HYDROELECTRIC KNOWLEDGE

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Introduction

The water cycle, triggered by the evaporation of the Earth's water, the formation of clouds and rain, provides mankind with the most extraordinary renewable energy source, the second after biomass. Its origin is once again the sun, the radiation of which causes evaporation. Although only 0.33% of solar energy received by the Earth leads to rainfall, it is still a remarkable amount of energy. Water includes two types of energy: potential and kinetic.

Energy from water

Potential energy. Both when it falls down as rain and when it comes out of a spring, water is forced to go "downwards" due to force of gravity. We all can see the energy of a waterfall; the higher the jump, the more energy will be produced by the water when it falls. Therefore, the higher the water is located with respect to the point of arrival, the more the energy that can be potentially developed. Potential energy is therefore the energy of the water mass at rest, according to the initial position of water and its point of arrival. It corresponds to the energy contained in the glaciers and natural or artificial basins located at high altitude.

Kinetic energy. Water kinetic energy is the energy of a moving water mass and corresponds to the energy contained in the water of rivers, water streams and the sea. It depends on the speed and the volume of the moving water. Hydraulic machines transform water movement into mechanic energy. It is simple to convert mechanic energy into electric energy.

How to obtain energy

Two procedures are available to obtain energy from fresh water: water wheels and hydroelectric power plants. The former produce mechanic energy, the latter electricity. Water is a source of energy marked by numerous advantages known by mankind. That is why it has been used for 4,000 years. It is a relatively abundant source, more or less free, renewable and environmentally friendly. Moreover, its efficiency in the production of electric energy can exceed 80%. Energy can be obtained from seawater too, by exploiting its movements (waves, tides and currents) and its thermal energy (water heating) by creating artificial basins and equipment exploiting temperature difference. However, such technologies still need further development and sometimes only lead to experimental applications.

Where it is

Water energy turned into hydroelectric energy a little more than a century ago and it has undergone a very rapid development which is still continuing in industrialised countries and developing countries of Asia and Latin America, potentially rich in resources. Also in terms of exploitation of available hydroelectric resources, Western Europe and the United States are the world leaders and use almost all the available resources. The use of hydroelectric energy is much more limited in

Eastern and developing countries, where the energy produced by hydroelectric power plants could be increased remarkably. The installed capacity of Africa is remarkably low as compared to the huge potential of the continent. In this respect, a dam on the Congo River alone would allow the production of as much energy as it is produced in Italy in one year. In terms of installed capacity and energy efficiency, hydroelectric energy remains one of the most widely exploited resources to produce electric energy. In 2019 hydroelectric energy accounts for over 16% of the world production of electric energy, although only 10% of the technically viable water resources are exploited.
(*Source: International Energy Agency (IEA) – Key World Energy Statistics 2021*)

Hydroelectric power in Italy

In Italy 40.7% of energy produced in 2020 by renewable sources comes from hydroelectric. According to the data of GSE (*Gestore dei Servizi Elettrici*), at the end of 2020, the hydroelectric power produced in Italy amounted to 47.552 GWh. In Italy in 1938, 14.6 GWh out of 15.5 GWh total energy produced, was hydroelectric power. This source contributed to the start of Italian industrialization in the 19th-20th Century. After being the main source of electric power up to the 60s (82% of the total), the percentage of this renewable source progressively decreased, while the quantity produced remained constant. In the 80s, the percentage of hydroelectric power had dropped to 25%, while thermoelectric power production, during the same period increased from 14 to 70%. The potential of the hydroelectric resources in Italy is exploited to about 90% and the maximum limit of possible exploitation has been reached. It therefore does not seem to be a sector that can expand further.
The fact that more favourable and convenient sites, from a technical and economical point of view, are already being utilized, contributes to the “closing” of this sector, and a number of technical, environmental and economic obstacles have arisen with regard to the realization of new high-capacity and high-output power stations. Consequently the future of hydroelectricity in Italy seems to consist in the realization of only the low-output.

Potential development

Compared to the other renewable sources, hydroelectric power has already reached a very high level of utilization of resources. The large hydroelectric power plants in fact have almost all been built. The road to follow in the future will be that of minor hydroelectric plants (mini-and micro-hydroelectric) with small plants serving isolated utilizers, that have the possibility of exploiting the water resource that is available in the vicinity. In particular, the term **mini hydroelectric**, indicates plants with an installed power that is less than 10MW while the term **micro hydroelectric** is used to indicate plants with a power that is less than 100 kW. Small power plants have a remarkable number of advantages: it is possible to exploit small differences in height and minimum river flow-rates to obtain electric power; they have a mild impact on the territory; low costs; and this type of power plants can satisfy the energy requirements of small communities, farms, individual families or small enterprises. Furthermore, these plants are ideal to provide energy to isolated areas or areas that are not connected to the national electricity distribution network. Generally, in industrialized countries where large power plants are present, the area of development is mini hydroelectric power. Instead in many developing countries the hydroelectric source of energy can be an interesting source of energy supply, both from large hydroelectric power plants and from mini hydroelectric plants.

A bit of history

Thousands of years ago mankind learned how to exploit the mechanic energy produced by falling water. The Greeks and Romans already used water mills to grind wheat. In Barbegal, France, and near Arles, an important port supplying Rome with wheat, 8-wheel water mills were found exploiting the same river at the same time (310 A.D.).
However, in Europe the exploitation of water power to obtain mechanic work was to become more common only during the 12th and 13th century. The main use was in the agricultural sector, i.e. grinding cereals, olives, salt and other minerals by means of water mills. Other machines powered by canals were developed between 1500 and 1600, although they were less common than water mills. One of the best manufacturers of this kind of machines was Leonardo da Vinci.
During the Middle Ages the water wheel invented by the Greeks became very popular. It was a sort of mill used to lift water and was used to reclaim swamp areas, to irrigate and in the mining field. The water wheel coupled with a camshaft (part of a machine that, fixed to a rotating axis, transmits a continuous rotating movement to another part of the machine by making it alternatively lift and lower) also allowed the production of an alternated vertical movement, similar to a hammer. It was used to print textiles and operate bellows, leading to a further development of the metal industry.
Great technical progress was achieved following the evolution of the water wheel into the turbine, i.e. an equipment capable of transforming mechanic energy into electric energy. The creation of the hydraulic turbine dates back to the end of the 1800s. Since then the turbine has been further developed and its current total efficiency in state-of-the-art plants exceeds 80%.

Energy from the glaciers

Most of the mountain regions in areas with a humid and temperate climate, including Italy, have a high production of hydroelectric power. This is an important item in the national energy accounts. The water of the mountain torrents flows down great drops, which determine an optimum energetic potential, but generally the outputs of the torrents are too variable to be exploited continually. Glacier melt waters guarantee a supply of large quantities of water in the summer season, when the other courses of water have run dry. It is sufficient to compare, with equal precipitation, the summer output of water courses in the Alps and in Central and Southern Italy, to realize the importance of the existence of glacier bodies in the surface water regimen.
For this reason many hydroelectric plants in the mountain areas are fed by ice melt waters, and in very many cases water is tapped directly from the torrents that form from the glaciers. Countries like Switzerland, Austria, Italy and New Zealand were among the first to exploit the productive

potentiality of ice waters. At the start of the Seventies, 64% of the energy requirement in Switzerland was covered by the production of the hydroelectric power plants, that were mostly fed directly or indirectly by water melting from the glaciers. In the Italian Alps, there are a number of examples in the mountain regions in the north, in the regions of Piedmont, Valle d'Aosta, Trentino-Alto Adige and Lombardy, where the presence of glaciers enables an intensive use of water as a source of energy.

One of the most imposing examples of exploitation of the water resources of the Alpine glaciers is the gravity dam in Dixence in Val des Dix in Switzerland. With its 285 m wall, it is the highest in the Alpine range and one of the highest in the world, supporting a reservoir with a capacity of 400 million m^3. With a network of over 100 km of underground galleries and channel shunts, it collects the waters of the Cheilon Glacier and the glaciers coming from Mount Rosa and the Matterhorn, with plants that cover an overall surface area of 357 km^2, half of which are covered by glaciers (data: Smiraglia, 1992).

The state of the glaciers

With only very few exceptions, glaciers around the world are receding, a phase which began at the beginning of the last century and briefly interrupted by a small advance of the alpine area around the 1980s. This puts at risk not only the existence of glaciers, but also an important renewable energy resource. Also the resulting ice and water therefore seem to be transformed into a source that is running out and is no longer renewed, as is the case with fossil fuels. In fact, the mass of most Italian glaciers is negative: summer melts more ice than is formed during the cold season and the mass of the glaciers decreases.

Unlike fossil fuels, whose exploitation depends on man and can be to some extent planned and programmed, possibly setting aside "strategic" reserves, the water produced by melting glaciers can only be used when it is available. This energy source depends on the weather conditions and, over the years, on climatic fluctuations, also influenced by human activity. For example, the torrid summer of 2003, hotter and dryer than average, facilitated the release of large quantities of melting water that was not fully exploited for energy production. Indeed, an artificial basin is constructed to contain only a limited amount of water and the technical characteristics of the plants are designed to produce that particular maximum amount of energy, even in the presence of an excess of the available resource. Water resources from glaciers are therefore difficult to manage: the only certainty they offer is their availability during the summer months. For how many years will it still be possible to exploit this resource?

The state of the glaciers in Italy. The intense reduction of the area of glaciers in the Italian mountains, which has been accelerating in recent decades, is reflected in all the other sectors of the Alps and in other mountain ranges on the Earth and is certainly one of the clearest and most obvious signs in nature of the climate changes in progress and in particular of the increase in average air temperature. In addition to being the most reliable climatic indicators, glaciers represent an important water, energy, landscape and tourist resource.

According to the New Land registry of Italian Glaciers in Italy (published in 2015), there are 903 glacial bodies in Italy, covering a total area of 370 km², equal to that of Lake Garda, present in 6 Italian regions, of which only one, Abruzzo, is not alpine. Making a comparison with the previous national glacier land registry, which was completed at the end of the 1950s by the Italian Glaciological Committee in collaboration with the National Research Council, it can be seen that the number of glaciers has increased from 835 to 903. What may appear to be a contradiction is actually not because the numerical increase is to attributed to the intense fragmentation of existing glacial units. The glacial surface area has indeed recorded a loss of 30% (157 km²), comparable to the area of Lake Como, from 527 km² to the current 370 km² (approx. 3 km² lost per year). There are therefore numerous Italian glaciers, albeit fragmented and of small dimensions (an average area of 0.4 km² can be estimated) with the exception of three glaciers with a surface area of over 10 km²: the Forni, in Lombardy (National Park of Stelvio), the Miage, Valle d'Aosta (Mont Blanc Group), and the Adamello-Mandrone complex, in Lombardy and Trentino (Adamello Park); the latter can be defined as the largest glacier in Italy, having been classified as a large unitary glacial unit due to its unusual shape, similar to that of the large Scandinavian glaciers, characterised by a plateau with many tongues.

Advantages of power from glaciers

There are many advantages in using glacier melt waters for the production of hydroelectric power. Glaciers are a source of water that is constant and sure during the summer months, unlike the water of rivers and torrents whose capacity is subjected to remarkable variations depending on precipitation. Consequently, in the summer months, when most of the water courses on the surface suffer a lack of water, the water courses fed by the glaciers instead, are rich in this precious resource. The energy obtained from glaciers can therefore be used in the periods in which the other water resources register minimum levels and due to the melting water of the glaciers it is possible to face situations of energetic emergency such as the recent summer black-outs.

The costs for the realization of a large hydroelectric power plants with all the connected structures (reservoirs, dams, channels, pipes, power plants and long distance power lines) are very high, but as most of these are plants that date back many years, the costs have partly been amortized and consequently the cost of hydroelectric power is relatively low. At present, due to economic and environmental reasons there is a preference for the construction of micro-plants that satisfy the power requirements of small local communities and are less costly and more ecological. It is a “clean” energy, as the production does not produce any polluting substances even though there are some repercussions on the environment.

Problems and solutions

Apart from the problem of having almost reached the maximum limit in the exploitation of this resource, a fact that has already been mentioned, the utilization of glacier melt waters for the production of hydroelectric power involves some technical problems, which have important economic repercussions. One of the most important technical problems concerns the solid load that is normally transported by glacier melt waters, that is generally very high. The waters that flow from a glacier always have a characteristic milky grey colour, due to the large quantities of very fine material that are carried in suspension. This characteristic does not make the melted waters particularly suited to be used for hydroelectric purposes. In fact the reservoirs and channels in which these waters flow and are collected are subjected to the deposits of the suspended material. So that the plants can operate efficiently and so that the capacity of the reservoirs is not modified, cleaning interventions are required, and the deposits must constantly be removed. These operations are costly and technically they are not easy. The progressive accumulation of material on the bottom of the reservoirs (known as silting process) gradually decreases their capacity and also the productive potentiality, because the utilization times are decreased and also the plant’s operative life.

The waters that are rich with material in suspension also create another severe technical problem: the particles hit the mechanical parts of the turbines at a high speed and with great force and provoke a rapid wear of the same. For this reason these waters must be subjected to a filtering process before they enter the plant. The filtering operations are difficult and they lead to the subsequent problem of the disposal of large quantities of limey mud and clay, without creating damages to the environment.

Another problem that is becoming more and more serious each year is tied to the progressive retreat of the glaciers’ front. Many intake or input units, including some large reservoirs, are located near the glacier fronts in order to collect the largest possible amount of water, and to avoid any dispersion in the detrital deposit. The progressive retreat of the fonts requires the adaptation of the intake units, thus requiring a continuous modernization of the structures and their adaptation to the changing position of the new front. This leads to an increase in the costs and the environmental problems connected with the realization of new structures. As an experiment, plants which take water directly within the glacier have been realized. These structures are mainly used for research and are generally associated with laboratories to study glacier dynamics. The most famous endoglacial laboratory is in Engabreen in Norway, and has been installed in the intake tunnel dug inside the glacier.

Also the example of the Argentière glacier located on the French slopes of the Mont Blanc group of mountains, is famous. In the Sixties tunnels were dug in the ice, under the front, in order to capture the melting waters for hydroelectric purposes. A characteristic of the sub-glacial torrents, however, is to continually change their course, with sudden variations in their direction, therefore the galleries soon became useless and were transformed into underground laboratories to study basal erosion.

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