The energy system

Introduction

With the term “energy system” we usually indicate the set of processes involving production, transformation, transport and distribution of energy sources. Energy systems are usually extremely complex, and require skills from all fields of science in order to build and manage them. In fact, just as it is simple to use the energy that is made available to us at home (we press a switch and the light turns on) so is it difficult and complex to produce that energy and bring it right into our homes.

The man and Energy

The energy system

Energy has by now become an inseparable partner of human beings, who use it at any time every day in all their activities. To ensure the possibility of benefiting from that resource in a simple, stable and constant way, mankind had to conduct studies and research for a long time, and only during the last decades of the 19th century did many nations, but not all, succeed in developing “energy systems” ensuring the quality and quantity of energy necessary for development.
The term “energy systems” usually describes the set of production, transformation, transport and distribution processes of energy sources. Energy systems usually are very complex and call for knowledge deriving from all scientific fields to be developed and managed. Although using the energy available in our homes is easy (we push a button and the light is switched on), producing that energy and conveying it into our homes is an extremely difficult and complex task.
The difficult and complex nature of the production and distribution of energy mainly derives from three factors.

Non-homogeneous distribution of primary sources

The first is that the production of the currently most exploited energy sources (fossil fuels) is concentrated under the surface of few countries, often far from the consuming countries. Therefore finding and extracting the energy source and developing ad hoc agreements between producing and consuming countries is necessary to ensure a stable and lasting provision of fossil fuels to the latter. Finally, the physical transportation of the energy sources from the producing to the consuming countries is to be taken care of.

Need to transform primary sources in order to obtain energy

Energy sources are not always usable as they are naturally (primary sources). They often need to be transformed to make their use by final users easier and more effective (witness the electric energy obtained from coal combustion, or petrol obtained by refining crude oil). Such energy sources artificially produced by human beings are called secondary sources and are the most widely known since they are used every day.
Also the processes of transformation from primary sources into secondary sources and the organization of their distribution to the final users are complex and require many people and much knowledge to be managed in the best possible way.

Safety

The problem of “the best possible” management leads to a third complexity factor: safety. In other words, all the activities making up the energy system need to be carried out in safety conditions for human beings and the environment. If control is lost over the energy sources, very serious damage to the health of human beings and the environment may ensue (just think of sea pollution caused by a damaged oil tank or the dreadful consequences of a leak of radioactive material from a nuclear power plant in case of accident). Therefore human beings constantly need to study and implement technologies capable of rendering the different stages of energy production, transportation, transformation and distribution to the final user safer. Much has already been done since the first years of intensive use of energy sources but a lot can still be done, by implementing new technological discoveries.

Energy: yesterday and today

The history of mankind has always been characterized by the search for new sources of energy: to ensure survival at first and then to improve the standard of living. At the beginning energy meant manpower, often supplied by slaves and beasts of burden; later the energy of wind (windmills) and water (water mill wheels and similar machines) started to be exploited.

Towards the end of the 19th century, thanks to the development of the industrial civilization, the need for energy was met thanks to the intensive use of coal. From the technological viewpoint a big step forward was made with the realization that heat, through the production of steam, could be transformed into mechanic energy. The first implementation of this new source of energy was the steam engine invented by Watt, which replaced traditional horses with the more modern "horse-power".

During the first decades of the 20th century, after a promising start of the hydroelectric energy, great oil field were discovered in the Middle East: the "black gold" rush had started.

During the 1960s, after half a century of unmatched domination by oil, natural gas proved to be a valid alternative, especially as regards domestic use (cooking and heating) thank to its smaller environmental impact.

At the beginning of the 1970s some countries started to develop nuclear energy, mainly to produce electricity. The development of nuclear energy, just like other alternative energy sources, can be explained by means of the marked increase in the oil prices caused by the "oil crises" which took place in 1974 and 1979 following the corresponding embargoes against the Arab oil exporting countries and, in 1990, during the Gulf war.

The range of currently available energy sources includes oil, natural gas, coal, hydroelectric energy and nuclear energy according to a variable percentage distribution depending on the country. Other sources can be added to the main sources. Although their quantity is still limited, they are renewable: geothermal energy, solar energy, wind power, the energy obtained from waste or from biomass.

The International Energy Agency (one of the main research institutes dealing with energy) expects that until 2020 the world energy consumption will increase by approximately 65% as compared to the current level. What sources will supply all the necessary energy to mankind? The availability of fossil fuels will be increasingly reduced over the years (owing to the depletion of resources) and to meet the growing demand for energy new sources will need to be exploited, especially renewable sources with a smaller environmental impact.

One of the possible alternatives to oil is hydrogen. Hydrogen is an element contained in many substances, (from water to natural gas) and widely available on Earth. Hydrogen can be used in fuel cells: a device capable of activating a chemical-electric process transforming the energy contained in hydrogen into electricity and heat avoiding combustion, which is the cause of numerous polluting emissions in the air.

The implementation of fuel cells will become possible in many sectors: transports (buses and cars), households (hot water production, heating and air conditioning) and electronics (mobile phones and computers). Currently available technologies for the production, preservation and use of hydrogen must be further tested and improved before this resource can be used on a wide scale.

The energy balance

The national energy balance

The importance of energy in modern society led man not only to create complex "energy systems", but also to try and measure how much energy he uses each year and understand which source he gets it from and from which Country he imports it from.

These problems have been solved by using adequate energy measurement units and a scheme representing the energy flows that enter a country and how energy is used in the different sectors along the year: the National Energy Balance.

Like any other balance, the energy balance collects information on energy input and output. The national energy balance is the most famous one and is a collection of information on how energy is produced and used within a Country during

the year.
How can the National Energy Balance (NEB) be read? To begin with, the energy available from the various sources is reported with a common unit of measurement mentioned before: the Tonne of oil equivalent. This allows the sum and the comparison of data relating to different sources.
The first piece of information contained in the NEB is the total available energy, subdivided according to the sources (also known as energy primary consumption and primary sources). Such data show how much energy is made available in a country to be consumed directly (for example, the electric energy imported or produced in hydroelectric power plants) or to be transformed into by-products to be launched on the final-user market afterwards (for example oil is refined into petrol and gas oil) or, finally, to be transformed into electric energy (coal, gas and oil used in thermoelectric power plants to produce electricity).
The energy supplied by primary sources can belong to the country concerned (national production: for example the natural gas extracted by Italy from the field of the Po valley or the Adriatic sea) or be imported (for example the oil Italy imports from the Middle East or the natural gas imported from Libya and Russia).
Mention should be made that during this definition stage of primary energy consumption the national production of electric energy only includes the production of hydroelectric, geothermal, solar and wind power plants or any renewable resources but, as was stated before, does not include the energy obtained by burning fossil fuels. This distinction was introduced to avoid that part of the energy available is counted twice, first as oil and then as electric energy produced by burning the oil. The exported energy and the variation of stocks are to be subtracted from the sum of the national production and imports of different sources. Thus the primary energy available is achieved (also said primary energy consumption or gross domestic consumption).

Information obtained from the NEB

The National Energy Balance is drafted every year. Thus comparing and contrasting the energy consumption is possible over the years by analyzing the different origin (whether imported or home produced), the different composition (which energy sources were exploited) and the development of national consumption (whether increasing or decreasing) of energy.
The information that can be obtained from the comparison of the energy consumption over the years is very important. For example, by comparing the primary energy consumption with the production data of a country one can see whether, over the years, the country succeeded in achieving a better management of the energy available, by using less energy to produce more. Else, one can check whether the renewable energy sources or those causing less polluting emissions in the air have progressively replaced the most polluting energy sources. A further useful piece of information is whether the country depends upon of energy imports. In countries like Italy, for example, energy resources under the surface are limited and there is a need to import over 80% of the primary energy from abroad. Since great part of our development and daily prosperity depends upon the energy available, countries like Italy, which are markedly dependent upon foreign energy supplies, need to maintain good and stable relations with the energy exporting countries.

Final use of energy

How does a country use the annual primary energy sources available? The answer is provided in the second part of the NEB containing data on the finale use of energy.
Energy uses include the energy consumption of households and enterprises (of course enterprises producing electric energy to be destined to final uses are excluded).
Therefore part of the energy available as a primary source needs to be transformed to be used. As seen before, the most important transformation is the thermoelectric transformation, i.e. fossil fuels becoming electric energy.
By moving from primary consumption to the final consumption we see that the composition of energy sources varies because the quantity of fossil fuels decreases and that of electric energy increases.
Besides in the composition of energy sources, there is a variation also in the quantity of available energy for final uses. The quantity which can be actually destined to final uses is smaller than the primary energy available because the

transformation processes involve consumption and losses. For example, the use of fossil fuels (coal, oil, natural gas) to produce electric energy approximately involves a 60% average loss of the energy originally contained in the fuel. It means that if among the primary sources 100 Tonne of oil equivalent of coal are available to produce electricity, at the final use stage only 40 Tonne of oil equivalent of electric energy will be available. The remaining 60 Tonne of oil equivalent were lost during the electric transformation process and cannot be used by households or industrial plants (final uses).
At this stage of the National Energy Balance we have the available energy quantity for the final uses, i.e. the quantity of energy consumed by industries (plants), transports (cars, lorries, trains, buses), citizens (households), agriculture and finally bunkering (the fuel consumption of ships).

Environment and territory

Impacts and protection of the air

Energy is an indispensable element to guarantee the well-being and development of the planet. Without a regular supply of energy, cities, industries, transportation and infrastructures would come to a halt. Moreover, the growth of the world economy and consumption in the 20th century, has been based mainly on exploiting fossil fuels: first coal, then petroleum and natural gas. These sources of energy, however, are not renewable and are destined, in the future, to become depleted. Furthermore, these sources of energy emit polluting substances during combustion, even if the amounts vary greatly, depending on which fuel is used.
Among the most important substances are: carbon oxides (COx), sulphur oxides (SOx), nitrogen oxides NOx), volatile organic compounds (VOC) and total particulate solids (TPS). These pollutants can be harmful for human health and for the environment if they exceed determined concentrations in the air. Among these are: the greenhouse effect, acid rain, air pollution caused by traffic in the cities and all the serious problems that experts and communication media discuss extensively for which, very often, a solution still has not been found.
The desire to protect the environment, the oil crisis of the Seventies and Eighties, and the current increase in the price of petroleum, have led the Governments of a number of industrialized countries to incentivize the development of sources of energy that are alternative to the ones that are dominant today. Notwithstanding these incentives and the rapidity of scientific and technological progress, it is estimated that these sources will cover a significant share of energy consumption only in many years' time. And therefore, in the short and medium period, most of the energy required by man will probably still be provided by the traditional fossil fuels (specially petroleum and natural gas). However man must learn to use the energy produced by fossil fuels in an increasingly efficient manner, (with a decrease in the amount of waste and an increase in the energy yield of different production processes) and must search for and make use of technological applications which will lead to a decrease in the emissions of pollutants in the air provoked by their combustion.

Challenges of the renewable energy sources

In 2012, the six primary sources of energy used in the world were: petroleum (31.4%), coal (29%), natural gas (21.34%), nuclear energy (4.8%), biomasses (10%), hydroelectric power (2.4%), and "new" renewable energy sources (1.1%, mainly obtained from solar energy and wind energy) (*Source: IEA, Key World Energy Statistics 2014*).
What immediately catches one's attention when looking at these data is that 80% of the world energy is obtained from fossil fuels which are precious sources that, however, are not renewable. And it is for this reason that it has become necessary to develop and increase the renewable energies, but to do so, a few rather difficult issues must be overcome. First of all it is necessary to successfully produce energy from the renewable sources so that they are economic and competitive when compared to the traditional energy sources. Secondly, so that the source of energy is profitable, it must be in a concentrated form that can be stocked and transported. Energy must be made available in a concentrated form in order to satisfy the large demand of energy, there must also be the possibility of stocking energy so that it can be accumulated and transported, in order to satisfy the demand of energy in areas that are distant from the area of

production. The success of fossil fuels in fact is due to the fact they satisfy these three essential requirements, while the renewable sources still have some limits which prevent their diffusion on a wide scale.
According to the aims set by the European Union, 20% of the energy requirements will have to be from renewable sources by 2020, and in particularly favourable areas the percentage of renewable energy may increase to much higher percentages. It is therefore evident that without opportune energy management strategies, the present electricity network will not be able to support these increases. Furthermore, we must not forget that renewable sources of energy are characterized by a great variability, therefore the greatest challenge is to successfully satisfy the demand of energy at peak times, exploiting sources of energy that are discontinuous and intermittent.