RECENT DEVELOPMENTS IN THE DESIGN AND APPLICATIONS OF UTILITY-SCALE ENERGY STORAGE PLANT

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SUMMARY

Innogy Limited announced the Regenesys® energy storage technology during the summer of 1999. The technology offers a novel solution to many technical and commercial constraints on a power network.

The need for energy storage

At the simplest level, energy storage can be used to balance fluctuations in the supply and demand of electricity. Over short time periods (of say less than 1 second) the requirement is essentially frequency control. Over longer time periods the requirements become those of energy management or provision of a contingency against an undesired event.

An energy storage device has applications within the transmission and distribution network. Networks have to be designed and built to carry the expected peak loading. This results in considerable over-sizing of transmission and distribution equipment. Additional wires, transformers and other equipment are needed to provide redundancy in the event of sudden loss of transmission capacity (such as a generator failure or an interruption to a transmission link). An energy storage device could also be used to assist the integration of renewable generation and distributed generation.

A description of the Regenesys energy storage technology

Flow batteries, or redox flow systems, are a new class of battery that have a number of features that make them attractive for utility-scale energy storage applications. They have a fast speed of response, are capable of integration into medium and high power configurations, and have the capability of a large energy storage capacity.

The polysulphide / bromide couple, forms the basis of the regenerative fuel cell technology known as Regenesys®, which has been developed by Innogy Technology Ventures Limited, a subsidiary of Innogy plc, a British energy company.

Utility-scale energy storage

A commercial agreement has been signed with the National Grid Company in the UK to provide a “black start” service at Little Barford Power Station in the UK. Commercial operation is planned for spring 2002.

Commercial Plant Prospects

The Tennessee Valley Authority of the USA has placed a contract for the construction of a 120 MWh Regenesys energy storage plant. The plant will reflect the development at Little Barford, and its construction will follow as part of an ongoing learning and development process.

Other sites are being considered for similar energy storage facilities and opportunities are being developed in North America and Europe. Similar plants could be used at many places in a transmission and distribution network and a number of follow-on plants are expected to be built and operated over the coming years. There are a number of proposals for use of energy storage as part of an energy trading activity, at large scale (25 MW / 300 MWh) and at smaller scale (5 – 10 MW), such as associated with a cogeneration or industrial power plant.

Other applications include the control of distributed resources and the integration of renewable energy sources, especially wind power.

The business structure of Innogy Technology Ventures Limited is being developed to enhance the commercialisation of this exciting technology in these areas.

Conclusions

An energy storage plant is a multi-functional tool on a power system. Energy management, provision of ancillary services, and integration of distributed resources and renewable generation have significant technical and commercial benefits. Modern forms of energy storage, such as those based on a regenerative fuel cell provide the capability to incorporate energy storage with sufficient power and energy thereby improving the technical and commercial operation of a power network.
DES DEVELOPPEMENTS RECENTS DANS LE DOMAINE DE LA CONCEPTION ET DES APPLICATIONS DES INSTALLATIONS DE STOCKAGE D’ENERGIE A L’ECHELLE DU RESEAU

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RESUME

Nécessité du stockage d’énergie
Le stockage d'énergie peut être utilisé pour équilibrer les fluctuations de l'offre et de la demande d'électricité. Pour des durées très courtes (de moins d'une seconde), il s'agit essentiellement de réguler la fréquence. Pour des périodes plus longues, il s'agit de gérer l’énergie à des fins commerciales ou d’assurer des réserves en cas d'événements imprévus.

Un dispositif de stockage d'énergie a des applications au sein des réseaux de transport et de distribution. Les réseaux doivent être conçus et réalisés pour transmettre la charge de pointe, ce qui conduit à un surdimensionnement des équipements de transport et de distribution. Câbles, transformateurs et autres dispositifs supplémentaires sont nécessaires pour assurer la redondance dans le cas d'une perte soudaine de la capacité de transport. Un dispositif de stockage d'énergie peut également être utilisé pour intégrer la production d'énergie renouvelable et la production d'énergie répartie.

Description de la technologie du stockage d’énergie Regenesys
Les piles rechargeables, ou systèmes rechargeables redox ("regenerative"), constituent une nouvelle génération de piles possédant certaines propriétés qui permettent le stockage d'énergie à l'échelle du réseau. Dotées d'une vitesse de réaction rapide, ces piles sont capables de s'Intégrer dans des configurations de moyenne et haute puissance et ont une grande capacité de stockage d'énergie.

Les deux solutions polysulfure / bromure, constitue la base de la technologie de la pile à combustible rechargeable ("regenerative fuel cell"), connue sous le nom de Regenesys®, qui a été développée par Innogy Technology Ventures Limited, une filiale de la société d’électricité britannique Innogy plc.

Stockage d’énergie à l'échelle du réseau
Un accord commercial a été signé afin d'assurer un service en “démarrage autonome” ("black start") dans la centrale électrique de Little Barford au Royaume-Uni. L'exploitation commerciale est prévue pour le printemps 2002.

Perspectives d’installations commerciales
Tennessee Valley Authority aux Etats-Unis a signé un contrat pour la construction d'une installation de stockage d’énergie Regenesys de 120 MWh. Cette installation devrait être basée sur l'expérience acquise lors du développement de Little Barford.

D'autres sites sont envisagés pour des installations semblables de stockage d'énergie. D'autres installations devraient être construites et exploitées au cours des prochaines années. Il y a plusieurs façons d'utiliser le stockage d'énergie dans le cadre des échanges commerciaux d'énergie, à grande échelle (25 MW / 300 MWh), et à plus petite échelle (5 – 10 MW), par exemple en conjonction avec une centrale de cogénération ou industrielle. Parmi les autres applications, on notera la régulation des ressources réparties ("distributed generation") et l'intégration des sources d'énergie renouvelable, en particulier l'énergie éolienne.

La structure commerciale d’Innogy Technology Ventures Limited est en cours de développement afin d’étendre la commercialisation de cette technologie.

Conclusions
Une installation de stockage d'énergie est un outil multifonctionnel dans un système d'énergie. La gestion de l'énergie, les prestations de services auxiliaires et l’intégration de la production des ressources réparties et renouvelables ont d'importants avantages techniques et commerciaux. Les formes modernes de stockage d'énergie, comme celles basées sur une pile rechargeable, offrent la possibilité d'incorporer le stockage d'énergie avec suffisamment de puissance et d'énergie ce qui permet d'améliorer l'exploitation technique et commerciale d'un réseau électrique.
RECENT DEVELOPMENTS IN THE DESIGN AND APPLICATIONS OF UTILITY-SCALE ENERGY STORAGE PLANT

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SYNOPSIS

Innogy Limited announced the Regenesys® energy storage technology during the summer of 1999. This paper highlights the developments and recent milestones in the commercialisation of this technology. The technology is applicable to the integration of distributed resources including renewable generation and the use of energy storage as a supplement or alternative to distributed generation or other methods of local network reinforcement. The technology offers a novel solution to many technical and commercial constraints on a power network.

THE NEED FOR ENERGY STORAGE

At the simplest level, energy storage can be used to balance fluctuations in the supply and demand of electricity. Over short time periods (of say less than 1 s) the requirement is essentially frequency control. Over longer time periods the requirements become those of energy management or provision of a contingency against an undesired event. Energy storage can not replace generation completely, but it can complement other forms of generation whether on a large power system or in a stand-alone or non-grid connected application. New peaking generating capacity could be deferred or avoided if the utilisation of existing mid-merit generating capacity was increased. Existing mid-merit capacity could be run at an increased load factor by storing the energy produced during off-peak periods. During peak periods, the energy can be discharged to meet peak demands.

An energy storage device also has applications within the transmission and distribution network. Networks have to be designed and built to be able to carry the expected peak loading, which may only exist for a very small part of its annual operating cycle. This results in considerable over-sizing of transmission and distribution equipment. Additional wires, transformers and other equipment are also needed to provide redundancy in the event of sudden loss of transmission capacity (such as a generator failure or an interruption to a transmission link).

An energy storage device can be used for many network applications. Storage can achieve multiple benefits by combining applications resulting in increased returns on investment. Examples of storage applications are listed in table 1.

<table>
<thead>
<tr>
<th>Generation duties</th>
<th>Ancillary services</th>
<th>Transmission and distribution</th>
</tr>
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<tbody>
<tr>
<td>Energy management</td>
<td>Frequency response</td>
<td>Voltage control</td>
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<tr>
<td>Load levelling</td>
<td>Spinning reserve</td>
<td>Power quality</td>
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<td>Peak generation</td>
<td>Standby reserve</td>
<td>System reliability</td>
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<tr>
<td>Ramping / load following</td>
<td>Long term reserve</td>
<td>Incorporation of renewables</td>
</tr>
<tr>
<td>Increase generation utilisation</td>
<td>Reactive power</td>
<td>Increase system utilisation</td>
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<tr>
<td>Reduce total required generating capacity</td>
<td>Allow unbundling of services from the generator</td>
<td>Defer investments</td>
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<td></td>
<td>Reduce cost of ancillary services</td>
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One of the axioms of energy storage is that an energy storage device should be located as close as possible to the end consumer of electricity. This is because the storage device can improve the utilisation of all components preceding it in the supply chain. In order to place a storage device close to the end consumer, the device would need to be matched for both power (kW or MW) and energy storage capacity (kWh or MWh) to the requirements of the consumer. The cost profile of storage devices varies according to the power and energy rating and a balance has to be achieved between the capital cost and the operating benefit. As devices become smaller, their specific capital and operating costs usually increase so moving the optimum position for a storage device in the network away from the consumer towards the generation source. Many storage devices might therefore be located near to substations or grid distribution points.

The characteristics of energy storage technologies. There are a number of storage technologies available to power system planners, which can be classified by technology type or by application. Technologies include

Mechanical: for example pumped hydro storage, compressed air energy storage, flywheels

Electrical: for example superconducting magnetic energy storage, capacitors / ultra capacitors
Electrochemical: for example batteries, flow batteries

Of these technologies, pumped hydro storage, compressed air and flow batteries have the capability of delivering energy at high power levels over periods of several hours or more. The other technologies are smaller scale.

A description of the Regenesys energy storage technology

Flow batteries (also known as redox flow systems or regenerative fuel cells), are a new class of battery that has recently made substantial technical and commercial progress. Flow batteries have a number of features that make them attractive for utility-scale energy storage applications. They have a fast speed of response, are capable of integration into medium and high power configurations, and can have a large energy storage capacity. They can be used for nearly all the applications of storage shown in table 1.

Many different electrolyte couples such as iron / chrome and zinc / chlorine have been proposed for use in flow batteries. Other electrolyte couples include vanadium / vanadium couple, zinc / bromine and polysulphide / bromide.

The polysulphide / bromide couple, described in previous papers and publications, (Price et al (1)) forms the basis of the regenerative fuel cell technology known as Regenesys®, developed by Innogy Technology Ventures Limited, a subsidiary of Innogy plc, a British energy company. The system uses electrolytes of concentrated solutions of sodium bromide and sodium polysulphide.

These salts are readily soluble, present few hazards in handling or storage and are abundant and available at the necessary degree of purity at moderate cost.

The electrolytes are pumped through an electrochemical cell which has two electrodes and a proton exchange membrane, which separates the two electrolytes. The bulk of the electrolytes are stored in tanks, outside the electrochemical cell, as illustrated in figure 1. By applying a potential across the electrodes, electrical energy is converted into chemical potential energy by 'charging' the two liquid electrolyte solutions and subsequently releasing the stored energy on discharge. The simplified overall chemical reaction, showing the discharge reaction from right to left, for the cell is given by:

\[
3 \text{NaBr} + \text{Na}_2\text{S}_4 \Leftrightarrow 2 \text{Na}_2\text{S}_2 + \text{NaBr}_3
\]

The discharge reaction is achieved by applying a load across the cell so providing the required power output dictated by the module voltage and discharge current.

The conversion of electrical to stored chemical energy and back again can be repeated indefinitely with high turnaround efficiency. There is no memory effect associated with the specific electrochemistry of the polysulphide / bromide system, and a full charge/discharge cycle can be completed without limitation of a theoretical maximum depth of discharge.

Figure 1. A single regenerative fuel cell
These technical characteristics mean that regenerative fuel cell technology is an ideal choice of energy storage technology for utility scale storage on a power network, in generation, transmission and distribution applications.

Individual fuel cells can be linked together to form a module which operates at a higher power rating. To construct a utility-scale energy storage plant, tens or hundreds of modules must be connected to give the required power rating. Modules are linked electrically in series to form a string of the required DC voltage and linked hydraulically in parallel. Additional strings are added electrically in parallel to give the required power rating of the plant. Electrolyte storage tanks of the required volume are added to establish the energy rating of the system. The storage capacity is only limited by the size and number of electrolyte tanks and so storage / discharge times of 12 hours or longer are possible.

A Power Conversion System is required for the interface between the AC network's electrical supply and the variable operating voltage of the DC modules.

A schematic of the components required for a regenerative fuel cell plant is shown in Figure 2. In addition to the main components there are auxiliary systems, for example a cooling system to maintain the electrolyte at a temperature for optimum performance, and a process plant package, to control pH and the purity of the electrolytes. The process plant also includes pumps and associated pipework.

The principles of the technology have been demonstrated at a 1MW capacity Operations, Training and Evaluation Facility in the United Kingdom over the past four years.

Utility-scale energy storage

The next stage in the commercialisation of the regenerative fuel cell technology was to develop and design a utility-scale energy storage plant. A commercial agreement has been signed with the National Grid Company in the UK to provide Black Start capability at Little Barford Power Station in the UK. Figure 2 shows an artist’s impression of the plant. The Black Start service requires the Regenesys plant to be able to start the main generating plant of the power station from shutdown without the use of external supplies. The Regenesys system is an alternative method instead of using a prime mover such as an open cycle gas turbine.

The plant design also includes the capability for energy arbitrage as well as voltage and frequency support. The energy storage rating of 120 MWh is split between 60 MWh reserved for Black Start and 60 MWh for other applications. Commercial operation is planned for spring 2002.

Commercial Plant Prospects

The Tennessee Valley Authority of the USA has placed a contract for the construction of a 120 MWh Regenesys energy storage plant, which will be located on a site within their operational area. The first part of the programme is to confirm the site of the plant, which is intended to improve the distribution reliability of part of the power system. Full details of this plant are not available at the time of submission of this paper, but the latest status of these projects will be made available.

The plant is expected to reflect the development at Little Barford, and its construction will follow as part of an ongoing learning and development process.

Other sites are being considered for similar energy storage facilities and opportunities are being developed in North America and Europe. Similar plants could be used at many places in a transmission and distribution network and a number of follow-on plants are expected to be built and operated over the coming years. There are a number of proposals for use of energy storage as part of an energy trading activity, at large scale (25 MW / 300 MWh) and at smaller scale (5 – 10 MW), such as associated with a cogeneration or industrial power plant.

Other applications include the control of distributed resources and the integration of renewable energy sources, especially wind power. Storage and wind generation are complementary as the storage plant can be used to time shift the energy output of the generator to increase its value, and to maintain frequency and voltage, especially on small systems. The attractive feature of this technology is the capability of long discharge periods (10, 20 or 30 hours).

The business structure of Innogy Technology Ventures Limited is being developed to enhance the commercialisation of this exciting technology in these areas.

Conclusions

An energy storage plant is a multi functional tool on a power system. Power system applications of energy storage such as energy management, provision of ancillary services, and integration of distributed resources and renewable generation have significant technical and commercial benefits. Modern forms of energy storage, such as those based on a regenerative fuel cell provide the
capability to incorporate energy storage with sufficient power and energy thereby improving the technical and commercial operation of a power network.

Reference:


Figure 2. Block diagram of an energy storage system

Figure 3. Artist’s impression of the Little Barford 120 MWh energy storage plant, (used with permission of Innogy Technology Ventures Limited)