Electrical Energy Storage - Technical Progress and Commercialisation

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1. Introduction

The EESAT conference series started in 1998, overlapping with the series of Utility Battery Conferences dealing with the large scale applications of electrical energy storage with particular reference to power systems. The EESAT conference was a follow-on activity to the work of the IEA implementing agreement on electrical energy storage which ran from 1995 until 1999.[[1]] . The IEA activity was to raise the profile of storage and help expand its use in the power industry. Although during the EESAT conference series several new technologies and applications have been proposed progress has been variable, almost to the point of disappointing, for many technical, commercial and organisational reasons. Nevertheless, the attitudes towards electricity storage have been quite different in different parts of the world and have changed over time. During the past ten or eleven years the drive towards sustainability and emission reduction has changed substantially, in the commercial world, the technology boom of 1999-2000 led to a brief increase in interest in the sector followed by a sharp decline. Now interest is growing again based on the need for energy security and financial stability.

There is anecdotal commentary that progress in development of advanced electrical energy storage has been slow. This paper uses contemporary information to identify key themes, and assess performance and to indicate areas for future attention.

2. The status of electrical energy storage in 1998

In 1998, although pumped hydro was widespread, other technologies were still in their early stages of deployment. Apart from power quality applications, there were few electrical energy storage installations larger than 1 MW.[[2]] Despite this, a market research report published in 1997 proposed that there should additions of 573 MW of battery energy storage installed in the USA by 2010.[[3]] It is clear that this target will not be reached. In Japan, there was a prediction that the requirement for energy storage should be between 10 and 15% of installed generation capacity.[[4]]. We note that this analysis excludes storage technologies such as ice storage or other thermal devices and that many thermal storage projects have been developed representing a significant equivalent storage capacity based on the deferred demand[5]. We have excluded this from the analysis as there is not a formal recovery into electricity at the end of the storage cycle. Pumped hydro has also been excluded on grounds of brevity rather than the status of technology development.

3. Learning rates

It is well known that development of new technologies can be a slow and expensive process, the energy sector is no exception with learning rates which are dependent on technology cost and scale of deployment.[[6]]

In some energy sectors, such as wind turbines or solar PV for example, it would be relatively easy to develop a curve showing the relationship between the break even capacity - that is the capacity addition necessary to drive the cost down to a competitive level, and the technology maturing costs, that is the investment costs needed to make the investment against an expecting learning rate. Wind power development has been estimated to have a learning rate of 30%, with PV at 18 - 20 %. The results of these high learning rates on the penetration of these industries is self evident. In 1995 the diameter of the largest wind turbine was 50 m, in 2005 it was 125 m. Wind and PV are applications in their own right, viewed as self standing green technologies, often heavily supported by tariffs or renewable obligations leading to favourable project economics.

Electricity storage is not a single technology, with many separate technology groups so the industry's performance can be assessed either as a group or in individual sectors. In seeking to deploy more electricity storage we should examine separate technologies, establish the starting point and current position and identify the factors that have contributed to progress or inhibited successful deployment. This paper takes both an overview and gives a snapshot of some parts of this industry. High learning rates have taken the wind and solar industries through revolution. The energy storage industry, in some sectors is still in the early stages of evolution because of the slow uptake and low rates of return offered by energy storage projects in comparison to other sectors.

4. The Beginning – a Review of EESAT 98

We reviewed past EESAT papers as an approximate indicator of the state of the art at the time. While this might not be precise, it offers insight based more on commercial status and intent, as opposed to strict technical development. We can track various companies and the underlying development across this period. We recognise that inclusion in the EESAT conference is a combination of self-selection and selection by the conference organisers so this analysis should not be considered to be rigorous and defensible. The purpose however is to look at the overall status and assess common factors in the development of electrical energy storage.

At EESAT 1998, 54 papers were presented. Fifteen of those came from developers of various storage technologies, including eight from battery developers, four from flywheel developers, two from SMES manufacturers and one on hydrogen. More theoretical studies came from research and academic institutions who presented papers on concepts such as seasonal storage using chemically bound hydrogen[.7]

Table 1 summarises the contributions by developers[8] over the conference series. Data for 2009 is provisional.

Table 1 – Analysis of Developer Papers at EESAT from 1998 – 2009

Technology	**1998**	**2000**	**2002**	**2003**	**2005**	**2007**	**2009**
Batteries	8	11	8	10	3	5	*10*
Flywheels	4	5	5	6	5	4	*3*
Hydrogen	1						
Supercapacitors		1	1	2	1		
SMES	2	1					
CAES			1	5	5	2	*2*

There were a range of other papers submitted by individuals, companies who were users of storage and Research and Academic Institutions. In this review theoretical papers proposing new technologies in advance of practical work have not been included in this analysis such as seasonal storage using hydrogen. [9]

Although papers on hydrogen based systems[10], appeared at the 1998 conference they have not been considered at other EESAT conferences as the hydrogen and fuel cell community is well represented by other conference series, and is covered by a separate US DOE Program.

5. Review of technologies

5.1 Compressed Air Energy Storage

In contrast to recent EESATs, no papers were presented on compressed air at EESAT 1998; but, papers on CAES appeared in subsequent conferences and reached their zenith in 2003 and 2005, with five papers presented at each conference. The number of CAES papers decreased in 2007; but, by that time, the interest in CAES was commercial, as opposed to technical. The CAES community includes companies with longevity. Their patience is necessary, as although there have been many studies and reports, we have still not seen any new plants other than those usually described in papers on CAES[[11]] developed since last century. Latest estimates for the commissioning of large or small scale CAES are in the 2012 timeframe, nearly 20 years after the last plant was commissioned in the USA.

5.2 Superconducting Magnetic Electricity Storage and capacitors / super capacitors

Superconducting magnetic electricity storage was covered at the 1998 and 2000 events; but its use as an energy storage system has been much less successful than had been anticipated. SMES is no longer being pursued as such, although one company is still operating successfully in the deployment of both superconducting materials and advances in system integration with renewable energy. However superconducting technology has re-emerged as a supporting technology for flywheel development.

In contrast, the use of capacitors and super capacitors, which were relatively novel in 1998, has been well reported, especially in 2003 and 2005.

5.3. Flywheels - Kinetic Energy Storage Systems

Over the past 10, years, flywheel development has been reported on by 16 companies. Some flywheel development companies have withdrawn from the market altogether; while others are still in existence. Individual flywheel developers have not necessarily presented papers at each conference and so it is not appropriate to use the number of papers as an indication of success for specific companies. Developments in high temperature, superconducting bearings[[12]] are regular presentations, illustrating the long lead times required to bring a technology to commercialisation. The deployment of flywheels offers a good example of progress and the steps needed to achieve success. Some companies have withdrawn from the market altogether (Urenco), others, such as; Pentadyne, Trinity, Beacon and Vycon are still in existence. Other projects such as Boeing continue to report each year on improvements and developments to their system, but this only illustrates the long lead times needed to bring a technology to commercialisation

5.4 Batteries

Throughout the EESAT series, batteries have been the main technology focus. The interest has been divided among the several battery types. There have also been a number of papers which have dealt with general battery issues, rather than focussing on an individual technology, as well as papers dealing with systems integration and commercial optimisation.

5.4.1 Lithium batteries

Lithium battery technology was first reported on by CRIEPI of Japan. CRIEPI had begun R & D on lithium batteries for load levelling in 1984; they presented a status report at EESAT 1998.[[13]] Many papers by others at subsequent EESAT, ESA meetings and other conferences followed that introduction. Now the technology is widespread with many companies actively pursuing this technology. Recent presentations at ESA meetings have reported on the installation of many MW-sized lithium batteries. This has been one of the success areas as a number of developers have been able to scale up from small size installations towards the MW ratings demanded by utility applications. This has been possible because the battery technology is relatively scalable.

5.4.2 Flow Batteries

The EESAT conference series has provided an excellent opportunity for flow battery developers and users to meet and discuss their developments. The two prevalent battery types, vanadium and zinc bromine, were well known at the time of EESAT 98, they have been joined by a number of other developers and flow battery chemistries since then. The development of flow batteries has oscillated with degrees of progress, commercial interest and the occasional session of corporate re-structuring. The vanadium system had already been demonstrated in Japan prior to the 98 conference and was reported then[14], but although the technical concept has remained the same, none of the original developers are still in existence. (Clearly developers and potential developers should not under-estimate the technical progress and commercial tenacity necessary for successful development of a new technology). Some of the developers have ceased trading, or been the subject of corporate takeover. Meanwhile other companies have started development. One developer of the vanadium system who did not present at the 1998 meeting, but sent representatives is still operating commercially.

The cerium range of flow batteries was announced at the 2002 meeting,[15] although this has not been the success that was proposed at that time. The polysulphide system was publicised during 1999 and proposals for a large scale development were discussed at the 2000 meeting[16] with further updates in subsequent meetings[17], until the project was closed at the end of 2003.

In contrast, the Zinc Bromine industry has maintained a consistent profile, demonstrating the need for taking a very long term approach and being able to 'ride out' difficult times. Two manufacturers were present ten years ago, and one company remains in business, the other is now operating under a different name and ownership.

5.4.3 Nickel Cadmium

The nickel cadmium battery was reported at the 1998 meeting (and again at the 1999 Utility Battery Group meeting) but it was with the development of the Golden Valley project that the NiCd battery was able to gain further prestige as the holder of the title of the world's most powerful battery.

5.4.4 High Temperature Batteries

The sodium sulphur battery had already been tested in Japan in 1998, but it took a further five or six years for the technology to become deployed outside Japan. It is now widespread. The initial paper was presented by the Tokyo Power Company [18], who were co-developers of the technology. The technology or its applications has been covered at every EESAT meeting, either by the developer, or by a host utility. It is notable that the sodium nickel chloride battery has not been considered at EESAT meetings, as its development has been aimed at the EV and small scale stationary market, but recent announcements indicate that large scale manufacturing of this product will commence soon, perhaps making this eligible for large scale utility applications.

5.4.5 Lead Acid Batteries

Although lead acid batteries are seen by many to be a 'historic' technology, constant development has ensured that new concepts have been discussed at every conference. Lead acid batteries are probably still the most prevalent in existence today and with a broad manufacturing base will remain a significant technology. The role of the US Department of Energy in supporting research programmes in this, and other technologies should be recorded, and the ongoing success of this sector indicates the benefits of support from the Energy Storage Program of the US DOE.

5.4.6 Other batteries

The Ultra battery, from CSIRO Energy Australia, will be presented at EESAT 2009.

6. Observations on the electricity storage industry

In 1998, commercialisation concentrated on high value and niche applications; in particular, power quality and uninterruptible power. The integration of storage on substations was in its infancy at that time, but it is now a widespread application for battery storage installations. Hybrid storage and generation projects[19] are now a regular part of the EESAT series.[[20]]

The environmental drivers prevalent today were only just emerging in 1998, as suggested by a paper on the storage potential in Japan,[[21]] which raised the impact of CO_2 emissions. The renewable energy drive had hardly begun, although papers such as Ruddell (1998) [[22]] and [[23]] have been seminal in demonstrating what can be achieved by operating storage as an integral part of modern networks. This paper was probably ahead of its time: despite the paper's intention of supporting the development of flywheel storage it is still a useful reference document for future authors on the linkage between storage and renewable energy.

The question posed by this analysis is whether sufficient technical and commercial progress in the development of electrical energy storage systems has been made over the past ten or so years. By the measure of achieving widespread deployment and substantial market share, the industry has not achieved success. We can acknowledge the growth in UPS and power quality devices, but the goal of using electricity energy storage to improve the use of distribution assets, optimise the use of variable renewable generation in hybrid systems and to deploy large systems for the provision of reserves and ancillary services has made only limited progress.

Clearly the slow deployment of storage technologies can be attributed to both technical matters as well as commercial issues. In some instances, the technology is not the rate limiting step. For example, compressed air technology uses mature systems, but project developers refer to delays in approvals and project financing as inhibitors to progress. Flow battery development has been subject to technical delays in scale-up, but the major inhibitor to progress seems to have been commercial, with companies seeking to finance manufacturing, project development and sales with only limited resources.

However, this simple model does not explain the overall low level of investment in utility applications of electrical energy storage. Only a few utilities have adopted advanced electrical energy storage, and even then, only as relatively small investments. The business case is not necessarily overwhelming, and the quest by manufacturers to increase sales in order to increase manufacturing and so lower costs presents a nearly unbreakable circle to market introduction. The text book marketing answers to this problem are to seek early adopters and niche applications which can command high value. However the utility industry is not well known for early adoption, and the ability of developers to extract high value is dis-incentivised because of the disaggregation of the power industry, meaning that it is difficult or impossible to aggregate income streams from different sectors of the industry.

7. Electricity Storage Industry Successes 1998 – 2009.

From the many companies and technologies represented at the beginning of the EESAT series and this year's conference we have selected three as examples of longevity and success in the industry. Naturally there are other companies that might be included in this list, but space does not permit a full report on all of them.

ZBB Energy Corporation and NGK Insulators Ltd were represented at EESAT 1998 and are represented at EESAT 2009. A third company, Beacon Power, which presented first in 2002 is included in this analysis.

ZBB Energy is one of the developers of the zinc bromine flow battery and providers of energy storage solutions. The company now produces and markets small and mid size containerised energy storage modules , complete with power conversion system for grid connected applications, and an alternative configuration for the direct integration of renewable and traditional energy sources. The energy storage modules can be grouped together to form a larger system. For many years, ZBB had promoted its battery system as part of an integrated package, thereby simplifying its product offering to potential customers, and emphasising its transportability and modularity as a key feature. The company has been fortunate to have received support from the US Department of Energy and has been provided with funds to support demonstration projects with various utility companies. Since successful completion of the demonstration projects, ZBB has now moved to commercial production and has been deploying energy storage system solutions for various on and off grid applications.

NGK is the developer of the sodium sulphur battery system. This product has been under development by NGK since the early 1990's. It was extensively tested in Japan before it was launched commercially in 2003. The company focussed initially on peak shaving applications in Japan. Its early applications in the USA were for peak shaving on utility transformer substations. Projects in Japan supported by Japanese Government agencies were used to demonstrate the battery's applications with renewable energy and NGK has followed this with overseas sales for similar applications. The support of the US Doeepartment of Energy working with American power companies to deploy MW size projects has given support not only to this company, but also raised the profile of how electrical energy storage fits into the strategy for the development of the power network. Future marketing by NGK will be expanded into the operation of smart grids and deployment for ancillary services.

Beacon has developed a flywheel energy storage system which can be used for frequency regulation on power grids. Following two demonstration programmes, partially supported by the US Department of Energy, which validated the concept, Beacon built and is now operating MW size installations in ISO New England under a pilot programme. The company intends to produce, develop, own and operate two large scale 20 MW flywheel systems one in New York State, and one in the PJM Interconnection
From these three examples of technology companies actively involved in electricity energy storage we observe a number of important metrics in the development of energy storage products

a) Product definition. Each company has identified market attributes which their product meets, for ZBB this is system integration and transportability, for NGK it is large scale power and energy, for Beacon it is frequency regulation in the ancillary services market.

b) Technical demonstration and performance.

c) Support from government or government agencies, especially for demonstration

d) A favourable home base for early deployment and verification

e) An ability to address the market. ZBB have developed a transportable system which makes reduces installation time for their utility and end user customers. NGK commercialisation developed from a close association with the Tokyo Electric Power Company, and was then directed towards other similar utility companies. In Beacon's case this has been by redefining the market and creating a new business proposition.

7 Concluding Observations

Successful developments have been made by companies that have taken a long view, developed a secure home base for their products, often with local or national support, and addressed a specific market sector; if necessary, redefining the market structure in order that their products can be deployed. Today, there are more companies involved in technical and commercial development of storage than in 1998; but, unless there is a step change in the deployment of storage, the learning rate for the technology will remain low. Our responsibilities to provide energy supplies that are secure, sustainable and affordable mean that the role of storage is certain to increase.

An objective of the EESAT conference was to raise awareness of and promote electrical energy storage. Undoubtedly the series has achieved this. Promotion of concepts does not lead to successful deployment – there must be a union of technical and commercial activity which meets a market or societal need. The successes of energy storage have been achieved by those developers who have been able to survive the long development periods needed for testing, demonstration and deployment.

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