

## On issue of hydroelectric power plants

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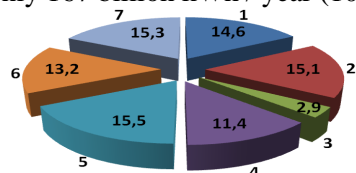
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**Abstract.** The paper presents data on the advantages of hydropower plants (HPPs). The diagram of hydropower potential of the RF rivers is given. It is noted that the most cost-effective construction is that of hydroelectric power plants on mountain rivers. An example of an autonomous complex of power supply with a power of 1 kW is considered. Its functional diagram is presented and the purpose of all nodes is explained. Also, the main parameters of each of the circuit nodes providing the given characteristics of the HPP under consideration are given. In addition to the synchronous generator with permanent magnets, the experimentally obtained dependences of the open circuit voltage and the short-circuit current on the generator speed at the output of the three-phase rectifier are presented. The proposed mini HPP can economically, safely and reliably provide the household and / or a small technological facility with electricity.

### 1. Introduction

The issues of power supply to sparsely populated areas or technological facilities remote from administrative centers were important at all times and remain relevant today. The conduct of power lines to these areas is not expedient or difficult for various reasons. This problem can be solved without significant financial costs using renewable energy sources. These are well-known solutions - solar batteries, wind power plants and hydroelectric power plants (HPPs) [1, 2].

The latter solution has several advantages. Particularly, the Russian Federation has a colossal hydro potential (Figure 1). But to date, 80% of hydropower resources remain undeveloped. The technical potential hydropower potential of the Russian Federation's rivers is 1,670 billion kWh / year, of which only 167 billion kWh / year (10%) are utilized at the HPPs [3].



**Figure 1.** Diagram of the possibilities of the regions of the Russian Federation for HPPs: 1 - Far East; 2 - North-West; 3 - Central; 4 - Privolzhsky; 5 - South; 6 - The Urals; 7 - Siberian.

Hydroelectric power plants are an ecological and economically expedient method for solving many problems related to energy security and energy deficit in some areas of our country. HPPs are in the second place after thermal power plants (TPPs) in terms of the amount of generated energy [4, 5].

It is economically advantageous to generate electricity from the submersible hydroelectric power plant that uses the energy of the free flow of a river of hydro structures of a simplified design; it is the so-called mini hydroelectric power plants. The most cost-effective construction is that of hydroelectric power plants on mountain rivers.



Mini hydro power plants do not adversely affect either properties or water quality. The water area where the mini hydro power plant is installed can be used for both fishing and economic activities and as a source of water supply for settlements. HPPs can function, using the energy of the flow of small rivers and even streams.

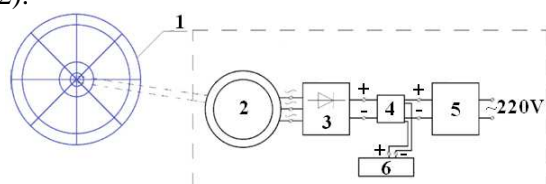
Another advantage of mini HPPs is a good resource of trouble-free operation. The average term is 40 years. One of the most important economic factors is the eternal renewability of hydraulic resources. Electric power generated by HPPs is almost four times cheaper than the electricity is received from thermal power plants. Hydroelectric power plants do not require the purchase of any fuel. In addition, they are characterized by a relatively simple technology of electricity generation, as a result of which labor costs per unit of capacity at HPPs are almost 10 times lower than at TPPs.

Also, the hydroelectric power plants, developed with the consideration of modern technologies, are automated and economical and easy to control [6-8]. In addition, such equipment does not require the presence of a person. Specialists note that the quality of the current produced by mini HPPs meets the requirements of GOST both in frequency and voltage. At the same time, mini HPPs can work as a part of the electricity network and autonomously too.

It is for these reasons that HPPs are increasingly being used to power electric power production facilities.

## 2. An example of a mini HPP structure

Let us consider an example of an autonomous power supply complex with a power of 1 kW (Figure 2).



**Figure 2.** Functional diagram of mini HPP (accepted designations 1 - water wheel, 2 - permanent magnet synchronous generator, 3 - thyristor rectifier, 4 - charge controller, 5 - rechargeable battery, 6 - inverter).

The water wheel 1 converts the energy of the water force into a mechanical one in the form of a shaft rotation, which in the synchronous generator 2 is converted into an electric one. Three-phase voltages at the output of the generator enter a three-phase rectifier 3, at the output of which a pulsating voltage is formed. The charge controller 4 is designed to monitor the state of the battery charge. Rechargeable batteries 5 are designed for accumulating of electrical energy from hydroelectric power plant and, if necessary, transferring it to the consumer. Inverter 6 is designed to convert DC to AC. It is used for the subsequent power supply of the consumer working from the 220 V network.

## 3. Choice of equipment

### 3.1. Water wheel

A water wheel is a wheel with blades are installed perpendicular to the surface of the water. The wheel is submerged in a stream of less than half. Water presses on the blades and rotates the wheel. The parameters of the water wheel are shown in Table 1.

**Table 1.** Parameters of the water wheel

Parameters of the water wheel	Value	Appearance
Wheel speed <sup>a</sup> , rad / s	2	
Efficiency of the wheel-generator system	0.75	
Wheel power, W	1,333	
Moment on the wheel axle, Nm	667	
Wheel pulley radius, m	0.2	
The circumferential gain on the pulley shaft of the generator, N	3,333	

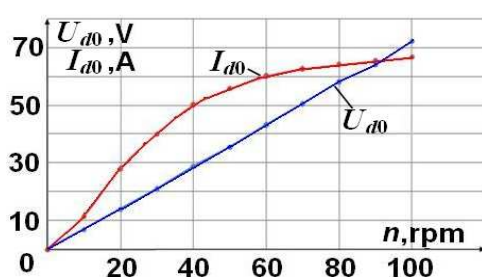
<sup>a</sup> The wheel speed is determined by the average speed of the RF rivers and is optimal from the point of

view of using this installation in practice.

It is possible to recommend installation of a water wheel of the lower type, which will allow minimizing the costs of its manufacturing and installation, as well as the improvement of the area around the installation. This type of wheels does not need to be coordinated in the water protection service of the Russian Federation and they are harmless to the environment.

### 3.2. Synchronous generator with permanent magnets

As an electrical generator for a mini HPP, for example, a synchronous generator with permanent magnets (SGPM), developed at the Mechatronics Design Bureau [9], can be used. The characteristics of idling and short circuit are one of the main indicators of a synchronous generator. The experimentally obtained dependences of the open circuit voltage ( $U_{d0}$ ) and the short-circuit current ( $I_{d0}$ ) of the generator installed after the thyristor three-phase rectifier are shown in Figure 3.




**Figure 3.** Dependences of the open circuit voltage and the short-circuit current on the generator speed at the output of the three-phase rectifier.

As can be seen from the graphs, the open circuit voltage  $U_{d0}$  is directly proportional to the rotational speed of the generator, and the short-circuit current  $I_{d0}$  reaches its maximum value at a generator speed of 100 rpm. The rated speed of the generator is 80 rpm, with  $U_{d0} = 58$  V,  $I_{d0} = 64$  A.

SGPM, due to its performance characteristics, is a promising machine in the range of small and medium capacities. Inside the generator, a sturdy hub is fitted, equipped with radial and thrust bearings, capable of carrying a water wheel weight of up to 100 kg together with a sealed housing. Also, the advantages of the SGPM include simplicity of design, no loss of excitation, high stability of the rotor speed. Table 2 shows the main technical parameters of the synchronous generator and its appearance.

**Table 2.** The main technical parameters of the synchronous generator and its appearance

Parameters	Value	Appearance
Rated voltage, V	24	
Rated current, A	42	
Rated power , kW	1	
Rated rotational speed, rpm	80	
Torque moment, Nm	9	
Rated torque, Nm	120	
Number of pairs of rotor poles	39	
Number of stator teeth	72	
Weight, kg	70	
Climatic performance	temperate climate; accommodation in an enclosed space without regulation of climatic conditions	
Degree of protection	IP55	


### 3.3. Three-phase rectifier

The operation of the SGPM with a rectifying load is accompanied by continuously repeating asymmetric processes. The ripple of the rectified voltage depends on the number of phases of the

generator, the rectification scheme used, the parameters of the generators and the load. These pulsations can be reduced by increasing the number of phases, while the mass and dimensions of the generator and rectifier block increase.

In the projected mini HPP, it is proposed to use a thyristor rectifier (TR) manufactured by «Zvezda Electronics». The thyristor rectifier is characterized by high reliability and stability of operation, the developed system of settings and relatively small mass-scale indicators (Table 3).

**Table 3.** Appearance and possible additional equipment for the TR


Name	Value	
Analog output card	Data output about of the output voltage	
Network filter	Suppression of higher harmonics	
Transformer	Galvanic isolation from the network	

At the heart of the TR there are six thyristors connected by a three-phase Larionov bridge and a pulse-phase control system (PPCS) for adjusting the output voltage.

### 3.4. Rechargeable batteries

The lead-acid accumulator starter battery used in the HPP consists of six alternately connected batteries (elements) assembled in a thermoplastic monoblock. The accumulators are assembled from blocks of negative and positive plates in volumes of 135.5x143 mm. They are separated each other. The battery of 6CT-195L produced by the “Tymen battery”, combines quality and power, is designed for operation in any climatic conditions, has a large reserve power, minimal self-discharge, increased corrosion resistance of electrodes, has a minimum amount of maintenance that does not require special training from the staff, as well as the use of complex and expensive equipment (Table 4).

**Table 4.** Basic technical parameters and appearance of the battery 6ST-195

Parameter	Value	Appearance
Number of batteries, pcs.	2	
Rated voltage, V	24	
Battery connection	consistent	
Nominal capacity at an electrolyte temperature of 23 ... 27 ° C in the mode of a 20-hour discharge, Ah:	195	
Current strength at 20-hour mode, A	9.5	
Overall dimensions, mm	519 x 238 x	
Weight without electrolyte, kg	57.2	
Weight with electrolyte, kg	71.7	

### 3.5. Inverter

As an inverter in the consideration mini HPP was selected inverter of the Novosibirsk company “A-elektronika”. It is a PROGRESS-24-6000-HYBRID (figure 4).

The inverter is designed specifically for working with alternative energy sources. In the inverter, the function of prohibiting the return of energy from alternative sources to the network is realized with the highest accuracy. The residual power consumed from the network does not exceed 10 W and therefore the energy of alternative sources is used as efficiently as possible.

Also in the inverter is implemented a programmable mode of priority use of energy stored in the battery. This option is enabled by the user, if necessary. For example, if the battery is charged from an alternate source, the inverter is disconnected from the network and goes into offline mode. If the battery discharges in the offline mode, it connects to the network.

The inverter has a large set of settings for working with substandard networks. It is possible to select the upper and lower threshold for switching to the network, as well as the thresholds for the allowed frequency of the source. The possibility of monitoring the sinusoidal network voltage is

realized. If the user has stringent requirements for the form of the supply voltage, the inclusion of this option allows having a qualitative voltage at the output of the inverter, and if the mains voltage becomes non-sinusoidal, then the inverter quickly (in units of milliseconds) determines and switches to the battery. You can disable this option.



**Figure 4.** Appearance of the PROGRESS-24-6000-HYBRID inverter (a) and its control panel (b)

### 3.6. Charge Controller

With direct connection of the mini HPP to the battery, the charging current will go to the battery terminals and the voltage at the terminals will gradually increase. This happens until it reaches the charge voltage limit, depending on the type of battery and its temperature. When the limit voltage is reached, it is usually about 14 volts, the controller will disconnect the battery from the mini HPP and the battery charge will stop, although in reality the battery will not be fully charged yet, but approximately 90%. To fully charge, it requires maintaining of the maximum voltage for a few hours. It should be remembered that a regular undercharge reduces the life of the battery.

Battery charge can be controlled manually and at the right time to disconnect the battery. If this is not done, the overcharge of the battery will lead to the boiling of the electrolyte and also to shorten the battery life.

This task will help to solve the PWM controller, which by means of the pulse-width conversion reduces the voltage to the desired value and supports it.

There are several important factors that should be considered when charging the battery. Qualitative charge controllers must take into account the temperature of the battery, have a temperature compensation of charging voltages and be able to choose the type of batteries, since different types have different charging curves. Also it should be remembered that for temperature compensation you can use both an internal temperature sensor and an external one. When using the latter, the accuracy of the charge controller is increased.

The principal difference of the proposed charge controller is that it locates and tracks the maximum power point of the generator and uses all available power by pulse-width conversion in all charge modes, and not only in the latter mode while maintaining the charge voltage limit.

In the developed mini HPP, it is proposed to use the controller produced by WESWEN (Figure 5). It is the model WHCM 2-0.6. It is a hybrid of a wind-solar controller with a wide range of possibilities.



**Figure 5.** The appearance of the charge controller

This hybrid controller is designed for off-grid power generation systems. The controller has an elegant design and easy to understand control interface. It provides an efficient and safe battery charge.

## 4. Conclusion

When introducing a small amount of the aluminium oxide powder, the distance between the axes of the second-order dendrites and the average grain size reduces. This implies that a considerable part of the powder particles is effective crystallization centres. When increasing the nanopowder content, the structure starts coarsening relatively that which was obtained using low powder concentrations.

Introduction of the large quantity of the modifier leads to its coagulation and reduction of its influence on the structure.

The main advantages of mini hydropower plant:

1. The variability of the equipment, i.e. for each specific case, equipment is selected that fully meets the customer's needs and such indicators as water pressure, flow speed and availability of the mini hydro power plant directly to the terrain.
2. Productivity, i.e. for an equal period of time, a hydro generator of equal capacity to a solar battery and a wind generator will produce more energy.
3. Lifetime, according to that obtained from various sources, is about 40 years with a payback period of 3-5 years in all - which is an advantage in selecting mini-HPP as the main source of electricity.
4. Environmentally friendly. Mini HPP does not produce greenhouse gases in the process of power generation and they do not pollute the environment with combustion products and toxic waste, which meets the requirements of the Kyoto Protocol [10]. They do not adversely affect the way of the population life, of the fauna and local microclimatic conditions.
5. In the example considered, equipment is selected that provides good technological indicators for the reliable operation of mini HPPs.

When the battery is fully charged, the charge controller switches the current from the three-phase rectifier to the quenching resistors.

The charge voltage of the battery is 24 V. The charge current appears at a generator speed of 30 rpm and higher. The current is 43 A at a nominal speed of 80 rpm. The power of the battery charge without using a DC-DC voltage converter also appears at a generator speed of 30 rpm and higher. The power is 1,090 watts at a nominal speed of 80 rpm.

## 5. Acknowledgments

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