Recent developments in the design and applications of a utility - scale energy storage plant

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1. Introduction

Innogy Technology Ventures Limited[2] (ITVL) publicised its development of the Regenesys® energy storage technology during the summer of 1999 and announced in August 2000 that construction has now started on a 120 MWh energy storage plant at Little Barford, in Cambridgeshire in the UK. This paper summarizes the developments and recent milestones in the commercialization of this technology.

2. Background

The Regenesys energy storage technology is based on a regenerative fuel cell. It has some similarities to a conventional primary fuel cell (it uses a proton exchange membrane) but it operates like a rechargeable battery. It can be connected to the grid system or form part of a large electricity consumer's installation. Two electrolytes flow through the fuel cell on either side of an ion exchange membrane. By applying a voltage across the electrolytes they change state and become 'charged'. The charged electrolytes flow out of the fuel cell to be stored in tanks. Just like a rechargeable battery, the process can be easily reversed. The 'charged' electrolytes can be returned through the fuel cell and electricity is produced. The fuel cells are made of low cost materials, can be mass-produced and operate at ambient temperature and low pressure. The details of the technology are described in several papers and publications. [1]

The Regenesys system can be compared with existing technologies, in particular, pumped-hydro and battery storage plants. It displays the benefits of a pumped-hydro plant but has a faster electrical response time and can be located anywhere on a power system. Though similar to a battery storage plant, a Regenesys plant has the advantage that the power output and storage capacity can be specified independently and long discharge times can be easily achieved. Most importantly, this technology will offer lower lifetime costs than either pumped-hydro or existing battery plants.

3. Development history

The project's aim was to develop an energy storage system that would be capable of operation at "utility scale", a definition intended to indicate that its power and energy rating would be of relevance to the commercial and technical operation of electric power utilities. A plant of utility size, such as a Regenesys plant, is multi-functional and can access multiple revenue streams. [2]

Laboratory work established the principles of operation but further development work required the construction of a 1 MW test facility, designed specifically for the requirements of the Regenesys energy storage system. The test facility, known as the Operations, Training and Evaluation Facility (OTEF), has operated at Aberthaw Power Station in the UK since 1996. The site for the OTEF was selected to take advantage of an existing building and an 11 kV electrical connection. The OTEF has also been used as a pre-commercial prototype demonstration. Cell performance and system integration issues have been verified giving confidence to proceed to the next step in the development.

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[2] Innogy Technology Ventures Limited is a subsidiary of National Power PLC, which is scheduled to de-merge into two separate companies in October 2000.

In order to achieve utility scale storage, ie multi MW power rating and several hours' energy storage capacity, it was necessary to develop the regenerative fuel cell module for cost effective manufacture and efficient integration into the plant. Modules of varying sizes and power ratings have been developed during the project and the current status of development is the XL200 module. Its key parameters are given in table 1 and it is illustrated in figure 1.

Bipole Components manufacture	Linpac, Birmingham, UK
Membrane type and supplier	Nafion ® manufactured by DuPont
Module Assembly	Elegenix, Oxfordshire, UK
Nominal discharge power rating	100 kW
Dimensions	Length 2100 mm, Width 940 mm, Height 1600 mm
Mass	2100 kg drained
Operating voltage range	150 – 360 V
Typical number of bipoles / cells in each module	200
Module no load voltage	300 V
Operating temperature	20 – 40 ° C range

Table 1 Parameters for the Regenesys XL 200 Module

Figure 1 The Regenesys XL200 module

The next stage in the commercialization of the Regenesys system was to design and provide cost estimates for a full utility-scale energy storage plant. Generic plant designs were developed for the purpose of feasibility studies and plant development. Hazard and operability studies as well as safety and environmental risk assessments were developed and used to optimise the plant design.

4. Manufacturing issues

Large-scale application of energy storage, using the Regenesys technology, requires the use of advanced manufacturing and mass production techniques. Individual components of the module are manufactured by specialist UK subcontractors to detailed proprietary designs using processes developed with the staff of ITVL. The ion-exchange membrane is supplied by Du Pont. Module components are delivered to ITVL's assembly facility, where final assembly and testing takes place. Because a large-scale energy storage plant needs several hundred modules, high quality manufacturing is critically important. Each stage of the manufacturing process has been developed so that in the future it may be automated, although at the present time, many of the processes are undertaken by hand.

5 The first utility-scale plant

An opportunity to use the Regenesys energy storage technology on a utility scale arose in response to a requirement by the National Grid Company of the UK to provide "black start" capability. The conventional means of providing "black start" is to use a gas turbine or diesel generator to produce sufficient works power to restart a power station, in the event of a system failure. Use of an energy storage plant means that additional value streams can be captured.

This first plant will be constructed at Little Barford, in Cambridgeshire in the UK, alongside the existing 680 MW combined cycle gas turbine power station owned and operated by Innogy plc. The choice of site was formally announced on 21 August 2000 and construction work started soon afterwards. In round terms, the plant is rated to provide 120 MWh of energy storage and up to 15 MW power output. This is expected to be one of the largest electricity storage plants of its kind in the world and once commissioned will operate commercially in the electricity market of England & Wales. There is a contract with the National Grid Company for the provision of a "Black Start" service at the Little Barford Power Station.

The plant has three key duties:

a) Standby capability to provide power to restart Little Barford Power station on an isolated network (Black start capability)
b) Energy management and arbitrage in the UK's electricity market
c) Frequency response and voltage control.

It is hoped to use the plant in conjunction with wind power generation. In addition, the plant will have a demonstration role as the "first of a kind" plant. Construction and operational experience gained will be invaluable in the construction of follow-on plants.

Parameters quoted in table 2 are specific to the project and are governed by the specific application required at Little Barford.

Process Plant Design	AGRA Birwelco Bristol, UK
Rated power output	14.9 MW
Energy storage capacity	120 MWh
Discharge duty cycle	10 hours
Design availability	95 %
Design turnaround efficiency	60 – 65 %
Predicted lifetime	> 15 years
Site area	< 3000 m^2

Table 2 Key parameters of the Little Barford Regenesys energy storage plant

Future Plants using the Regenesys energy storage technology can be designed to have:

- higher availability (in excess of 95%)
- higher turn around efficiency (in excess of 70%)
- reduced specific site area

6. Construction programme and plant description

Various consents were required before construction could start. The UK Health and Safety Executive, Environmental Agency and public authorities were consulted on environmental and consenting issues. At the same time, a programme of work was carried out to select suppliers and contractors for the construction of the plant.

The plant will be constructed within a low rise building on a site less than 3000 m^2. Construction on site proceeds in parallel with the assembly of the 120 regenerative fuel cell modules, which form the basis of the plant. The regenerative fuel cell modules will be connected electrically and hydraulically in an array of strings on the upper floor of the building. Twelve modules are connected electrically in series to form a string. Ten strings are connected electrically in parallel. The power conversion system and control equipment are to be located on the ground floor of the building. The modules, electrical equipment and other components will be installed on site during the latter part of the construction period.

The electrolytes, aqueous solutions of sodium bromide and sodium polysulphide, will be stored in two tanks, each with a volume of 1800 m^3 to provide 120 MWh, approximately 15 m^3 / MWh for each electrolyte. The electrolytes are delivered to the site in a chemically stable and inert state.

In order to provide "Black Start" capability, the plant includes two header tanks, situated above the regenerative fuel cell modules. In the unlikely event that electrical supplies are lost, the header tanks can be used to fill the modules by gravity feed. A specialist contractor, AGRA Birwelco Ltd), designed the plant and will construct it as part of an Engineer, Procure and Construct (EPC) contract.

The plant will be commissioned by an in-house team who will take the plant into commercial operation and provide operations and maintenance support. The total period from start on site to project handover is expected to take about 18 months. Future plants are expected to have shorter delivery times.

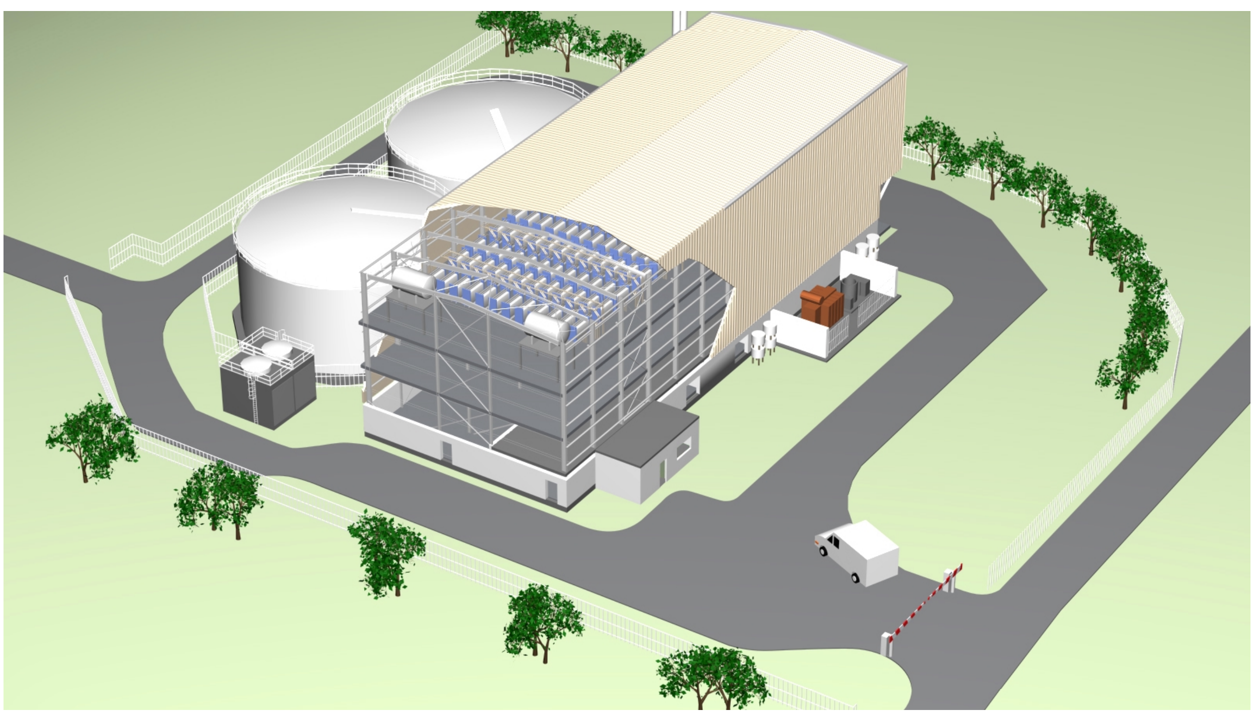

Figure 2 An Artist's impression of the 120 MWh Regenesys energy storage plant to be constructed at Little Barford

7. System integration issues

The regenerative fuel cells are connected to the grid through a Power Converter System (PCS) to convert alternating current (AC) to direct current (DC) so that the store can be charged from and discharged to the grid. The PCS provides the interface between the electrical supply and the variable operating voltage of the DC modules. The control unit adjusts the incoming and outgoing voltages and currents in real time to maintain the required energy exchange between the energy storage system and the grid. The parameters of the PCS are described in table 3. The PCS supplied for future plants will vary according to the supplier and specification of the PCS and the particular applications of the energy storage plant.

Supplier	ABB Industrie AG, Switzerland
Power rating	15 MW, 18 MVA
Design ramp rate	+ 15 MW to – 15 MW or vice versa in < 100 ms
Design response time	< 100 ms
DC link operating voltage	± 2400 V
Inverter AC output voltage	6600 V

Table 3 Parameters of the power conditioning system

A proprietary method of "electrolyte polishing" has been developed to ensure that both the electrolytes remain at the same state of charge over the course of many charge and discharge cycles. Equipment for monitoring and controlling this process is included in the process plant design.

The plant design incorporates high standards of plant safety, with minimal environmental impact, ease of operation and incorporating compact/novel design ideas. The Regenesys technology is an innovative approach to the development of a compact utility-scale resource capable of future unmanned operation, with low maintenance and high reliability and availability.

8. A competitive plant

The 15 MW /120 MWh facility has an estimated total specific capital cost of around £1000/kW. As it is a storage plant rather than purely a generating plant, the specific capital cost as a function of storage capacity is also a useful guide in comparing plant economics. For this plant it would be around £100/kWh (for a 10-hour discharge) and is competitive with many other storage technologies. Future plants to a similar design are expected to have considerably reduced specific costs.

Utility scale energy storage has many applications on a power system. Its benefits are both technical and commercial and can be achieved in both centralised and distributed applications [3]. Some examples of storage applications are listed in table 4.

Generation duties	**Ancillary services**	**Transmission and distribution**
Energy management	Frequency response	Voltage control
Load levelling	Spinning reserve	Power quality
Peak generation	Standby reserve	System reliability.
Ramping / load following	Long term reserve	
Integration of renewables		

Table 4 Applications of large scale energy storage

Large-scale energy storage can replace existing or planned conventional plant, which is used for reserve, standby, peaking or intermediate load factor duties. As the stored energy is drawn from more efficient base load plant, there are positive commercial and environmental benefits. These factors are expected to become more significant as pressure from governments, consumers, and environmental groups increase. Utility scale energy storage can be used to "time shift" energy to balance supply and demand at all timescales from cycle to cycle or hour to hour. It will have applications in the integration of stochastic generation [4] from renewables such as wind or solar and can be used as a centralised or distributed resource. Energy storage is a valuable, flexible and viable technology that has a major part to play in system planning and operation. The Little Barford Regenesys energy storage plant will be a valuable demonstration of the use and application of large-scale energy storage.

9 References

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