ENTRY TO STOCKHOLM JUNIOR WATER PRIZE

PRACTICAL IMPLEMENTATION OF THE MAGNETOHYDRODYNAMIC EFFECT IN THE TIDAL CURRENTS OF THE BARENTS SEA: A FEASIBILITY STUDY

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The Russian Federation

2021

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Executive summary

Utilization of pollution-free and renewable energy sources, including tidal energy, have become a relevant area of research in the energy sector of the 21st century.

Leo Bernstain was the pioneer of this research in Russia, with his model of a floating tidal power station (TPS) unit introduced in 1938. He also supervised the construction of Kislogubskaya TPS in Murmansk region [1].

A unique feature of seawater is its natural electrolytic property, as it contains myriads of positive and negative ions. Under proper conditions, seawater can be an inexhaustible source of electricity, but this would require a special construction that makes the water move in the ‘right’ direction.

The subject of this study was a magnetohydrodynamic (MHD) effect: generation of electric current in a conducting fluid (or ionized gas) flowing under the influence of an external magnetic field.

In my study of MHD effect, I suggested that my region, the coast of the Barents Sea, possessed vast amounts of moving seawater and offered a unique opportunity to create new combined sources of electricity by harnessing of tidal forces. It is here that the first and only tidal power station in Russia was constructed. I think that additional conversion of seawater energy to electricity by means of MHD effect will increase the efficiency of tidal power stations, which makes my study quite ***relevant***.

The goal of this study was to assess feasibility of utilization of MHD effect by the tidal power stations. To achieve this goal, I addressed the following tasks:

1. Review the theoretical foundations of this research;
2. Conduct experiments to study the influence of physical properties of the electrolyte and the external magnetic field on the electromotive force (EMF) of the current source;
3. Assess feasibility of combined generation of electricity by the turbines that use the tidal force and MHD effect at the same time;
4. Summarize the obtained results and make conclusions.

1. Theoretical aspects of this research

1.1 Problem formulation

The Russian Federation possesses vast amounts of natural resources. Until the turn of this century, its economy was predominantly oriented at utilization of fossil fuels, nuclear energy and large-scale hydropower. More recently, the better understanding of environmental problems related to climate change and resource limitations led to development of economically justified regional-scale programs in the energy sectors of many countries including Russia. These programs included utilization of renewable energy sources (RES).

The north of European Part of Russia, and especially the Murmansk region, have a large potential of RES. Murmansk is situated on the Kola Peninsula. Its climate belongs to subarctic type; it is rater harsh, with a mild touch of the warm North Atlantic current.

The Murmansk region has a variety of renewable energy sources: solar, wind, hydropower of small rivers, tidal currents, etc. These ‘alternative’ sources can economically compete with the traditional ones, or complement them, bringing significant economic benefits. The potential resource of tidal power in the Kola Peninsula is about 11 billion kWh, which is about 70% of the regional energy demand [2].

The Kola nuclear power plant and 17 hydropower plants now constitute the backbone of the power grid of the Murmansk region. A balanced combination of an advanced nuclear power plant with spatially distributed network of small-scale hydropower brought down the net production costs of electricity. The Murmansk region is a net exporter of electricity; it exports about one-quarter of locally generated electricity.

At the same time, only a small fraction of this electricity is used for the regional heat supply. About 90% of the regional heat demand is covered by imported fuels, mainly, petroleum products (their share in energy imports is more than 80%). The Murmansk region annually imports 4,1 million tons of oil equivalent (toe). Such dependency on the imported fossil fuels undermines the environmental safety of the Murmansk region [3].

The renewable energy sources, including tidal power, if used wisely and prudently, would rectify the misbalance between overproduction of electricity and dependency upon imported fuels. The achieved reductions in fossil fuel consumption would increase overall environmental safety of the region.

1.2 Tidal energy and its advantages

Tidal energy can be converted to electricity by using either the kinetic energy of the tidal currents or the variations of the sea level; the latter is considered the most effective mode of utilization of energy associated with the natural phenomenon of ocean tides.

The tidal height in the open sea is not very large, but certain local features of the seacoast significantly increase the daily amplitudes of the tides; the tidal heights can be as large as 16 meters.

A reduction of energy flow in the estuary (the expanding river mouth) creates a problem for TPS construction. This happened with the world’s largest TPS on Rance River in France, commissioned in 1966. Since then, the energy flow fell by 20%. Nevertheless, the average capacity of this station is 160 MW of electricity, with the peak capacity of 240 MW [4].

Natural conditions in Russia are favorable for utilization of tidal power. The total potential of TPS is about 120-150 GW of installed capacity, which is equivalent to 270 TWh of annual electricity production [5]. This potential is mainly concentrated in non-freezing areas of the White, Barents, and Okhotsk Seas.

Fig.1. TPS sites on the coast of the Barents Sea:
1-Kislogubskaya; 2- Severnaya (projected); 3-Lumbovskaya (projected)

The resources of tidal power in the Kola Peninsula are lined along its 1000 km long shoreline (Fig. 1). The Murmansk region possesses the potential of 2 billion kWh of electricity production from tidal power [5].

However, Kislogubskaya TPS remains the only currently operating tidal power station in Russia. It is situated in Kislaya Guba harbor of Motovsky Bay in the Barents Sea (Fig. 2). A narrow straight connects Kislaya Guba with Ura Bay; this configuration allowed construction of a tidal power station with relatively low cost. The station was constructed afloat; the main building was assembled in the Murmansk dock and then transported by sea to Kislaya Guba where it was mounted on the foundation that had been previously constructed underwater.

Fig. 2. Kislogubskaya tidal power station

The station consists of two parts. The old part was built in 1968, to which the new part was added in 2006. The station currently has two orthogonal hydroelectric units; their capacities are 0,2 MW and 1,5 MW, so that the total capacity is 1,7 MW.

The experience of its operation confirmed that the station had the following important advantages: environmental safety and low cost of electricity production. This cost is approximately 30% lower than that of traditional hydropower plants and 50% lower than that of thermal power plants [6]. This is explained by relatively low maintenance costs. Once the station is commissioned, it does not require additional costs. Besides, the barrage structure has a very long lifespan: up to 200 years [7], and the operational life of a TPS is 120 years [8]. For comparison, the lifespan of a windmill is only 15-20 years [9].

Another important advantage of tidal power is the absence of noxious air emissions. TPS construction does not involve any significant changes in the local terrain or the coastal landscape; consequently, there is no risk of flooding of the adjacent territory.

The disadvantages of TPS are cyclicality of its operation and high construction costs. The first disadvantage can be overcome by adding a TPS to the grid of ‘traditional’ power stations that use other sources of energy: large-scale hydropower, or pumped storage power plants. Such combination can help both during regular and peak loads.

The construction cost can be reduced as the technologies advance. For example, a floating structure does not involve construction of stationary dams. Russian experience also confirmed that an orthogonal two-way power unit could be quite efficient and technologically simple. The engineering solutions implemented at Kislogubskaya TPS enabled continuous electricity generation for 4-5 hours, with one- or two-hour breaks, leading to four operational cycles per day. The more complex schemes involve construction of two or three basins to increase the length of these cycles, but the construction costs increase dramatically.

An orthogonal (non-reversible) turbine is simple in design and continuously rotates in one direction irrespective of the direction of the water flow. This turbine costs less, and it is more efficient than the traditional rotating-blade (Kaplan) or capsule turbines with horizontal axis, installed at the tidal power stations in Canada and France [10].

1.3 A study of MHD effect in seawater with the model of a turbine in a tidal channel

Magnetohydrodynamic effect is an induction of electric field and current in a conductive fluid or ionized gas that moves in magnetic field [11].

A MHD generator consists of a channel with moving fluid, a system of magnets and the electrodes used to take-off the electric current (Fig. 3).

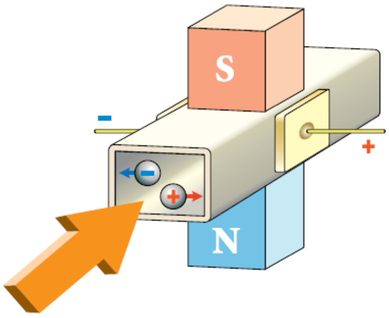

Fig.3. A model of MHD generator

When the working medium flows through the area with the orthogonal magnetic field, the Lorentz force deflects each charged particle; positive and negative charges are deflected in the opposite directions and accumulate on the opposite electrodes, creating electromotive force (EMF). Electric current will run if the electrodes are connected in a circuit.

I used the water from the Barents Sea in my experiments with MHD effect. The first stage of the experiments was to determine the optimal temperature of the electrolyte to maximize the potential difference. In this experiment, I heated up the seawater in the presence and in the absence of the magnetic field.

I found out that temperature rise led to an increase in the potential difference in the beginning of the experiment. Then, as the fluid heated up uniformly, and the velocity of the thermal motion decreased, the potential difference fell down (Fig. 4a).

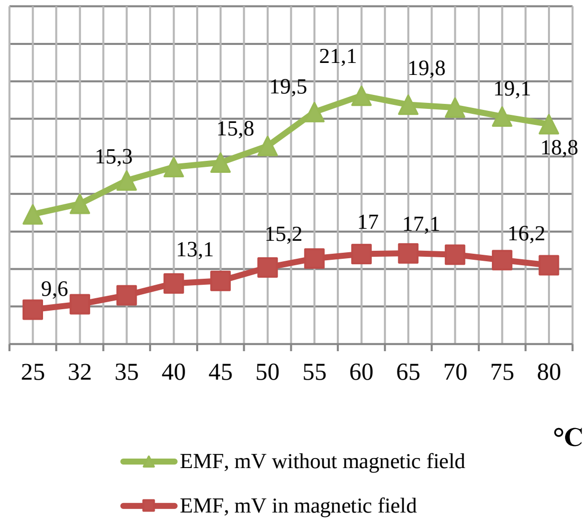

Fig.4a. EMF measurements when the electrolyte is heated up

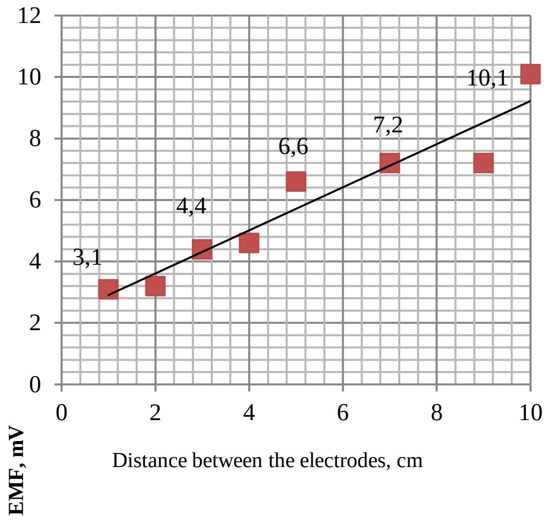

Fig.4b. EMF measurements when the distance between the electrodes is changed

The distance between the electrodes also influenced the potential difference (Fig. 4b). The wider the MHD channel was, the greater voltage could be achieved.

The second stage of the experiments was to assemble a model MHD generator and to conduct calculations. I used the four 11 cm × 2 cm Plexiglas plates to assemble the MHD channel and plate copper to make the electrodes. I placed the ferrite magnets along the MHD channel with the alternate poles looking inside the camera (Fig. 5).

The voltage U between the electrodes was the main calculated parameter of the model.

The work of external (magnetic) forces that separate the electric charges in a moving electrolyte is A = qU, then $U = \frac{A}{q}$ (1), where U is the voltage and q is the ion's charge.

This work can be expressed as $A = F_L \cdot d$ (2), where d is the distance between the electrodes and F_L is the Lorentz force. This force F_L = q*V*B (3) appears when the ion moves with the velocity *V* in the orthogonal magnetic B-field; the strength of the field is measured in tesla units (T). The equations (1-3) lead to the following expression for U: $U = \frac{\text{qVBd}}{\text{q}} = VBd$ *(4)* [11].

Fig.5. A model MHD generator

The ions move in the channel with the velocity of the electrolyte flow: $V = \frac{4Q}{S}$ (5), where Q is the water throughput measured in cubic meters per second [m^3/s], and S is the cross-sectional area measured in square meters [m^2]. I calculated the water throughput using the period taken by the electrolyte to pass the camera.

The calculated parameters are summarized in Table 1:

Distance between the electrodes d, m	Electrolyte velocity V, m/s	Magnetic induction B, T	Calculated voltage U, mV	Measured voltage U, mV
0,02	13,0	0,3800	98,8	101,7

It took four seconds for five liters of water to pass the camera, which gave the following estimate of the throughput: Q = 0,005m^3 /4s ≈ 0,0013 m^3 /s.

I used the barium ferrite magnets (grade Y3OH-1) in my experiments. Their magnetic induction was 0,38-0,40 T according to the manufacturer's specification.

The electrolyte velocity in the channel was: $V = \frac{4 \cdot 0{,}0013}{0{,}02 \cdot 0{,}02} = 13 m/s.$

I used Eq. (4) to calculate the voltage: U= 13·0,38·0,02=0,0988 V=98,8 mV

The maximum voltage measured in the experiment was: U=101,7 mV.

My experiments confirmed that MHD effect could be used to generate electricity from the natural seawater at a hybrid tidal power station.

2. Feasibility of implementation of MHD channel in the system of turbines of Kislogubskaya TPS

2.1. Calculation of main characteristics of MHD channel

My calculations were based on the following assumptions:

- The ocean tide at the mouth of Kislaya Guba Bay regularly happens two times per day;
- The average amplitude of the tide is 2,27 m;
- The area of the TPS basin is 0,97-1,5 km^2.

Table 2. The main parameters of the power turbine of Kislogubskaya TPS [12]

Parameter	Value
Blade wheel diameter, m	5,0
Nominal frequency, rpm	36,9
Nominal electric power, kW	1500
Maximum efficiency of the turbine, %	71,4

Figure 6 shows the diagram of water flow inside the floating TPS unit with the orthogonal turbine.

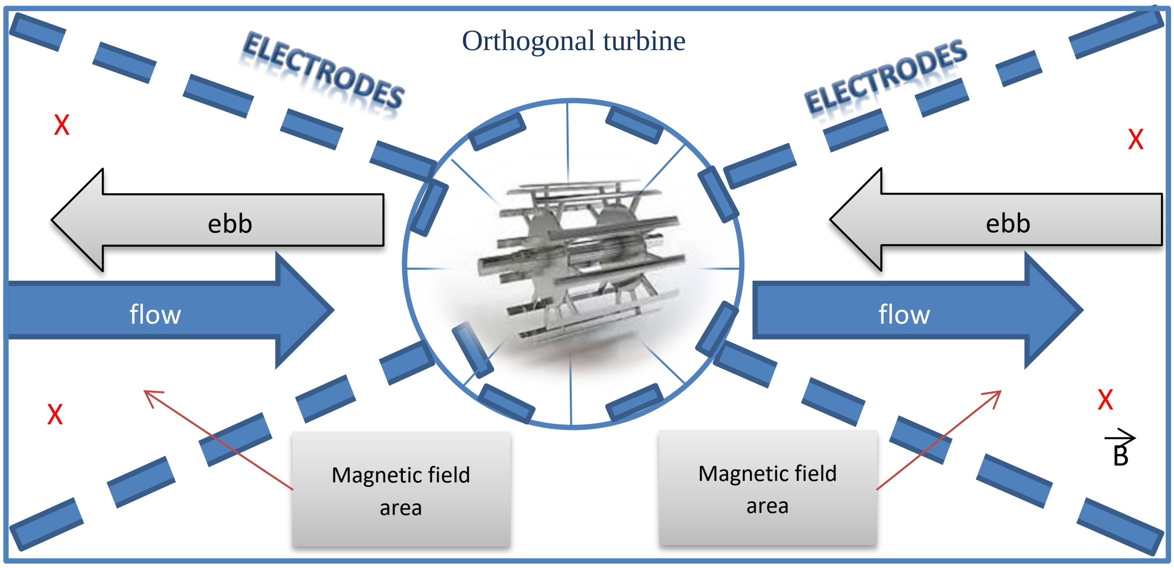

Fig.6. The diagram of water flow inside the MHD channel

The dimensions of the floating unit are 36×15,35×18,3 meters. To avoid the hydraulic shock, the diameter of the channel before the turbine should be equal to at least 80% of the turbine diameter, which is 4 m. Thus, I assumed the following values of the parameters: the channel before the turbine had a square section with 4×4 m area and 15 m length; the value of magnetic induction was 5 T, and the electric power output was 200 kWh.

For my model, I chose a Faraday conductive channel with the solid electrodes. Such a channel generates relatively low EMF (up to several kV) but the electric current can be very high: several hundreds of kiloamperes (a “high-current” channel).

I calculated the velocity of the water flow in the open bay during the flux using the tide height of 2,27 m and the law of conservation of energy. I assumed that the height of the center of water mass was 1,135 m to calculate the potential energy of the tide. This energy is transformed to the kinetic energy of the current, $mgh = \frac{m\,v^2}{2} \Rightarrow v = \sqrt{2gh}$ (1).

Then, the velocity of the tidal current is: $v = \sqrt{2 \cdot 9{,}8255 \cdot 1{,}135} = 4{,}72 m/s$, where g=9,8255m/s^2 is the gravity acceleration at the altitude of Murmansk city.

The turbine wheel rotates with the transversal speed of $v = 2\pi\nu R$ (2), where ν = 36,9 rpm = 0,615 Hz is the frequency of turbine rotation, and R = 2,5 m is the radius of its wheel, which gives v = 9,66 m/s.

Thus, the speed of the water flow immediately before the turbine should be increased by a factor of two, for the optimal operation of the turbine. To accelerate the water flow, one needs to reduce the dimensions of the channel before the turbine.

Very low compressibility of water means that the same volume of water passes through all cross-sections per unit of time, so that: $S_1 v_1 = S_2 v_2 = S_3 v_3$ (3).

The cross-sectional area of the intake section of the floating unit was calculated with Eq. (3): $S_1 \cdot 4{,}72 = 4^2 \cdot 9{,}66 = 32{,}7$ m^2. Therefore, the width of the intake channel S_1 equals to 6 m.

The electrolyte moving in the magnetic field generates the following EMF between the electrodes: $\varepsilon = vBd = 9{,}66 \cdot 5 \cdot 4 = 193{,}2\ V$.

I used the Ohm's law for the closed circuit to calculate the load current: $I = \frac{\varepsilon}{R+R_L}$ (4), where R is the channel's resistance, and R_L is the load resistance.

The MHD channel power is $P_C = \frac{\varepsilon^2}{R+R_L}$ (5); the net power (i.e., taken from the generator by the external circuit, and absorbed by the load) is $P_N = \frac{\varepsilon^2 R_L}{(R+R_L)^2}$ (6), and the power loss is $P_L = \frac{\varepsilon^2 R}{(R+R_L)^2}$ (7).

Substituting P_N = 200 kW and ε =193,2 V in Eq, (6), it can be rewritten as:

$5{,}36\,(R + R_L)^2 = R_L$ (8).

For efficient operation of the channel, the power loss should be less than 10% of the net power [13], which leads to the following expression:

$\frac{\varepsilon^2 R}{(R+R_L)^2} \leq 0{,}1 \frac{\varepsilon^2}{R+R_L} \Rightarrow R \leq 0{,}11\, R_L$ (9)

The solution of the system of equations (8-9) gives the following estimate of the channel resistance: R≈0,0166 Ohm≈0,02 Ohm.

The resistance of the seawater channel can be also expressed as $R = \frac{\rho L}{S} = \frac{\rho L}{dh}$ (10), where ρ≈0,3 Ohm·m is seawater resistivity, which gives R=0,28 Ohm, that is 14 times greater than the optimal value.

The resistance of the seawater flow can be reduced if the concentration of the charged particles increases, but this is hardly possible with natural seawater.

The maximum output capacity of a MHD generator is achieved if R_L=R=0,28 Ohm [14] and equals to: $P_{max} = \frac{\varepsilon^2 R_L}{(R+R_L)^2} = \frac{\varepsilon^2 R}{(R+R)^2} = \frac{\varepsilon^2}{4R}$ (11), which leads to the following estimate: P_{max}=33327 W≈33 kW.

If the channel operates efficiently, then the load resistance is R_L=0,28/0,11≈2,55 Ohm, and the channel power equals to $P_C = \frac{\varepsilon^2}{R+R_L} = \frac{193{,}2^2}{0{,}28+2{,}55} = 13189\ W \approx 13{,}2\ kW$.

The net power equals to $P_N = \frac{\varepsilon^2 R_L}{(R+R_L)^2} = \frac{193,2^2 \cdot 2,55}{(0,28+2,55)^2} = 11884\ W \approx 11,9\ kW$, and the efficiency of the canal is $\eta = \frac{P_N}{P_C} = \frac{11,9}{13.2}$ ≈0,90=90%.

Actual efficiency will be somewhat lower because of losses of heat and the magnetic field.

The above calculations confirmed that the net power, taken from the MHD channel and absorbed by the external circuit, can be adjusted by changing the following parameters: the channel resistance (which depends upon its cross-section and length), the water current velocity, or magnetic induction.

Since the described above power unit generates direct current, the electric energy can be accumulated and stored in an economically viable way.

Utilization of permanent magnets in my system is preferable because of their relatively small dimensions and weight. This engineering solution excludes additional sources of power, simplifies the whole structure, and reduces the construction and maintenance costs. The ferrite magnets can be used for this purpose; they are resistant to corrosion, relatively cheap and operate under varying temperature conditions (between -30°C and +300°C) [15].

2.2. Assessment of cost-effectiveness of implementation of a MHD channel

I considered the following parameters in my analysis of economic feasibility of implementation of MHD channel with the turbines of Kislogubskaya TPS:

- An increase in production of pollution-free electricity from the ocean energy;
- A possibility of storage and subsequent utilization of this energy in the economy of the Kola Peninsula;
- Reduction of supplies of fuel oil for heating of the residential sector in the Kola Peninsula and consequent savings of heating costs;
- Enhancement of environmental safety of the Peninsula due to emission reductions.

My calculations showed that the net power generated by the MHD channel was 11,9 kW. Kislogubskaya TPS currently utilizes two orthogonal turbines; each turbine can be equipped with two MHD channels, the one before and the other after the turbine, which gives the total of 47,6 kW ≈ 50 kW.

Thus, the total output of this station, including the power of the turbines, will be P=1750 kW. The annual electricity production of this station is $W = ICUF \cdot T \cdot P$, where $ICUF$ is the installed capacity utilization factor, T is the number of operational hours per year, and P is the total power output of the station [16].

ICUF value is an important characteristic of a power plant. It is the ratio of the mean capacity and the installed capacity, calculated over a certain period, usually one year. *ICUF* value for a typical TPS is 0,20-0,25.

The cyclic character of TPS operation is caused by the periodicity of the tides. The idle intervals (between flow and ebb) usually take one or two hours. Assuming four such cycles per day, the station works for 16 hours per day.

The annual energy production of Kislogubskaya TPS with MHD channel is

$$W = 0{,}25 \cdot 16 \text{ hours} \cdot 365 \text{ days} \cdot 1750 \text{ kW} = 2555000 \text{ kWh} \approx 2{,}6 \text{ GWh}$$

According to the Ministry of Energy and Communal Sector of Murmansk region, the average annual production of energy by Kislogubskaya TPS is W_{avg} = 0,545 GWh, which is almost five times less than the estimated value.

This difference is explained by the experimental nature of the station: it works only during the peak energy demand of the regional power grid (for about two hours per day).

Had it worked at the maximum capacity all year round, it would have produced enough electricity to cover the energy demands of five nine-story residential buildings with 180 apartments each.

My family consumes 250 kWh of electricity each month (an average value measured by the meter), which amounts to 3000 kWh per year. Therefore, the energy production by Kislogubskaya TPS should be sufficient to meet the demands of 866 households.

The heating season in my region typically lasts for 9 months, and the municipal boiler houses are fired by fuel oil. The electricity produced by Kislogubskaya TPS can also be used for heating of residential houses, kindergartens, and public schools. Using the electricity-to-heat conversion factor, the annual electricity production of Kislogubskaya TPS is equivalent to m = 0,123·2,6 GWh = 320 toe (tons of oil equivalent), or 233,6 tons of fuel oil [17].

The price of fuel oil in the Murmansk region in 2021 was 17350 Rubles per ton (236 USD/t). Thus, the annual electricity production of Kislogubskaya TPS, if used for heating, would have substituted the amount of fuel oil with the consumer value of 4052960 Rubles (55242 USD).

The residential heating tariffs in Kola Peninsula are among the highest in Russia, because there are no supplies of natural gas and the heating demands are covered by fuel oil. Let us calculate the total cost of residential heating energy, that is equivalent to combustion of 233,6 tons of fuel oil. The calorific value of fuel oil is q= 41,15 MJ/kg. Therefore, combustion of 233,6 tons of fuel oil produces $Q=qm=41{,}15\cdot10^{6}\cdot233{,}6\cdot10^{3}=9{,}6\cdot10^{12}$ J $\approx 2{,}3\cdot10^{12}$ cal = 2300 Gcal of heat energy.

The residential heating tariff is 3457,63 Rubles/Gcal. Using this unit price, the total cost of heating is C=7952549 Rubles (108351 USD).

The residential electricity tariff is 2,086 Rubles./kWh. If all electricity produced by Kislogubskaya TPS had been used directly for residential heating, then the population would have paid C = 2,6 million kWh · 2,086 RUR/kWh = 5423600 Rubles (73895 USD).

Such transition from fuel oil combustion to utilization of emission-free electricity (an important benefit in itself for the environment) would have saved 2,6 million Rubles, or 35424 USD.

I calculated the potential CO_2 emission reductions of such a transition with the following formula [16]: $E = m \cdot K_1 \cdot q \cdot K_2 \cdot (44/12)$, where E is annual CO_2 emissions [tons/year], m = 233,6 t/year is annual consumption of fuel oil, $K_1 = 0{,}99$ is the coefficient of carbon oxidization (the efficiency of fuel combustion), $q = 41{,}15 \cdot 10^9$ J/t is the calorific value, $K_2 = 77{,}4 \cdot 10^{-12}$ ton/J is the coefficient of unit CO_2 emissions, 44/12 is the coefficient of conversion of elemental carbon to carbon dioxide (44 is the molecular weight of carbon dioxide and 12 is the atomic weight of carbon).

$$E=233{,}6\cdot 0{,}99\cdot 41{,}15\cdot 10^9 \cdot 20{,}84\cdot 10^{-12} \cdot 3{,}667\approx 727{,}3 \text{ t/year}$$

Consequently, the environmental benefit of avoided emissions is 727 tons of CO_2 per year. This co-benefit can be achieved by the conversion of residential heating to the environmentally safe electricity generated by Kislogubskaya TPS with MHD channel, if the station operates at its full capacity. Using the world's average value of the carbon tax (10 USD/t), the potential income of the regional budget can reach 7300 USD or 538000 Rubles. This income can be used to purchase the equipment for the research projects of high school students.

The flowchart 7 illustrates the effectiveness of operation of Kislogubskaya TPS with MHD channel.

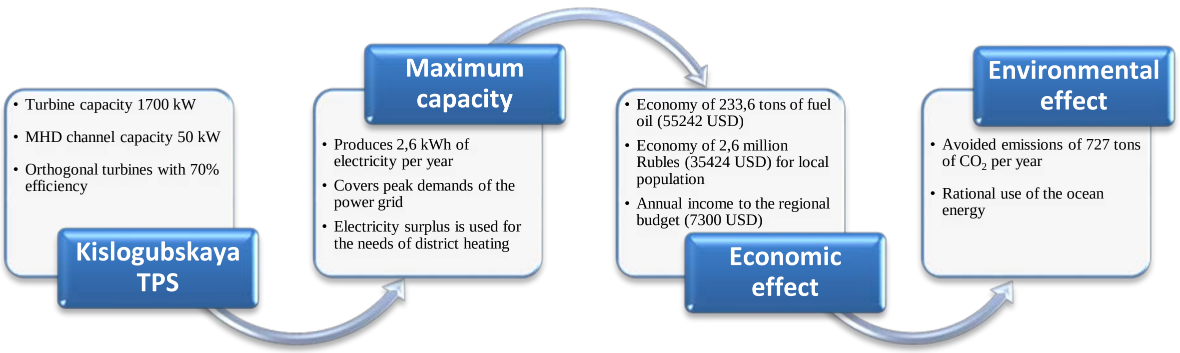

Fig.7. Effectiveness of TPS operation

In conclusion, let me note that an effective operation of a tidal power station with MHD channel would require implementation of the full circle of its functioning. Only in this case, total annual electricity production may reach 2,6 million kWh.

I live in Snezhnogorsk – a small town with 14,000 residents. The conversion of residential heating in this town to electricity produced by a tidal power station would help to avoid the emissions of 700 tons of greenhouse gases and bring additional income to the municipal budget.

2.3 Possible uses of electricity generated by a tidal power station with MHD channel

I have pointed out earlier that supply of electricity generated by a tidal power station to the grid is associated with certain difficulties. The problem is rooted in the cyclic nature of the tides. The natural tidal cycle does not match the periodicity of daily consumer demand in electricity. To solve this problem, electric power can be stored in hybrid storage batteries that smooth out the daily variations in electricity demand. These batteries accumulate electricity and supply power to the grid during the periods of peak demand.

I think that the potential of tidal power can be fully utilized by wide implementation of intellectual power distribution systems. Such systems operate in real time and redirect electricity where it is needed the most.

Electricity surplus can be used for street lighting of the towns in the Murmansk region during the polar night.

Another problem in my region is the need to heat up the automobile engines during the long winter. The starting preheaters are fairly cheap and simple; they are powered by household electric supply. In Scandinavian countries, the electric sockets are mounted even in the supermarket parking lots for this purpose. Russia does not have such infrastructure. This problem can be solved by implementation of a discount tariff for charging of passenger cars, electric scooters, motor boats and the like. The discount tariff can be applied during the peaks of TPS electricity generation. The share of electric cars in total electricity consumption is growing steadily, and such cars can be recharged during the peaks of electricity supply by the tidal power plants.

3. Conclusions

- The aim of this research was to assess feasibility of electricity generation from the kinetic energy of the tidal waves and the kinetic energy of the charged particles (seawater ions) moving in the magnetic field.

- I studied the physics of MHD effect and developed a model generator that utilized this effect.

- I calculated the EMF value for Kislogubskaya TPS with a MHD channel (193,2 V). The maximum output of my model generator was 33 kW. I assumed that the maximum efficiency of the MHD channel could be attained if only 10% of total power output was lost due to heating losses. Under this assumption, the power output of the model generator was 13,2 kW, of which the net power was 11,9 kW, and the efficiency of the MHD cannel was 90%.

- The net power taken from the MHD channel and absorbed by the external circuit, can be adjusted by changing the channel resistance (changing its cross-section and length), the water current velocity, or magnetic induction.

- Generation of direct current suggested that accumulation of electric energy by the hybrid storage batteries could be economically viable. This solution can be used to meet the energy demands during both peak and off-peak hours.

- Residential heating in the Murmansk region heavily (by 90%) depends upon the imported fuel oil. This dependency undermines the environmental safety of the region. For this reason, a full-scale utilization of Kislogubskaya TPS would help to redistribute a certain fraction of its electricity surplus for residential heating purposes. This solution would increase the level of environmental safety in the region.

- The environmental benefit of the proposed solution is associated with CO_2 emission reductions (727 t/year). These reductions can bring additional income to the regional budget (half-million Rubles).

- Electricity surplus can be used for street lighting during the polar night, preheating of car engines in winter, charging of electric cars, scooters, or boats (in future).

4. Literature

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