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QUALIFYING PAPER

For the degree of

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topic: **POWER SUPPLY AND WATER SUPPLY OF COUNTRY HOUSES FROM PHOTOVOLTAIC BATTERIES**

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ABSTRACTS

Bachelor work « Power supply and water supply of country houses from photovoltaic batteries » contains: 70 pages, _26_ figures, 7 tables, _7_ references and __ pages of A4 presentation.

The goal of the work: to improve the mathematical model of the solar battery-battery system for the control system and to develop on its basis an autonomous individual power supply system.

To achieve this goal, the following tasks are solved in the work:

- to analyzed the use of photovoltaic batteries in the power supply of suburban facilities
- to simulated the mode of operation of the solar converter for an autonomous consumer;
- to analyzed the autonomous consumer;
- justified the choice of storage system;
- to offered the scheme of the autonomous individual system of electric water supply.

Keywords: SOLAR ENERGY, PHOTOVOLTAICS, ELECTRICAL ENERGY GENERATION.

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INTRODUCTION

Relevance of work. Currently, the use of renewable energy sources is receiving serious attention. These energy sources are seen as a serious addition to traditional ones. At present, the need for the development of non-traditional renewable energy sources is due to the following factors:

- the ability to solve problems of construction of power lines for remote, inaccessible and environmentally stressful areas;
- reduction of construction volumes of power lines, especially in hard-to-reach and remote places;
- their participation in the optimization of equipment loading schedules at power plants, taking into account their seasonal use;
- reduction of CO2, NOx and other emissions, which allows to finance construction by paying "emission quotas".

Renewable energy sources include wind, hydraulic, solar, geothermal energy; biomass energy. Among all energy sources, solar radiation is the most promising in terms of resources, environmental friendliness and ubiquity. The annual amount of solar energy reaching the Earth's surface is estimated at 1.05 · 1018 kWh. Without harming the environment, 1.5% of all energy falling on the Earth can be used, ie 1.62 · 1016 kWh per year, which is equivalent to 2 · 1012 tons of conventional fuel.

Therefore, the use of solar energy for electricity and water supply is relevant

The goal of the work: to improve the mathematical model of the solar battery-battery system for the control system and to develop on its basis an autonomous individual power supply system.

To achieve this goal, the following tasks are solved in the work:

- to analyze the use of photovoltaic batteries in the power supply of suburban facilities

- to simulate the mode of operation of the solar converter for an autonomous consumer;

- to analyze the autonomous consumer;

- justify the choice of storage system;

- to offer the scheme of the autonomous individual system of electric water supply.

Work structure. The work consists of a settlement and explanatory note and a graphic part. The settlement and explanatory note consists of an introduction, 4 parts, conclusions and a list of references. Scope of work: settlement and explanatory note - sheet. A4 format, graphic part - presentation sheets.

1 ANALITYCAL SECTION

1.1 Solar Photovoltaic System

Solar photovoltaics is a direct conversion of solar radiation into electricity.

Recently, there has been a growing interest in plants that directly convert solar radiation into electricity using semiconductor photoconverters. The cost of electricity produced by photovoltaic plants today is much higher than that produced by thermal power plants. However, photovoltaic systems are being actively implemented in both developed and developing countries. There are two opposite trends.

In developing countries, it is a question of application of rather small installations for power supply of individual houses in remote villages, for equipment of the cultural centers, where thanks to photovoltaic installations, it is possible to use TV sets, etc. In these cases, the application is not the cost of electricity, and the social effect.

Photomultiplier tube (PMT) implementation programs in developing countries are actively supported by international organizations, and the World Bank participates in their financing on the basis of its "Solar Initiative".

In industrialized countries, the active implementation of PMTs is explained by several factors. First, PMTs are considered as environmentally friendly sources that can reduce the harmful effects on the environment. Secondly, the use of photomultiplier tubes in private homes increases energy autonomy and protects the owner in the event of possible interruptions in the centralized energy supply. Some governments encourage the use of PMTs by private owners, paying extra for energy companies if they buy surplus electricity from them at a higher price.

A characteristic feature of PMTs is their modular design, the required power is achieved by using the appropriate number of modules. In world practice, two types of such modules are used: flat photovoltaic modules that use natural density solar radiation, and modules with a system for tracking the position of the Sun, which work on concentrated solar radiation.

A solar photovoltaic system consisting of one or more solar panels is a solar power plant that uses a method of directly converting solar radiation into electrical energy. The panels are placed on a supporting structure or frame on the roof of a residential building or on the ground, a set of batteries, a battery charge-discharge controller, and an inverter if you need to have AC voltage.

Solar panels are assembled from individual solar cells, the principle of operation of which is based on the phenomenon of internal photoelectric effect in semiconductors. Silicon photovoltaic converters use silicon with the addition of other elements that form a structure with a pn junction.

There are three main types of solar photovoltaic systems:

1. Autonomous systems for individual houses (Fig. 1.2).
2. The systems are connected to the network (Fig. 1.3).
3. Backup systems (Fig. 1.4).

Autonomous photovoltaic systems are used where there is no centralized power supply.

The system consists of a solar panel, a controller, a battery, cables and a supporting structure.

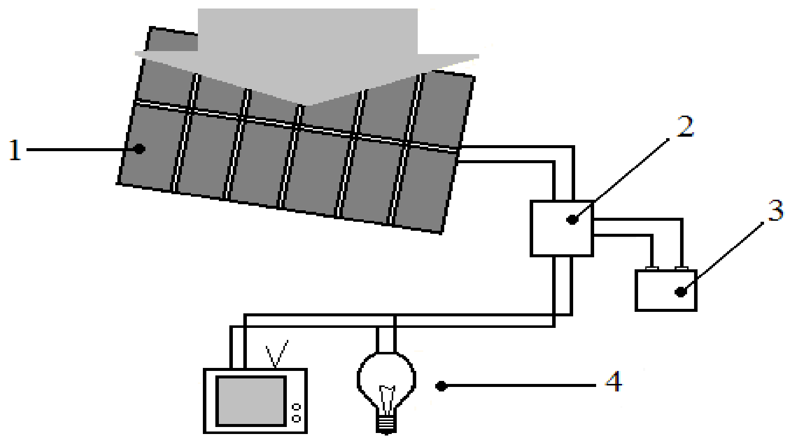


Fig. 1.2 Scheme of an autonomous photovoltaic system:

1 - solar panel; 2 - controller; 3 - rechargeable battery; 4 - load

The battery is used in the dark or in the absence of bright sunlight. This type of system is mainly used for autonomous power supply of individual houses. Small systems usually feed the base load (lighting, TV, refrigerator). More powerful systems can also power a water pump, refrigerator, etc.

Mains-connected systems are used in conjunction with the mains. With a sufficient number of connected photovoltaic modules, a certain part of consumers can be powered by solar electricity.

The inverter is used to connect photovoltaic panels to the network (conversion of direct current into alternating current 220/380 V, 50 Hz).

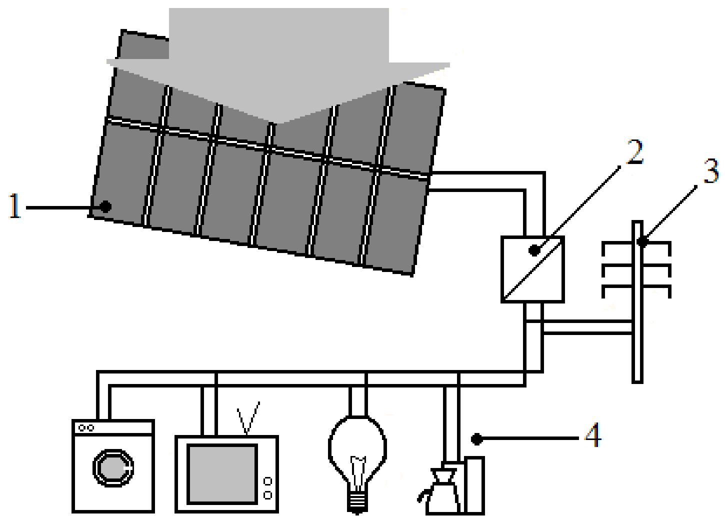


Fig. 1.3. Scheme of a photovoltaic system connected to the network:
1 - solar panel; 2 - inverter; 3 - network; 4 - load

Backup solar systems - centralized power supply is used, but the network is not reliable. Used for power supply in periods when there is no main power supply.

Small backup solar power systems are used for the most important load - lighting, computer and communications (telephone, radio, fax, etc.).

Larger systems can also provide power to a refrigerator during a power outage.

The greater the power required to power a responsible load, and the longer the periods of power outage, the greater the power of the photovoltaic system.

The system consists of photovoltaic modules, controller, battery, cables, inverter, load and support structure.

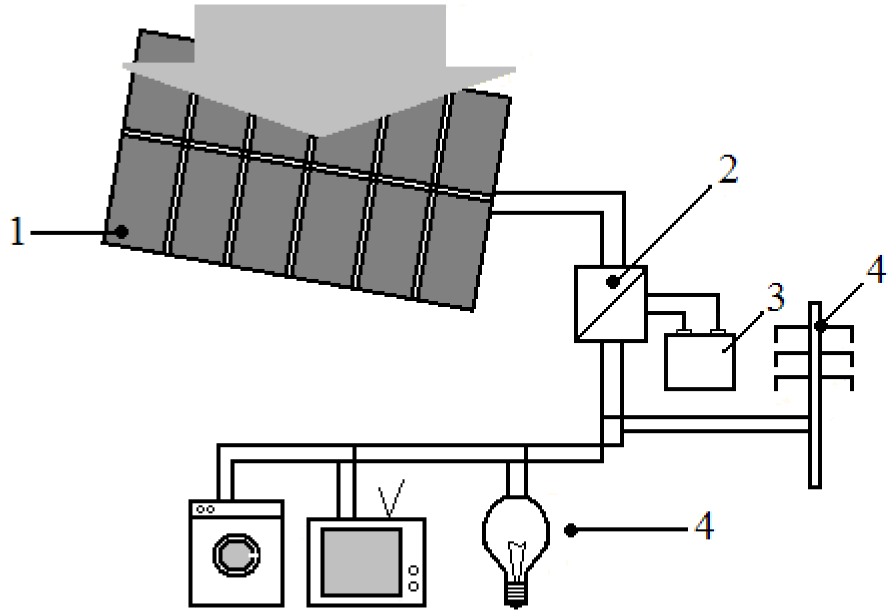


Fig. 1.4. Scheme of backup photovoltaic system:

1 - solar panel; 2 - inverter; 3 - rechargeable battery; 4 - network; 5 - load

Solar photovoltaic systems have a number of advantages:

1. Their work is mechanically very simple, there are no rotating parts, and no maintenance is required, except for periodic cleaning of the surface of solar panels.
2. Solar panels produce electricity that can be stored in batteries and used depending on the capacity of the battery.
3. The generation of electrical energy by the photovoltaic process is completely silent and does not produce any carbon dioxide or other toxic fumes.
4. Photovoltaic solar panels are indispensable in hard-to-reach and remote areas, where the laying of power lines is economically unprofitable.

The block diagram of the solar photovoltaic station is presented in fig. 1.5. The service life of such a station is 20-30 years, operating costs are minimal.

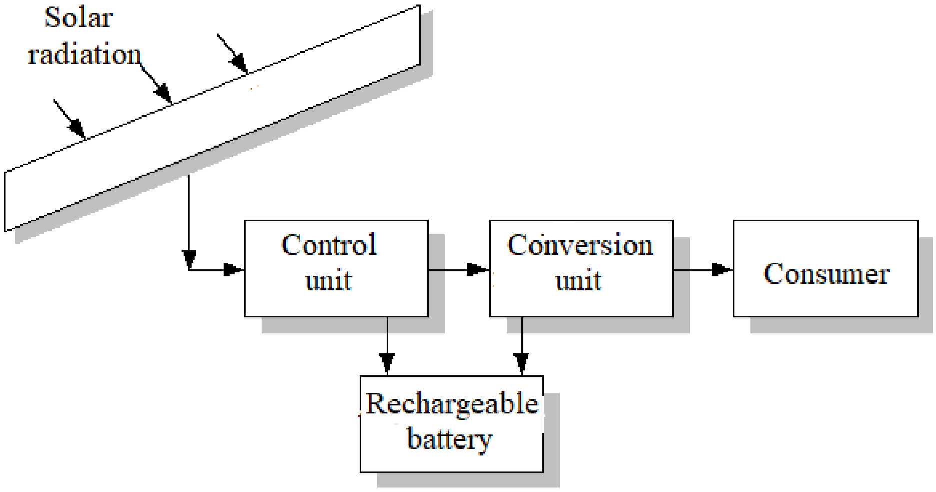


Fig. 1.5. Scheme of a solar photovoltaic installation

Solar photovoltaic stations are used to power water pumps, telecommunications systems, cathodic protection of pipelines, in households, etc.

1.2 The use of photovoltaic batteries in the power supply of suburban facilities

The power supply system for a country house is more important than for a city apartment. If a power outage in the city causes minor inconveniences, then outside the city it can lead to a real catastrophe. But in suburban conditions, in contrast to the metropolis, there is a choice of energy source.

Exacerbation of problems with the connection of country houses and remote facilities to the centralized power supply networks are forcing to look for alternative ways of power supply. Of great interest are systems using renewable energy.

Solar panels, which are installed on the roofs of houses, can work not only during the day, but also during the low solstice or in cloudy weather. Neither wind nor low air temperature is an obstacle to energy collection. In addition, these batteries are silent, which is different from wind systems.

Unsurprisingly, in terms of solar panels, Europeans assess our market as very promising, primarily due to the high rate of development of suburban construction. Significant growth of suburban property also increases the demand for alternative energy sources. In addition, it should be borne in mind that we often have cases where there is no district heating and gas supply in cottages, strict limits on electricity are introduced. And then solar systems can come to the rescue.

To reduce capital investment in the system on solar panels, it is necessary to use electrical equipment with high energy efficiency.

When choosing household appliances it is necessary to pay special attention to the class of energy efficiency.

For lighting, you can use LED lamps, which are 10 times more efficient than incandescent lamps, and more than 2 times more efficient than energy-saving fluorescent lamps. Solar panels have the maximum efficiency when the sun's rays "fall" perpendicular to the surface of the module. Since the sun is constantly "moving" across the sky, for the effective use of the panel, it is possible to use devices for tracking and rotating the panel to the sun.

There are two types of photovoltaic systems: autonomous and connected to the mains. The latter give the excess electricity to the grid, which serves as a reserve in the event of an internal shortage of electricity. Household solar panels carry out practically autonomous power supply of the house, using only solar energy. Recently, more and more often you can see mobile homes with similar electrification systems. Solar low-power batteries for giving allow not to depend on municipal power supply and forever release from the payment for the electric power.

The modern method of finishing facades with glass and aluminum can be not only beautiful, but also useful, in particular to provide backup power supply to the building. For this purpose it is necessary to replace front glass with solar amorphous transparent and not transparent batteries which besides, within 25 years will be guaranteed to provide additional or reserve electricity. Photovoltaic panels generate electricity not only in direct sunlight, but even on cloudy days. Finishing the facade with solar panels does not disrupt the ventilation of the building. From an economic and technical point of view, it is very advantageous to use photovoltaic panels in the decoration of the house .

In many countries, the development of "solar" housing has become one of the areas of public policy. UNESCO, the European Commission, the United Nations, and the United States Department of Energy deal with energy-saving construction. "Solar" houses are especially widely introduced in Germany within the framework of the national program "500 thousand" solar "houses". Such a "solar house", equipped with an efficient heating system, can fully meet the needs of its inhabitants in heat and light, even without the use of other energy sources. Moreover, the state helps citizens to switch to alternative energy sources, offering interest-free loans and discounts on the purchase of equipment.

Practical experience with the use of solar panels show that in our climate, these power plants are able to provide electricity to the house in the right amount.

Solar panels as a backup power supply to a country house have a number of advantages: no need for fuel, no harmful emissions into the environment, absolute quietness, ease of maintenance and operation.

In addition, the use of solar panels does not require approval from regulatory authorities, and the service life of the panel is about 20 years.

Modern technologies for the manufacture of solar panels, in combination with energy-saving and LED lamps, provide a guaranteed power supply and lighting for a smart home in any climate zone. When electrifying a house using solar panels, it is important to install solar panels taking into account all the recommendations and without errors. If the house is only in construction plans, it is necessary to provide in advance the possibility of using solar panels as a roofing material. It is not necessary to cover the entire slope of the roof with solar panels. One row at the level of human growth is enough. Five to eight standard solar panels on a sunny day will generate 5 to 12 kW of environmentally friendly, free energy, they will add an aesthetically pleasing, ultra-modern charm.

Solar power plants can be used where power outages and outages are not uncommon, mainly in the suburbs, which leads to the shutdown of all appliances, as well as to spoiled rest and inconvenience (such as defrosted refrigerator with food or inability to watch your favorite TV show), when connected solar power plant of the required capacity these problems disappear.

Backup, autonomous power supply for suburban housing is more important than for a city apartment. Power outages in large cities are rare, mostly in cold winters, but outside the city, in cottage villages, campsites, motels, tourist complexes, it leads to serious financial losses and difficulties.

Power supply systems and solar equipment during the period of greatest activity of the Sun (from March to August) fully provide electricity to a house, cottage. First of all, it depends on the chosen power of solar equipment.

A solar house with an autonomous connection is a house with an independent and uninterrupted power supply. The main thing in the concept of a residential "solar" house - the maximum use of solar radiation, its conversion into heat and conservation of thermal energy in the house with the least losses. The solar panel connects autonomously to the battery, charge controller and home appliances.

The calculation of a solar power plant means determining the nominal power of solar modules, their number, battery capacity, power of the inverter and charge-discharge controller. The number of solar modules should be chosen based on the amount of energy consumed, the area of the roof of the house (or any suitable site required for the placement of solar modules), as well as the cost indicators. Rechargeable batteries are required to store energy. When choosing an inverter, calculate all the total load of devices that need to be connected and multiply by 30% (such devices as: compressor refrigerator at startup consumes 12 times more power, submersible pumps 3-4 times more than the passport).

Required data for the calculation of the solar power plant:

1. Location area.
2. Existing eyeliners (if any).
3. The total area of the house.
4. Number of rooms.
5. What electrical appliances will be used.

6. Heating and hot water supply.
7. It is necessary to specify the total maximum power of all electrical appliances.
8. It is necessary to indicate the approximate operating time of each of the consumers.

In fig. 1.6 shows a basic view of the installation for powering household appliances in the cottage. In addition to solar panels, which are placed on the facade or roof of the cottage, the installation also includes two other important devices - chemical batteries and a regulator - converter. During the day, solar panels power both electrical appliances and charge batteries. At night and in low light conditions, the power source is exclusively batteries. Converters are needed to automatically control the charging and discharging processes of batteries, switching the load of the solar panel - the battery and to match the output voltage of the battery with the nominal value of the equipment. Estimates show that even in medium latitudes, a small cottage will have enough batteries with a capacity of 2-3 kW, which can be easily placed on the roof, as it covers an area of only 20-30 M^2.

The effect of using solar panels increases if more economical energy consumers are used, specially designed to work with photovoltaic modules (lighting lamps, refrigerators, pumps, TVs).

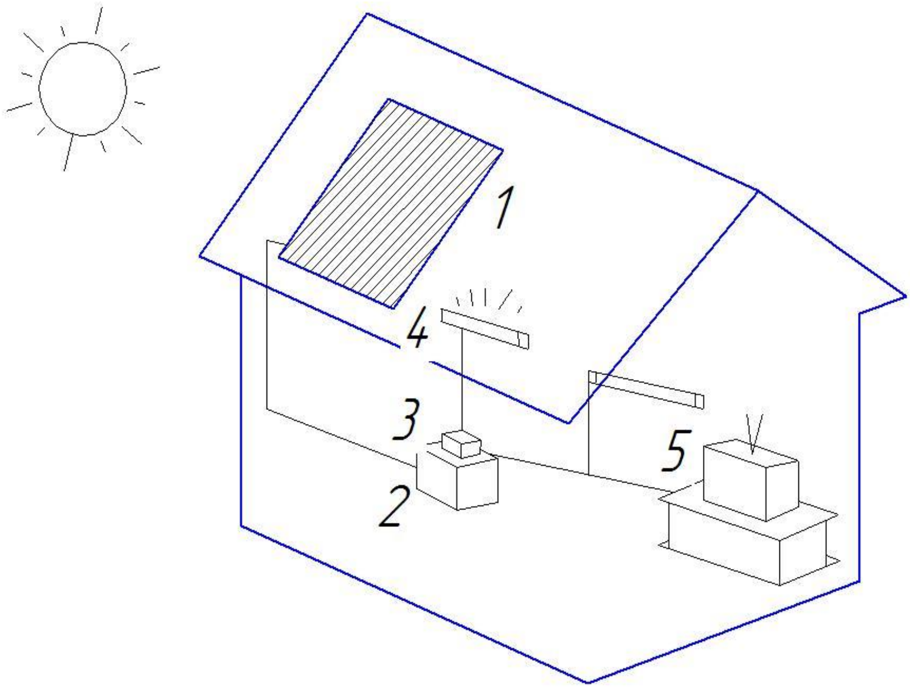


Fig. 1.6 The scheme of power supply by solar batteries of a cottage:

1 - solar battery, 2 - chemical batteries, 3 - regulator-converter, 4 - electric cable and lighting, 5 - TV or other electricity consumer

1.3 Conclusions to section 1

One of the most promising areas of energy supply today is solar energy due to the fact that solar radiation enters in sufficient quantities on almost the entire surface of the Earth. The advantage of the solar system is the absence of moving parts that make noise and wear, you do not need to use any type of fuel. Solar panels are currently too expensive for domestic use, but it is possible that this type of energy will become widespread in the future.

Therefore, improving the energy efficiency of household photovoltaic batteries is now extremely important. Next, we will consider methods of power selection and ways to improve the efficiency of such systems.

2 CALCULATIONS AND RESEARCH SECTION

2.1 Methodical principles of power selection from a solar battery

2.1.1 Simulation of the solar converter operation mode for an autonomous consumer

Estimation of the arrival of solar radiation has demonstrated the variable nature of solar radiation. Under these conditions, the solar module produces power other than the nominal power and power differences may occur. Thus, the task of this section is to optimize the production of the solar module at a given luminous flux. The solar battery gives its energy to the battery and the equivalent load, as a result of which an integral part of this task is to diagnose the condition of the battery as an element of the control system of the solar module.

To justify the choice of a solar module, it is necessary to consider their main types, the principle of operation of the solar cell. With a reliable replacement scheme and parameters of all elements of the system, it is possible to create a control system that provides maximum power from the solar panel.

2.1.1.1 Solar module model

The solar module (SM) can be represented in the form of an equivalent circuit presented in (Fig. 2.1, a). The conversion of energy in the SM is based on the photovoltaic effect, which occurs in inhomogeneous semiconductor structures when exposed to solar radiation. In this case, through the p-n junction in both directions will flow a current of non-basic, non-equilibrium charge carriers – photoelectrons and photon holes and the current of the main charge carriers is prevented by the potential barrier formed at the junction, which determines the possibility of obtaining photo-EMF in SM. Current $I_{ф}$ generated by the element, coincides in direction with the electric field inside the element, which when the circuit is open is represented by the no-load voltage V_{xx}. SM illumination leads to a decrease in the potential barrier and as a consequence of the increase of diffusion fluxes of the main carriers, i.e., to the occurrence of the so-called leakage current $I_{д}$.

$$I_{д} = I_{зг}\left[e^{\frac{qv}{kT}} - 1\right], \tag{2.1}$$

where $I_{зг}$ - reverse saturation current; V - High-voltage; q - electron charge; k - becomes Boltzmann's constant.

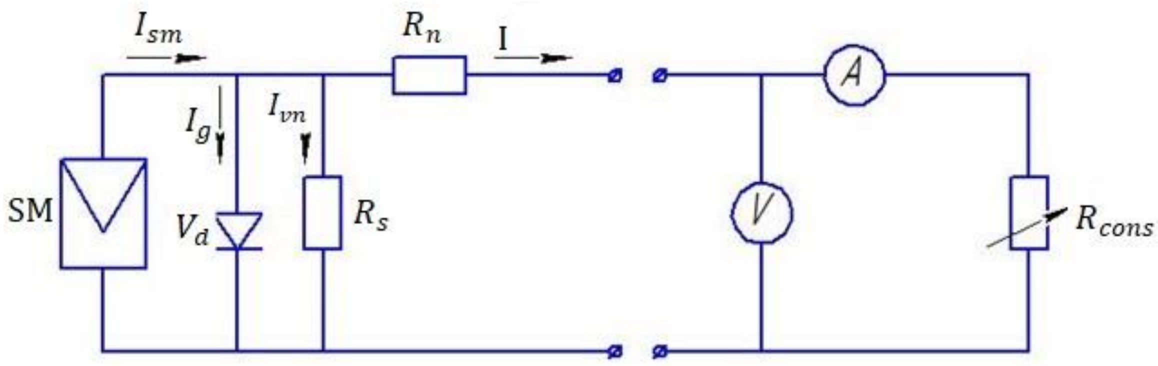
If the SM is connected to a load R_n, the steady state will be established at lower voltage V_n and current in the outer circuit I will be equal to:

$$I = I_{ф} - I_{д} = I - I_{зг}\left[e^{\frac{qv}{kT}} - 1\right]. \tag{2.2}$$

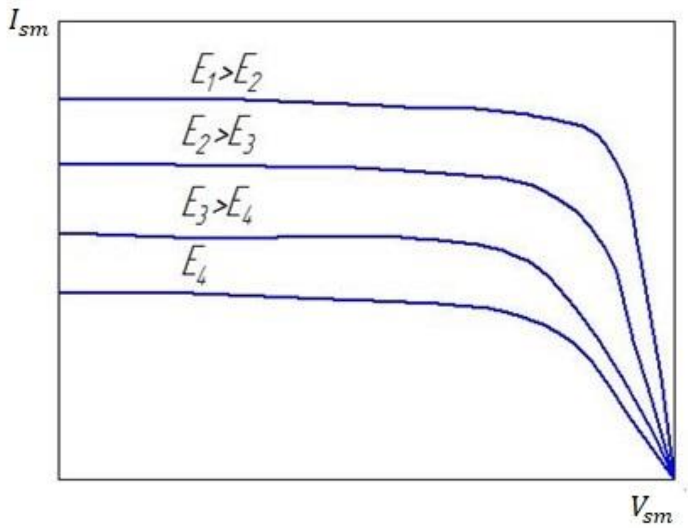
This equation describes the volt-ampere (I – V) characteristic of an ideal SM with a pn junction.

In real SM, along with the considered losses in current and voltage, there are losses associated with the series resistance of the photoconverter $R_{п}$ and processes in the pn junction, such as shunting R_s, tunneling, emission, etc. To assess the degree of approximation of the parameters of the real element to the characteristics of the ideal, a coefficient A is introduced, which is different for each photocell and is determined experimentally. Thus, we obtain:

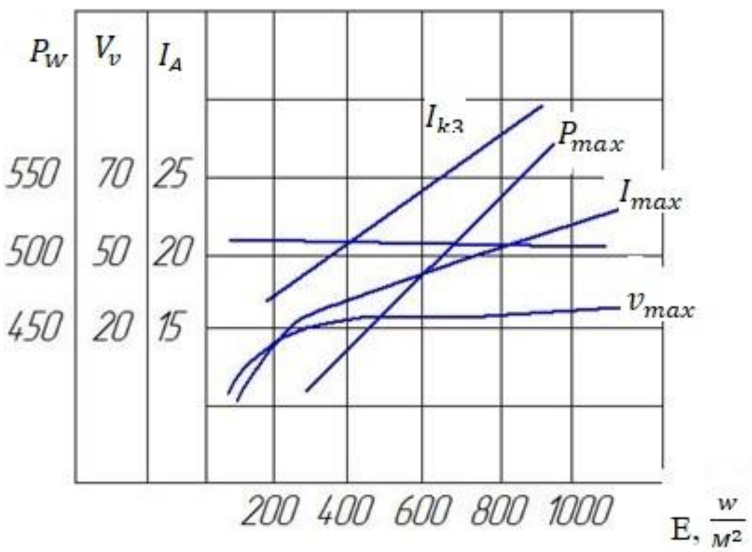
$$I = I_{ф} - I_{зг}\left[e^{\frac{q(V+IR_n)}{AkT}} - 1\right]. \tag{2.3}$$



a) the equivalent circuit of the solar module



b) vol-ampere characteristic



c) the main dependences of the parameters of the solar module

Fig. 2.1. Solar module parameters

$$V = \frac{\text{AkT}}{q} \ln\left[\frac{I_{\text{ф}} - I}{I_{\text{зв}}}\right] - \text{IR}_n. \quad (2.4)$$

Equations (2.3) and (2.4) allow to calculate the I – V characteristics of the real SM (Fig. 2.1, b). Output power corresponding to peak rated power, P_{nom} can be estimated from the ratio:

$$P_{nom} = (I_n \cdot V_n)_{max} = \text{К}' \cdot \text{К}'' \cdot \text{I}_{\text{кз}} \cdot V_{\text{кз}}, \quad (2.5)$$

where K'- the coefficient of filling of the I – V characteristics (I – V filling factor); K'' - power losses in the real SM, arising from shunt resistance and other effects.

The efficiency of SM depends mainly on its own temperature, which increases when using concentrators of solar radiation or when working in space. However, in terrestrial conditions and when using flat photovoltaic panels, the temperature varies in a narrow range (from $20°$ to $45°C$), which does not significantly affect its efficiency. However, when the temperature changes, the efficiency of the solar cell is determined by the following formula:

$$\eta = \eta_r\big(1 - \Delta(T_s - T_r)\big), \quad (2.6)$$

where T_r - reference temperature of SM; T_s - true temperature of SM; η_r - reference efficiency of SM; Δ - temperature coefficient (for silicon can be taken $45 - 10^{-4}\ °C$).

The operation of the solar battery in terrestrial conditions occurs at a variable density of radiation, the receipt of which depends on daily changes, weather conditions and other factors. Note that the change in rated power is mainly due to changes in current (Fig. 2.1b), voltage changes are within a narrow range. Analyzing the dependences of the main parameters of the SB on the level of radiation, we can establish that with increasing intensity of sunlight, we have increasing current I_n and power P_n while the voltage V_n varies in a narrow range of intensity changes. However, this law is preserved only for relatively high values of intensity, at low (E <100 W/M^2) the voltage drops sharply to zero, and hence the other parameters of the SB. Therefore, at direct inclusion of SB to the consumer there can be power differences. Hence the need to introduce into the model restrictions on the minimum level of intensity, at which it is still possible the normal functioning of the SB and the system as a whole.

2.1.1.2 Solar operation mode

Solar modules consist of separate photocells that are connected in series to obtain a given voltage of the module and in parallel, which provides the required load capacity of the module in current. In turn, the solar modules placed on the platform are connected in series with the number n_{ser} to obtain the required voltage of the solar module (SM). To ensure the required load capacity of the SM, current series are connected to each other in parallel. Number of parallel groups - n_{par}.

Based on the average technical data of the output power of the module P_{user} = 36W, the number of modules is calculated п_n, providing the nominal power of the SFEU range. Based on the geometric dimensions of the module and recommendations for the number of consecutive modules, the operating voltage V_o, number of parallel modules (п_{par}) and serial modules (п_{ser}) are determined. The calculation data are summarized in table. 2.1.

Table 2.1 - Recommendations for connecting modules

Planned rated power of SFEU, W.	Number of modules in the SB (n_{sb}), pcs	Recommended operating voltage, V	Square SB, M^2	Number of consecutive and parallel groups	
				n_{ser}, pcs	n_{par}, pcs
500	18	12.5 (12)	4.5	1	18
1000	36	25 (24)	9	2	18
1500	50	25 (24)	13.5	2	25
2000	72	50 (48)	18	4	18
3000	100	50 (48)	27	4	25
4000	136	50 (48)	36	4	34
5000	180	75 (72)	45	6	30
7500	252	75 (72)	67.5	6	42
10000	360	75 (72)	90	6	60

Extensive research of the MSW-36-12 module provides a sufficient basis for solving the tasks.

The family of volt-ampere characteristics is shown in Fig. 2.2.

As can be seen from Fig. 2.2 the characteristics of the module are nonlinear. Determine the load current at different values of E, at which the power output of the module will be maximum. To do this, for each of the 4 curves (Fig. 2.2) were constructed dependences:

$$P = V_{sm} \cdot I_{sm}. \quad (2.7)$$

The maxima of these curves are determined. This construction is illustrated in Fig. 2.3, and the results of processing the curves are given in table. 2.2.

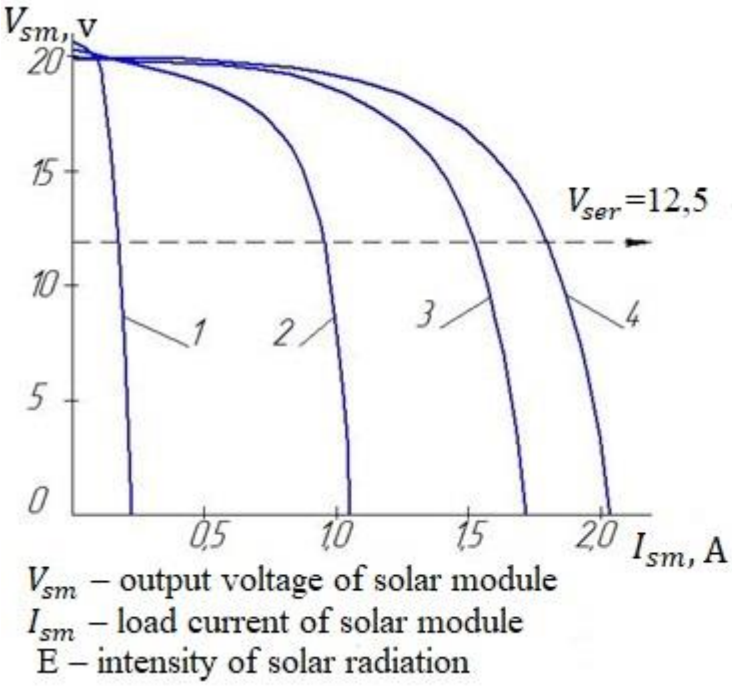


Fig. 2.2. Family of external volt-ampere characteristics of the MSW-36-12 module at average and maximum intensities of radiation E:

1 - 200 W/M^2; 2 - 500 W/M^2; 3 - 800 $W/M^2$4 - 1000 W/M^2

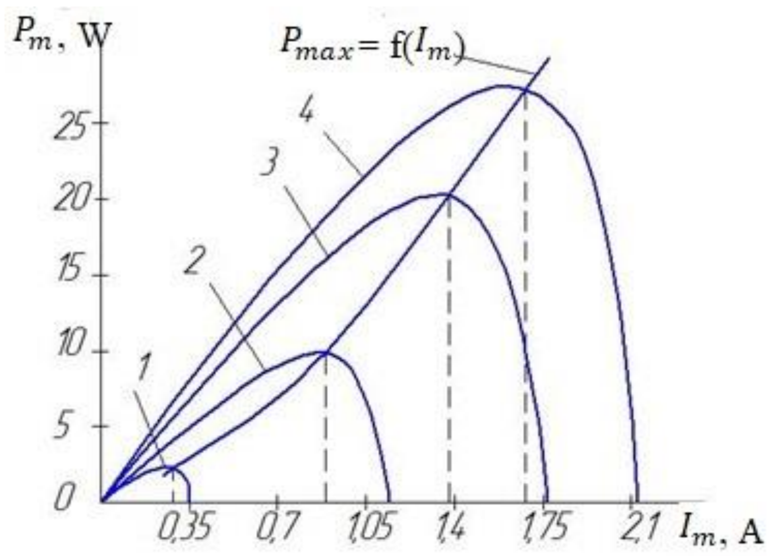


Fig. 2.3. The family of characteristics of the power dependence of the module MSW-36-12 at radiation intensities E:

1 - 200 W/M^2; 2 - 500 W/M^2; 3 - 800 W/M^2; 4 - 1000 W/M^2

Table 2.2 - Optimal values of current, voltage and power at different lighting values

Average maximum illumination, W/M^2	Optimal current, A	Optimal voltage, V	Optimal power, W.
200	0,38	11,08	4,2
500	1,06	13,42	14,3
800	1,77	15,40	27,3
1000	2,1	16,92	36

Thus, the dependence of the optimal load current on the current intensity of solar radiation was constructed (Fig. 2.4).

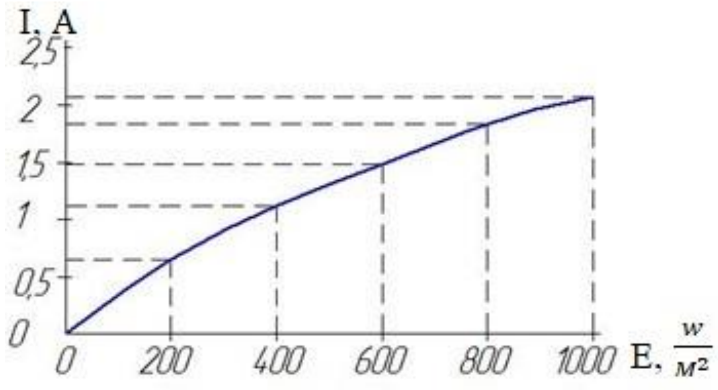


Fig. 2.4. Dependence of the optimal current load of the solar module on the intensity of solar radiation, $I_M = f(E)$

Let's establish an analytical relationship $I_\text{M} = f(E)$, for which we use the method of interpolation, using a polynomial of the 1st order of the form $I_\text{max} = k_0 + k_1 E$. In this case, $K_0 = 0$, $k_1 = 2 \cdot 10^3$.

$$I_\text{M} = k_0 + k_1 E. \qquad (2.8)$$

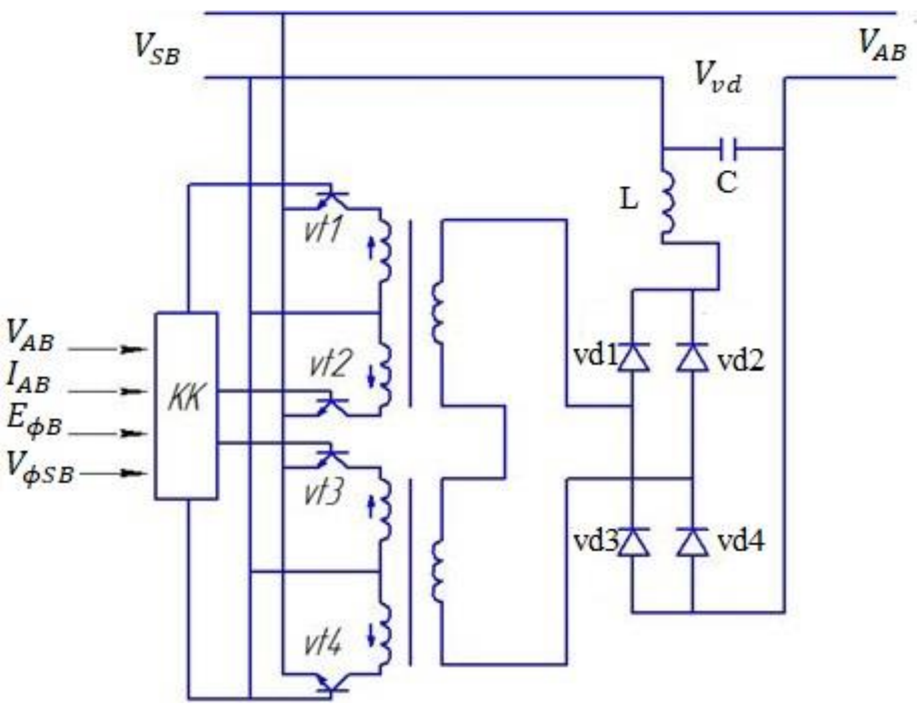


Fig. 2.5. Schematic diagram of the power controller

Using this dependence, it is easy to create a control system that provides the return of the optimal value of power from the battery in any of its lighting (Fig. 2.5).

The principle of operation of the system is obvious. Dependence $I_{\mathrm{M}} = f(E)$ sewn into the memory of the control controller (CC). According to the measured current value of illumination $E(\theta)$, the optimal value of the battery load current is determined $I_{\max}(t)$. This value is compared to the current value of the battery current $I_{\mathrm{SB}}(t)$ and static error $\Delta \mathrm{I}_{\mathrm{SB}}(t) = I_{\mathrm{SBmax}}(t)$-$\mathrm{I}_{\mathrm{SB}}(t)$ will become a control effect for the controller. Volt additional output voltage of the controller is added (subtracted) from the voltage $V_{\mathrm{AB}}(t)$ increasing (decreasing) the battery current. Thus, the principles of the SB control system are established, which provide the optimal parameters of electricity generation.

2.1.2 Autonomous consumer analysis

One of the necessary parameters for creating a power supply system is the average daily load of consumption(W_{avg}, W · Hr/Day), which consists of the power of electrical appliances used and the effective time of their use.

$$W_{avg} = \sum_{\mathrm{i}=1}^{24} P_i \cdot \Delta t. \tag{2.9}$$

It is necessary to take into account the type of consumption and the daily schedule of load distribution. Based on research, a simplified relationship was found between the area of the house and the average daily load (Table 2.3).

Table 2.3 - Categories of consumers

House area, м^2	Average daily consumption, W · Hr/day	Rated power of SFEU P_{SFEU}, kW
50	3600	1.0
70	4150	1.0
90	4900	1.5
130	5700	2.0
160	6250	2.0
190	6800	2.0
220	8000	3.0
250	8700	3.0

Consider the average daily load (Table 2.4) for a cottage area of 50 m^2 and consumption of 3600 W · Hr (Fig. 2.6). It should be noted that the domestic load differs from the industrial one by a pronounced unevenness. It is known that most of the consumption occurs in the morning and evening, when the arrival of solar energy is insufficient or absent, which leads to the use of the battery. In addition, electrical appliances mainly use alternating current, which requires the use of an inverter. In addition to the normal load, it is also necessary to consider the connection of the pump motor intended for water supply of the house. It is assumed that the normal operation of a stand-alone installation based on solar energy also depends on the mentality of the consumer, the need to use energy-intensive devices during periods of maximum arrival of SE, as well as reducing electricity losses.

Table 2.4 - The average daily load of a consumer with a house area of 50 m^2

Load	Installed power, W.	Usage time, year / day	Energy consumption, W · Hr/day
Lighting	360	1.8	650
Refrigerator	200	6.25	1250
Power tools	780	0.3	230
TV	70	5.71	400
Iron	1000	0.15	150
Washing machine	2500	0.33	820
Small electrical appliances (blender, hair dryer, razor, etc.)	500	0.2	100
Total	5410		3600

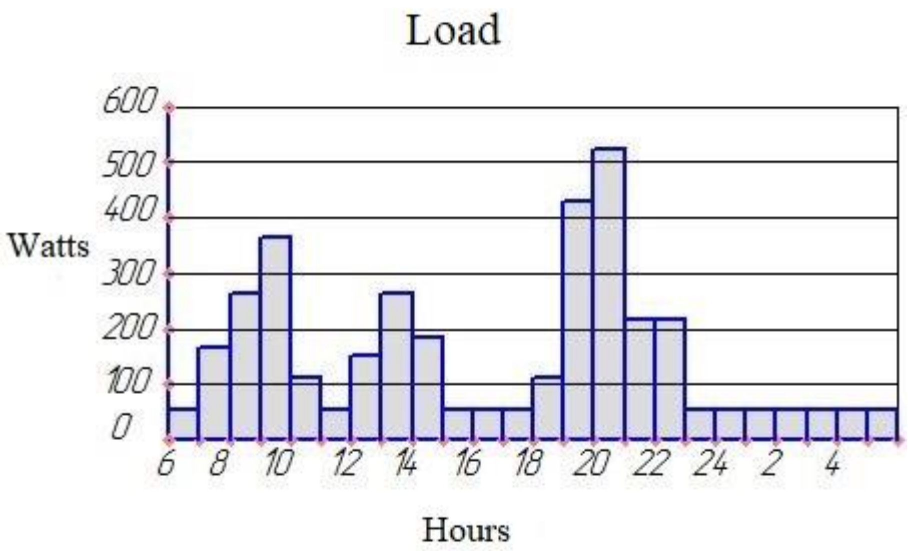


Fig. 2.6. The average daily load of a consumer with a house area of 50 m^2

Assume that the power supply of these consumers is carried out from individual SFEU, made by structure: flat solar panels with orientation to the Sun, stabilizers of the output voltage of the batteries, battery, semiconductor inverter that converts DC voltage into AC.

The electricity produced by SFEU per day can be estimated by the expression:

$$W_{SFEUavg} = P_{pmt.nom} \cdot T_{\text{T}} \cdot \kappa_{vrd} \cdot \kappa_{sp} \cdot \eta_{kim} \cdot \eta_{pr}, \quad (2.10)$$

where $P_{pmt.nom}$ - rated power of the photovoltaic installation (kW); T_{T} - length of daylight from east to west (12 years); κ_{vrd} - the coefficient of dimming during the day (in the morning and evening); $\kappa_{\text{vrd}} = 0{,}7 - 0{,}8$; κ_{sp} - coefficient of seasonal attenuation of illumination due to summer-winter fluctuations of solar radiation and clouds ($\kappa_{\text{sp}} = 0{,}9$ in summer $\kappa_{\text{sp}} = 0{,}6$ in winter); η_{kim} - the energy efficiency of the battery ($\eta_{\text{kim}} = 0{,}6 - 0{,}8$); η_{pr} - efficiency of semiconductor stabilizer and inverter ($\eta_{\text{pr}} = 0{,}7 - 0{,}8$ depending on the power of the installation).

For the consumers listed in Table 2.4, the following inequalities must be satisfied:

$$W_{\text{avg}} \leq W_{\text{SFEUavg}}. \quad (2.11)$$

Then the rated power required for the power supply of this object can be determined from the expression:

$$P_{pmt.nom} \geq \frac{W_{avg}}{\text{T}_{\text{T}} \cdot \text{K}_{vrd} \cdot \text{K}_{sp} \cdot \eta_{kim} \cdot \eta_{pr}}. \quad (2.12)$$

An approximate estimate of the required nominal power of the PMT can be performed by the ratio:

$$P_{pmt.nom} \geq \frac{W_{\text{avg}}}{3{,}5 \div 4{,}2}, \quad (2.13)$$

where a factor of 3.5 is valid for capacities $1 < P_{pmt} < 3$ kW;

coefficient of 3.8 at $3 < P_{pmt} < 8 \div 10$ kW;

coefficient of 4.2 at $10 < P_{pmt} < 15$ kW

The results obtained in table. 2.3, indicate that the nominal capacity of the SFEU for the bulk of consumers should be within $1 < P_{SFEUpmt} < 3$ kW

The system of electrical equipment of photovoltaic installations, converts solar energy into electricity, its accumulation, storage and subsequent conversion of DC voltage into output AC voltage, sufficiently developed and produced in a complex, or individual units, dozens of companies around the world. As a rule, when developing new SFEU intended for specific consumers, it is necessary to solve a number of sometimes not simple engineering problems. The stages of this work are as follows:

4. The quarterly (monthly in some cases) demand for electricity of the customer is estimated and the required capacity of the photomultiplier tube is determined in advance.
5. Taking into account the geographical latitude of the location of the object and the presence of free space on the object of the installation, the issue of constructive layout of SFEU is solved: fixed on the roofs of buildings, with uniaxial tracking of the Sun, with two-coordinate system.
6. The schedule of quarterly (sometimes monthly) value of specific power of a light stream arriving on a surface of a solar battery, taking into account latitude of a place, weather meteorological conditions, (probable values of shading of SB by cloudiness and coefficient of transparency of atmosphere), constructive characteristics batteries. It is specified taking into account the received dependence of expected generation of the electric power and finally taking into account the schedule of loadings, the question of the necessary area of the established photovoltaic batteries, i.e. about nominal capacity of SFEU is solved.
7. Comparing the temporary daily schedules of expected electricity generation and consumption at the facility for all seasons of the year (sometimes for each of the months of the year) determine the maximum required reserves of electricity storage for evening and night and taking into account energy efficiency factors (η_{AB}) the required capacity of the battery is estimated.
8. Selected by the maximum output power, the coefficient of allowable current overloads and the required operating voltages, the controller that provides the charge mode and control of the battery and the output inverter (if the consumer has AC loads).
9. The choice of signal, information, diagnostic and protective electrical equipment and other necessary auxiliary elements, sensors and systems is created.

Firms producing SFEU do not disclose their internal documents and no scientifically sound complete methods of developing and designing SFEU have been found in the technical literature. Usually the messages are advertising in nature and they indicate some technical and economic parameters and some operational characteristics of the SFEU.

And although this problem is of some interest and some of its stages were solved to an extent in this work, for example, when choosing the optimal layout and design of SFEU, we study the electrical equipment of the solar energy conversion channel to solve the problem of optimizing solar module production at a given light flux.

Thus, we considered the main types of consumers for which an autonomous power supply system is required and estimated the limits of the required installed

capacity.

2.1.3 Rationale for the choice of storage system

There are different ways to store energy. We summarize them in the following scheme (Fig. 2.7).

The use of AB batteries as energy storage for operation of the installation in low light hours or at night is an attempt to improve the energy and transient characteristics of the SFEU system - equivalent load and motor-pump, as it does not require coordination of mode and characteristics of motor-pump (load) from the I – V characteristics of solar photovoltaic installations.

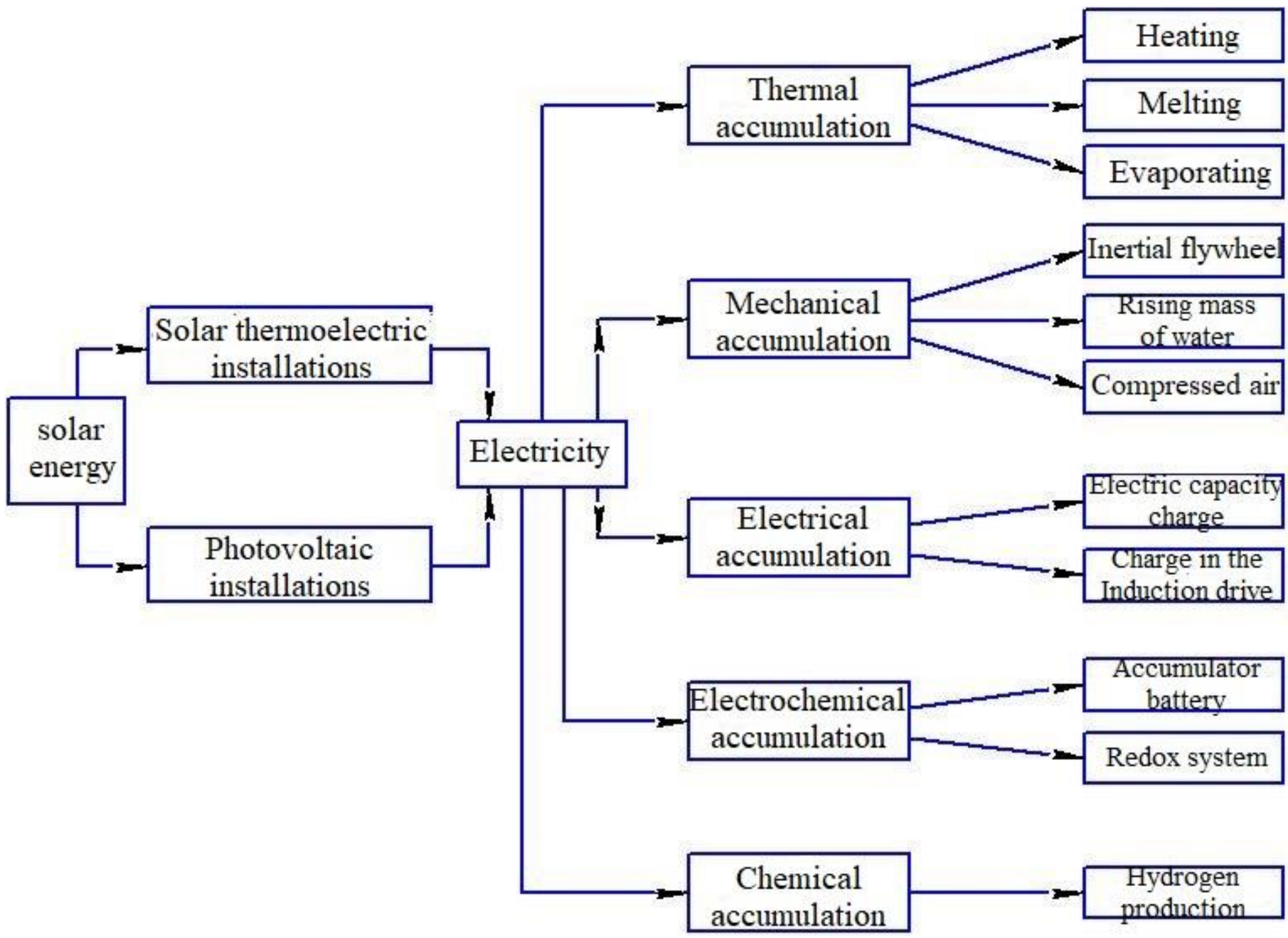


Fig. 2.7. Scheme of accumulation methods

The most appropriate for autonomous low-power consumers is the use of electromechanical batteries. Various types of AB have been developed in the world, the main characteristics can be summarized in table. 2.5.

Given that the most important characteristics of AB, working in conjunction with the World Bank, are the life cycle and cost $kW \cdot Hr$, the best choice will be lead-acid AB. Choosing a rechargeable battery requires a trade-off between capacity and service life. They are interconnected by the maximum working capacity or depth of discharge.

Table 2.5 - Characteristics of electromechanical batteries

Type	Brand	Specific capacity, $A \cdot hr/м^3$
Silver zinc	SCP-300	146621.8
Nickel-zinc	NC-125 NC-200	52292.9 89974.3
Nickel-cadmium Prismatic nick.-cad.	NK-125 NKG-200	32880.9 47062.4
Nickel-iron (traction)	TNZh-300U5 TNZhK-350U3	29779.3 54015.7
Nickel-cadmium (traction)	TNK-300MT2 TNK-350T5 TNK-400U5 TANK-55OTZ	36981.4 25098.4 35158.4 23217.2
Leaden	SK-100 SK-120 SK-148	11679.5 11830.3 12066.7

If the battery is discharged by more than 80% of its capacity, its voltage is usually unacceptably low, and the service life (in cycles) is sharply reduced. A 100 percent discharge can cause irreparable damage to the battery. However, the smaller the discharge depth, the greater the capacity and, consequently, the cost of the batteries.

Each scheme of inclusion of AB in system of pump installation has the properties and features. For example, the accumulation of all energy from the SFEU in the battery with its subsequent consumption leads to the choice of large capacity battery, but the battery tank in this case is absent.

In addition, such a scheme of inclusion of system elements can provide:

- reliable start of the DC motor;

- operation of the electric pump in the field of nominal parameters Q_{nom}, η_{nom}, H_{nom};

- increasing the power utilization factor of the SFEU.

There are many options for including AB in the SFEU system - equivalent load and motor-pump. Depending on this, its capacity, duration of operation of the installation during the day and power of the electric motor are determined.

2.1.3.1 Choice of AB capacity

Let's develop a method of determining the required capacity of the battery.

9. Daily consumption:

$$W_{SP} = P_{avg} \cdot \mathrm{T}_{SD} + W_{nas}. \qquad (2.14)$$

2. The average output power of the SFEU during daylight hours T_{SD} = 14 Hr:

$$\mathrm{P}_{SFEUavg} = \frac{W_{SP}}{\mathrm{T}_{SD}}. \qquad (2.15)$$

3. Average power of a photovoltaic battery P_{SBavg}which it must produce during daylight hours:

$$P_{SBavg} = \frac{P_{SFEUavg}}{\eta_{inv} \cdot \eta_{AB} \cdot \eta_{SC}}, \quad (2.16)$$

where η_{inv} - efficiency of the inverter, $\eta_{\text{inv}} = 0{,}9 - 0{,}97$; η_{AB}- the rate of return on battery power. For lead-acid AB with a discharge duration of 5-6 hours, $\eta_{\text{AB}} = 0{,}85$; η_{SC} - efficiency of the power controller, $\eta_{\text{SC}} = 0{,}95$.

4. The minimum required capacity of the battery at operating voltage $V_{\text{ABn}} = 24$

$$C_{AB} = \frac{P_{SBavg} \cdot T_{SD}}{V_{ABn}} \cdot K_{ex} \cdot K_{\text{c}} \quad (2.17)$$

where K_{ex}- the coefficient of excess energy reported to the battery when charging, is determined by the accuracy of the system for diagnosing the condition of AB. Usually $K_{ex} = 1{,}05$; K_{C}- consumer ratio, which is determined by the consumer's belonging to a particular category. For household consumers $K_{\text{C}} = 0{,}5 - 0{,}7$.

5. Select the battery closest to the larger capacity in the catalog, and determine the number of batteries n_{AB} to provide the required rated voltage.

$$n_{\text{AB}} = V_{\text{ABmax}} / \text{V}_{\text{AB}}. \quad (2.18)$$

6. Coefficient of reduction of power of the solar module K_{Φ} at low luminous flux:

$$K_{\Phi} = \frac{E_{avg.se}}{E_n}, \quad (2.19)$$

where $E_{\text{avg.se}}$ - the average value of the intensity of light flux in the most unfavorable period; E_n- the nominal calculated value of the luminous flux intensity, which provides the nominal output power of the SM.

7. Average power removed from one solar module during daylight hours:

$$P_{Pavg} = P_{np} \cdot K_{\Phi}. \tag{2.20}$$

8. The number of modules of the solar battery, providing the production of a given power:

$$n_M = \frac{P_{SBavg}}{P_{Pavg} \cdot K_{SM}}, \tag{2.21}$$

where K_{SM} - power reduction factor at sunrise and sunset.

We choose SFEU with the nearest big value. It is easy, given the variation of the range of rated capacities of the SFEU, to make sure that the plan to produce a number of SFEU with a capacity of 1 kW to 3 kW will require the inclusion of batteries with a capacity in the range of 100< C_{AB} <300 $A \cdot$ hr.

Lead-acid batteries are available in two main types:

a) automobile, provide short-term currents with a large multiplicity (load time - units, tens of seconds);

b) stationary, characterized by increased plate thickness and designed to work with long, slowly changing currents (load time from 1 to 20 hours).

In this case, taking into account the nature of the load, we suggest using stationary batteries.

A review of technical and economic indicators of stationary batteries of the world's leading companies was performed. Comparative analysis of the unit cost of batteries of Russian and foreign companies is twice as expensive as the Russian-made battery at comparable technical indicators. Here are some technical data of the battery series OPzS (Table 2.6).

The AB parameters depending on the discharge mode are given in table. 2.7.

Table 2.6 - OPzS series battery settings

Battery type	OPzS - 150
Battery voltage, V: 5. nominal 6. open circuit charged 7. open circuit discharged 8. maximum charge 9. discharged at the beginning of the charge 10. charged at the beginning of the discharge	 2 2.15 1.75 2.5 1.75 2.15
Nominal capacity C_n, $\mathrm{A \cdot hr}$	150
Maximum charge current, A	122
Energy efficiency at 5-hour discharge	0.82

Table 2.7 - AB parameters depending on the discharge mode.

Regime	Discharge current, A	Capacity, A · Hr
10 years	0.1Q	Q

5 years	0.165Q	0.82Q
3 years	0.25Q	0.75Q
1 year	0.5Q	0.5Q
30 min	0.7Q	0.35Q
15 min	0.88Q	0.22Q

2.1.3.2 Creating a mathematical model of the state of AB

The solar battery communicates its energy in parallel to the AB and the inverter. To ensure optimal energy recovery modes of operation of the system - solar battery (SB) - rechargeable battery (AB) - equivalent load $R_{\mathrm{C}}(t)$ it is necessary to have a reliable replacement scheme of the battery and the inverter.

The inverter on the calculation circuit can be replaced by an equivalent, time-varying active resistance $R_{\mathrm{inv}}(t)$, the value of which depends on the current capacity of the consumer $R_{\mathrm{C}}(t)$. For $R_{\mathrm{inv}}(t)$ you can write:

$$R_{inv}(t) = \frac{P_C(t)}{\eta_{inv} \cdot V_{AB}^2(t)}, \quad (2.22)$$

where $V_{\mathrm{AB}}(t)$ - battery output voltage.

The battery is a non-linear and non-stationary element. The voltage of each of the accumulators in the battery can vary from $V_{\mathrm{Amin}} = 1{,}75$ at full discharge to $V_{\mathrm{Amax}} = 2{,}5$ at full charge (Fig. 2.8).

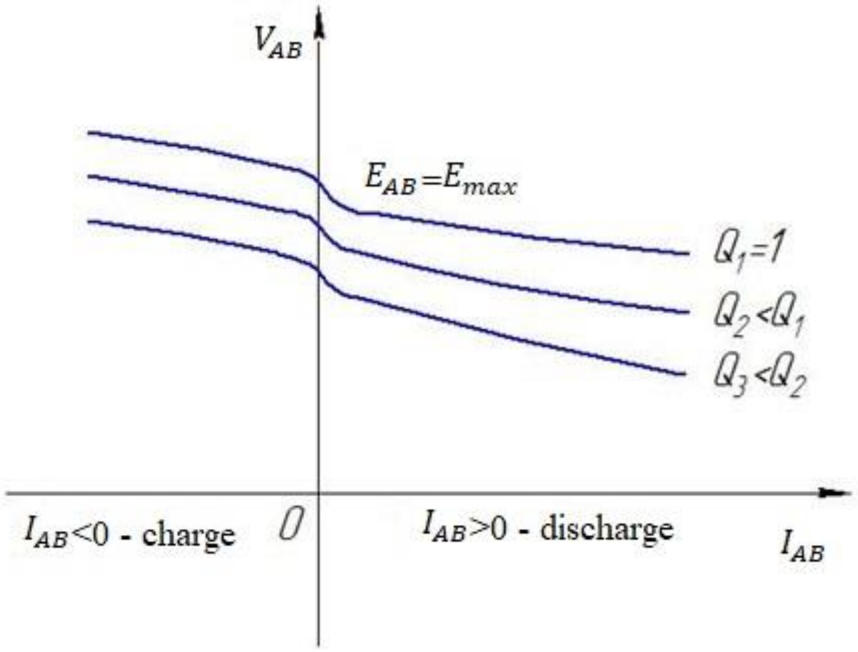


Fig. 2.8. Changing the Voltage AB

The internal resistance of the battery also depends on the degree of discharge of the battery and the direction and magnitude of its current.

Based on the works and a number of monographs with acid batteries, we will develop a model that will reflect the real physical processes in the system "SB-AB-R_{inv}”.

Battery terminals voltage V_{AB} can be represented as the sum of two components:

$$V_{AB} = \mathrm{E}_{AB} \pm \mathrm{i}_{AB} \cdot R_{AB}, \tag{2.23}$$

where E_{AB} - battery emf; R_{AB} - internal resistance of AB; i_{AB} - battery current, "+" when charging, "-" when discharging.

The equilibrium EMF of the battery and its internal resistance are variables. Yakubovsky V.Ya. calculations were performed to obtain the dependence of these values on the degree of charge of the battery, and the latter was characterized by the value of the current battery charge:

$$Q = \int_0^t i_{\mathrm{AB}} \mathrm{dt}. \quad (2.24)$$

The EMF of the battery within the nominal discharge capacity varies almost linearly, which allows you to implement this dependence in the model by simple means.

Then the following equations are valid for building a mathematical model of the battery:

$$\begin{cases} E_{AB} = E_p = E_{in} \pm k \cdot Q \pm E_n \\ V_{AB} = E_{AB} \pm i_{AB} \cdot R_{AB} \end{cases} \quad (2.25)$$

where E_{in} - initial EMF of the battery; E_{p} - equilibrium EMF of the battery; K - coefficient of proportionality; Q is the discharge capacity; "+" When charging, "-" when discharging; E_{AB} - EMF of the battery; R_{AB} - internal resistance of the battery, $E_{\mathrm{п}}$ - EMF polarization.

The model is considered for $n_{\mathrm{AB}} = 1$ (number of batteries in the battery). To calculate the battery parameters, the values $\mathrm{E_{AB}}$ and R_{AB} are obtained and will be multiplied by the required value n_{AB}.

Size of E_{in} depends on the density of the electrolyte in the battery. Calculations of the equilibrium EMF [26] show that in the range of electrolyte densities 1.20 - 1.34 г/см^3, you can accept:

$$E_{in} = 0{,}32 + 1{,}43d, \quad (2.26)$$

where d - electrolyte density, г/см^3.

The coefficient of proportionality in the EMF equation depends on the amount and density of the electrolyte. The density of the electrolyte in the considered range affects the value of the coefficient quite slightly, and this effect can be neglected. The dependence of the coefficient on the amount of electrolyte established by calculation has the form:

$$k = \frac{2 \cdot 10^{-3}}{V}, \quad (2.27)$$

where V is the amount of electrolyte in the battery, l.

Accurate polarization calculation presents significant difficulties. Sometimes the polarization can be taken into account approximately, assuming the EMF of polarization is constant. Recommended for values of charge currents (discharge) within $0{,}1C_{\mathrm{ABn}} \leq i_{\mathrm{AB}} \leq 0{,}25\mathrm{C}_{\mathrm{ABn}}$ take the value of the EMF polarization $\mathrm{E}_{\text{п}} = \pm 0{,}075\mathrm{In}$, the sign "+" when charging and the sign "-" when discharging.

The internal resistance of the battery consists of the resistance of the battery plates, separators and electrolyte. The specific conductivity of the active mass of the plates (lead dioxide and spongy lead) in the charged state is close to the conductivity of metallic lead. The active mass of the discharged plates contains a large amount of lead sulfate, which is a poor conductor of the electric field. Therefore, the resistance of the plates depends on the degree of charge of the battery. The minimum resistance of the battery corresponds to the full charge of the battery. As the resistance of the plates increases.

Electrolyte resistance is predominant in the internal resistance of batteries. The resistance of serviceable separation is so insignificant that it can be neglected. The resistance of the plates, if the battery is not very old or sulfated, is also not crucial.

The internal resistance of the battery increases with discharge due to a decrease in the specific gravity of the electrolyte, and an increase in the resistance of the active mass of the plates, due to its transition to lead sulfate. The value of the internal resistance of the battery at the same dedicated capacity depends on the magnitude of the discharge current. The higher the discharge current, the more vigorously there is a decrease in the concentration of electrolyte in the pores of the plates and near them. This leads to an increase in electrolyte resistance.

When charged, the electrolyte concentration increases, its internal resistance decreases, and lead sulfate is reduced to lead dioxide and spongy lead. In fig. 2.9 shows the change in the internal resistance of the battery during charging and discharging.

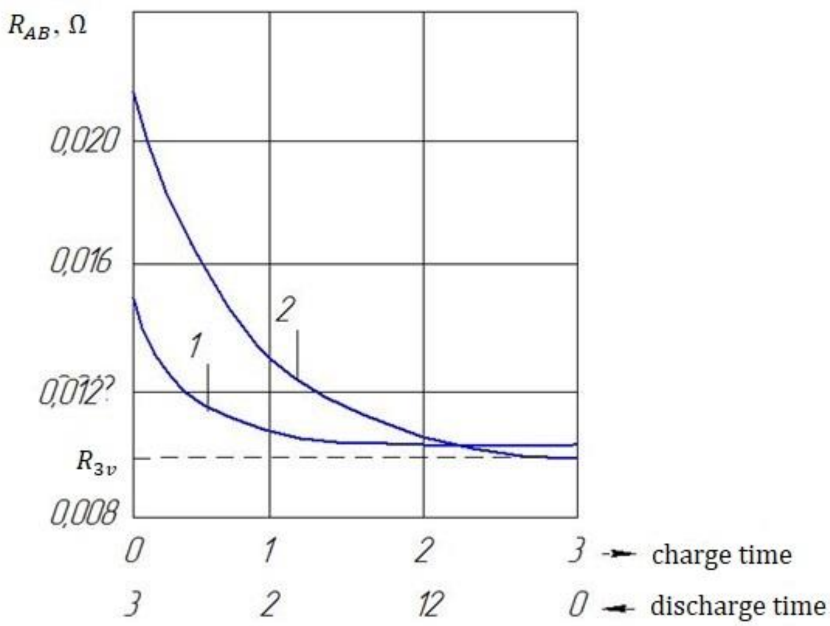


Fig. 2.9. Changing the internal resistance of the battery during charging (1) and discharge (2)

The schedule of change of internal resistance of other accumulators of this type having other nominal capacity, can with an error no more than 5% be calculated on a ratio:

$$R_{bn} = R_{bn.nom} \frac{C_{ABnom}}{C_{AB}}, \quad (2.28)$$

where $C_{ABnom} = 1{,}25\ A \cdot hr$ - nominal battery capacity; C_{AB}- nominal capacity of the used AB. We find from this figure the dependence of the internal resistance of the battery on the given capacity:

$$R_{bn} = \left[1 - \frac{0{,}95}{C_{ABnom}} \cdot Q + \frac{3{,}7}{C_{ABnom}^2} \cdot Q^2\right] \cdot R_{3v}, \quad (2.29)$$

where $R_{3v} = 0{,}0091$ Ohm, C_{ABnom} - nominal battery capacity.

Knowing that the difference between the internal resistance of the battery in 10-hour and 3-hour discharge modes does not exceed 30%, you can find the correction factor for the dependence (2.29), which depends on the discharge current.

This correction factor $K_{п}$ is equal to:

$$K_{п} = 0{,}5 + 0{,}2 \cdot \frac{i_{AB}(t)}{i_{(10)}},, \quad (2.30)$$

where $i_{(10)}$ - 10-hour battery discharge current, and $i_{AB}(t)$ - real discharge current.

Then, taking into account the amendments made by expressions (2.28) and (2.30), expression (2.29) will be transformed into the form:

$$R_{bn} = \left[1 - \frac{0{,}95}{C_n} \cdot Q + \frac{3{,}7}{C_{in}^2} \cdot Q^2\right] \cdot R_{3v} \cdot \left[0{,}5 + 0{,}2 \cdot \frac{i_{AB}}{i_{(10)}}\right] \cdot \frac{C_{ABnom}}{C_{AB}}. \quad (2.31)$$

Turning to the assembly of the battery model, we note that to calculate its parameters must be measured:

I_{AB} - battery current;

V_{AB} - voltage at the battery terminals;

t_e - electrolyte temperature;

d is the density of the electrolyte.

The developed model allows to define on the measured input sizes: $V_{AB}(t)$, $E_{AB}(t)$, $R_{AB}(t)$ and the degree of charging (discharging) AB - $k_{discharge}$. These data are input variables for the control microcontroller, optimizing the return mode of the SB and the system for diagnosing the state of the AB.

2.1.3.3 Analysis of the joint work of SB-AB

In the previous sections of this section, the issue of ensuring maximum power output from the solar battery when working at active load was considered. AB as a load has a number of specific properties.

AB can be considered as a voltage generator with a very small internal resistance, changing over time.

The EMF of the battery also changes over time depending on the degree of its charge (discharge) and the direction of current, and in the process of charging this change takes place from $E_{ABmin} = 1{,}9. n_{AB}$ to $E_{ABmax} = 2{,}35. n_{AB}$, ie almost one quarter of the rated voltage $V_{ABnom} = 2{,}0 \cdot n_{AB}$.

An approximate estimate of the internal resistance of a lead-acid battery can be made by the known expression:

$$R_{AB} = \frac{0{,}3}{C_{AB}} \cdot n_{AB}, \qquad (2.32)$$

ie at $C_{AB} = 100$ A · hr we have $R_{AB} = \frac{0{,}3}{100} \cdot 12 = 0{,}036\Omega$.

For the solar module MSW-36-12 it is possible to linearize the current-voltage characteristic (fig. 2.10), having replaced it with two rectilinear segments.

When changing the intensity of the solar flux of the module V_{xx} varies slightly (not more than 5%). Operating voltage V_p, at which the SM gives the maximum power, also almost does not change.

The short-circuit current varies in proportion to the magnitude of the luminous flux, and the incident parts of the I – V characteristics of the solar module are shifted almost in parallel. It is the falling sections of the I – V characteristics that are the working ones, on which, as a rule, the working point B is located.

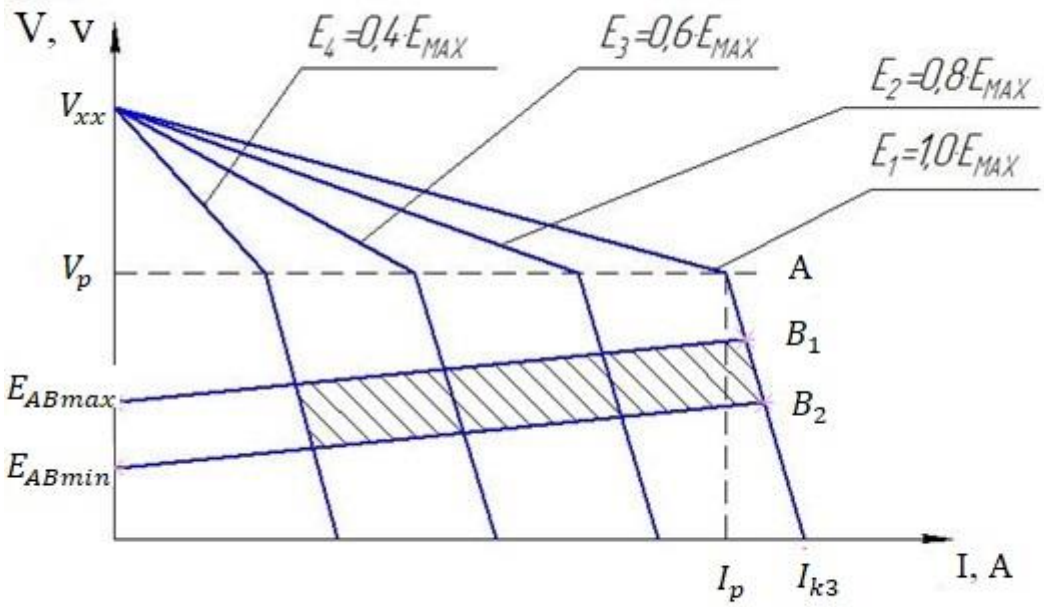


Fig. 2.10. Approximate I – V characteristics of the solar module

With this arrangement of the operating point SB can be replaced by a controlled current generator $I_{кз}$, shunted resistor with resistance:

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$$R_{м} = \frac{V_{p}}{I_{кз} - I_{p}}, \quad (2.33)$$

and the model SB can be described by the equation:

$$I_{м} = \frac{\partial I_{м}}{\partial E} \cdot E - \frac{\partial I_{м}}{\partial V_{м}} \cdot V_{м} = k_{ф} \cdot E - \frac{V_{м}}{R_{м}}. \quad (2.34)$$

Solar modulus conversion factor:

$$k_{ф} = \frac{\partial I_{м}}{\partial E}, \quad (2.35)$$

can, given the parallelism of the falling parts of the I – V characteristics, be determined by the expression:

$$k_{ф} = \frac{I_{кзi} - I_{кзi+1}}{E_{i} - E_{i+1}},, \quad (2.36)$$

where $I_{кзi}$ and $I_{кзi+1}$ - short-circuit currents of adjacent characteristics, E_{i} and E_{i+1} - the intensity of solar flux in these two characteristics.

The resistance shunting the ideal current generator can be determined by the expression:

$$R_{м} = \frac{\Delta V}{\Delta I_{м}}_{E_{i}=const} = \frac{V_{p}}{I_{кзi} - I_{pi}}. \quad (2.37)$$

To find the operating point B, where the SB will work on the load type battery, apply in the same coordinates I – V

AB in accordance with the equation:

$$V_{AB} = \mathrm{E}_{AB} + \mathrm{I}_{AB} \cdot R_{AB}. \qquad (2.38)$$

Taking into account that $I_{\mathrm{AB}} = \sum_{i=1}^{n} I_{\mathrm{min}}$, reception n = 36 for SFEU-1000, give the current scale AB to the current scale of the module, dividing it by 18. Then in the coordinates $V_{\mathrm{м}}$, $I_{\mathrm{м}}$ voltage drop on R_{AB} we evaluate as:

$$\Delta V_R = I_{\mathrm{м}} \cdot n_{par} \cdot R_{AB}. \qquad (2.39)$$

Since the EMF of the AB during charging may vary from E_{ABmin} to E_{ABmax}, then on the plane of the I – V curve, two boundary characteristics of AB are constructed. The points of intersection of I – V curves AB and I – V characteristics of the SM determine the operating current of the module and the operating voltage in the system “solar module - AB”. At $E_1 = E_{\mathrm{max}}$ the position of the operating point B will lie within the segment $B_1 B_2$. When changing solar radiation, the operating point will be in the area shown in Fig. 2.10. The same problem can be solved analytically by a joint solution (2.34), (2.38) and (2.39).

Thus, graphically (Fig. 2.10) or analytically it is possible to find the mode of operation of the system SB-AB in the conditions of variable solar radiation. The proposed mathematical model of the system can be used for any configuration of the SB with different changes in solar radiation.

As a result of the above, we offer a mathematical model of the system SB-AB, which allows the control system to adjust the mode of operation, coordination and selection of maximum power from the system as a whole.

3 PROJECT DESIGNING SECTION

3.1 Development of an autonomous individual power supply system

The task of this division of work is to choose the most economical version of the power supply system, taking into account the water supply. Traditionally, for a typical planning cottage of about 50 м² the water supply system is created in such a way that drinking water is supplied centrally to tanks with a volume of about 10-20 м³ located in the basements of houses. To use it, each house has an electric pump that raises water through a pipeline to the upper tank, which is located on the roof and the volume of which is limited. A typical graph of water consumption is presented in Figure 3.1, and energy consumption - in Fig. 2.6. From the upper pool, water flows for consumption as needed by gravity. Therefore, in addition to household electricity, it is necessary to provide regular connection of the water supply system.

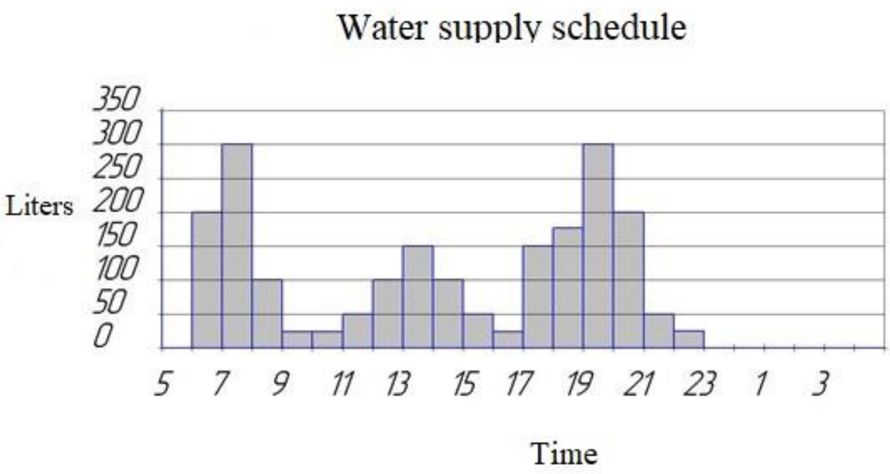

Fig. 3.1. Daily water consumption schedule

Based on a review of technical options for power supply systems offered by leading firms, the following possible options for power supply system (SEVP) were selected.

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Compliance		Koval V.P.						
Head of Dp.		Tarasenko M.H.						

Option with an induction motor (Fig. 3.2).

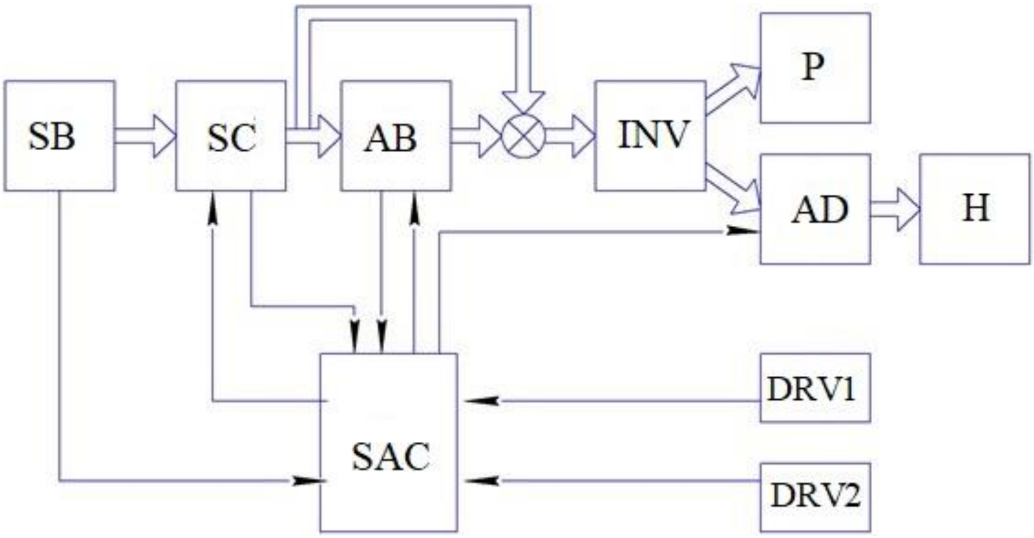

Fig. 3.2. Functional diagram of option № 1:

SB - photo battery; SC - power controller; AB - rechargeable battery; Inv - semiconductor inverter; P - household consumer; DRV1 and DRV2 - water level sensors in the upper and lower basins; AD - asynchronous pump motor

A feature of this system is the multiple conversion of energy on the way from the SB to the consumer. The condition of system efficiency is:

$$K_1 \cdot K_2 \cdot \tau_{SB} \cdot P_{SB} \geq W_{1cons} \cdot \frac{1}{\eta_{inv} \cdot \eta_{sc}} + (W_{2cons} + W_{avg}) \cdot \frac{1}{\eta_{inv} \cdot \eta_{SC} \cdot \eta_{AB}},, \quad (3.1)$$

where K_1 - coefficient of reduction of SB production during sunrise and sunset; K_2 - coefficient of reduction of SB production due to shading of the atmosphere by industrial emissions and clouds; W_{1cons}, W_{2cons} - consumption of household appliances and lighting system during the day and night; W_{avg} - average daily energy consumed by the water supply system.

Based on this condition, we determine the parameters of the SEVP for a typical cottage area of 50 m^2. According to the schedule of electric load of the consumer presented in fig. 2.6 and the schedule of water supply in fig. 2.11, total electricity consumption is $W_{cons} = 3600\text{w} \cdot \text{hr}$, water consumption in such a cottage is about 2 m^3 per day. This allows the use of a 620W AC pump with a capacity of 2.5 m^3/ year. The power of the solar battery consists of two components, one of which is determined by the electrical load of the consumer, and the other depends on the mode of operation and the type of pump, we have:

$$P_{SB} = P'_{SB} + P''_{SB}, \qquad (3.2)$$

$$P'_{SB} = \frac{W_{1cons}\frac{1}{\eta_{inv}\eta_{SC}} + W_{2cons}\frac{1}{\eta_{inv}\cdot\eta_{SC}\cdot\eta_{AB}}}{K_1 \cdot K_2 \cdot \tau_{SB}}, \qquad (3.3)$$

$$P''_{SB} = \frac{P_{avg}\cdot t_{is}\frac{1}{\eta_{\text{інв}}\cdot\eta_{SK}\cdot\eta_{AB}}}{K_1 \cdot K_2 \cdot \tau_{SB}}. \qquad (3.4)$$

For our conditions:

$$P'_{SB} = \frac{1928\frac{1}{0,8\cdot 0,95} + 1672\frac{1}{0,8\cdot 0,95\cdot 0,85}}{0,85\cdot 0,9\cdot 14} = 478,22\text{W},$$

$$P''_{SB} = \frac{620\cdot 0,8\frac{1}{0,8\cdot 0,95\cdot 0,85}}{10,71} = 71,7\text{W}.$$

So:

$$P_{SB} = P'_{SB} + P''_{SB} = 478,22 + 71,7 = 549,9\text{W}.$$

For the accepted type of solar battery MSW-36-12 the number of modules will be $n = 549,9/17,3 = 31,8$. We accept $n = 32$.

The capacity of the battery is determined in accordance with the procedure discussed in section 2.1.3.1.

$$C_{AB} = \frac{1672}{24 \cdot 0,85} \cdot 1,05 = 86\ A \cdot \text{hr}.$$

Option with a DC motor (Fig. 3.3).

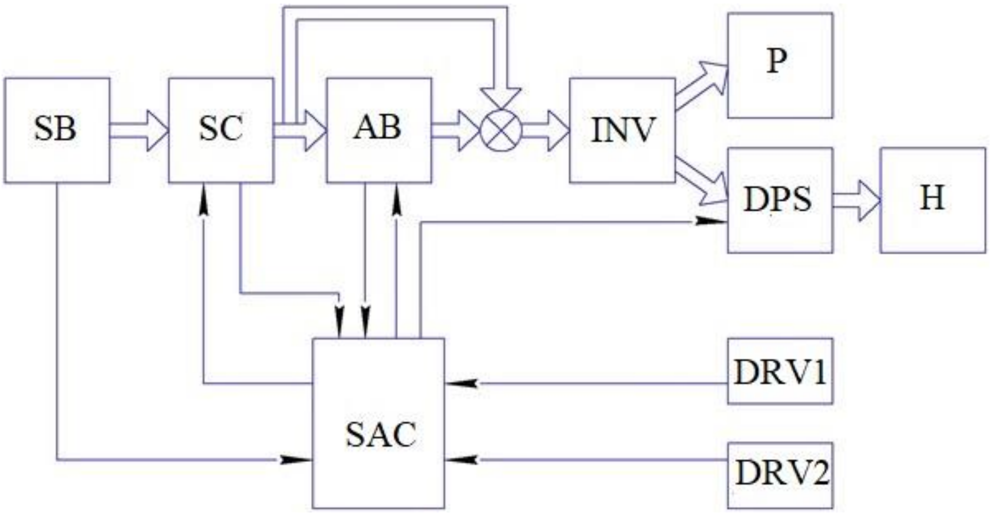

Fig. 3.3. Functional diagram of option № 2

A distinctive feature of this option is the use of a DC motor (DPS) of independent excitation, selected for a voltage equal to V_{ABn}. In this case, the motor is turned on in parallel with the inverter and the power supplied to it depends on the mode of operation of the whole complex.

The mode of operation of SEVP provided by the automatic control system (SAC) is chosen by us so that DPS was connected to SB and AB at small loadings of the consumer during the day, at performance of a condition:

$$P_{SB} \cdot K_1 \cdot K_2 \cdot \tau_{SB} \geq \frac{P_{cons}}{\eta_{inv} \cdot \eta_{AB} \cdot \eta_{SC}} + \frac{P_{avg}}{\eta_{SC}}. \quad (3.5)$$

And, duration of work of the pump on former we accept equal 48 minutes. This allows, as for the previous version, to select the power of the SB from the condition:

$$K_1 \cdot K_2 \cdot \tau_{SB} \cdot P_{SB} \geq W_{1cons} \cdot \frac{1}{\eta_{inv} \cdot \eta_{sc}} + W_{2cons} \cdot \frac{1}{\eta_{inv} \cdot \eta_{sc} \cdot \eta_{AB}} + W_{avg} \cdot \frac{1}{\eta_{sc}} = P'_{SB} + P''_{SB}. \quad (3.6)$$

Substituting numerical values, we have:

$$P'_{SB} = 478{,}22\text{W},$$

$$P''_{SB} = \frac{496 \frac{1}{0{,}95}}{10{,}71} = 48{,}7\text{W},$$

$$P_{SB} = P'_{SB} + P''_{SB} = 478{,}22 + 48{,}7 = 526{,}9\text{W},$$

$n = 526{,}9/17{,}3 = 30{,}4$. We accept $n = 30$.

At the installed power of the SB and capital costs, option № 2 is more economical than option № 1, due to the fact that in option № 1 the induction motor has

1.8-2.8 times the starting currents, which at the overload capacity of the inverter in 20-30%, makes you choose an inverter almost 1.5 times more power.

Option № 3 with a direct connection of DPS and SB (Fig. 3.4).

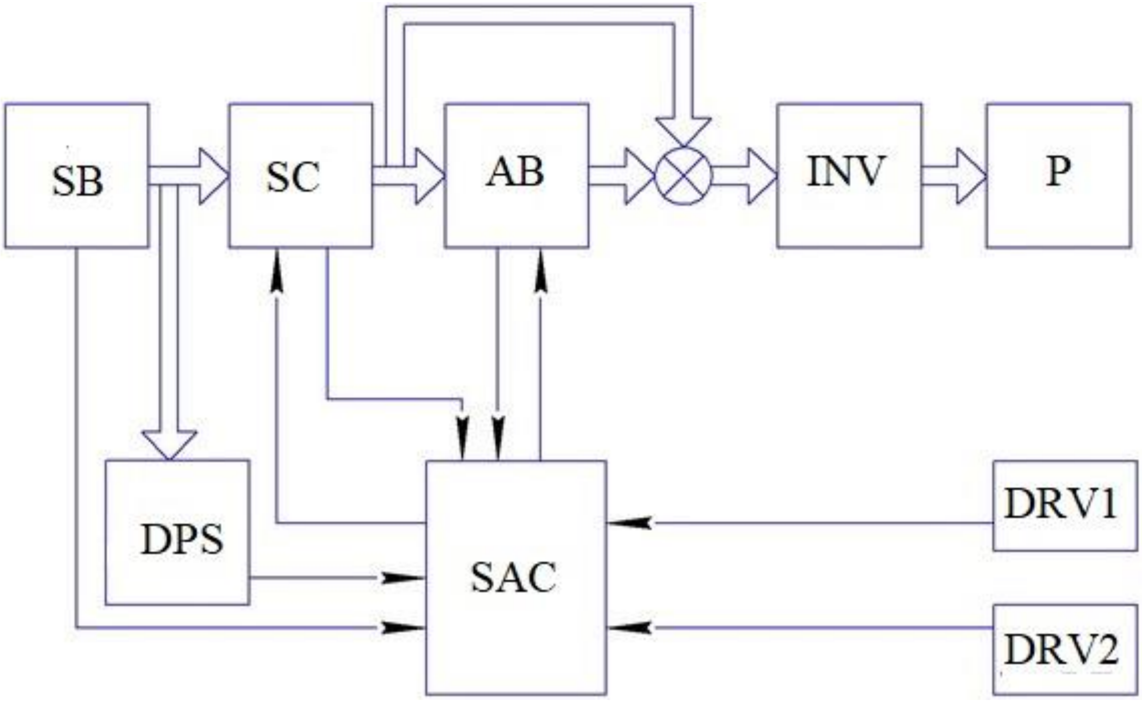

Fig. 3.4. Functional diagram of variant № 3

The desire to reduce losses in additional elements, puts forward a decision to directly connect the DPS to the SB. In this case, the load on the SC decreases and the power loss decreases. The area of the SB can be determined by the condition:

$$P_{SB} = P'_{SB} + P''_{SB} = P_{SB} = P_{SB} + \frac{W_{avg}}{K_1 \cdot K_2 \cdot \tau_{SB}}. \quad (3.7)$$

Where,

$$P'_{SB} = 478{,}22\text{W},$$

$$P''_{\text{SB}} = \frac{620\cdot 0{,}8}{10{,}71} = 46{,}3\text{W},$$

$$P_{\text{SB}} = P'_{\text{SB}} + P''_{\text{SB}} = 478{,}22 + 46{,}3 = 524{,}52\text{W},$$

$$n = 524{,}52/17{,}3 = 30{,}3. \text{ We accept } n = 30.$$

In terms of energy, the option is almost no different from the previous version. But in this case, it is necessary to consider the coordination of the characteristics of the DC motor and SB.

Option № 4 with hydraulic energy storage (Fig. 3.5).

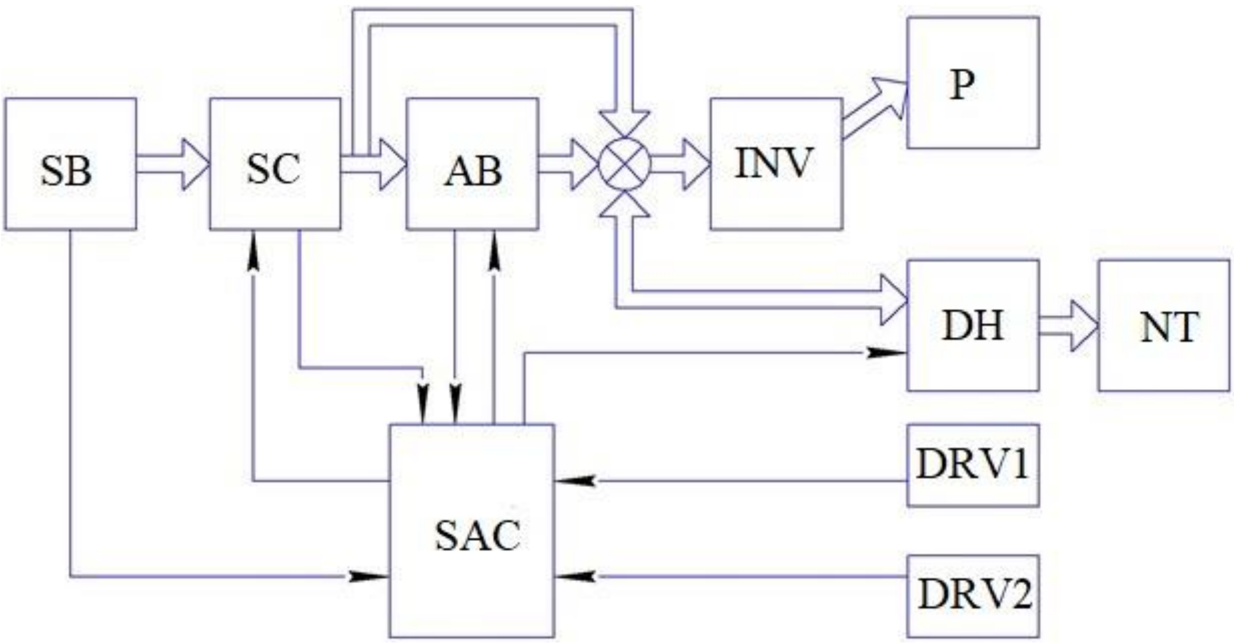

Fig. 3.5. Functional diagram of option № 4

A distinctive feature of the option is the use of energy storage. The pump operates in reversible mode and not only pumps the water needed for consumption, but also creates an excess supply of water, which, if necessary, ensures the operation of the pump in turbine mode (NT). In this case, the drive motor operates in the mode of generating energy, which in the hours of the evening maximum load can enter the system through the inverter. It is assumed that the upper pool allows the accumulation of the required amount of water in excess of daily household consumption.

Calculate the value of the relative change in the area of the SB at different ratios of energies passing through the AB and the hydroaccumulation system (HA). We choose as a variable component K_3 - the share of energy consumed by the evening load W_2 from AB (Fig. 3.6). Thus, part of the energy coming to this load from the HA can be represented as $K_3 = 1$. The introduction of this factor allows you to analyze all the variety of possible options for the mode of operation of this scheme. From the case when hydroaccumulation is not used ($K_3 = 1$), which corresponds to option № 2, to the extreme case when the evening load is fully covered by HA ($K_3 = 0$).

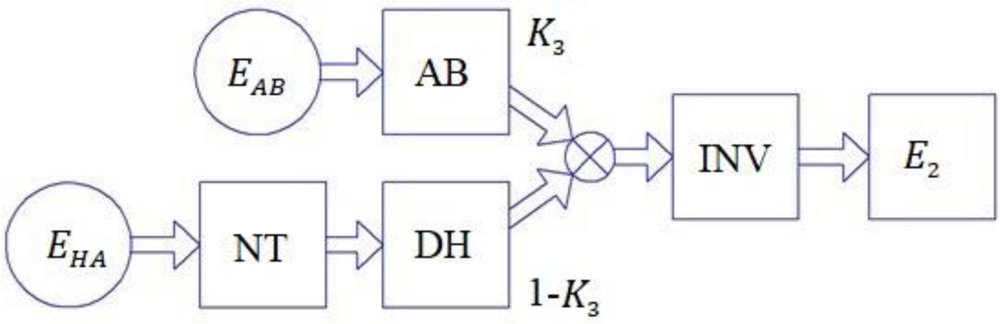

Fig. 3.6. Ensuring night energy consumption

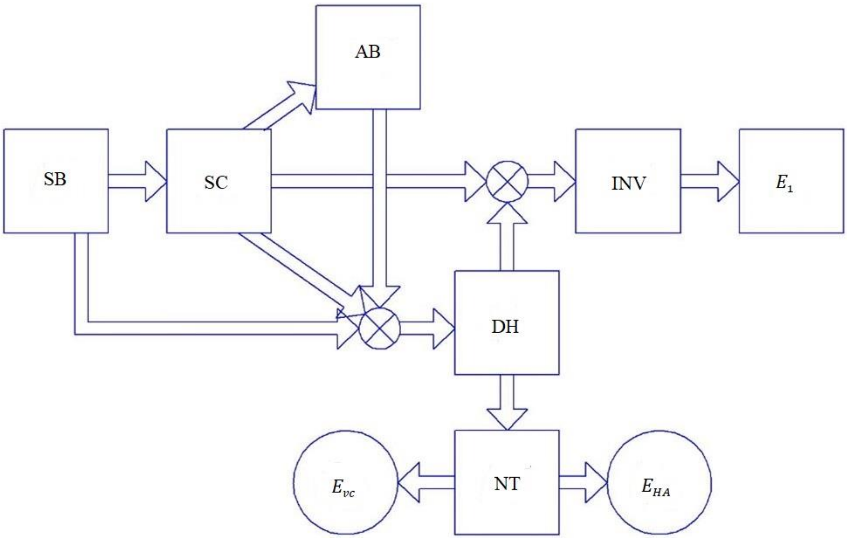

Fig. 3.7. Operation of the power supply system during the day

Determine the area of the SB depending on the ratio of energy accumulated in the AB and in the pool of hydroaccumulation while maintaining night energy consumption $W_2 = \text{const}$.

Suppose that the SB after passing through the power controller of the SC produces during daylight energy equal to $K_1 \cdot K_2 \cdot \tau_{SB} \cdot P_{SB} \cdot \eta_{SC}$. After covering the daily load W_1, and the necessary water supply to the house W_{avg}, there is some excess energy, which, regardless of the type of accumulation, must be sufficient to ensure night consumption W_2:

$$\left[K_1 \cdot K_2 \cdot \tau_{SB} \cdot P_{SB} \cdot \eta_{SC} - \frac{W_1}{\eta_{inv}} - W_{avg}\right] \times (1 - K_3) \cdot \eta_{pum} \cdot \eta_{turb} \cdot \eta_{in} + \left[K_1 \cdot K_2 \cdot \tau_{SB} \cdot P_{SB} \cdot \eta_{SC} - \frac{W_1}{\eta_{inv}} - W_{avg}\right] \times K_3 \cdot \eta_{AB} \cdot \eta_{inv} \geq W_2, \quad (3.8)$$

where η_{Pump}, η_{Turb} - Efficiency of the electric motor in pump and turbine modes.

Other designations are the same as in the previous version. From where, after the necessary transformations we get:

$$K_1 K_2 \tau_{SB} P_{SB} \geq W_1[(1-K_3)\eta_{pump}\eta_{turb} + K_3\eta_{AB}] + W_2 + W_{avg}[(1-K_3)\eta_{pump}\eta_{turb} + K_3\eta_{AB}]\eta_{inv}/\eta_{SC}[(1-K_3)\eta_{pum}\eta_{tur} + K_3\eta_{AB}]\eta_{inv}. \quad (3.9)$$

It is easy to demonstrate that equation (3.9) at $K_3 = 1$ (absence of HA), is converted into equation (3.6).

Consider in Fig. 3.8 how much the installed capacity P_{SB} increases with an increase in the share of HA. Obviously, the calculation P_{SB} it is more convenient to conduct not in absolute, but in relative units, taking as a unit basis P_{SB} - installed capacity of the SB at $K_3 = 1$, which corresponds to the variant №2. As a result, using the dependences (3.6; 3.9), we have:

$$P'_{SB} = \frac{P_{SB}}{P_{SB6}} = \frac{\frac{W_1}{\eta_{SC}\cdot\eta_{inv}} + \frac{W_2}{\eta_{sc}\cdot\eta_{inv}\cdot((1-K_3)\cdot sv\cdot\eta_{tur}+K_3\cdot\eta_{AB})} + \frac{W_{avg}}{\eta_{sc}}}{K_1\cdot K_2\cdot\tau_{Sv}\cdot P_{sb6}}. \quad (3.10)$$

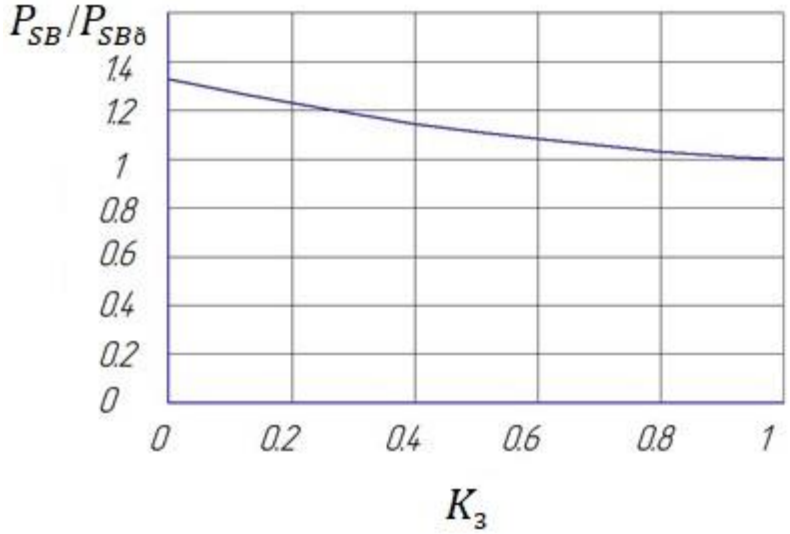

Fig. 3.8

Increasing the degree of use of HA (1-K_3), the capacity of the AB decreases (Fig. 3.9).

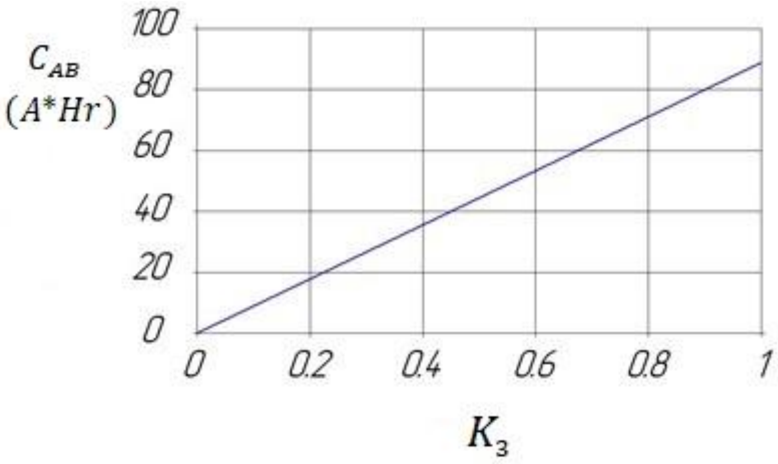

Fig. 3.9. Graph of dependence of AB capacity on the share of HA use

The advantage of the HA system is that:

1) capital costs when using the upper pool with standard volumes of 5 or 10 m^3 and serial pumps that work well in reversible modes will be minimal;

2) with the increase of energy accumulated in the HA system, the required capacity of the AB decreases (Fig. 2.19), however, as follows from (Fig. 2.18), at the same time increases the installed capacity of the SB.

There is a technical and economic contradiction, which in its solution makes it possible to find the optimal solution.

3.2 Conclusions to section

Analysis of the characteristics of solar modules and the principles of their operation using equivalent schemes helped to determine their advantages and disadvantages. The modes of operation of solar modules, energy needs during the day were considered, as well as the capacity of the battery was selected and the compatibility of the operation of the solar and battery was checked. After calculating the required number of modules for different schemes of electricity and water supply, we chose the best option

SECTION 4

LABOUR OCCUPATIONAL SAFETY AND SECURITY IN EMERGENCY SITUATIONS

4.1 Help with electric shock

Electric shock is occurs as a result of contact between a person and an electrical energy source. Electrical energy flows through a portion of the body causing a shock. Exposure to electrical energy may result in no injury at all or may result in devastating damage or death. Electricity requires a complete path (circuit) to continuously flow. This is why the shock received from static electricity is only a momentary jolt: the flow of electrons is necessarily brief when static charges are equalized between two objects. Shocks of self-limited duration like this are rarely hazardous.

Without two contact points on the body for current to enter and exit, respectively, there is no hazard of shock. This is why birds can safely rest on high-voltage power lines without getting shocked (Fig 6.1): they make contact with the circuit at only one point.

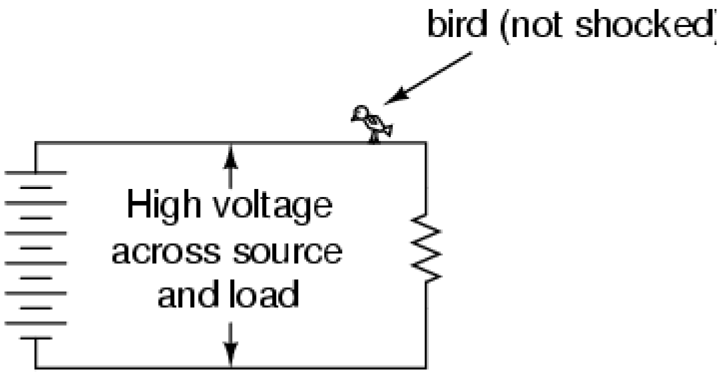

Figure 4.1 - High voltage across source and load.

For electrons to flow through a conductor, there must be available voltage to excite them. Voltage is always relative between two points. There is no such thing as

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Compliance		Koval V.P.					
Head of Dp.		Tarasenko M.H.					

voltage “on” or “at” a single point in the circuit, and so for example the bird contacting a single point in the above circuit has no voltage applied across its body to establish a current through it. Even though they rest on two feet, both feet are touching the same wire, making them electrically common. Electrically speaking, both of the bird’s feet touch the same point, hence there is no voltage between them to motivate current through the bird’s body.

This might lend one to believe that it’s impossible to be shocked by electricity by only touching a single wire. Like the birds, if we’re sure to touch only one wire at a time, we’ll be safe, right? Unfortunately, this is not correct. Unlike birds, people are usually standing on the ground when they contact a “live” wire. Many times, one side of a power system will be intentionally connected to earth ground, and so the person touching a single wire is actually making contact between two points in the circuit (the wire and earth ground):

The ground symbol is that set of three horizontal bars of decreasing width located at the lower-left of the circuit shown, and also at the foot of the person being shocked. In real life the power system ground consists of some kind of metallic conductor buried deep in the ground for making maximum contact with the earth.

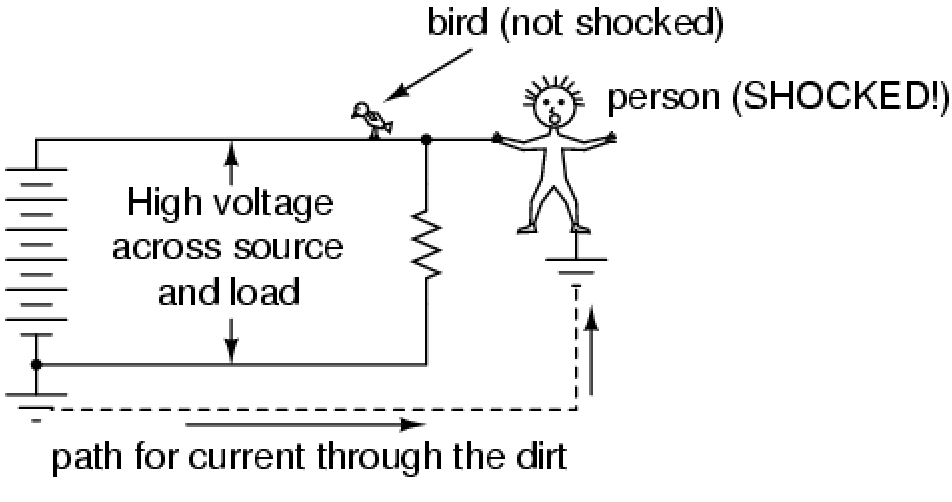


Figure 4.2 - High voltage across source and load

That conductor is electrically connected to an appropriate connection point on the circuit with thick wire. The victim’s ground connection is through their feet, which are touching the earth.

4.1.1 Causes of electric shock

Extension cords. These cords are found in every home and office and also in smart meters. They are the source of many electrical shocks and burns. What causes these electric shock are damaged insulation on electrical cords

Electric Outlets. Unfortunately, most electric outlets are located where young children easily can reach them. This is a drawback in the height and construction of these outlets as a result electric shock is inevitable According to the United States Consumer Product Safety Commission (CPSC), about 4000 people are treated in hospital emergency rooms each year due to injuries relating to electric outlets. If there are young children at home, it's recommended to use sliding outlet covers.

– Accessible live parts of the energy meter.
– The association of current transformer secondary.
– Single component fault.
– Electrical spacings over-surface and through-air.
– Endurance of load control switch or the lack thereof.

4.1.2 Effects of electric shock

Burns are usually most severe at the points of contact with the electrical source and the ground. The hands, heels, and head are common points of contact.In addition to burns, other injuries are possible if the person has been thrown clear of the electrical source by forceful muscular contraction.

Pain in a hand or foot or a deformity of a part of the body may indicate a possible broken bone resulting from the electric shock causing violent muscle contraction.

4.1.3 Electric Shock Treatment

In cases of severe electric shock it would be advisable to call the health care emergency line. There are two methods of approaching the treatment of electric shock.

Self-Care at Home

Brief low-voltage shocks that do not result in any symptoms or burns of the skin do not require care. For any high-voltage shock, or for any shock resulting in burns, seek care at a hospital's emergency department. A doctor should evaluate electric cord burns to the mouth of a child.

Medical Treatment

Treatment depends on the severity of the burns or the nature of other injuries found.

Burns are treated according to severity:

– Minor burns may be treated with topical antibiotic ointment and dressings.
– More severe burns may require surgery to clean the wounds or even skin grafting.
– Severe burns on the arms, legs, or hands may require surgery to remove damaged muscle or even amputation

Other injuries may require treatment:

– Eye injuries may require examination and treatment by an ophthalmologist, an eye specialist.
– Broken bones require splinting, casting, or surgery to stabilize the bones.
– Internal injuries may require observation or surgery.

4.2 The primary fire extinguishing means

Electric meter fires, when they occur, can put utility customers, workers and company reputation in jeopardy. News coverage of these events at times struggles to determine what caused the problems. Yet much is known on safe installations. A body of knowledge has emerged around socket safety: what to do before, during and after installing advanced meters.

Hot sockets are a very serious and very prominent concern for the metering industry. Meter socket safety issues, including fires, are nothing new. Due to the rise in AMI deployments throughout the world and more readily accessible information, the number of reported hot socket incidents is on the rise. There has been significant debate both inside and outside the industry about the root cause of these events. Are they caused by the new meters' being installed? Perhaps a defective meter socket is to blame? Could it be that the meter was improperly installed? Some have suggested environmental factors such as vibration are to blame.

It is not merely a matter of looking at ways to avoid trouble, either. When utilities remove old meters, they create an opportunity to inspect equipment that may have been covered up for years, perhaps even decades. By detecting signs of deterioration or damage at the meter site and acting to make repairs, utilities can proactively ensure the safety of their networks for years. Too often, the industry has not recognized this moment as a once-in-a-generation chance to act.

While the causes of meter fires can be many and complex, a body of knowledge has emerged to reduce risk and enhance both the customer experience and the utility business case. Yet many utilities are not aware of the range of solutions available.

4.2.1 Causes of fire

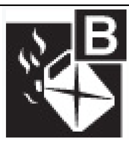
To prevent hot socket issues, one first has to understand what causes these incidents. Several features or sources can cause hot sockets, but among the most prevalent are:

– Mechanical breakdown of components;
– Excessive moisture;
– Environmental contaminants;
– Frequent meter change outs (resulting in loss of jaw tension);
– Excessive electrical load (overload or short circuit);
– Loose or melted conductors;
– Vandalism;
– Ground settling; and
– Storm damage.

Becoming informed and establishing methods to address hot socket issues is paramount for manufacturers and utilities. Developing a process that proactively identifies and mitigates problem sites is crucial in getting in front of hot socket issues.

When issues with hot socket arises and there is fire afterwards, we have to know how to deal with it primarily before it escalates or the fire service arrives. The primary way of putting out the fire is with the use of fire extinguishers. All fire extinguishers are not made equal, there are several classes of fire extinguishers. Each class identifies the type of fuel involved and allows appropriate fire extinguisher media to be identified.

Table 4.1 - Fire Extinguisher Classes

Class Icon	Name of Class	Type of Fire / Fuel involved
	Class A Fires	**Freely Burning Materials** i.e.: Wood, Paper, Straw, Textiles, Coal etc.
	Class B Fires	**Flammable Liquids** i.e.: Petrol, Diesel, Oils, Paraffin etc.
	Class C Fires	**Flammable Gases** i.e.: Methane, Propane, Hydrogen, Natural Gas etc.
	Class D Fires	**Flammable Metals** i.e.: Magnesium, Aluminium, Lithium etc.
	Class F Fires	**Combustible Cooking Media** i.e.: Cooking Oil, Fats, Grease etc.
	Electrical Fires	**Electrical Appliances** i.e.: Computers, Stereos, Fuse boxes etc.

Fire extinguishers are manufactured with a red body and have a band of a second colour covering between 5-10% of the surface relating to the extinguisher's contents. Each different type of extinguisher agent has a corresponding colour making identification easier for the user.

GENERAL CONCLUSION

1. Based on the analysis of the state of development of renewable energy sources, the efficiency of their use for decentralized energy supply to low-power consumers is shown.

2. It is established that the priority is the use of solar energy and its conversion into electricity in a single autonomous system of energy and water supply.

3. The method of determining the maximum output power of the SAT at a variable value of the intensity of solar radiation has been improved.

4. The principles of SB control are offered, which allow to provide optimal power selection depending on the state of AB.

5. The choice of the type of storage system is substantiated, the mathematical description of AB as an element of the control system is given and the model of definition of current parameters and diagnosis of its condition is developed. As a result of the study of energy characteristics and the relationship of the elements of the power supply system, four characteristic structures are proposed.

6. The technical features of the options are considered, and their parameters are selected to meet the load schedule. A method for determining the operating parameters of pumps in the reversible turbine mode has been developed for the power supply system using the principles of hydroaccumulation.

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