The Costs and Benefits of Electrical Energy Storage

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1 INTRODUCTION

There is currently considerable interest in electrical energy storage technologies, for a variety of reasons. These include changes in the worldwide utility regulatory environment, an ever increasing reliance on electricity in industry, commerce and the home, the growth of renewables, as a major new source of electricity supply, and all combined with ever more stringent environmental requirements. The rapidly accelerating rate of technological development in many of the emerging electrical energy storage systems, together with anticipated unit cost reductions, now makes their practical application look very attractive.

The widespread adoption of renewable energy sources is, in many instances, constrained by the variable and intermittent nature of their output. Their appropriate integration with storage systems will allow for greater market penetration, with associated primary energy and emissions savings. Also, the environmental impact of electricity generation is heavily influenced by the operation of older and less efficient power plant, particularly for peak lopping purposes. The appropriate integration of storage in the electricity network will reduce the need for such plant, with corresponding primary energy and emissions savings.

The market penetration achieved by electrical energy storage systems to date has been heavily constrained by their cost and the limited operational experience, resulting in high associated technical and commercial risk. However, the potential for energy storage is increasingly evident, especially for those companies operating in a competitive electricity market. Scientific advances in combination with a global shift in emphasis towards competitive utility industries has accelerated developments and there are now growing numbers of demonstration projects around the world illustrating the versatility of energy storage.

2 UTILITY APPLICATIONS OF ENERGY STORAGE

Energy storage enables the decoupling of energy supply from energy demand. This is of particular importance to the electricity industry since electricity demand is subject to substantial hourly, daily and seasonal variations. Also, electricity supply, particularly from renewable sources, is also subject to significant variability, both short term (over a few seconds) and longer term (e.g. hourly, daily, seasonal). Here, we examine the particular requirements of energy storage systems for electrical utility networks, identifying applications in the electricity industry where energy storage may be useful. Such applications include:

- spinning reserve
- load levelling
- integration of renewables
- frequency and voltage regulation
- network stability
- asset management
- enhanced quality of supply/power quality
- enhanced overall energy efficiency
- emissions and environmental benefits
- demand-side management
- deferment of new generation, transmission and distribution equipment

The biggest application area for electrical energy storage in utility applications lies within the distribution network. Key applications include:

- quality of supply/power quality
- deferral of capacity/asset management
- integration with renewables/embedded generation

2.1 Quality of Supply/Power Quality

A loss of electricity supply can cause costly interruptions in production for commercial and industrial customers. An energy storage system can increase power reliability by providing the power demand during such a supply outage. In the event of a fault, the energy storage system would automatically disconnect the customer's building from the supply network and provide all of the power required to maintain normal operations. The system would need to provide utility-grade power almost instantaneously (i.e. within one mains cycle).

The complete loss of electricity supply is thankfully quite a rare event for the vast majority of customers and so mitigation measures against such events can normally only be justified in special circumstances (i.e. a very valuable/sensitive production process or a particularly poor-performing area of supply network). However, there is growing awareness of the effect of power quality phenomena such as voltage dips. Voltage dips occur much more frequently than complete supply outages, with many tens of events occuring per year in some areas. Commercial and industrial customers, especially those with continuous automated production processes, often operate sensitive electronic systems that cannot tolerate voltage sags. The duration of a power sag may only be a few cycles (i.e. fractions of a second) but its effects can be costly. Microcontrollers on assembly lines and computers shut down and production and data processing suffer.

To cope with a complete supply interruption, an energy storage system would have a typical power rating measured in megawatts and an energy rating measured in megawatt-hours for a moderately sized industrial or commercial customer. The power rating would be slightly less for a power quality application, since some power is still available from the utility supply during a voltage dip. Also, the energy storage requirement is much less in a power quality system for voltage dip mitigation, since the duration of a voltage dip is rarely more than a few seconds.

2.2 Capacity Deferral/Asset Management

As load demand approaches the capacity of the network, utilities need to add new lines and transformers. To allow for future growth, utilities install facilities that exceed existing load demands. Therefore, utilities under-utilise expensive distribution facilities during the first few years of service. Energy storage systems can be used to help the existing assets meet the growth in demand until such time as the level of demand fully justifies an upgrade of the existing facilities.

An energy storage system to defer installation of new distribution capacity requires power measured in megawatts and sufficient storage capacity to provide rated power for typically 1 to 3 hours. In a typical distribution facility, the energy storage system would operate about 30 times per year. The system would operate most frequently during daily high-load periods that occur during seasonal peaks.

2.3 Renewable Applications

Energy storage systems have several potential applications for renewable systems. For example, an energy storage system can help to deliver renewable energy at times when it is most needed. Energy is stored when the renewable energy system produces power and and the energy storage system is discharged at times of peak demand, when the rate for energy is highest, which therefore gives the renewable energy a greater economic value.

Another example is the "firming up" of renewable energy sources, by increasing the predictability of future availability (generator output). This is important because electricity suppliers must be able to guarantee the amount of power they have available for their customers. Thus, energy storage makes variable renewable sources more viable, and adds to their economic value.

A typical energy storage system used for the integration of renewable energy sources would require megawatts of power, with storage capacity in the 2 to 4 hour range. The energy storage system would typically go through a discharge/charge cycle once or twice a day, mainly during weekday peaks/troughs.

3 STORAGE TECHNOLOGIES FOR UTILITY APPLICATIONS

Many storage technologies have been considered in the context of utility-scale energy storage. These include:

- Pumped Hydro
- Batteries (including conventional and advanced technologies)
- Superconducting magnetic energy storage (SMES)
- Flywheels
- Fuel Cell/Electrolyser Systems
- Conventional Capacitors
- Supercapacitors/Ultracapacitors

Considering storage technologies and systems for electrical energy storage, four systems have emerged as true contenders for utility-scale electrical energy storage applications in the short to medium term. These systems are:

- Batteries
- SMES
- Flywheels
- Capacitors

Each technology has its own particular strengths and operational characteristics.

3.1 Battery Energy Storage

Battery technology includes lead-acid, advanced lead-acid and advanced battery (i.e. zinc bromine, sodium sulphur, vanadium, etc.) technologies. Conventional lead acid is the most proven technology, but has the lowest performance quotient. However, with good battery management and a well optimised operational regime, these systems have been shown to be financially viable in some applications. Not all batteries are the same and so care should be taken in the application requirement specification to ensure that the requirements placed on the battery storage media are well matched to the battery performance. Parameters involved in the battery specification include the number of anticipated discharges, depth of discharge, rate of discharge, rate of recharge, system lifetime, etc. The main drawbacks with battery systems are the low power and energy densities, which may be a problem if the available space is limited. The advanced battery technologies offer improved power and energy densities, but do not have such a proven track record. Also, advanced battery technologies are currently more expensive, but as the volume of sales increases, the costs will fall. The zinc bromine battery is a good example of an advanced battery where the manufacturing process is inherently low cost and so volume manufacture will bring the cost of these batteries down considerably in the future.

The flexibility of batteries is illustrated in the range of applications for which they have been used, from the 10MW/40MWh CHINO installation to the sub-KW/kWh UPS systems available for computer applications. For the larger battery systems, typical power-to-energy ratings result in a storage requirement from ½ hour to 4 hours. The upper limit of 4 hours is set typically by the cost of conventional generation, whilst the lower limit is set by the discharge characteristics of the battery (the faster the energy is extracted, the more batteries are required, and hence the cost increases).

A battery storage system which is currently generating a lot of interest "regenerative flow-cell" battery storage system. A regenerative fuel cell electrochemical system is coupled to dual liquid electrolytes contained in separate storage tanks to create an electric circuit. An important feature is that the power rating is governed by the size of the cell, whilst the energy rating is governed by the size of the electrolyte tanks.

3.2 Superconducting Magnetic Energy Storage

By comparison, SMES technology is generally still in the research and development phase, with currently one commercially available product (the American Superconductor SSD device). Other laboratory scale demonstrators are currently being evaluated for power quality applications. Superconducting technology can be neatly divided into low temperature superconductivity (LTS) and high temperature superconductivity (HTS). The main distinctions here are that superconducting wire can currently only be made out of LTS. It is easier to make coils (a key component in a SMES device) out of LTS wire than it is out of HTS ceramics. The cryogenic overheads and extra design complexities count against LTS systems, but HTS ceramics are currently very expensive. At the moment, most applications-based research uses LTS, due to the greater flexibility of the material, whilst most technology-based research is based on HTS materials to produce a cheaper material and in wire form. The ultimate goal is to achieve the implementation of the systems first developed using LTS material in HTS material, reducing both raw material and cryogenic costs.

The high cost of energy storage using SMES means that SMES is currently restricted to high-value/low-energy-requirement uses, such as quality of supply and power quality applications. Two of the main advantages of SMES is that the energy can be transferred very quickly (limited normally by the cost of the power conversion components) and unlike batteries, the number of charge/discharge cycles is virtually unlimited. SMES is thus most suitable where the storage requirement is for less than a few seconds, with power requirements up to 1 or 2 MW.

3.3 Flywheel Energy Storage

Flywheels are emerging as a viable technical option, sitting between batteries and SMES in terms of power/energy ratio. This makes flywheels most attractive in applications which require energy storage in the 5 second to 5 minute range. Modern high speed flywheels are made of composite materials and exhibit high rotational speeds typically in the range 20,000 to 60,000 rpm. For example,the composite flywheel design from Urenco is for a 100kW/3kWh unit, which can be paralleled to achieve higher power and energy ratings. The feasibility of using flywheels for utility network applications looks promising, but has yet to be proven in a full-scale demonstration programme.

3.4 Capacitor Energy Storage

Capacitors are an option for power quality applications where the energy requirement is not large. An example of a commercially available product is the Westinghouse DVR, which is rated at 2MVA, with 400kJ of energy storage.

4 MODELLING THE COST/BENEFITS

There are many energy storage technologies currently available which can be used in a variety of energy storage applications. Therefore, identifying the storage technology which best matches the application requirements can be a difficult task. Each storage technology has particular characteristics which makes it suitable in some situations, but less desirable in others. It is important to identify the key features of different storage media and to match the storage technologies with the most appropriate end-use applications (including the realisation of multiple-application systems) in order to achieve an optimum cost-benefit solution. A techno-economic cost/benefit model has been developed to aid the assessment process, based on simple spreadsheet models. The model calculates a cost-benefit ratio based on a standard "net present value" calculation.

The model allows a first-pass economic assessment of energy storage systems as applied to various utility network applications and is intended for use as a screening tool to identify those application/technology matches which merit more detailed investigation.

The storage system costs are broken down into:

- storage media cost (as a function of cost per kWh)
- power conditioning unit (as a function of cost/kW)
- balance of plant (as a function of cost/kW)

Whilst the determination of systems costs can be carried out reasonably accurately, quantifying the value of the benefits accrued is much more difficult, since the benefits are often less tangible, separable or attributable. However, it is possible to make sufficiently accurate estimates for the purpose of identifying the most promising applications/technology matches.

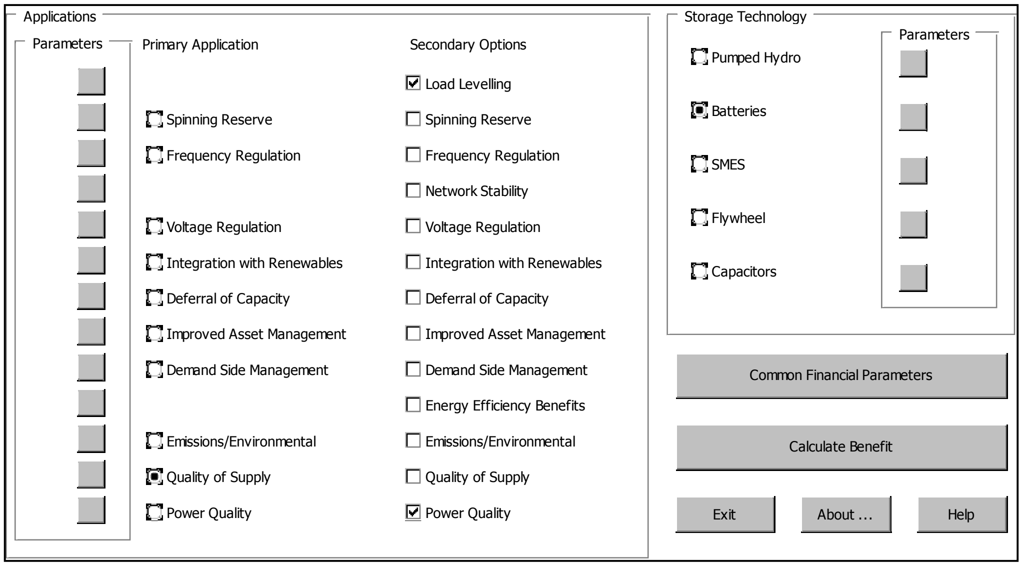

Figure 1: Cost-Benefit Model Data Entry Interface

The Cost-Benefit Model data entry interface can be seen in figure 1. The model is applications-driven, which means that a primary application is selected first. At this point, initial estimates are made for the likely system size. An energy storage technology can then be selected and the system cost is calculated based on system size and storage media. The model output shows how the benefit-to-cost ratio varies with system lifetime, based on initial purchase price, ongoing operating and maintenance costs and annual benefit (i.e. income) predictions. An example of a cost-benefit calculation before and after system optimisation is shown in figure 2.

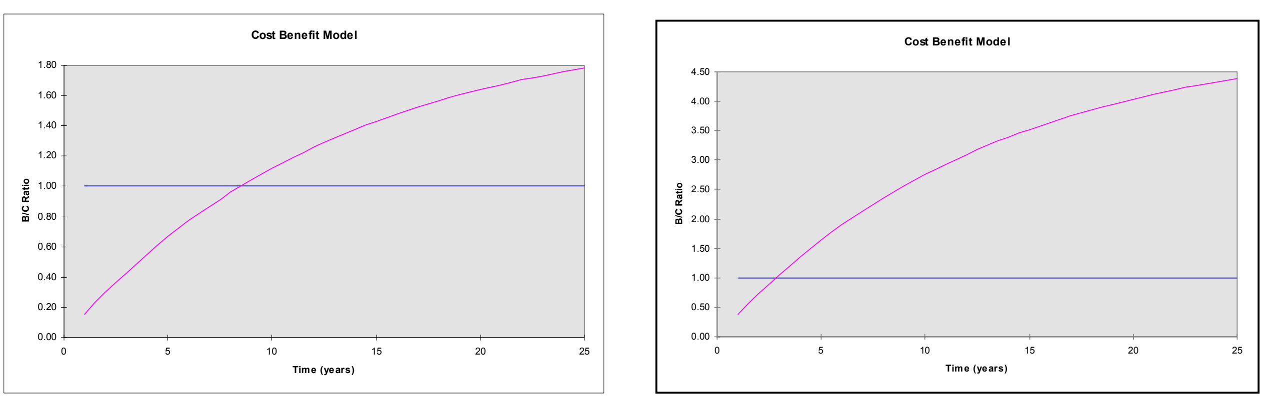

Figure 2: Preliminary cost-benefit analysis of an energy storage system and subsequent optimisation

The cost-benefit model makes it possible to compare the cost-benefits achievable with different storage system technologies. In addition, it is also possible to add in the additional benefits that could be accrued by so-called "secondary" benefits.

5 CONCLUSIONS

There are several application/technology matches that are worthy of consideration in utility-scale energy storage systems. Power quality applications tend to show the highest cost-benefit quotient, principally because the "energy storage" requirement is relatively low. Since the amount of stored energy required is relatively low, the power conversion and interface equipment start to become the dominant cost elements, based on power ratings rather than energy. Thus, systems for power quality applications have been realised using many different storage media (i.e. batteries, SMES, flywheels, capacitors).

Where energy storage is needed for hours rather than seconds then the choice of storage media is greatly reduced. To date, electrical energy storage systems needing multi-megawatt/mult-megawatt-hour ratings have only been implemented using lead acid or sodium sulphur-based batteries. Energy storage systems based on lead-acid batteries have been shown to perform well in previous demonstration projects, as long as the correct type of lead-acid battery is used and good battery management is carried out. However, they are probably only commercially viable in high value applications, due to the high cost per kWh. This illustrates the importance of optimal system design, to achieve the maximum benefits from the minimum amount of necessary energy storage. However, developments in new battery technologies, especially flow cell battery technologies, which are able to decouple the system power and energy ratings by design, show great potential in applications requiring significant energy storage.

Another important concept is that of designing the system control functions in a way which can permit the realisation of "multiple benefits" from a single storage system, i.e. a system that has been configured to match several different applications concurrently. An obvious important consideration here is to ensure that the target applications do not impose mutually exclusive demands on the storage system and when conflicting demands are placed on the system that the highest priority need is met.

The role that energy storage can play in the integration of new and renewable enegy sources is now starting to be recognised. A new initiative is just about to be launched within the International Energy Agency to develop knowledge and understanding in this area and those interested in this subject are encouraged to become involved in the collaborative studies.

ACKNOWLEDGMENTS

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Further information on energy storage is available at:
www.cevre.cu.edu.tr/eces/, and www.eatechnology.com/utilities_business/storage.cfm

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