JOURNAL OF NORTHEASTERN UNIVERSITY

Volume 25 Issue 04, 2022 ISSN: 1005-3026 https://dbdxxb.cn/ Original Research Paper

CALCULATION OF A PHOTOELECTRIC SYSTEM FOR LOW-POWER CONSUMERS OF ELECTRIC ENERGY

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Abstract

Usually, consumers of low-power photovoltaic systems consume less energy and consume energy in a high energy saving mode. If the cost of the designed and installed photovoltaic installation for such consumers becomes unacceptably high, it will be necessary to optimize their loads and carry out calculations according to a strict algorithm. Such calculations make the photovoltaic system inexpensive and without excessive losses.

Key words: photovoltaic system, photovoltaic module, load, alternating current, direct current, battery.

Introduction.

Below is a simple step-by-step method for calculating a solar power plant (SPP) for small power consumers. This method helps to determine the requirements of the consumer for the system and to choose the components of the necessary power supply system. Photoelectric system calculation consists of 4 main steps:

1. Determination of load and required energy;
2. Determining the required inverter power and battery capacity;
3. Determination of the necessary number of photoelectric modules based on the data on the solar radiation falling on the place of installation of the system;
4. Calculation of system costs and costs.

After completing step 4, if the cost of the system is unacceptably high, the following options should also be considered to reduce the cost of the autonomous power supply system:

- reducing energy consumption by replacing the existing load with energy-efficient devices, as well as excluding heat-generating and unnecessary loads (for example, turning off refrigerators, air conditioners or replacing them with more efficient ones);
- replacement of alternating current loads with direct current loads. In this case, it is possible to win at the expense of getting rid of losses in the inverter (from 10 to 40%). However, here

Submitted: 21/10/2022 **Accepted**: 30/11/2022

it is necessary to take into account the characteristics of the system for the low-voltage DC circuit;

- adding an additional generator of electricity to the power supply system - a wind, diesel, gasoline or gas generator;
- it is necessary to take into account that there will not always be electricity. Also, the more the system power differs from the consumer power, the greater the probability of power outages.

The efficiency of a cell (photocell) is determined by the structure of the cell and the type of base crystal used, which is usually p-type or n-type silicon. It is FIKi that is determined by the filling factor (coefficient) (FF), which is calculated as the maximum conversion efficiency of the optimal working voltage and current value of this photocell.

Photocell design plays an important role in the efficiency of the photovoltaic module. Key features include silicon type, busbar configuration, and passivation type (PERC). Panels made on the basis of high-cost IBC technology elements are currently the most efficient photovoltaic cells due to the low losses due to the high purity n-type silicon base and low tire shading (20-22%). However, to date, panels assembled on the basis of the latest monocrystalline PERC elements and more advanced hetero-structured (HJT) elements have also achieved efficiencies above 20% (Figure 1).

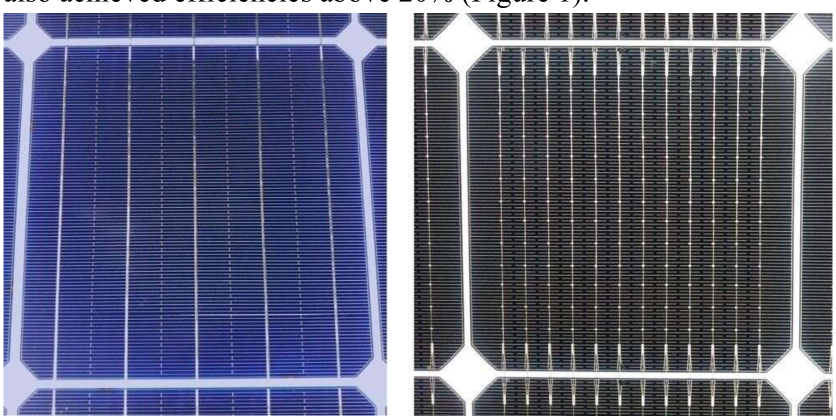
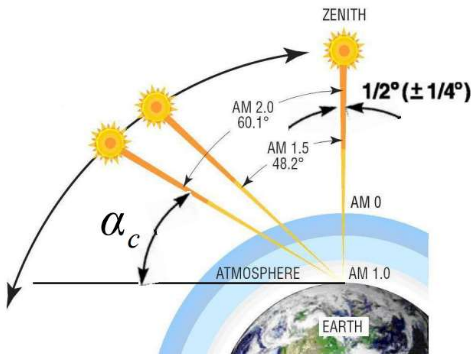


Figure 1. Left: Close-up of the Trina Honey M plus 310 W panel p-type monocrystalline cell with 5 busbars. Right: A close-up of the LG Neon 2 335W panel's 12-bus n-type, more efficient cell.

Solar panel efficiency is measured under Standard Test Conditions (STC) at cell temperature of 25°C, solar radiation intensity of 1000 W/m^2, and atmospheric mass of AM1.5. The efficiency (%) of the panel is effectively calculated by dividing the maximum power Pmax (W) by the total area (surface) of the panel (m^2) at STC.

Θ_z – zenith angle of the Sun; AM - atmospheric mass, i.e. the path of sunlight through the atmosphere (Fig. 2).



$$AM = \frac{1}{\cos \Theta_Z} = \frac{1}{\cos \alpha_c}$$

Solar module efficiency

$$\boldsymbol{E = \frac{P_{max}}{S \cdot 1000\, W/m^2} \cdot 100\%}$$

Intensity of solar radiation at STC – 1000 W/m²

P_{max} *– maximum power of the module*

S – the surface of the module

Figure 2. Information on solar radiation incidence angles and atmospheric conditions.

Many factors can affect the overall efficiency of the module, including; temperature, illumination level, cell type and cell interconnection. Surprisingly, even the color of the protective layer can affect the performance. A black back may look aesthetically pleasing, but it absorbs more heat, resulting in a higher cell temperature, which increases resistance and in turn slightly reduces the overall efficiency of converting solar energy to electricity (Fig. 3).

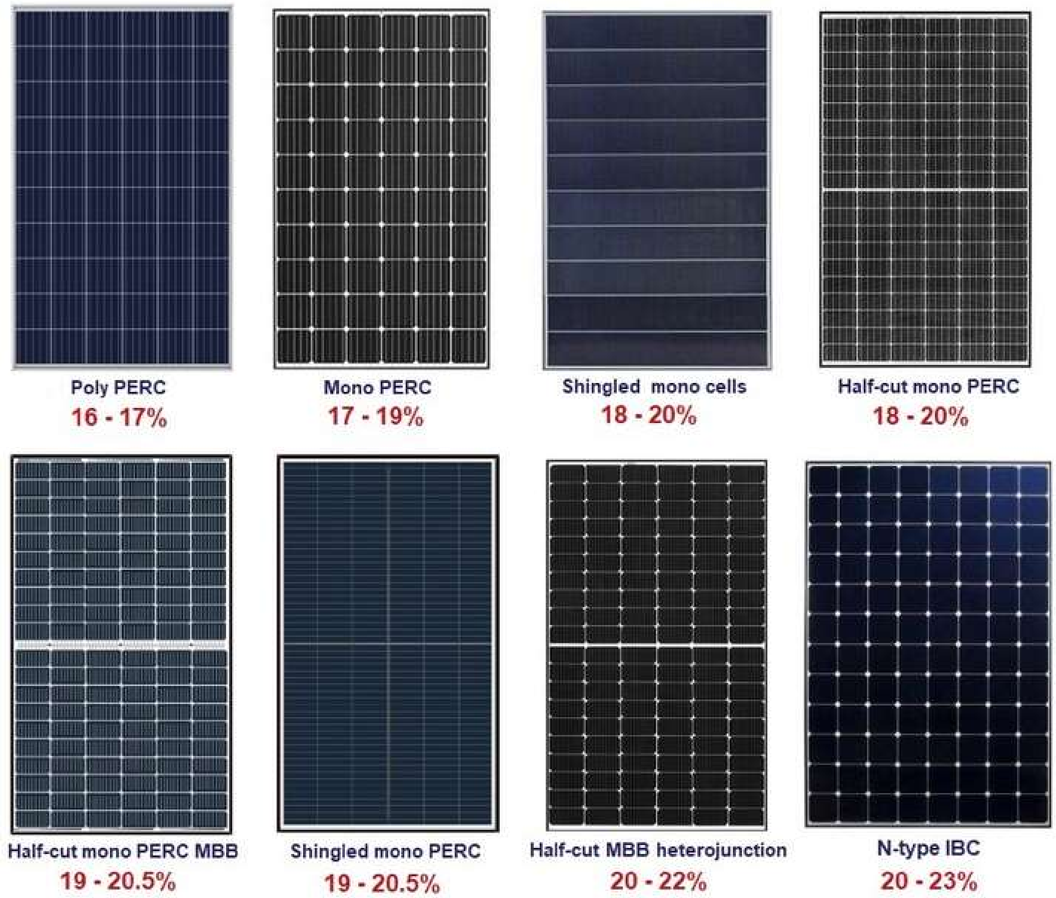


Figure 3. Information on the types of solar cells and their efficiency.

The most efficient are the modules assembled on the basis of modern and improved IBC photovoltaics, including heterojunction (HJT) cells, half-cut and multi-band monocrystalline PERC cells, and tile-coated cells. 60-cell poly or monocrystalline modules are generally the least efficient and least expensive panels.

Calculation of an autonomous photoelectric plant

1. Determination of energy consumption

A list of energy-consuming devices powered by FES is compiled. Their consumption during work is determined. Most devices are marked with the nominal power consumption in W or kW.

After knowing the information about the required consumption power, it is necessary to fill in table 1. This table is used to determine the total daily energy consumption.

Calculation of load power of alternating current consumers.

If we do not have such a load, we can skip this step and continue to calculate the power of constant current consumers.

1.1. Determine all alternating current (AC) loads, their rated power and weekly operating hours. Power is multiplied by the number of working hours for each device. By adding the obtained values, the total variable power consumption during the week is determined.

Table 1. Information about all AC loads

Alternating current load	W	x	hours/week	=	W·h/week
		x		=	
		x		=	
		x		=	
		x		=	
			Total		

1.2. Then, how much constant power is needed is calculated. To do this, the total obtained value is multiplied by a factor of 1.2, and it is necessary to take into account the losses in the inverter.

1.3. The value of its input voltage is determined from the technical characteristics of the selected inverter. Usually this is 12 or 24 V.

1.4. The resulting value of item 1.2 is divided by the value of item 1.3. In this case, the value indicating the necessary energy required during the week to provide alternating current load comes in amperes-hours (A·h).

Calculation of direct current load

1.5. Below is the direct current (DC) load information:

Table 2. Information about all direct current loads

Direct current load	W	x	hours/week	=	W·h/week
		x		=	
		x		=	
		x		=	
		x		=	
			Total		

1.6. Determines the value of direct voltage in the system. Usually it is 12 or 24 V (as in 1.3).

1.7. The value required for a direct current load during the week is determined in amperes hours (A·h) (divide the resulting value of clause 1.5 - W·h/week - by the value of clause 1.6).

1.8. Add the value of paragraph 1.4 and paragraph 1.7 to determine the total required battery capacity. This indicates the current capacity (A·h) consumed per week.

1.9. If we divide the value of paragraph 1.8 by 7 days, we get the daily value of the consumed current capacity.

2. Load optimization.

At this stage, it is important to analyze the load and try to reduce power consumption as much as possible. This is important for any system, especially for the electrical supply system of a residential building, because saving electricity here has a significant positive effect. First identify large and variable loads (such as water pumps, outdoor lighting, refrigerators, washing machines, electric heaters, etc.) and try to remove them from the system or replace them with gas, DC it is necessary to replace tools and other similar models.

Ushbu bosqichda yuklamani tahlil qilish va quvvat sarfini iloji boricha kamaytirishga harakat qilish muhimdir. Bu har qanday tizim uchun muhim, ayniqsa, turar-joy binosining elektr ta'minoti tizimi uchun juda ahamiyatlidir, chunki bu yerda elektr energiyasini tejash sezilarli ijobiy ta'sirga ega. Avval katta va iste'mol quvvati o'zgaruvchan yuklamalarni (masalan, suv nasoslari, tashqi yoritish chiroqlar, sovutgichlar, kir yuvish mashinasi, elektr isitgichlar va boshqalar) aniqlash va ularni tizimindan chiqarib tashlashga harakat qilish yoki ularni gaz, o'zgarmas tok bilan ishlaydigan asboblar va boshqa shunga o'xshash modellari bilan almashtirish zarur.

The initial cost of DC devices and appliances is usually higher than the same AC devices (because they are not produced in such mass quantities), but we get rid of various losses in the inverter. In addition, DC devices are often more efficient than AC devices (in many household appliances, especially electronic devices, AC is converted to DC, which causes energy loss in the equipment's power supply).

If available, it is necessary to replace incandescent lamps or fluorescent lamps with light emitting diode lamps (LED). LED lamps provide lighting at the same level as their analogues, which consume 5-10 times less electricity. Their service life is long, up to 100 thousand hours. If there are loads that cannot be excluded or abandoned, consider using it only during sunny periods or only in the summer. It is advisable to revise the list of downloads (consumers) and recalculate the data.

3. Determination of the composition and size of the accumulator battery (AB).

It is important to choose the type of battery to use. It is desirable to use low-cost lead-acid batteries with the best operational and economic parameters, hermetic, maintenance-free (depending on the financial situation, more expensive gel batteries can be used).

Then, it is necessary to determine how much energy is needed from the battery, that is, how much power is needed, that is, the capacity of the battery. Often, this is determined by the number of days that the battery can independently charge the load without being under the process of charging. In addition to this parameter, it is necessary to take into account the nature of the power supply system. For example, if the system is installed for homes that are visited only on weekends, it is better to choose a larger battery pack, because it can be charged during the week and only provide power on weekends. On the other hand, if photovoltaic modules are added to an existing electricity supply system based on a diesel or gasoline generator, the battery may have a lower capacity than calculated, since it can recharge the batteries at any time when the above generator is started. After determining the required battery capacity, you can proceed to consider the following very important parameters.

3.1. Determining the maximum number of consecutive "sunless days" (ie, when there is insufficient solar energy to charge the battery and power the load due to bad weather conditions or cloudiness). This parameter can also be taken as the number of days during which the battery can provide the load with independent power without charging.

3.2. We multiply the daily consumption measured in A·h by the number of days specified in the previous paragraph (see paragraph 1.9 above of energy consumption calculation).

3.3. We determine the permissible value of the discharge depth (level) AB. It should be remembered that the greater the depth of discharge, the faster the batteries fail. Generally, a depth of discharge of 20% (no more than 30%) is recommended, that is, you can use 20% or 30% of the battery's nominal capacity. To be more precise, we only use a factor of 0.2 or 0.3. In no case should the battery discharge exceed 80%!

3.4. We divide the result of point 3.2 by the value of point 3.3.

3.5. The coefficient is selected from the table below, taking into account the ambient temperature in the room where the batteries are installed. This usually includes average winter temperatures. This coefficient shows the decrease in battery capacity with a decrease in temperature.

Table 3. Temperature coefficient of the accumulator battery.

Temperature indicator		**Coefficient**
Fahrenheit	**Celsius**	
80F	26,7C	1.00
70F	21,2C	1.04
60F	15,6C	1.11
50F	10,0C	1.19
40F	4,4C	1.30
30F	-1,1C	1.40
20F	-6,7C	1.59

3.6. We multiply the value of clause 3.4 by the corresponding coefficient of clause 3.5. Then we get the total capacity of the battery.

3.7. We divide this value by the nominal capacity of the selected battery. We round the obtained value to the largest whole number. This number will be the number of batteries connected in parallel.

3.8. We divide the nominal DC voltage of the system (12, 24 or 48 V) by the nominal voltage of the selected battery (usually 2, 6 or 12 V). If we round the obtained value to the largest whole number, we get the number of batteries to be connected in series.

3.9. To calculate the required number of batteries, we multiply the value of paragraph 3.7 by the value of paragraph 3.8.

4. Determining the amount of daily maximum hours of sunshine for a given geographical latitude.

Several factors affect how much solar energy our solar panel receives:

- When will the system be used? Summer, winter or all year round?
- Typical weather conditions in the area.
- Is the system oriented towards the sun?
- Location and angle of inclination of photovoltaic modules

To determine the average monthly amount of solar radiation, we can use the table with information about the amount of solar radiation for some regions of Uzbekistan.

Table 4. Amount of monthly and annual GTI, kW·h/m^2, falling on the surface of 1m^2 frontal surface of a flat solar energy device facing south.

	Tashkent		**Kashkadarya**		**Samarkand**		**Navoi**		**Namangan**	
Months	**The angle of deviation of a flat plane relative to the horizon**									
	30°	**41°**	**30°**	**38°**	**30°**	**39°**	**30°**	**40°**	**30°**	**41°**
I	84	92	82	88	77	83	81	88	63	68
II	116	123	118	123	107	113	107	113	89	95
III	128	132	132	135	131	134	134	138	135	140
IV	170	169	166	165	168	167	170	168	167	167
V	206	196	212	205	216	207	211	201	207	197
VI	221	206	221	209	220	207	223	207	209	196
VII	234	218	231	219	230	217	239	221	218	205
VIII	227	218	230	223	226	217	229	218	204	200
IX	194	193	205	204	198	198	202	200	173	175
X	142	148	161	165	153	158	141	146	138	143
XI	93	100	102	107	96	102	97	103	80	85
XII	83	91	78	83	84	90	82	89	68	74
Annual GTI	1898	1886	1938	1926	1905	1891	1914	1892	1751	1747

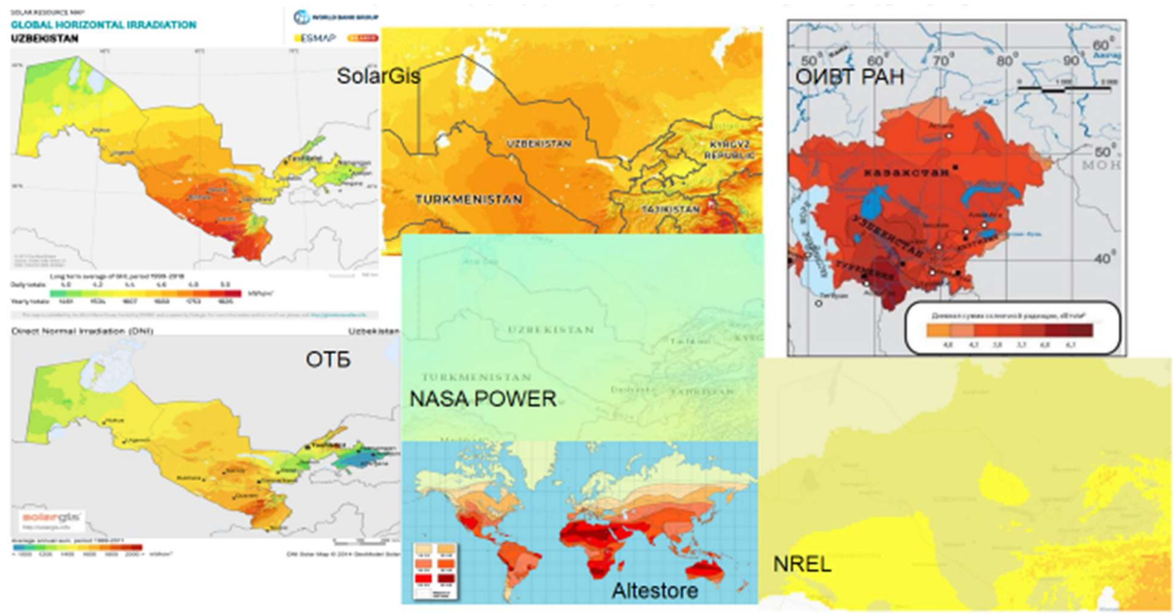


Figure 4. Assessment of solar energy resources of Uzbekistan.

The production of electricity by a solar photovoltaic cell (FEB) depends on the angle of sunlight falling on the FEB. Maximum energy production occurs at an angle of 90 degrees. When it deviates from this angle, the solar radiation is not absorbed by the FEB, but most of the radiation is reflected or reflected back.

In winter, due to the fact that the days are shorter, there are more cloudy days, and the sun is located lower in the dome of the sky, the value of the incident radiation is much less. If the system is used only in summer, it is better to use summer values, if it is used all year round, it is better to use winter values. For reliable electricity supply, it is advisable to choose the smallest of the average monthly values for the period when the photoelectric plant is used.

The average monthly value selected for the month with the lowest index should be divided by the number of days in this month. Then, we get the monthly average of the maximum number of sunny hours.

5. Photoelectric battery calculation.

We choose the module we need from the list of offered modules. To determine the characteristics and prices of photoelectric modules, the catalog of products offered by manufacturers, their official site, and the corresponding page of an online magazine are used. Next, we determine the total number of modules required for the system.

The value of I_{mpp} at the maximum power point can be determined from the specifications of the module. Also, I_{mpp} can be determined by dividing the nominal power of the module by the voltage at the maximum power point U_{mpp} (usually U_{mpp} =17-17.5 V for a 12 V module).

5.1. To calculate the losses in the charge-discharge mode of the battery, the value of paragraph 1.9 is multiplied by a coefficient of 1.2.

5.2. We divide this value by the average number of maximum sunny hours in the area. Through this, we get the amount of current that QB should generate.

5.3. To determine the number of modules connected in parallel, we divide the value of item 5.2 by the Impp value of one module. We round the resulting number to the nearest maximum whole number.

5.4. To determine the number of modules connected in series, we divide the DC voltage of the system (usually 12V, 24V, 48V) by the nominal voltage of the module (usually 12V or 24V).

5.5. The total number of required photoelectric modules is equal to the product of the values of paragraph 5.3 and paragraph 5.4.

Calculate the cost of the system

To calculate the cost of the photoelectric power supply system, we need to add the costs of QB, AB, inverter, AB charge controller and metal structure (conductors, cables, switching devices, fuses, etc.).

Multiplying the value of paragraph 5.5 by the price of one module equals the price of QB. The price of a battery of accumulators is equal to the value of paragraph 3.9 multiplied by the price of one battery. It is desirable to use inverters with a good sinusoidal output voltage. The price of the used metal structures can be equal to approximately 0.1-1% of the system price.

Thus, it is recommended to use a special table that calculates the photoelectric system in the form of an MS Excel spreadsheet, so that it is convenient to calculate the optimization of the system after the implementation of the above technical measures. Using the Excel file developed for the calculation of the photoelectric system, it is good to carry out the calculation process based on the algorithm.

It is also possible to use online forms for the calculation of a photovoltaic system, which immediately calculates almost all the technical parameters of an autonomous photovoltaic system.

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