



**Report**

**IEA Implementing Agreement on Energy  
Conservation through Energy Storage**

**Electrical Energy Storage Technologies for Utility  
Network Optimisation**

**Annex IX (Phase 2)  
Operating Agent's Final Progress Report**

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Report No: 5290

Project No: A4205

July 2000

**"adding value by developing and deploying innovative technologies"**

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## **Electrical Energy Storage Technologies for Utility Network Optimisation**

### **Annex IX (Phase 2) Operating Agent's Final Report July 2000**

by

Dr Alan Collinson

## **Summary**

This final report has been prepared for the Executive Committee of the IEA ECES Implementing Agreement and is intended to provide an executive overview of Annex IX. The Annex IX (Phase 2) project is now successfully completed. The project has produced several useful reports, including a case study report of energy storage systems and a project definition report, which defines the framework for two potential demonstration projects (one for a power quality application and one for a utility-scale bulk storage project). A computer model for evaluating power quality applications has been developed and a requirement specification has been produced for the definition of a network applications model. General awareness of energy storage has been raised through the production of additional promotional material, including the Annex IX publicity brochure, two Annex IX newsletters and two “how-to” guides (one looking at the application of energy storage to power quality problems and the other looking at utility-scale energy storage). Use has also been made of the internet, with a dedicated Annex IX web site, operated by one of the annex participants. Annex IX participants will use the EESAT 2000 conference in September 2000 as a further opportunity to disseminate information related to electrical energy storage technologies and applications.

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# 1 Introduction

This final report has been prepared for the Executive Committee of the International Energy Agency (IEA) Implementing Agreement on Energy Conservation through Energy Storage (ECES) and is intended to provide an executive overview of the Annex IX project entitled “*Electrical Energy Storage Technologies for Utility Network Optimisation*”. The report is prepared for formal presentation to the 49th Executive Committee meeting, to be held at the CRIEPI offices, Tokyo, Japan, 6/7/8th November 2000.

## 2 Annex IX Phase 2 - National Participants

The participants in Annex IX Phase 2 included the following countries:

- Canada
- Finland
- Germany
- Netherlands
- Spain
- Sweden
- United Kingdom
- United States

The **Canadian** utility, **Hydro Quebec**, discharged the role of Canadian participating agent. Unfortunately, Hydro Quebec had to withdraw from the project halfway through due to pressures of other work.

**Finland's** formal participation was funded by **Tekes** (the National Technology Agency) and was implemented through the **Helsinki University of Technology (HUT)**, with a National Team, including representatives from the power utility **Fortum** and the Technical University and governmental laboratory, **VTT Energy**.

**Germany's** formal participation was through **EUS**, with support from their National Team, which included the electronics companies of **Siemens** and **ABB**, the German utilities **RWE**, **PreussenElectra** and **EVB**, as well as storage technology companies such as **Piller**, **Magnet Motor** and **Hagen Batterie**.

The **Netherlands** Agency for Energy and the Environment, **NOVEM**, provided the Dutch contribution towards the Operating Agent budget and **KEMA T&D** discharged the role of the Netherlands Participating Agent.

**Spain's** formal participation was through the utility company of **Iberdrola**.

**Sweden's** formal participation was through the offices of **Elforsk**, the R&D company of the Swedish power utilities, who co-ordinated the Swedish National Team.

**EA Technology** took the role of UK Participating Agent, representing the UK National Team, which included **First Hydro, Rolls Royce, National Power, Eastern Electricity, Urenco, London Underground** and **Railtrack**.

The **Department of Energy (DoE)** and the International Lead Zinc Research Organisation, **ILZRO**, provided the US contribution towards the Operating Agent budget, whilst **Sandia National Laboratories** performed the role of the designated US Participating Agent. In addition, the **Energy Storage Association (ESA)**, formed a very effective interface with the predominant utility and industry groupings, which included **Texas Utilities, Southern Company, Commonwealth Edison, Pacific Gas & Electric, Georgia Power, Omnion, American Superconductor** and **GNB Technologies**.

### 3 Work Programme

The Annex IX Work Programme consisted of the following subtasks [1]:

- Subtask 1: Applications Case Studies
- Subtask 2: Project Definitions
- Subtask 3: Applications Modelling
- Subtask 4: Information Collation & Dissemination
- Subtask 5: Complementary R&D Programmes
- Subtask 6: Project Management

#### 3.1 Subtask 1: Applications Case Studies

Task complete. The applications case studies report [8] presents a selection of case studies on the applications of electrical energy storage. The focus of the report is on storage systems as the solution to a particular problem, and is aimed at potential users who may be relatively unfamiliar with the field. A set of pre-existing electrical energy storage installations is described from the perspective of end-user application, as distinct from the particular storage technology employed.

#### 3.2 Subtask 2: Project Definitions

Task complete. The Project Definition report [9] focuses on two energy storage applications, namely a power quality project and a primary sub-station project. The Project Definition report presents a cost breakdown for the various electrical energy storage system solutions currently available. Generic information is provided as far possible, without concentrating on any single suppliers' solutions, or any particular site. It is intended that the data presented in the report will assist those interested in preparing for future proposals to funding bodies for support in developing storage as a viable option in electricity network applications.

#### 3.3 Subtask 3: Applications Modelling

Task complete. This task was split into two main activities:

- general specification for an energy storage network applications model
- software tool for modelling the application of energy storage to power quality problems

### **3.3.1 Energy Storage Network Applications Model Specification**

Modelling is the key to quantifying the realisable benefits of an energy storage system as part of an integrated network. The purpose of the software specification [10] is to allow developers of distribution network models to create an integrated network applications model to suit the needs of the particular software package being used. The model specification covers the applications of distribution capacity deferrals, peak shaving, frequency regulation, spinning reserve and stability. The specification was written in accordance with the IEEE Recommended practice for software requirement specification (IEEE Std 830-1993).

### **3.3.2 Model for the Application of Energy Storage to Power Quality**

The purpose of the power quality application model [11] is to help the user to optimise the design of an energy storage system to meet the needs and requirements placed on it. The model uses a benefit/cost calculation to give the optimum system scaling for a given set of parameters. The model consists of a stand alone executable file written in Borland Delphi (32 bit) for use with MS Windows 95/NT/98 or above. It is intended that the model be used by system designers to help make the decision as to whether energy storage is viable, which storage technology is best suited and to define the optimal system scaling in terms of power and energy requirements in a particular case.

## **3.4 Subtask 4: Collation and Dissemination of Information**

Task complete. Key features of this activity included:

- Reports
- Newsletters and “How-to” Guides
- Web Site
- EESAT 2000

### **3.4.1 Annex IX Reports**

In addition to the subtask reports for subtasks 1, 2 & 3 there is an Annex IX Phase 2 Final Report [12]. The final report is a summary report, containing the background to Annex IX Phase 2 and an introduction to the project. It focuses on reporting the main conclusions of the work (including recommendations for future complementary R&D activities).

### **3.4.2 Newsletters and “How to” Guides**

In addition to the “Annex IX” brochure, two newsletters were also produced (in December 1998 and June 1999). Other information produced for publication included the two “How-to” guides:

- The Application of Energy Storage to Power Quality Problems (see Appendix III)

- Utility-Scale Energy Storage (see Appendix IV)

### 3.4.3 Annex IX Web Site

Implementation of the Annex IX web site was carried out by EUS (the German Participating Agent) under sub-contract to EA Technology. The web site included a public information area used to promote energy storage in general. The web site also included a private information area, accessible via password for Annex IX participants.

### 3.4.4 EESAT 2000

Final arrangements are in hand for the next energy storage conference, EESAT 2000, to take place at the Hotel Royal Plaza, Orlando, Florida, USA, on the 18th to 20th September, 2000 (See Appendix V). The conference itself takes place outside of the Annex IX framework, but Annex IX participants formed the majority of the organising committee (as with EESAT '98 [6,7]).

Sandia National Laboratories is responsible for co-ordinating the conference (with support from the US DoE) and is teaming up with the Energy Storage Association (ESA) in the organising of the event. Mr. John Boyes (SNL) is taking the lead role in organising the conference, and has subcontracted the conference logistics to a professional conference organisation (Complete Meeting Concepts Inc.).

## 3.5 Subtask 5: Complementary R&D Programme Activities

Task complete. Consideration has been given to the opportunities for electrical energy storage in the recent call for proposals within the Framework V programme. Since FP5 is a four-year programme, energy storage research and demonstration projects are likely to be eligible in future calls also.

## 3.6 Subtask 6: Project Management and Reporting

Task complete. Project management for Annex IX was achieved through several mechanisms. Regular experts/participating agent meetings were arranged and where a physical meeting of participating agents was not practical, then use was made of teleconferences. Electronic mail and one-to-one telephone communications were used for day-to-day project management issues. Progress was also reported to the ECES Executive Committee every six months [2,3,4,5].

### 3.6.1 Experts/Participating Agents Meetings & Teleconferences

The following experts/participating agents meetings and teleconferences took place during the course of the project:

- |                            |                           |           |
|----------------------------|---------------------------|-----------|
| • First Experts/PA Meeting | EA Technology Offices, UK | June 1998 |
| • Second PA Meeting        | Atlanta, USA              | Oct. 1998 |

- First Teleconference Europe, USA Dec. 1998
- Second Teleconference USA/Europe Feb. 1999
- Third Teleconference USA/Europe Mar. 1999
- Third Experts/PA Meeting Elforsk Offices, Sweden June 1999

### 3.6.2 Annex IX Workplan and Budgets

The project workplan and timescales are shown in Appendix I. The current progress position is shown below:

Subtask 1:	Applications Case Studies	100% complete
Subtask 2:	Project Definitions	100% complete
Subtask 3:	Applications Modelling	100% complete
Subtask 4:	Information Collation & Dissemination	100% complete
Subtask 5:	Complementary R&D Programmes	100% complete
Subtask 6:	Project Management	100% complete

It was originally planned to carry out the project over an 18-month period, with completion in September 1999. The project overran slightly on those timescales, with final completion of all deliverables in November 1999. The project is now complete. The project budget overspent by approximately 20% (£155,000 total expenditure against an income of £127,000), see Appendix II).

## 4 Beyond Annex IX Phase 2

The Annex IX work programme was recently reviewed by the Renewable Energy Working Party (REWP). The REWP members found that the Annex IX focus was on near-term utility needs and did not undertake enough work on longer-term renewable-related energy storage needs. Indeed, the need for more work in the area of "integration with renewables" was also identified by the Annex IX participants and the Operating Agent.

Other Implementing Agreement representatives agreed to detail their needs and describe previous work carried out on storage in order to help define the next steps. The main needs for electrical energy storage come from the wind, photovoltaic and electric/hybrid vehicle implementing agreements.

### 4.1 Energy Storage and Wind Power

Energy storage can act as a buffer for small wind turbines. Variable wind turbine output requires short-term storage to produce a constant output over a variety of timeframes, ranging from seconds (wind gusts), minutes (local fluctuations) and hours/days (daily/seasonal variations).

Energy storage can be used in both off-grid applications (e.g. the integration of wind into small diesel systems) and grid-connected applications (e.g. to bestow the benefits of "generation capacity" and "generator security" on renewable generators). The joint issues of generation capacity and generator security will become increasingly important in the future as the trend for "commodity-style" trading of electricity increases as part of the deregulation and liberalisation process of electricity markets around the world.

### 4.2 Energy Storage and Photovoltaics

Photovoltaic power production has application in both grid-connected and stand-alone applications. In grid-connected applications the storage need is similar to wind turbines (i.e. low energy, high power). In stand-alone applications there is a need for medium energy, low-medium power energy. Batteries are considered to be one of the most vulnerable elements in stand alone PV systems. The Photovoltaic Power Systems Implementing Agreement has already done some work looking at batteries and controllers. The main needs for research concern:

- battery management: optimisation of charging/discharging under specific conditions
- individual cell/battery behaviour: when to replace
- state of charge: measurement needs to be cheaper and more reliable
- life cycle analysis

### **4.3 Energy Storage and Electric/Hybrid Vehicles**

Electric and hybrid vehicles require a high energy and power density by unit of weight and volume and a high number of charge-discharge cycles. In hybrid vehicles, power density is even more important. The Implementing Agreement on Electric and Hybrid Vehicles has a specific annex dealing with batteries and supercapacitors which addresses the IA's need for information on these technologies. That IA is also in contact with the Hydrogen Implementing agreement concerning their work on metal hydride batteries.

## **5 Annex 15 - Electrical Energy Storage and the Integration of New and Renewable Energy Sources**

### **5.1 Introduction & Background**

Electrical energy storage is widely recognised as a key emerging technology likely to find widespread use within electricity generation, transmission, distribution and supply applications as well as other major industrial and commercial end user applications. The benefits of bulk energy storage applied to the increasing levels of embedded generation, especially from new and renewable energy sources, are also beginning to be recognised. Annex 15 is a natural development borne out of Annex 9 and focussing specifically on the issues of electrical energy storage and how it can be used to assist in the successful integration of new and renewable energy sources into existing electrical networks.

Although generation from renewable energy sources reduces the production of energy from conventional sources, it may not be capable of displacing significant generating plant capacity, due to its inherently intermittent nature. This reduces the value of energy from renewable sources. Energy storage can be used to recover this lost value, whilst at the same time adding value in other ways.

### **5.2 Aims and Objectives**

Annex 15 aims to build upon the successful foundation of the previous work carried out within the Annex 9 work programme. The focus of the work will be to develop a firm understanding of the technical issues and commercial implications of applying electrical energy storage technologies to the integration of renewables and to develop awareness of the capabilities and uses of existing and developing energy storage systems as applied to renewables.

It is a stated objective of this work to move storage systems towards commercial market implementation, via the mechanism of technological and applications demonstrations. Whilst it is beyond the scope of Annex 15 to implement an actual demonstration project, it is fully intended that much of the necessary groundwork will be covered within the project to make a demonstration project the next logical step in electrical energy storage system market development. Such a move towards market uptake will represent a significant advance in the application of storage systems, permitting their very real benefits in terms of improved integration of renewables to be realised.

Benefits include identifying how energy storage can be used to increase the value of renewable generation. This has advantages for both owners of renewable generators and suppliers of energy storage systems. It also has direct benefit in helping Governments achieve their Kyoto emissions targets.

### **5.3 Annex 15 Work Programme**

The approach proposed for developing the Annex 15 work programme will be similar to that successfully adopted in establishing the work programme for Annex 9. Initially, it is intended

to set up a Workshop. It is intended that this workshop will bring together experts from the fields of energy storage and renewables from all over the world. The size of the target audience is in the range 50 to 100 people, with roughly equal numbers from each field of expertise. An event of such magnitude requires significant planning time and therefore it is provisionally intended to hold the "Energy Storage & Renewables" workshop in October 2000.

The workshop will be either a one or two day event, dependent on the number of speakers. The event will be self-supporting, financially, with delegate fees set at a level to cover the costs of organising and holding the event.

The details of the work programme are not defined as yet, but a basic framework will focus activities on:

- the need for storage from a renewables perspective
- modelling of network/renewables/storage interaction
- implementation strategies for storage-based solutions
- the costs of storage
- the benefits of storage
- alternatives to storage

### **5.3.1 The Need for Storage**

It is important to establish the need for storage as a market pull rather than a technology push and so this subtask will examine the primary requirements of a renewable energy generating source. One of the major barriers to the continuing increase in the levels of embedded generation (including new and renewables) is that it is not currently considered as an integral part of the electricity network. Embedded generation is presently treated more like a "special case", since it does not fit in readily with current methods of electrical network planning, design, management, operation and maintenance. There is a need to be able to optimise the performance of the energy storage system/renewable generator combination in terms of its commercial operation.

### **5.3.2 Modelling of Network/Renewables/Storage Interaction**

The commercial value of energy storage to the operation and development of large power systems with embedded renewable generation can be modelled by looking at:

- generator levelling/peak lopping
- standing/spinning reserve
- primary/secondary frequency response
- stability
- transmission and distribution network constraints (thermal and voltage constraints)
- reactive power compensation and loss reductions.

### **5.3.3 Implementation Strategies for Storage-Based Solutions**

There is a recognised requirement for a more general raising of awareness of the benefits and applications of storage systems. Such educational and promotional activities are primarily intended

to be for the benefit of the non-specialist, with relatively little previous exposure to the concepts, systems and applications potential of different storage systems. In particular, it is hoped that the educational and promotional material will appeal to a range of senior managers and decision-makers, across a range of utility and other end-user industries. Specifically, it is intended to address the following, via a series of publications:

- electrical energy storage overview document, including reference to the parent Annex 15 work programme
- a 'how to' guide, leading the reader through the various selection/decision making processes and introducing the various cost/benefit arguments.

#### **5.3.4 The Costs and Benefits of Storage**

Current understanding of the costs and benefits of storage systems is continually being refined, as more data becomes available. This is resulting in systems that are better designed in terms of optimal performance. Cost-effective operating strategies for an energy storage system require:

- optimum power/energy ratios
- optimum location

Further work will be carried out to improve the definition of optimal system performance parameters.

### **5.4 The Way Forward**

Annex 15 is seen as a key enabling mechanism in moving the application of energy storage to the integration of new and renewable energy sources significantly closer to market realisation. It is intended that the participation base will be expanded from the existing Annex 9 participative organisations and so the new Annex welcomes participation from countries and organisations who have not previously been involved in the IEA Implementing Agreement's work on electrical energy storage.

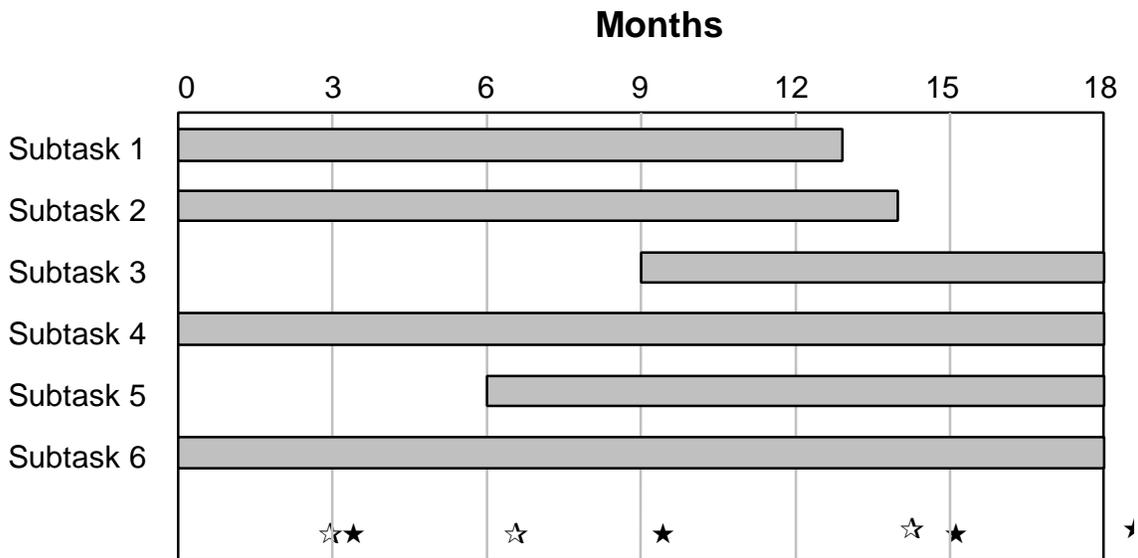
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## Appendix I - Annex IX Phase 2 Work Programme

Annex IX (Phase 2) is an 18 month work programme, started in March 1998. The programme and timescales are as follows: -

- Subtask 1: Applications Case Studies
- Subtask 2: Project Definitions
- Subtask 3: Storage Systems Network Application Modelling
- Subtask 4: Collation and Dissemination of Information
- Subtask 5: Complementary R&D Programme Activities
- Subtask 6: Project Management and Reporting



☆ Participating Agents Meeting    ★ Executive Committee Meeting

Programme Commencement Date: March 1998

1st Participating Agents' Meeting June 1998

2nd Participating Agents' Meeting : October 1998

3rd Participating Agents Meeting: June 1999

44th ExecCo Meeting: June 1998

45th ExecCo Meeting: December 1998

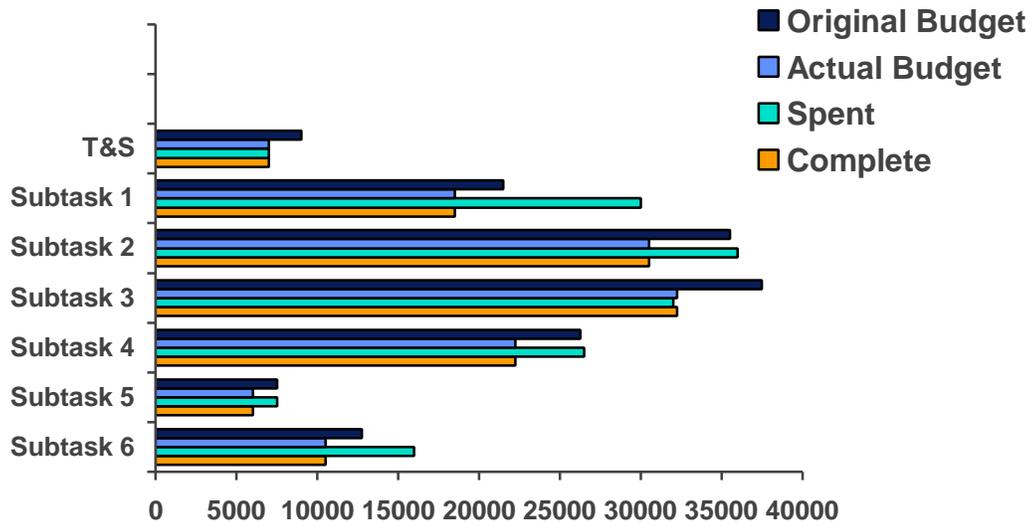
46th ExecCo Meeting: June 1999

47th ExecCo Meeting: November 1999

## Appendix II - Annex IX Budgets

### Annex IX Income

Canada	£7,000
Finland	£15,000
Germany	£20,000
Netherlands	£10,000
Spain	£15,000
Sweden	£10,000
United Kingdom	£20,000
United States	£30,000
Total Income	<b>£127,000</b>
(Target Budget	£150,000)



## **Appendix III- Energy Storage Promotional Sheet 1**

***“The Application of Energy Storage  
to  
Power Quality Problems”***

# The Application of Energy Storage to Power Quality Problems

## The Problem

- Is your manufacturing plant process shutting down for no apparent reason?
- Do your process controllers suddenly reset themselves?
- Do your computer systems crash unexpectedly?

If the answer to any of these questions in **YES**, then your mains equipment may be suffering problems with the local power quality levels. Voltage dips, where the electricity supply voltage can momentarily reduce to between 50 and 90% of its nominal value for typically up to a second, are an intrinsic part of our electricity supply. Such events have always existed and are mostly caused by the normal operation of protective devices on the electricity transmission and distribution networks during fault conditions. For example, local lightning activity or other severe weather conditions can interfere with or cause damage to distribution network equipment and so circuit breaker protection devices are triggered when a fault is detected in order to protect the rest of the network. The operation of these protective devices can cause a momentary voltage dip on the electricity supply network. There can be as many as twenty to fifty voltage dip events on a typical network in an average year, the actual number depending exactly on local features as well as prevailing annual weather conditions.

## Understanding the Problem

Awareness of Power Quality as an issue is a fairly recent occurrence, as the amount of microcomputer-based equipment increases, especially in environments where complex continuous manufacturing processes are involved. In these circumstances, the financial impact of a process shutdown can be very severe.

# The Solution

Power Quality problems can be tackled in a number of ways.

- The best solution is to prevent problems occurring in the first place. This can be achieved by investigating the local power quality levels through thorough **Power Quality Monitoring** before critical production process or IT equipment is specified.
- The results of PQ monitoring can then assist in specifying immunity level requirements for the mains equipment, controllers and other IT equipment.

*“It is not always possible to anticipate power quality problems and consequently, many problems only become apparent after equipment has been installed and operated for some time. In these circumstances, some form of retrospective action is required.”*

- Conventional uninterruptible power supply (UPS) systems can be used to protect particularly sensitive items of plant. This solution works well when the problem is isolated to one or two small independent items, such as computers or other similar IT equipment. Typical UPS ratings cover sub-kilowatt systems as well as systems capable of delivering hundreds of kilowatt for a duration of typically ten to thirty minutes.
- There may be circumstances where the problem is not isolated to one or two items of electrical equipment. In these cases, the problem is more widespread and therefore a more integrated solution is required. The answer here is to consider one of the new Energy Storage systems which have recently been developed.

## Energy Storage

Most people would immediately think of lead-acid batteries when talking about Electrical Energy Storage. Indeed, lead-acid batteries are used in many energy storage systems. However, several other Electrical Energy Storage systems have been developed in recent years and are now entering the market as pre-commercial and (in some cases) fully commercial systems or technology

demonstrators. Available storage technologies for use in Power Quality Applications include:-

- Batteries, including flooded and valve-regulated lead-acid (VRLA)
- Advanced batteries, including advanced lead-acid, sodium sulphur, zinc bromine, vanadium, etc.
- Flywheels (both steel and composite flywheel technology)
- Superconducting magnetic energy storage (SMES)
- Capacitors

## Comparing Storage Technologies

It is true to say that not all battery technologies are the same and so it is even more valid to say that not all energy storage technologies are the same. Therefore, some basic background is required before appropriate choices can be made.

## Battery Energy Storage

Lead-acid battery technology is reasonably mature technology and so has well known performance characteristics. Because of this, lead-acid batteries offer the most flexible solution for energy storage and is the best choice when a significant amount of energy storage is required. Although lead-acid batteries are relatively cheap, they have a low performance quotient in terms of energy and power densities. However, in applications where space is not a serious constraint this may not pose a significant problem. Additionally, battery energy storage systems are often optimised to give the best possible performance for a given application. This optimisation may include the actual design of the battery cell and so it is important to understand the different performance parameters that effect battery design. These include:

- power requirements
- energy requirements
- charge/discharge rates
- number of discharge cycles

## Advanced Batteries

Much research has been carried out to develop new battery technologies that overcome some of the shortfalls of lead-acid technology, especially in terms of power and energy densities. One successful battery technology, especially in stationary applications, is the **sodium sulphur** battery, which has received much attention in Japan. This battery operates at elevated temperatures (300-400°C) and has been used in several large utility network applications. The zinc bromine battery and the vanadium battery belong to the class of flow cell batteries. In these systems, the cell stack (which determines the battery's power rating) is physically separated from the liquid electrolyte storage tanks (which determines the battery's energy storage capacity). Decoupling of the power and energy rating allows the system designer an extra degree of freedom when designing the system.

## Flywheel Energy Storage

Flywheel energy storage systems can be conveniently divided into two types; conventional steel flywheels and new composite flywheels. Conventional steel flywheels rotate at moderate speeds (3,000 to 5,000 rpm), whilst composite flywheels rotate at very high speed (30,000 to 50,000rpm). Flywheels are used when several seconds of storage energy is required.

## SMES Systems

Superconducting magnetic energy storage (SMES) sounds like rocket science, but the concept is simple; below its critical temperature, the resistance of a superconducting element becomes zero. Therefore, there are no losses when a current flows through a superconducting device. If the device is in the form of a continuous ring, then the electrical current will flow indefinitely - true electrical energy storage! Low temperature superconductor (LTS) material has a critical temperature of around 4K (i.e. 4 degrees above absolute zero) and it is relatively easy to make wire from the material. On the other hand, high temperature superconductor (HTS) material has a critical temperature much higher, of around 70K (liquid nitrogen temperature), but it is a ceramic material and therefore very difficult to make wire components (which is important

factor to allow the material is to be usefully incorporated into electrical assemblies). A commercial system has been developed using this technology for power quality applications. It provides 400kJ of energy storage at a maximum power delivery of 750kVA.

## Capacitor Energy Storage

In some power quality applications, the power requirement by far outweighs the energy requirement. In these circumstances, speed of response is very important and so a system based on capacitor energy storage is often the best solution.

## Summary of Storage Technologies

Storage Technology	Energy Rating	Power Rating	Comments
Lead-Acid Battery	1kWh to 40MWh	1kW to 4MW	flooded <sup>1</sup> , VRLA <sup>2</sup>
Advanced Battery	10kWh to 100MWh	25kW to 10MW	sodium sulphur <sup>3</sup> , zinc bromine <sup>4</sup> , vanadium <sup>5</sup> , other <sup>6</sup>
Flywheel	1kWh to 5kWh	5kW to 750kW	steel <sup>7</sup> or glass fibre/ carbon fibre composite <sup>8</sup>
SMES	400kJ	750kW	LTS <sup>9</sup> , HTS <sup>10</sup>
Capacitors	660kJ	2MW	dynamic voltage restorer <sup>11</sup>

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<sup>1</sup> Omnion, East Troy, USA  
<sup>2</sup> GNB Technologies, Chicago, USA  
<sup>3</sup> Japan company  
<sup>4</sup> ZBB Technologies, East Troy, USA  
<sup>5</sup> VRB technologies, Australia  
<sup>6</sup> National Power, Didcot, UK  
<sup>7</sup> Piller, Germany  
<sup>8</sup> Urenco/Siemens, Capenhurst, UK  
<sup>9</sup> American Superconductor, USA  
<sup>10</sup> EUS, Germany  
<sup>11</sup> Westinghouse/Siemens & Dynamic Power

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**Acknowledgement:**

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Operating Agent's Final Progress Report

Implementing Agreement on *"Energy Conservation through Energy Storage"*.

## **Appendix IV - Energy Storage Promotional Sheet 2**

***“Utility-Scale Energy Storage: A How-to Guide”***

# Utility Scale Energy Storage

## A “How to” Guide

### Introduction

There is an ever-increasing reliance nowadays on electricity in industry, commerce and the home. In addition, changes in the worldwide utility regulatory environment effect the way electricity is supplied to the end-user. As part of these changes, there are growing pressures to operate the electrical network more efficiently whilst still maintaining high standards of quality of supply and power quality to customers. Also, the growth of renewables as a major new source of electricity and ever more stringent environmental requirements are combining strongly to further influence electricity companies' decisions on how they should be developing their future network designs. Against this background, the rapidly accelerating rate of technological development in many of the emerging electrical energy storage technologies, with anticipated system cost reductions, now makes their practical application look very attractive.

### Utility Network Applications

Utility scale energy storage systems have power and energy ratings typically in the MW/MWh range. Key application areas for utility scale energy storage systems are:

- quality of supply/power quality/voltage regulation
- distribution capacity deferrals/peak shaving/demand management
- integration of renewables into the utility distribution system

### Power Quality

Awareness of Power Quality is increasing as the amount of microcomputer-based equipment increases, especially in environments where complex continuous manufacturing processes are involved. In these circumstances, the financial impact of a process shutdown can be very severe. Voltage dips, where the

electricity supply voltage can momentarily reduce to between 90 and 50% of its nominal value for typically up to a second, are an intrinsic part of our electricity supply. Such events have always existed and are mostly caused by the normal operation of protective devices on the electricity transmission and distribution networks during fault conditions. Circuit breaker protection devices are triggered when a fault is detected in order to protect the rest of the network. The operation of these protective devices can cause a momentary voltage dip on the electricity supply network. There can be as many as twenty to fifty voltage dip events on a typical network in an average year, the actual number depending exactly on local factors as well as prevailing annual weather conditions.

## **Distribution Capacity Deferrals**

Electricity utilities meet increasing loading on their distribution networks by updating or adding new lines and transformers. Forward planning is an important part of network planning and design to ensure load demand remains within the capability of the system. Distribution networks are therefore under-utilised for substantial periods following an upgrade. Addition of energy storage systems to distribution networks would assist utilities in meeting current demand without reinforcement of the network until it is fully justified. This allows capital expenditure on new facilities to be deferred.

## **Integration of Renewables**

The benefits of bulk energy storage applied to the increasing levels of embedded generation, especially from new and renewable energy sources, is beginning to be recognised and raises the issue of how electrical energy storage can be used to assist in the successful integration of new and renewables into existing electrical networks. Although generation from renewable energy sources reduces the production of energy from conventional sources, it may not be capable of displacing significant generating plant capacity, due to its inherently intermittent nature. This reduces the value of energy from renewable sources. Energy storage can be used to recover this lost value, whilst at the same time adding value in other ways.

## Energy Storage Systems

Electrical **energy storage** systems typically fall into one of the following categories:

- **electrochemical** (including battery storage, flow cell and fuel-cell/electrolyser systems)
- **electromechanical** (such as flywheel storage)
- **electromagnetic** storage (superconducting magnetic energy storage, SMES)
- **electrostatic** devices (capacitors and super-capacitors)
- **pumped hydro** and **compressed air systems**.

A complete storage system requires the integration of the storage medium with a charge/discharge control system and a power conditioning system and other balance of plant, such as switchgear and protection devices to integrate with the utility network. Most people would immediately think of lead-acid batteries when talking about electrical energy storage. Indeed, lead-acid batteries are used in many energy storage systems. However, several other energy storage systems have been developed in recent years and are now entering the market as pre-commercial and 4(in some cases) fully commercial systems or technology demonstrators. Available storage technologies for utility-scale energy storage applications include:

- Batteries, including flooded and valve-regulated lead-acid
- Advanced batteries, including advanced lead-acid, sodium sulphur, zinc bromine, vanadium, etc.
- Flywheels (both steel and composite flywheel technology)
- Superconducting magnetic energy storage (SMES)
- Capacitors

In utility scale energy storage applications where a significant amount of electrical energy storage capacity is required, the only option is to go for a battery storage system. However, it is true to say that not all battery technologies are the same and so some basic background information is required before appropriate choices can be made.

## Battery Energy Storage

Lead-acid battery technology is reasonably mature technology and so has well known performance characteristics. Because of this, lead-acid batteries offer the most flexible solution for energy storage and is the best choice when a significant amount of energy storage is required. Although lead-acid batteries are relatively cheap, they have a low performance quotient in terms of energy and power densities. However, in applications where space is not a serious constraint this may not pose a significant problem. Additionally, battery energy storage systems are often optimised to give the best possible performance for a given application. This optimisation may include the actual design of the battery cell and so it is important to understand the different performance parameters which effect battery design. These include:

- power requirements
- energy requirements
- charge/discharge rates
- number of discharge cycles

## Advanced Battery Energy Storage

Much research has been carried out to develop new battery technologies which overcome some of the shortfalls of lead-acid technology, especially in terms of power and energy densities. One successful battery technology, especially in stationary applications, is the **sodium sulphur** battery, which has received much attention in Japan. This battery operates at elevated temperatures (300-400°C) and has been used in several large utility network applications. The **zinc bromine** battery and the **vanadium** battery belong to the class of **flow cell** batteries. In these systems, the cell stack (which determines the battery's power rating) is physically separated from the liquid electrolyte storage tanks (which determines the battery's energy storage capacity). Decoupling of the power and energy rating allows the system designer an extra degree of freedom when designing the system.

## Summary of Storage Technologies

Battery Storage Technology	Energy Rating	Power Rating	Examples
Flooded Lead-Acid	1kWh to 14MWh	250kW to 20MW	PQ 2000, Omnion, East Troy, USA GNB Technolgies, USA
Valve-Regulated Lead-Acid	1-5MWh	1-5MW	Metlakatla, Alaska - GNB Technologies, USA
Sodium Sulphur	48MWh	6MW	Tokyo Electric Power Co & NGK Insulators, Japan
Zinc Bromine	50kWh-400kWh	12.5kW-100kW	ZBB Technologies, East Troy, USA Powercell Corporation, California, USA
Vanadium	200kWh	200kW	VRB Technologies, Aust. Kashima-Kita, Japan
Regenesys	1MWh-100MWh	1-100MW	Innogy (National Power), Didcot, UK

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**Appendix V - EESAT 2000**

# EESAT 2000

## Electrical Energy Storage Systems Applications and Technologies

This conference will cover the full range of electrical energy storage technologies, including conventional and advanced battery energy storage, supercapacitors, SMES, flywheels, CAES and pumped hydro.

Papers describing complete systems, components, applications and research are invited.

Both technical and economic papers are encouraged.

**Components** of interest are the energy storage, power electronics, control and data acquisition systems

**Application** areas include generation, transmission, distributed resources, distribution power quality, energy management and customer applications

**Research** into advanced systems and components, identification of the potential users and needs for energy storage and the future of the deregulated utility are of interest.

**Conference**

September 18th - 20th, 2000  
Hotel Royal Plaza,  
Lake Buena Vista,  
Florida, USA

**Schedule**

Call for papers: September 1999  
Abstracts due: January 2000.  
Final papers: June 2000.  
Final agenda: August 2000

Sponsored by the US Department of Energy and Sandia National Laboratories in co-operation with the Energy Storage Association.

Point of contact - John Boyes: 505 845 7090, e:mail [jdboyes@sandia.gov](mailto:jdboyes@sandia.gov)

## Appendix VI - Annex 15 - Outline Proposal

International Energy Agency  
Implementing Agreement  
on  
Energy Conservation through Energy Storage

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### Annex 15

## Electrical Energy Storage and the Integration of New and Renewable Energy Sources

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**Introduction:** Electrical energy storage is widely recognised as a key emerging technology, likely to find widespread use within electricity generation, transmission, distribution and supply networks as well as other major industrial and commercial end user applications. In 1996, the developing interest in electrical energy storage resulted in the establishment of a collaborative work programme under the auspices of the International Energy Agency (IEA) Implementing Agreement on Energy Conservation through Energy Storage (ECES). Identified as Annex 9 of that agreement, it involved the participation of Governmental and non-Governmental organisations in the UK, US, Canada, Germany, Netherlands, Sweden, Finland and Spain.

The benefits of bulk energy storage applied to the increasing levels of embedded generation, especially from new and renewable sources, are being increasingly recognised. Annex 15 is a natural development borne out of the previous Annex 9 work programme, focusing specifically on the issues of electrical energy storage and how it can be used to assist in the successful conservation of energy by the integration of new and renewable energy sources into existing electrical networks.

**Aims & Objectives:** It is a stated objective of this work to move storage systems towards commercial market implementation, via the mechanism of technology and applications demonstrators. Whilst it is beyond the scope of Annex 15 to implement an actual demonstration project, it is fully intended that much of the necessary groundwork will be covered within the project to make a demonstration project the next logical step in electrical energy storage system market development. Such a move towards market uptake will represent a significant advance in the application of storage systems, permitting their very real benefits in terms of improved integration of renewables to be realised.



### **Work Programme Definition Workshop:**

A Programme Definition Workshop will be held in Autumn 2000 which will provide the platform for pulling together the Annex 15 participants. The workshop will also provide prospective participants with a direct opportunity to shape the detail of the Annex 15 work programme. Whilst the detail of the work programme will be defined at the workshop, key issues which will be addressed by Annex 15 include:

- the need for storage from a renewables perspective
- modelling of network/renewables/storage interaction
- implementation strategies for storage-based solutions
- the costs of storage
- the benefits of storage
- alternatives to storage

### **Timescales:**

**Workshop:** *“Electrical Energy Storage and the Integration of New and Renewable Energy Sources”*

To take place October 2000, Chester, UK.

**Annex 15:** Work Programme to be presented at 49th Executive Committee meeting, with a view to commencing the project in January 2001.

**Benefits:** Annex 15 is seen as a key enabling mechanism in moving the application of energy storage to the integration of new and renewable energy sources significantly closer to market realisation. Key elements of this strategy include the modelling of the interaction between the electricity network and the energy source as well as producing targeted educational and promotional material to increase awareness of the growing potential of energy storage-based solutions.

For further information, contact the project manager, Dr Alan Collinson, at

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More information on this initiative is available on the ECES Website at:

<http://www.cevre.cu.edu.tr/eces>