ENERGY STORAGE WITH WIND POWER

4/10/2017

INTRODUCTION

To overcome the intermittence of wind power systems, backup systems as well as ingenious methodologies for energy storage are being suggested. The stored energy could then be used during the periods when the wind is not blowing or wheeled to distant locations for consumption.

The electrical grid system could in fact on a wide scale basis be considered as an energy storage system, since the wind blowing at some location can produce energy that can be used at another distant location where it is not blowing at some time.

FREE HYDROGEN PRODUCTION

Hydrogen as an energy carrier and storage medium can be generated through the electrical electrolysis of water:

$$2H_2O \rightarrow 2H_2 + O_2 \quad (1)$$

This reaction occurs in an electrolytic cell that is exposed to an electric direct current starting the process of electrochemical separation of water molecules into its two components. The gases are emitted from the electrodes and are separated and captured in the cell. The gases go through a back flash valve, water trap and dehumidifier, before they are ready for use.

Hydrogen can be produced in small units near its intended point of usage, in a manner known as “distributed production.” Distributed production may be the most viable approach for introducing hydrogen in the near term, in part because the initial demand for hydrogen will be low.

Hydrogen may also be compressed and stored as a metal hydride in cylinders or kept at low pressure in a gas tank. Compressed hydrogen can be used in a fuel to directly produce an electrical current at an efficiency of 60-70 percent.

A hydrogen economy requires an infrastructure to deliver hydrogen from where it is produced to the point of end-use, such as a dispenser at a refueling station or a stationary power site.

The required infrastructure includes the pipelines, trucks, storage facilities, compressors, and dispensers involved in the process of delivering the hydrogen as fuel.

Hydrogen production has been implemented in association with the HGenerators 3 kW Wind Turbine Electricity Generator. It can produce both electricity and hydrogen approximately at 600 kWhr per month using an average wind speed of 12 m/s and 210 hours of operation per month. The cost is just under $6,000 for the entire wind turbine.

Figure 1. HGenerators 3.4 kW electricity and hydrogen producer wind turbine.

Figure 2. Row of HGenerators 3.4 kW turbines along water shore.

Table 1. Technical Specifications of HGenerators turbine.

Peak power	3.4 kW
Wind wheel diameter	5 m
Start-up wind speed	2 m/s

Cut-in wind speed	2.5 m/s
Rated wind speed	10 m/s
Stop wind speed	25 m/s
Survival wind speed	45 m/s
Rated rotational speed	400 rpm
Protection level	IP54
Insulation level: B	B
Cooling Mode	IC0141
Operation Temperature	40-60 ^{o}C
Drive Mode	Direct, driven by wheel
Adjust Speed Mode	Automatic
Adjust Direction Mode	Manual/Automatic
Tower Height	9 m
Rated voltage	240 V
Insulation level	B
Proposed battery configuration	20 12 V 100 AH batteries

BOUND HYDROGEN PRODUCTS

In the form of a gas, free hydrogen is highly reactive, and even explosive, as demonstrated by the Hindenburg experience.

Compressed hydrogen gas interacts with metal forming hydrides, which embrittles its containment vessels and causes explosions.

Being a small molecule it tends to readily diffuse and leak through its containers.

The safest and most manageable form of hydrogen is bound hydrogen whether confined in the lattice of a metal such as palladium, titanium, or uranium; as a hydride, or as a hydrocarbon.

Hydrogen bonds with carbon through alkane bonding producing isooctane, butane, and methane, as relatively safe methods to bind hydrogen. If hydrogen is turned into methane, it could be distributed through the existing natural gas pipeline system, or used in fuel cells.

It could also be turned into methanol as a liquid fuel.

PUMPED STORAGE

Somewhere in North America of in Europe and North Africa, the wind is blowing or the sun is shining, and all that is needed is to coordinate the balance between excess supply and demand. But computers alone are not sufficient. Instead, storage facilities are needed to collect the electricity, store it for days and weeks and release it as needed.

Compressed air reservoirs store compressed air in underground caverns. In Germany most of these reservoirs are already filled with natural gas. Hydrogen storage systems achieve only a moderate, 40-percent degree of efficiency. Lithium ion batteries are expensive and not very efficient. The idea of using the batteries of electric cars as a buffer suffers from the fact that there are very few electric cars on the road today.

Pumped storage is associated with hydroelectric power generation but has not been used with wind power generation in spite of its promise. Water would be pumped to an elevated reservoir when the wind is blowing and then used to drive a hydraulic turbine when energy is needed at a turn-around efficiency of 70 percent. The Dinorwig pumped storage project in the UK has an installed capacity of 1,890 MW.

Pumped storage hydroelectric power plants are considered as the most efficient alternative. The technology has been in use for 80 years at the Schluchsee, a reservoir in Germany's southern Black Forest region.

Up to 6,472 gallons or 24,500 liters of water shoot down through a pressure shaft every second, coming from the Eggberg reservoir, which is about 400 meters above the Schluchsee.

The mode can be switched within only 90 seconds, so that hydroelectric power production can be stopped and water is pumped back up to the upper basin. No other system can be adjusted as quickly to whether current is needed or has to be stored at any given time. In comparison, a brown coal power plant takes 12 hours to boot up to full capacity. This flexibility makes a pumped storage hydroelectric power plant so valuable.

At the Schluchsee, the growing supply of wind energy benefits the plant. The water turbines are currently being switched between operating modes 60,000 times a year.

Another power plant is planned in the region, in the town of Atdorf. At a site where a hiking path now passes along a ridge, a reservoir will be dug and a tunnel will be excavated through gneiss and granite, 600 meters down to a second reservoir on the Rhine River plain. About 272 acres or 110 hectares of land will have to be dedicated to the pumped storage hydroelectric power plant.

Figure 3. Dinorwig pumped storage system, UK. Source: BBC.

A Dutch engineer, L. Lievense proposed the linking of 1,000 wind turbines of 3 MW of rated power each to pump water into a 165 km^2 water basin. The wind turbines would pump the water to a higher level than the surrounding Ijsselmeer into the basin.

The water would be later allowed to drive water turbines at peak electrical demand or at the times where there are no productive winds.

Figure 4. Eggberg reservoir supplies water to the Schluchsee power plant. Schluchseewerg AG Photo.

Figure 5. Schluchsee pumped storage hydroelectric power plant. Schluchseewerg AG Photo.

BATTERY STORAGE

Electrical batteries or accumulators are regularly used in solar energy applications and can be charged by a coupled wind and solar energy system.

Lead acid batteries are a good choice since they are well suited to trickle charging. In terms of electrical output they have a high efficiency of 80-90 percent, and in terms of energy, their efficiency is 70-80 percent. Thick plates are used in special batteries for large installations. Small installations can use bank of ordinary automotive batteries. The main cause of deterioration is overcharging or being left for too long in a discharged state.

Nickel cadmium batteries are not usually used in wind power applications since they have low efficiencies at low intensities and lower than lead acid batteries at all intensities. Their advantages are that they are not damaged by overcharging, nor by occasional over discharging, they do not self discharge, and not easily damaged by freezing temperatures compared with the lead acid batteries.

FLYWHEEL ENERGY STORAGE SYSTEM, FESS

Wind energy using fast rotating flywheels can be used to store wind power. Around 1950 Oerlikon gyrobuses were used in Switzerland using the energy stored in a flywheel.

Composite metallic and polyester resin materials can be used in flywheels with an efficiency:

$$\eta = \frac{\text{Restored energy}}{\text{Consumed energy}} = 80\, percent. \qquad (1)$$

With a flywheel rotating at 15,000 rpm on magnetic bearings in a vacuum chamber, it is theoretically possible to store 400 W.hr/kg for a period of 24 hours. A limitation shared with nuclear fuel enrichment centrifuges exists: beyond a certain critical rotational speed the centrifugal stresses would cause a catastrophic failure of the device.

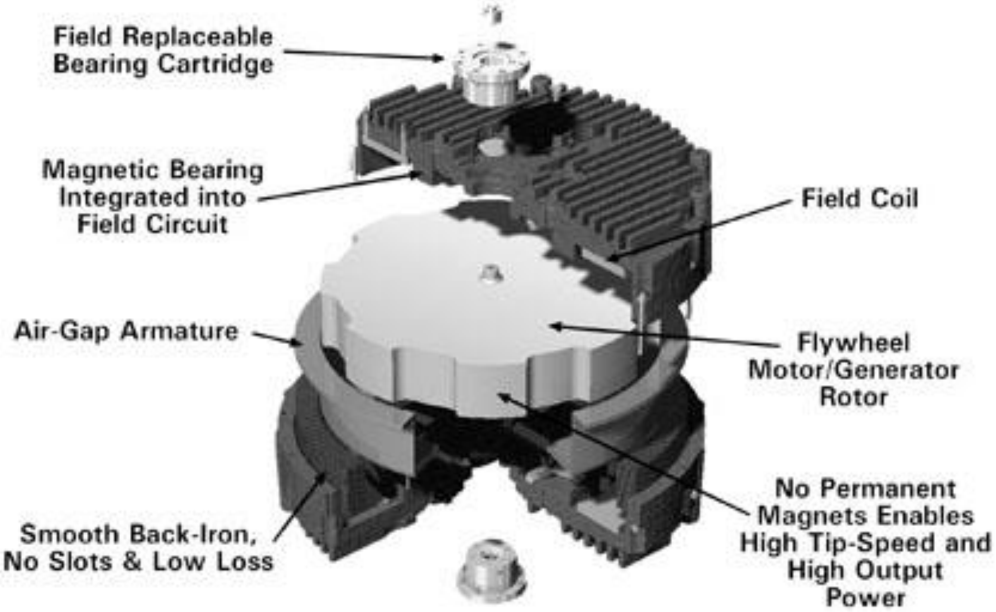

Figure 6. Flywheel motor-generator. Source: CleanSource.

Figure 7. Enercon Flywheel. Source: Enercon.

COMPRESSED AIR STORAGE

Wind turbines could compress air for storage in tanks or underground cavities. When needed, it can be used through its direct expansion in a compressed air motor.

Alternatively, the compressed air can be injected into an internal combustion turbine where the oxygen it contains can be burned with fuel, possibly hydrogen, in a combustion chamber to supply mechanical energy at an efficiency of 80 percent.

THERMAL STORAGE

Many alternatives exist for the thermal storage o wind energy: water heating, heating of gravel or stones, or melting of a substance with a low melting point such as paraffin wax or lead. The molten substances would give back their latent heat when returned to their initial state. This approach would be useful for space heating application because of the low grade heat involved.

SUPERCONDUCTING MAGNETIC ENERGY STORAGE, SMES

Superconducting coils or magnets can store energy in the form of a. magnetic field. Being superconducting, the ohmic resistive losses can be minimal. The stored energy can be released in the form of an electrical current to power transportation systems such as automobiles or Magnetically Levitated (Maglev) trains. This could be coupled with a cryogenic hydrogen transmission system for a national efficient electrical grid and transportation system.

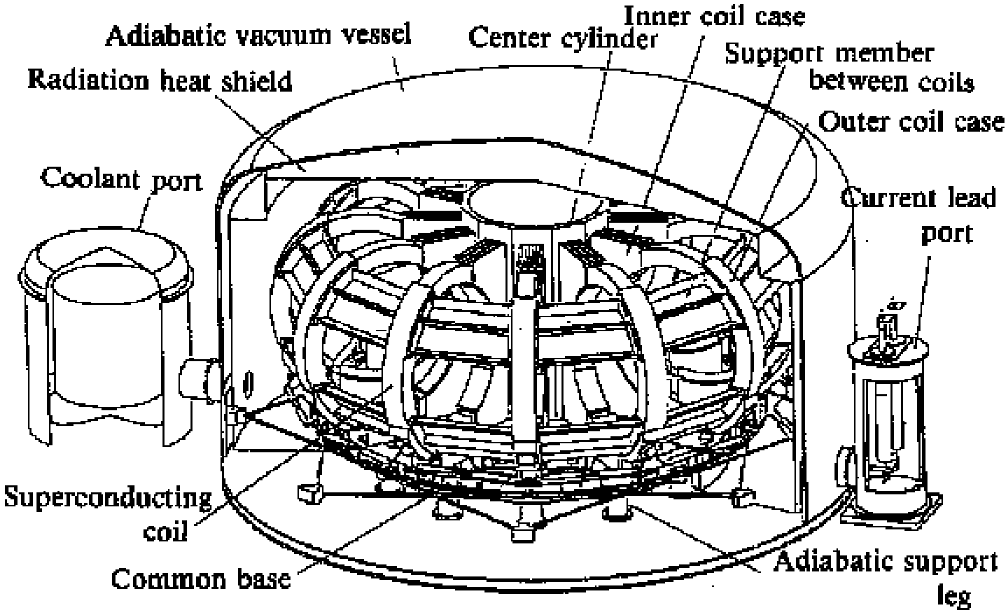

Figure 8. Conceptual design of a superconducting coil for the 100 kWhr small scale SMES, Japan.

Japan's International Superconductivity Technology Center (ISTEC) conducted a three year feasibility study starting in 1988 on SMES, under a program sponsored by MITI's Agency of Natural Resources and Energy.

Superconductors such as Nb-Ti and Nb_3Sn were the primary choice. Demonstration of a small-scale SMES, whose size is closely related to that needed for power system stabilization, would address many major technical issues facing the large-scale diurnal storage SMES, such as AC losses, power conditioning, and refrigeration.

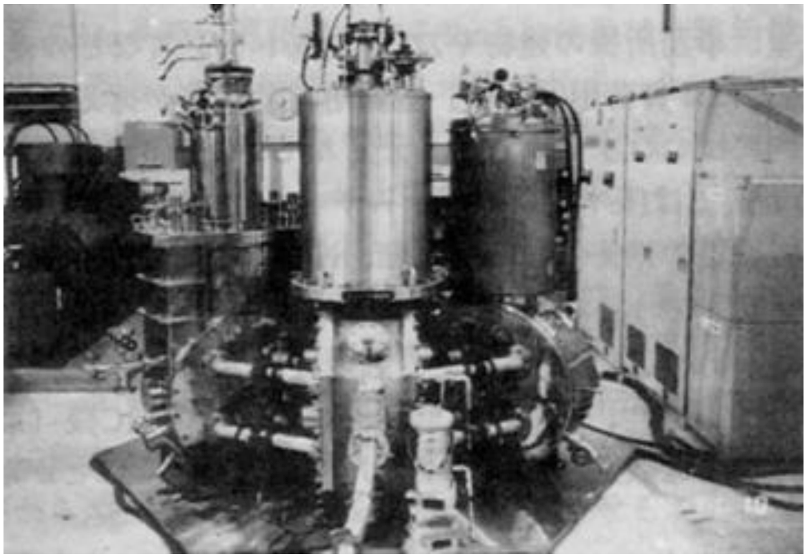

Figure 9. Kansai Electric Power Company (KEPCO) three coil torus with 400 kJ per coil.

A 100 kWh/20 MW system used a toroidal magnet with an outside diameter for the cryostat of ~12 m. A half size prototype coil was constructed by Toshiba. The test coil used a forced flow Nb-Ti cable in conduit conductor and demonstrated 20 kA at 2.8 T, which is the rated current for the basic design.

The initial testing was conducted at the Japan Atomic Energy Research Institute (JAERI), with further tests at Lawrence Livermore National Labs (LLNL) in the USA.

SMART GRID CONFIGURATION IN EUROPE FOR WIND AND SOLAR ELECTRICITY

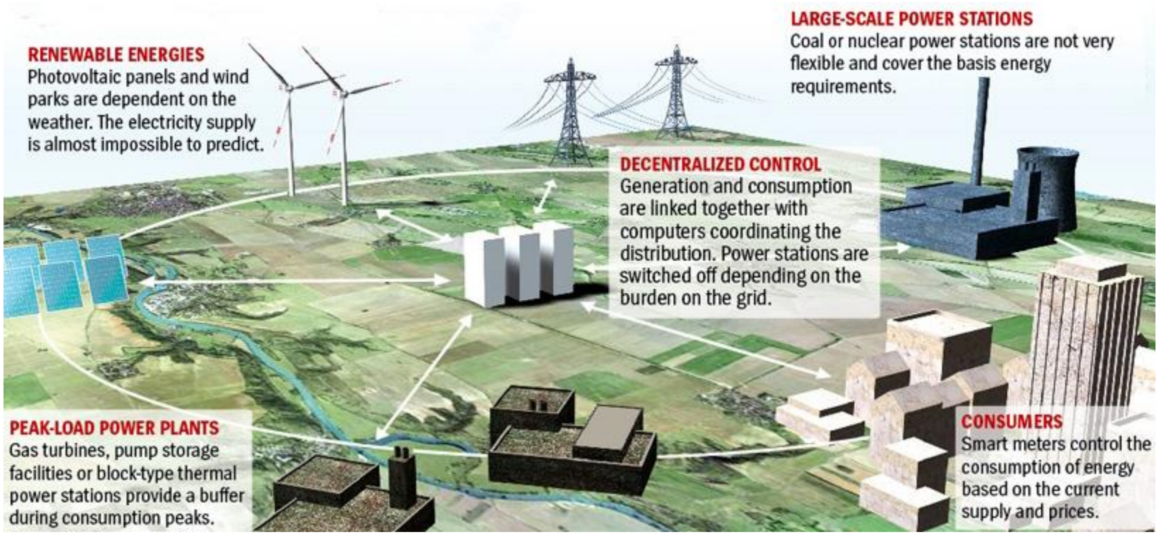

Figure 10. Smart Grid Configuration. Source: Der Spiegel.

Electrical grids in the industrialized nations must grow larger as well as flexible and smarter using modern information technology to perfectly coordinate energy distribution, making them more efficient and reliable.

The global electricity industry is spending billions on building new, transnational power lines to harness electricity from renewable energy sources. The Smart Grid system is meant to make the distribution of electricity more reliable and efficient. As an example, the European power grid is 6,875 miles or 11,000 kilometers in length. When the electrical consumption and supply are perfectly balanced does the grid remain stable.

A new variable affects the equation: everything can be planned, except for the wind availability. It fluctuates between gentle breezes and powerful storms. New wind turbines and solar panels are added every day.

In Europe, the grid operators are required by law to give priority to the clean forms of energy when feeding electricity into the grid. The problem is that the sun and the wind are very unpredictable. The fluctuations complicate their work with the grids reaching their maximum loads more frequently.

Germany plans a massive expansion in renewable energy and expects it to make up 30 percent of total power production by 2020. Giant offshore wind power projects are being implemented in the North and the Baltic Seas. The Mediterranean countries intend to utilize the massive potential of solar energy with the Desertec project in the deserts of North Africa and export the electricity using High Voltage DC (HVDC) cables under the Mediterranean to Europe.

A vision of wind power from the north and solar energy from the south is being realized foe the European and African continents.

What is missing is a modern power grid that will transport green electricity to consumers in the center of Europe and is capable of integrating fluctuating loads into the existing system.

Without such a system the situation could turn disastrous with an elevated number of critical grid situations could arising in the coming years leading to bottlenecks within the network.

Such a bottleneck occurred to millions of households after 10 pm on November 4, 2006. The engineers with the network operator E.on had shut down an important transmission line during the transit of a cruise ship, and had incorrectly assessed the consequences. The rest of the grid became overloaded, causing one line after the next to shut down automatically. A blackout occurred and the electricity consumers were in the dark for about one-and-a-half hours.

Such blackouts are expected to become more frequent as a result of the fluctuations in the levels of electricity being fed into the grid from wind turbines. If the transformation of the system proceeds as planned in the next 10 years, wind turbines generating a total of 42 gigawatts (GWs) will be installed in Germany. Photovoltaic systems will be generating about 21 GWs. This is more than is needed on some weekends, when demand can drop to less than 30 GWs. If the sun is shining and the wind is blowing at the same time, the grid would be thrown off balance.

Ironically, the European electric utilities are paying others to take the excess electricity off their hands during nighttime storms. The operators of an Austrian pumped storage hydroelectric power plant benefit from the available free energy to pump water into lakes at higher altitudes. Once prices have recovered, they release the water from the lakes, which drives generators that produce electricity that is then sold. Such a unique situation makes it clear how urgent it is that the providers modernize the infrastructure and grid management.

The electrical utility companies are embarking on a radical change in their history. Power highways that will cost billions to build are needed to connect renewable energy sources in the north and south to the markets in-between. Massive power lines will be installed across Europe and North Africa, some through desert sand and some on the sea floor.

The power companies are incorporating a multitude of small and very small energy sources. Homeowners are taking advantage of the net-metering rules effectively turning into producers of electricity as they install solar panels on their roofs and cogeneration plants in their basements.

There are many hurdles to be overcome, including technical problems that are proving to be a serious challenge for engineers, but the political world is supportive.

SMART METERING

Figure 11. Smart meter, Germany. Source: Yello Strom subsidiary of EnBW Energy Company.

On a micro scale, some consumers are getting a glimpse of the new world of intelligent grids. The old black electricity meters, with their rotating metal disks, have been replaced by digital meters. These smart meters record all data in real time, which allows consumers to determine which of their household devices consume large amounts of electricity.

To save on their electrical usage, people have installed power strips in their homes and turn off their lights when they leave a room and take shorter showers.

With the help of the smart meters, electricity service providers hope to be able to handle fluctuations in the grid more effectively. They are betting on a classic market mechanism: When they have a lot of electricity available, they reduce prices, making it more attractive for customers to consume more electricity.

The vision is that the smart meters will eventually switch on washing machines during off-peak hours, when electricity is cheapest. Or they will remotely reset the temperature in the freezer from minus 18 degrees Celsius to minus 24, so that the freezer can then be shut off for a while later on, when electricity rates are higher. Household devices would communicate with one another, so that they can be controlled more efficiently.

Such ideas represent a complete departure from the existing electrical business philosophy. Providers base their energy production levels solely on consumption. They would offer the amount of electricity that consumers and industry need at any given time. They charge a largely uniform price for that electricity, regardless of fluctuations in the load on the grid.

In the future, consumption could be adjusted to conform to the fluctuating supply, and prices will fluctuate accordingly. The providers are currently developing variable pricing models much like the the phone market. In the future, customers could change electricity providers or they could buy entire packets of kilowatt hours at preferred prices, which would essentially amount to a pre-paid electricity system.

On the other hand, whoever still wants to use as much electricity as he happens to need at a given time will have to pay a premium for the convenience.

TECHNICAL CONSIDERATIONS

In Germany it will cost the industry an estimated $50 billion or €40 billion to modernize and expand the grid by 2020. The estimated cost of producing solar electric power in the Mediterranean region and transmitting it to northern Europe is even higher at about €400 billion. As in the days of the California Gold Rush, the equipment makers are the ones who will rake in the profits first. The smart grid is expected to be several times the size of the Internet. The companies that will benefit most are the suppliers of the hardware, companies like Siemens and ABB, which manufacture and install the necessary generators, distribution stations and high-voltage lines.

To connect offshore wind farms with the terrestrial grid ABB's engineers had to address that task 125 kilometers off Germany's North Sea coast, on the Borwin 1 platform. In rough weather, they laid a thick cable through the region's tidal flats. A special ship was used to drive the heavy copper cable with each meter weighing 84 pounds or 38 kilograms into place on the sea floor. The cable leads to a transformer station in the East Frisian town of Diele.

ABB employed a special technology known as High Voltage Direct Current (HVDC) transmission for the €300-million project. The method is considered to be ideal for transporting current across long distances. On an HVDC line, only 3 percent of the electrical energy is lost for every 1,000 kilometers of transmission. By comparison, the distribution loss on a heavily used alternating current line is almost twice as high for only 100 kilometers.

The high-tech lines are part of a network plan recently unveiled by the European Network of Transmission System Operators for Electricity (ENTSO-E). Under the plan, more than 42,000 kilometers of high-voltage lines will be built or replaced throughout Europe by 2020. The hope is that the larger the grid, the more opportunities there will be to balance supply and demand.

DISCUSSION

Even though everyone supports turning away from oil, coal and gas and the growing use of the use of solar and wind power, with many even accepting billions in subsidies in return, citizens are often completely unwilling to accept the need to transport and store energy.

Citizens' opposition groups do form wherever new swathes are to be cut into forests, demanding that if new power cables are necessary, they should only be buried deep underground. This is often five times as expensive as installing above-ground transmission lines.

The lack of social acceptance could seriously delay the implementation of expansion projects, not to mention the difficulties that crop up when new technologies are being used.

The HVDC systems are considered relatively vulnerable, particularly the giant converter stations that convert direct current into alternating current. The connection between the Netherlands and Norway was out of commission for three months because of a cable defect.

The expansion of the alternating current grid is causing problems. Because today's high-voltage grid, with a maximum capacity of 380 kilovolts, is reaching its limits, the construction of individual 740-kilovolt lines is under consideration. The 70-meter-high pylons are enormous and they require a 100-meter-wide corridor, an unlikely alternative in densely populated regions.

The focus on a few, heavily loaded transit hubs poses the risk that a breakdown could jeopardize the stability of the entire network.

It is uncertain that consumers will take advantage of the possibilities smart meters offer. To save a few cents, will they give up the convenience of being able to wash their clothes at any time instead of only when electricity is cheap. A large proportion of customers do not desire change.

The current electric meters tend to be of limited intelligence, and communication with electronic devices in the household often fails because of a lack of standards.

Privacy groups warn that smart meters are not hacker-proof.

The contribution consumers make to the grid revolution will likely remain modest. Instead, the speed at which the power lines and storage facilities are upgraded and expanded will have a decisive impact on the smart grid. Political will is also a critical factor.

A strange consequence results from the different approaches to promoting renewable energy. The Dutch network operation Tennet is considering laying an underwater cable from the Netherlands to Denmark, but it will not connect the German wind farms to the cable, even though they are located halfway along the proposed route. The reason is that German consumers subsidize wind power by paying a fixed price for it, and that price is significantly higher than the Danes or the Dutch would be willing to pay.

The 50 Hertz frequency in Europe and 60 Hz in the USA indicates to the grid operators a sacred equilibrium that is proving more and more difficult to maintain. The situation would already be critical if the frequency dropped from 50 to 49.8 Hertz. In this case reserves must be activated. If the frequency were to slide down even farther brownouts and blackouts would occur.

REFERENCES

1. Alexander Jung, “Building the Internet of Energy Supply,” Der Spiegel, May 12, 2010.