Living with energy intermittency

THE INTERMITTENCY OF RENEWABLES IS FORCING ENERGY PROVIDERS TO LOOK AT WAYS TO STORE ENERGY – AS A WAY TO GUARANTEE STABLE SUPPLY. IN A NEW REGULAR COLUMN LOOKING AT THE ENERGY STORAGE CONUNDRUM, **BENT SØRENSEN** FROM ROSKILDE UNIVERSITY IN DENMARK LOOKS AT A CLASSIC CASE OF ENERGY STORAGE – VEHICLES THAT USE BATTERIES AND FUEL CELLS.

Several renewable energy sources flow intermittently or at varying rates. For example, **solar radiation** is zero at night, and affected by cloud cover and air turbidity during the day. And its seasonal distribution doesn't complement space heating demand, in fact quite the opposite, though solar-driven air conditioning and cooling has been shown to have potential.

Wind energy also varies according to weather systems passing over a given location, with recurrence times typically between one and three weeks. On the other hand, its seasonal variations are fairly modest and generally follow those of power demand.

Hydro Power is generally stable, but varies seasonally as dictated by the components of the water balance. For run-of-the-river hydro these variations may change over the course of a few weeks, while for reservoir-based hydro there are no short-term problems. However, there is also the general question of having sufficient precipitation (and snow-melt where that is relevant) coming into the reservoirs, normally relative to some average-year situation, for which the system is designed.

Could hydrogen conversion be a way of storing excess renewable energy in the future? UK-based ITM Power has unveiled a hydrogen home refuelling station, which it paired at the launch with a petrol-engined Ford Focus car converted to run on hydrogen. The station aims to help overcome the lack of a hydrogen refuelling infrastructure and utility supply network

Wave energy, being essentially accumulated wind energy, shows an even larger deviation from its average level.

It is clear to see that only biofuels behave like fossil fuels, i.e. they can be stored in containers and used when called for.

Energy stores

So with this in mind, one area of major focus for the renewables industry is to find ways of storing energy, in order that it not be wasted, as well as offering back-up power in scenarios where renewables are used in some way.

Two examples of energy stores directly associated with renewable energy are biomass and hydro power storage. Secondary storage devices can also fall into this category, examples being:

- Compressed gas stores;
- Heat-capacity or phase-change based heat stores;
- Storage in chemical reaction-capable materials (batteries, fuel cells or external deposition of compounds, storing energy for later release through designed processes);
- Further short-term load-levelling devices such as flywheels or capacitors.

The cost of using each of these storage forms vary widely, and several of the options are only feasible in particular consumer segments. The lithium-ion battery for example, has traditionally been used exclusively for consumer products with a very small energy demand (such as watches) – but it is currently climbing up the energy-ladder to products like video cameras, laptop computers and lawn movers, and is ultimately targeting the automobile market (*some of these devices will be highlighted in future issues of the column – ed*).

The disadvantage of energy stores is that they often have to store energy in a form different from its original state, as well as the energy required by the final user. For example, storing electricity in underground hydrogen caverns requires three stages, each with its own operating equipment, at a cost, and with an efficiency of less than 100%:

- Electricity is first turned into hydrogen by alkaline electrolysis, or some other reverse fuel cell principle;
- It is then put into the cavern, excavated at a cost, using pumps, not to mention cooling devices;
- Finally, electricity is regenerated from hydrogen using either some form of *Carnot-engine* (combustion followed by driving, say, a steam turbine and generator) or a fuel cell.

Losses through chains of conversion like the one above are the reason huge efforts are being put into the possibility of altering the way energy is used. One example sees excess wind power stored as hydrogen, and then used directly for vehicles in the transportation sector. This would avoid a scenario where the hydrogen has to be converted back to electricity, and thus avoid a loss which is 50% or more in today's terms – whether you use advanced steam engines or fuel cells.

The cause for this new belief in battery-operated vehicles is that advanced lithium-technology batteries can now finally be built at sizes that lend themselves to consumer vehicles. Like fuel cells, the cost of such batteries is much higher than that of the rest of the car, but there is potential for cost reduction.

Vehicles as storage devices

Looking into the future, several of the technologies mentioned above are at a stage of early development. They are far from ready to enter the market, certainly not if we use today's economic costing methods, nor idealised lifecycle costing (where indirect costs and costs of impacts elsewhere in our society such as environmental or climate costs are all included – usually at some highly-uncertain numerical value).

Take fuel cells for example. They promise higher efficiencies, as well as the ability to operate on fuels such as hydrogen created from renewable sources without pollution. However, they don't currently come cheap. Demonstration fleets of vehicles have been equipped with current state-of-the-art fuel cells costing more than the rest of the vehicle put together. Evidently the costs will go down when (and if) it comes to mass-production, and the efficiency will eventually grow from its current level (30%, not much more) to somewhere closer to a theoretical maximum of about 65%.

But then there is also lifetime costs to consider. Current cells have significant degradation after one or two years and the research goal of the car manufacturers (on record from a time before the current financial problems kicked in) is five years. Consumer cars today have an average lifetime exceeding 15 years, so this would require two or three exchanges of the fuel cell unit in the car. This factor makes the idea of the 'preinstalled fuel cell' in a car prohibitively high in terms of cost. Then add to that the cost of installing the replacements.

Ten years ago, some car manufacturers claimed that there would be a major penetration of fuel cell vehicles by now. But despite many 'programs' and public relations efforts from some manufacturers, this penetration into the mainstream has not materialised. Despite fuel cells moving forward, especially in certain applications (backup power, leisure vehicles, and portable equipment) the consensus in the car industry is that electric vehicles are probably a better alternative; hybrids if the car has a range above around 100 km.

Batteries in vehicles

During the 1970s and 1980s, advanced batteries were the centre of attention, but it was never possible to reach the five-year lifetime of the old lead-acid technology. Therefore, batteries were abandoned for automotive applications during the 1990s, and research centred instead on the fuel cell – and notably the low-temperature proton-exchange membrane cell. This line of research, at first enthusiastic, has slowed down during the last decade or so, for exactly the same reasons as those halting battery development. During the same period, the lifetime of small batteries has improved to around the five-year goal and have also begun to expand in terms of their capacity potential.

Batteries and fuel cells are two very similar technologies, which differ only in that the chemicals capable of producing energy when allowed to interact are stored **within the cell in a battery**, but **outside it in a fuel cell**. In both cases, modern devices have a polymer membrane or electrolyte (with a finite lifetime) and two electrodes (prone to degradation and shrouding by debris deposited on their surfaces).

But the cause for this new belief in battery-operated vehicles is that advanced lithium-technology batteries can now finally be built at sizes that lend themselves to consumer vehicles. Like fuel cells, the cost of such batteries is much higher than that of the rest of the car, but there is potential for cost reduction.

Hybrid the key?

The interesting thing about the two technologies is that they have some complementary properties that make hybrid technologies very promising. Even with the low weight of lithium-ion batteries relative to metal-hydride and lead-acid batteries, the increased energy demand of the additional mass of the batteries begins to be a limiting factor, as ranges above 100 km are contemplated. For fuel cells, the cost increases with nameplate rating, and to match a fossil fuel-powered car in accelerating uphill, even a small car will need some 85 kW of fuel cells (even if the power level averaged over long periods of driving is only 5 kW).

This points to the **battery/fuel cell hybrid** as the ideal solution. The fuel cell could be rated slightly above the average power level and the electric engine could operate on batteries to provide the maximum power output when required. A further advantage is that this hybrid car would be a natural continuation of the **diesel-battery** hybrids likely to gain first place in what many believe will be an oil-constrained future (diesel, not petrol because of the recent breakthrough in diesel engines, making them substantially more efficient than any petrol-driven *Otto* engine).

Energy storage solutions vary widely in their capacity ranges and in the amount of energy that can be stored. The characteristic storage requirements of different renewable energy systems, used to cover some specific type of load, will often point to the type of storage that might be suitable. The vehicle example used above is looking to batteries – and compressed hydrogen containers – as a replacement for present day fossil-fuel containers.

Methanol as a means of getting closer to the current technology was tried in the 1990s, but on-board reformation of methanol-to-hydrogen turned out to be more complex than anticipated. If fuel cell development continues to slow down, then advanced biofuels (so-called **second generation** technologies based only on biomass residues, and no use of direct food crops other than food crop residues) may well take over.

New horizons

Competition to energy storage may come not only from storable biofuels, but also from new ways of arranging the entire energy system. If demand management could change demand profiles that take into account the variations in renewable energy availability, that would solve some of the problem; for example, you put your clothes into the washing machine but it only starts when receiving a signal through the power line that there is available excess wind power (this is fine if the lull doesn't extend for two weeks).

Another target would be the many rechargeable batteries we use in portable equipment. With more standardisation, one could recharge enough batteries during high-wind periods to last for a two-week long lull. However, with present distribution of total demand, the load management is unlikely to alleviate much more than 10% of the intermittency problem that would arise if renewable energy was to take a dominant share in energy supply.

Also, biofuels could not cover much more than half of the energy needs of the transportation sector, even with a substantial efficiency improvement. So what other avenues are available?

The variations in solar and wind energy are not the same at different geographical locations. Solar energy (as well as demands) varies with longitude, and some levelling may be achieved with transmission between time-zones. For wind energy, dispersed location within a region takes care of short-term variations in the production of individual turbines, but long-distance transmission can take care of at least part of the wind production variations, as sites separated by more than 500 km usually experience different weather systems.

Interregional power transmission is already in place in many countries, but they will probably have to be reinforced in capacity (at a known cost) in order to serve as mitigating options for renewable energy intermittency, in addition to the present use of transmission lines (providing peak and emergency power). Any remaining mismatch between supply and demand must be covered by active energy storage. One thing is certain. For any of these ideas to materialise, the entire energy system will need to change substantially over the coming decades.

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