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Renewable energies – Future perspectives

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Abstract. The Global Energy Scenario is analyzed starting from a global energy consumption still sustained by fossil sources. Comparing the time to reach as much as the 50% of the market share of traditional sources with the trend of renewable ones, it appears that this growth is too slow taking into account the urgent request to lessen CO_2 emissions. Some supporting technologies are presented with reference to the use of storage systems to mitigate the intermittent nature of energy produced by photovoltaic and wind plants. The adoption of power electronics systems to increase the energy saving quote is finally explained.

1 Introduction

The Global Energy Scenario in the last century has been characterized by expectations and disappointments. During the sixties, the oil price was ignored by media (its cost was almost as much as a dollar for barrel) and the growing demand of electrical energy seemed to go toward the use of the nuclear energy. Twenty years later, during the second energetic crisis, the oil price became the greatest worry and only France was counting on nuclear energy. The oil price fell down in 1985 boosting the consumptions, but at the beginning of the XXI century this scenario dramatically changed for the worry of an imminent fall of oil extraction. During the same period the human role in increasing the greenhouse effect, mainly due to carbon dioxide produced by the combustion of fossil fuels, became more apparent. In this scenario the use of renewable sources (RES) appears a valid option, so that their wide use seems highly predictable in the near future. Unfortunately they exhibit a slow growth compared to the energy demand that is still satisfied by fossil fuels and moreover CO_2 emissions are likely to grow further. It seems clear that for RES to be increasingly used, there is a need of supporting technologies related to short and medium term actions [1–3].

2 Consumptions vs. Global Energy Scenario

The global energy consumption scenario highlights that we are still using too much energy produced from fossil fuel (coal, oil and natural gas). As a matter of fact in USA this value equals 87% (whereas in the world this value equals 84%) as shown in Figure 1. It can be taken into account that generation and consumption practically do not differ, since the stored energy is negligible. It is also interesting to note that the per capita energy consumption is highest in USA where as much as the 4% of the population consumes nearly 300 GJ/year × person or 8 tons of oil (corresponding to 50 oil barrels). This should reflect a high quality of life standard, on the other hand, Japan and the richest European countries consume about 150 GJ/year × person of oil, but their quality of life is the same as the one in the USA and not as much as the half. In addition, in Switzerland, which has the highest standard of living, the CO_2 emissions are lower than 1/4 of those of the USA. On the other hand, Brazil has a good standard of living with a low per capita emission: in Brazil, typically 90% of energy (in electrical form) comes from hydroelectricity, the large Amazon rain forest reduces CO_2, and 50% of its automobiles run on renewable sugarcane-based biofuel.

It is noteworthy that the energy consumption in USA has remained practically stable since 1970 (317 GJ/year × person), in 1985 it was about 359 GJ/year × person, before the 2007 crisis it was about 355 GJ/year × person and in 2010 it was about 330 GJ/year × person. Against the use of renewables there has been an increase of consumptions (think, for example, of the diffusion of the SUVs and of the aerial transport). By observing the mean gasoline consumption it is easy to note that the current value does not differ from the one in 1930 (see Fig. 2).

By adopting hybrid and diesel engine vehicles, this value could reach as much as 15–17 km/l allowing a relevant saving on the oil imports (about 1500 billion dollars in the first decade of the twenty-first century). China has started with consumptions less than 20 GJ/person in 1976 and in 2010 this value has reached 70 GJ/person. Actually this increase is mainly based on coal (79% in 2008). On the other hands there are some countries that would need to increase their energy consumption. In 2010 India consumed about 20 GJ/person and Ethiopia 2 GJ/person. These considerations show that some countries should decrease consumptions taking into account that this reduction does not correspond to a reduction of the quality of life [2–5].

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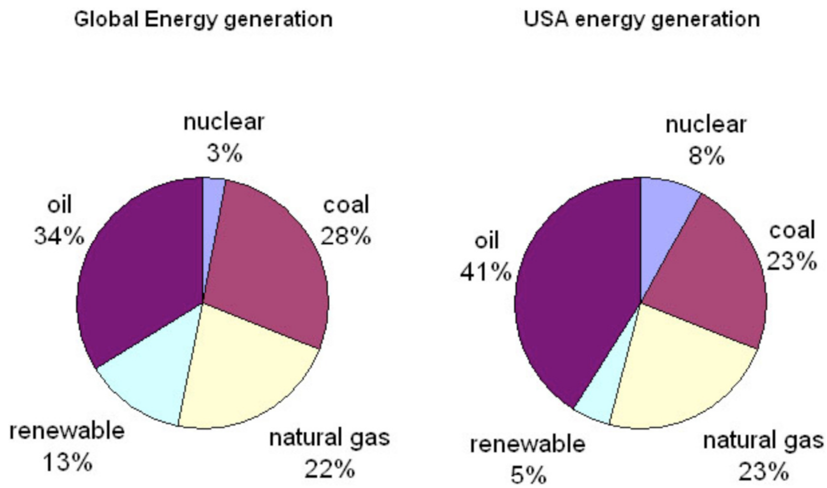

Fig. 1. Global and USA energy generation scenarios.

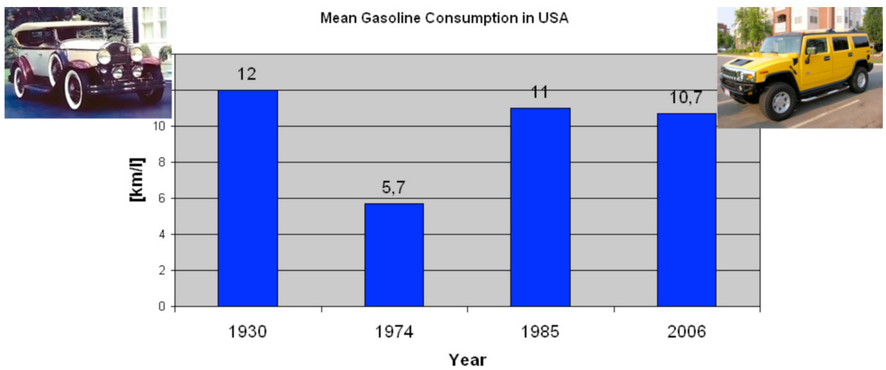

Fig. 2. Mean gasoline consumption in USA vs. time.

3 The slow growth of solar and wind energy

Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tides, waves and geothermal heat. Moreover, RES contain several aspects of scientific interest, while presenting political and ethical implications as well. Indeed, they allow the reduction of the cost of energy contributing to reduce poverty in underdeveloped countries and regions. Fossil fuel resources are located in the subsoil and many of the products originated from the combustion are detrimental to people's health; on the contrary, renewable energy sources, like solar and wind ones, are available all around the world. As for electricity production, the reduction of the combustion of fossil fuels lessens the concentration of carbon dioxide, CO_2, in the atmosphere, hindering the increase of the earth's average temperature.

Despite these advantages the growth of renewable source market share appears relatively slow and comparable with the growth of other sources in the past. As a matter of fact the fossil coal began to satisfy the 5% of the market share in 1840, this quote increased to a quarter on 1875 and arrived to one half of the market share at the end of 19th century. The oil started to cover the 5% of the market share on 1915 and arrived to 50% (overtaking coal) in 1964 whereas the natural gas quote was 5% in 1930, it became 25% in 1985. Actually only in few countries has this value raised over 50%. As for the growth of renewable sources, considering, for example, the energy generated in USA in 2011, it can be remarked that the energy delivered from renewables is the 9.39% of the total generated energy (102.652×10^{18} J) as shown in Figure 3. Traditional renewable sources total 6.01% obtained with hydro plants (3.25%), wood from production waste (2.04%), biomass and geothermic energy (0.72%). Only the remaining 3.35% has been obtained with new renewable sources like biofuels (2%), wind energy (1.19%) and solar energy (0.16%).

It is clear that, in the next future, the last three sources will have to give the highest contribution, since the other sources will show a reduced potential growth. At present, in the USA, the target is to increase this share to as much as 20% by 2030. A study of the UN IPCC (Intergovernmental Panel on Climate Change) reports that 50% of the total world energy can be met by renewable resources by 2050 [6].

On the other hand there are many drawbacks in using wind and solar energy, since energy production peaks rarely fit the energy demand. First and foremost their main inconvenience is due to their intermittent nature for which generated energy can range from a negligible value to a value satisfying most energy demand. These variations

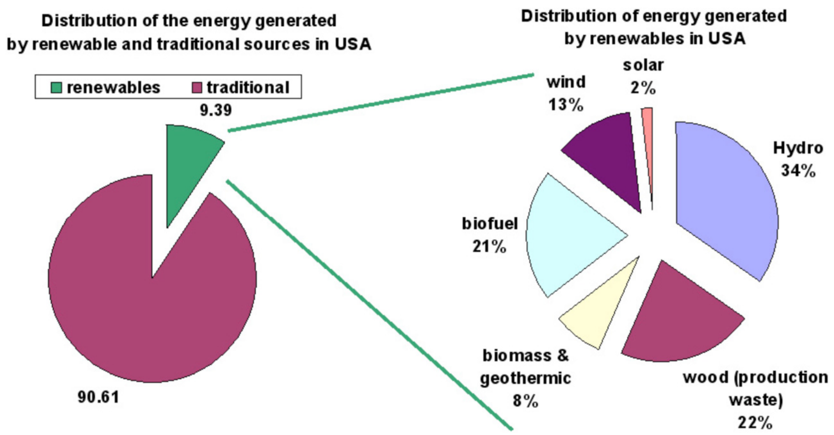

Fig. 3. Distribution of the energy generated by renewables in USA (2011).

should be buffered by gas or coal-fired power plants or dedicated storage systems. An extreme case occurred in Sicily (the largest island in the Mediterranean Sea), Italy on April 2012 when the energy share produced by RES reached 94% abating the price of energy to zero.

An interesting case study occurs in Denmark in winter when both wind turbines generate electric energy and coal-fired power stations are made to operate together to guarantee the central heating. In this case the offered energy overcomes the local demand resulting in energy prices falling down. In this case neighboring states can buy this energy at a cheap prize; when the wind is not sufficient the energy can be purchased but the price is different [7].

Finally solar and wind energy must be produced where the sun or wind can ensure a good production, and this implies its transportation with power grids by either using the existing ones or installing new grids.

From what described above, it seems that both the time required by renewable sources to cover 50% of the market and the growing consuming demand will not allow CO_2 emissions to be significantly reduced in the next future. However, a considerable help can be given by storage system technologies [3,8].

4 Storage systems

Storage technologies can significantly push the use and growth of renewable generation [6]. As a matter of fact they can store energy in off-peaks hours and return it during peak hours. In this way a plant can be operated for a fairly constant load operation below peak demand, reducing the high capital costs of power plants as well as avoiding the drawbacks due to intermittent nature of energy produced by photovoltaic and wind plants.

Storage systems can be classified on the basis of the time interval in which they are operated: transients (microseconds), very short term (cycles of the grid frequency), short term (minutes), medium term (few hours), long term (several hours to days), planning (weeks to months). The storage systems of interest for large-scale system energy management range from hours to days/months. In general energy can be stored as gravitational energy in hydraulic systems, as thermal energy, as chemical energy in batteries or compressed air systems (Fig. 4).

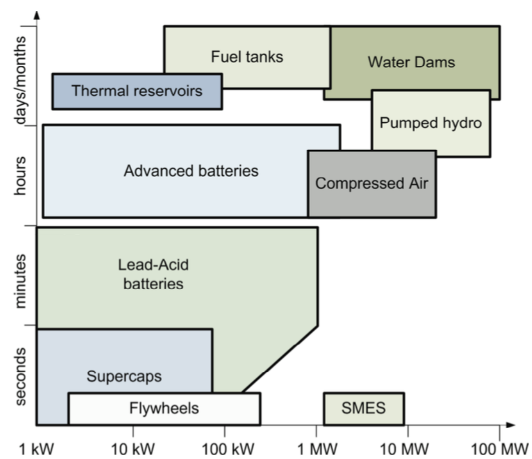

Fig. 4. Classification of storage technologies.

4.1 Pumped hydroelectric with storage (PHES)

This technology is based on traditional hydropower generation plants; during off-peaks hours energy is used to pump water to a reservoir located at higher altitude. During peak hours the water stored in the upper reservoir flows through a hydraulic turbine producing electricity. These systems are relatively cheap and reliable; in modern plants losses are lower than 20%. On the other hand they need a suitable topography with difference in altitude. At present in USA PHES plants can store about 2% of the national production, whereas in Europe the stored energy amounts to 5% and to about 10% in Japan. One of the most ambitious projects is the Eagle Mountain Pumped Storage Project (south of California) able to generate about 1.3 GW [9]. The Gravity Power company (California) has devised a big sink in which a steel cylinder is placed. The cylinder is left up by pumped water during storage phase, during production phase it descends the sink pumping the pressurized water in a turbine [10,11]. This solution could be used anywhere.

4.2 Compressed air energy storage

In this storage technology, the air is compressed and stored in reservoirs, aquifers or underground cavities. The stored energy is released during periods of peak demand, expanding the air through a turbine. When air is compressed for storage, its temperature increases, the generated heat can be stored and used during energy production, in which the air is expanded, avoiding the risk of freezing the turbines. If additional heat is required, it can be obtained by using natural gas. In McIntosh, Ala., there is a 110-MW Compressed Air Energy Storage (CAES) facility by PowerSouth Energy cooperative; the CAES generator is capable of producing up to 110 MW of electrical power within 14 min of startup during periods of high peak demand [12].

4.3 Advanced batteries

In batteries chemical energy is converted into electrical energy by oxidation and reduction of their materials. They consist of a base unit, which is combined with others, in series or parallel, to obtain the required levels of voltage and current. In principle, batteries are easy to charge; moreover they can be turned on and off very quickly. On the other hand they are expensive both for the material and the production costs.

Many types of electrochemical batteries have been developed, which can be used in electric power systems, including: lead acid (flooded type, valve regulated), sodium sulfur, lithium ion, metal air, flow batteries, vanadium redox, zinc bromine, nickel cadmium, etc. [5,13,14].

In general, battery exhibits a high cycle efficiency (typically 90%) but high cost (typically >$0.1/kWh), probably the most expensive. Recently NiCd, NaS, Li-ion and flow batteries (such as vanadium redox) are drawing attention. A NiCd Battery Energy Storage System (BESS) was installed by ABB in Fairbanks, Alaska, USA and it is able to pick up 26 MW of load for 15 min (or 40 MW for 7 min) in the event of power plant outage or transmission line equipment failure [15].

4.4 Thermal systems

A storage system can be realized by collecting heat directly generated by the sun (or alternatively by other sources as wind turbines). In this case, the heat increases the temperature of a fluid (like mineral oil), it can be stored and utilized to produce electricity producing steam for a turbine at night.

In Siracusa (Italy), the Archimede project aims to demonstrate in an industrial scale an innovative Concentrating Solar Power (CSP) technology using molten salts as heat transfer fluid in parabolic trough collectors. Hot salts have been stored (>500 °C) since June 2011 in two tanks (each one 930 m^3): the stored Energy is 80 MWh and the equivalent storage time is about 7 h [16].

Finally, thermal energy can be stored by producing ice with existing package air-conditioning units for peak demand management.

4.5 Flywheels

Flywheels store electric power as kinetic energy. The maximum stored energy is limited by the tensile strength of the flywheel material. On the basis of the material of the rotor, two types of flywheels can be recognized: (1) With an advanced composite rotor, such as graphite or carbon-fiber, which provide high specific energy. (2) With a steel rotor, which allows traditional designs (with large diameters, low speed and low power and energy densities) and new high performance flywheels. Flywheels can provide an amount of energy in a relatively short time interval, so they can play an important role in primary frequency regulation.

Stephentown, New York is the site of Beacon Power's first 20 MW plant (40 MW overall range) and provides frequency regulation service to the NYISO. This facility includes 200 flywheels. Initial commercial operation began in January 2011 and full output was reached in June 2011. Flywheels perform between 3000 and 5000 full depth-of-discharge cycles a year [17].

5 Energy saving and the role of power electronics

Actually, more than one third of the global energy use is based on electricity. There are many advantages related to the use of electric energy: its final form is relatively clean, centralized fossil fuel power stations can effectively use emission control strategies and is one of the easiest means of transporting energy over long distances [6,9–18]. Also for these reasons the demand for electricity is growing much faster in comparison with other energy forms over the next three decades. It is expected that the consumption, in comparison to other forms, will grow to 60% by 2040 [19].

Unfortunately a big amount of electric energy before utilization is lost as heat along the supply chain. Indeed, conversion loss from mechanical to electric energy is about 60%, then, during the energy distribution, additional 15% is lost, including AC/DC and DC/AC conversion over long lines. In AC/DC/AC conversion for motor drives, traction or home appliances losses are about 20% and a further 20% is lost in the last AC/DC conversion for power supplies and in DC/DC conversion for point of loads.

Power electronics plays a key role through the chain of transformation from generation to storage and distribution cycle of energy: as a matter of fact the conversion is performed by power converters in all ranges of power levels (from a few W to MW) [20,21]. Roughly 70% of electrical energy in USA is now processed through power electronics which will eventually expand to 100%.

Power electronics control can guarantee a higher efficiency conversion thanks to power semiconductor switches operated in switching mode (on or off state). According to EPRI (Electric Power Research Institute) of Unites States, about 65% of the grid energy is consumed by motor drives and 75% of these are used to move pumps, fans and compressor-type drives in industrial applications. Many of these use a conventional control based on a throttle or damper which is opened when the motor is operated at rated speed with consequent energy waste due to the fluid vortex. The use of a power electronics based motor speed control allows the throttle to remain open and the drive to save about 20% at light load. The same amount can be saved by the adoption of power electronics based load proportional speed in air conditioner/heat pumps. It is noteworthy that the additional cost of power converters can be recovered in a short period. An interesting example is the hybrid ship propulsion diesel-electric based on multi-megawatt drives in which a considerable amount of fuel is saved. Another load that consumes about 20% of the grid energy is lighting: the use of solid state LED lamps replacing compact fluorescent lamps or incandescent lamps can reach 50%. Finally an interesting improvement can be achieved in vehicles where the adoption of a regulated fuel pump can reduce the power consumption up to 40%, an active alternator up to 10%, a controlled power steering up to 75% leading up to saving about 1 kW for the whole vehicle. In general, it can be estimated that the widespread efficiency improvement in power electronics with existing technologies can save as much as 20% of the global energy demand [6,18].

Electricity-saving technology is evolving so quickly that most of the best options now on the market did not exist at all last year. Nowadays, one can save twice as much electricity as five years ago, at only a third of the real cost. Practically every building or equipment, modern as they may be, can be made much more efficient. The unit of power representing the amount of energy (measured in watts) saved is known as "negawatt". The term was coined by the chief scientist of the Rocky Mountain Institute and environmentalist Amory Lovins in 1989 [22]. The concept of a negawatt could influence a behavioural change in consumers by encouraging them to think about the energy that they spend. A negawatt market can be thought of as a secondary market, in which electricity is allocated from one consumer to another consumer within the energy market. In this market, negawatts could be treated as a commodity. Commodities have the ability to be traded across time and space, which would allow negawatts to be incorporated in the international trading system.

Power electronics appears "the" key enabling technologies to efficiently use, distribute and generate electrical energy, or to produce negawatts. Despite this tremendous importance, in the well informed general public or in the politicians' points of view there is often a lack of awareness of its role compared to e.g. microelectronics and nanotechnology with a negative impact for attracting students and allocating research funding [19].

6 Conclusions

Despite great expectations for renewable sources, a great amount of energy consumption is still sustained by traditional fossil sources.

The energy consumption, though fundamental for the growth of nations, in some of these is excessive: it could be reduced without worsening the quality of the life of their inhabitants.

Solar and wind plants appear a viable solution for replacing fossil fuels and abating CO_2 emissions, but they need to be supported by other technologies. Among these, storage systems could ensure the required supply continuity against the intermittent production by solar and wind plants. Moreover, the massive use of power electronics converters is able to guarantee an energy saving of as much as 20% in a short period. A similar amount could be saved by preventing waste. The energy saving is the most profitable resource.

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