ISSN 1453 – 7303 **"HIDRAULICA" (No. 3/2017)**
Magazine *of Hydraulics, Pneumatics, Tribology, Ecology, Sensorics, Mechatronics*

Increasing Energy Efficiency and Optimizing the Operation of Systems That Produce Clean Energy from Renewable Sources

PhD. Eng. **Corneliu CRISTESCU[1],** PhD. Eng. **Cătălin DUMITRESCU[1],**
Prof. PhD. Eng. **Valeriu DULGHERU[2],** PhD. Eng. **Teodor Costinel POPESCU[1]**

[1]Hydraulics and Pneumatics Research Institute INOE 2000-IHP, Bucharest; cristescu.ihp@fluidas.ro

[2]Technical University of Moldova, Chișinău; dulgheru@mail.utm.md

Abstract: *This paper presents some general issues regarding the development of research concerns in the field of renewable energy worldwide, as well as some research directions for increasing the efficiency of renewable energy conversion systems, addressed in the Institute INOE 2000-IHP in the field of energy efficiency and functional optimization of the systems that obtain clean energy from renewable resources. In the end, there are presented some techniques, methods and ways for optimization, in terms of structure and operation, of wind and hydraulic energy conversion parts and systems, and the paper denominates several practical achievements of the Technical University of Moldova in Chisinau, Republic of Moldova, which is the collaborator of the Institute in the implementation of a project on renewable energy.*

Keywords: *Renewable energy, energy efficiency, functional optimization, clean energy, wind energy, hydraulic energy*

1. Introduction

The concept of energy efficiency (or optimization of energy consumption) has currently become one of the main concerns of mankind across the globe.
Human society has become more aware of the need to develop a sustained strategy to increase energy efficiency and implement energy efficiency programs amid the worrying depletion of the Earth's fossil fuel reserves.
Today, we can talk about a global energy policy and a concerted strategy to reduce pollutant emissions into the atmosphere, both based on practical technical and economic solutions for the rational use of fossil fuel reserves (which still have the main share of energy production); we can also talk about increasing, on a wider scale, the use of renewable energy resources, the so-called "*clean*" energies or unconventional energies, an alternative to the current system of energy recovery of the Earth's fuel reserves. The environmentally friendly renewables (solar, wind, hydraulic, etc.) are today unable to cover these ever-increasing needs [1].
Renewable energy comes from natural resources that are constantly renewed over relatively short periods of time. Currently, the functioning of the world economy relies heavily on energy from non-renewable resources (coal, oil, natural gas). Factors such as greenhouse gas emissions that favour global warming (Figure 1), pollution, acid rain, all caused by the use of these conventional resources, but also the alarm signals that draw attention to the fact that oil - the main fuel source for transport - is about to run out, have triggered a significant global investment process in order to **capitalize on renewable energy resources** [2]. Renewable energy sources can be used both as centralized energy sources and, to a large extent, as decentralized sources. The latter are extremely advantageous especially for rural or isolated consumers, but there are special issues about operating stability and energy storage [1].
The year 2015 was an extraordinary one for renewable energy, with the largest global capacity additions seen to date, although challenges remain, particularly beyond the power sector. The year saw several developments that all have **a bearing on renewable energy**, including a **dramatic decline in global fossil fuel prices;** a series of announcements regarding the lowest-ever prices for renewable power long-term contracts; a significant **increase in attention paid to energy storage** [3].
Now, in the world annually there adds more renewable power capacity than it adds (net) capacity from all fossil fuels combined. In 2015, renewables accounted for an estimated more than 60% of net additions to global power generating capacity, and for far higher shares of capacity added in

several countries around the world. By year's end, renewables comprised an estimated 28.9% of the world's power generating capacity – enough to supply an estimated 23.7% of global electricity, with hydropower providing about 16.6%.

The top countries for total installed renewable electric capacity continued to be China, the United States, Brazil, Germany and Canada. China was home to more than one-quarter of the world's renewable power capacity–totalling approximately 495 GW, including about 296 GW of hydropower. Considering only non-hydro capacity, the top countries were China, the United States and Germany; they were followed by Japan, India, Italy and Spain, Figure 1.

Among the world's top 20 countries, for non-hydro renewable power capacity, those with the **highest capacity amounts per inhabitant** were: Denmark, Germany, Sweden, Spain and Portugal.

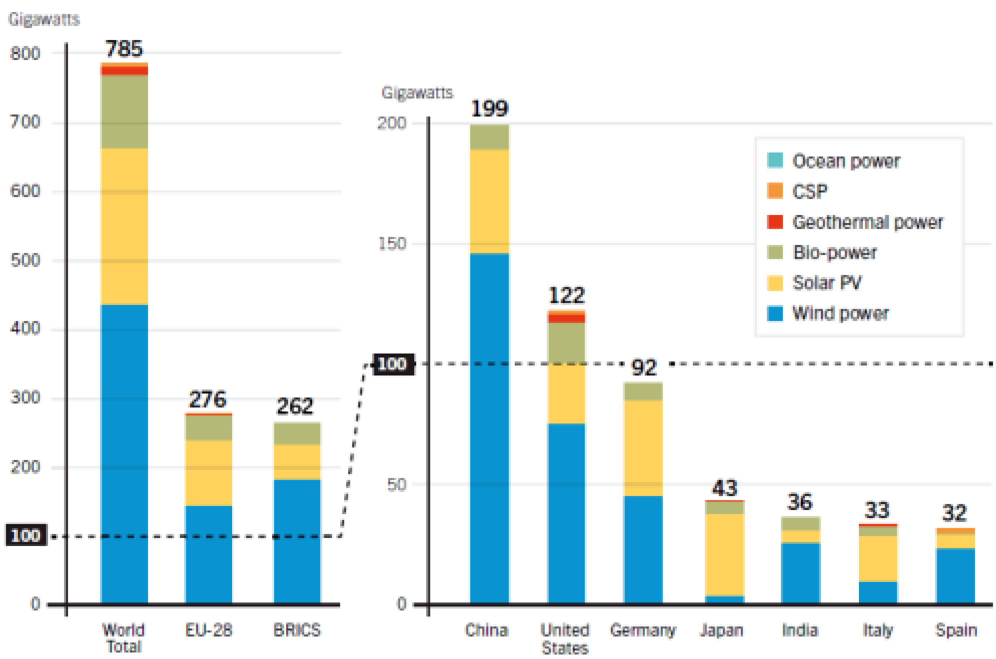


Fig. 1. Renewable Power Capacities in World, EU-28, BRICS and Top Seven Countries [3]

The **Wind and solar PV** both saw record additions for the second consecutive year, together making up about **77% of all renewable power capacity** added in 2015.

Renewables are now established around the world as **main-stream sources of energy**.

Emphasis on **activities to improve energy efficiency** in all sectors **increased during 2015** at all levels. There is growing recognition worldwide that **energy efficiency** can play **a key role** in reducing energy-related emissions and that it can provide multiple economy-wide benefit– such as enhanced energy security, reduced fuel poverty and improved public health [3].

In this context of the evolution of renewable energies, efforts of researchers in the field aim at **increasing the energy efficiency** of renewable energy conversion systems, identifying new technologies and improving the existing ones, through **analysis and optimization** of all technical and functional aspects, as we shall see below.

2. Research directions to increase the efficiency of renewable energy conversion systems

Given **the trend of continuous growth** of systems using renewable energy sources, respectively growth of the production of energy from these sources, a current but also prospective issue is, on the one hand, that of **increasing the efficiency of clean energy production systems,** and on the other hand, **optimizing their associated consumption**.

In this respect, for each type of system of obtaining energy from renewable sources, techniques, technologies and appropriate energy capture systems have been developed, but also **methods and techniques to increase the efficiency** and **optimize the associated consumption**.

To increase the efficiency, research has focused on **optimizing technical solutions of turbines and existing systems** which capture wind and hydraulic renewables, on the one hand, and on the other hand, on **identifying / designing new technical solutions of turbines and systems** which capture energy from wind and hydraulic sources.
Also there has been conducted research on **optimizing the associated consumption**, both to producers and consumers, in order to have, in the end, **higher energy efficiency. For the consumer,** it is essential **the amount of energy** delivered, the form of useful energy needed, how big energy losses are there and how much he has to pay for the energy delivered [1].
Energy, either fossil or renewable, **conversion methods** are characterized by **the efficiency factor *E*.** The higher the *E* efficiency, the less input primary energy will be spent to produce an output unit of energy [1].
The efficiency factor *E* is determined as the ratio:

$$E = (E_{useful} / E_{primary} \text{ x } 100 \quad [\%] \tag{1}$$

Most of **the primary energy sources** on Earth are carbon-based fossil fuels. **Depletion of** oil and natural gas **reserves,** increased difficulties related to their capitalization, that will inevitably lead not only to **price increase** but also to awareness of **ecological disaster** to which mankind is heading, **will change the balance in favour of renewable energy sources** which are very environment friendly.
The issue of increased efficiency and **functional optimization** of renewable energy conversion systems **is very complex**; this is also due to the multitude of conversion technologies and equipment; therefore, only a few of them will be addressed in the following parts of the paper.
The main research directions for increasing efficiency and optimizing renewable energy conversion systems consist in:
- optimizing technical solutions for wind turbines and existing wind and hydraulic systems;
- optimizing hybrid systems provided with energy storage;
- designing new technical solutions for turbines and wind and hydraulic systems.

Here below are some of the world's concerns targeting increased efficiency and optimization of renewable energy conversion systems.

3. Optimizing the technical solutions for wind turbines and systems

Concerning the **generation and use of electricity** from **wind energy**, the world's undeniable leader is the EU-27 European community with a share of 65%, followed by the USA and India. No other global industry sector experiences such a spectacular development. *Wind energy is certainly one of the fastest growing technologies and it plays an important role, contributing to the creation of a sustainable and competitive energy policy in Europe* [1]. When settling a large number of wind turbines, the question that rises is related to **optimization of the wind farm** [4].
Thus, after **identifying a location** for the construction of a **wind farm**, we need to **analyze / verify the possibility for connection** or not of the wind farm to the electrical grid in the area. Another issue is related to **choosing the turbine type;** its **sizes**, and also **the number of turbines** are very important elements of optimizing a wind farm, figure 2.
It is also possible to **optimize the distances between the turbines**, to road access and to the grid. This optimization can reduce the cost of investment using **less material, shorter cable routing**; one can also better design the **access ways** and permanent or temporary **mounting platforms**.
The basic principle of a wind turbine has remained almost unchanged and consists of **two conversion processes** made by the main components, figure 3, [5]:
♦ **the rotor,** which **extracts the kinetic energy of the wind** and **converts it into generator torque**;
♦ **the generator,** which **converts this torque into electricity** and delivers it to the grid.

Fig. 2. Wind farm in California during winter [5]

Fig. 3. The structure of a wind power station [5]

The amount of electricity produced by a wind power station depends on the type and sizes of the turbine and also on the installation site. Although apparently unchanged, wind power station **technology** has received **a number of improvements**, being made both the **optimization of the basic components**, particularly the turbine, and the **optimization,** as a whole, of **operation of existing wind systems / power stations**. The latest achievements are equipped with a **tilt angle control device** which changes the angle of the rotor blade when there are unfavourable weather conditions.

3.1 Conversion of the kinetic energy of the airflow into mechanical energy. The Betz limit

As is known from the literature [1], actually, not all wind power can be converted into mechanical energy. When the air flows at a certain speed, the turbine converts only some of the kinetic energy of the air, and a considerable amount of energy will be retained in the air flow leaving the turbine, otherwise the turbine will not work. Figure 4 shows the variation in the specific power of a flow of air depending on the speed. The rated estimated wind speed for modern high-capacity turbines rages from 12.0 to 15.0 m/s (shaded area), and Figure 5 shows schematically an air flow at the initial speed *V0*, which crosses the circular area *A0* and interacts with the turbine rotor with the swept area *A1*. In the section *A1* the airflow encounters resistance, the pressure increases, and the speed drops to *V1*. Leaving some of the energy, the airflow leaves the turbine at speed *V2*, which is lower, resulting that *A2>A1>A0*.

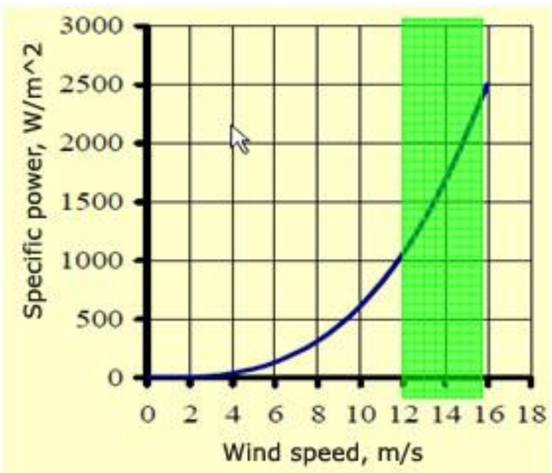


Fig. 4. Variation of specific airflow power [1]

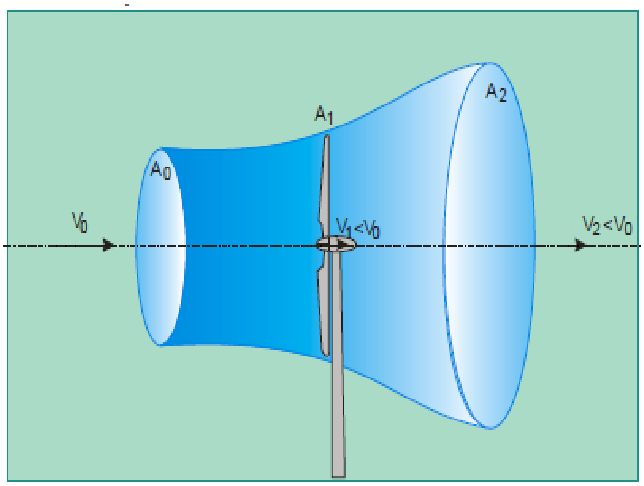


Fig. 5. Turbine effect on the airflow [1]

According to the theory of Betz (German physicist), the maximum theoretical power can be 59.3% of the flow power, but practically neither the best and optimized turbines can exceed 45-50%.

3.2 Determining the optimal number of blades in wind turbines

Betz's theory does not indicate the operation mode for the turbine or what construction the rotor should have so that the maximum power factor is reached. **Efficiency of airflow energy conversion** into mechanical energy will be **lower than the optimum value** if:

1. **The turbine rotor has a large number of blades** (the ratio of solidity is high) or the rotor rotates at a very high speed and each blade moves into an air flow disturbed (turbulent) by the blade in front of it;

2. **The turbine rotor has a small number of blades** (the ratio of solidity is low) or the rotor rotates at a very low speed and the air flow crosses the surface of the rotor without interacting with it.

It follows that, in order to obtain **maximum energy conversion efficiency**, **rotation speed of the rotor must be correlated with wind speed**.

To characterize wind turbines with different aerodynamic characteristics, the dimensionless parameter *λ*, called \`tip speed ratio\`, is used. Speed ratio connects in one formula three important turbine variables: rotation speed *ω,* the radius (or diameter) of the rotor *R* and wind speed *V*, and it is defined as the ratio of the linear velocity of the blade tip *U* and wind speed:

$$\lambda = \frac{U}{V} = \frac{\omega R}{V} \tag{2}$$

A turbine of some kind of structure can operate in a wide range of variation in tip speed ratio *λ*, but it will have maximum efficiency *Cp* only for an optimal value of tip speed ratio, in other words, if the linear speed *U* will be equal to the wind speed multiplied to the optimum value of the tip speed ratio.

Figure 6 presents the characteristics *Cp–λ,* taken from [6], for turbines with a different number of blades. Analyzing these features enables us to draw the following conclusions:

1. **The lower the number of blades**, the higher the optimal tip speed ratio for which the power factor or **the energy conversion efficiency is maximal**.

2. **Two turbines with equal power** but with a different number of blades differ in the fact that **the turbine with many blades will develop a high torque and will have lower rotational speed** and the other way around – the turbine with few blades will develop a small torque but will have a higher rotational speed.

3. **The three-bladed turbine** has **the highest efficiency factor**. The difference between the maximum efficiency factors of 2 to 5-bladed turbines is not significant. Advantages of turbines with a **small number of blades** consist of the possibility of operating in a **wider area of variation in tip speed ratio**, in which **the efficiency factor has a maximum value** or close to the maximum one.

4. The maximum efficiency factor (Betz) of the 12 to 18-bladed turbine is lower than the one of the 3-bladed turbine and does not exceed 0.35.

3.3 Optimizing the ratio of the power and the diameter of the turbine

The mechanical power generated by the turbine is proportional to the square of the rotor diameter. With increasing in diameter, respectively increasing in tower height, the wind speed will also increase. Small power turbines have towers with relatively greater heights than high power turbines. This is explained by the need to exclude the negative influence of the surface layer of the soil and the influence of obstacles on the wind speed. For rotor diameters between 5 and 10 m the ratio of the tower height to the rotor diameter is equal to 6 – 2. Starting with diameters equal to or greater than 30 m this ratio varies around number 1. Obviously, the specific costs of small turbines will be higher.

As said before, with increasing in diameter, respectively increasing in tower height, the wind speed will also increase. Usually, the increase in wind speed is considered proportional to the ratio of heights to the 1/7 degree [3, 5]. Thus the power of the turbine is proportional to the diameter of the rotor to the (2+3·1/7) = 2.42 degree. For the turbines currently on the market a good approximation is given by the formula:

$$P = 0.06 \cdot D^{2.42} \tag{3}$$

in which *D* – is the diameter of the rotor, in m; *P* – power, in kW.
Figure 6 presents the qualitative and quantitative evolutions of power of modern turbines [1], [6]. The continuous line in Figure 7 corresponds to the analytical formula (3).

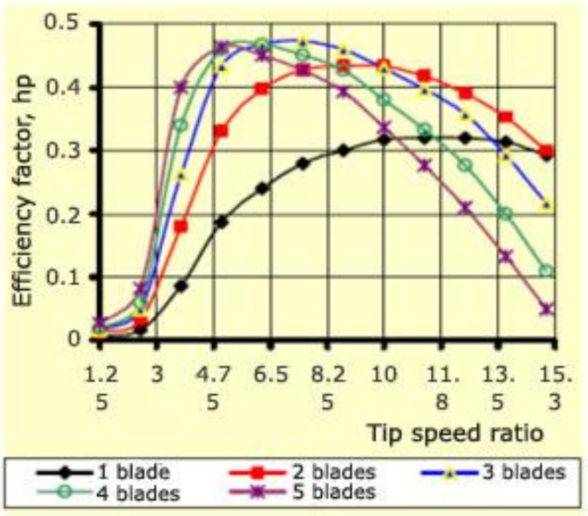


Fig. 6. Aerodynamic characteristics of wind turbines with different numbers of blades [1]

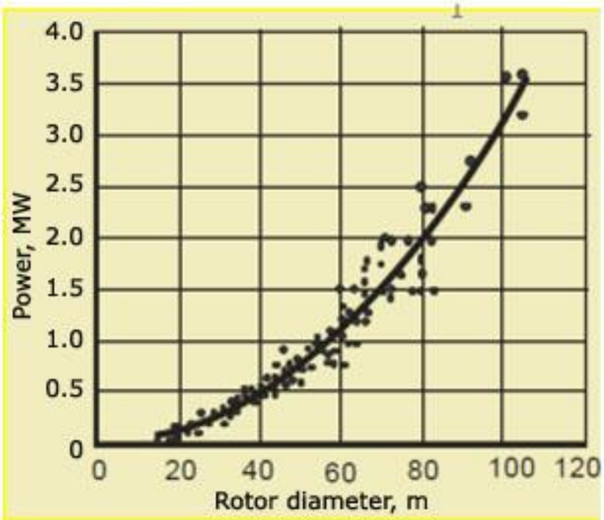


Fig. 7. The rated power of the turbines on the market relative to the rotor diameter [1]

Worldwide there is a tendency to increase the diameter of the rotor, even if the rated power remains the same.
The evolution of the wind turbine diameters over time is shown in Figure 8, [7].

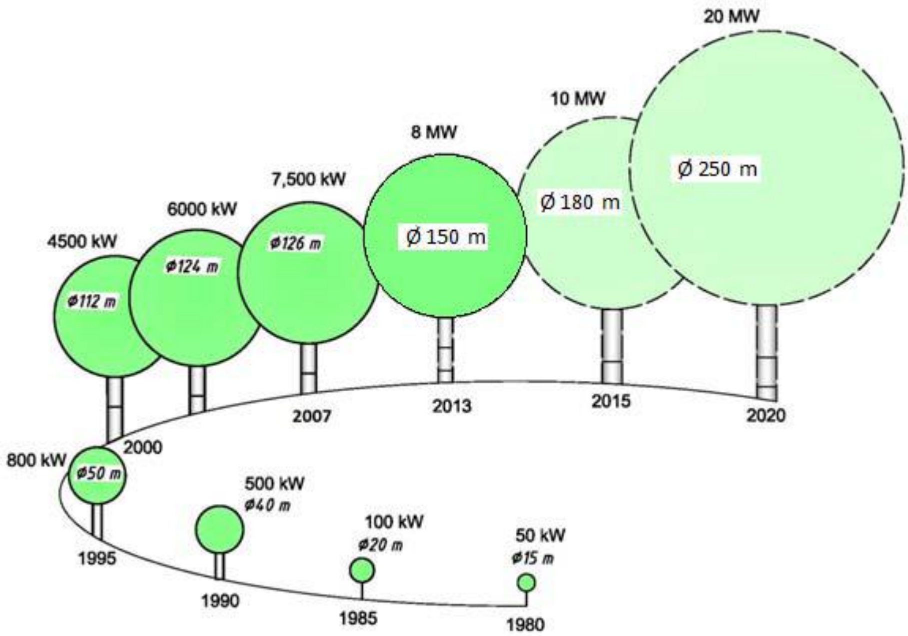


Fig. 8. Increase of the rotor diameter and the power of the turbines on the market [7]

Increasing rotor diameter leads to increased power extracted from the wind. But if the rated power remains the same, the estimated wind speed can be reduced. This increases the use of wind turbines, which may also include other areas with medium and low wind potential, where average wind speeds are somewhat lower, but can generate the same rated power, by using a larger wind turbine diameter.

Another important aspect, which should be optimized in functioning of wind turbines, is the noise that a careless design can generate. It is known that the linear speed of the blade tip is the product of the angular rotational speed of the turbine and the rotor radius. For example, for turbines with rated power of 0.6 – 3.6 MW the linear speed varies from 43.0 to 90 m/s (155 – 325 km/h).
Such linear speeds require a rigorous design of the aerodynamic profile, ensuring good blade surface quality and excellent rotor dynamic balancing. All these measures lead to a considerable reduction of noise, which allows the optimal location of modern wind turbines even around villages and towns.

3.4 Optimizing wind turbine operation by controlling power

The wind turbine will supply the rated power in the grid if the wind speed is equal to the calculation one, usually 11–15 m/s. For higher wind speeds, we need to limit the mechanical power, i.e. over-stress on the blades of the rotor, the multiplier, the generator, the tower, etc. This raises the need for turbine power control [1].
The most common are the following control methods:
1.- **Passive aerodynamic braking** (*passive stall control*);
2.- **Adjusting the angle of attack** (*active pitch control*);
3.- **Active aerodynamic braking** (*active stall control*);
4.- **Removing the turbine rotor from the direction of the wind** (*yaw control*)

1. Power control by using passive aerodynamic braking (passive stall control) is the simplest method and can be used for turbines with constant rotational speed, In other words, the speed of rotation does not depend on the wind speed or it varies insignificantly (1–2 %). The constant rotation speed of the turbine can be obtained in control systems equipped with asynchronous generators or synchronous generators connected directly to public electrical grids (Figure 9 b). The rotor blades are rigidly fixed and have an aerodynamic shape that ensures laminar flow of air for wind speeds ranging from the start speed *Vp* and the calculated one *Vc* (Figure 9 c). For wind speeds higher than *Vc* (Figure 9 a), the movement of the air flow above the blade becomes turbulent, the lift force decreases, and the resistance one increases, and respectively the mechanical power decreases.

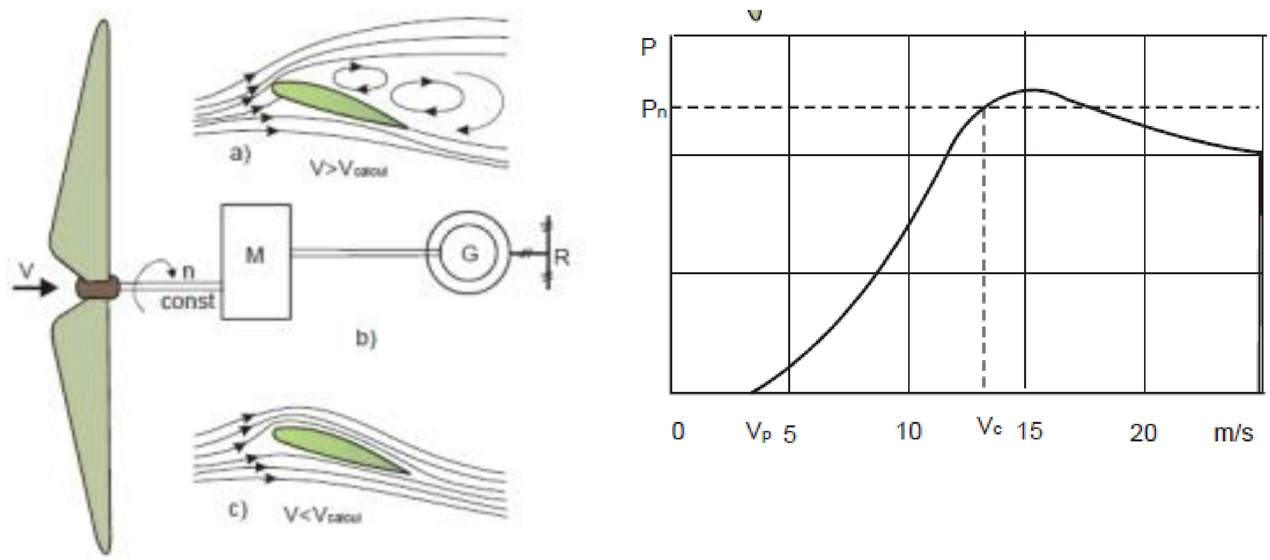


Fig. 9. The principle of controlling the power provided in the grid by using aerodynamic braking [1]

2. Power control by using adjustment of the angle of attack (active pitch control) is achieved by adjusting the angle of attack α (Figure 10 a). For this purpose the blade is rotated by a special mechanism around the longitudinal axis. The rotational speed of the turbine may be variable. To maintain constant frequency, the synchronous generator is connected to the grid via the frequency converter (Figure 10 b).

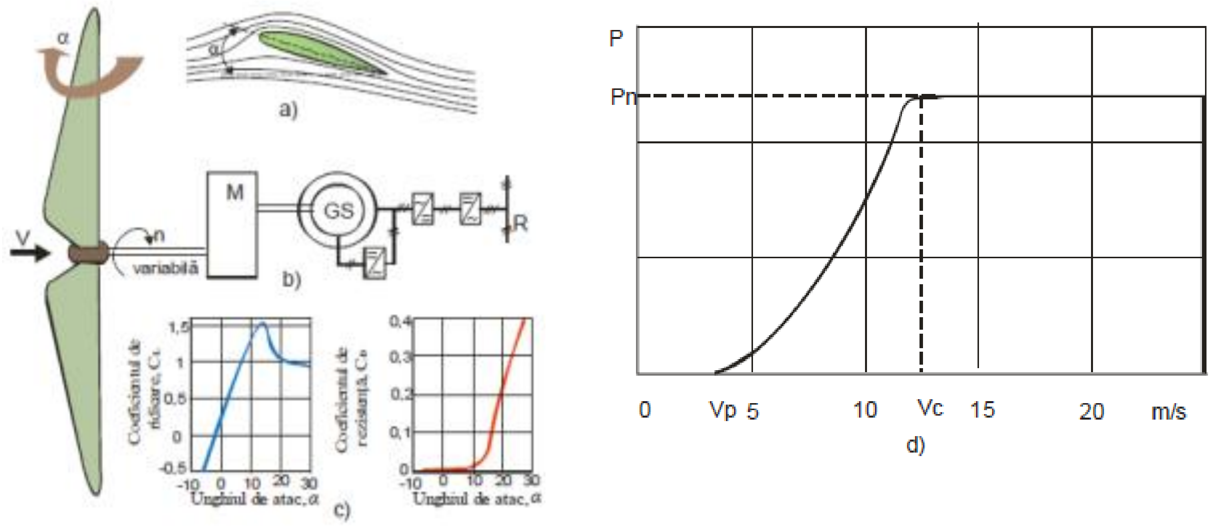


Fig. 10. The principle of controlling the power provided in the grid by using adjustment of the angle of attack [1]

For small attack angles ranging from 0 to 13 / 15 degrees, aerodynamic lift force increases linearly with increasing attack angles.
The main advantage of active angle adjustment is the reduction of mechanical stress on the blades, rotor and tower; at the same time it increases the efficiency of wind energy conversion at lower speeds than the nominal one by 2-4%.
Active aerodynamic braking is a combination of the two above-mentioned methods, namely aerodynamic braking and adjustment of the attack angle.

4. Optimizing the technical solutions for hydraulic turbines and systems

Hydraulic energy is the oldest form of renewable energy used by humans and currently has become one of the most commonly used renewable energy sources, being also one of the best, cheap and clean energy sources. **Hydraulic energy**, as a renewable energy source, can be captured under two extra-energy forms: **potential energy** (energy of freefall water) and kinetic **energy** (energy of water flows), with arrangements of different sizes [1].
Large hydropower is a **clean energy** source, uses **advanced technology**, being **the most efficient way to generate** electricity, as hydro power turbines **can convert up to 90% of the potential energy of the water** into electricity, but requires the construction of dams, which are very expensive, generating social and environmental problems as well.
For now, small hydropower plants, **micro hydropower,** are **not a major option** for the future in developed countries, for various reasons, such as the environment.
However, there is an increasing number of concerns in this regard.
More efficient use of hydraulic energy, in terms of ecological and social impact, is **<u>conversion of the kinetic energy of flowing water</u> of the rivers, without the construction of the dams**. What are the main advantages of this type of energy? This is a **technology with enormous potential**, which must exploit the hydraulic resources to meet the needs, in the first place the needs of **rural consumers with low access** to conventional energy sources. The electric hydro micro-turbines are the most efficient and cheapest electricity generators.
Analysis of existing **micro-hydropower plants which convert the kinetic energy of flowing water** showed that **there are reserves to increase the efficiency** of the turbines used. The **Betz coefficient, equal to 0.593,** is **maximum theoretical efficiency of** hydraulic energy **conversion**. Most **existing systems provide** a coefficient of use of the kinetic energy of the water **within the range of 0.2.** Only some **modern systems exceed the efficiency of 30%.** In this line, there are **sufficient reserves to increase the efficiency of flow water turbines**, which are increasingly tempting for engineers and inventors in the field.

In this line, outstanding achievements have been made in the **Republic of Moldova**, which are a good example for **Romania** [1]. For this purpose, the Centre for the Development of Renewable Energy Conversion Systems (CESCER) has been established in the Technical University of Moldova; it benefits from **qualified human potential, high performance engineering design and research infrastructure.**

4.1 Micro-hydropower plant with vertical rotor shaft and hydrodynamic profile of blades

Of particular interest are floating micro-hydropower plants. In terms of costs, **the floating micro-hydropower plants** are more efficient because they do not include essential costs related to the construction of dams. To **avoid building a dam**, the kinetic energy of the river can be used by means of **water current turbines.** This type of turbine is easy to install, simple to operate and maintenance costs are convenient. The current speed of 1m / s represents an energy density of **500W/ m^2** of the cross section. **The main advantages** of these types of micro-hydropower plants are:
- low environmental impact;
- no civil engineering works are required;
- the river does not change its natural course;
- the possibility of using local knowledge to produce floating turbines.

Another important advantage is that it is possible to **install a series** of micro-hydropower plants along the river at short distances (about 30-50 m) as the influence of turbulence caused by neighbouring installations can be excluded. In order to increase the coefficient of conversion of the kinetic energy of water (the Betz coefficient) there have been **elaborated and patented a series of structural diagrams of floating micro-hydropower plants,** which include a **rotor with vertical axis** with **vertical blades** and **hydrodynamic profile** in the normal section. The blades are connected to each other by a mechanism for directing them towards the direction of the water currents. The nodes listed are fixed to a **platform** installed on floating bodies. **The platform is connected to the shore** via an articulated metal frame and strain relief cables, as one can see in the Figure 11.

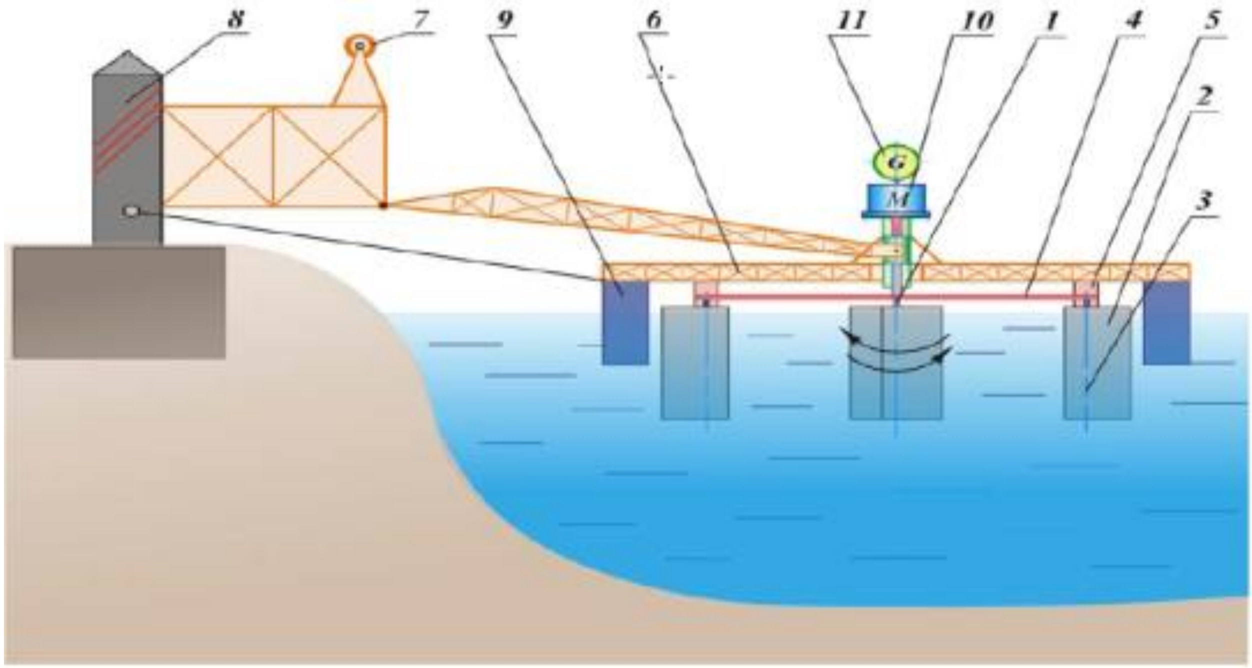


Fig. 11. Floating micro-hydropower plant with blade orientation mechanism [1]

Conceptual design of the rotor with hydrodynamic profile of the blades and adjustable to water currents is shown in the Figure 12, and positioning of the blade against the water currents - in the Figure 13.

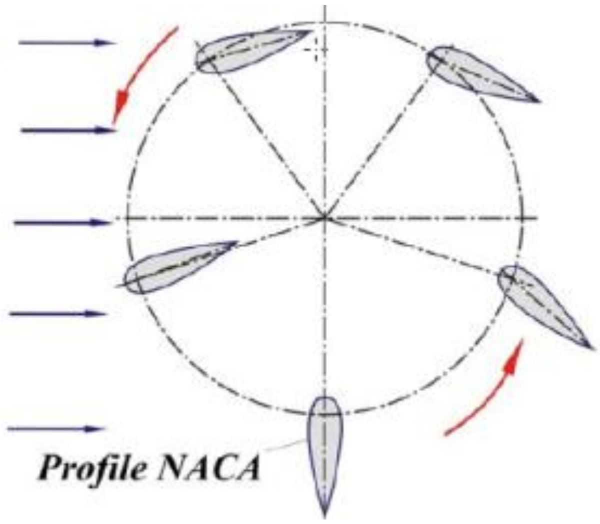


Fig. 12. Diagram of hydrodynamic profile adjustable blade rotor [1]

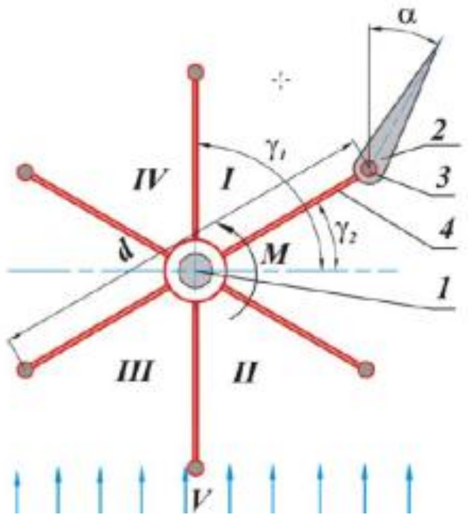


Fig. 13. Positioning of the blade against water currents [1]

The rotational movement of the rotor with a vertical axis is **multiplied** by means of a **mechanical transmission system** and it is conveyed to an **electric generator** or a **hydraulic pump** [1].

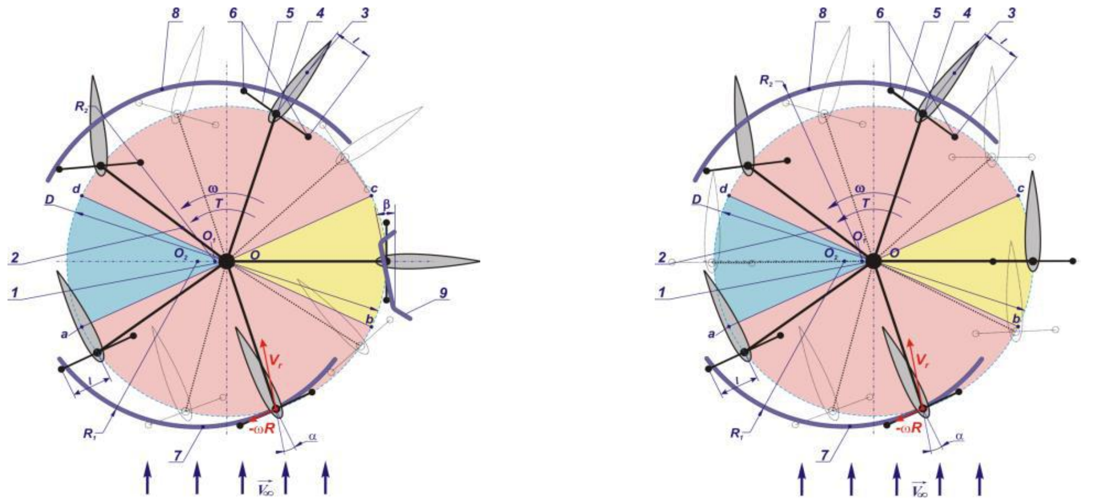
4.2 Structural and functional optimization of micro-hydropower plants

Structural and functional optimization of micro-hydropower plants is achieved by **choosing the optimal hydrodynamic profile of the blades**, which enables **increased conversion coefficient** (the Betz coefficient) due to **hydrodynamic buoyancy forces**. Increasing conversion rate is also achieved through **ensuring the optimal position of the blade** against water currents in various rotor rotation phases, using a blade orientation mechanism. Thus, virtually all blades (even those that move against water currents) **are simultaneously involved in generating torque** summary. The blades which move in the direction of the water currents use both hydrodynamic forces and water pressure exerted on the surfaces of the blades to generate the torque. The blades that move against the water currents only use hydrodynamic buoyancy forces to generate the torque. Due to the fact that the **relative speed of the blades** to the water currents **when the blades move against the water currents is virtually twice as big**, the hydrodynamic buoyancy force is relatively high, and the torque generated is commensurable with the one generated by water pressure [1].

In the micro-hydropower plant in the Figure 11**,** the turbine *1* includes the blades *2*, made with **hydrodynamic profile** and mounted on the axles *3*, fastened with the top in the extreme ends of the bars *4*, with the possibility of rotation around their axes. Position of the blades *2* at the angle α relative to the direction of flow of water is ensured by **the adjusting mechanism *5*.** The platform *6* is additionally secured with a winch *7*, fixed on the frame immovable on the shore pillar *8*. The turbine *1* together with the blades *2* is placed in the water stream of the river. The blade position relative to the water level is adjusted by the floating bodies *9* and by the blades *2* themselves, which are hollow. **The multi-blade rotor** is kinematically and coaxially connected through **the multiplier** *10* with the electric generator *11*. For technical servicing of the turbine *1*, which requires its removal from the water, the **winch** *7* is used. The blade *2,* in the Figure 13, is positioned against the water course at an angle *α,* which is variable depending on its position relative to the flow direction of the water.

As for the hydrodynamic rotor, to ensure for it maximum efficiency of kinetic energy conversion for each blade in different stages of rotation, there has been developed a **mechanism for blade orientation** relative to water currents; it has two configurations [8], as shown in the Figure 14:

1. Positioning of blades according to the angle of attack and the speed of water flows $V \leq 1.0$ *m/s* (Figure 14 a);
2. Positioning of blades according to the angle of attack and the speed of water flows $V > 1.0$ *m/s* (Figure 14 b)



a) for a speed of water flows V≤1.0 *m/s* b) for a speed of water flows V>1.0 *m/s*

Fig. 14. Diagram of the mechanism for continuous blade orientation relative to the direction of flow [8]

The difference is given by the positioning of the blade in the neutral zone, at the angle of attack **f**= 90^0*,* at a speed of water currents of V≤1.0 *m/s,* using the directrix *9* in the Figure 16 a, and in the latter case, the self-positioning of the blade in the neutral zone, at the angle of attack **f** = 0^0, takes place, and the directrix *9* is removed from the structure of the orientation mechanism. Thus, the orientation mechanism becomes a key mechanism in the optimal operation of the power plant.
In order to increase the coefficient of conversion of the kinetic energy of water a series of structural diagrams of floating micro-hydropower plants have been developed and patented; they include a rotor with a vertical axis with vertical blades and hydrodynamic profile in the normal section [8]. These optimized constructive solutions, some of them patented, have led to the **maximum energy efficiency** of turbines for running water. A series of theoretical and experimental research have also been carried out, resulting in optimization of the structural and functional parameters [9].
Following these theoretical and experimental research activities there has been achieved an experimental model of a hydrodynamic rotor micro-hydropower plant for converting the kinetic energy of the river into mechanical energy further used for pumping water, shown in the Figure 15, which has been located on the Prut River, Figure 16.

Fig. 15. Micro-hydropower plant with vertical rotor and blade with hydrodynamic profile [9]

Fig. 16. The industrial prototype of the micro-hydro power plant installed on the Prut River [9]

To achieve such performances, mathematical models, numerical methods and algorithms in CFD have been applied in the theoretical research for numerical simulation of turbulent flow in the hydraulic rotor area, especially near the hydrodynamic blades, namely through the boundary element method coupled with the Head model, implemented in the MATLAB software to simulate two-dimensional flow around the hydrodynamic blades, with preliminary determination of geometric, constructive and functional parameters [9]. Similar research has also been conducted in other areas of renewable energy sources, which also led to outstanding results in terms of increasing energy efficiency [7], [10], [11].

5. Conclusions

This paper has made an analysis of the methods of increasing energy efficiency and optimizing the operation of systems for clean energy production from renewable sources, being presented some practical examples in the sector of wind energy and hydraulic energy of running waters.
There has been presented the technical problem related to constructive solutions, methods and technologies for obtaining / capturing and storing energy from renewable resources, in order to increase the energy efficiency in capture, storage and reuse of renewable energies.
Worldwide, for each type of renewable energy system, appropriate energy capture techniques, technologies and systems have been developed, and also methods and techniques for increasing energy efficiency and optimizing their operation.
As a result of the global population growth and the decrease in oil and natural gas reserves, research and development have focused, in particular, on the field of renewable sources, which will ensure the energy future of mankind. In this line, the paper gives several research directions for increasing energy efficiency and optimizing renewable energy conversion systems, and in the end it presents some research and outstanding results achieved in the Technical University of Moldova in the Republic of Moldova, the collaborator of the Institute INOE 2000-IHP in the implementation of a project on renewable energy.

Acknowledgments

This paper has been developed in INOE 2000-IHP, as part of a project co-financed by the European Union through the European Regional Development Fund, under Competitiveness Operational Programme 2014-2020, Priority Axis 1: Research, technological development and innovation (RD&I) to support economic competitiveness and business development, Action 1.1.4 - Attracting high-level personnel from abroad in order to enhance the RD capacity, project title: *Establishing a high level proficiency nucleus in the field of increasing renewable energy conversion efficiency and energy independence by using combined resources*, project acronym: *CONVENER*, Financial agreement no. 37/02.09.2016.

References

[1] I. Bostan, V. Dulgheru, I. Sobor, V. Bostan, A. Sochireanu, "Renewable Energy Conversion Systems.- Wind, Solar, Hydraulic" („Sisteme de conversie a energiilor regenerabile - eoliană, solară, hidraulică"), Tehnica-Info Publishing House, Chişinău, 2017;
[2] E. Maican, "Renewable energy systems" („Sisteme de energii regenerabile"), Printech Publishing House, Bucharest, 2015;
[3] *** Renewables 2016 Global Status Report. REN21 Renewable Energy Policy Network for 21st Century. Paris, 2016; On: http://www.ren21.net/wp-content/uploads/2016/05/GSR_2016_Full_Report_lowres.pdf;
[4] *** Wind Power Energy. Cum se face optimizarea parcului eolian: Microsite-ing, 30 Oct. 2008; On: http://wpe.ro/cum-se-face-optimizarea-parcului-eolian-microsite-ing/;
[5] *** Wind and Solar. Why renewable Energy? In: Clean Line Energy Partners. http://www.cleanlineenergy.com/technology/wind-and-solar;
[6] T. Burton et al., "Wind Energy Handbook", John Wiley & Sons, New York, 2001, ISBN 0 471 48997 2; On: http://library.uniteddiversity.coop/Energy/Wind/Wind_Energy_Handbook.pdf;
[7] M. Guțu, "Optimization of aerodynamic blade resistance structure for wind turbines" („Optimizarea structurii de rezistenţă a palelor aerodinamice pentru turbine eoliene"), PhD thesis, Technical University of Moldova, Chişinău, 2017;
[8] Patent no. 601 Z, MD, F03B7/00; F03B13/18. Floating hydraulic power plant (Centrală hidraulică flotantă) / V. Bostan, O. Ciobanu, V. Dulgheru, A. Sochireanu, V. Gladîş, Published on 30.09.2013, BOPI no. 2/2013;
[9] O. Ciobanu, "Contributions regarding the research of the working body of the flow micro-hydropower plants" („Contribuţii privind cercetarea organului de lucru al microhidrocentralelor de flux"), PhD thesis, Technical University of Moldova, Chişinău, 2014;
[10] C. Cristescu, C. Dumitrescu, I. Ilie, L. Dumitrescu, "Hydrostatic transmissions used to drive electric generators in wind power plants", *Hidraulica Magazine,* No.1/2015, pp.60 – 72, ISSN 1453-7303;
[11] C. Cristescu, C, Dumitrescu, G. Vrânceanu, L. Dumitrescu, A-M. Popescu, "Combined energy systems for obtaining energy from renewable sources used in isolated areas", *Hidraulica Magazine*, No. 4/2016, pp.33 - 40, ISSN 1453 – 7303.