Balancing Costs and Benefits with a Combination of Storage and Generation

Jim McDowall (Saft America Inc, North Haven, Connecticut, U.S.A); jim.mcdowall@saftbatteries.com

Introduction

Bulk energy storage is an attractive concept that is in everyday use around the world, in the form of hydroelectric generating facilities. The storage may simply be water behind a dam or it may be an upper lake or reservoir that is repeatedly replenished by reversing the turbines and pumping water back uphill. The large scale of these facilities, typically hundreds of megawatts or larger, results in a low installed cost per megawatt-hour, with the result that dams and pumped hydro systems have been constructed wherever geologically feasible and environmentally acceptable.

When this concept of bulk storage is scaled down to the level of batteries, however, it is much more difficult to make the numbers add up so that the benefits outweigh the costs. A review of the calculated value of bulk storage in a number of applications shows that the cost of many battery systems would have to be reduced by 70-80% to be economical on a life cycle costing basis. To be sure, some battery technologies offer the long-term prospect of such large cost reductions, but in the meantime the 'viability gap' can only be bridged by subsidizing the systems.

To overcome this problem in the short- to medium-term, storage system developers should concentrate on what battery storage does best. In a power delivery network, batteries can excel at providing continuity and stability of power and also ramping and bridging support for generation; functions that are typically performed over time periods of up to 15 minutes or so. Batteries are much less effective, however, at competing with that same generation for the provision of energy over a period of several hours.

A question of scale

According to the Energy Information Administration[1] pumped storage hydroelectric capacity in the USA amounted to 20.5 GW in 2004, in addition to 77.9 GW of conventional hydroelectric generation. Yet it is increasingly difficult for new projects to be built, since most practical sites have already been developed. There is even now environmental pressure in some locations to remove existing dams so that flooded valleys can be returned to their original state. Nevertheless, pumped hydro sites continue to be developed elsewhere in the world. One example is the Goldisthal installation in Germany, with a rated output of 1.06 GW and maximum stored energy of 8.5 GWh. The huge scale of such an installation results in a low cost of storage, approximating to $90/kWh in 1997 dollars.

Today's largest battery systems, rated in tens of megawatt-hours, are on a much smaller scale and this is reflected in their costs. Even inexpensive lead-acid batteries, which have too many shortcomings for deep daily discharging in bulk storage applications, cost around $200/kWh at the factory gate and their final installed cost with power electronics and balance of plant would be $400/kWh or more. Although the cost of some newer bulk storage battery technologies may come closer to the level of pumped hydro in the longer term, they are currently too expensive to be widely adopted without some sort of subsidies.

The value of storage with renewables

Several studies have been made on the value of electricity storage with renewables. In one study commissioned by the California Energy Commission (CEC) and the US Department of Energy, and reported in the EPRI-DOE Energy Storage Handbook[2], the lifecycle financial benefit over 10 years for 'renewables contractual time-of-production payments' is $655/kW and at least 6 hours of storage would be required to realize this benefit. This figure works out to about $110/kWh, so a project such as the Goldisthal pumped hydro facility could achieve payback within 10 years on this basis.

Another study was presented by the Danish transmission operator Eltra[3]. The large amount of wind generation on the Danish grid can make it difficult to balance the system and it was suggested that this would create an arbitrage opportunity for energy storage on the spot market. It was stated that stored energy of 1,000 MWh, discharging over 20 hours, would have an arbitrage value of approximately DKK 5M per year, or about $0.8M. A further benefit would be found in reduced purchases of regulating power to balance deviations from wind forecasts, amounting to DKK 10M per year, or $1.6M. It was not stated whether both value streams could be realized simultaneously but assuming they were, and applying the same factors as in the CEC study, the lifecycle benefit of the storage would amount to only $18/kWh. It is quite likely that the storage capacity could be reduced, particularly if the discharge time were the same as the 6-hour minimum from the CEC figures. The payback on such a facility might also be improved by rejecting the lower-value arbitrage benefits in favor of the balancing benefits. Even so, the final value would probably be below the CEC figure of $110/kWh.

Another study by the UK Department of Trade and Industry[4] looked at the value of storage with generator intermittency. It concluded that for generation systems with limited flexibility and added wind generation the value of storage, in terms of capitalized fuel cost reductions over 25 years is £470-800/kW. Applying the same factors used by the CEC over a 10-year period (which would be more realistic for the life of a storage device with daily cycling) works out to roughly $90-160/kWh – broadly in line with the CEC figures.

Perhaps more important, though, is a secondary conclusion from the DTI report. It looked at the cost of providing the same reserve functions with open cycle gas turbine (OCGT) plant and found that the value of storage over the use of OCGTs was reduced to £60-120/kW over 25 years. To be sure, the study did not consider other benefits of storage, nor did it assign a value to CO_2 emissions, but this indicates one of the major barriers to widespread acceptance of bulk battery storage in mainland grids – that it is difficult to justify the cost of large battery systems compared to flexible generation.

Ancillary services

In a presentation about the Goldisthal pumped storage hydro installation, Hassenzahl[5] stated that the facility's value for arbitrage was low (which is in agreement with the numbers previously quoted from Eltra), but that the value for ancillary services would result in a 3 to 4-year payback of the project investment. This underlines the high value of these services in the electric power network. The main types of ancillary services are:

- Standing and synchronized (spinning) system reserves
- Black start capability
- Reactive power compensation

System reserves are divided between primary, secondary and tertiary reserves. A recent paper described the obligations for Eltra under the rules of the Union for the Coordination of Transmission of Electricity (UCTE)[6]. Eltra's 2005 obligations are summarized in Table 1 below.

Table 1 – Eltra 2005 reserve obligations under UCTE rules

Reserve type	Power (MW)	Activation time	Duration
Primary	± 32	0-30s	≤ 15 min
Secondary	± 100	30s-minutes	As req'd
Tertiary	+ 520, - 200	15 min	As req'd

It can be seen that fastest-acting primary reserve is also the smallest requirement in power terms. This lends itself very well to the 'instant-on' characteristics of conventional batteries. The power levels for secondary and tertiary reserves are much higher and the duration commitments would be longer. This combination results in ballooning energy requirements, and hence rapidly escalating costs for battery plant. Bearing in mind the results of the DTI study mentioned above, it seems logical to think in terms of battery storage to meet the primary reserve needs, bridging to OCGT plant for the longer-duration reserves.

Due to the relatively fast startup times for OCGT units (compared to combined-cycle gas turbines, for example) this arrangement would mean that the amount of reserve available from spinning turbines could be minimized. The OCGT plant could be used as standing reserves with little or no penalty in the form of increased battery runtime. Reduced spinning reserve would minimize the 10-20% loss of efficiency involved with running part-loaded generators and would yield significant fuel savings.

The benefits of fast-starting short-duration battery power are most pronounced in weak or stressed networks. Such networks are frequently located in remote areas where fuel for generation can be expensive. A prime example of this is the system operated by Golden Valley Electric Association (GVEA), located in Fairbanks, Alaska. The GVEA network is essentially an electrical island, with a single 186-mile intertie to Anchorage in the south and no onward connections to Canada or the lower 48 states. GVEA has heavy imports over the intertie, and one consequence of this is that the loss of a 110 MW generator in Anchorage results in frequency decay of 0.8 Hz/second in Fairbanks. The complete loss of the intertie results in a frequency decay of 7 Hz / second. Because of high fuel costs there have not been enough synchronized reserves to respond to such events, and in fact there is some doubt as to whether such reserves could respond quickly enough to the more extreme events in order to prevent load shedding. This led GVEA ultimately to install its battery energy storage system (BESS), as described in the next section of this paper.

Going beyond the use of battery energy storage for system reserves, the same installations can be used for other ancillary services. Such battery systems generally employ four-quadrant converters so they can supply or absorb reactive power under most conditions of charge or discharge. This reactive power can be used for normal network support or for energizing transmission lines. Battery power can also be used for black-starting gas turbine generators, generally requiring 5-15 minutes of power for starting motors.

Combining storage with generation – the GVEA BESS

The BESS has been in commercial operation for two years, providing a nominal 27 MW to the GVEA network for up to 15 minutes, during which time additional generation can be brought online. The BESS was built by a consortium of ABB and Saft, with ABB providing the converter and balance of plant and Saft providing the pocket-plate nickel-cadmium battery. The system was accepted by GVEA for commercial service in September 2003. GVEA fully implemented the SCADA interface late that year and the BESS has seen frequent service since then. GVEA periodically estimates the number of customer disconnections saved by the BESS and those numbers are summarized in Table 2. Despite being used more frequently than GVEA originally predicted, the BESS maintained an availability level of 99.1% over the first 18 months of operation.

Table 2 – GVEA BESS: customer disconnections saved

Year	**Number of events**	**Disconnections saved**
2003	3	11,122
2004	56	286,598
2005 (to Sep. 15)	31	211,280
Totals	**90**	**509,000**

Although there are seven operating modes for the BESS the bulk of the benefits to date have resulted from three characteristics:

- Power system stabilizer – providing instant response to damp out system oscillations when large loads are turned on or off, or in the event of a generator trip or transmission line fault.
- Spinning reserve characteristic – if system frequency decays beyond a certain limit the BESS responds with active power in a preset pattern.
- VAR support – on a full-time basis the BESS provides reactive power to support the system voltage.

Figure 1 – the GVEA BESS

In normal operation, GVEA dispatchers set the maximum BESS output to a level that the battery can support for 15 minutes, currently around 32 MW (the battery output will degrade over time to the nominal 27 MW level). That time is sufficient for them to fix the original problem or bring up other generation on the system. The battery output is ramped down once the other resources are in place.

In this way GVEA avoided paying much more money for hours of battery runtime. By limiting the battery duty to the functions that cannot be provided by generation they were able to maximize the output power of the BESS and hence its impact on their system.

Renewables in remote systems

The vulnerability of weak grids to disruption is a particular issue when a stochastic generation source such as wind power is added to the network. Miller[7] summarized a report by the National Renewable Energy Laboratory (NREL)[8] on the typical variability of wind farms, and presented the approximations shown in Table 3.

Table 3 – Typical wind farm variability (NREL/Miller)

Control requirement	**Time frame of variation**	**Approx. std. dev. σ (% of wind plant rating)**
Regulation (AGC)	1 s	0.2%
Load following	1 min	1%
Dispatch and commitment	1 hr	10%

As with the data on system reserves in Table 1, balancing needs for short durations can be met with relatively low power levels (assuming the rated power for balancing would be a multiple of the standard deviation). As the time increases, so too does the power level, with the approximate result that an increase of one order of magnitude in time would lead to an increase of two orders of magnitude in the energy required for balancing. This relationship obviously has a serious impact on the size and cost of storage systems intended for long-duration balancing.

It is certainly possible to use flywheels or supercapacitors to smooth out the second-to-second power quality effects of wind farms, and this was the subject of a recent presentation by Mattern[9]. However, this would not reduce the need for synchronized reserves to provide the necessary balancing function for durations longer than a few seconds, and would thus require the ongoing consumption of expensive fuel for those reserves.

That fuel use could be reduced by prolonging the discharge duration of the storage plant, with appropriate adjustments to the power output as already noted. The problem with this approach is that there are diminishing returns as the energy store is increased. This principle was clearly evident in the results of a feasibility study for wind power use in the Galapagos Islands, presented by Krummen[10]. The point of this project was to displace as much of the existing diesel generation as practical using wind power. Various combinations of wind turbines and battery sizes were studied and one of the results is shown graphically in Figure 2.

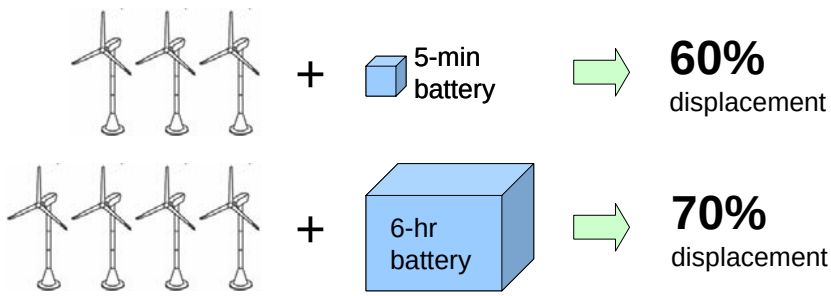

Figure 2 – Displacement of diesel generation with wind power and storage; San Cristobal, Galapagos study

This result clearly shows the reduced returns for larger storage systems. A wind farm with a relatively small battery could achieve 60% displacement of the existing diesel generation, but a 33% increase in wind output and 7,100% increase in battery runtime, with a much higher cost, could only improve this figure to 70% displacement.

The Miller paper[7] described above proposed the use of next-generation OCGT plant to balance the output of wind farms and make the power dispatchable. Such an arrangement could also provide constant loading of transmission lines. The new turbines are highly maneuverable and have better efficiency at part load and lower emissions than their predecessors. They would still produce significant amounts of CO_2, however, thus detracting from the 'greenness' of the wind power.

An alternative solution would be to implement a combination of short-duration storage and the new OCGT plant. From the Galapagos study a battery system with up to 15 minutes of runtime would provide the primary balancing source and would displace a large portion of the OCGT operation and the associated CO_2 emissions. Such a system would clearly cost more than the OCGT plant alone but would be less expensive than a battery-only option. The viability of such a hybrid system would probably depend in part on the existence of a regulatory framework that accounts for CO_2 emissions.

CO_2 emissions

The effective cost of CO_2 emissions varies greatly depending on whether such emissions are simply ignored, are partially regulated, or are fully sequestered. A study on the cost of generating electricity in the UK[11] provides lifecycle costs of generation from various sources and indicates a cost for CO_2 sequestration of £30 per metric ton (approximately $50/ton). This sequestration burden, if fully implemented in a regulatory framework, would

increase the cost of generation from fossil fuels by approximately 50%. Establishing such a framework could be a significant benefit for electricity storage used in conjunction with renewables, since it would establish an additional value stream in favor of storage and against generation.

Having said this, regulations on CO_2 emissions could be a double-edged sword for storage. If bulk storage were charged from coal-fired baseload generation and the energy were released in competition with relatively 'clean' gas-fired combined cycle gas turbines there would be a large net increase in emissions, particularly when the storage efficiency losses are factored in.

Competition for bulk battery storage

Any strategy for implementing bulk energy storage must take its competition into consideration. There are several technologies and programs that compete to a greater or lesser extent with bulk battery storage:

Distributed generation (DG), whether implemented at the local substation or in a so-called microgrid, avoids T&D losses and can therefore offer efficiency gains, especially if generated heat can be captured and used locally. DG provides an alternative to storage for T&D upgrade deferral. (It is worth noting that DG can benefit from operation in conjunction with short-duration storage, since when used alone it cannot provide effective response to rapid load changes or demand spikes.)

Controllable loads often involve an alternative form of storage, such as water heating, ice making, electrolysis and water pumping. Such loads, if controlled in response to the output of renewable generation, could at least partially eliminate the need for battery storage for balancing.

Load control programs, such as the direct control of residential air conditioner compressors now implemented by many utilities, reduce peak loading and provide a means for upgrade deferral.

Demand response programs provide certain industrial users with favorable tariffs in return for supply curtailment on peak power days. Such programs can also defer the need for T&D upgrades.

Roadmap for increased implementation of storage

This paper has outlined a number of opportunities for the use of short-duration battery storage in conjunction with generation. This combination can be significantly more cost-effective than bulk battery storage in the short term. In particular, there are opportunities in weak or stressed grids that can be explored, and the GVEA BESS is an excellent example of this.

Increasing the number of electricity storage installations through such opportunities will increase public awareness of the value of storage and provide potential users with an improved level of comfort with the concept. In turn, this will provide a firm base for market expansion towards bulk battery storage. To achieve that expansion will require a number of steps by the industry and others:

- Achievement of significant reductions in the cost of bulk battery storage
- Market recognition of the true value of ancillary services
- Development of effective arguments for battery storage and against the alternatives
- Implementation of a regulatory framework dealing with CO_2 emissions
- Responsiveness to changing market conditions, especially fuel costs for generation

The most important factor from the above list, of course, is the cost. The extent to which the cost can be reduced will ultimately determine the level of success achieved by bulk battery storage.

References

[1] Energy statistics published at http://eia.doe.gov
[2] *EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications*, report number 1001834, December 2003, Table 2-1, page 2-6
[3] J.K. Jensen, *The Value of Energy Storage in the Western Danish Power System*, presentation at CIGRÉ 2002
[4] DTI publication, *The Future Value of Storage in the UK with Generator Intermittency*, contract number DG/DTI/00040/00/00, URN number 04/1877, 2004
[5] W.V. Hassenzahl, *Pumped Storage Hydroelectric: Yesterday, Today, Tomorrow*, presentation at the 2005 Electricity Storage Association annual meeting
[6] P. Andreasen, P. Eriksen, J. Pedersen, K. Søbrink and A. Price, *Feasibility Study Regarding the Application of Large Batteries to Provide Ancillary Services in a Transmission Grid with a Substantial Amount of Wind Power*, proceedings of the 24th International Power Sources Symposium, 2005
[7] N. Miller, K. Clark, *Hybrid Wind and Advanced Gas Turbine Farms: Firm Dispatchable Power for Weak Grids*, proceedings of the 2005 IEEE Power Engineering Society General Meeting
[8] Y. Wan, D. Bucaneg, *Short-term Power Fluctuation of Large Wind Power Plants*, NREL report NREL/CP-500-30747, January 2002
[9] K. Mattern, *Electronic Shock Absorber – Controlling Power Flow of Wind Farms*, presentation at the 2005 Electricity Storage Association annual meeting
[10] D. Krummen, *Case Study: San Cristobal, Galapagos, Repowering Project*, presentation at the 2004 Electricity Storage Association annual meeting
[11] *The Cost of Generating Electricity – a commentary on a study carried out by PB Power for The Royal Academy of Engineering*, March 2004, available from www.raeng.org.uk