annual solar radiation in the southern part of our country. Considering the conditions of Termez, we can conclude that it has a huge potential for renewable solar energy [19]. The electrical parameters of the monocrystalline panel used in the study are presented in Table 1.

There are three different methods for measuring the electrical parameters of different types of PV modules [20]. In our study, the electrical parameters of stationary PV modules were measured every 20 minutes. In this case, the PV modules are installed in a traditional way, as in photovoltaic power plants. In regions located in the northern hemisphere, the PVs are installed facing south.

3. Results and discussions

The electrical parameters of the PV modules were measured on October 18, 2024, at an air temperature of 18-20^{0}C, a wind speed of 3-4m/s, and an atmospheric pressure of 765 mm Hg, during the day from 9:40 to 14:40. Solar radiation intensity is an important factor for PV modules, as it determines the energy generation capacity of batteries. In general, although solar radiation intensity is important for PVs, its negative effects should also be considered. At high intensities, sunlight causes the temperature of the batteries to increase. An increase in temperature can reduce the efficiency of the PV module, as well as shorten their service life. When the temperature is high, the internal resistance of the batteries increases, which leads to energy losses. High intensity increases the efficiency of the batteries, which leads to more electricity generation. The time dependence of the intensity of solar radiation falling on the surface of the PV models on this date is shown in Fig. 2.

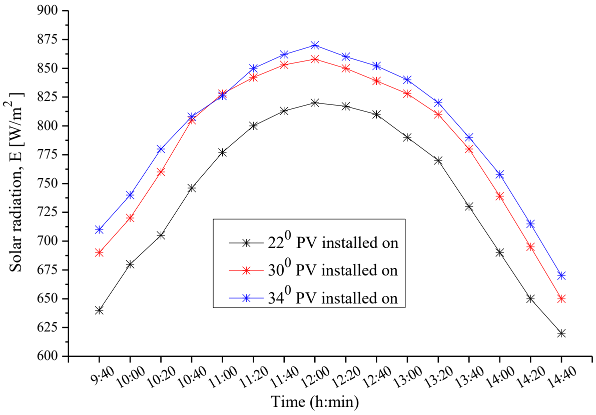

Fig.2. Time dependence of the intensity of solar radiation falling on the surface of PVs

From the graph above, the solar radiation intensity value is 34^0, which is the maximum, and it is 870W/m^2. The solar radiation intensity was measured using a DT-1307 Solar Power Meter. Dust and clouds in the atmosphere also cause a decrease in the light radiation intensity. During the test, the dependence of the starting voltage, solar radiation density, short-circuit current and electric power on time was studied. If the PV panel is isolated, the panel cannot reach the maximum power in a stationary state [21]. The reason is that as the temperature of the PV panel increases, the starting voltage decreases sharply, which leads to a decrease in power. Starting voltage indicates the overall efficiency of the battery. When evaluating the efficiency of batteries, the combined effect of voltage and current (for example, volt-ampere characteristic) is considered. Fig. 3 depicts the dependence of starting voltage on time.

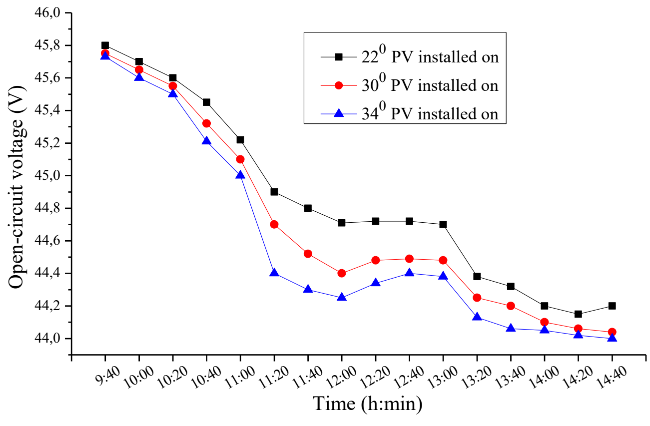

Fig.3. Time dependence of PV voltages during the day

As you can see, from 9^{40} to 14^{40}, the dropout voltage of the PV panel mounted at an angle of 22^0 decreased by ~1.6V, the dropout voltage of the PV panel mounted at an angle of 30^0 decreased by ~1.71V, and the dropout voltage of the PV panel mounted at an angle of 34^0 decreased by 1.73V. Increasing the tilt angle of the PV module led to a decrease in the dropout voltage. This is because the more sunlight falls on the front surface of the PV module, the higher its temperature. An increase in temperature reduces the dropout voltage. Currently, one piece of crystalline silicon-based solar cells, which is widespread, produces open-circuit voltage of up to ~0.6V between its contacts.

The following equation is used to calculate the open-circuit voltage as a function of temperature:

$$U_{(T)} = U_0 + \beta(T_0 - T); \quad (1)$$

here, U_0 – open-circuit voltage of a PV module at standard temperature, β – voltage temperature coefficient (mV/ºC), T_0 =25⁰C – standard temperature.

The temperature coefficient of voltage is shown to decrease linearly by – 2.3mV/ºC for each degree above 25⁰C [22]:

$$\frac{\partial U_{o.c.}}{\partial T} = -\frac{2{,}3mV}{°C}. \quad (2)$$

The short-circuit current in PV modules depends on the intensity of the incident solar radiation. Fig. 4 shows a graph of the short-circuit current versus time.

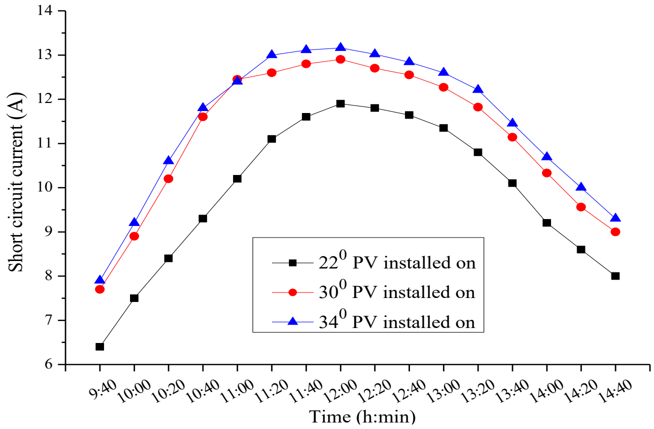

Fig.4. Time dependence of the short-circuit of a PV module during the day

In the graph shown in Figure 4, the maximum short-circuit current of the PV panel installed at 22⁰ was ~11.8A, that of the PV panel installed at 30⁰ was ~12.7A, and that of the PV module installed at 34⁰ was 13.02A. The relationship between the open-circuit voltage of the PV module and the short-circuit current is important in the process of solar energy generation. The short-circuit current generally determines the efficiency and voltage level of the solar cell, which is necessary for energy generation. The decrease in open-circuit voltage was approximately 0.4% for each degree of temperature, and 0.5% for maximum power. The increase in temperature showed a small increase in short-circuit current of 0.06%. Therefore, the main factor reducing the power is the open-circuit voltage [23].

Using the data presented in the above graphs of short-circuit current and peak voltage, the dependence of the PV module's electrical power on the time of day is shown in Figure 5.

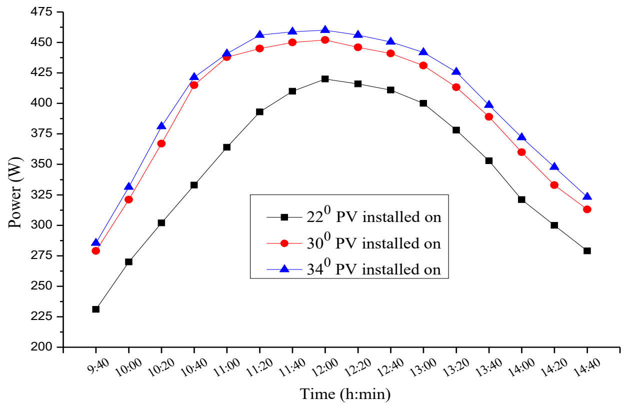

Fig.5. PV module power versus time during the day

The electrical power of a PV module is determined by the following formula (3):

$$P = ff \cdot I_{s.c.} \cdot U_{o.c.}\ ; \quad (3)$$

where, $I_{s.c.}$ – short-circuit current, $U_{o.c.}$ – open circuit voltage ff – is the filling factor of the volt-ampere characteristic (VACh) of the PV module, an important parameter determining the efficiency of energy generation. It is used to assess the energy losses during the filling process of the modules and their operating efficiency. The filling factor of modern PV modules is 0.75 – 0.8, and it varies depending on the PV module manufacturing technology.

In the power graph shown in Fig. 5, the daily average power generation of a PV module installed at an angle of 22^0 is ~349W, for a PV module installed at an angle of 30^0 it is ~394W, and for a PV module installed at an angle of 34^0 the daily power generation is 404W. A 100kW solar power plant consists of 182 PV modules with a power of 550W. Based on this, it was found that the average power generated by a solar plant installed at an angle of 34^0 in an average of 6 hours per day is 11.2kW higher than that installed at an angle of 30^0, and 60kW higher than that installed at an angle of 22^0.

4. Conclusion

The power generated by PV modules is affected by the following factors: the angle of incidence of sunlight, geographical location, seasonal changes and environmental conditions. Research has shown that a PV module installed at an optimal angle produces maximum power, since in this case the sunlight falls more often at an angle close to perpendicular to the panel surface. As the angle of inclination increases or decreases, the amount of solar energy reaching the PV module decreases, reducing the efficiency of power generation.

According to the results of the study, the main factor in determining the optimal installation angle of PV modules in the southern regions of our Republic is its geographical latitude. For the city of Termez, the best angle for installing a PV module at a constant (stationary) angle was between 34^0-38^0. As for seasonal installation angles, it is recommended to increase the recommended angle (34^0-38^0) by 10^0-12^0 degrees for the winter season, and reduce it by the same number of degrees for the summer season. Also, if the highest efficiency is required, it is recommended to use a tracker system that automatically changes the angle depending on the movement of the sun.

To effectively use a PV module system, the following recommendations can be considered: properly positioning and regularly cleaning solar panels to maximize energy production, as well as implementing energy storage systems. In addition, it is advisable to use modern control systems to optimize energy consumption.

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