Increasing the efficiency of using renewable energy sources for energy supply of autonomous highland objects

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Abstract. Ways of increasing the efficiency of using renewable energy sources in the autonomous power supply of highland facilities are considered. Descriptions of autonomous multifunctional energy complexes that simultaneously use converters of various types: sunlight, wind and water flows into electrical energy, patented in NCIMM (STU) are given. The prospects of using renewable energy sources for autonomous power supply of highland facilities are substantiated.

1. Introduction
Renewable energy sources (RES) are currently finding wider and more diverse applications [1–3].

One of the most popular and effective applications of RES is autonomous energy supply of low-power facilities and private residential households. This is particularly true for remote highland settlements that are not provided with centralized power transmission lines.

2. Articulation of issue
This energy drawback of highland settlements is fully compensated by the presence (and, therefore, the ability of using) of powerful and almost constantly acting natural energy flows: air (wind), water (mountain rivers) and sunlight. The latter play a special role in providing individual objects with energy. Suffice it to say that in some countries the so-called "solar houses" are already in operation. These are houses in which energy for domestic needs is fully generated from sources of solar panels.

Figure 1 shows a diagram of the conversion and use of energy in autonomous generating complexes operating on RES. The first operation is to capture a part of the total energy flow for its further transformation.

A significant difficulty in the use of RES is the dispersion of natural energy flows (for example, the small specific energy of solar radiation, i.e., energy per unit area of the irradiated surface).

To increase the power generated by the primary converters to the required consumed value, various methods and devices are used. For example, to increase the total power of solar panels, the total irradiated surface area is increased (for which roofs are often used, for example). The concentration of solar flows occurs using special devices – reflectors, directing the sun's rays on the working surface of solar panels.

Both methods can be used to power private houses, for instance, mountain settlements.

In the conditions of mountainous territories, mountain rivers are an effective source of energy raw materials.
Possibilities of using RES for energy supply of remote highland settlements.

Natural energy flow

![Diagram of energy flow]

**Figure 1.** The diagram of the conversion and use of energy in generating complexes

The part of the natural energy flow received by the primary consumer (producer) is even used to convert its energy into energy convenient for further use (electric, thermal). Energy is transferred to the consumer and as a result of its use (second converter), the energy state of the consumer changes, as well as energy dissipates into the surrounding production.

Micro Hydro Power Stations can be installed directly on mountain rivers (for instance, cantilevered HPS) or on branches taken away from them (hose HPS).

If the use of solar generators related to a daily change in solar radiation, then the use of hydro generators in the mountains related to a seasonal change in the water level in rivers, which should be taken into account when designing and operating micro HPS.

Wind is constantly blowing in the mountain gorges, which provides conditions for the development of wind energy, despite certain instability of the wind flow.

To make the picture of the mountain energy flow complete, it is important to note the possibility of using in some cases geothermal energy sources.

3. Materials and methods
Natural energy flows have different energy potentials, different affordability, and various environmental characteristics. For example, for North Ossetia-Alania, the total (estimated) hydropower potential is 22723.4 million kWh per year; solar radiation and wind energy potential are 16,000 and 1.666, respectively.

The output characteristics of real generating plants operating on RES are, to one degree or another, random. This largely characterizes the autonomous energy systems, designed, for instance, to work in high altitude conditions.

Changes in wind speed, solar radiation intensity, volume and pressure of water in rivers in mountainous conditions occur quite often and do not have a strict regularity. As a result of this, mathematical models describing the processes in RES plants should be statistically distributed and be analyzed by appropriate methods.

In the most general case, the energy state of a system using renewable energy sources can be expressed by the energy balance equation

$$\sum S_i = \sum S_{nomp} + S_{ue}$$

(1)
where $\sum S_i$ is the total power of the transducer generating component of the overall system; $\sum S_{\text{npmp}}$ is the total power of the consumed system; $S_{\text{nk}}$ is power transmitted to the storage device.

With excess generated power, part of it is transferred to the storage device and it works in consumer mode ("+" sign). With a lack of generated power (compared with that required for the normal operation of consumers), it comes from storage devices to the consumption system, and the power has a "−" sign. Formally, the summand "−" can be transferred to the left side of the equation with the "+" sign, which corresponds to the operation of the storage device in generator mode, i.e. in power transfer mode to the consumer.

Equation (1) is written for mean values over a certain time. From a mathematical point of view, expressions written for instantaneous power values will be more correct

$$\int_0^t \sum_i S_i(t)\,dt = \int_0^t \sum_n S_n(t)\,dt + \int_0^t S_{\text{nk}}(t)\,dt$$

Equation (2) is statistically distributed, since all terms under integral sign are random functions.

To calculate autonomous multifunctional power plants, it is necessary to work and analyze the equation (2). As you know, there are two main ways to work statistically distributed equations: the transition to the mathematical expectations of the members of the equation, and the Monte Carlo method. For practical purposes, we can use equation (1) for average power values, given that the generated $S_i$ and consumed $S_n$ power are explanatory variables, and the accumulated power $S_{nk}$ is a dependent variable, determined by the values of generated and consumed power.

4. Results and discussion
Two types of devices are being developed at NCIMM (STU): devices for converting one type of natural energy flows into a convenient one for further use [4–6], as well as multifunction devices that simultaneously convert the energy of various types of natural energy flows [7–9].

The wind wheel proposed by Professor Yu.S. Petrov [4], allows rotation of the panels in one direction regardless of the direction of the wind, which is essential for areas with changing parameters of the wind flow vector. The machine is designed for small capacities and application for power supply of autonomous low-energy facilities, for instance, in mountain conditions.

Solar battery proposed by M.K. Khadikov [5], differs in small dimensions and high efficiency in the use of sunlight in a limited installation volume. It is supposed to be used in the system of autonomous energy supply, for instance, objects of highland settlements.

Professor I.D. Alborov and PhD student I.Yu. Zorina proposed an original design of the solar collector, which allows increasing the efficiency of thermal converters of this type by about 2 times. The machine has a wide range of performance and can be operated in conditions of autonomous power supply of objects of various capacities. The most promising use of the machine is to power individual high altitude facilities.

A series of inventions relates to machines of a hybrid type, using the conversion of radiant and wind energy in power supply at the same time. The simultaneous conversion of natural energy flows of various types (in this case, wind and sunlight) in the power supply has a number of positive qualities. Firstly, the machine capacity is increased; secondly, the reliability of power supply is increased (at least one generating stream is gradually eliminated); thirdly, the area occupied by the hybrid installation is reduced in comparison with the total area that would occupy two sections separately; In addition, the environmental load on the environment is reduced (compared to using each converter separately).

Currently, NCIMM (STU) is developing samples of autonomous multifunctional energy complexes – (AMEC), with a view to their subsequent use in mountain conditions.

One of the existing factors hindering the use of AMEC is the need for an energy storage device of sufficient capacity. The role of the accumulating mechanism is to absorb (store) the excess of generated
energy and compensate (if necessary) for its lack in the consumption system. The problem of creating an energy storage device that fully meets modern requirements has not yet been resolved.

5. Conclusion
In NCIMM (STU), work is underway, for instance, to create an integrated heat-electric storage device, which, according to its characteristics (calculations and experiments show), can quite satisfy the AMEC requirements of average power.

The use of AMEC is quite promising, especially in mountain conditions. The use of the energy of natural energy flows circulating in the surrounding space, in particular, on the basis of AMEC, will not only simplify the energy supply to high mountain regions, but also significantly ensure the environmental sustainability of the mountain region.

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