Integration of RES in AC grids

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PART 1

1. Introduction

Electricity has existed as lightning in the skies since the beginning of the universe, even before there was life on earth. Early cave people probably recognized the force of electricity when lightning struck and used its thermal effects to get the fire. The ancient Greeks considered it the rage of Zeus (Fig .1).

Fig.1. Zeus in action

The earliest and nearest approach to the discovery of the identity of lightning, and electricity from any other source, is to be attributed to the Arabs, who before the 15th century used the much latter Arabic word for lightning (*raad*) applied to the electric ray.

A Greek mathematician named Thales of Miletus; around 600 B.C. are credited with the discovery that amber when rubbed with animal fur acquired the property of attracting light objects like feathers, making that the first observation on static electricity and its effects. The word electricity comes from "elektron" the Greek word for amber and was introduced by Democrit.

The Parthians, it seems where the first to use electricity on religious purposes. In 1936, in a temple from the old Babylon was discovered the famous Baghdad Battery, which resembles a galvanic cell.

The wind power, of the moving air and the hydraulic one, of the moving water were the first sources of natural, free of charge energy used first of all in navigation. Other possible applications of hydro energy were suggested in a poem of the Greek poet Antipater, who in 400 BC., recommended how to convert it in rotating mechanical energy used for irrigation

Otto von Guericke (1602-1686) who became famous for his Magdeburg vacuum experiments developed a first simple electrostatic generator. It was made of a sulphur ball which rotated in a wooden cradle. The ball itself was rubbed by hand. As the principles of electric conduction had not been discovered yet, von Guericke transported (Fig. 2) mechanically by a isolated rod the charged sulphur ball to the place where the electric experiment should happen

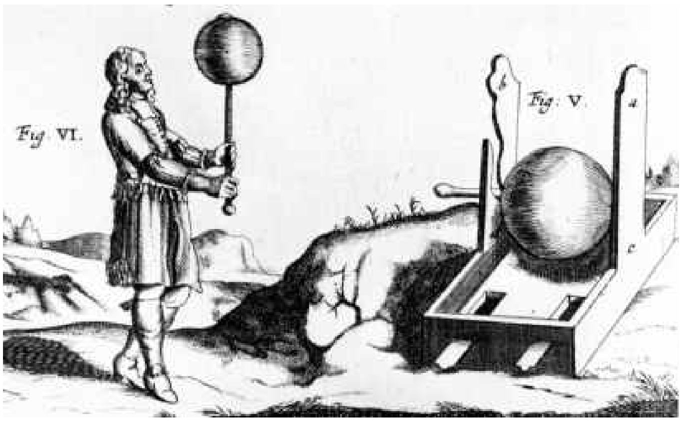


Fig.2. Otto von Guericke producing and transporting static energy

Glass proved to be an ideal material for an electrostatic generator. It was cheaper than sulphur and could easily be shaped to disks or cylinders. An ordinary beer glass turned out to be a good isolating rotor in Winkler's electrostatic machine.

Machines like these were not only used for scientific research, but become the preferred toy for amusement. In the 18th century, everybody wanted to experience the electric shock. Experiments like the "electric kiss" were a salon pastime (Fig. 3).

Fig.3. The kissing machine

2. *AC distribution grids.*

The first commercial DC grids were created by Edison in New York, electrical energy being produced locally by steam engines and DC generators. Cheaper electrical energy could be produced at Niagara Falls at 100 km distance but the transport and distribution at DC higher voltage was extremely difficult to be done. Westinghouse and Tesla solved this problem by producing electrical energy AC voltage by three-phase synchronous generators, low voltage, 60 Hz, increased the voltage by three phase transformers at tens of kV, transported the energy on aerial lines and at the end downloaded the voltage by means of three phase transformers and distributing it at 3x120 V. In the mean time Tesla invented the three phase induction motor which solved the problem of converting the AC energy in mechanical one. For many years this centralized solution was at the base of production, transport and distribution of electrical energy (Fig. 4 left).

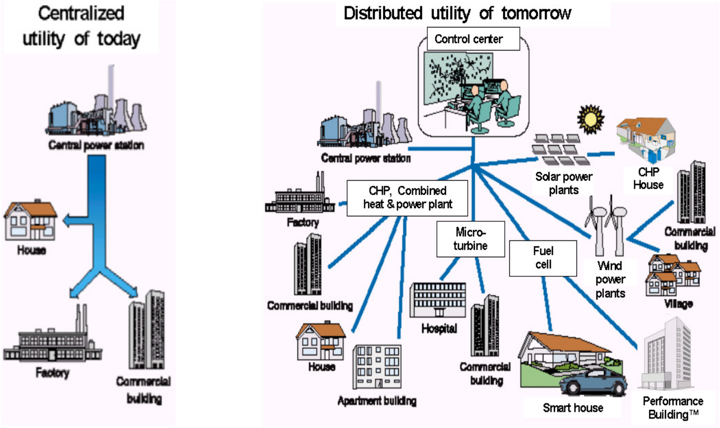


Fig.4. Centralized and distributed solutions

3. *The demand for electrical energy and available sources*

If in the ancient times Egyptians, Greeks and Romans used slaves who produced intelligent human energy, nowadays electricity became the favorite form of energy in most industrial and home applications. The problem is that the demand is much higher and most intensive: 2 equivalent “Spartacus” for supplying a single modern TV set, 15 for a washing machine and 1600 for an electrical car (Fig. 5). Consequently, the total demand of primary energy increased dramatically and worst than that the demographic bomb (Fig. 6) in the last years exploded and the demand multiplied several times. As the most of primary energy is of fossil nature, coal, oil, natural gas which are of limited quantity, produce green house gases, mainly CO_2. Then the effects are damaging people’s health and also have an impact on global heating. To avoid this situation the only solution is to use as primary energy as much as possible the renewable sources as hydro, wind, geothermal, solar and even nuclear (Fig. 7).

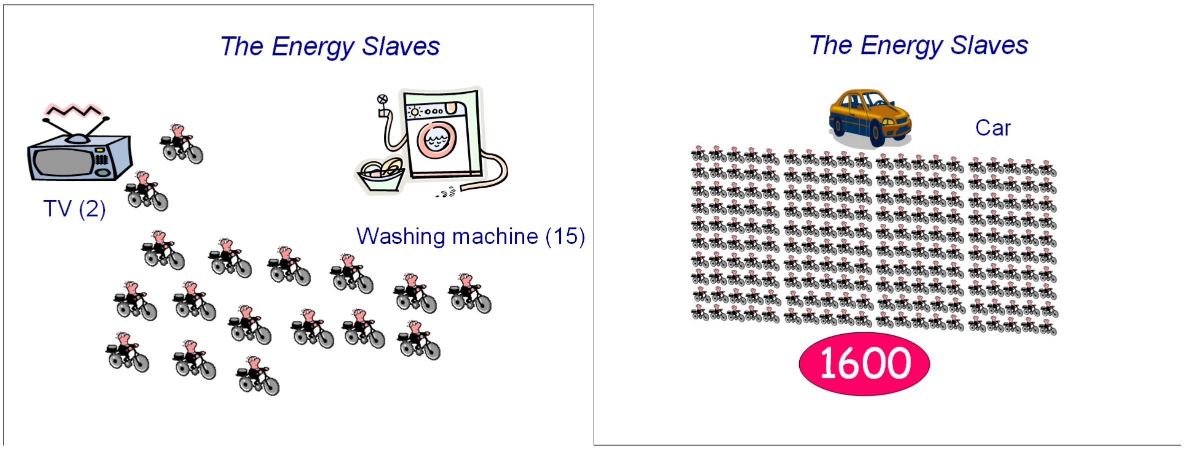


Fig.5. Equivalent power

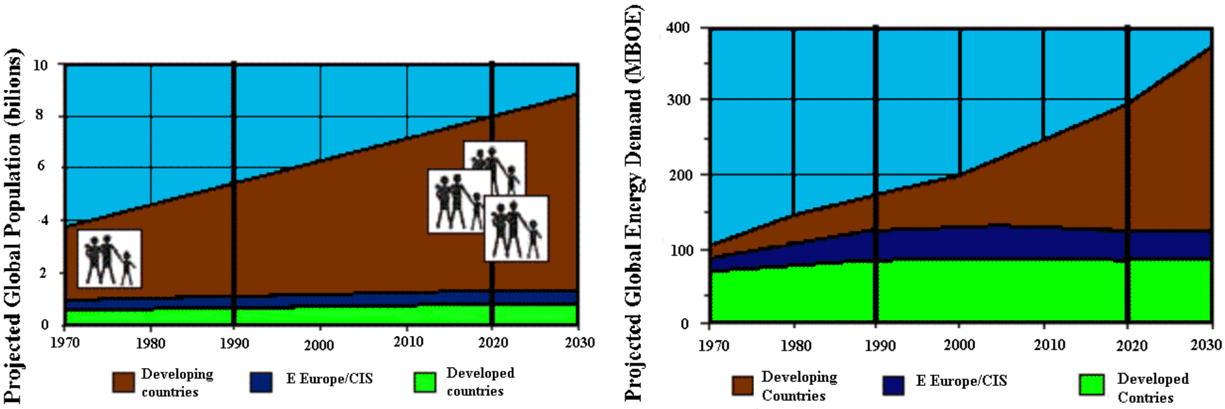


Fig.6. Projected global population (left) and energy demand (right)

Renewables growth: Electricity projections by 2020

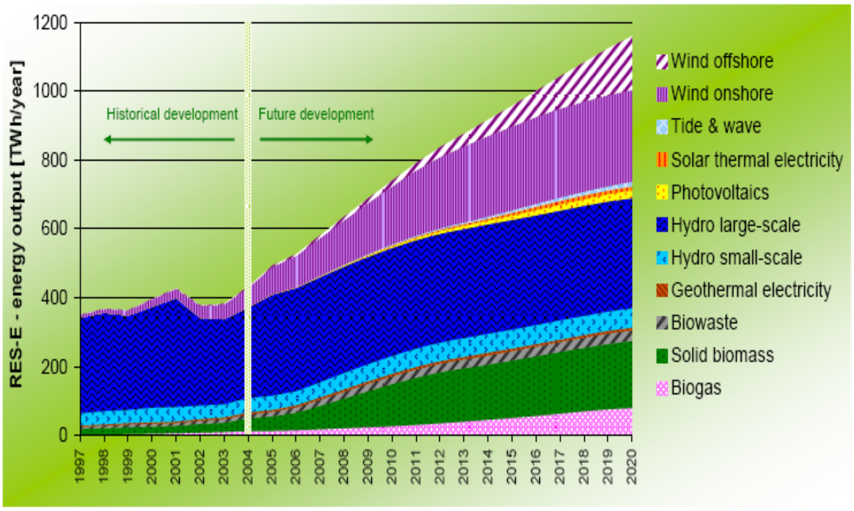


Fig.7. Primary resources

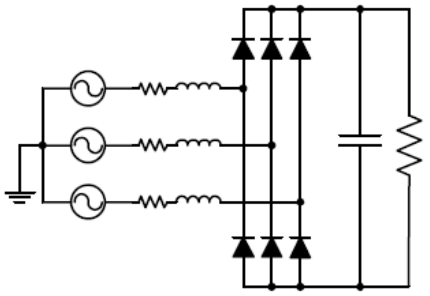


Fig.8. The diode bridge rectification of AC input

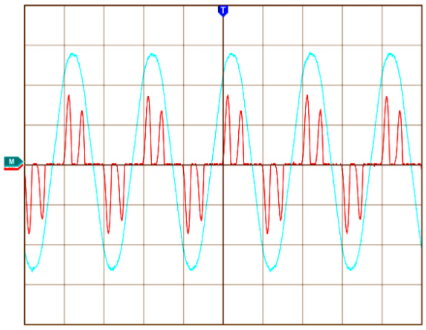


Fig.9. Measured AC stator voltage (blue) and instantaneous currents (red).

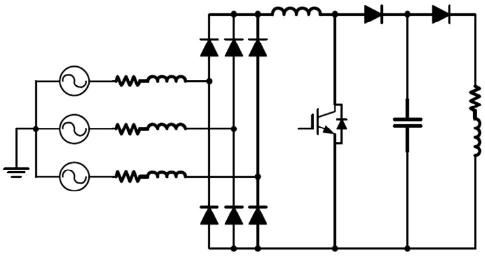


Fig.10. Rectification with booster circuit.

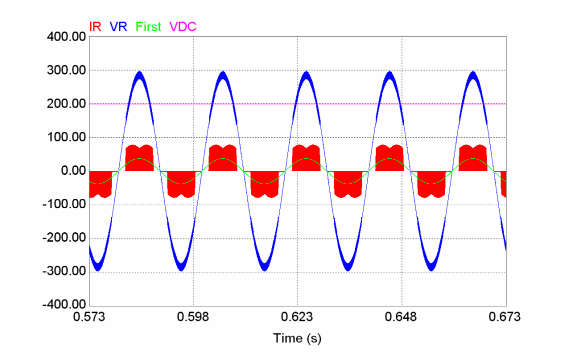


Fig.11. AC stator current (red) and fundamental (green). The AC voltage (blue) and DC output voltage (magenta).

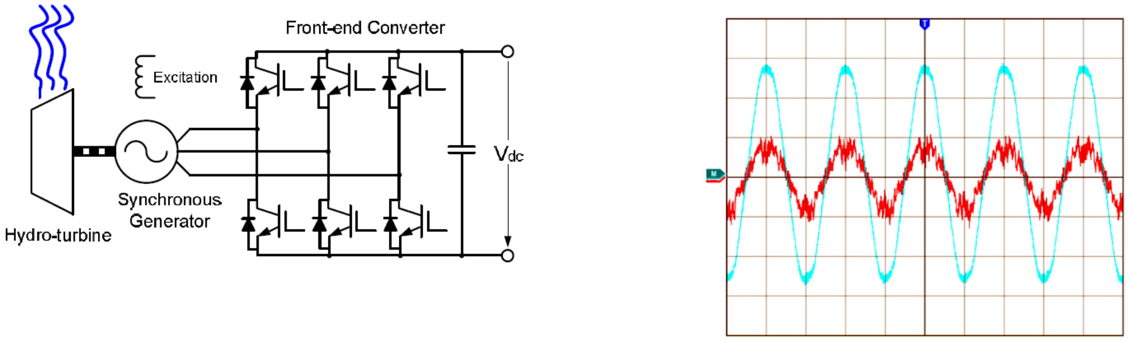


Fig.12. Synchronous generators with front-end rectifier (diagram and results)

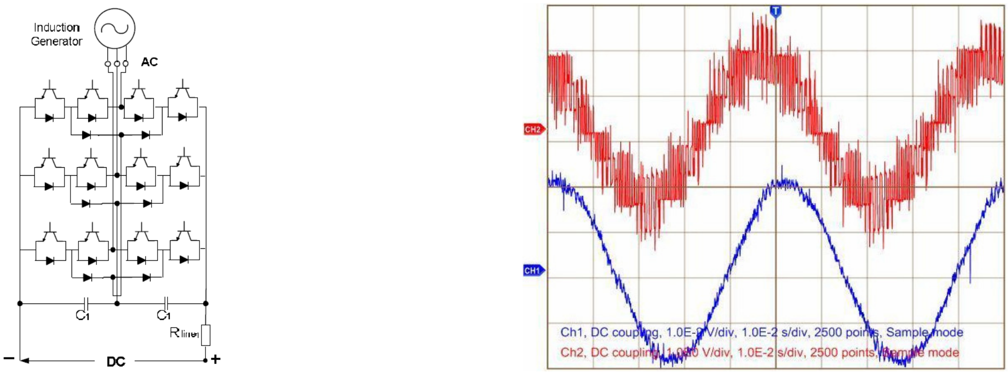


Fig.13. Three level front-end converter (diagram and results, red-voltage, blue-current)

For higher voltage and power induction generators it is recommended to use a three level converter, in this way eliminating the connection transformer. Although, the voltage has relatively high level of harmonics it can be seen (Fig. 13) that the current is nearly sinusoidal.

5. Storage

The Lithium-ion battery has a large market share for small portable equipment because of its high energy density and high efficiency. Due to the interest of car manufacturers in Li-Ion battery technology for hybrid vehicle operation, if they are generally accepted, their cost and performance will probably make them very attractive. Li-ion batteries have none of the memory effects seen in the rechargeable Ni-Cd batteries. The cathode in these batteries is a lithiated metal oxide ($LiCoO_2$, etc.) and the anode is made of graphitic carbon with a layer structure. The electrolyte is made up of lithium salts (such as $LiPF_6$) dissolved in organic carbonates. Both the anode and cathode are materials into which lithium inserts and extracts. The process of lithium moving into the anode or cathode is referred to as insertion, and the reverse process, in which lithium moves out of the anode or cathode is referred to as extraction. When discharging of the cell, lithium is extracted from the anode and inserted into the cathode. When charging the cell, the exact reverse process occurs: lithium is extracted from the cathode and inserted into the anode. The main problem with the Li-Ion battery is the ease with which it can be damaged during use: the Li-Ion battery carries a very large amount of energy in a small package. Combined with the fact that the internal resistance is fairly high, you have the potential for a very dangerous product: if the cell is accidentally shorted, it could get hot enough to burn and possibly explode (Fig. 14).

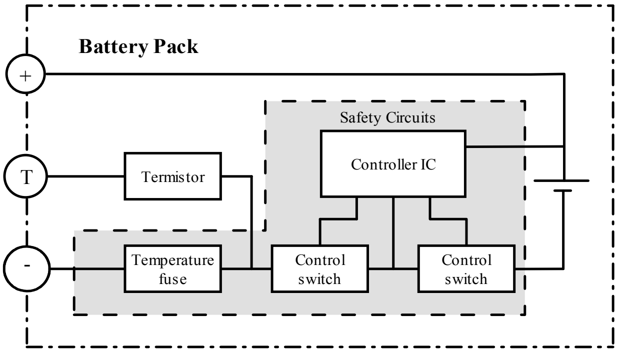


Fig.14. A typical structure of Li-Ion battery pack (block diagram)

Flow battery technology essentially consists of two electrolyte reservoirs from which the electrolytes are circulated through an electrochemical cell comprising a cathode, an anode and a membrane separator. The energy density of such systems is entirely dependent on the volume of the electrolyte being stored. Power density in flow-battery systems is essentially dependent on the rates of the electrode reactions occurring at the anode and cathode respectively. Flow batteries differ from conventional rechargeable batteries in one significant way: the power and energy ratings of a flow battery are independent of each other (Fig. 15). This is made possible by the separation of the electrolyte and the battery stack (or fuel cell stack). A flow battery, on the other hand, stores and releases energy by means of a reversible electrochemical reaction between two electrolyte solutions.

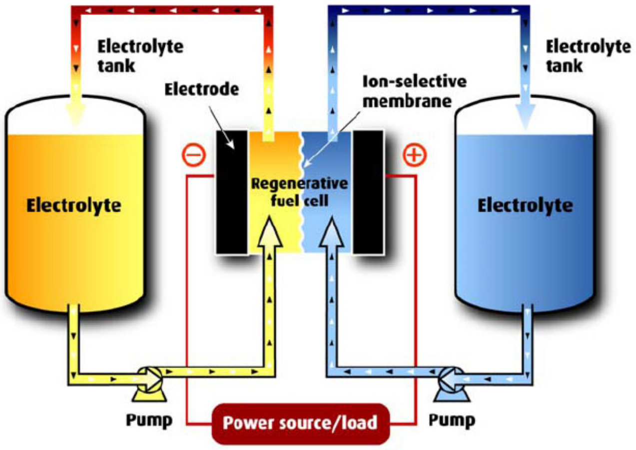


Fig.15. Flow batteries operating principle

In each cell of a ZnBr battery, two different electrolytes flow past carbon-plastic composite electrodes in two compartments separated by a micro porous polyolefin membrane (Fig. 16). During discharge, Zn and Br combine into zinc bromide, generating 1.8 V across each cell. This will increase the Zn^{2+} and Br^- ion density in both electrolyte tanks. During charge, metallic zinc will be deposited (plated) as a thin film on one side of the carbon-plastic composite electrode. Meanwhile, bromine evolves as a dilute solution on the other side of the membrane, reacting with other agents (organic amines) to make thick bromine oil that sinks down to the bottom of the electrolytic tank. It is allowed to mix with the rest of the electrolyte during discharge. The net efficiency of this battery is about 75%. The ZnBr battery was developed by Exxon in the early 1970's. Over the years, many multi-kWh ZnBr batteries have been built and tested. Meidisha demonstrated a 1MW/4MWh ZnBr battery in 1991 at Kyushu Electric Power Company. Some multi-kWh units are now available pre-assembled, complete with plumbing and power electronics.

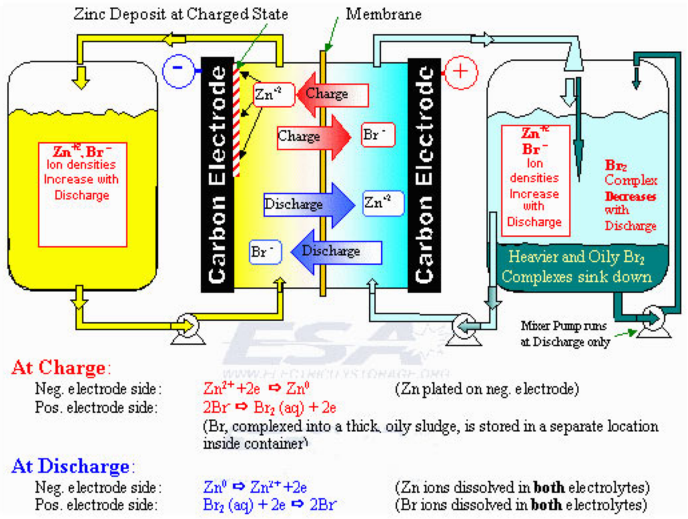


Fig.16. Zinc bromine (ZnBr) flow battery operation principle.

The requirements on power and energy rating of the energy storage devices depend on the applications that these devices are used for. While in some applications a high power with short discharge duration is desired, in others a low power and long duration are required. Fig. 17 depicts the requirements of different applications listed above. In recent years, the application of energy storage to improve transmission system stability and to enhance power quality and reliability has drawn increasing attention. In these applications, voltage source converters are usually deployed to interface the energy storage devices with the power system. The possible application of energy storage for damping of power system oscillations has been intensively investigated. Power oscillation occurs when there is a trip of transmission lines, loss of generation, or large changes in electric load. The short-term energy storage can be used for the improvement of power quality and reliability. Voltage sags, usually caused by faults in the electrical system, are the most common disturbances in power systems and thus cause very much concern. Voltage sags can also occur during the start up of large motor loads or during the operation of special electrical equipment such as welders, arc furnaces, smelters, etc. The voltage source converters with energy storage capability should be able to provide the necessary energy for a duration in the order of some 100 ms. This can be done by conveniently choosing the DC bus capacitor and the DC voltage level. The standard aluminum electrolytic capacitors are used, or the more recent power film capacitor, which are replacing electrolytic capacitor in high demand applications. The converter is forced to provide active power into the network during the fault transients; hence the rating of the dc side energy is a concern. For a weak system, a certain energy storage capacity will effectively help with the system recovery from faults. This incurs extra cost for the increasing dc voltage rating and size of the dc side capacitor, and the overall rating of the converter.

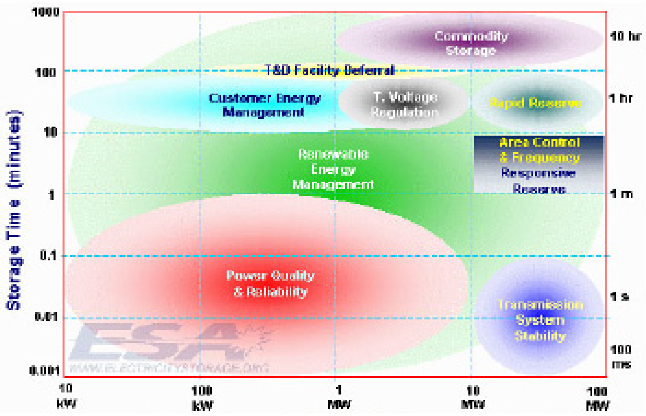


Fig.17. Storage power requirements for electric power utility applications

The energy storage flywheel or "mechanical battery" converts electrical energy into kinetic energy by spinning a rotor (or flywheel) at high speed and then converts the kinetic energy back into electricity through a generator as the rotor slows down. Flywheel systems store energy kinetically rather than chemically. Commercially available rotary systems are used for the smaller size uninterruptable systems. These rotors normally operate at 4000 rpms or less and are made of metal. Advanced flywheels are made of high strength carbon-composite filaments which spin at speeds from 20,000-100,000 rpms in a vacuum enclosure. Magnetic bearings are necessary as speeds increase to reduce friction found in conventional mechanical bearings. Quick charging is done in less than 15 minutes. Long lifetimes, plus high energy (~ 130 Wh/kg) and high power are positive attributes. The main feature of flywheel energy storage (FES) systems generally is that they can be charged and discharged at high rates for many cycles. Typical state-of-the-art composite rotor designs have specific energy of up to 100 Wh/kg, with high specific power. The state-of-charge is easily assessed as a function of angular velocity, which is readily measured. The main drawbacks of flywheels are the high cost, and the relatively high standing losses. The lowest self-discharge rates currently achieved for complete flywheel systems, with electrical interface powered, are around 20% of the stored capacity per hour. Flywheel energy storage technologies broadly fall into two classes: low speed flywheels, which are commercially available; and high-speed flywheels, which are just becoming commercial. Low speed flywheels, with typical operating speeds up to 6000 rev/min, have steel rotors and conventional bearings. For example, a flywheel system with steel rotor developed in a collaborative project at CCLRC in the 1980's had energy storage capacity 2.3 kWh, 5000 rev/min, and rated power 45kW. (rotor specific energy 5 Wh/kg, specific power 100 W/kg) (Fig. 39, 40). High-speed flywheels, with operating speeds up to 50,000 rev/min, using advanced composite materials for the rotor, are under intensive development to increase the energy storage density and reduce unit cost. High strength is needed to achieve maximum rotational speed. Therefore, advanced composite rotors enable the storage of greater amounts of energy on a specific weight basis, in comparison with other materials. A few high-speed flywheel systems have been installed in field trials, and are now being commercialised. Currently the main stationary applications are in uninterruptible power supplies (UPS), power quality (PQ) systems, and trackside support in traction (rail) systems. Several manufacturers foresee possibilities of applications in peak shaving in electrical power systems, and for power smoothing in renewable energy systems. A recent survey reports that only a few manufacturers share most of the The

European market for new energy storage technologies (SMES, Supercapacitors, and Flywheels) has rosen \$104 million in 2002 to \$215 million in 2009, representing a compound annual growth rate of around 11%. Currently flywheels represent 96% of new energy storage technology sales, and sales are expected to grow by around 8% annually. The key factors driving the market include the expected growth in utilisation of renewable energy, as well as regulatory aspects of electricity supply, and requirements for Uninterruptible Power Supplies (UPS) and power quality.

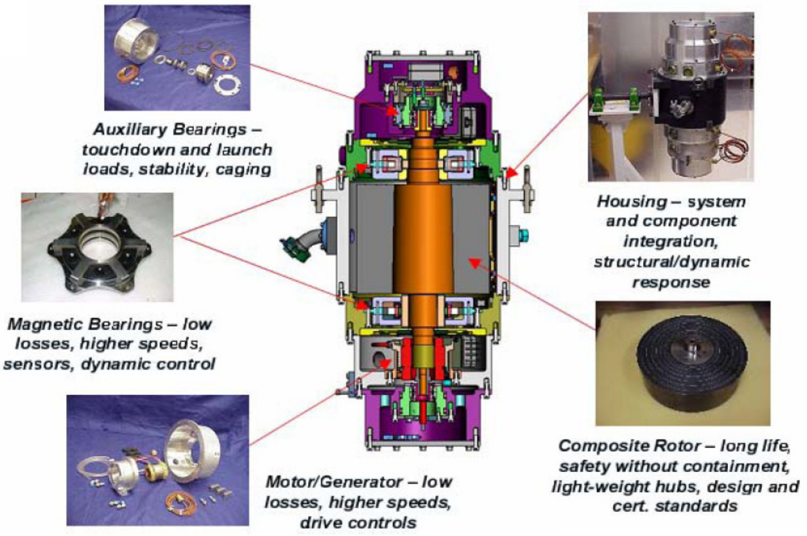


Fig.18. Components of the Flywheel Energy Storage System

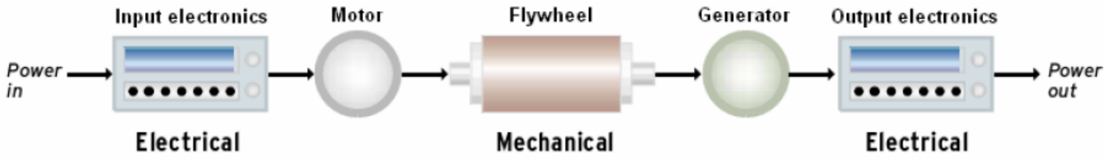


Fig.19. The basic structure of a FES

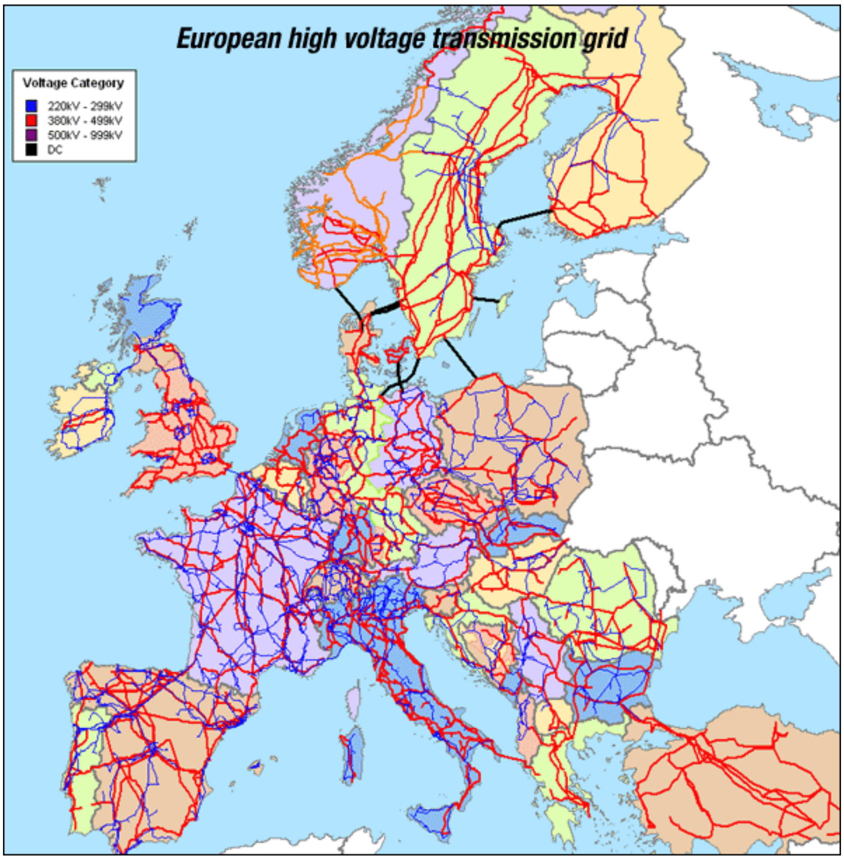
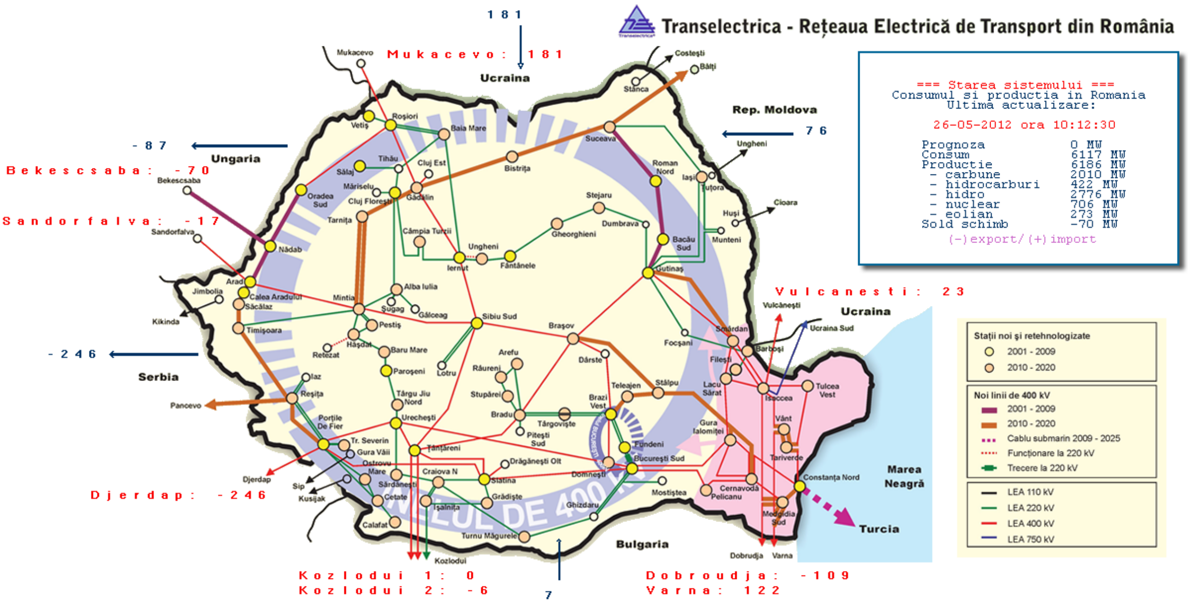


Fig.20.



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=== Starea sistemului ===
Consumul si productia in Romania
Ultima actualizare:

26-05-2012 ora 10:12:30

Prognoza             0 MW
Consum               6117 MW
Productie            6186 MW
 - carbune           2010 MW
 - hidrocarburi      422 MW
 - hidro             2776 MW
 - nuclear           706 MW
 - eolian            273 MW
Sold schimb          -70 MW
   (-)export/(+)import
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Fig.21.

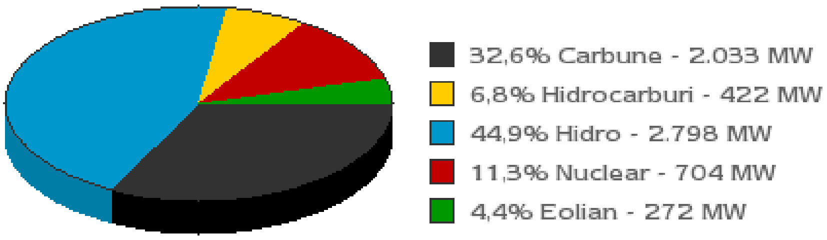

Fig.22.

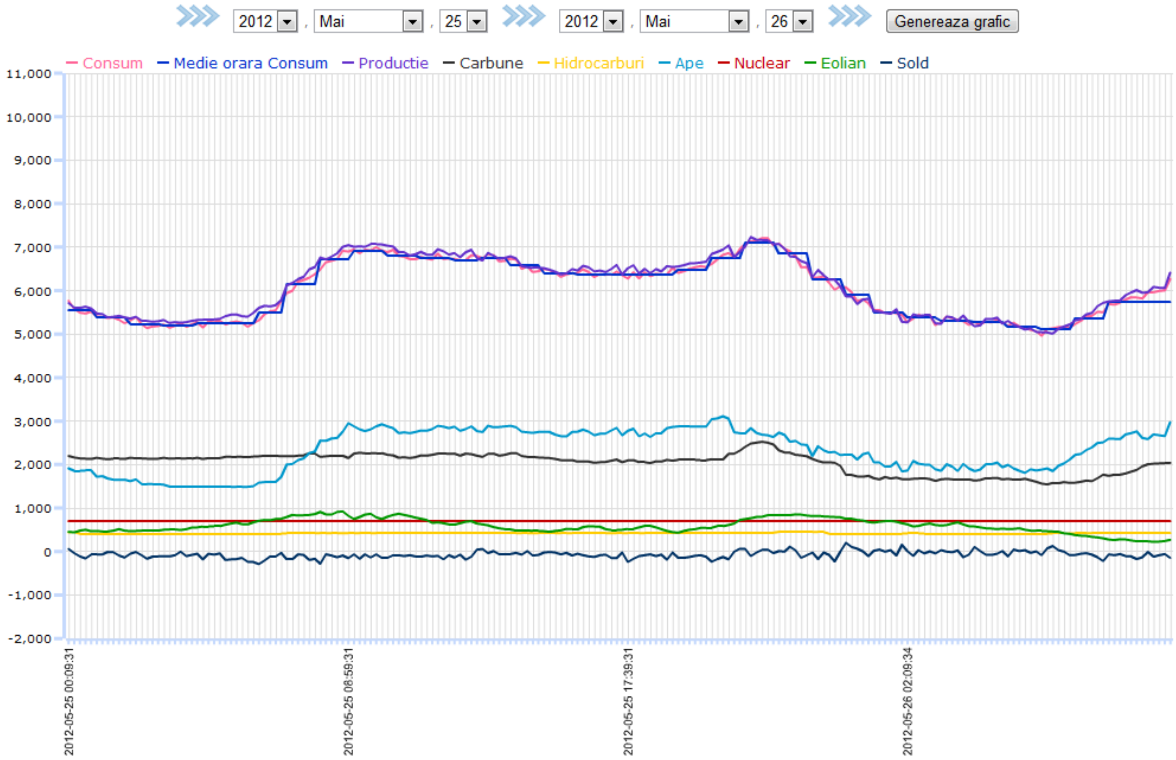

Fig.23.

Conclusions

One of the main characteristics of renewable sources is the lack of constancy in their generation and usage. Photovoltaic cells can generate energy only when there is sun in the sky or at least light, the Aeolian energy is even more unpredictable and the hydro energy for the on river power plants is highly dependent of the flow. In these conditions in order that the energy converted to be used it is necessary to normalize the output parameters for current, voltage and frequency, and this can be done only by using power electronic equipments. Due to the fact that there is not synchronization between the moment of generation and the moment of usage it is obvious that storage for the exceeding energy and a supply from this storage when the demand exceeds the available generated energy is needed. The presented solutions for the storage are used in respect to the generators and loads characteristics and their price is in the end the main reason in choosing one solution. It can be said that only coordination between the sources, converters (electromechanical or electrochemical), power electronic interfaces and storage equipments may provide an optimal operation from technical and economical point of view.

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