Development and design of a hybrid power supply system

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Abstract. The work is devoted to the development and design of a hybrid power supply system for Northern climatic conditions on the example of the village of Solovetsky based on non-traditional renewable energy sources and fuel cells.

1. Introduction.
Western countries prove that in a market situation it is difficult to achieve a permanent power supply when there is a power system with mainly powerful power plants. The current direction of development of the global energy market confirms the constant growth of demand for working on various types of fuels autonomous sources of heat and electricity. Historically, most of our country is located far from centralized energy supply. This is the reason for the autonomisation of energy production.

For distributed power generation, a significant increase in the efficiency of generating electricity from organic fuels using hybrid power plants is achievable.

Low emissions and virtually no pollutants in fuel cell installations based, no greenhouse gas emissions. Such installations emit only water vapor, which does not pollute the environment.

The purpose of this work is to determine the feasibility and efficiency of using a combined hybrid system to provide a mode of Autonomous supply of heat and electricity to remote (island) consumers in Northern climatic conditions.

2. Fuel cells
Due to the high demand for creating environmentally safe transport and energy installations that operate with high efficiency, there is a need for the development of fuel cells in the fields of space technology, transport and energy, and the need to protect the environment. Currently, the development of fuel cell-based installations is going in several directions. This is the creation of stationary power plants based on fuel cells (both for centralized and decentralized power supply), energy installations for transport and power sources for portable devices [1].
Figure 1. The simplest scheme of a fuel cell on the example of a hydrogen-oxygen element.

In fuel cells, instead of burning, electrochemical reactions occur, so they need an easily oxidized substance such as hydrogen. High-temperature fuel cells can also use carbon monoxide (CO). This makes them more flexible to fuel and more efficient by using available fuels such as natural gas, propane, etc. $H_2$ and CO can be obtained from natural gas and other fuels, for example, through steam conversion [2].

Solid oxide fuel cells and molten carbonate fuel cells have a few advantages when used in hybrid power plants. However, in stationary installations with a capacity of 0.5-400 kW, solid oxide fuel cells are used, since they have a higher temperature of the outgoing gases, the electrolyte is simple and reliable in operation and it is not necessary to organize complex schemes for the circulation of the liquid phase. In addition, solid oxide fuel cells allow the use of internal steam conversion of fuel, in which all the fuel is converted completely to hydrogen and carbon monoxide, suitable for electrochemical reactions in the fuel cell [3].

Table 1. Examples of the use of fuel cells in various fields.

| Field              | Capacity  |
|--------------------|-----------|
| Stationary unit    | 5-400 kW  |
| Transport          | 25-150 kW |
| Portable units     | 1-50 kW   |
| Portable devices   | 1-500 W   |

3. Object

3.1. Basic information

To determine the feasibility and efficiency of using a combined hybrid power plant to provide a mode of autonomous supply of heat and electricity, consider the example of the Solovetsky Islands, located in the White sea.

The settlement is in the IIA construction and climate area. The climate is marine with long mild winters, frequent thaws, and short cool summers. Frequent Atlantic cyclones cause significant cloud cover and large amount precipitation throughout the year. The absolute minimum reached -37, the absolute maximum +30. The design temperatures for heating and ventilation design are -34 and -14, respectively. The duration of the heating period is 266 days.

The Solovetsky historical and cultural complex is included in the UNESCO world heritage list. The population of the island as of 2018 was 931 people, but during the year Solovki is actively visited by tourists and pilgrims.
3.2. Supply of heat and electricity of island

Now, the village is supplied with electricity from a diesel power station. The mode of operation of diesel generators is as follows: two working diesel generators and one standby diesel generator. In normal mode, the power system capacity is

\[ 2 \cdot 1 MW \cdot 0.8 = 1.6 MW \]  

where 0.8 is the load factor of the diesel generator.

Centralized heat supply in the settlement of Solovetsky is provided to consumers of the housing and communal sector only of the southern part of the island. In the Northern part of the village and on the territory of the Solovetsky Kremlin, heating is mainly stove.

Heat supply is provided by thermal power plants. The boiler room has two "Avant" hot water boilers with a heat capacity of 2 MW each. Diesel fuel and depleted diesel oil are used as fuel.

The thermal scheme of the boiler room provides:
- preparation of mains water for heating needs with a temperature of (90-70) °C using a closed heat supply scheme;
- using the heat from the flue gases of diesel generator sets to cover part of the heating load. The heat recovery system is guaranteed to generate 2,051 GJ/h of heat.

Heat loads of consumers in the settlement of Solovetsky considering losses in heat networks are:
- heating – 2.63 MW (9,462 GJ/h).
- there is no hot water supply or ventilation.

The total wear of the power grid already exceeds 60%, and in some sections – 80%, including the wear of power equipment of transformer substations. In this regard, technical losses in electric networks significantly exceed the normative ones, and in 2011 amounted to 698.93 thousand kWh. Wear of heat networks - 50%.

Due to the special ecological and cultural status of the Solovetsky archipelago, the relevance of energy saving of the settlement does not need additional justification.

4. Experiment

4.1. Factors of a choice of circuit conceptions
- Ecological compatibility;
- Parsimony;
- Visual aesthetics, due to the relation of the Solovetsky historical and cultural complex to the UNESCO world heritage list.

4.2. Load definition

The average daily active power in winter is 1440 kW, in summer - 721 kW. It should be considered that the tourist season in Solovki falls on June-August, and the power consumption of hotels and related facilities in summer is higher than in winter. From the data provided, it follows that a significant part of the electricity consumed (at least 50%) in winter is spent on electric heating, which is constantly switched on.

Electric heating is not cost-effective, since the efficiency of a diesel generator set does not exceed 40%. As a result, most of the energy of the burned fuel is wasted. Due to the gradual transfer of objects in the village to heating from heating networks, it is possible to reduce the electrical load in winter by 30-40%, which will save significant funds on the purchase and delivery of diesel fuel.

For power supply of the settlement, as the main equipment, it is possible to place wind and solar installations and a fuel cell.
Figure 2. Thermal and electrical load graph for Solovetsky island now

![Thermal and Electrical Load Graph](image)

Figure 3. Schedule thermal and electrical load for the island of Solovki with the use of energy-saving measures

Average daily load on hot water supply:

\[
Q_{daily}^{1000} = \frac{100}{24} \cdot 50 \cdot 1000 \cdot 1 = 208 \text{ thousands kcal/h} = 0.24 \text{ [MW]},
\]

(2)

where \( \frac{100}{24} \) is the rate of water consumption per person per hour, \([\text{l/h per}]\); 50 - hot water temperature, \([\text{°C}]\); 1000 – number of people consuming hot water; 1 – coefficient for conversion to kcal, \(\frac{\text{kcal}}{\text{lon per °C}}\).

\[
Q_{daily}^{1500} = \frac{100}{24} \cdot 50 \cdot 1500 \cdot 1 = 312.5 \text{ thousands kcal/h} = 0.36 \text{ [MW]}
\]

(3)

Based on the calculation that the heat load per 1000 people is 2 \(\frac{\text{Gcal}}{\text{h}}\), and the hot water supply is at a peak of 0.3÷0.35, the heating load from May to September will be 1.7 \(\frac{\text{Gcal}}{\text{h}}\) = 1.98 [MW].

As a result of energy-saving measures, it is possible to reduce the load in the settlement in the spring and autumn period by 15%, and in the winter – 30%.

4.3. Solar energy

Electricity generation using photovoltaic panels is one of the most promising areas in the field of renewable energy sources. Thanks to the great prospects and high level of investment, the number of researches in the field of solar energy has grown significantly in recent years, as well as the number of publications in journals.
Published works on the topic of solar energy and photovoltaic panels consider ways to obtain energy, its advantages and disadvantages, the current market situation, costs, and technologies. The Solovetsky Islands are located 250-300 km from Arkhangelsk. Thus, the intensity of solar radiation is similar in comparison with the city of Arkhangelsk. In the city of Arkhangelsk there are 76 sunny days per year. Due to the short duration of the solar period, it is not practical to install a solar installation. However, in the manufacture of solar collectors, silicon tandem thin-film technology is used, which allows converting thermal energy from scattering sunlight.

Prospects for the use of solar energy:
- Unlimited amount of energy.
- Electricity generation does not pollute the atmosphere.
- The system for generating such energy is safe and reliable.
- Materials can be recycled and reused.
- Easy maintenance of the equipment.
- Use of electricity in far rural areas.
- Fast payback of modules.
- Supply reliability.

4.4. Wind energy
The maximum average monthly speeds for the Solovetsky Islands occur during the cold season and coincide with the seasonal peak of heat and electricity consumption. The site for the installation location is selected based on the distance from cultural and historical sites, the proximity of roads, and the openness of the area. The distance from the village helps not to disturb the visual perception of cultural monuments, to keep quiet for a comfortable stay of the residents of the village. Existing roads will facilitate the installation of wind turbines. Since the Solovetsky Islands are included in the UNESCO world heritage list, deforestation on the territory is unacceptable. Also, the forest area located near wind turbines creates turbulent flows that significantly reduce the efficiency of their operation.

Prospects for the use of wind energy:
- The cost of a single windmill is estimated to be 3 times lower than a solar installation of the same capacity.
- The wind blows day and night, in winter and summer, in rain and snow, and the sun shines less often, especially in the Northern regions of Russia.
- During prolonged rains and cloudy weather, solar installations lose their power by a factor of 5.
- The efficiency of solar installations decreases with each year of operation.

4.5. Elements of system
In this hybrid power supply system, the following equipment is used to cover thermal and electrical loads at different times of the year:
- Fuel cells (40 units of 5 kW).
- Wind power plants (6 units of 150 kW).
- Solar power plants (10 units of 14 kW).
- Solar collectors (207 units of 1.5 kW).
- Diesel generator sets and their heat recovery system.

Each season has its own set of equipment for covering electrical and thermal loads in rational proportions.
4.6. Technical and economic assessment

The total cost of hybrid power plants, according to preliminary estimates, amount to 845,043,900 rubles. The high cost is due to the high cost of the fuel cell, but it is cheaper than high-quality electric heating and modernization of outdated heating networks, which will cost more than 10 billion rubles.

Figure 4. Designed hybrid power supply system for Solovetsky Island in general form.

5. Conclusion

The article is devoted to the relevant problem – the development of Autonomous power supply sources. In this paper, hybrid power plants based on solid oxide fuel cells have been developed and designed, and their application efficiency for the settlement of Solovetsky has been considered. Since fuel cells are made of different materials and have different temperatures, each type of fuel cell has its own application area, features, and advantages, but they all have a high efficiency potential and low environmental impact.

A good wind speed throughout the year makes it possible to install (vertical-axial) wind power plants. Due to the small number of sunny days per year, it is not practical to install solar power plants. However, it is possible to install solar power plants on scattering solar panels as an experiment. Unfortunately, it is not possible to completely abandon diesel generator sets.

Hybrid power plants based on fuel cells are highly efficient and also benefit both the owner and the environment. It is possible to accumulate energy. Energy saving consists in introducing more wind power plants and fuel cells into the scheme and minimal use of diesel generator sets. Thus, the efficiency of the installation increases, and overall costs are reduced.
List of designations
FC — Fuel cell.
DGS — diesel generator set.
SC — Solar collector.
SPP — Solar power plant.
WPP — Wind power plant.
B — Battery.
HP — Heat pump.
HE — Heat exchanger.

Bibliographic list
[1] Kuleshov N V and Korovin N V 2003 Solid-polymer electrolytes for fuel cells J. Electrochemical power engineering p 3
[2] Korovin N V 2005 Fuel cells and electrochemical power plants (Moscow: Moscow State University Press) p 208
[3] Nefedkin S I 2018 Autonomous power plants and systems: textbook (Moscow: Moscow State University Press) p 220