BOTTLING THE WIND

The green energy boom has opened up cracks in the electricity sector to force to the surface problems which until recently were of only marginal interest. Wind power in particular has provoked forceful debates. Among the subplots are questions over how to manage intermittency. The result is a multiplicity of paths to innovation, one of which leads directly to electricity

The costs of intermittency

As electric utilities have long known not all kilowatt hours (kWh) are created equal. The costs of production are variable and while some plants are required to supply baseload demand others have more flexibility. Renewable energy resources, such as solar power, are sensitive to the vagaries of weather patterns that can create peaks and troughs in supply, and what is true for solar is even more so for wind. Impact can be determined over the course of a single day as well as spread over an entire annual cycle. Western Europe for example follows a seasonal pattern and peak demand occurs during winter cold spells or summer heat waves that correspond to periods when high-pressure systems produce a noticeable absence of wind.

In places where solar or wind power account for only a small percentage of overall resources, intermittence is of little consequence. But green energy is playing an ever increasing role in the long-term energy strategy of many parts of the world forcing grid operators to take the associated consequences much more seriously. In March 2011 for example, wind power represented the primary source of electricity in Spain generating 4738 GW and meeting 21% of demand (averaged over the course of a year, wind power has surpassed coal-fired plants and satisfies close to 15% of demand making it the third most important generation technology on the Iberian peninsula). Red Eléctrica de España provides real time consumption data that show clearly identifiable spikes in the system: on 14 January 2010 at 1:33 a.m. an instantaneous power value of 11,693 MW was registered which means wind power represented 42% of Spanish electricity supply at that particular moment in time.

A momentary reduction of other forms of production ensures grid stability during demand fluctuations and hydroelectric power is particularly well suited to the task. Grid operators rely on weather forecasts when making adjustments to the overall energy mix and may, for example, reduce the role of thermal power stations to account for day/night differences in wind strength. The current strategy is already pushing up against its own limitations however and if wind power continues to grow (the Spanish target is to make wind the country's primary source of electricity by 2040) its intermittent nature could become increasingly problematic.

A heated debate on the subject has erupted in the UK where, according to National Grid data, the industrial-scale development of huge offshore wind farms means wind turbines are now capable of delivering 10% of total electricity needs. A number of contradictory reports have been published since 2005 either to highlight the excessive cost of a kWh of wind generated electricity or, on the contrary, to revise estimates downward.

In some other contexts the overriding challenge is different and turns on questions over how to cope with the geographical constraints. In Germany, development is set to remain focused on the construction of large offshore wind farms in the Baltic and North Sea which lie a considerable distance from regions where demand is the highest. The construction of high-voltage transmission networks to the industrial powerhouses of the Ruhr and Bavaria provides the most obvious solution to this problem but will have to overcome significant hurdles in terms of cost, time required for construction, and public acceptability. Moreover, because of the 700-800 km distances involved, losses of power between the source and destination are inevitable and will be significant.

In yet another example, island dwellers could no doubt benefit from an expansion of wind-based capacity as a complement to solar but, as with any other part of the world, they will still be faced with the problem of intermittency.

Given the dilemmas faced within these differing contexts, electricity storage has emerged as a primary area of focus for those interested in the future of wind power or other intermittent sources of energy. As a solution it is elegant and could be used as a supplementary tool for grid operators charged with managing various resources. It could even allow islands to break their dependence on small gas- and coal-fired plants. And yet how do you capture and store the wind?

Mechanical Solutions

One approach to the question of storage relies on the conversion of kinetic energy produced through wind harvesting into useful work. Depending on the situation three models have emerged to meet this basic requirement.

Flywheels, which work by harnessing the power of a wind turbine to a heavy steel rotor and spinning it at high speeds when wind is abundant, can be employed to keep grid power steady. As the flywheel ramps up it requires enormous amounts of energy but once it is up and spinning friction with bearings (and the flywheel itself) is reduced. When the wind refuses to blow and the laws of inertia take over the stored energy is released to be converted into useable electricity. The effect is to smooth over any fluctuations in production and the theoretical underpinnings are relatively simple and well understood. The downside is the level of investment required as some rather expensive technology must be deployed for the system to be effective (to minimize friction modern flywheels are enclosed in a drum evacuated of air to create a vacuum).

A second model relies on *hydroelectric installations* and tighter integration between wind farms and pumped storage systems. Water can simply be moved between reservoirs at different elevations when wind is abundant or at times when demand is low (e.g. weekends). This principal has already found application in France where reversible turbine/generator assemblies pump water to higher elevations during periods when the cost of grid electricity is reduced (for instance, by night). This system has achieved remarkable success and is capable of transforming up to 80% of energy into useable electricity. Given these results it is not too much of a stretch to imagine a wind-driven system of electrification completely independent from the national grid. A thorough economic analysis is required but at a theoretical level the concept would seem to make sense, especially in corridors where wind is abundant. The only hitch is that offshore wind farms, as well as those on the rural plains, are generally located far from any existing hydroelectric dams placing limits on plans for any direct link between wind power and water pumping turbines. Although complex, one possible solution would be to create indirect links via the electricity grid.

Compressed air storage as a model could upon initial inspection appear somewhat farfetched but offers a solution that is much less dependent on geographical constraints. Industrial-scale facilities have been operating for some time both in Germany, ~~since~~1978 (Huntorf, 290 MWh), and in the United States (Alabama) since 1991, but levels of efficiency are modest and hover around 40%. Germany’s third largest energy company EnBW has recently developed a much improved solution to exploit the power of compressed air, and the heat generated as it is released, in an attempt to achieve operating efficiencies of 70%.

All these concepts represent the current state of the sector and will require extensive testing and economic analysis before they reach maturity. Moreover, all the technologies, especially flywheels and compressed air storage, require complex infrastructure and therefore significant levels of capital investment.

Batteries, Accumulators, and Ultracapacitors

An alternative approach to the challenge of electricity storage is provided by another group of technologies, at an even greater stage of infancy than those that have just been discussed, and with the same set of hurdles to be overcome. Yes, battery technology is well understood and has evolved in incremental steps over the last century. Steady progress has been made but the only really disruptive innovations have taken place within the military industrial complex, at massive cost, and where budgetary constraints bear little relation to the realities of commercial industry. In recent years there has been a shift however and a fresh focus on R&D has opened up various new paths for exploration. The main driver for change has been the rise of the market for electric vehicles but the development of wind power can also claim some of the responsibility for the creation of a broader playing field.

As a general rule, and despite the progress being made, innovative storage technologies have yet to demonstrate their ability to be scaled up to grid-level capacity, not least because of the gulf that exists between the price of a kWh of stored electricity when compared to that transmitted from the grid. To address the problem of intermittency, different approaches must be taken to different applications and some have demonstrated the potential to scale to the needs of individual communities, particularly those that are isolated from a national grid.

There is considerable hype surrounding the Japanese firm NGK and a technology they have developed to store up to 7.2 MWh of energy in a new type of sodium-sulfur battery weighing a massive 80 metric tons. This would represent enough electricity to service several hundred households at a cost of US $5.4 million per installation which while certainly expensive is not completely out of proportion with the budget of isolated communities. As an example of industrial-scale development, Systèmes électriques insulaires, an entity of the French energy giant EDF charged with networks of electrification on isolated islands, has already deployed 1 MW of the new batteries on the overseas district of La Réunion, and after six months of testing the technology has proven a viable solution to the island's energy needs. Testing by the U.S.-based Xcel Energy has demonstrated equally promising results.

The main competition to NGK emanates from a type of accumulator known as a vanadium redox flow battery and is founded on principals that have been well understood since the 1950s. The rise of industrial-scale wind production has made the idea more relevant than ever and the best example of the technology can be found instorage facility located on Australia's King Island which sits between Tasmania and the mainland. Another example can be found in the Tapbury wind farm in Ireland. In essence, liquid electrolytes flow past solid electrodes, separated by an ion exchange membrane which allows charged species to move back and forth, with one direction corresponding to discharge and the other to charging. These exchanges occur between individual cells which combine to create electricity and the amount of power generated depends simply on the number of batteries. They behave differently than traditional lead-acid batteries, not least because they can be cycled tens of thousands of times, but also because the energy is stored in an external circuit which pumps energy chemicals out of the battery into storage tanks.

The advantages of this method are high levels of operating efficiency, which could reach as high as 70%, and the inherent qualities of vanadium. It is a transitional metal, the formation of an oxide layer stabilizes the metal from oxidation, and it can act as both an oxidizing agent as well as reduction agent (thus the term 'redox') creating a continuous flow of electrons and stable long-term solution to storage needs. Moreover, the system is extremely agile and responds well to sharp variations in wind speed. The system has two principle weaknesses however as not only is vanadium highly toxic (requiring reinforced safety and security measures) but the installations also take up a large amount of space. Nevertheless these vanadium-based accumulators open up some promising avenues for R&D and could result in turbines that are much more reactive to the ebb and flow of the wind than is the case for those in current operation.

For King Island the result has been remarkable. Wind power now responds to 40% of customer demand (for only 12% ten years ago) at an installation cost that is comparable to the NGK system and electricity supply is much less dependent on diesel-powered generators.

To round out this family of technologies another area of innovation can be found in the deployment of supercapacitors to act as a complement to accumulators. This development promises both the creation, and improved optimization, of high-performance storage systems. Supercapacitors are based on the same principles as ordinary capacitors (energy is stored in an electrostatic field). The former store considerably more energy however and contain a significantly enlarged electrode surface area compared to more conventional models. They are capable of rapid charge and discharge and are ideally suited to smooth over any momentary fluctuations in production. In cases of longer interruptions accumulators would be available to pick up any slack. The beauty of this solution is it provides not only a more sophisticated tool for frequency regulation but also extends the working life of the associated accumulators.

Gas at the Crossroads

To complete our perspective on the future of storage technology there is another possible approach which relies on the creation of hybrid plants that make use of a mixture of wind power and traditional gas powered combustion to exploit the energy creating potential of hydrogen. The trick is to use the energy produced by wind turbines to produce hydrogen that can be stored and used when the wind refuses to blow.

At a technical level the approach appears simple as it employs mature technology... but it is also, literally, a gas-fired plant! Producing hydrogen presents no particular difficulties and is merely a matter of employing turbines to pass the wind-generated electricity through water to split it into hydrogen and oxygen. Afterwards, the hydrogen can be stored and deployed later using an internal combustion engine to power a generator.

Operating efficiency remains stalled at a modest 40% but a number of experimental projects have been launched to search for improvements. In the United States the National Renewable Energy Laboratory has launched the Wind to Hydrogen project through a mixture of public and private funding. Europe is also leading the way as can be seen by the construction of a wind-to-hydrogen plant on the Norwegian island of Utsira or initiatives taken by Sotavento in the Galicia region of Spain.

A new hydrogen-hybrid power station was recently inaugurated in Prenzlau, just north of Berlin, and is unique in the world as it relies on biogas (methane in particular) to produce energy when the wind refuses to blow and wind-produced hydrogen when it does. The hydrogen can later be blended with methane to create a more robust source of energy.

With such a vast array of approaches what are we to make of these experiments? Certainly we could conclude we have reached a turning point and have entered into a particularly dynamic phase of R&D. The horizon is punctuated by numerous perspectives as solutions continue to multiply. In such an open field competing technologies will have to struggle amongst themselves, as well as with future innovations, to boost market penetration. In the medium-term the most likely scenario is an increasing level of specialization as opposed to a one-size-fits-all solution.

Drawing from recent experience suggests that all the technologies contain the potential to meet, if not always fully at least partially, the need for efficient storage as the green energy sector continues to expand. For the moment, the greatest successes have been achieved in somewhat isolated circumstances (islands, remote areas) where they serve as complements to existing infrastructure rather than real alternatives. Finally, questions over the scalability of the proposals will linger until they demonstrate their capacity to operate at a truly industrial level. Until this target is reached it is difficult to envisage any real competition with more traditional sources of electricity. While it is still too early to make any definitive pronouncements on the economic sense of the current path evidence suggests we are moving in the right direction and the limits of what is possible are beginning to expand.

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