Conversion and use of Solar Energy Calculation Methodology for Photovoltaic Systems

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Abstract: The needs of the population and industry for electrical energy are limited by oil and gas reserves, which leads to the need to use renewable energy sources. Myanmar is one of the developing countries in Asia. Its specific power consumption is low compared to neighboring countries. Currently, one of the most important tasks of the electricpower industry is to ensure reliable, uninterrupted power supply to all industrial and domestic facilities. At the same time, the development of small solar photovoltaic installations (PMT), operating both in parallel with the grid and in autonomous mode, can improve the power supply of closely located consumers more efficiently and faster than the development of a large power system. Therefore, the work devoted to the improvement of the equipment of a small solar photovoltaic installation is relevant and of great practical importance.

1 INTRODUCTION

RES should transform the energy sectors of the countries of Central Asia, but, most importantly, they should help vulnerable categories of the population who are disconnected from the main power grid or face regular and prolonged power outages. Therefore, the importance of off-grid solar and wind power plants, rooftop solar panels or small and mini-hydro power plants should not be underestimated. Unfortunately, these aspects of the transformation of the energy sector in the countries of Central Asia are often neglected [1,2]. The transition to a diversified energy mix in Central Asia, where the predominant share of energy consumption will be covered by renewable energy, is a long-term initiative and requires comprehensive measures [3]. The purpose of this policy brief, however, is to draw attention to the priority tasks that already today require an urgent response from the authorities in order to stimulate the development of renewable energy in eachof the Central Asian countries. This policy brief examines the development of renewable energy in Central Asia from three parallel perspectives:

- restoration of intra-Central Asian electricity trade in order to effectively use the hydropower potential of the region;
- construction of large solar and wind power plants that will supply electricity directly to the central power grid;
- creation of autonomous objects of renewable energy sources in order to supply electricity to settlements that are disconnected from the central energy system, or those in which there is a regular and prolonged shortage of electricity [4,5].

All photovoltaic (PV) systems can be divided into two types: autonomous and connected to the electrical network. Stations of the second type transfer excess energy to the network, which serves as a reserve in the event of an internal energy shortage.

An autonomous system (Figure 1) generally consists of a set of solar modules placed on the roof, a storage battery (AB), a discharge controller - battery charge, and connecting cables. To obtain alternating voltage, an inverter-converter of direct voltage to alternating voltage is added to the kit.

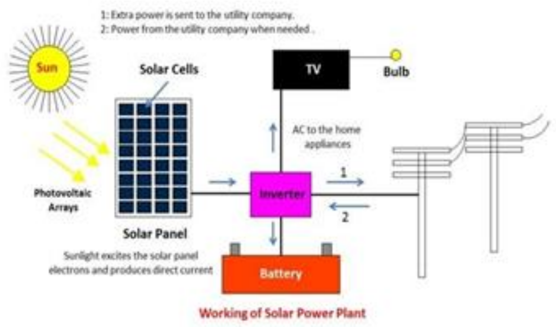

Figure 1: Structural diagram of an autonomous photovoltaic station.

2 METHODS AND MATERIALS

The calculation of FES means the determination of the nominal power of modules, their number, connection scheme; choice of type, operating conditions and capacity of AB; inverter and charge-discharge controller capacities; determination of parameters of connecting cables [6,7].

It is necessary to first determine the total (calculated) power of all consumers connected at the same time. This power is indicated in the product data sheets.

The amount of energy consumed W (kWh) during the time T is determined (1):

$$W = P_{cal} \times T, \quad (1)$$

where $P_{cal.}$ is the calculated load power, kW.

It is believed that solar power supply is economically feasible with a daily energy consumption of up to 4 kWh [8,9].

The calculated load power $P_{cal.}$ is determined by the statistical method [10,11].

According to this method, the calculated load of a group of receivers is determined by two integral indicators: the general average load P_h (kW) and the general standard deviation σ from the (2):

$$P_{cal} = P_h + \beta \cdot \sigma , \quad (2)$$

where β is a static coefficient depending on the distribution law and the accepted probability of exceeding the load P according to the load schedule from the level P_h; σ - standard deviation for the accepted averaging interval.

The standard deviation for the group graph is determined by the (3):

$$\sigma = \sqrt{D_P} = \sqrt{P^2{}_{nor.\,kvt} - P_h^2} , \quad (3)$$

where $P_{nor.\,kvt}$ is the active rms power, kW.

The root-mean-square (rms) value of the active power of a separate power receiver (EP) for the considered period oftime is determined by the (4):

$$P_{nor.\,kvt} = \sqrt{\frac{\sum p_i^2 t_i}{\sum t_i}} , \quad (4)$$

where $P_{nor.\,kvt}$ is the root mean square value of the active power of the electrical receiver, kW; p_i is the active power consumed by the ED for the considered time interval t_i (determined from the load graph for active power), kW; t_i - time interval for which p_i is determined, min, h.

The statistical method allows you to determine the design load with any accepted probability of its occurrence. In practical calculations, it is quite sufficient to take the probability of exceeding the calculated load from the average by % 5, 0, which corresponds to β=2.5 then (5):

$$P_{cal} = P_h + 2{,}5\ \sigma . \quad (5)$$

Based on the known load power, the inverter power is selected, which, taking into account the losses in the inverter, should be at least 25% more than the calculated power, i.e. (6)

$$P_{ind} \geq 1{,}25\ P_{cal} . \quad (6)$$

The nominal power range of inverters (Figure 2) is 150, 300, 500,800, 1500, 2500, 5000 W. For powerful stations (more than 1 kW), the station voltage is selected at least 48 V, because At higher powers, inverters work better with higher input voltages [12,13].

Figure 2: Appearance of the inverter.

The capacity of the storage battery AB is selected froma standard range of capacities rounded to the side greater than the calculated one. Estimated battery capacity (Ah) is determined by the (7):

$$C_{cal} = \frac{W}{U_{AB} \times \delta} \quad (7)$$

where W is the amount of energy consumed (Wh); U_{AB} – battery voltage; δ is the admissible depth of AB discharge.

When calculating the battery capacity in a fully autonomous mode, it is necessary to take into account the presence of cloudy days, during which the battery must ensure the operation of consumers [14, 15]. For the maximum number of consecutive “days without sun”, you can take the set number of days during which the battery will feed the load on its own without recharging. The service life of the battery depends on the depth of discharge of the battery δ. The larger δ, the faster the AB will fail. The recommended value of the depth of discharge is 20% (no more than 30%). This means that it is possible to use 20% of the value of the nominal battery capacity. Under no circumstances should the battery discharge exceed 80%. The time of complete discharge of a battery with a capacity of SAB under the influence of a load of power P can be determined (8):

$$T_{cal}=\frac{C_{AB}\cdot 8.5}{P}\ . \quad (8)$$

The battery capacity also depends on the ambient temperature. The decrease in AB capacity with decreasing temperature takes into account the temperature coefficient K_c, the values of which are taken from the graph (Figure 3). Total required battery capacity (9):

$$C_{AB}=C_{cal.}\cdot K_c \quad (9)$$

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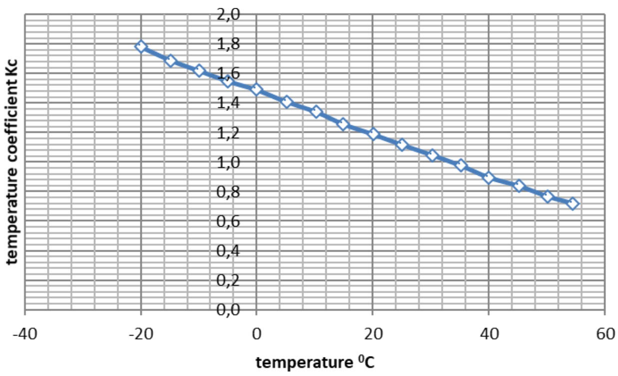

Figure 3: Dependence $K_c= f\,(T)$.

The cables connecting the inverter and batteries carry a very large current. Therefore, it is necessary to correctly select the cable section based on the maximum currents that the inverter can consume [16]. In order to minimize the voltage drop in the wires between the battery and the inverter, and thereby increase the efficiency of the inverter, the cable should be thick and short enough [17].

When choosing a cable section with a length of 2 m, depending on the power of the inverter and the voltage of the battery, it is recommended to use [18].

In order to calculate the required wire size for a particular installation, you need to know the power of the inverter or charger, or the maximum current flowing through these wires. You also need to know the distance from the battery to the inverter and the DC voltage in the system [19].

Typically, most 12V systems operate in the 11 to 12V range. not more than 0.25 V.

For 24V or 48V systems, the cable length can be 2 or 4 times longer. For a voltage of 220 V, the length can be 20 times longer. To calculate the cross section of the wire, you can also use the (10):

$$r = \frac{\Delta U}{I\cdot L}\ , \quad (10)$$

where r is the resistivity of the wire, Om/m; ΔU is the maximum allowable voltage drop in the wire, V; I is the passed current, A; L is the total cable length in the system in meters (multiply by 2 for the positive and negative wires) [20].

The resistivity must not be less than 0.0024 Om/m. According to [21], the minimum wire cross-section is determined - 6 mm. The thicker the wire, the less will be the loss in the transfer of energy from the battery to the load [22].

3 RESULTS AND DISCUSSION

The solar module is made in the form of a panel enclosed in an aluminum profile frame (Figure 4). Thepanel is a photovoltaic generator consisting of a glass plate, on the back side of which solar cells are placed between two layers of a sealing (laminating) film, electrically interconnected by metal tires. The modules are made from pseudo-square monosilicon photovoltaic cells (PVCs) coated with an anti-reflection coating. The operating voltage of photovoltaic modules is usually 12V or 24 V. Specifications of solar modules are given in Table 1.

Factory-made photovoltaic cells have a specific power rating, expressed in watts of peak power (Wh) [23]. This is anindicator of their maximum power under standard test conditions, when solar radiation is close to its maximum value of 1000 W/m^2, and the surface temperature of the photocell is 25 °C. In practice, photocells rarely have to work in such conditions. One solar module, depending on the number of plates, has a power of 100 to 3000 watts. During a selected period of time, a module with a power of P_m generates an amount of energy equal to (11):

$$W_M = \frac{P_M\cdot E\cdot \eta}{1000} \quad (11)$$

where W_M is the generated amount of electricity, kWh; 1000 is the maximum value of solar radiation, W/m^2; η – system performance coefficient (0.5 in summer and 0.7 in winter); E is the value of insolation for theselected period for a given latitude, kWh/m^2.

a)

b)

Figure 4: Installed view of solar power plant for utility house: a) Installation of a solar power plant on the ground; b) Installing the solar power plant on the roof of the house.

The value of E for latitude 52.5° is given in Table 1. By dividing the energy consumed by the load during the selected period by the energy generated by one module during the same period, we determine the required number of modules of the photovoltaic system [24] (12):

$$\eta_M = \frac{W}{W_M} . \quad (12)$$

The values of solar radiation power (W/m^2) and incoming solar energy (kWh/m^2) in the settlement are given in Table 1 and Table 2 (according to the weather station).

Table1: Solar radiation power, W/m^2.

No.	month, decade	Month							
		April	May	June	July	August	September	October	November
1.	1	170,72	195,59	121,96	249,99	159,84	139,08	49,02	28,52
2.	2	188,31	139,40	196,20	166,50	165,44	100,44	37,89	23,64
3.	3	180,14	167,48	194,38	243,93	73,40	77,16	52,29	15,34
4.	Average	179,72	167,49	170,85	220,14	132,89	105,56	46,40	22,5
5.	For a month	539,17	502,47	512,54	660,42	398,68	316,68	139,2	67,5

The total capacity for the period from April to November in the region is 3136.66 kW/m^2, solar energy input – 75.28 kWh/m^2

The cost of a solar power plant for an autonomous powersupply system consists of the cost of solar modules, a storage battery, an inverter, an AB charge controller and connecting fittings (wires, switches, fuses, etc.)

Table 2: Solar energy input, kWh/m^2 day.

No.	month, decade	Month							
		April	May	June	July	August	September	October	November
1.	1	170,72	195,59	121,96	249,99	159,84	139,08	49,02	28,52
2.	2	188,31	139,40	196,20	166,50	165,44	100,44	37,89	23,64
3.	3	180,14	167,48	194,38	243,93	73,40	77,16	52,29	15,34
4.	Average	179,72	167,49	170,85	220,14	132,89	105,56	46,40	22,5
5.	For a month	539,17	502,47	512,54	660,42	398,68	316,68	139,2	67,5

The cost of a solar battery is equal to the product of the number of modules and the cost of one module. The costof the inverter depends on its power and type. The costof connecting fittings can be taken approximately equal to 0.1 - 1% of the system cost.

The payback period of FES is determined (13):

$$\mathrm{T} = \frac{K}{C \times 8760 \times \xi(Z)} , \quad (13)$$

where K - capital unit costs; C is the electricity tariff; Z - annual operating costs; ξ - rated power utilization factor (14):

$$\xi = \frac{W}{P_H \times 8760} = \frac{\sum_1^{365} E_i \times S \times k_{Ti} \times \eta}{P_{max} \times S \times k_{Tmax} \times \eta \times 8760} = \frac{\sum_1^{365} E_i \times k_{Ti}}{P_{max} \times k_{Tmax} \times 8760}, \quad (14)$$

where E_i is the daily value of daily irradiance in clearweather during the year, kWh/m^2 day; S – working surface of the receiver, m^2; η – Efficiency of converting solar energy into electricalenergy; k_{Ti} –daily value of the Clarity Index; k_{Tmax} – the same - the maximum value P_{max} – maximum value of solar radiation fluxdensity, kW/m^2.

Figure 5: Measuring solar energy at a height of 2 metersand weather conditions at a height of 3 meters.

Tashkent State Technical University named after Islam Karimov, together with the Department of Alternative Energy Sources and Juru Energy, conducted experimentsaccording to the above Figure 5 by definition of albedo in vox-zones.

Performed in accordance with ASTM E1918-16 using two pyranometers in the following versions:

1) 1.5 m height measurement from descending pyranometer to surface;
2) measurement at a height of 2 meters as the worst case scenario.

The weather sensor AWS-600 was installed at a heightof 3 m, in order to obtain the necessary data, it was decided to choose a height of 3 m from the ground, which was also recommended manufacturer's representative and instruction manual.

To measure solar radiation and weather conditions, 3 sets of the following instruments were used:

1) 2x SMP-11V/CMP-10 pyronometers (Kipp&Zonen);
2) 1x Tripod (for mounting sensors at appropriate heights);
3) 1x Logbox SE-Logbox (Kipp&Zonen);
4) 1x Weather station WS-600 (Lufft);
5) 1x Power supply kit (12V battery).

Temperature dependence of sensitivity show in Figure 6.

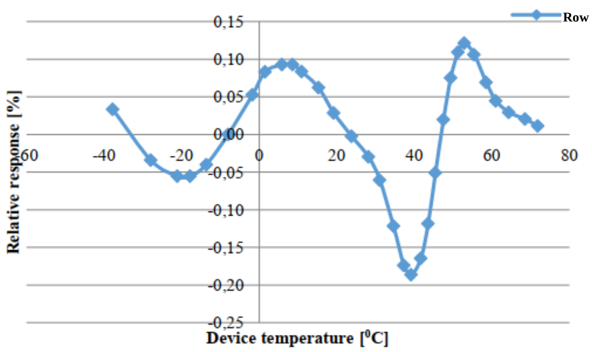

Figure 6: Temperature dependence of sensitivity.

Conventional temperature dependence measurements during final inspection. The pyranometer is installed inside the climate chamber and is illuminated by a white light source at normal incidence. A CMP22 pyranometer outside the chamber is used to monitor lamp stability.

The pyranometer is tested in the temperature range from 70°C to 40°C in steps of 10°C. The relative temperature dependence is shown below. The measurement error of this characteristic is ±0.1% (k=2).

3 CONCLUSIONS

A methodology has been developed for calculating the power of autonomous solar power plants and its elements, which allows taking into account the change in load during the day. Taking into account the change in the load schedule at the interval of the night time of the day allows you to accurately determine the required capacity of the battery. The expression for determining the required battery capacity of an autonomous solar power plant can be easily generalized for any number of changes in the steps of the load curve. The developed method for calculating the power of autonomous solar power plants makes it possible to exclude unjustified overestimation of the power of the elements of the power plant and the rise in the cost of an autonomous solar power plant.

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