Chapter 6. HYDROPOWER

6.1. Overview

The inevitable increase of global energy consumption and the risk of a major environmental impact and climate change as a result of burning fossil fuels open wide prospects for the exploitation of renewable energies. Hydropower, as a renewable energy source, will have an important role in the future. International research confirms that the emission of greenhouse gases is substantially lower in the case of hydropower compared to that generated by burning fossil fuels. From the economical point of view, the utilisation of half of the feasible potential can reduce the emission of greenhouse gases by about 13%; also it can substantially reduce emissions of sulphur dioxide (main cause of acid rains) and nitrogen oxides.

Hydraulic energy is the oldest form of renewable energy used by man and has become one of the most currently 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 in two extra power forms:

– potential energy (of the natural water fall);

– kinetic energy (of the water stream running).

Both extra power forms can be captured at different dimensional scales. Table 6.1 presents a simple classification of hydraulic plants according to the electrical energy output.

Hydropower, in general, has become now the most important source of clean renewable energy, economically feasible. Hydroelectric power plants, integrated in multifunctional schemes, have performed various works such as irrigation, water pumping, etc. It is clear that hydropower will play an important role in the future both in terms of ensuring energy supply and water resources development. Under these options, it is necessary to develop these resources in conformity with the social, economic, technical and environmental standards. It is easy to forecast that global energy needs, especially electricity, will grow significantly during the twenty-first century, not only under demographic pressure, but also because of rising living standards in the underdeveloped countries, which will be 7 billion people in 2050 (78% of total population). From the point of view of this situation more alternative energy sources will be required, however, for environmental considerations, an important priority must be given to developing, technically, the full feasible potential of environmentally friendly renewable sources, in particular, hydropower.

Table 6.1. Classification of hydroelectric power plants according to electrical energy output.

Large scale hydro power	More than 100 MW, usually connected to a large electricity network
Medium scale hydro power	15–100 MW, usually connected to a large electricity network
Small scale hydro power	1–15 MW, usually connected to a large electricity network
Mini hydropower	about 100 kW, often is isolated, but sometimes can be connected to a large electricity network
Micro hydropower	From 5 kW to l00 kW, usually for a small community or rural industry
Pico-hydropower	From several hundreds of watts to 5 kW, usually for remote (isolated) consumers

6.2. Hydraulic energy conversion systems: brief history

Renewable energy has been used by man since the oldest times. The burning of biomass for heating and lighting was practiced from prehistoric times, without mentioning the use of organic products as energy for survival. Wind mills and water mills employed natural resources during many decades, as earliest source of energy production for agriculture and small-scale industrial processes. The existence of water on the Earth has conditioned the emergence and development of life. From the times immemorial, man has chosen a place to live near rivers and lakes to meet their natural needs in water, but also for carrying out basic irrigation works. Floating or rowing led human thought by observation, to use water force and energy. Thus, the mechanical power of running water can be considered one of the oldest tools.

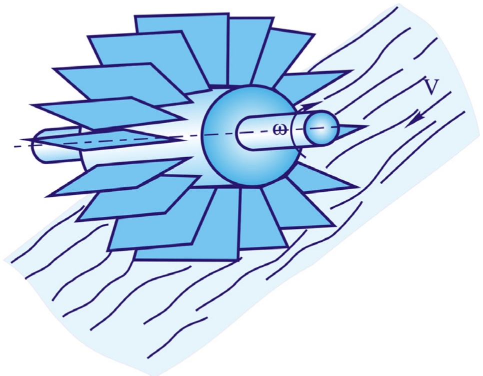


Figure 6.1. Power wheel, ancient age.

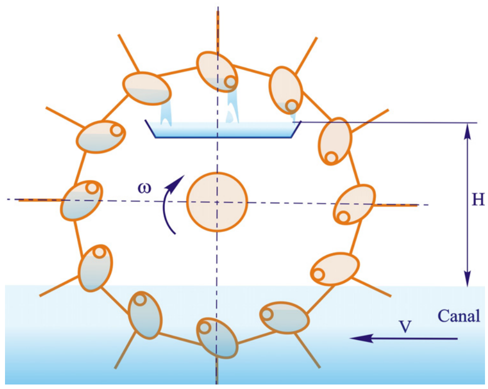


Figure 6.2. Chinese water wheel ancient age.

The means of water use and exploitation have evolved from a historical epoch to another, from one nation to another, in relation to the natural conditions, depending on the level of production relationships and forces. Thus, water energy uses has marked stages of development of the social systems from the primitive to modern society.

Historical research, ancient engravings and writings show that in ancient times in India (by about 4000 years before Christ) [9] (fig. 6.1) and China (about 5000 years ago) [10], dams and canals were built thousands of kilometers long, serving for irrigation and navigation. The Chinese hydraulic wheels, invented and used during the Han Dynasty to grind grains, served to use energy supplied by the water velocity from canals and rivers (ancient power wheels - Fig. 6.2). Those hydraulic wheels turned the linear velocity of water V into rotational motion with angular velocity ω of a shaft on which paddles were trusted, at first primitive, then, over time, improved in the form of blades. Last several thousands of years people living

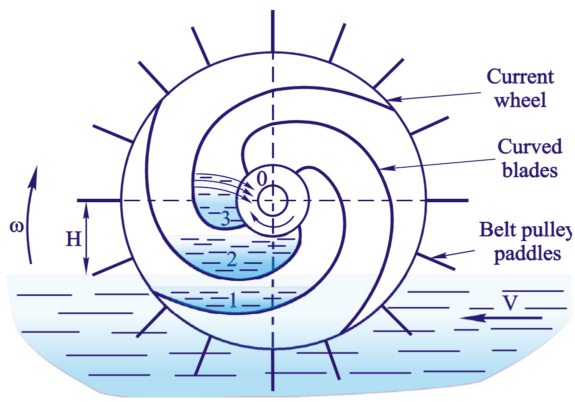


Figure 6.3. Ancient tympan.

in the valleys of the Himalayas have used water mills, or *chakki* for different usages. Water mills are much older than the wind mills.

The first hydraulic transformer was known about 4000 years ago; it served to raise water at height H with the help of primitive buckets, attached to a paddle wheel (Fig. 6.2). In low position the buckets filled with water and after rotation, reaching the top positions, emptied into a water trough located at H meters above the water trough. As an improvement the "*tympan*" was created in ancient Greece (Fig. 6.3), which peripheral paddles rotate the power wheel by ω. The power wheel is composed of two parallel discs, between which curved or polygonal blades rise water (as shown in successive positions 1 - 2 - 3). From position 3, the water is emptied into the trough that is concentric with the shaft (a). At tympan the water is raised to a height H smaller than that of Fig. 6.2. The pre-Roman experience, accumulated over several thousand years, was described by Heron of Alexandria, renowned inventor of the ancient times, in his known book "*Hydraulics*", which served as a guidebook for generations of builders of water wheels from ancient to modern times. During the Roman period the most famous inventor of hydraulic wheels was the famous Vitruvius.

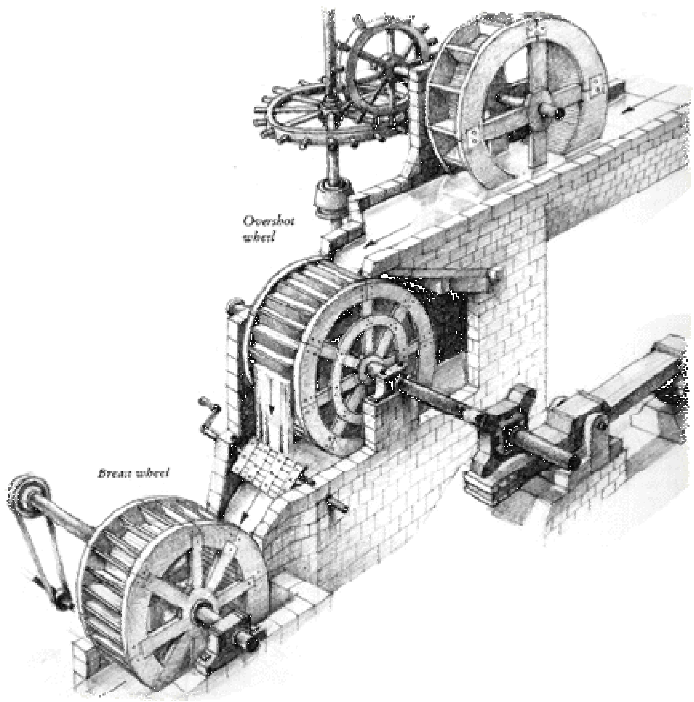


Figure 6.4. Roman water mill.

During the Roman Empire fixed and floating water mills have been used and widely spread in other countries of the Empire. So-called Greek Mills had vertical axis. They were older and simpler, and operated at high water velocities only with smaller diameter of water wheel. Roman mills had horizontal axis and were more complicated in terms of their construction (Fig. 6.4) [11]. They needed gear wheels for transmitting power from the main shaft to a shaft installed vertically.

The Cistercian Order built in the middle ages a complex of water mills in Western Europe. Fig. 6.5 [12] shows a water mill with horizontal shaft built in a small town in Belgium in the 12th-century. Monasteries of the Cistercian Order widely used water wheels to drive water mills for various destinations. Another early example of the use of water wheels in the XIIIth century was the Cistercian monastery *Real Monasterio de Nuestra Senor Rueda* in the Aragon region of Spain. Water wheel remains competitive to the steam engine of the Industrial Revolution period.

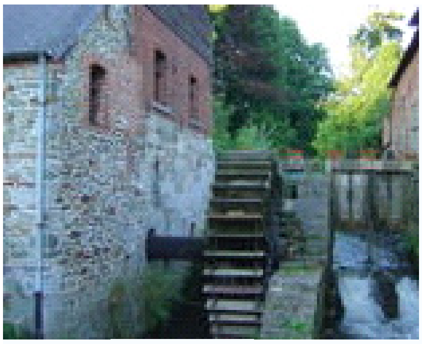


Fig. 6.5. Water mill in Braine le Chateau, Belgium, 12th century.

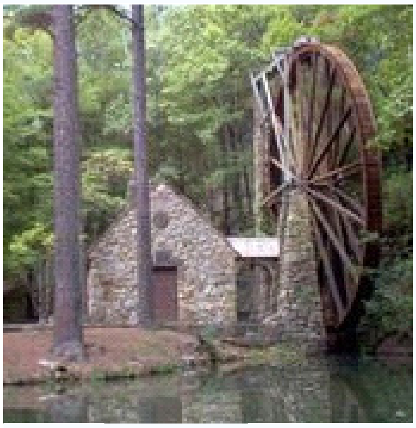


Fig. 6.6. Open water mill, Rome, Georgia, USA

Fig. 6.7. The Laxey Water Wheel, Isle of Man, UK.

The use of water wheels on the British Islands dates back to the year 900. But water wheels have developed extensively in England in the XVIIIth century by its famous persons, John Smeaton and James Brindley, following the theoretical calculations and practical experiments in France and elsewhere. They have justified the possible areas of use of open and submersible wheels. Open wheels allowed large dimensions of wheels (more than 2 m) associated with small water reservoirs. Half- submersible and submersible wheels can be used only on very deep rivers and reservoirs. Fig. 6.6 [12] shows an open water wheel with a diameter of approx. 10 m, operating an old mill in Rome, Georgia, USA. The Laxey Wheel (also known as Lady Isabella) is a large water wheel built in the village of Laxey in the Isle of Man, United Kingdom (Fig. 6.7 [12]). Designed by Robert Casement it has a 22 m diameter and revolves at approximately three revolutions per minute 3 min^{-1}.

Water wheels have accompanied us over thousands of years. They were cheap and easy to build. Thousands and thousands of water wheels were built in America by farmers, millers, mine operators, etc. The water wheel was used practically in every household located on the waterfront. The wheels were of all dimensions and different designs: from very large diameters, to slightly narrow and small. In one of the oldest mills in the mountains of North Carolina [13], restored subsequently, the water wheel has a 7 m diameter and its width is about 1 m (Fig. 6.8); it is equipped with an observation cabin located at the top. Through a number of gear wheels and a belt transmission it drives a

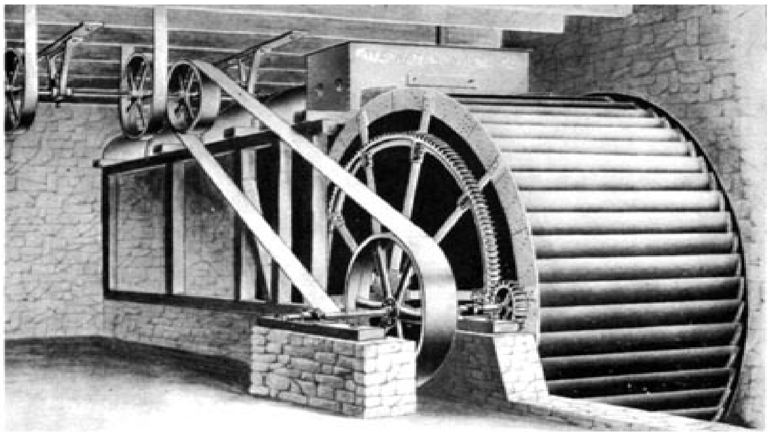


Figure 6.8. Water wheel linked via mechanical transmissions to a working machine.

working machine. The book "*Water Wheel Factory"* written by Robert Vitale gives advice on how to build a real water wheel, using the technical means and materials at hand. The operating principle of the hydraulic system is shown in Fig. 6.9 [13]. Until the widespread use of electricity, hydropower was used for irrigation, grain milling, textile manufacturing, etc. In the 1700s, the mechanical power of running water captured by water wheels was used extensively for water mills

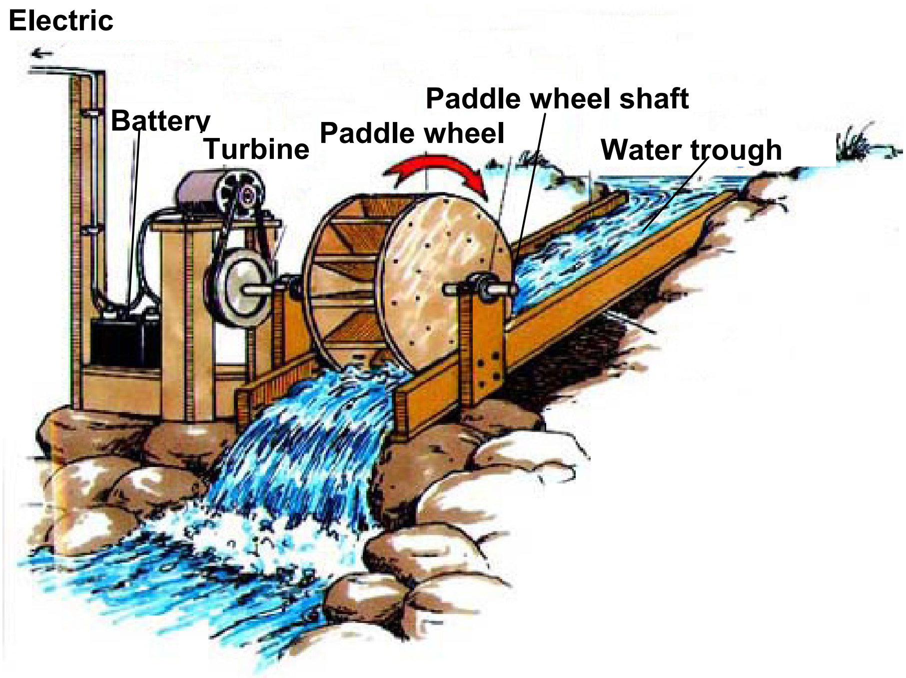


Figure 6.9. Principle diagram of a water wheel system.

and water pumping. In the period of the Industrial Revolution, water wheels have become a new profession - they drove various technological facilities. Their number increased continuously, in the 19th century their number reached about 20000. In 1830, in the era of canal construction, hydropower was used to transport barges. Nowadays, hydropower is widely used to produce electricity. But some rural water mills, located in the northern U.S., have operated commercially until the 1960s.

The use of water wheels on the territory between the Prut and Nistru rivers dates back to the times of Dacians before the arrival of the Romans.

6.3. Hydropower resources at global and national levels

6.3.1. Global energy potential

Hydropower, in general, has become now the most important source of clean renewable energy, economically feasible. Hydroelectric power plants, integrated in multifunctional schemes, have performed various works such as irrigation, water pumping, etc. It is clear that hydropower will play an important role in the future both in terms of ensuring energy supply and water resources development. Under these options, it is necessary to develop these resources in conformity with the social, economic, technical and environmental standards. It is easy to forecast that global energy needs, especially electricity, will grow significantly during the twenty-first century, not only under demographic pressure, but also because of rising living standards in the underdeveloped countries, which will be 7 billion people in 2050 (78% of total population). Primary energy consumption will grow by mid-century, and growth will be higher for electricity [14]. From the point of view of this situation more alternative energy sources will be required, however, for environmental considerations, an important priority must be given to developing, technically, the full feasible potential of environmentally friendly renewable sources, in particular, hydropower. Of all renewable energy sources, hydro (or energy of the running water) has been mostly exploited, although lately the implementation of hydropower schemes in developing countries was temporarily halted for financial, social or environmental reasons. Currently only a small part of hydropower potential is used in the developing countries: 5% - in Africa, 8% - in Latin America, and 9% - in Asia. Nowadays, China operates approximately 10% of its enormous exploitable potential (about 378 GW), which is the largest in the world. Taking note of the rise of macro hydropower in the twentieth century, it has had a large development in the countries with considerable hydropower potential. Today, hydropower provides about one fifth of the global electricity needs. If the remaining hydro power potential would have been used, the overall needs of mankind in electricity could be satisfied.

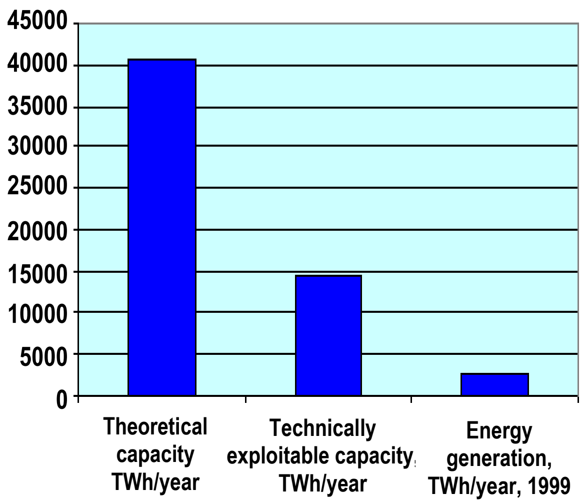


Figure 6.10. Global hydro power capacities: theoretical, technical explorable, and overall energy production in 1999.

Hydro power potential. Today, hydropower provides about 19% (2650 TWh/year) of the global electrical energy. Information received from members of the WEC (Water Economic Committee), supplemented by data published in *The*

International Journal on Hydropower & Dams, show that technically feasible hydropower potential is about 14400 TWh/year (Fig. 6.10) [15], of which nearly 8000 TWh/year are considered now economically feasible for development. Hydroelectric generating capacities of about 692 GW have been already installed, with about 110 GW under construction. The remained potential, economically

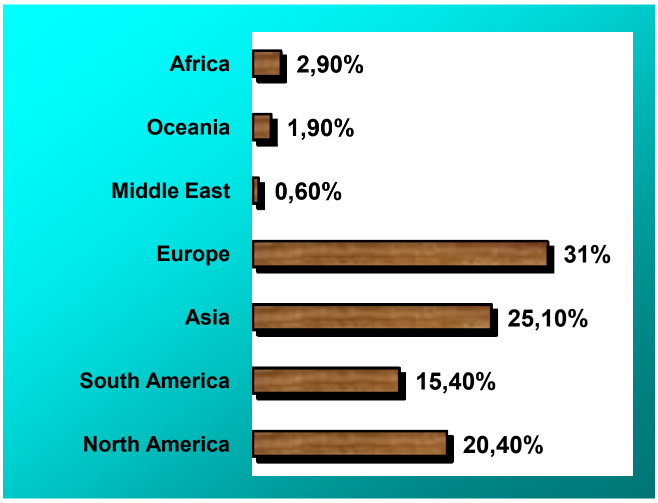


Figure 6.11. Installed hydropower capacity till 1999, by regions.

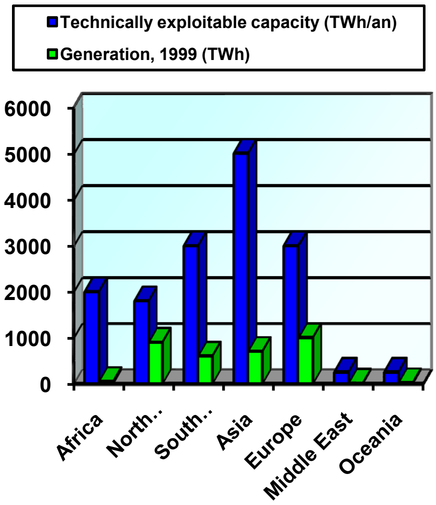


Figure 6.12. Installed hydropower capacity till 1999, by regions.

exploitable, is about 5400 TWh/year: the exploitation of this potential would require the construction of about 1400 GW of hydropower capacity (double the present installed capacity). Investment of at least U.S. $1500 billion will be needed to implement such a program. Considering that a hydroelectric power plant capacity is between 50 MW and 100 MW it will be necessary to build about 20000 hydroelectric power plants (very large constructions like Three Gorges (China) and Itapúa (Brazil) will not be the norm). A simple analysis shows that currently only about one sixth of the technical exploitable hydropower potential is explored. Installed hydropower capacities until 1999, by regions, are presented in Fig. 6.11 [16]. The top regions with the highest installed capacity of hydropower are Europe and North America. Global hydropower capacities (theoretical, technically exploitable and generated energy) for 1999 are listed in Fig. 6.12.

Technically exploitable capacities (output) of hydropower and hydroelectric energy production for 1999 by global regions are shown in Fig. 6.12. The existing hydropower potential is best exploited in North America: Canada and the U.S. produce about a quarter of hydroelectric

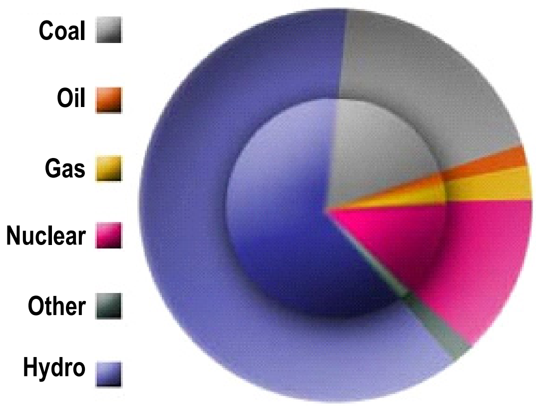


Figure 6.13. Sources of electrical energy production in Canada.

Table 6.1. Comparison of international hydropower, 2002.

Country	Production, GWh	Capacity, GWh
Canada	353000	67100
USA	300000	76000
Brazil	300000	64000
China	258000	82700
Russia	174000	44700
Norway	121000	27600
World total	**2740000**	**729000**

power energy. Canada, with its abundant water resources, has had good opportunities to produce low-cost, clean electricity. This fact had an important role in the economic and social development of Canada over the past two centuries. According to the diagram in Fig. 6.13, hydropower is the main source of electricity in Canada, representing about two thirds of the total energy produced. Most (about 59%) comes from large hydroelectric plants [16], such as the giant complex James Bay that borders the province of Quebec; its capacity is over 15000 MW. As shown in Table 3.1, in 2002 Canada *was the world leader in producing hydraulic* power. But Norway is the country where 99% of the electricity produced is of hydraulic origin. In New Zealand this indicator is 75%. Asia, with the highest energy potential in the world, stays behind by the degree of its utilization. But the recent rapid economic development of China has placed it first in the world in 2006. In this connection, there is interest in information on major countries, which contribute essentially to the global production of hydroelectric power [17,18]:

- China – 416700 GWh (128570 MW installed) (2006);
- Canada – 396700 GWh (68974 MW installed);
- Brazil – 285603 GWh (57517 MW installed)(1999);
- USA – 260400 GWh (79511 MW installed);
- Russia – 169700 GWh (46100 MW installed)(1999);
- India – 125126 GWh (33600 MW installed)(2006);
- Norway – 180800 GWh (27528 MW installed);
- Japan – 88500 GWh (27229 MW installed);
- France – 56100 GWh (25335 MW installed).

The largest hydroelectric power plants in the world have a total capacity of 2 to 10 MW. The largest hydroelectric power plant with a capacity of 14 MW is built on the Amazon River in Brazil.

6.3.2. National energy potential

In Romania, the explored hydropower potential of the biggest rivers is relatively high (Fig. 6.15, 6.16). The installed capacity of hydropower is 6,715 MW, representing a third of Romania's total installed electricity generating capacity. The country's hydropower potential is extremely large, with an estimated additional potential of over 9 GW.

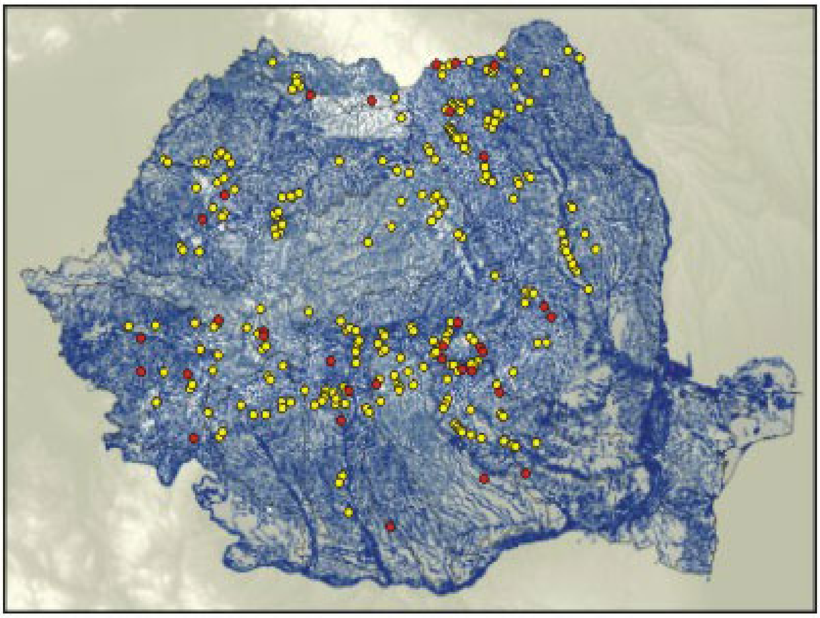


Figure 6.15 România hydropower potential.

The hydropower potential estimates 40TWh in Romania, of which 12 TWh are exploited. 362 hydro-power plants with an installed capacity of 6120 MW amount 27,9% of the total installed capacity of Romanian power system. It is expressed in macro and micro power units (under 10 MW/hydro units) [12]:

– big power plants (34000 GWh/year);

– small power plants (6000 GWh/year).

Small hydropower plants – up to 3,6 MW – divide into:

– big hydropower plants (HPU) – hydropower units of more than 3600 kW or equal;

– hydropower under 3600 kW, divided into three subcategories:

- small hydropower units (SHPU) with installed capacity between 200 kW and 3600 kW;
- micro hydropower plants (MHPP) with installed capacity between 20 kW and 200 kW;
- artisan hydropower units (AHPU) with installed capacity under 20 kW.

The most important water basins are: Olt, Lotru, Bistrita, Somes, Dragan, Arges, Dambovita, Raul Targului, Sebes, Raul Mare, Cerna, Bistra, Buzau, Motru, and Danube. Other hydrographical resources include the more than 2,500 lakes, ranging from the glacial lakes of the mountains to those of the plains and the marshes of the Danube delta region.

Romania has a total of at least 767 hydroelectric power plants. A majority, 621 of these plants are small hydroelectric plants, with less than 10 MW of capacity. The small hydroelectric plants in Romania have a total capacity of 1,125 MW.

At least 146 large hydroelectric plants are operating in Romania. The large plants have a capacity of approximately 5,550 MW (UDI, 2009). Hydroelectric plants in Romania produce about 6.28 billion kW of electricity each year (EIA, 2007). Opportunities for hydropower development in Romania are very high. About 5000

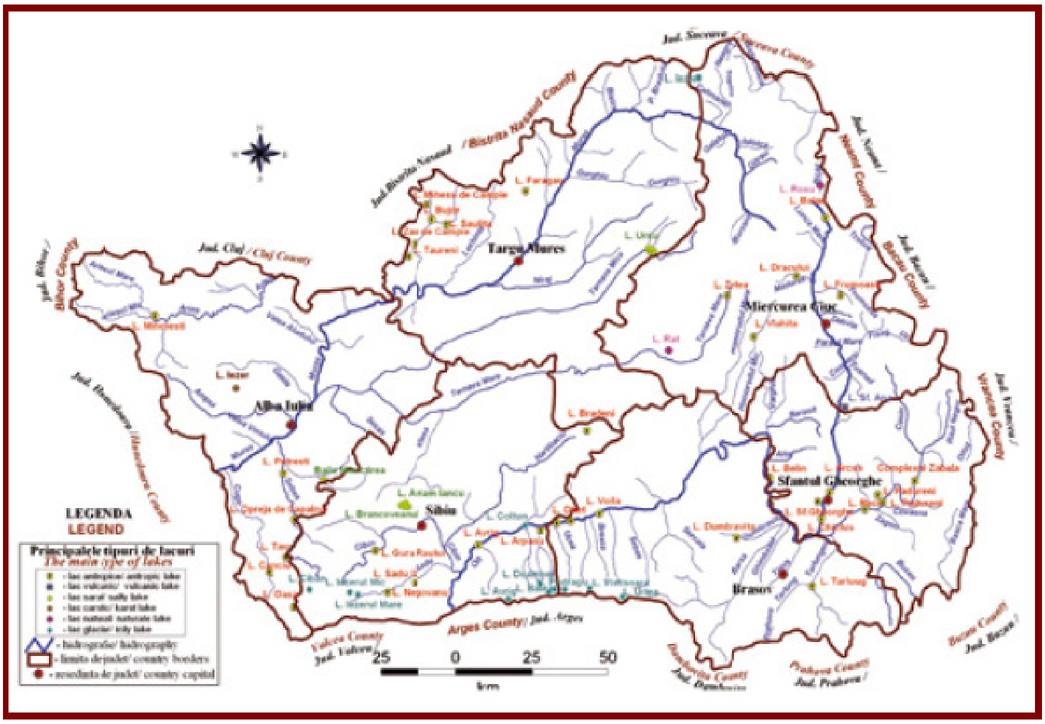


Figure 6.16. Map of hydro energy resources within central development region.

locations from Romania are favorable for the development of small-scale hydropower.

In Republic of Moldova. The Republic of Moldova are available for use the hydropower with the potential 300 toe (Table 3.2). The RES-e is dominated by hydro, which accounted for 100% of renewable electric energy production in all years. Table 3.2 presents historical and planed data for electricity production by two hydro: Costesti - Stanca and Dubasari. Given the EU directives to increase the share of hydropower operation of two hydroelectric optimization allows a slight increase in production of two hydroelectric power in a period until 2020 (see table 3.2).

Table 6.3. Historical and planned data for electricity production by two hydro: Costesti - Stanca and Dubasari, mil. kWh [19, 20].

Indices/years	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2020**
CHE Dubasari	220,0	239,7	256,7	295,0	327,9	392,0	392,0
CHE Costesti Stanca	37,4	84,5	58,43	84,583	79,07	86,0	89,0
Total	**257,4**	**324,2**	**315,13**	**379,58**	**327,9**	**424,0**	**435,0**

6.4. Hydropower characteristics

The most important characteristics of hydro power can be summed, as follows:

1. hydropower resources are widely spread around the globe. There is hydropower potential in about 150 countries, and about two thirds of the economically feasible potential have to be developed, especially in the developing countries where these capabilities are urgently required;

2. advanced technologies are used, based on a secular experience. Modern power stations provide a highly efficient degree of conversion;

3. hydropower is a clean energy source. It has a major role in reducing the emission of greenhouse gases; prevent annual burning of 22 billion gallons of oil and 120 million tons of coal. Hydropower is a relatively small source of atmospheric emissions compared to fossil fuels;

4. hydropower is the most effective way of generating electricity. Modern hydro turbines can convert up to 90% of the water potential energy into electricity. The best fossil fuel plants have an efficiency of about 50%. In the U.S., the cost of produced electricity is approximately 0.85 cents/kWh. This constitutes about 50% of the cost of nuclear electricity, 40% - of the cost of electricity produced by burning fossil fuels (except gas), 25% - of the cost of energy produced from burning gas. Hydroelectric power has reduced operational costs and long lifetime, compared with other options for large-scale electricity generation. The diagram in Fig. 6.17 shows approximate comparative costs for 1 kWh of electricity produced from

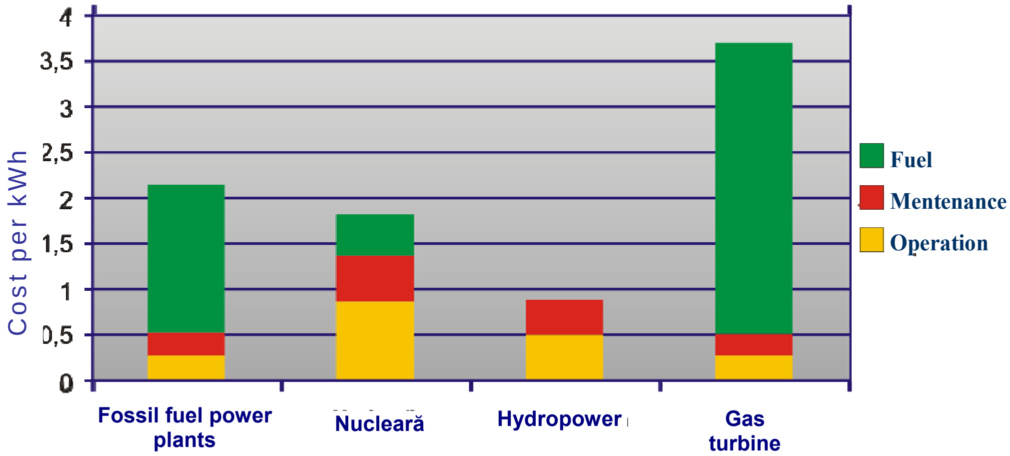


Figure 6.17. Estimate production expenditures for 1kW electrical energy.

different sources. The lowest cost (of the four sources) is for hydropower. The most important is that a basic component is excluded from the complex of expenditures, such as the costs for buying fuel. Once the initial investments have been allocated to the construction of the dam, the lifetime of the hydropower plant can be extended economically by relatively cheap maintenance and periodic replacement of the electromechanical equipment;

5. if the hydropower plant is integrated into multifunctional development, the project can help meet other basic human needs (e.g. irrigation of agricultural lands, providing domestic and industrial water, etc.). Water basins can be used for other purposes such as fisheries, adjustment of water level for navigation;

6. "*The fuel*" (water) is renewable and does not depend on the market fluctuation costs. Hydropower can provide energy independence to many countries.

6.5. Macro-, mini- and micro hydropower

Global hydro power energy today is about 715000 MWe, or about 19% of global electricity (16% in 2003). However, macro hydro power is not a major option for future energy production in the developed countries in terms of industrial purposes for various reasons, such as the environmental one.

Construction of dams on rivers created major environmental and social problems. Development of huge artificial water reservoirs by damming the Earth's major arteries has led to climate and wildlife change in the region, to misbalancing of migration processes of some species of fish, to creating some generating sources of greenhouse gases (the formation and elimination of methane in the atmosphere). More recent studies of large water reservoirs created by hydroelectric dams have shown that the processes of decay of aquatic vegetation can lead to the emission of greenhouse gases quantities in the atmosphere that are equivalent to the emissions from other electrical energy sources. For example, in tropical regions, macro hydro power can lead to greenhouse gas emissions, comparable with emissions of an electric power plant based on fossil fuels. According to Philip Fearnside (researcher at the National Research Institute of Brazil), during the first 10 years of operation, hydroelectric power plants could produce four times more gas emissions than a thermal power plant. These data cast doubts on the plans to build dams in the underdeveloped countries, including the 5 billion U.S. dollars project proposed for the Congo River. On the contrary, small hydroelectric power plants without dams and reservoirs are not sources of greenhouse gases.

The biggest impact of hydroelectric dams is the flooding of vast agricultural lands and forests. Grande Dam project in the James Bay region of Quebec has flooded about 10000 km^2 of land, which will increase as expansion plans, reaching an area larger than Switzerland. Flooding of large areas bordering the rivers has created major social problems, dozens of villages were flooded and hundreds of thousands of inhabitants from these villages have been removed (fig. 6.18).

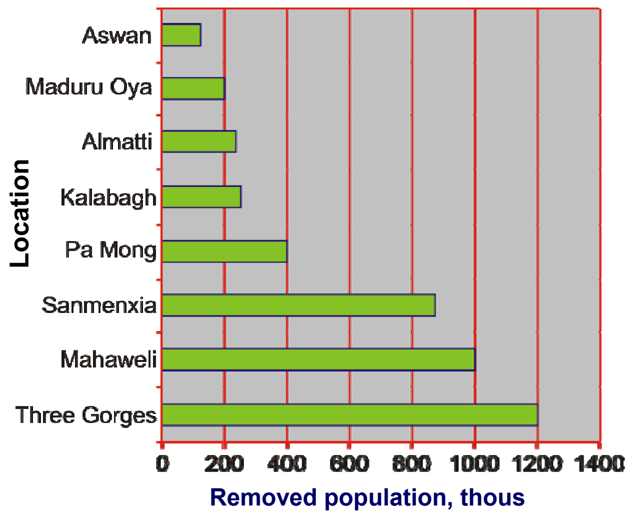


Figure 6.18. Removal of inhabitants as result of dam construction.

Large dams and reservoirs can lead to water quality deterioration by accumulation of large quantities of mud and various bacteria. Bacteria present in decaying vegetation can also change mercury, present in rocks underlying a reservoir, into a form, which is soluble in water. The mercury accumulates in the bodies of fish and poses a health hazard to those who depend on these fish for food. A more efficient use of hydraulic energy, in terms of environmental and social impacts, is the conversion of kinetic energy of running river water without dams' construction. What are the main advantages of this type of energy? First, the relative simplicity of these energy conversion systems. Also, the density of water is considerably higher than, for example, air density, and, thus, contains a greater amount of energy in itself. The kinetic energy of water is available 24 from 24 hours. It does not create noise pollution of the environment and doesn't affect aquatic creatures. The new Laws of the environment affected by the danger of global warming consider hydraulic energy obtained from small stations much more relevant. The use of hydropower potential at very small-scale is substantiated and in terms of its cost. The analysis of economic viability of the most widely used types of energy with a capacity of 10 kW, made by the U.S. Office of Technology Support, is presented in Table 6.4. In the case of micro hydroelectric power the negative environmental impacts associated with large hydroelectric power stations are also eliminated.

Table 6.4. Analysis of economic viability of various forms of energy of 10kW capacity.

Form of energy	Cost
Micro hydro	0,21$/kWh
Wind	0,48$/kWh
Diesel	0,8$/kWh
Network extension	1,02$/kWh

These mini-hydroelectric power plants can meet energy needs of consumers, particularly in rural areas. Local industry should be encouraged to use this power for its sustainable development. This is a technology with enormous potential, which should exploit water resources to meet, in the first place, the needs of consumers in rural areas with little access to conventional sources of energy. An important success in this respect belongs to the countries of Latin America, which at the end of construction and according to the prognosis will double their annual energy production. According to experts, the cost of 1 kW of installed capacity of micro hydro electric power plants is $ 400-500 with an efficacy of 40-50% and the redemption period of 1-2 years.

Micro hydroelectric power plants have been used extensively in the past for various practical applications or to supply electricity to towns. Later, due to low cost of fossil fuels, to the economic level of macro-hydroelectric power and massive quantities of energy required, micro hydroelectric power plants have been partially abandoned. In remote areas the installation of diesel units or the network mapping was preferred instead of micro hydroelectric power plants. The basic argument was high investment costs. Today, when the price of fossil fuels and the expenses for environmental protection grow continuously, micro hydroelectric power plants win in the competition related to energy supply, primarily, of remote localities and isolated objects. Also, they offer additional advantages because they are environmentally friendly, does not require big additional civil engineering works, such as access roads, temporary houses for workers, etc.

Not everybody is lucky enough to have a river near his home, but for those who fall into this category, micro hydro turbines are the most reliable and cheap source of alternative energy. A small turbine can produce energy as long as there is water non-stop, regardless of weather conditions. In this context, the following advantages of micro hydroelectric power plants are highlighted:

- suitable for small power requirements, decentralized (light industry, farms and private enterprises, rural communities) and for operations external to the main network;
- require low-voltage distribution networks and, eventually, micro sub-regional networks;
- can be used as private property, in co-ownership or joint ownership with a semi-qualified labour force required and with a joint or separate administration;
- short period of construction using local materials and skills of people in the area can have a significant impact on the quality of rural life;
- their flexibility, particularly in regard to adapting to variable charges depending on the inflow rate, making them a prime component in any integrated power systems;
- plants can operate a long period. Some have been built 70 years ago and are still running. Plants that are ready to become operational in the near future can register even longer life and serve consumers over several generations without polluting the atmosphere;
- small investments in hydroelectric power plants have proved to be safe and reliable for several decades.

Production of electricity, using water as primary source, is an energy conversion process in which water is an effective means of transmission and transformation of the flow gravitational potential energy into mechanical and electrical energy.

6.6. Classification of hydropower plants

6.6.1. Overview

The evolution of the modern hydropower turbine began in the mid-1700s when a French hydraulic and military engineer Bernard Forest Belidor wrote "*Architecture Hydraulique*" in four volumes. During the 1700s and 1800s, water turbine development continued. At the end of 1800, the invention of the Pelton wheel (named after the inventor) encouraged many owners of water mills to replace conventional water wheels with the Pelton turbines.

In 1826, the Frenchman, Jean Victor Poncelet, proposed a machine that included a fully submersible water wheel, where water had to run into the wheel otherwise than along it [13]. Jean Victor Poncelet worked on increasing the efficiency of the submersible water wheel, using the physics of modern hydraulics. Following this concept, the American Samuel Howd patented the first turbine in 1838. James Francis improved its design later by assigning the blades a radius of curvature. Known as the Francis turbine, this is the first water turbine.

In 1879 T. A. Edison demonstrated the incandescent electric bulb. The electric dynamo machine was first used for lighting Michigan in 1880; it was driven by a water turbine. And in 1881 an electric dynamo connected to a water mill produced street lighting in Niagara Falls, New York. These two projects have established the basis of direct technology of the electric current use. In 1882, the first hydroelectric plant in the world was built in Appleton, state of Wisconsin, USA. Ottawa, in 1885, became the first city in the North America, which signed a contract for lighting the streets.

The hydraulic turbines have replaced quickly the water wheels in driving mills and textile plants. The end of the nineteenth century was the golden era of the hydraulic power. Thousands of low-power hydraulic plants have scattered the riverbeds with thousands of turbines manufactured in the country. In the late nineteenth century a new use of hydraulic turbines was found: the generation of electricity. The hydroelectric power represented about 40% of the electricity produced in the U.S. in 1920, and in 1940 it was about 40% of the worldwide generated electricity. With the industrial development of other forms of power generation and rural electrification programs the share of hydropower has declined steadily, now constituting about 10% of the electricity produced in the U.S. Slowly, the manufacturers of micro hydro power turbines went out of business, the windmills were destroyed and the hydraulic turbines abandoned. Today, we observe a revival of hydro power as a source of clean and renewable energy. Modern hydraulic plants have increased in size from micro hydro power turbines to giant systems with dams, like Hoover Dam, which generate electricity for millions of people daily.

In contrast, to early water wheels and turbines, modern turbines are compact, highly efficient and capable of operating at very high speeds. Hydropower is the best source of renewable non-pollutant energy that can be easily integrated into the irrigation and water supply projects.

China has more than 85000 small dimension hydraulic plants, producing electricity. Over the past decades, micro hydro power plants have played an important role in the developing countries, in the economic development of rural areas, especially mountainous areas. Micro hydro power plants can provide energy for industrial, agricultural and domestic use via direct use of mechanical energy or by turbine coupling to electrical generators.

6.6.2. Classification of micro hydro power plants

Micro hydroelectric power plants are the most efficient and cheapest generators of electrical energy. If you have a small creek or a river near the chalet or house that can provide at least 5 litres/sec. water drop from a difference in level of at least 3 m, or 0,5 litres/sec. from a difference of level from at least 10 m, do not hesitate to use a hydroelectric generator. You'll have clean, free and unlimited energy.

Hydropower is the most important energy source, which has no carbon dioxide, sulphur dioxide, nitrogen protoxide or any other type of pollutant emissions in its composition, and does not produce any solid or liquid waste. Micro hydroelectric power plants can be divided into two basic types: without dams, based on the conversion of kinetic energy (fixed or floating) of river water; with small dams, which use natural or artificial water drop of a river. They encompass the main advantages compared to other energy sources, saving coal, fuel or firewood, being independent at the same time.

A micro hydroelectric power plant without dams practically does not require civil engineering constructions, except the ground foundation, which connects the micro hydroelectric power plant with the shore. The main components of a hydro power plant without dams are as follows (fig. 6.19) [14]:

- *Shore foundation*, that includes a complex connection system (rigid and flexible);
- *Hydraulic turbine*: it is a part of the plant where water power is converted into mechanical energy;
- *Generator*: the mechanical energy transmitted to the turbine maintains the generator rotor velocity, producing electricity in accordance with the laws of electromagnetics;

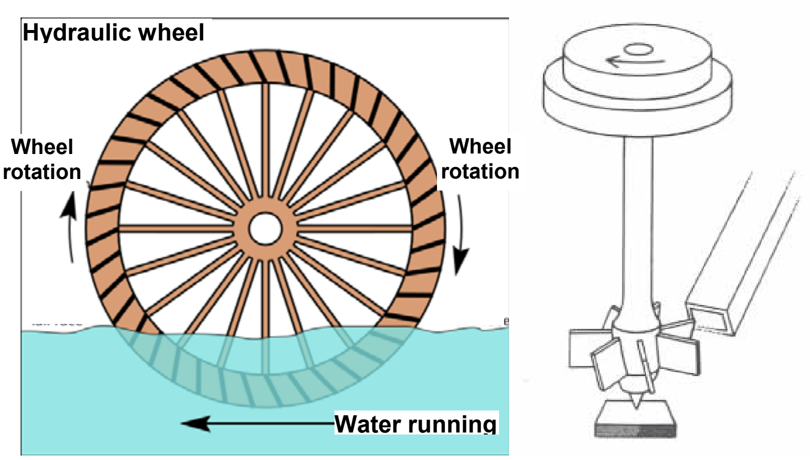


Figure 6.19. Operation principle of the water wheel engaged by the flow.

- *transformer station and transmission line*: electrical energy is run and converted in order to be connected to the grid for electricity supply to consumers.

The quantity of the produced energy depends on the running water velocity.

Main components of a small power hydro plant with dam are as follows (fig. 6.20):

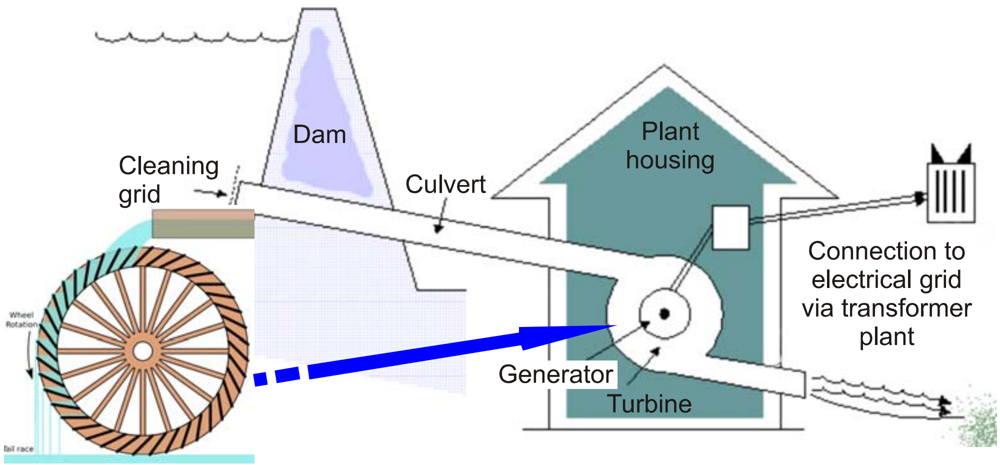


Figure 6.20. Main components of a micro hydroelectric power plant with dam.

• *storage*: is a form of available potential energy storage;

• *transfer system*, which includes the capture device (flooding valve equipped with grid) and the transfer circuit (trough, sluice gate valve, weir, culvert, off take or discharge) where a part of the available energy is converted into kinetic energy;

• *hydraulic turbine*: is a part of the plant where water energy is converted into mechanical energy;

• *generator*: mechanical energy transmitted to turbine maintains the generator rotor velocity producing electrical energy;

• *transformer station and transmission line*: electrical energy is transmitted and transformed in order to be connected to the grid with further delivery to the consumers.

The quantity of generated energy depends on two factors:

–*Vertical water fall height* (VFH): the higher water fall, the greater the power generated;

–*Water flow rate moving through the turbine*: the power produced is proportional to the volume of water passing through the turbine in a unit time (seconds, minutes).

6.6.3. Classification of water turbines

The potential energy of water can be converted into mechanical energy in the turbine through two fundamental, but absolutely different, mechanisms:

– Water pressure may apply a force on the blade surface, which decreases when passing through the turbine. The turbines operating under this mechanism are called reaction turbines. They are fully submerged in the water flow. Francis and Kaplan turbines fall into this category.

– Water pressure is converted into kinetic energy before entering the turbine. The kinetic energy is in the form of a high speed jet acting on some blades, mounted at the periphery of the turbine. The turbines, operating under this mechanism are called impulse turbines. The most usual turbine of this type is the Pelton turbine.

Micro hydroelectric power systems for the conversion of water potential energy are divided into two major categories of turbines (table 6.5):

- Turbines for big water heights and small flow rates, impulse turbines.
- Turbines for small water heights and big flow rates, reaction turbines.

There is a wide range of structural and functional varieties of water turbines. The choice of turbine depends primarily on the height available (for the conversion of potential energy) and the parameters of the river (to convert the kinetic energy of running water). According to Table 3.7, in a simple way, the hydraulic turbines can be classified in turbines of high, medium and low height according to the water fall height (VFH).

Table 6.5. Classification of hydraulic turbines.

Turbine type	**Classification by heights of water falling**		
	High (>50m)	**Medium (10-50m)**	**Low (<10m)**
With impulse	Pelton Turgo Pelton multi-jet	Banki Turgo Pelton Multi-jet	Cross flow
With reaction		Francis (spiral case)	Francis (open) Kaplan with propeller

Turbines for big water heights and small flow rates, impulse turbines (fig. 6.21). The power produced by an impulse turbine is integrally the result of the moment of water impact on the turbine blades. This water creates a direct or impulse push of blades, hence the name.

Turbines for small water heights and big flow rates, reaction turbines (fig. 6.20). The reaction turbines are rotated by the water force of reaction hitting the rotor blades. They can operate at very small water heights of up to 0,6 m, but need a much larger quantity of water compared with the impulse turbines.

The turbines used for small or medium water falls are most frequently reaction turbines and include the Francis and Kaplan turbines with fixed or variable blades. The turbines used for large installations are impulse turbines, including the Pelton, Turgo and Cross-flow (cross flow) turbines. The turbine with cross flow is sometimes called the Cross-flow turbine. It is used for a wide range of falls, covering the areas of Kaplan, Francis and Pelton turbines. It is suitable for water runnings with high flow rates and small falls. The turbine selection, geometry and dimensions depend mainly on the fall, flow rate and rotor speed. Water "*force*" is actually a combination of the water fall height and flow rate(or the stream). The water fall height is the pressure created by the vertical distance between the place where water enters the influent conduit and the location of the turbine, and is measured in meters or as pressure.

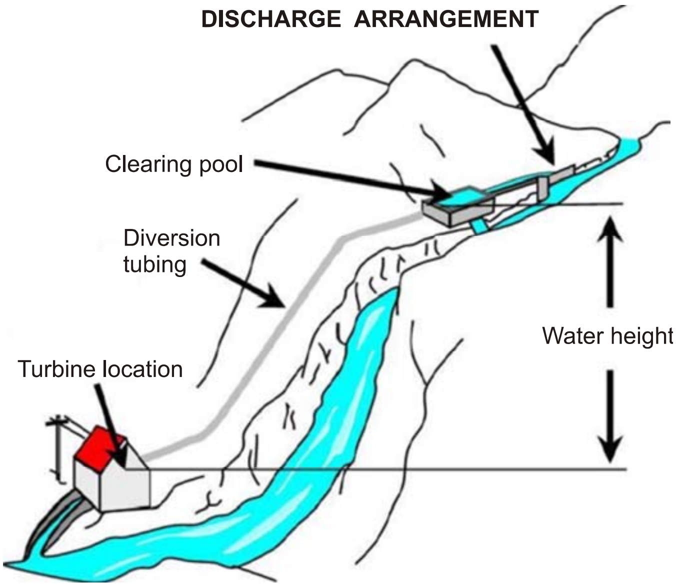


Figure 6.21. Diagram of micro hydroelectric power plant with big height and small flow rates.

The flow rate is the *amount* of water (in volume per time) that flows through the influent conduit in a given period of time and is measured in cubic meters per second or litres per minute. Water is collected in a micro basin and then channelled through a pipe directly into the turbine inlet. The vertical water fall (WFH) creates the pressure needed at the lower end of the influent conduit to make the turbine move. The higher the flow or vertical water fall height will be, the more electricity we get. As shown, the values of these two criteria are important for determining the amount of electricity (potential) for a location in order to implement a micro hydro system based on micro hydro power turbines. The difference between the impulse and reaction turbines can be explained in a simple way: impulse turbines can operate in a wide range of vertical heights, and reaction turbines operate in a wide range of flows, but at low heights.

The reaction turbine rotor is completely immersed in the water currents, and the hydrodynamic profile of blades generate a lift force. Reaction turbines exploit water currents for the generation of hydrodynamic lift forces that rotate the blades. All reaction turbines have a diffuser known as the exhaust pipe through which water is discharged. The exhaust pipe reduces the static pressure of water on the diffuser and thus increases the effectiveness of the turbine. Approximate scales of height, flow and power applied to different types of turbines are shown in the diagram (Fig. 6.22) (up to 500kW). These data are approximate and depend on the design and manufacturing accuracy. Fig. 6.23 shows the areas of application of impulse (action) and reaction turbines [15]. Mostly used impulse turbines are the Pelton, Turgo and Cross-flow turbines; the reaction turbines are the Francis and Kaplan turbines with propellers. An important factor in the comparison of different types of turbine is their efficiency. To better understand the operation of water turbines, the following is an explanation of their basic parameters [16].

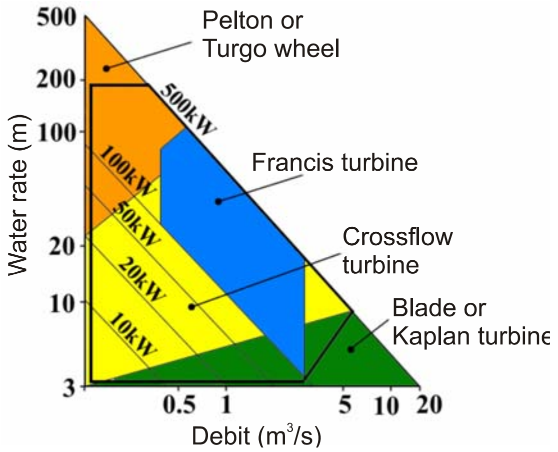


Figure 6.22. Vertical water fall height-flow rate scale of the micro hydro power turbines.

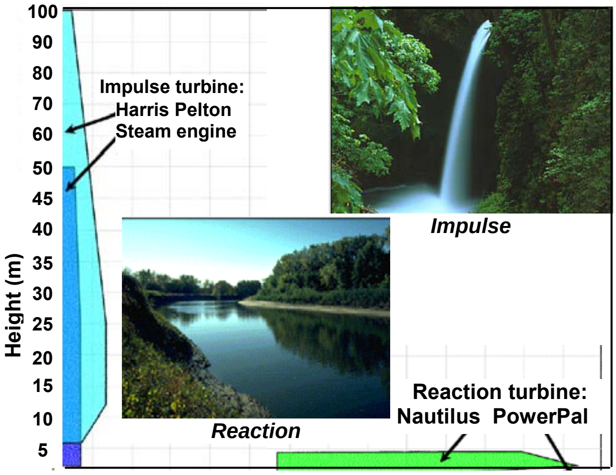


Figure 6.23. Application areas of water impulse and reaction turbines.

6.7. Floating micro hydroelectric power plants for river water kinetic energy conversion

Floating micro hydro power plants are of special interest. In terms of costs, floating micro hydro power plants are efficient because they do not include essential costs related to civil engineering [17]. The conceptual scheme of these micro hydroelectric power plants is shown in fig.6.24. The water wheels or the open hydro turbines (usually, with propellers) are used as working body. Next the most representative examples of small flow hydropower plants with different working bodies will be considered.

6.7.1. Floating micro hydroelectric power plant with water wheel

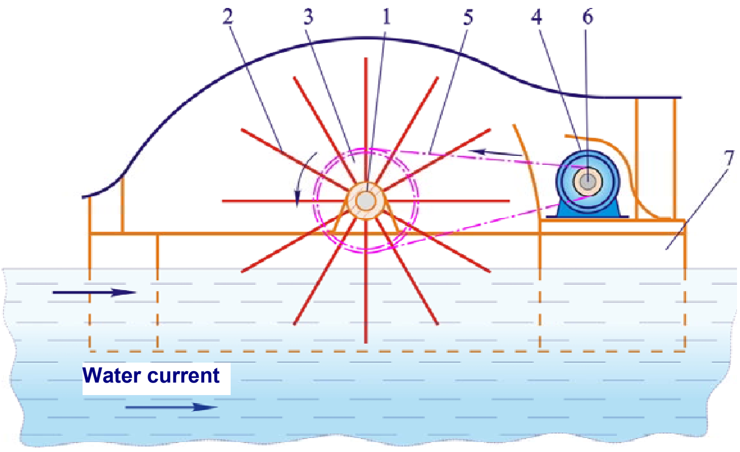


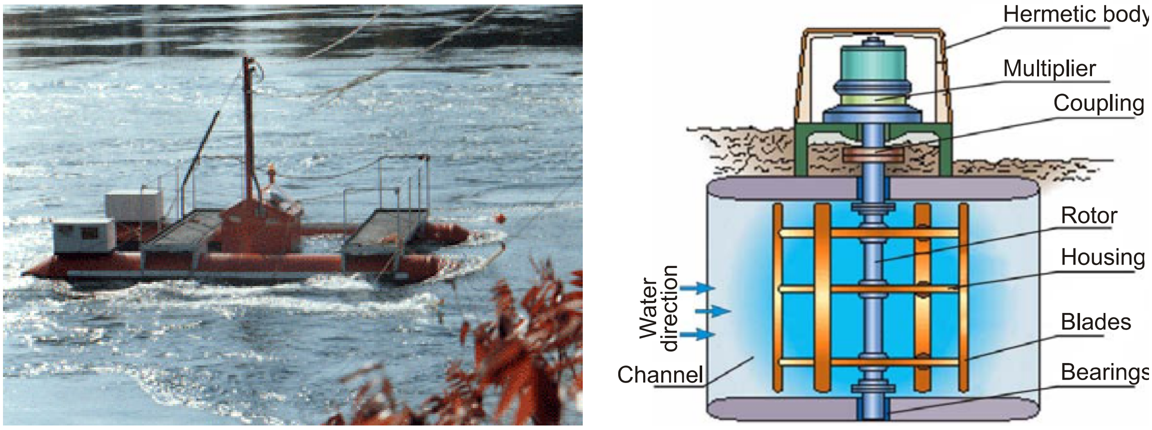
Figure 6.24. Floating micro hydroelectric power plant with water wheel.

The floating micro hydro power plant (Fig. 6.24) is the achievement of an ancient idea: the old water wheel installed on a floating platform, transforms the kinetic energy of flowing water from rivers into electricity or mechanical energy (for irrigation). The design of micro hydro power plant is simple. Rotational movement of the water wheel with the horizontal main axis 1 and blades 2 by belt pulley 3, is transmitted to the electric generator 4 through the belt transmission (belt pulley 3, 6 and belt 5). The water wheel and the electric generator are installed on the floating platform 7. The main advantages of the micro hydro power plant are: the lack of dams which excludes the negative environmental impact; the automatic control of the water wheel position depending on the water level and the running water course.

6.7.2. Floating micro hydroelectric power plant with Davis turbine

The Davis hydraulic turbine is of special interest [18]. In 1984 a small hydro power plant with Davis hydraulic turbine and vertical axis was designed and tested on the Harbour

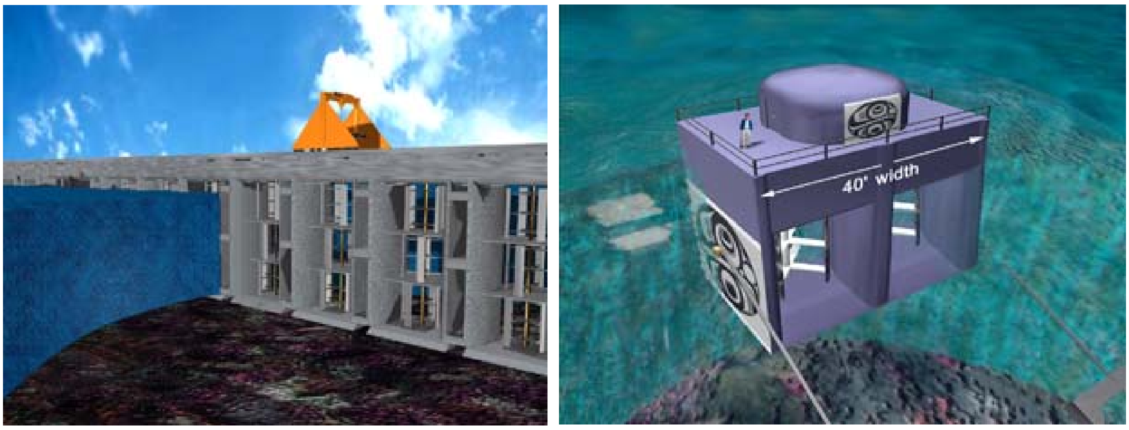
River, Nova Scotia, (Fig. 6.25, a); it produced 100 kWh. The Davis turbine consists of 4 blades with hydrodynamic profile, fixed rigidly on the rotor (fig.6.25,b). The rotor is coupled



a) ***b)***

Figure 6.25. Micro hydro power plant with Davis turbine.

through a coupling to the multiplier input shaft (planetary gear of speed multiplication). The power generator is mounted on the multiplier output shaft. All nodes are mounted on the platform, that is fixed on two pontoons. To obtain electricity from the kinetic energy of the running water a similar construction of the Davis turbine was built and tested in Florida Bay (Fig. 6.26) in 1985. The obtained power was 5 kW. The project was funded by *Nova Energy*



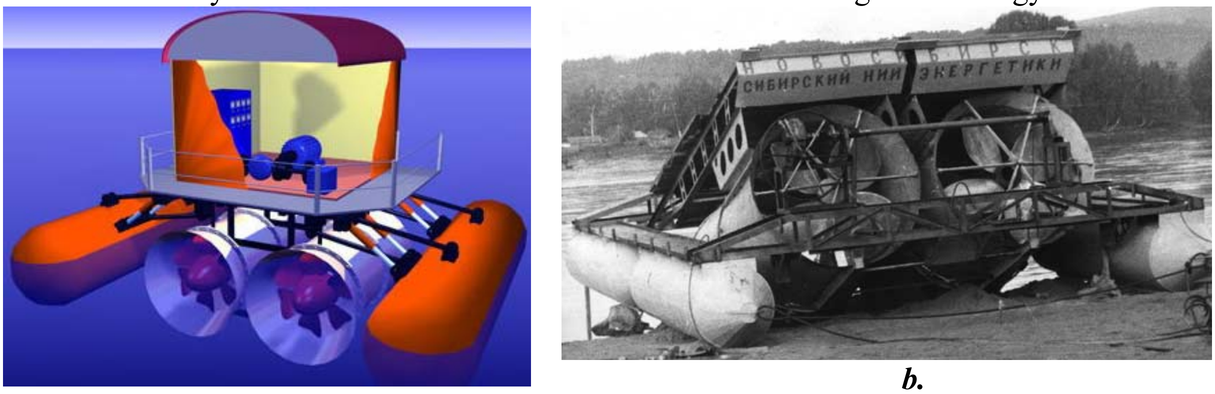
a) ***b)***

Figure 6.26. Computer models of Davis rotor modules:
a – for oceans; b – for rivers.

Ltd company,Texas, and was called the Davis turbine VEGA–I. The turbine was operating at a 65 m depth, in order to impede its collision with large cargo ships. To get more power several Davis turbines were joined in modules (blocks) mounted vertically or horizontally. Thus it was possible to obtain a summary power range of the kinetic energy of running river water from 5 to 500kW and a 200-8000MW power – from the kinetic energy of the ocean water. Figure 6.26 a, b shows the computer models of the Davis turbine modules of 7-14MW power - for oceans and of 250kW power - for rivers.

6.7.3. Floating micro hydroelectric power plant with propeller turbine

Another type of floating micro hydropower plants having a new principle of operation is the micro hydroelectric power plants with helical turbine. One of the first works is a report on a prototype of horizontal axis turbine developed by Harwood (1985, National Institute of Amazonian Research (INPA). It used two propeller turbines with a 4 m diameter, mounted in the nozzle. For micro hydro power plant equillibrium, the turbines are made with rotation in opposite directions. The rotational movement of the turbines is summed and transmitted through a multiplier system to the electric generator. The turbine housings are rigidly fixed on a metal construction, which in its turn is rigidly installed on two pontoons. The micro hydropower plant is anchored to the river. This equipment has been tested in areas of the Amazon River at water speeds between 0,7 to 1,5 m/s. Fig. 6.27,a shows a computer model of the floating micro hydropower plant with two multi-blade turbines mounted in the nozzles. The rotation of turbines in different directions ensures stability to the micro hydropower plant. Based on this principle, the engineers from the Scientific Research Institute in Novosibirsk, Russia, manufactured a micro hydropower plant with two propeller turbines (Fig. 6.27,b) [19]. The micro hydropower plant contains a floating movable structure, which can be easily moved throughout the riverbed when the water level changes and, as well, improve the turbine efficiency on the basis of a more efficient use of the running water energy. The micro



a. *b.*

Figure 6.27. Micro hydropower plant with two multi-blade helical turbines.

hydropower plant contains a platform on which the following components are rigidly fixed: the generator; the housings of the propeller turbines with the nozzles; the floating bodies in the form of pontoons mounted to the platform; the lifting and sinking mechanism of the propeller turbines. The testing of this construction was carried out on the rivers in Altai and Iakutia, Russia, during a whole season. The tests have shown good efficiency, technical characteristics, operation and installation simplicity.

6.7.4. Floating micro hydroelectric power plant with vertical axis and multi-blade hydrodynamic rotor

The content of this part has the goal to introduce the reader into the complexity and width of the issues under study on the segment “from the idea to the launch into production of the final product”. This issue is quite important for the execution of the renewable energy conversion system, for instance, - of the micro hydroelectric power plant for the conversion of the river water kinetic energy into electrical or mechanical energy using the hydrodynamic effects. The micro hydropower plant is a complex technical system that includes constructive components with distinct functions: rotor-turbine that draws off a part of the water kinetic energy at its interaction with the water flow; mechanical transmissions for the transformation of the converted energy; pumps and generators for useful power generation, etc. The conversion efficiency of the micro hydroelectric power plant depends on the performances of each component.

Conceptual diagrams. To avoid the construction of dams, it is possible to use the river kinetic energy by utilizing water flow turbines. This type of turbines can be mounted easily and are simple in operation. Their maintenance costs are rather convenient. The stream velocity of 1m/s represents an energy density of 500W/m^2 of the flow passage. Still, only part of this energy can be extracted and converted into useful electrical or mechanical energy, depending on the type of rotor and blades. Velocity is important, in particular, because the doubling of water velocity leads to an 8 times increase of the energy density. The section of Prut River is equivalent to 60 m^2 and its mean velocity in the zones of exploration is (1-1,3) m/s, which is equivalent to approximately (30-65) kW of theoretical energy [4]. Taking into account the fact that the turbine can occupy only a part of the riverbed, the generated energy could be much smaller. There are various conceptual solutions, but the issue of increasing the conversion efficiency of the water kinetic energy stands in the attention of the researchers. The analysis of the constructive diversion of micro hydroelectric power plants, examined previously, does not satisfy completely from the point of view of water kinetic energy conversion efficiency. The maximum depth of blade's immersion is about 2/3 of the blade height *h* in a classical hydraulic wheel with horizontal axle (Fig. 6.28). Thus, only this surface of the blade participates at the transformation of water kinetic energy into mechanical one. As well, the preceding blade covers approximately 2/3 of the blade surface plunged into the water to the utmost *(h''≈ 2/3h')*, that reduces sensitively the water stream pressure on the blade. The blade, following the one that is plunged into the water to its utmost, is covered completely by it and practically does not participate in the water kinetic energy conversion. Therefore the efficiency of such hydraulic wheels is small.

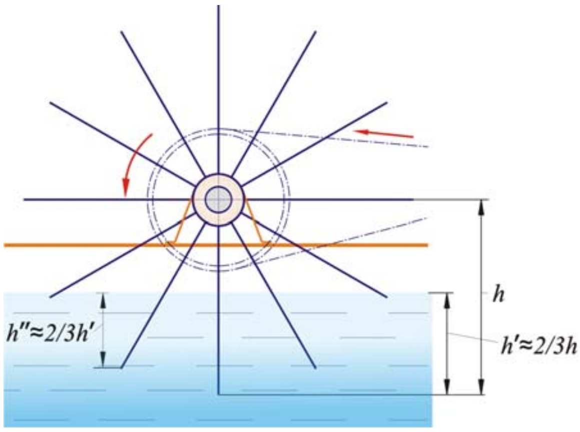


Figure 6.28. Conceptual diagram of the water wheel with rectilinear profile of blades.

Insistent searches of authors have lead to the design and licensing of some advanced technical solutions for outflow micro hydroelectric power plants. They are based on the hydrodynamic effect, generated by the hydrodynamic profile of blades and by the optimal blades' orientation towards water streams with account of energy conversion at each rotation phase of the turbine rotor (Fig. 6.29). To achieve this, it was necessary to carry out considerable multicriteria theoretical research on the selection of the optimal hydrodynamic profile of blades and the design of the orientation mechanism of blades towards the water streams.

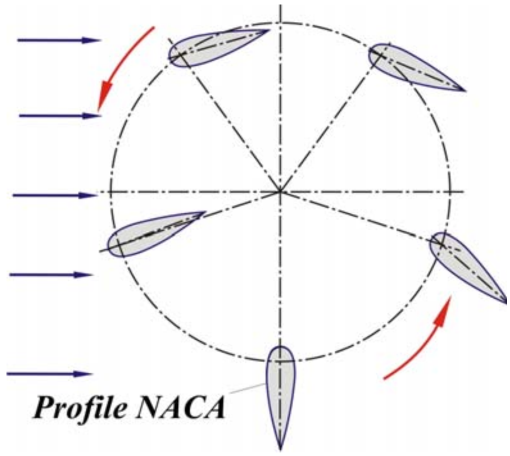


Figure 6.29. Conceptual diagram of the water rotor with hydrodynamic profile of blades with its orientation towards the water streams.

The main advantages of these types of micro hydroelectric power plants are:

- reduced impact on the environment;
- civil engineering works are not necessary;
- the river does not change its natural stream;
- possibility to produce floating turbines by utilizing local knowledge.

Another important advantage is the fact that it is possible to install a series of micro hydro power plants at small distances (about 30-50 m) along the river course. The influence of turbulence caused by the neighboring plants is excluded.

The results of investigations conducted by the authors (on the water flow velocity in the selected location for micro hydro power plant mounting, on the geological prospects of the river banks in the location of installing the anchor foundation and on the energy demands of the potential consumer) represent the initial data for the conceptual development of the micro hydro power plants and the working element.

In order to increase the conversion factor of water kinetic energy (Betz coefficient), a number of structural diagrams of floatable micro hydro power plants has been developed and patented [20-22]. The micro hydropower plants comprise a rotor with vertical axis and vertical blades with hydrodynamic profile in normal section. The blades are connected by an orientation mechanism towards the water streams direction. The rotational motion of the rotor with vertical axis is multiplied by a mechanical transmissions system and is transmitted to an electric generator or to a hydraulic pump. The mentioned nodes are fixed on a platform installed on floating bodies. The platform is connected to the shore by a hinged metal truss and by a stress relieving cable.

The selection of the optimal blades hydrodynamic profile is very important for functional optimization of micro hydro power plants. It will allow increasing the conversion factor (Betz coefficient) due to the hydrodynamic buoyant force. As well, conversion increase is achieved by ensuring the optimal position of blades towards the water streams at various phases of rotor revolution, employing an orientation mechanism of blades. Thus, practically all blades (even those blades which move against the water currents) participate in the generation of the summary torque. Moving in the water currents direction, for torque generation the blades use both the hydrodynamic forces and the water pressure exercised on the blade surfaces. Moving against the water currents direction the blades use only the hydrodynamic lift force for torque generation. Due to the fact that the relative velocity of blades concerning the water currents is twice bigger, practically, at their motion against the water currents, the hydrodynamic lift force is relatively big, and the generated torque is commensurable to the one generated by the water pressure. This effect makes the basis of all patented technical solutions. These technical solutions allow essential increasing of the river water kinetic energy conversion coefficient. Full description of the most representative technical solution and brief description of the conceptual diagrams of micro hydro power plants properties are given below.

In micro hydro power plant (Fig. 6.30) [20,23], the turbine 1 comprises blades 2, executed with the hydrodynamic profile and mounted on the axles 3, fixed by their upper part on the extreme ends of the bars 4, with the possibility to rotate around their axles. The position of the blades 2 at angle α to the direction of water flow is ensured by the controlling mechanism 5. Platform 6 is consolidated additionally by a winch 7 fixed on the truss that is mounted unshiftable on the shore pillar 8. The turbine 1 and the blades 2 are placed in the river water flow. The floating bodies 9 and the hollow blades 2 themselves control the position of turbine 1 and blades 2 concerning the water level. The multi-blade rotor is connected cinematically and coaxially to the electric generator 11 by the multiplier 10. The winch 7 is used for turbine 1 maintenance which fact requires its removal from the water. The blade 2 (Fig. 6.31) is positioned under angle α towards the water flow; it changes depending on the blade position to the water flow direction.

The components of force ***F***, acting on the blade, are determined from the relationships:

$$F_x = C_x \cdot \frac{\rho \cdot v^2}{2} \cdot S,$$

$$F_y = C_y \cdot \frac{\rho \cdot v^2}{2} \cdot S, \qquad (6.1)$$

where: ρ is water density; v is the water flow linear velocity; s is the blade surface; C_x, C_y are lift and drag (resistance) coefficients of the blade profile. Coefficients C_x and C_y depend on the blade entering angle $\boldsymbol{\alpha}$ (the angle between the blade and the water flow direction) and on the profile shape. The angle is determined either experimentally or by numerical calculations.

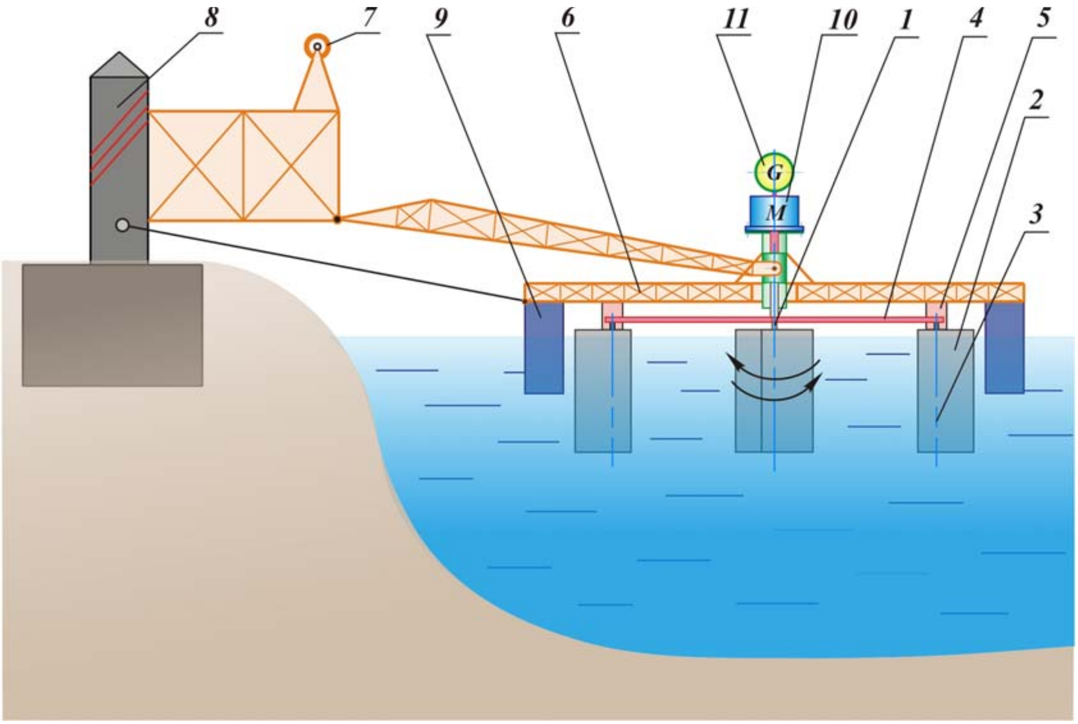


Figure 6.30. Floatable micro hydropower plant with blades orientation mechanism.

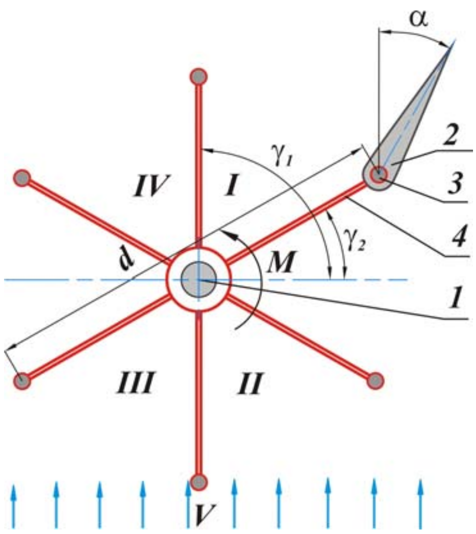


Figure 6.31. Positioning of blades towards the water currents.

The torque developed by one blade is described by the equation;

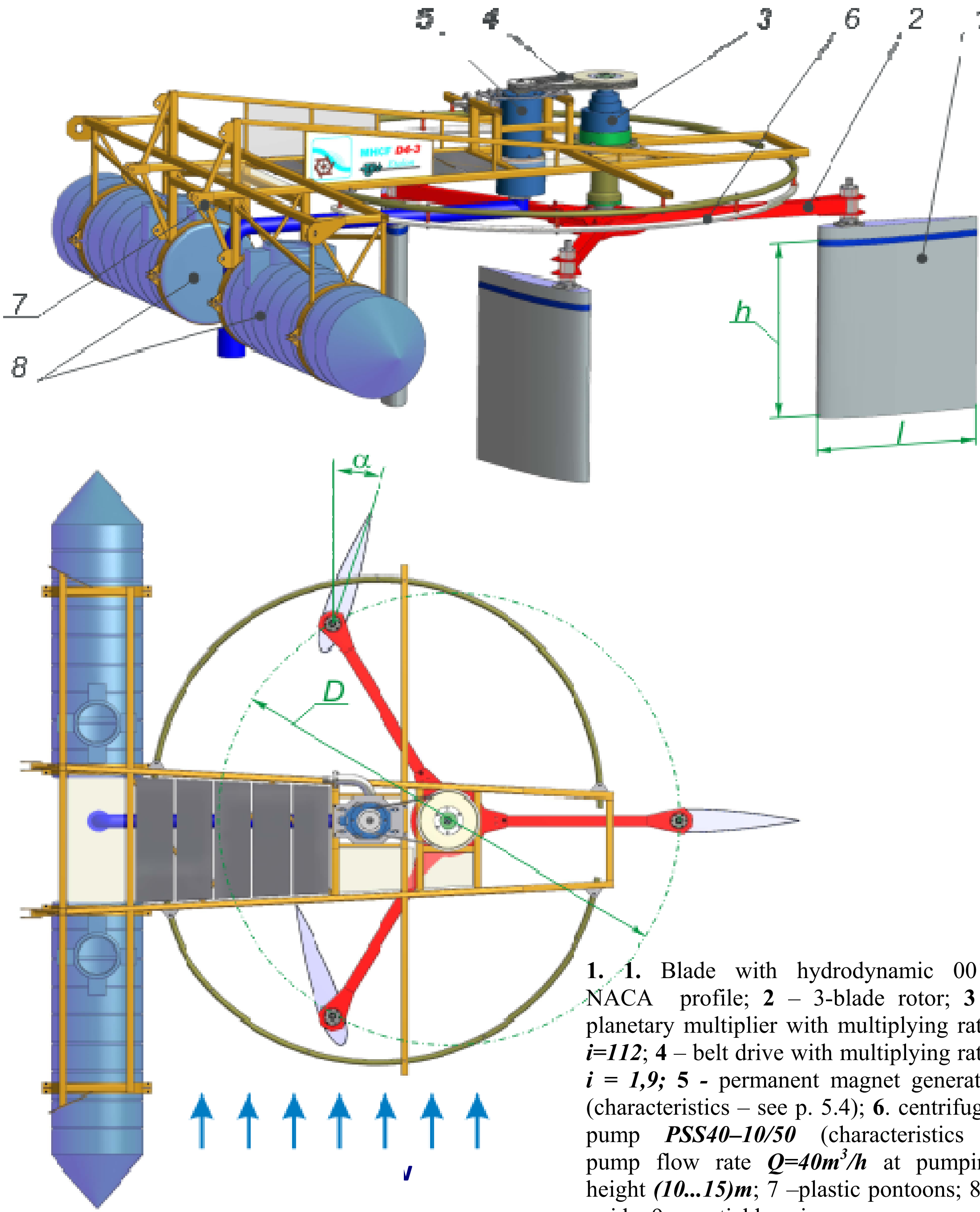
$$M = F_\tau \cdot \frac{d}{2} = (\cos\gamma \cdot F_y - \sin\gamma \cdot F_x)\frac{d}{2}, \qquad (6.2)$$

where $\boldsymbol{F_\tau}$ is the projection of force $\boldsymbol{F}$ on the tangent drawn to the path of motion of the blade axis.

The summary torque includes the general component of the resistance force $\boldsymbol{F_h}$. The torque moment generated by the turbine consists of the torques generated by each separate blade. Currently only one blade will not generate positive moment (it will generate a negative moment – the resistance one). Thus, the torque generated by the proposed turbine will be essentially bigger than the torque produced by the existing turbines for the same geometrical (blades dimensions) and kinematical parameters of water. The proposed micro hydro power plant allows the transformation of the water flow kinetic energy into mechanical or electrical energy with an increased utilization coefficient of water energy.

Micro hydropower plant with hydrodynamic rotor for river water kinetic energy conversion into mechanical energy [23]. This model of hydro power plant is designed to convert river water kinetic energy into mechanical energy used to pump water into irrigation and sewerage systems, and supply industrial water etc. with the flow rate $Q = 40\ m^3/h$ at the height pumping $H = (10 – 15)\ m$.

Static description of the microhydro power plant. The blades 1 (fig. 6.32) are connected to the hydrodynamic rotor 2 by roller friction bearings to ensure their orientation under a certain entering angle α. The hydrodynamic rotor 2 is mounted on the input shaft of



1. **1.** Blade with hydrodynamic 0016 NACA profile; **2** – 3-blade rotor; **3** – planetary multiplier with multiplying ratio ***i=112***; **4** – belt drive with multiplying ratio ***i = 1,9;*** **5** - permanent magnet generator (characteristics – see p. 5.4); **6**. centrifugal pump ***PSS40–10/50*** (characteristics – pump flow rate ***Q=40m³/h*** at pumping height ***(10...15)m***; 7 –plastic pontoons; 8 – guide; 9 – spatial housing .

Figure 6.32. Micro hydropower plant with hydrodynamic rotor for river kinetic energy conversion into mechanical energy for water pumping (flow rate Q = $40m^3/h$, pumping height H = 10...15 m).

the planetary multiplier 3 through an auxiliary shaft, which is fixed on the bearings. The belt pulleys of the transmission 4 are mounted on the output shaft of the planetary multiplier - the big one, and the small one - on the input shaft of the centrifugal pump 5. The hydrodynamic rotor 2 and blades 1, the multiplier 3, the centrifugal pump 5 and guides 6 are mounted on the spatial housing 7, installed on the pontoons 8.

Functioning principle. The river flowing water with the energy potential dependent on the flow velocity drives the hydrodynamic profile blades 1 (fig. 6.33), oriented continuously by the entering angle ***α***, and revolving in their relative movement in relation to the rotor through the bearings mounted in body 5. The micro hydropower rotor 2 comprises three blades oriented at an entering angle α, which is dependent on the water flow velocity. In the areas of blades 1 location, inefficient from the point of view of river kinetic energy conversion, under hydrodynamic forces the blades 1 are repositioned at an angle of 90° to the currents of water or are carried by the water unhampered to the angle $\alpha = 0$. Thus, the respective positioning of blades allows the increase of water kinetic energy rate converted into useful energy. As result, the water currents transmit a part of their kinetic energy to the blades 1, stressing them under the hydrodynamic forces and reporting rotational motion with angular frequency ω_1 and torque T_1 to the rotor 2.

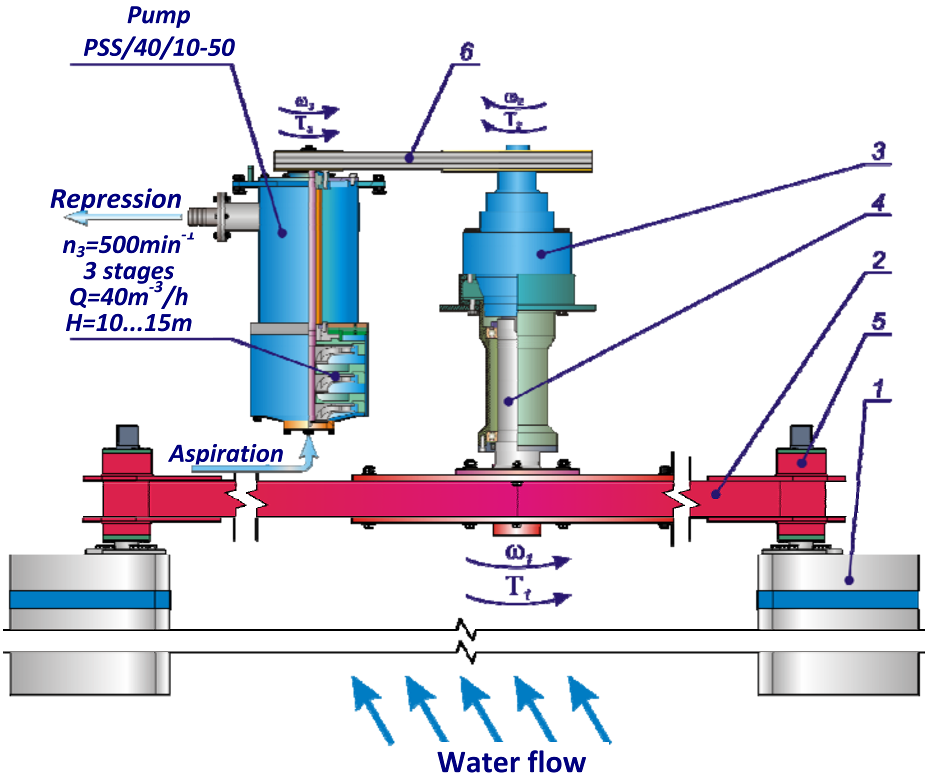


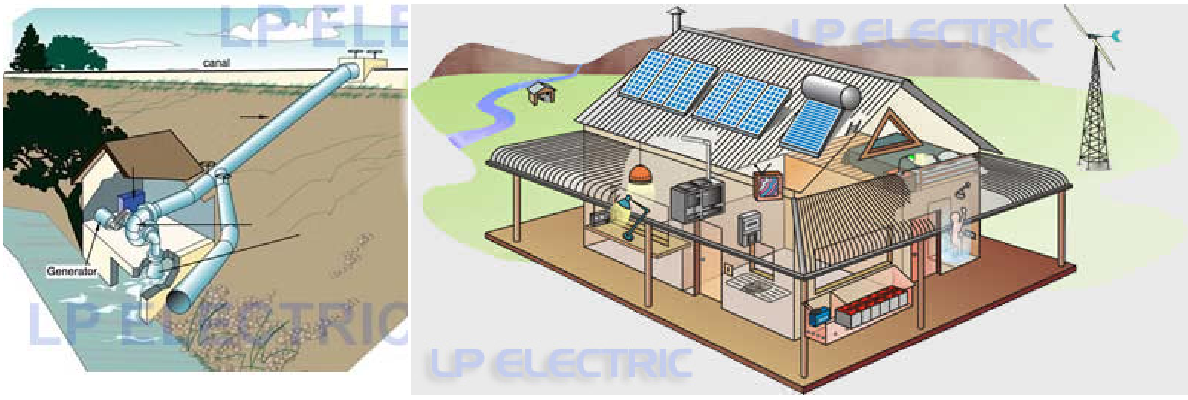
Figure 6.33. Kinematics of micro hydropower plant MHCF D4x1,5 M.

Rotor 2, rigidly coupled by means of auxiliary shaft with the input shaft of the multiplier 3, transmits rotational motion to the last with angular frequency ω_1 and torque T_1. The multiplier reproduces the rotor 2 revolutions up to $n_2 = \frac{30\omega_1}{\pi} \cdot i_1 (min^{-1})$, where i_1 represents the multiplying ratio of the multiplier (i_1=112). Rotational motion at angular frequency $\omega_2 = \frac{\pi n_2}{30} (s^{-1})$ is transmitted from the multiplier input shaft via a transmission belt 4 of the centrifugal pump input shaft with multiplying ratio $i_1 = 2,25$.

$$n_3 = \frac{30\omega_3}{\pi} = 500\, min^{-1}.$$

6.8. Micro hydroelectric power plants integrated with other renewable energy conversion systems

One of the most common applications of alternative energy is power supply of isolated consumers: a vacation house or cottage, a motel or other social objects, located in an area without access to the public grid. To ensure fully the electricity needs, micro hydro power plants are often integrated into a complex energy system that includes both renewable energy conversion systems (wind, solar, thermal, biomass, hydrogen, etc.) and conventional energy systems (diesel and gas stations, etc.). Integration can be done in two ways: integration into a single power system of several renewable energy conversion systems (wind, hydro, solar, etc.); creation of joint operating energy facilities (e.g., the main shaft, which is linked to power generator, is driven by both a wind turbine and a hydraulic turbine). Their combined use is always possible. Fig.6.34,a shows a diagram of an individual power system for home, cottage, motel, etc., based on the use of hydraulic, solar and wind energy. Fig. 6.34,b shows a modern cottage, which energy needs are satisfied by an integrated complex system, based on the use of hydraulic, solar and wind energy. It is difficult to imagine a modern cottage or a motel located in an inaccessible location without refrigerator, television, lighting, hot water, stereo, microwave and other essential elements of a comfort level requirements.



a. ***b.***

Figure 6.34. Modern cottage with a power supply complex system.

Renewable energy technologies are intermittent in nature, so they are not constantly available. Solar energy is not available at night. Wind stations will stop in the lack of wind. Although micro hydro power plants are the most reliable renewable energy source, they also depend on the water flow rate, which is dictated by multicriteria optimization considering the following variables:

- Irrigation;
- Navigation;
- Flood control;
- Recreation;
- Energy demand.

It is therefore appropriate to integrate renewable energy conversion systems. Globally, some activities have been initiated with limited scope for the exploration of associated purposes with the operation of integrated hydro-wind power. The results obtained from the growing number of pilot studies and investigations, and he synthesis of best practices are being enriched in this respect. The lessons learned in the past can now be investigated for future projects.

The program will initiate case studies of hydro-wind power integration in the U.S. The program will also involve international experts in activities related to the integration of hydroelectric power and its application on the U.S. market. The main objective of the program is to establish a dialogue between energy producers and to accelerate immediate maintenance activities and market development of hydropower sustainable market under ecological, economic and political aspects.

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