ENERGY STORAGE FOR POWER FLOW MANAGEMENT AND VOLTAGE CONTROL ON AN 11KV UK DISTRIBUTION NETWORK

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ABSTRACT

The use of energy storage on distribution networks continues to attract interest as a means to increase the penetration of distributed generation from renewable resources and provide wider network performance improvements. In mid 2009 a 600 kW, 200 kWh Lithium-Ion battery with a STATCOM power electronic interface will be field tested on an 11kV radial distribution network in the UK. Load flow modelling is being used to assess the operating procedures that should be trialled to achieve selected network performance improvements. At present two targets have been evaluated; reduce the steady-state voltage fluctuation at the point of common connection, and reduce the reverse power flow when distributed generation is exporting more power than the local demand. Several modes of operation have been used to achieve these goals, and their strengths and weaknesses have been evaluated.

INTRODUCTION

During 2009 an energy storage system (ESS) will be installed on an 11kV radial distribution network operated by EDF Energy Networks in the East of England. The battery capacity will be sufficient to provide 200 kW of power continuously for one hour and a 600 kW peak output will be possible for short durations. In addition to the real power capability a reactive power source/sink rated at 600 kVAr will always available.

This article reports on work that is being done prior to commissioning, to model the effect of the ESS on the network and thereby inform the operating procedures to be used. A short description of the Status of Energy Storage places this work in context. Detail of the energy storage plant is provided in the description of the SVC Light Energy Storage Concept. The Test Network section describes the characteristics of the 11kV network to which the ESS will be attached. Methods used to investigate the addition of storage to the case study network are described, followed by the Results of the modelling. Finally, Conclusions are given.

STATUS OF ENERGY STORAGE

The integration of energy storage systems into transmission and distribution networks has the potential to provide significant benefits at all points in the supply chain. Increasing penetration of distributed generation (DG), particularly that based on renewable energy resources, is driving the need for distributed energy storage to provide services that will allow existing network assets to continue to deliver reliable, high quality electricity [1, 2].

Energy storage systems are deployed across the world using hydro pumped storage, lead acid batteries and compressed air energy storage [3]. Existing systems tend to provide utility level assistance to solve specific problems. Widespread uptake of storage solutions remains low because of high capital costs, a lack of proven methods for providing revenue streams and the relatively recent maturation of distributed energy storage systems.

There are several technologies able to provide energy storage, their different characteristics make them more or less suitable to operate at particular power and energy levels. Solutions such as flow batteries are able to disassociate the performance characteristics by having an active area that determines the power and an independent storage volume dictating the energy reserve. Battery systems are not able to separate their power and energy capabilities to the same degree, such that a particular mass of battery can store a specific quantity of energy and transfer of that energy can only occur within a fixed range of power levels. For discussion of available storage technologies see [4, 5].

The Li-Ion battery technology chosen for this project benefits from several features: high power density, many cycles before end-of-life, mature technology, high round-trip efficiency, and high charge retention. The battery is interfaced to the network by a STATCOM as described below.

SVC LIGHT ENERGY STORAGE CONCEPT

The SVC Light Energy Storage is based on the STATCOM SVC Light® combined with Li-Ion battery storage.

SVC Light

ABB's STATCOM concept is called SVC Light®. It utilizes a voltage source converter (VSC) connected in shunt to the grid at both distribution and sub-transmission level. In order to match the very high power ratings required by the VSC modules, series-connection of Insulated Gate Bipolar Transistors (IGBTs) is employed. A number of plants for considerably high power and voltage, based on the VSC technology have been built for both industrial [6-7] and power system [8-9] applications. Today, the upper power limit is approximately ±120 MVA. Some of the applications of SVC Light are:

- Reactive power compensation;
- Power factor correction;
- AC voltage control;

- Dynamic voltage balancing when the loads are unsymmetrical and rapidly fluctuating;
- Active filtering of low order current harmonics;
- Flicker mitigation of Electric Arc Furnace (EAF) by using a fast reactive power control;
- Power oscillation damping.

In the left side of Figure 1, a single-line diagram of SVC Light is presented. Each phase-leg of the VSC is connected to a phase reactor. Moreover, a passive shunt-filter is connected between the reactor and the Point of Common Connection (PCC) to remove harmonics. Depending on the PCC voltage, a step-up transformer can be inserted after the filter towards the PCC.

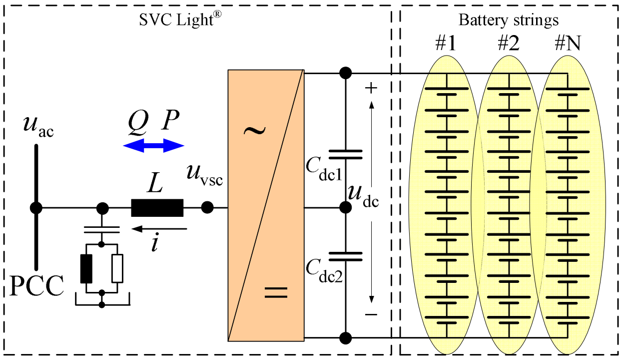

Figure 1: Single-line diagram of SVC Light® with parallel battery strings, consisting of series-connected batteries.

Li-Ion battery energy storage

Since SVC Light is designed for high power applications, and series-connected IGBTs are used to adapt the voltage level, the pole-to-pole voltage u_{dc} is high. Therefore, a number of batteries must be connected in series to build up the required voltage level in a battery string. To obtain higher power and energy, a number of parallel battery strings are added. The schematic layout in Figure 1 shows the complete dynamic energy storage device consisting of an SVC Light together with a number of series-connected battery strings on the DC-side. Thus, the device can both inject reactive power, as an ordinary SVC Light, and active power due to the batteries.

The grid voltage and the VSC current set the apparent power S_{VSC} of the VSC, whereas the energy storage requirements decide the battery size. As a consequence, the peak active power of the battery may be much smaller than the apparent power of the VSC: for instance, 10 MW battery power for an SVC Light of 50 MVA.

To manage the required active power, 8 Intensium Flex racks from Saft have been connected in series. Each Intensium Flex rack weighs 400 kg, is 2.3 m high and consists of 13 battery modules together with a control unit. The maximum voltage is 720V. Each battery module uses 14 VL41M medium power battery cells with a capacity of 41 Ah. Only one battery string is used due to the high performance battery cells. The total voltage of the 8 series connected batteries is 5.8 kV.

Energy storage project

The layout of the energy storage system in Figure 2 as it will be installed shows the AC yard located to the left of the building. It includes the phase reactors, filters, voltage measurements and a transformer. To the right, the breaker, disconnectors and measurement units are located. The building is built up from two containers containing a control room, VSC room, battery room and combined storage and pump room, necessary because the VSC valves are water cooled.

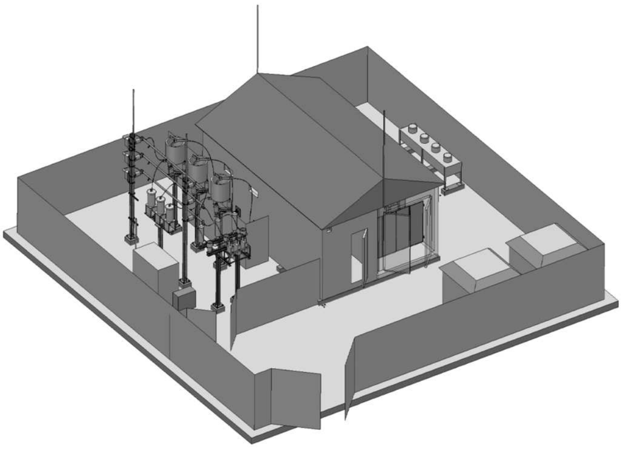

Figure 2: Layout of SVC Light Energy Storage

TEST NETWORK

Figure 3 shows where the ESS will be placed, at a normally open point near the remote ends of two 11kV feeders from different substations. Only one feeder will be connected to the ESS at any single moment, but it will be easy to switch between feeders. Physical network information such as line and transformer data has been provided by the DNO as well as half-hourly operational data comprising feeder current and DG output.

A mixture of residential areas, rural areas and seasonally occupied accommodation are supplied by the feeders in this region. The typical load on the feeders is 1.15 MW and 1.30 MW with peaks of 2.3 MW and 4.3 MW respectively. A windfarm with 2.25 MW installed capacity is attached midway along the first of these feeders. This installation has fixed speed induction generators, so there is significant reactive power demand while generating.

Daily load profiles show that the two feeders have quite different characteristics. On the first, the most significant demand occurs during the night, due to a high number of homes heated by night storage heaters. Summer loading is lower than that during winter. The second feeder has much less storage heating, and in this case summer loading is higher than during winter. These dissimilar characteristics mean that events requiring ESS support are likely to occur at different times, maximising the utilisation of the ESS.

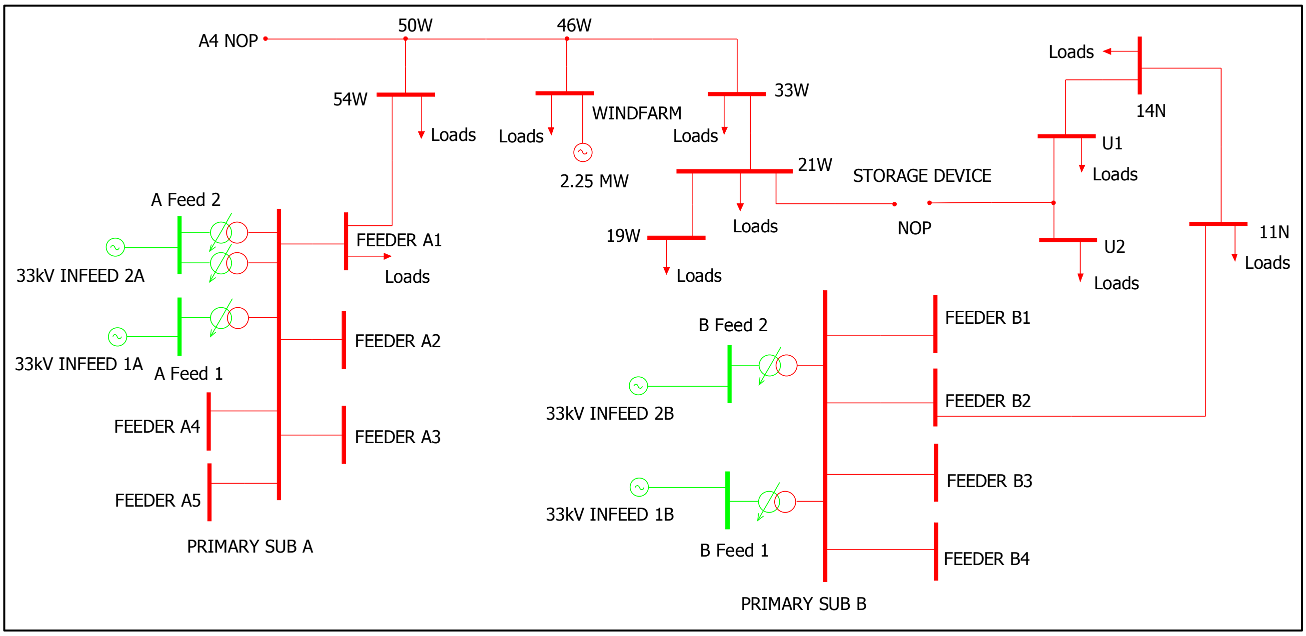

Figure 3: SLD of test network showing location of ESS.

METHODS

Although ABB’s SVC Light is capable of a dynamic response, only steady-state conditions are of interest for the control actions that have been implemented here.

The control actions are simulated in a load flow using IPSA+, under the control of a script written in Python. This method allows one year of data (17520 load flows) to be analysed in a few minutes. Logic for operating the ESS is contained within the Python script and follows the procedure shown in the flow chart of Figure 4.

The input data for the IPSA+ network model comprises load demand, DG output and ESS conditions. An out-of-limit event is considered to have occurred if the desired control target is not met. Several ESS response algorithms have been trialled, based on different priorities and ratios of real and reactive power.

The power flow is limited by the converter rating, and because the battery’s charge is a finite resource, the ability to supply or absorb power is dependent on past events. These limitations must be checked before implementing a requested control action.

After the out-of-limit event is resolved or the ESS has no capability to respond, critical network parameters are logged before moving on to the next time point and repeating the process.

The control algorithms can use real power, reactive power, or a combination of both. Those applied were selected from the following six possibilities:

1. P-priority – increase the real power contribution to maximum, then also use reactive power,
2. Q-priority – increase the reactive power contribution to maximum, then also use real power,
3. Q:P – use reactive and real power in equal measure,
4. 2Q:P – use twice as much reactive as real power,
5. 3Q:P – use three times as much reactive as real power,
6. P-only – do not use any reactive power.

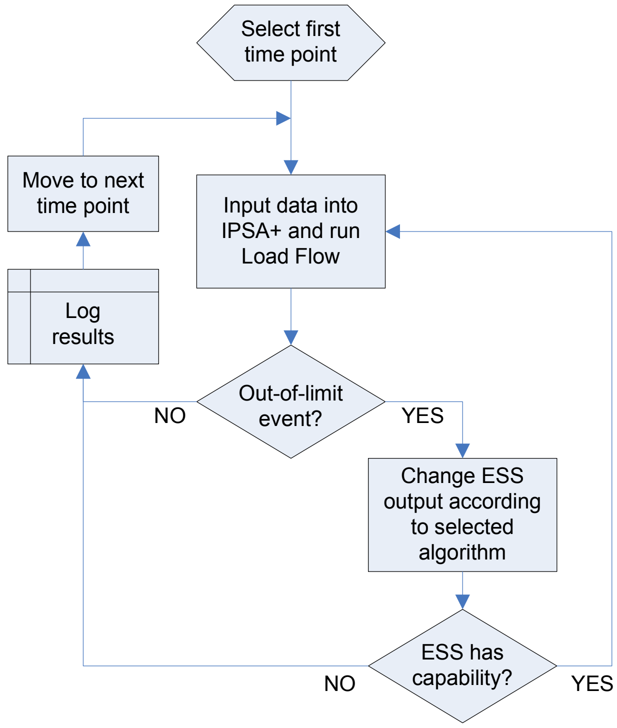

Figure 4: Flow chart of script used to analyse ESS response to out-of-limit events.

RESULTS

Two scenarios are presented here. In both cases the ESS is attached to the feeder from Substation A in Figure 3. The first control target is to prevent the voltage seen at the ESS PCC falling below 0.985pu or rising above 1.0pu. The second is a reduction in reverse power flow off the feeder when local generation exceeds demand. The ESS starts operating when a threshold of -0.5 MW is crossed.

Voltage control at PCC

For this simulation, the state of charge (SOC) of the battery is not accounted for. The demand is bi-directional which makes the problem of deciding on the waiting state of the battery rather complicated. It is assumed for the moment that the flow into and out of the battery balances. This shortcoming will be addressed in later work.

Referring to Table 1, the last three strategies are all able to eliminate out-of-limit events. Using only real power is the least successful strategy. The losses associated with each strategy are also closely linked to the contribution of real power. The Q-priority strategy is the only one seen to also reduce losses.

Reduction of reverse power flow

To implement this control action, real power flow is always into the battery, which makes SOC management both more important and easier to implement. The reduction in energy export from the feeder is used to judge success.

Since this action is responding to real power flows it is not surprising that those strategies in Table 2 with a higher proportion of real power involved are generally more successful. A substantial number of out-of-limit events are not solved by ESS intervention, this results from the finite ability of the battery to absorb energy.

All the strategies result in a reduction in losses on the network. Increasing the reactive power contribution tends to cause the greatest reduction in losses.

Table 1: Results for voltage control at PCC.

Control Strategy	Out-of-limit event count		Voltage variation at PCC (%)	Change in losses (kVA)
	<0.985pu	>1pu		
No ESS	500	257	4.90	0
P-only	93	40	4.71	+671
Q:P	23	6	3.84	+115
2Q:P	0	3	2.94	+15
3Q:P	0	0	2.50	0
P-priority	0	0	2.50	+648
Q-priority	0	0	2.50	-46

Table 2: Results for reduction of reverse power flow.

Control Strategy	Out-of-limit event count	Change in energy export (MWh)	Change in losses (kVA)
No ESS	383	0	0
2Q:P	249	-5.11	-498
3Q:P	249	-5.17	-542
P-only	263	-5.23	-150
P-priority	263	-5.26	-190
Q:P	263	-5.37	-358

CONCLUSIONS

These studies show that placing an ESS in this 11kV radial distribution network provides the capability to control the voltage at the PCC and reduce the quantity of energy exported from the feeder. The selected control strategies have varying success depending on the ratio of real and reactive power and the priority with which they are applied. In these test cases, the network losses are found to be more favourable when using a higher proportion of reactive power.

It is noted that achieving one control objective can negatively impact on other network parameters. Controlling for voltage at the PCC is seen to increase the voltage variations elsewhere in the network under most control strategies.

The movement of real power into and out of the ESS is time limited by the battery's capacity. Deciding how to allocate this finite resource is a sophisticated problem which requires an ability to anticipate the upcoming short-term demands.

Ongoing work will explore alternative control targets and seek solutions to the management of real power capacity.

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