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Energy Storage Technologies and Renewable Energy Sources

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Renewable energy sources are expected to play an important role in preventing climate change, but they are confronted with a number of barriers, such as their intermittency and high costs. Energy storage presents an excellent opportunity for them to overcome intermittency obstacle. Conventional thermal, compressed air, pumped hydro, batteries, fly-wheels, as well as new hydrogen fuel cell, wind, solar, and different hybrid energy storage technologies are described and a number of promising examples highlighted.

Key words: *renewable energy sources, energy storage technologies, intermittency*

Energy storage – a challenge for renewables

Oil shortage and climate change issues

The recent spike in the price of crude-oil brings most consumers view gasoline prices as the problem, but, in reality, they are only a symptom of a more serious problem. The problem is that oil soon will become scarce so that demand will outstrip supply, and the mere threat of oil shortage drive the price of oil up. Oil production will peak worldwide sometime soon and begin to decline. Meanwhile, oil demand will continue to grow unless some very aggressive fuel conservation and implementation of alternatives to oil take place. Virtually all accept this as the most serious issue facing the world, and this issue opens the door for more renewable and other energy sources.

Another issue in favour of renewable sources is climate change. Human activities have changed the climate of the Earth, with significant impacts on ecosystems and human society, and the pace of change is increasing. The largest of all of the human and natural influences on climate over the past 250 years has been the increase in the atmospheric concentration of carbon dioxide resulting from deforestation and fossil-fuel burning (in recent decades, which have been responsible for the largest part of this buildup, have come 75 to 85% from fossil fuels (largely in the industrialized countries) and 15 to 25% from deforestation and other land-cover change (largely from developing countries in the tropics). Even if human emissions could be instantaneously stopped, the world would not escape further climatic change. The slow equilibration of the oceans with changes in atmospheric composition means that a further 0.4 to 0.5 °C rise in global-average surface temperature will take place as a result of the current atmospheric concentrations of greenhouse gases and particles. If concentrations continue to grow, the global average surface temperature is expected to rise by 0.2 to 0.4 °C per decade throughout the 21st century and would continue to rise thereafter. The cumulative warming by the year 2100 would be approximately 3 to 5 °C over preindustrial conditions [1]. There is no doubt that to combat climate change, society must switch to carbon-free, renewable energy sources as quickly as possible.

Intermittency and penetration of renewable energy sources

Major renewable energy sources are intermittent in nature. The intermittency of renewable energy sources such as the sun and wind cannot be controlled to provide power when it is needed. Hydro power can also be intermittent depending on the configuration of hydroelectric plant (plants in the dam configuration may be considered dispatchable, but run of the river plants will typically have limited or no storage capacity, and may be intermittent on a seasonal or annual basis). As a matter of fact, all energy sources have some degree of unpredictability, and demand patterns (while relatively predictable) drive large swings in the amount of energy required, but the sources are designed to match supply with demand, and the introduction of an intermittent energy source may not be well-matched to demand cycles.

Intermittency therefore may introduce additional costs that are distinct from or of a different magnitude than for traditional generation types. Using a variety of energy sources in combination can help to overcome intermittency. For example, stormy weather, bad for direct solar collection, is generally good for wind power. Electricity produced from solar energy could be a counter balance to the fluctuating supplies generated from wind. In some locations, it tends to be windier at night and during cloudy or stormy weather, so there is likely to be more sunshine when there is less wind, while in other locations electricity demand may have a high correlation with wind output, particularly in locations where cold temperatures drive electric consumption.

Intermittency inherently affects solar energy, as the production of electricity from solar sources depends on the amount of light energy in a given location. The extent to which the intermittency of solar-generated energy is an issue will depend to some extent on the degree to which the generation profile of solar corresponds to demand cycles. In areas with high solar production possibilities, and where air conditioning is a driver of demand and corresponds to periods of high sunlight, variability may actually be beneficial. For example, solar power plants are ideally matched to summer peak loads in areas with significant cooling demands. Using thermal energy storage systems, solar thermal operating periods can even be extended to meet base-load needs.

Wind-generated power is also a typical variable resource, and the amount of wind-generated electricity will depend on wind speeds, turbine characteristics, and other factors. Wind energy storage may also be used to arbitrage between periods of low and high demand. As the fraction of energy produced by wind (penetration) increases, different technical and economic factors affect the need for grid energy storage facilities. As additional operating reserve is needed if additional wind does not correspond to demand patterns, at high penetrations (more than 30%), solutions for dealing with high output of wind during periods of low demand may be required.

There is no generally accepted maximum level of penetration, as each system's capacity to compensate for intermittency differs, and the systems themselves will change over time. Large networks, connected to multiple wind plants at widely separated geographic locations, may accept a higher penetration of wind than small networks or those without storage systems or economical methods of compensating for the variability of wind. In systems with significant amounts of existing pumped storage, hydro power or other peaking power plants, this proportion may be higher. Isolated, relatively small systems with only a few wind plants may only be stable and economic with a lower fraction of wind energy although mixed wind/diesel systems have been used in isolated communities with success at relatively high penetration levels. The maximum proportion of wind power allowable in a power system will thus depend on many factors, including the size of the system, the attainable geographical diversity of wind, the conventional plant mix, and seasonal load factors (heating in winter, air-conditioning in summer) and their statistical correlation with wind output. Wind power generation tends to be higher in the winter and at night (due to higher air density), so the appropriateness of wind power may be weakest in the hot summer months, and particularly during the day when air conditioning demand is highest. Conversely, systems where heat is electrical may be well-suited to higher penetration of wind power [2].

Systems with existing high levels of hydroelectric generation may be able to incorporate substantial amounts of wind, although high hydro penetration may indicate that hydro is already a low-cost source of electricity. Storage capacity in hydro power facilities will be limited by size of reservoir, and environmental and other considerations. Increased wind penetration may raise the value of existing peaking or storage facilities and particularly hydroelectric plants, as their ability to compensate for wind's variability will be under greater demand. Pumped storage hydro power is the most prevalent existing technology used, and can substantially improve the economics of wind power. The cost of compensating for the variability of wind is expected to rise with higher penetration levels, particularly so if storage needs to be purpose-built for wind.

Energy storage

Energy storage became a major factor with the widespread introduction of electricity, which, unlike the other common energy carriers, has to be used as it is generated. Storing of some form of energy that can be drawn upon at a later time to perform some useful operation requires special equipment to be added. The energy storage technologies can be based on the following storage methods: electrochemical (batteries, flow batteries, fuel cells), electrical (capacitor, supercapacitor, superconducting magnetic energy storage), mechanical (compressed air energy storage, fly-wheel energy storage, hydraulic accumulator, hydroelectric energy storage), and thermal (molten salt, cryogenic liquid air or nitrogen, seasonal thermal storage, solar pond, hot bricks, steam accumulator). An early solution to the problem of storing electricity was the development of the battery. A similar solution with the same type of problems is the capacitor. Electrochemical devices called fuel cells were also invented at the same time as the battery, but were not developed until the advent of manned space-flight and are now being commercialized to allow the efficient conversion of chemical energy stored in refined hydrocarbon or hydrogen fuels directly into electricity. Energy can be stored as water pumped to a higher elevation, compressed air, and spinning fly-wheels, but mechanical methods of storing energy have limited capacity or efficiency.

Energy storage systems complement renewable resources with siting flexibility and minimal environmental impacts. They can be used to reduce the stress on transmission lines that are near peak rating by reducing substation peak load. Energy storage can serve customers as a controllable demand-side management option that can also provide premium services. Finally, energy storage is also used in stand-alone applications, where it can serve as an uninterruptible power supply units used for back-up power and only activate in cases of power outages unlike the energy storage systems discussed herein that perform a number of on-line applications. This is particularly the case in isolated, remote locations, without connection to electricity grids, where some type of back-up power must be considered if an intermittent renewable energy source is used.

Solar or wind energy generated at the home, in addition to being renewable, would avoid the distribution loses between power plants and homes. Wind energy is a fast growing energy sector and has recorded consistent growth of over 20% over the last ten years. The world's largest unit size of wind turbine is 5 MW (with a three-bladed rotor at a diameter of 126 meters), while projects to build units in the 10 MW size range are considered. An energy storage system linked with a wind farm could guarantee an uninterrupted supply of green power to the grid, improve efficiency of the energy and remove financial risk. The energy storage technology may allow wind energy generated during off-peak periods to be stored and supplied to the national grid at a scheduled time.

Overview of energy storage technologies

Pumped water storage

Pumped storage hydroelectricity is a method of storing and producing electricity to supply high peak demands by moving water between reservoirs at different elevations. At times of low electrical demand, excess generation capacity is used to pump water into the higher reservoir, where it can be stored as potential energy. Upon demand, water is released back into the lower reservoir, passing through hydraulic turbines which generate electrical power.Reversible turbine/generator assemblies act as pump and turbine (usually a Francis turbine design) by the use of the height difference between two natural bodies of water or artificial reservoirs. Pure pumped-storage plants just shift the water between reservoirs, but combined pump-storage plants also generate their own electricity like conventional hydroelectric plants through natural stream-flow, fig. 1.

Pumped water storage has been in use since 1929, making it the oldest of the central station energy storage technologies. In fact, until 1970 it was the only commercially available storage option for generation applications. In many places, pumped storage hy-

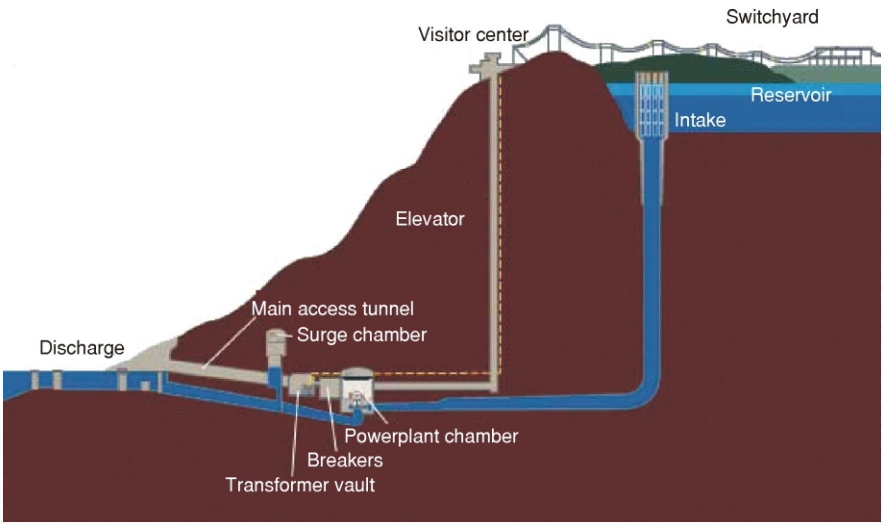

Figure 1. Schematic of a pumped water storage plant

droelectricity is used to even out the daily generating load, by pumping water to a high storage reservoir during off-peak hours. During peak hours, this water can be used for hydroelectric generation, often as a high value rapid-response reserve to cover transient peaks in demand. Taking into account evaporation losses from the exposed water surface and conversion losses, approximately 70 to 85% of the electrical energy used to pump the water into the elevated reservoir can be regained. There is over 90 GW of pumped storage in operation, which is about 3% of global generation capacity. The technique is currently the most cost-effective means of storing large amounts of electrical energy on an operating basis, but capital costs and the presence of appropriate geography are critical decision factors. The relatively low energy density of pumped storage systems requires either a very large body of water or a large variation in height.

A new use for pumped storage is to level the fluctuating output of intermittent power sources. The pumped storage absorbs load at times of high output and low demand, while providing additional peak capacity. It is particularly likely that pumped storage will become especially important as a balance for large scale wind or photovoltaic generation. The new concept in pumped-storage by utilizing wind energy to pump water can make this a more efficient process. For example, the Vlasina Wind Power project in Serbia makes use of the existing Lisina (lower) and Vlasina (upper) lakes and Vrla I to IV hydroelectric plants to achieve flexibility with an optimum storage of the wind energy without extra investments [3].

Compressed air storage

Another grid energy storage method is Compressed Air Energy Storage (CAES) that uses off-peak electricity to compress air, which is usually stored in an air-tight underground storage cavern (an old mine or some other kind of geological feature). When electricity demand is high, the compressed air is released from the cavern, heated with a small amount of natural gas and expanded and expanded through a combustion turbine to generate electricity [4]. Intermittent wind energy may replace the grid off-peak electrical energy for use to compress and store the air, fig. 2.

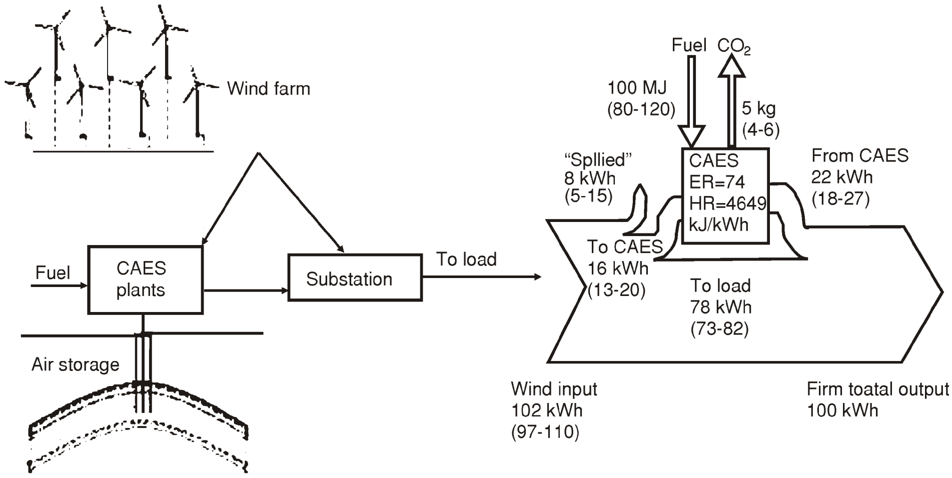

Figure 2. Wind/CAES energy storage arrangement and its energy balance

Compressed air storage is safe, non-toxic and energy dense at high pressures. Round-trip efficiency is fair due to heat rejection during compression, but some of this heat reclaimed during gas expansion. The CAES technology requires an unused empty salt dome, aquifer or abandoned mine for compressed-air storage and is not self-contained, as it depends on supply natural gas for the combustion chamber. For these and other reasons, CAES has been attempted in utility-scale generating plants, typically over 100 MW. The breakthrough in combining energy storage technologies was deciding to take elements of both fly-wheel and CAES technology to create a self-contained energy storage system. Compressed air and thermal energy drive the expansion turbine for long-duration outages, while a small fly-wheel system gives instantaneous response to step loads and short outages.

A conventional turbine engine has three stages: a compression stage for pressurizing incoming air; an ignition stage, where the fuel and compressed air are injected into a combustion chamber and ignited, and an expansion stage, where the expanding exhaust gas drives the turbine blades connected to the output shaft of the engine [5]. Since the new hybrid product stores compressed air in gas cylinders and heats the air, only the third stage of the turbine (the expansion stage) is required. The heated compressed air is used to spin a simple single-stage expansion turbine. The low inertia enables it to reach full operating speed (70,000 rpm) in less than two seconds.

To eliminate the disadvantages associated with fossil fuel used by the CAES turbine and to reduce opposition to transmission line siting in agricultural areas, alternative completely renewable baseload wind system is replacing natural gas with farm-derived biofuel [6]. This alternative system also provides unique opportunities for the use of biofuels that might otherwise be unavailable. Unlike fossil fuels, biomass crops are a renewable energy source, and largely carbon neutral over the entire cycle of harvest, combustion, and regeneration. As a result, the use of biofuels in the CAES turbines reduces the net greenhouse gas emissions, while increasing overall price stability [7]. High transportation costs, and other land restrictions are expected to limit the size of standard power plants to below 200 MW, which is typically much smaller than desirable for the development of dedicated long distance transmission.

Thermal energy storage

Thermal energy storage can refer to a number of technologies that store energy in a thermal reservoir for balance energy demand between day time and night time. The thermal reservoir may be maintained at a temperature above (hotter) or below (colder) than that of the ambient environment. The principal application today is the production of ice, chilled water, or eutectic solution at night, which is then used to cool environments during the day. Off-peak electricity can be used to make ice from water, and the ice can be stored until the next day, when it is used to cool either the air in a large building, thereby shifting that demand off-peak, or the intake air of a gas turbine generator, thereby increasing the on-peak generation capacity.

Thermal energy storage technologies may include active solar collectors to produce and store heat in an insulated repository for later use in space heating, domestic or process hot water, or to generate electricity. Most practical active solar heating systems have storage for a few hours to a day's worth of heat collected. There are also a small but growing number of seasonal thermal stores, used to store summer heat for use during winter. Molten salt has been proposed as a means to retain a high temperature thermal store for later use in electricity generation.

The most widely used form of this technology is in large building or campus-wide air conditioning or chilled water systems. Air conditioning systems, especially in commercial buildings, are the most significant contributors to the peak electrical loads seen on hot summer days. In this application a relatively standard chiller is run at night to produce a pile of ice [8]. Water is circulated through the pile during the day to produce chilled water that would normally be the daytime output of the chillers. A partial storage system minimizes capital investment by running the chillers 24 hours a day. At night they produce ice for storage, and during the day they chill water for the air conditioning system, their production augmented by water circulating through the melting ice. A full storage system minimizes the cost of energy to run the system by shutting off the chillers entirely during peak load hours, but requires chillers somewhat larger than a partial storage system, and a larger ice storage system, so that the capital cost is higher.

Thermal energy storage is also used for combustion gas turbine air inlet cooling. Instead of shifting electrical demand to the night, this technique shifts generation capacity to the day. To generate the ice at night, the turbine is often mechanically connected to the compressor of a large chiller. During peak daytime loads, water is circulated between the ice pile and a heat exchanger in front of the turbine air intake, cooling the intake air to near freezing temperatures. Because the air is colder, the turbine can compress more air with a given amount of compressor power. Typically, both the generated electrical power and turbine efficiency rise when the inlet cooling system is activated.

Battery storage

Battery storage was used in the very early days of electric power networks, but is no longer common, because batteries are generally expensive, have maintenance problems, and have limited life-spans. In a battery, charging causes reactions in electrochemical compounds to store energy from a generator in a chemical form. Upon demand, reverse chemical reactions cause electricity to flow out of the battery and back to the grid. Batteries are manufactured in a wide variety of capacities ranging from less than 100 W to modular configurations of several megawatts. Battery storage has relatively high efficiency, as high as 90% or even better.

Battery storage devices are currently available in a wide variety of chemical models. One possible technology for large-scale storage are large-scale flow batteries. Sodium-sulphur (NaS) batteries could also be inexpensive to implement on a large scale. Vanadium redox (reduction-oxidation) batteries and other types of flow batteries are also beginning to be used for energy storage including the averaging of generation from wind turbines. A flow battery is a form of rechargeable battery in which electrolyte containing one or more dissolved electroactive species flows through a power cell in which chemical energy is converted to electricity. Various classes of flow batteries exist including the redox flow battery, in which all electroactive components are dissolved in the electrolyte.

Because flow batteries can be rapidly "recharged" by replacing the electrolyte, they have been proposed for electric vehicles, and the use of vanadium redox flow batteries for load levelling in wind farm applications is already showing promise. The vanadium redox battery energy storage system is designed to allow wind energy generated during off-peak periods to be stored and supplied to the national grid at a scheduled time. The storage system has the potential to increase the supply reliability of wind energy and reduce the cost of the reserve requirements from generation plants. Batteries can be used to maximize wind intensity in rural regions by providing high quality power output and storing excess wind power for later release. In this way, increased wind penetration can be achieved more rapidly by deferring the cost of grid upgrades.

The utilities are installing the NaS batteries at substations to meet peak loads and delay costly substation upgrades. Despite the fact that NaS batteries are costly, they have a great advantage over power generation inside a city, precisely at the right place and the right time the power is needed. Hence utility scale batteries that can store solar photovoltaic energy and support demand side management are also extremely valuable resources to urban utilities. NaS batteries have the advantage of extremely quick response time, making them more suitable for power quality applications (smoothing short term spikes in demand). This, along with their better efficiency, is why NaS batteries currently are used by utilities seeking to delay transmission and distribution upgrades.

In applications for electrical energy storage systems, hybrid electric vehicles and grid-enhanced management architectures, it is essential to achieve larger batteries using cheaper, less toxic materials, delivering higher energy densities at higher rates and with better charge/discharge cycling. However, currently, no single technology is able of fulfilling all the requirements for energy storage, and next generation of energy-storage cost efficient, long-life, and high-power advanced lithium energy storage systems are being developed, based on the use of nano-powder and nano-composite electrodes and electrolytes, thus ensuring high quality electricity and enabling the development of grid-enhancement management architecture incorporating renewable energy sources and advanced battery systems, while controlling environmental pollution.

Fly-wheel storage

A fly-wheel storage device consists of a fly-wheel that spins at a very high velocity and an integrated electrical apparatus that can operate either as a motor to turn the fly-wheel and store energy or as a generator to produce electricity on demand using the energy stored in the fly-wheel. Mechanical inertia is the basis of this storage method. A heavy rotating disc is accelerated by an electric motor, which acts as a generator on reversal, slowing down the disc and producing electricity. The use of magnetic bearings and a vacuum chamber helps reduce energy losses. A proper match between geometry and material characteristics influences optimal wheel design. Fly-wheels are currently being used for a number of non-utility related applications, but recently, however, utility energy storage applications are considered as well. Fly-wheel power storage systems have storage capacities comparable to batteries and faster discharge rates. They are mainly used to provide load leveling for large battery systems, such as an uninterruptible power supply and for maintaining power quality in renewable energy systems.

Fly-wheel energy storage (FES) works by accelerating a rotor (fly-wheel) to a very high speed and maintaining the energy in the system as rotational energy. Electricity is thus stored as the kinetic energy of the disc. Friction must be kept to a minimum to prolong the storage time. The energy is converted back by slowing down the fly-wheel. Most FES systems use electricity to accelerate and decelerate the fly-wheel, but devices that directly use mechanical energy are also being developed. Advanced FES systems have rotors made of high strength carbon-composite filaments that spin at speeds from 20,000 to over 50,000 rpm in a vacuum enclosure and use magnetic bearings. Compared with other ways of storing electricity, FES systems have long lifetimes, high energy densities and large maximum power outputs. The energy efficiency of fly-wheels can be as high as 90%.

Electrochemical capacitors

Electrochemical capacitors (also known as ultracapacitors or supercapacitors) are developed as an energy storage technology for electric utility applications. An electrochemical capacitor has components related to both a battery and a capacitor. The charge is stored by ions as in a battery, but, as in a conventional capacitor, no chemical reaction takes place in energy delivery. An electrochemical capacitor consists of two oppositely charged electrodes, a separator, electrolyte and current collectors. Presently, very small supercapacitors in the range of seven to ten watts are widely available commercially for consumer power quality applications and are commonly found in household electrical devices. Development of larger-scale capacitors has been focused on electric vehicles.

Currently, smal-scale power quality (<250 kW) is considered to be the most promising utility use for advanced capacitors.

Conventional capacitors have enormous power, but store only tiny amounts of energy, while batteries can store lots of energy but have low power and they take a long time to be charged or discharged. Supercapacitors offer a unique combination of high power and high energy. Batteries are charged when they undergo an internal chemical reaction, and deliver the absorbed energy, or discharge, when they reverse the chemical reaction. In contrast, when a supercapacitor is charged, there is no chemical reaction. Instead, the energy is stored as a charge or concentration of electrons on the surface of a material. Supercapacitors are capable of very fast charges and discharges, and apparently are able to go through a large number of cycles without degradation.

Small scale hybrid storage systems

In a normal residential application, a household is served simultaneously by a local power source (the wind turbine, for example) and the utility electrical system. Usually there are no batteries in a modern residential wind system, but small wind systems for remote applications must operate by the use of batteries for energy storage. A combination of the wind and solar systems may take the advantages of both. They are connected to the utility grid in case the weather is insufficient for the solar or wind system, but they also have batteries to store electricity in case the utility grid goes down as well, fig. 3.

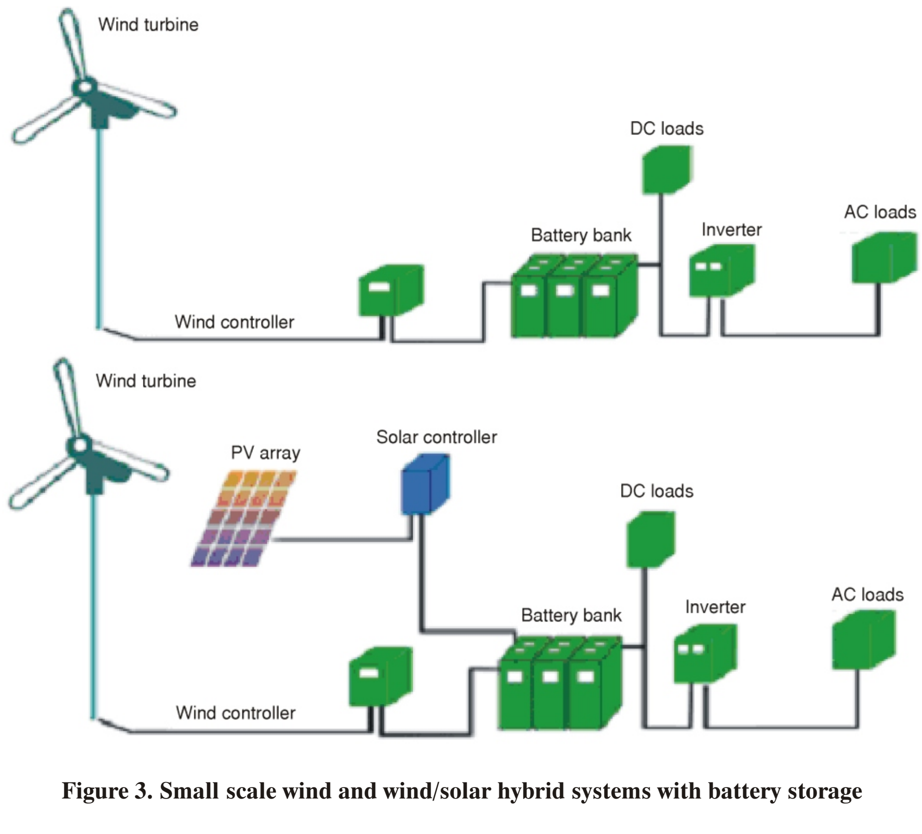

Figure 3. Small scale wind and wind/solar hybrid systems with battery storage

A wind turbine collects kinetic energy from the wind and converts it to electricity that is compatible with utility system. If the wind speeds are below cut-in speed there will be no output from the turbine and all of the needed power is purchased from the utility. As wind speeds increase, turbine output increases and the amount of power purchased from the utility is proportionately decreased, and when the turbine produces more power than needed, the extra electricity is sold to the utility. The design and installation of these systems is rather complicated and expensive, but they are the most effective in providing constant, reliable electricity supply.

Fuel cells

A fuel cell is an electrochemistry energy conversion device that produces electricity from external supplies of fuel (on the anode side) and oxidant (on the cathode side). These react in the presence of an electrolyte. Generally, the reactants flow in and reaction products flow out while the electrolyte remains in the cell. Fuel cells differ from batteries in that they consume reactant, which must be replenished, while batteries store electrical energy chemically in a closed system. Additionally, while the electrodes within a battery react and change as a battery is charged or discharged, a fuel cell's electrodes are catalytic and relatively stable. However, the fuel cells cannot store energy like a battery, but in some applications, such as stand-alone power plants based on discontinuous sources such as solar power or wind power, they are combined with electolysis and storage systems to form an energy storage system.

Fel cells are very useful as power sources in remote locations, such as spacecraft, remote weather stations, and in certain military applications. The overall efficiency (electricity to hydrogen and back to electricity) of such plants is between 30 and 50%. While a much cheaper lead-acid battery might return about 90%, the electrolyzer/fuel cell system can store indefinite quantities of hydrogen, and is therefore better suited for long-term storage. With intermittent renewables such as solar, small hydro and wind, the output may be fed directly into an electricity grid. At penetrations below 20% of the grid demand, this does not severely change the economics; but beyond about 20% of the total demand, external storage will become important. If these sources are used for electricity to make hydrogen, then they can be utilized fully whenever they are available, fig. 4.

Hydrogen is a portable energy storage method, because it must first be manufactured by other energy sources in order to be used. However, as a storage medium, it may be a significant factor in using renewable energies. Hydrogen may be used in conventional internal combustion engines, or in fuel cells which convert chemical energy directly to electricity without flames, similar to the way the human body burns fuel. Making hydrogen requires either reforming natural gas with steam, or, for a possibly renewable and more environmental friendly source, the electrolysis of water into hydrogen and oxygen. The former process has carbon dioxide as a by-product [8].

Solid-oxide fuel cells produce exothermic heat from the recombination of the oxygen and hydrogen. This heat can be captured and used to heat water in a combined heat and power (CHP) application. When the heat is captured, total efficiency can reach 80-90%. A new application is micro CHP, which is cogeneration for family homes, office

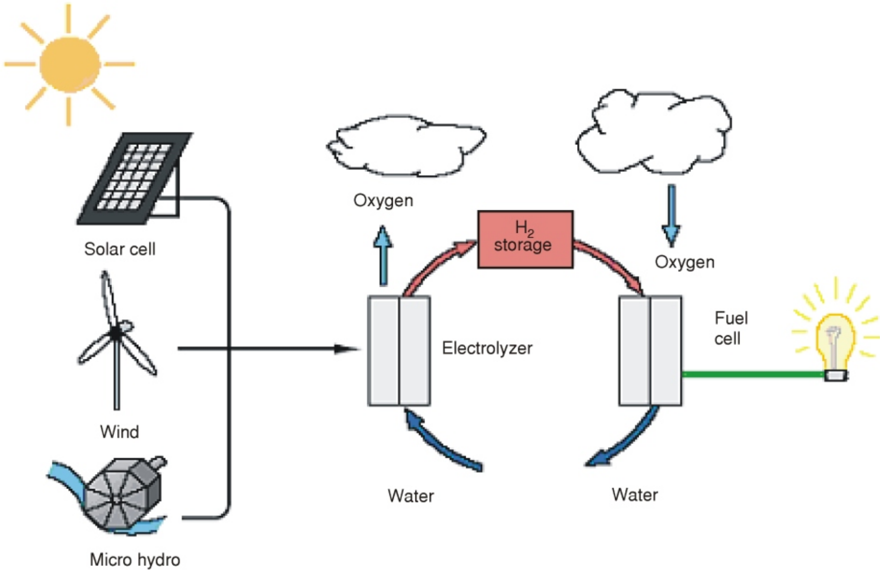

Figure 4. Renewable energy storage by the use of fuel cell

buildings and factories, with combined heat and power efficiency is typically around 80%. Because fuel cells have no moving parts, and do not involve combustion, in ideal conditions they can achieve up to 99.9999% reliability.

Superconducting magnetic energy storage

Superconducting magnetic energy storage systems store energy in the magnetic field created by the flow of direct current in a superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature. Once the superconducting coil is charged, the current will not decay and the magnetic energy can be stored indefinitely. The stored energy can be released back to the network by discharging the coil. Superconducting magnetic energy storage systems are highly efficient; the efficiency is greater than 95%, but the high cost of superconductors is the primary limitation for commercial use of this energy storage method.

The energy output of a superconducting magnetic energy storage system is much less dependent on the discharge rate than batteries. These systems also have a high cycle life and, as a result, are suitable for applications that require constant, full cycling and a continuous operation mode. Although research is being conducted on larger superconducting magnetic energy storage systems in the range of 10 to 100 MW, recent focus has been on the smaller micro devices in the range of 1 to 10 MW.

Summary and conclusion

Global warming, finite fossil-fuel supplies and environmental pollution conspire to make renewable energy an imperative. This makes it necessary for renewable energy sources to overcome present burdens of their intermittency by energy storage and thus be more competitive with the conventional energy sources. A future ”green energy” economy must be based on small, distributed generators that exploit a diversity of technologies such as wind, solar, fuel cells, *etc.* [9]. For example, as wind doesn't always blow, a battery or other storage technology is required to preserve energy generated until needed.

A pressing need will therefore arise for energy storage systems to balance supply with demand. In their contribution to combat global warming, the major issues to be considered in evaluating energy storage options is the amount of energy that is lost in the storage process. The estimates of the typical energy efficiency of several available or emerging energy storage technologies that are generally recognized as having commercial potential reached or expected in the near future is presented in tab. 1, which also summarizes particular system size ranges (existing and potential) and development status.

Table 1. Comparison of major energy storage technologies

Energy storage technology	Status of development	Unit sizes		”Round trip” energy efficiency
		Existing	Potential	
Compressed air	Commercial	100-300 MW	30 MW	80%
Pumped hydro	Commercial	5-2100 MW	2000 MW	75-80%
Batteries (conv.)	Commercial	1 kW	10 MW	50-90%
Flow batteries	Limited commercial	20 MW	1000 MW	70-75%
Magnetic	Limited demo.	10 MW	100 MW	90%
Fly-wheels	Limited demo.	1 MW	1-1000 MW	80%
Fuel cells	Commercial	50 kW-1 MW	100 MW	40-80%

Also, with transportation accounting for a great deal of emissions, hybrid electric vehicles have a well-defined part to play; hence rechargeable batteries are needed. Furthermore, the development of technological advance and mobility makes it inevitable for electricity providers to modify their present distributed electricity networks, and develop grid-enhanced management architectures combining renewable energy sources with batteries and other energy storage technologies for meeting peak-power demands while providing high-power quality.

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Апстракт

Миодраг МЕСАРОВИЋ

Енергопројект – Ентел, Београд, Србија

Технологије акумулације енергије и обновљиви извори енергије

Обновљиви извори треба да играју важну улогу у спречавању промене климе, али су конфронтирани са једним бројем баријера, као што су прекиди и високе цене. Акумулација енергије им пружа одличну могућност да превазиђу ману прекидности. Описане су конвенционалне технологије акумулације топлоте, компримовањем ваздуха, пумпањем воде, батерија, замајаца, као и нове акумулационе технологије у виду горивних ћелија, соларне и енергије ветра и разне хибридне верзије, уз наглашавање перспективних примера.

Кључне речи: обновљиви извори енергије, технологије акумулације енергије, прекидност

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