EARLY FINDINGS OF AN ENERGY STORAGE PRACTICAL DEMONSTRATION

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ABSTRACT

The first deployment of an energy storage system onto a UK electricity distribution network brings with it considerable challenges. This article discusses the perceived role of electrical energy storage and modelling and simulation efforts designed to justify these roles. The deployment and subsequent testing and evaluation programme is outlined, with consideration given to instrumentation and control system requirements. The viewpoint of the distribution network operator is reported.

INTRODUCTION

Interest in electrical Energy Storage Systems (ESS) is increasing as the electricity supply industry is faced with growing pressures including the accommodation of distributed generation, management of ageing assets and avoidance of network reinforcement. The multifaceted nature of energy storage provides a flexibility that would be broadly embraced if sufficient benefits can be accrued from what continues to be a significant capital investment.

UK Power Networks (UKPN) have installed an energy storage device as part of the Engineering and Physical Sciences Research Council (EPSRC) funded Autonomous Regional Active Network Management System (AuRA-NMS) project undertaken in collaboration with ABB, Scottish Power Energy Networks and six universities [1]. UKPN wanted to demonstrate that the benefits derived from ESS that have been proposed could be realised. A site was selected such that the maximum number of benefits could be considered from a single installation. A rural 11 kV distribution network in North Norfolk with a 2.25 MW windfarm connection was selected. The storage device is installed at an open point between two primary substations. Installing the device at a primary substation would have removed any benefit to the 11 kV feeders, limiting the benefits to the higher voltage circuits supplying the primary substation.

A series of network studies had to be carried out to ensure the device would not have a detrimental impact on the selected network location. The size of the energy store was determined by the cost that could be reasonably justified as an R&D project. ABB integrated a battery system with a Voltage Source Converter (VSC) system that can independently source or sink real power up to 600 kW and reactive power up to 600 kVAr. The system is controlled by their MACH2 controller used in a number of Flexible AC Transmission System (FACTS) installations. In this case the DC side of the VSC is connected to Lithium-ion batteries with a capacity of 200 kWh. The MACH2 system controls both the VSC and the battery system.

Relying on extensive modelling and simulation work undertaken at Durham University, a test programme has been devised to ensure that operation of the ESS will bring measureable benefits to the distribution network. Coupled with this programme is an instrumentation strategy that will allow changes in the behaviour of the distribution network to be quantified.

Funding for the monitoring and evaluation phase of the work has been secured from the GB regulator Ofgem as a Tier One Low Carbon Networks (LCN) Fund project. The LCN Fund will provide £500M over five years to 'help all distribution network operators (DNOs) understand what they need to do to provide security of supply at value for money as Great Britain (GB) moves to a low carbon economy' [2]. DNOs in the deregulated GB electricity market operate and maintain the networks between grid supply points and load customers.

ELECTRICAL ENERGY STORAGE

Storage of electrical energy has always been a difficult and expensive challenge that struggles to compete with primary fuel sources [3]. Energy storage technologies are defined by several characteristics including power density, efficiency, lifetime, cost, scalability and readiness for application. A review of storage technologies is given by Hall and Bain [4].

A high-level framework for the assessment of individual and aggregated benefits of energy storage is given by Eyer and Corey in which they assemble value propositions likely to enable profitable storage installations [5]. Simulation of a distribution network operating with energy storage by Wade et al. has evaluated multiple benefits across multiple networks [6].

The number of energy storage installations worldwide is set to increase considerably in the near future. Established energy storage installations have used lead-acid batteries, nickel-cadmium batteries, CAES, flow batteries and pumped hydro [7]. The next generation of grid storage technologies is now being trialled with lithium-ion and flywheel storage installations gradually coming on-line. In the US, funding from the American Recovery and Reinvestment Act alone is contributing to in the order of twenty new energy storage projects [8].

The ESS deployed by UK Power Networks was designed and built as a turn-key project by ABB. It is an add-on to the established SVC Light product, a fast PWM-controlled IGBT based converter used for tasks such as flicker mitigation and active filtering. Lithium-ion battery technology was selected for calendar lifetime (15 years, more than adequate for the 5 year operation life of this project), charge/discharge lifetime of 3000 cycles with 80% depth of discharge and high round-trip efficiency of the order of 90%. Safety and protection is ensured by interlocking and supervision and control from cell to system level. A CAD drawing giving a representation of the installed plant is shown in Figure 1.

MODELLING AND SIMULATION

A range of modelling and simulation work has been carried out by Durham University to evaluate the most effective way to operate the ESS on a distribution network. To do this, physical network data and historical power flows and voltages have been supplied by UK Power Networks. As well as considering the actual network to which the ESS will be deployed, simulation work has extended to alternative loading and generation patterns and different ESS locations. The deployment programme makes use of findings that consider the alternative ways to operate the installed equipment. As an example, Figure 2 shows how varying the maximum permitted power level of the converter affects the number of reverse power flow events at the primary substation. Such events are driven by wind farm generation and are tackled by the ESS importing power. The figure shows the number of reverse power events that occur in each 30 minute period throughout the course of one year of simulation time and how the count changes with different converter limits.

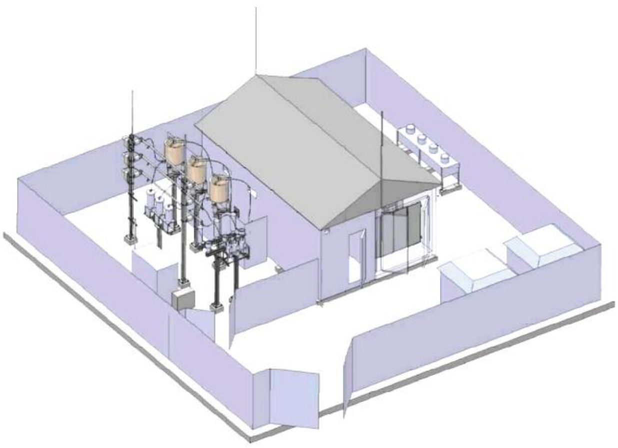

Figure 1. CAD drawing of installed ESS plant.

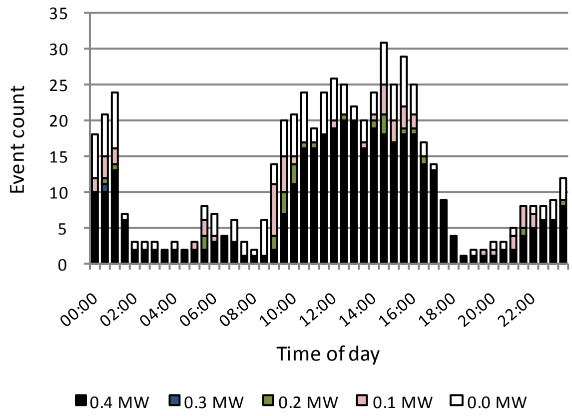

Figure 2. Change in reverse power events at primary substation with converter power ratings from zero to 0.4 MW.

NETWORK INSTRUMENTATION

Typical GB distribution networks are sparsely instrumented, usually limited to current and voltage at the Primary substation. In order to provide the most value from the first deployment of an ESS of this kind in the UK a more complete set of measurements will be made. Relays will be added to the current and voltage transformers on existing ring main units at the strategic locations shown in Figure 4. This will increase the visibility of the network state for two functions:

- to understand changes in power flows and voltages across the network due to ESS operation, and
- provide inputs to the control algorithm used to govern the ESS actions.

The relays will transmit their measurements over the GPRS network to a substation computer at the primary substation as indicated in Figure 3. Here data will be archived for later analysis and key measurements will be used by the control algorithm hosted on the substation computer to determine ESS set-points.

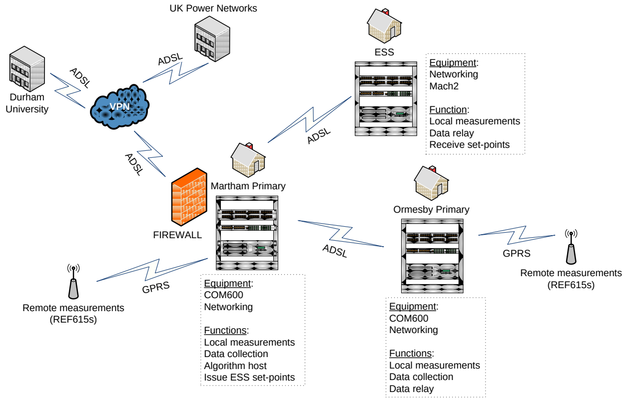

Figure 3. Communication and control equipment.

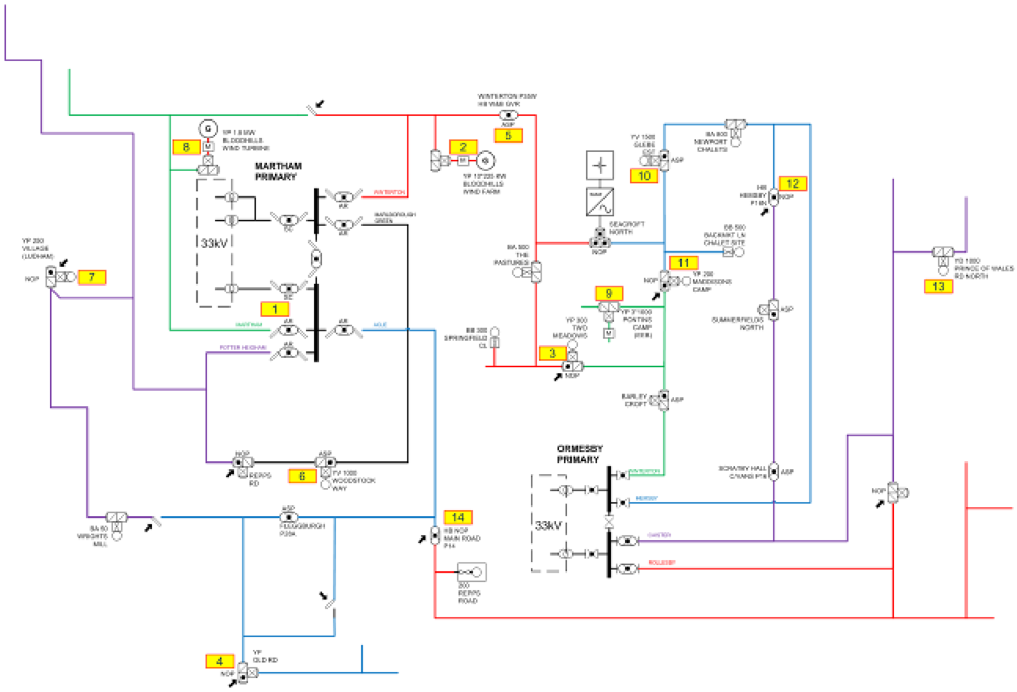

Figure 4. Network instrumentation placement.

CONTROL SYSTEM

The ESS plant is managed by ABB's Mach2 control system; interaction with the wider electrical network is implemented through an industrial pc at the primary substation. ABB's COM600 substation computer is used for this purpose. Measurements are processed by IEC61850 compliant REF615 relays.

The ESS plant can operate in an automatic mode where local voltage measurements are used to determine the required injection of reactive power to stabilise the voltage at the ESS. In order to make decisions on ESS control from a wider range of measurements taken from across the network, such measurements are collected and processed by algorithms on the COM600 computer. Decisions are then issued as ESS set points for real and reactive power settings.

TEST PROGRAMME

A test programme has been formulated that will allow the ESS to be introduced onto a UK distribution network for the first time. It is important that normal network operation is not disrupted, yet the ESS must produce a measureable effect so that the benefits brought to network operation can be quantified.

Testing methodology

To achieve this, a two-stage methodology has been adopted. During the initial stage, an incremental approach will gradually build up the power exchanges between the network and ESS. Operation will only take places at times when a favourable network state can be relied upon.

The incremental approach will follow these first steps:

- local manual time-of-day operation,
- remote manual time-of-day-operation,
- automated time-of-day-operation, and
- voltage control at PCC.

Following successful operation in this stage and verification of modelling results, testing will move into an operational stage. Here the operation of the ESS will adopt what will be considered to be routine objectives in the future, working to contribute to a series of benefits to the stakeholders in the electricity value chain.

Algorithm objectives

Control of the ESS set-points for real and reactive power transfer will be managed by an algorithm hosted on a substation computer that has access to measurements collected across the distribution network. During the test programme the algorithm will be tested against a series of objectives.

During initial deployment:

- operation in automatic voltage control mode to maintain the PCC within narrower voltage limits, and
- charge/discharge at fixed power levels (with slow ramp rates) at fixed time of day based on knowledge of historical load profiles.

In the operational phase the following will be trialled:

Voltage control:

- tightening of voltage limits in response to wind-farm measurement, and
- tightening of voltage limits in response to remote-end measurement.

Power flow management:

- supply of reactive power to wind-farm,
- supply of real power in response to thermal constraint,
- peak shaving,
- absorption of real power in response to wind-farm over-generation,
- absorption of real power in response to reverse power flow, and
- loss minimisation.

ENERGY STORAGE DEPLOYMENT

Although there are significant research elements to this project, it is also a live technology deployment on an operating electrical distribution network. This brings the need for a high level of scrutiny by the DNO in accepting the equipment and operating practises onto their network. Boxes 1 and 2 highlight some of these issues from the perspectives of the DNO as a whole and the operational challenges in particular.

BOX 1: Challenges seen by the distribution network operator

"Deciding how to approve this new piece of equipment so different to anything else approved for connection to our distribution networks was a big challenge. It exports energy into the network, but can be programmed to prevent voltage rise at the point of connection. The VSC uses IGBT valves to control the power flow to and from the energy store and can maintain the voltage at a particular level irrespective of the import or export of real power. On UK distribution networks the use of power electronic devices e.g. FACTS is uncommon. Our engineers are experienced in passive devices e.g. transformers, cables, overhead lines, capacitors and reactors, all of which have a predictable behaviour and can be easily modelled. Different modelling methods have been developed to predict its behaviour considering time as an important variable."

BOX 2: Operational challenges

It is essential to understand how the MACH2 control system operates to ensure that customers continue to experience a safe and reliable electricity supply after installation of the ESS. When a fault occurs on the distribution network that requires the ESS to trip, the control system quickly disconnects the device from the network. It monitors the network and blocks the IGBT valves after a few milliseconds to prevent the ESS supplying a small amount of load in island mode. There is a redundant computer ready to seamlessly take over control should the computer controlling the system fail. If the second computer fails there is a back-up protection system that disconnects the device from the network.

SUMMARY

The deployment of energy storage onto electricity distribution networks is a new and potentially difficult proposition for DNOs. This article has covered a number of the steps needed to make deployment a reality. Modelling and simulation, instrumentation, control and testing have been described. The view of the DNO with regard to new challenges in operating the network has been given.
This is the first time an electrical energy storage device has been installed on an 11kV distribution network in the UK. Commissioning of the installation is expected in January 2011 and then the models that have been developed will start to be verified.

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