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COUNTER-ROTATING ROTOR AND STATOR GENERATOR AND FARADAY GENERATOR

Conventional generation methods are reviewed, which have low performance compared to newly developed ones. A method for generating electrical energy, protected by several patents, is proposed. The essence of the method consists in applying the counter-rotation of both the rotor and the stator, which allows the relative rotation speed of the generator to reach the sum of the rotor and stator speeds. Increasing the rotation speed leads to an increase in the frequency of the electromagnetic field; this allows for reduced generation power [losses], decreased weight and dimensions of the magnetic circuit due to operation at higher frequencies, and an improved material utilization factor. It is shown that the power changes proportionally to the cube of the velocity V and the square of the diameter d of the wind turbine. This means that when the wind speed or blade length increases by a factor of 2, the power (energy) of the airflow increases by 8 and 4 times, respectively.

The developed wind energy extraction method enables the utilization of low-potential wind speeds: the starting torque of the rotor is significantly reduced, allowing generation to begin at lower wind speeds compared to traditional single-rotor systems.

In fact, with this generation method, it is possible to double the electricity output for the same equipment and financial costs. The structural changes are minor in terms of complexity and are fully feasible for implementation.

The application of wind turbines based on the author's patents will allow for a significant reduction (up to 40–50%) in the capital expenditures for wind farm construction, which, on a national scale, will reduce the funding required for the deployment of wind power units.

The localization of wind turbine production with these properties will ensure attractiveness for buyers in terms of the price-to-power generation ratio.

Keywords: renewable energy sources, coaxial wind turbines, enhanced efficiency, autonomous power supply, small wind power.

Introduction

In the context of rising electricity demand and the growing consumption trends in industry and agriculture, the implementation of renewable energy sources is becoming increasingly important. Small-scale wind turbines with a capacity of 3–10 kW are of particular significance for small enterprises located in remote areas, as transmitting more than 1 kW of power over a distance of 1 km becomes economically unviable due to transmission losses. Providing power to industrial and agricultural facilities is further complicated by the fact that many of these sites are situated at a considerable distance from centralized power supply networks.

Autonomous power supply for organizations can be implemented in various ways. Power supply from diesel and gasoline generators, due to its extreme high cost, is not widely used and is reserved for categorized strategic facilities. As alternative energy sources, wind turbines are employed as they possess sufficient energy potential; solar panels are used, though they have a lower electricity output compared to wind turbines; and hydrogen and biogas plants are utilized, which are characterized by insignificant generation volumes. Hydropower offers high efficiency but requires substantial capital expenditures, comparable to those of nuclear, thermal, and district power plants, and most importantly, it requires the presence of water arteries suitable for hydroelectric dam construction.

Given the steady upward trend in fuel prices, coupled with the decreasing cost of equipment for wind energy, rapid construction timelines (6 months), tariff reductions, and subsidy policies in most countries – including Kazakhstan – the study of power supply for remote autonomous consumers using renewable sources, specifically wind energy, is highly relevant and holds significant scientific and practical interest.

Object of Research: A wind turbine with a counter-rotating rotor and stator.

Subject of Research: Derivation of the dependence of power generation on wind speed.

Goal: To investigate the capabilities and potential of counter-rotating wind turbines.

Objectives: To demonstrate the advantages of generators with counter-rotating stators and rotors; to present a methodology for calculating the relationship between wind speed and generated electric power; to evaluate the technical and economic efficiency of counter-rotating rotor and stator wind turbines.

Materials and Methods

This article is based on the research materials of established solutions in the field of electric generator and wind turbine design, incorporating a review of historical engineering experience. The study builds upon recognized developments and research in wind energy systems, including those published in patents and articles within Kazakhstan and internationally. The research methodology includes a systemic analysis of existing devices [1; 2; 3; 4] and a comparative study of the design features of single- and dual-rotor horizontal axis wind turbines (HAWTs). Furthermore, the work utilizes generalized results from laboratory and field experiments, experimental methods (physical modeling), and a feasibility study (techno-economic assessment) presented in this paper and the author's previous publications listed in the references.

Results and Discussion

The first electrical generator was constructed in 1831 by Michael Faraday. The generator consisted of a horseshoe-shaped permanent magnet and a copper disc rotating between the magnetic poles (Fig. 1, a). As the disc rotated, a constant EMF (electromotive force) was induced between its axis and its edge [5].

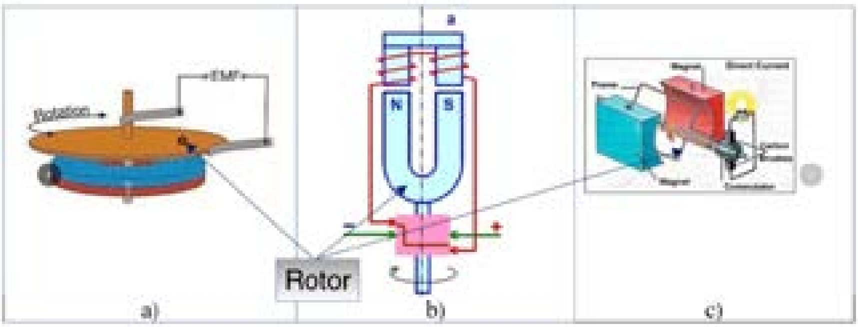

Figure 1 – Electric power generators:
a – Faraday generator, b – Pixii generator, c – modern generators

In 1832, Hippolyte Pixii improved upon Faraday's generator (Fig. 1, b), though the operating principle remained unchanged. More advanced homopolar generators, which are still in use today – albeit relatively rarely – are designed based on this same principle (Fig. 1, c).

The fundamental principle of conventional electricity generation is based on the rotation of a rotor relative to a stationary stator (Fig. 1).

Rotor rotation is considered most optimal from the perspective of design simplicity: a fixed stator and a rotating rotor.

A more detailed analysis of the power generation process reveals that to generate electricity, a magnetic field – for instance, from a permanent magnet – must intersect an electrical circuit (coil). This causes an EMF to arise at the ends of the circuit. When the circuit is closed, an electric current flows. The intersection of the circuit by a magnetic field implies that the magnetic field possesses a gradient – it changes in magnitude over time. This is most easily implemented through rotation. In this case, the induction value changes according to a sinusoidal law: it increases and decreases, passing through zero between these intervals.

Faraday and Pixii do not specify which component must rotate: the frame or the permanent magnet (Fig. 1, a and b). According to the law of electromagnetic induction (Faraday, 1831), a change in the magnetic flux through a closed circuit induces an electric current within it.

Core Principle

The foundations of this principle were established in 2010. The first results were published in the Republic of Kazakhstan innovative patent for invention No. 26105, titled "Wind Wheel," authored by Drobinskiy A. V., Shapkenov B. K., and Kaidar A. B., dated September 14, 2012, Bull. No. 9 [6].

In a conventional electrical machine, only the rotor rotates while the stator remains stationary. In a counter-rotating design (Fig. 2), both magnetic circuits can rotate in opposite directions, creating:

– a relative rotation speed equal to the sum of the rotor and stator speeds, rather than the difference or the single speed of the rotor alone (Fig. 3).

This allows for an increase in electromagnetic performance without increasing the overall dimensions.

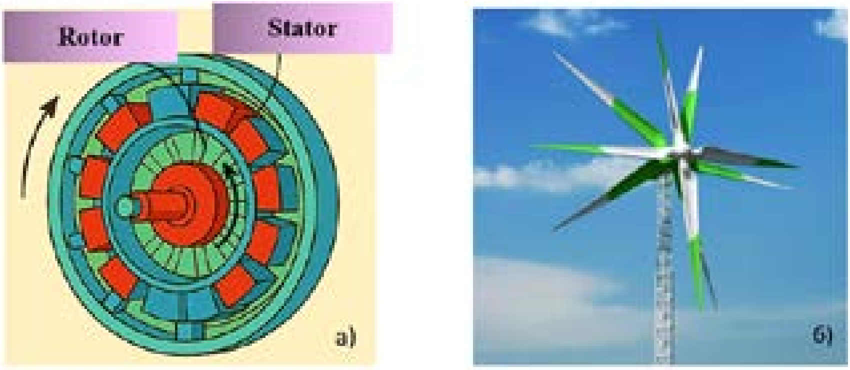

Figure 2 – Counter-rotation of the rotor and stator:
a – design, b – implementation

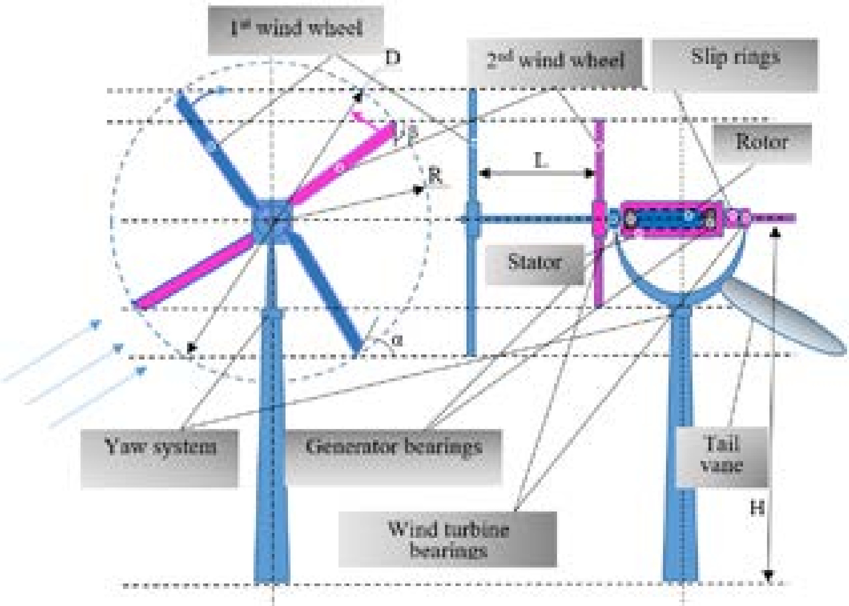

Figure 3 – A design variant of a wind turbine with counter-rotating wind wheels based on the author's patents [6; 7; 8; 9]

In a conventional generator, the permanent magnets of the rotating rotor (or its excitation winding) induce an EMF in the stator. In a counter-rotating rotor and stator configuration, the magnetic flux changes more rapidly due to the increased total relative velocity $\omega_{relative}$:

$$\omega_{relative} = \omega_{rotor} + \omega_{stator} \quad (1)$$

That is, the EMF increases linearly as a function of both rotations.

Substituting ω=2πf and dividing both sides by 2π, we obtain:

$$f_{relative} = f_{rotor} + f_{stator} \quad (2)$$

The combined frequency of the field and the generated EMF increases accordingly (2).

This means that the frequency of the EMF generated in the stator depends on the total relative velocity of the rotor and stator.

An increase in frequency allows for:

- increasing the power output;
- reducing the size of the core iron (due to operation at higher frequencies);
- improving the material utilization factor.

The interaction between two moving magnetic systems significantly enhances the generator's capabilities. It increases the power output and, when applied in wind energy, allows for the utilization of weaker winds. This expands the potential for electricity generation under low-wind conditions, where single-rotor systems operate with negligible efficiency.

The wind power (energy) – a crucial parameter for the calculation and selection of wind turbines – depends on the wind speed. The relationship between these characteristics is directly proportional and is expressed by formula (1):

$$N_p = \frac{\rho \cdot S}{2} V^3, \quad (3)$$

where:

- N_p – air flow power (W);
- V – air flow velocity (m/s);
- ρ – air density (kg/) (its standard value at a temperature of +15°C and a pressure of 760 mm Hg is 1.225 kg/)

– S – rotor swept area () (is practically equal to the area of the circle described by the edges of the wind turbine blades that are furthest from the axis of rotation); it is calculated using formula (4):

$$S = \pi \cdot d^2/4, \tag{4}$$

where:

– $\pi = 3{,}14$;

– d – rotor diameter (m).

From the given formulas, it follows that the power N_p changes proportionally to the cube of the speed V and the square of the diameter d of the wind generator turbine. This means that when the wind speed or the length of the blades increases by 2 times, the power (energy) of the air flow will increase by 8 and 4 times, respectively. Taking the area S equal to 1m^2. Setting V from 3 to 25 m/s, we get

Calculation for 3 m/s: $N_p = \frac{1{,}225 \cdot 1}{2} \cdot 3^3 = 16{,}5$ W/m^2.

The more visually presented information is shown in Table 1:

Table 1 – Dependence of power N_p on speed V according to formula (3)

Wind speed (m/sec)	3	4	5	7	10	14	16	20	25
Specific Power N_p of the air flow (W/)	16,5	39	76,5	210	612	1681	2509	4900	9570

The above arguments and formulas are purely theoretical. In reality, it is impossible to convert all the energy of the wind flow passing through the wind wheel into mechanical energy. Part of it is lost to the resistance of the wind turbine to the movement of air particles, part to friction; a significant part of it passes further with the flow, bypassing the wind generator.

Taking everything into account, the power of the wind generator on the wind turbine shaft can be calculated using formula (5) [9]:

$$N = V^3 \cdot d^2 \cdot \xi/2080 \tag{5}$$

where:

– N – wind generator power without accounting for losses in bearings and transmissions (W).

– V – wind speed (m/sec).

– d – diameter of the wind wheel (m).

– ξ – wind energy utilization factor (shows what part of the air flow power a specific wind generator can turn into mechanical energy).

– 2080 – empirical coefficient accounting for air density $\rho \approx 1.225$ kg/m^3) and conversion factors of circle geometry ($\pi/4$).

The value of the coefficient ξ depends on the design of the wind engine, the quality of manufacture and shape of its wings, and other factors. For high-speed wind engines equipped with blades of an aerodynamic streamlined profile, the value of the coefficient can be 0.42…0.46. In slow-speed units equipped with a large number of blades, this indicator is in the range of 0.27…0.33.

Advantages

Increased specific power. Due to the increase in the relative rotation speed, the change in magnetic flux is accelerated.

This allows obtaining more power at the same machine size or reducing dimensions at the same power.

Increased torque. Torque is proportional to the product of the interacting magnetic fields.

Simultaneous rotation increases the effective shaft torque, especially in motors for aviation, robotics, and UAVs.

Higher Efficiency (in some implementations). When optimizing the magnetic circuit, it is possible to reduce losses in iron and copper.

For turbomachinery and ventilation units: counter-rotation increases aerodynamic efficiency and reduces power demand.

Possibility of energy recovery. In some systems, stator rotation can be used to generate additional power circuits, or for energy transfer to neighboring nodes.

Compactness. It is not required to increase the length of the active part or the diameter to achieve high revolutions.

This is advantageous for compact high-power electric drives.

For wind power plants, the product cost remains equivalent to that of a single-rotor system plus the cost of an additional rotor, which does not exceed 10 % of the total cost of the primary equipment: the wind generator, tower, rectifier-inverter system, and battery storage. In fact, total capital expenditures are reduced by 40–50 %.

Main Architectures of Counter-Rotating Machines

There are 3 basic variants.

1. With two independent rotating parts:

– Internal rotor – permanent magnets or winding.

– Outer rotor (actually a moving “stator”) – also a magnetic system.

Used, for example, in motors for coaxial propellers.

Plus: maximum torque.

Minus: complexity, heavy bearings.

2. Rotor plus rotating stator (via bearings):

The stator receives mechanical motion not from the electrical supply, but from an external mechanism.

Used in specialized generators.

3. Bi-directional machines with double inverters (double feed):

When:

– the rotor is controlled through excitation;
– the stator is controlled by a separate inverter;
– rotations are synchronized by electronics.

This is the most modern variant.

<u>Where Counter-Rotation Gives Maximum Effect</u>

Electric aviation

For coaxial propellers:

– counter-rotating blades reduce vortex losses;
– and a double-rotation electric motor reduces weight and increases the efficiency of the propeller group.

Efficiency gain can be 10–25 %.

Unmanned Aerial Vehicles (UAVs) and helicopters.

Allows reducing the gearbox or completely abandoning it.

A gearbox is a source of noise and losses → abandoning it gives a large gain.

Marine screw-rotor installations

Coaxial screws increase the efficiency of propulsion systems by 15–30 %, and direct electric control allows abandoning complex mechanics.

High-speed generators

For example, in wind turbines:

– counter-rotation increases generator power without increasing the diameter [6; 7; 8].

Conclusions

The provided analysis is more accessible and clearer when presented in tabular form.

Table 2 – Advantages and disadvantages of counter-rotating wind generators

Parameter	Advantages	Disadvantages
Power	Higher ≈ 2 times at the same dimensions	—
Torque	Significant growth	—
Efficiency	May be higher	—
Construction	More compact	More complex
Reliability	—	Reduction in reliability
Cost	—	Higher up to 10%

The developed method of wind energy extraction allows engaging low-potential wind speeds: the starting of the wind wheel occurs at lower speeds, which allows starting generation at lower wind speeds compared to traditional single-rotor ones.

With such a method of generation, with the same hardware and financial costs, it is possible to increase electricity generation by 2 times. Changes in construction are technically insignificant in quantitative embodiment, and are quite feasible in execution [9; 10].

The application of wind generators according to the author's patents will significantly (up to 40-50 %) reduce capital costs for the construction of wind power plants, which on a state scale will reduce funding for the use of wind units.

Localization of the production of wind generators with the specified properties will ensure attractiveness for buyers from the point of view of price – generation power.

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ҚАРАМА-ҚАРСЫ АЙНАЛАТЫН ЖЕЛ ДӨҢГЕЛЕКТЕРІ БАР ЖЕЛ ГЕНЕРАТОРЛАРЫНЫҢ ТИІМДІЛІГІН НЕГІЗДЕУ

Жаңадан әзірленген әдістермен салыстырғанда өнімділігі төмен дәстүрлі генерациялау тәсілдері қарастырылды. Бірнеше патентпен қорғалған электр энергиясын өндіру тәсілі ұсынылды. Тәсілдің мәні – ротор мен статордың қарама-қарсы айналуын қолдануда, бұл генератордың салыстырмалы айналу жылдамдығын ротор мен статор жылдамдықтарының қосындысына дейін жеткізуге мүмкіндік береді. Айналу жиілігінің артуы электромагниттік өріс жиілігінің жоғарылауына әкеледі, бұл генерация қуатын оңтайландыруға, жоғары *жиілікте жұмыс істеу есебінен магнит өткізгіштің салмақ-өлшемдік көрсеткіштерін азайтуға және материалды пайдалану коэффициентін жақсартуға мүмкіндік береді. Қуат мәні жел турбинасының жылдамдығының V кубына және диаметрінің d квадратына пропорционал өзгеретіні көрсетілген. Бұл жел жылдамдығы немесе қалақтардың ұзындығы 2 есе артқанда, ауа ағынының қуаты (энергиясы) сәйкесінше 8 және 4 есе арататынын білдіреді.*

Әзірленген жел энергиясын алу тәсілі төмен потенциалды жел жылдамдықтарын пайдалануға мүмкіндік береді: жел дөңгелегінің іске қосылу сәті айтарлықтай төмендейді, бұл дәстүрлі бір роторлы генераторлармен салыстырғанда желдің төмен жылдамдықтарында генерацияны бастауға жағдай жасайды.

Іс жүзінде, генерациялаудың мұндай тәсілінде аппараттық және қаржылық шығындар бірдей болған жағдайда электр энергиясын өндіруді 2 есе арттыруға болады. Конструкциядағы өзгерістер техникалық тұрғыдан маңызды емес және орындалуы толықтай іске асырылатын деңгейде.

Автордың патенттері бойынша жел генераторларын қолдану жел электр станцияларын салуға жұмсалатын күрделі шығындарды айтарлықтай (40–50 %-ға дейін) төмендетуге мүмкіндік береді, бұл мемлекеттік ауқымда жел агрегаттарын пайдалануды қаржыландыруды азайтады.

Аталған қасиеттері бар жел генераторлары өндірісін локализациялау (жергіліктендіру) сатып алушылар үшін «баға – генерация қуаты» тұрғысынан тартымдылықты қамтамасыз етеді.

Кілтті сөздер: жаңартылатын энергия көздері, коаксильді жел генераторлары, жоғары тиімділік, автономды электрмен жабдықтау, шағын жел энергетикасы.

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ГЕНЕРАТОР СО ВСТРЕЧНО-ВРАЩАЮЩИМИСЯ РОТОРОМ И СТАТОРОМ И ГЕНЕРАТОР ФАРАДЕЯ

Рассмотрены традиционные способы генерации, которые по сравнению с вновь разработанными имеют низкую производительность. Предложен способ генерации электрической энергии, запатентованный несколькими патентами. Суть способа состоит в применении встречного вращения и ротора, и статора, что позволяет обеспечить относительную скорость вращения генератора до суммы скоростей ротора и статора. Увеличение частоты вращения приводит к увеличению частоты электромагнитного поля, что позволяет уменьшить мощность генерации, уменьшить массогабаритные показатели магнитопровода за счет работы на более высоких частотах, улучшить коэффициент использования материала. Показано, что мощность изменяется пропорционально кубу скорости V и квадрату диаметра d ветротурбины ветрогенератора. Это означает, что при увеличении скорости ветра или длины лопастей в 2 раза мощность (энергия) воздушного потока возрастет в 8 и 4 раза, соответственно.

Разработанный способ извлечения энергии ветра позволяет задействовать низкопотенциальные скорости ветра: пусковой момент ветроколеса значительно снижается, что позволяет начинать генерацию при более низких скоростях ветра по сравнению однороторными традиционными.

Фактически при таком способе генерации при тех же аппаратурных и финансовых затратах возможно в 2 раза повысить генерацию электроэнергии. Изменения в конструкции технически несущественные в количественном воплощении, в исполнении вполне реализуемо.

Применение ветрогенераторов по патентам автора позволит существенно (до 40-50 %) снизить капитальные затраты на строительство ветроэлектростанций, что в масштабах государства снизит финансирование на использование ветроагрегатов.

Локализация производства ветрогенераторов с указанными свойствами обеспечит привлекательность для покупателей с точки зрения цена – мощность генерации.

Ключевые слова: возобновляемые источники энергии, встречно-вращающиеся ветрогенераторы, повышенная эффективность, автономное электроснабжение, малая ветровая энергетика.

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