the theory needs to be revised for the conditions under which high efficiency is attained because the bulk forces influence the velocity-field structure.

Figure 6 shows $\varphi(x)$ that define the optimum potential distribution on the electrodes for various q_0 from (4.4).

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COMPARISON OF PROSPECTIVE ENERGY SOURCES WITH THOSE IN USE

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In the Middle Ages the main energy source was the wind. Its energy was utilized by the sailing fleet and windmills. According to data of the Third International Symposium on Renewable Energy Sources (Turkey, 1977) the yearly per capita production of energy in Europe in the Middle Ages was 200 kWh. Windpower technology was particularly highly developed in Holland and Denmark.

At the present time half of all the world's power production is based on a very rapidly diminishing nonrenewable energy source — oil. The index of oil reserves, defined as the ratio of the proved recoverable reserves to the yearly extraction, is steadily declining. Before this index reaches values of the order of 10 or smaller, scientists must find a suitable economical equivalent, preferably from renewable sources, and succeed in becoming familiar with it on a large scale before power failures occur with all the consequent national economic shocks.

Coal reserves are practically inexhaustable in the present epoch, but difficult mining conditions keep its cost high.

The prime cost of oil in the world market and the selling price based on it have risen continuously in recent years. From 1970 to the present time the cost of 1 ton of crude oil has increased more than tenfold. The prime cost of 1 kWh of electric energy generated by a thermal electric power plant operating with fuel oil is 0.8-0.9 kopecks [1].

Water power, which makes up 19% of the total installed power of all electric power plants in the Soviet Union, cannot be considered a serious successor of oil energy resources [2]. The prime cost of 1 kWh generated by a hydroelectric power plant is 0.4 kopecks [3].

At the present time atomic power supplies a still smaller fraction of the total power supply. Taking account of the continuously increasing demands for purity of the environment, one can assume a continuous increase in the cost of 1 kWh of atomic energy. Its unprofitableness in stationary units will manifest itself more and more strongly with time. In addition to the purely monetary expressions of the high cost of atomic energy, its nonrenewability is further aggravated by the fact that it diverts a disproportionately large number of highly qualified workers from other understaffed branches of engineering where they might better serve the national economy.

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The possible renewable energy sources being studied at the present time can be divided into two main groups.

I. Those Using Organic Materials: 1) vegetable oils as liquid fuel. According to press reports, the use of sunflower oil instead of petroleum is being studied in the United Arab Republic, and alcohol in Brazil. For many centuries man has made large scale use of organic fuel for everyday purposes.

II. Those Using Materials of Inorganic Origin: 1) transformation of wind energy; 2) solar heat sources; 3) photochemical and biological transformations of light into chemical energy; 4) utilization of the variation of temperature with height in the air and ocean; 5) use of the kinetic energy of ocean currents; 6) tidal electric power plants; 7) electric power plants transforming the energy of wind waves on the surface of a liquid.

Since a comparative analysis of technicoeconomic indicators shows that wind power may be of the greatest interest, we devote a considerable amount of the following discussion to it. It should be noted that M. A. Lavrent'ev was always very interested in the phenomenon of strong winds in the region of the Novorossiisk bora, and considered their commercial utilization expedient.

So far solar power plants are extremely expensive. For example, according to press reports a 100-200 kW solar power plant costs eleven million dollars, or about 100,000 dollars per kW.

An important difficulty with solar power plants which people commonly forget in discussing them is the relatively rapid tarnishing of the reflecting surfaces, which have a large area and have to be cleaned by hand. The transparent or reflecting surfaces in proposed solar power plants are many times larger than the glazed surfaces of factory buildings where no inexpensive way of increasing their transparency has been found.

Photochemical and biological transformers of light into chemical energy have the same problem of the rapid decrease of transparency of surfaces, and in some cases there are additional difficulties. For example I. V. Berezin, a corresponding member of the Academy of Sciences of the USSR, together with the group led by him, developed an original method for obtaining hydrogen from water by using algae placed in a special aquarium. They showed that it was possible to obtain 24 W/m^2, and for the relatively small area of 10^5 km^2 in the desert such a source could supply the power requirements of the whole Soviet Union [4]. In addition to the problem of the transparency of the surface, there are problems of sealing the aquaria, the necessity of decontaminating them inside of hydrogen in the surroundings, and many other technical problems difficult to solve on a large scale.

Utilization of the temperature difference between layers of the ocean requires the development of fantastically large heat exchangers because of the low thermodynamic efficiency. Such heat exchangers operating under normal conditions, like ships, would become covered with mussels, and be subject to corrosion. Their thermal resistance would increase rapidly. As a result the cost of obtaining energy would exceed the cost of obtaining energy from other sources.

During the last ten years designs have appeared in various countries for utilizing the kinetic energy of ocean currents. For example, it has been proposed to slow down the current in the Bering Straits, transforming its kinetic energy into work. Recently a number of ingenious proposals have been made for using the branch of the Gulf Stream which flows past the shores of France. Such proposals are irresponsible, and their realization would be dangerous for the climate of the northern hemisphere. Ocean currents permit heat exchange between the tropical and polar regions, and the slowing down might lead to catastrophic consequences for people living in the temperate zones. Slowing down the current in the Bering Straits would lead to irreversible consequences.

Tidal electric power plants are in use here and there, but the large capital investments required for their construction prevent them from being considered as serious energy sources of the future.

Appreciable power can be obtained from floating electric power plants which utilize wind waves on the surface of a liquid. To understand the principle of their operation it is appropriate to mention papers by M. A. Lavrent'ev and M. M. Lavrent'ev which explain the swimming of snakes and fish in a curvilinear channel formed by a connected mass of water [5].

The muscles of the animals are strained in such a way that at each point along the body there is a variable bending moment. At points where the curvature of the channel along the path of motion of the animal decreases as a function of time their muscles perform work in straightening, and conversely, at points of increasing curvature the animal's muscles perform work of flexing the body. According to the law of conservation of energy, in a perfectly smooth channel the work expended in acceleration is completely spent in moving the animal forward along the curvilinear channel, e.g., along a sine curve.

Floating electric power stations behave in a similar way. Imagine a long float consisting of a number of pontoons connected by hinges, and we have a rotated picture of a swimming snake. In the present case the float is anchored and remains at rest relative to the shore, and the curvilinear channel formed by the wind waves moves along the float. In contrast with the snake which bends in the horizontal plane, the float bends in the vertical plane. The waves forcing the bending of the float cause the pontoons to rotate with respect to one another at the hinged joints with a large bending moment of the order of magnitude of the weight of each pontoon times the distance from its center of gravity to the hinge. Water pumps mounted at the hinges slow down the bending of the float and convert the work done in rotating the hinge into hydrostatic energy of the water which later is easily transformed into electrical energy by high-speed turbines.

Floating electric power stations could be used along the coast of the Far Eastern region of Kamchatka, Sakhalin, and the Kurile Islands where the wave field is stable and there is a large change of curvature near the shore, even without wind.

Of all the renewable energy sources, the most promising, in our opinion, is wind power. It was not by chance that several centuries ago our ancestors considered this the principal energy source.

Approximate calculations show that for a carefully constructed wind plant the cost of 1 kW of power can be decreased to 100-200 rubles, and the cost of energy to 0.1 kopecks per kWh.

The area of a windwheel should intercept as large a cross section of the wind stream as possible for minimum weight of the structure. In constructing wind plants it is necessary to take account of the very important parameter $\lambda = u_{max}/v$, where u_{max} is the maximum velocity of a hurricane occurring once in several decades, and v is the root-mean-cube of the wind velocity during a year.

In a strength calculation, a wind plant must withstand u_{max}, but it must operate continuously for wind velocities several times smaller than u_{max}. For the Far Eastern seaboard an approximate value is $\lambda = 4\text{-}5$.

A wind plant must be completely stable against random incoming wind streams.

Thus, if we require a safety factor of 2 for a hurricane wind, the operating safety factor must reach a value of the order of 50.

The windwheel must be positioned with respect to the path of the wind behind the tower. In contrast with existing structures, those being built should not have just a single cantilever bracket.

Vanes having a large sail area for the direction of the axis of the windwheel along the wind direction are very much less stable in a hurricane. In constructing a vane builders do not take account of the fact that during a hurricane one may not be concerned with just a plane parallel displacement of the wind stream, particularly close to the earth. Single strong vortices with a vertical or curvilinear axis acting on the vane fracture it instantaneously and rotate the whole wind system about a vertical axis.

In order to produce a more economical structure it is necessary to give up completely the dogmatic recommendations that the ratio of the diameter of the windwheel to the height of the tower be 1:2 and the attempt to expose the windwheel to an undisturbed wind stream.

The diameter of the windwheel should be chosen from considerations of convenience of mounting, using methods of loading which are common at the time. Taking account of the size of rolled steel which can be supplied and the height of present day movable cranes (height of the axis of the wheel 15 m), the most suitable diameter of a wind vane is close to 30 m. In this case the lowest point of the windwheel must be close to the ground.

TABLE 1

Year	Country	% of power of wind electric plant of total power potential	Reference
1995	USA	10-15	[12]
1907	Denmark	20-25	[13]

To estimate the prospective development of wind power in Siberia and the Far East it is necessary to perform an approximate calculation of the wind power resources. The main wind regions which must be considered are the seacoast, the large flat parts of the tundra, and regions of steady wind [6].

Wind plants can be located on the shore and on boats. Using the fact that the length of the seacoast of the eastern-most Urals is of the order of 30,000 km, and that the territory extending 100 km inland from the seacoast can make effective use of the wind stream, the total area with a relatively strong wind is $6 \cdot 10^6$ km^2. On this area the root-mean-cube wind velocity is close to 10 m/sec.

We estimate the wind power N expended on the area S considered to overcome friction with the surface of the earth by the expression

$$N = \int_S k \frac{\rho u^3}{2} dS, \qquad (1)$$

where k is the coefficient of friction, approximately 0.01 for the natural roughness of the earth, and ρ and u are the density and velocity of the air near the earth.

The power obtainable must be averaged over time, i.e., over 1 year.

Naturally the evaluation of these integrals will be more accurate the more accurately we estimate their components. A rough estimate without taking account of the many factors which are not presently available in the scientific literature can be performed by taking instead of Eq. (1)

$$N = Sk\rho v^3/2,$$

where S is the area of the earth on which the wind is blowing, equal to $6 \cdot 10^6$ km^2; v, root-mean-cube velocity of the wind, close to 10 m/sec; ρ, density of the air. With these values of S, ρ, and v, $N = 3 \cdot 10^{10}$ kW.

For comparison let us say that the total power developed by all the electric power plants of the Soviet Union is a little more than $2 \cdot 10^8$ kW. Thus, the wind power reserves are ≈150 times larger than the present electric power requirements and are essentially inexhaustible, and from the point of view of the ecology, ideally clean.

In designing wind plants it is convenient to use the following expression for the cost of 1 kWh:

$$C = \sum_{i=1}^{n} \frac{C_i}{E_i}, \qquad (2)$$

where E_i is the energy passing through subassembly i which costs C_i before its complete deterioration.

Each term in Eq. (2) corresponds to one subassembly of the wind plant. This formula enables one to compute quickly, to reject easily the unprofitable structural decisions, and to reduce the cost of 1 kWh to the smallest possible value. The sharpest decrease in cost is achieved by using special light multipolar ring dynamos mounted on the windwheel shaft and ensuring the necessary power generation at a relatively low angular velocity because of the large diameter.

The extensive use of thyristors and other semiconductor devices permits the complete automation of the operation of wind plants, and the direct transmission of the electric power generated into the power grid.

TABLE 2

Year	Country	Form of power	Cost of 1 kWh	Reference
1976	USA, Gulf of St. Lawrence	Wind power plant P = 200 kW	2.49 ¢/kWh	[14]
1957	Denmark	Diesel Wind power plant P = 200 kW	5.25 ¢/kWh 1 kWh 20% cheaper from wind power plant than from thermal electric power plant	[15]
1977	USA	Wind power plant P = 1500 kW Electric power plant	1.65-2.02 ¢/kWh 1-5 ¢/kWh	[16]
1977	USSR	Grid system Siberia	1.5-0.5 kopecks/ kWh	[17]

That wind power is rapidly receiving more attention all over the world can be judged from the number of patents issued each year for wind power equipment. Since 1976 this number has increased by a factor of 20-30 in comparison with preceding years, and remains approximately constant.

The possibility of using wind electric power plants to supplement existing power plants during the next two decades is being studied abroad.

Small European countries are interested in wind power plants employing balloons or dirigibles at a height of 10 km where a strong steady wind permits the establishment of a 50-MW wind power plant. It is proposed to use two cables connecting the wind plant with the ground substation to transmit the power to the earth [7].

In the United States experiments on the utilization of wind energy are being conducted on a national program. Goverment appropriations for wind power research increased by a factor of 30 from 1973 to 1979, and in 1979 were 60 million dollars [8].

Research performed in the United States which took account of many factors, including the character of the earth, the turbulence of the atmosphere, the coefficient of utilization of wind energy by a wind motor, and the efficiency of a wind power system, showed that 0.7% of the energy of solar radiation is transformed into wind energy in the layer next to the earth, and that ~10% of this, corresponding to an average power of $0.25\ W/m^2$, or $N = 1.3 \cdot 10^{14}$ W, can be utilized. Under the assumptions made, the total wind power potential of the earth is 20 times larger than that required. These studies confirm the substantial excess of wind power potential of the earth over that of other renewable energy sources [9].

In the Federal Republic of Germany, Switzerland, and a number of other foreign countries, research is being performed on the possibility of utilizing wind energy, and the optimum technical and economic characteristics of wind plants are being determined. On this basis it is predicted that the cost of wind power can be lowered to 400 dollars/kW, which is commensurate with thermal electric and atomic power plants [10].

The NU-101 wind plant built in Japan is operating satisfactorily at an antarctic station in Soya for wind velocities of 50 m/sec [11]. Tables 1 and 2 show certain characteristics of wind power plants and their relation to other power sources.

Thus, wind power will become cheaper than any other form now regarded as primary (oil, gas, coal).

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MAGNETIC COURSE GENERATORS USING THE TRANSITION OF A SEMICONDUCTOR MATERIAL INTO A CONDUCTING STATE

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At the present time there are a number of known explosion-type generators designed to obtain powerful pulses of an electric current and strong magnetic fields [1-6]. In these devices, the energy of an explosive is converted into electrical energy using conductors moving in a magnetic field. Thus, in MC (magnetic course) generators, the role of the moving conductors is played by the metallic parts of the electrical circuit, and, in MHD generators, by a high-velocity flow of conducting explosion products.

In [7], a method differing from the above is proposed for the formation of a moving conductor. For this purpose, a material having a semiconductor—metal-phase transition at reasonable pressures is used. With the passage of a shock wave over such a material, a conducting layer is formed behind its front. If the shock wave is propagated across the magnetic field, an inductive emf will be excited in the layer, which, with a closed configuration of the shock waves and the bounding conductors, can lead to the capture of the magnetic flux and its cumulation.

In the present article, experimental results from tests of generators working on silicon are given as well as some estimates of their parameters, made within the framework of an electrotechnical model.

1. Experiments were made in generators of flat and coaxial constructions. The working substance was brand KP-1 silicon, in the form of a powder with a grain size of 0.1-0.15 mm. The pressure of the phase transition of crystalline silicon was determined in [8] from static experiments and amounts to around 120 kbar; the conductivity of silicon in the metallic phase is close to the conductivity of the usual metals.

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