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INTEGRATION OF ENERGY STORAGE TO IMPROVE UTILISATION OF DISTRIBUTION NETWORKS WITH ACTIVE NETWORK MANAGEMENT SCHEMES

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ABSTRACT

Active Network Management (ANM) has been developed over the past decade in the UK as a potential solution to facilitate integration of Distributed Generation (DG) in distribution networks. It is used to manage network limits and allows significantly cheaper and faster connections for DGs, compared to the network reinforcement. However, ANM can help with the DG penetration only to a certain extent as new DG connections in constrained networks will result in curtailment. This paper investigates the levels of energy storage and locations of its placement in reducing curtailment of DGs and improving utilisation of distribution networks with ANM solutions. It evaluates and compares energy storage values of energy storage capacity at different locations, and using the real network and wind data provided by SP Energy Networks (SPEN) Accelerating Renewable Connection (ARC) project.

INTRODUCTION

The growing penetration of distributed generation (DG) connected at lower voltage levels, has introduced significant network management issues, which requires more actively operation of the networks by Distribution Network Operators (DNOs). Instead of costly and time consuming network reinforcements, a cheaper and faster solution known as the Active Network Management (ANM) has been developed over the past decade in the United Kingdom (UK) [1]. Since, in the UK, the costs of network reinforcement due to DG connections are passed to those generators, ANM can allow cheaper and timely connections for DGs.

ANM extends traditional limits on DG capacity of the existing network through real time management of generation (and potentially loads) on the network to match the available network capacity [1]. It monitors the real time network capacity and manages connections in accordance with their commercial arrangements and Principles of Access (PoA). There are two main types of commercial arrangements:

- 'firm connection' which allows generator to export power to the network at all times, and
- 'non-firm connection' which does not guarantee access to the network at all times but rather stipulates that the generator would need to curtail its output whenever instructed to do so by a DNO to avoid network limits being exceeded., e.g. periods of low demand and high generation.

The ANM scheme manages specific generators based on the location of network constraints within the so-called ANM zones. When multiple non-firm generators connect within a particular ANM zone, there is a need for introducing PoA, a method for fair distribution of the limited network capacity between the generators. The most commonly used PoA in the UK is the Last in First off (LIFO), in which the last connected generator is restricted before the first. However other methods have also been investigated [2].

The first ANM scheme in the UK was installed on Orkney distribution network [3]. Although the Orkney Islands have significant potential for wind generation, the ability of Orkney distribution network to accept further DG connection has been limited by the thermal export capacity of two 33kV submarine cables connecting the network with the UK mainland. Since the reinforcement option would have cost an estimated £30 million, an ANM scheme with a total cost of £0.5 million was installed instead [3]. ANM has also been rolled out on the Shetland Islands as a method of managing the stability of the islanded distribution network [4]. On the UK mainland, ANM has been proposed in the areas where the network capacities are close to their limits in terms of DG connections. These are part of a number of Low Carbon Network Fund projects [5], such as Low Carbon Hub [6], Flexible Plug and Play [7] and Accelerating Renewable Connections (ARC) [8]. The ARC project deployed the ANM scheme at 11kV level and investigated different ways of integrating new DG connections to distribution networks that were considered full under existing management strategies.

This paper investigates how the application of energy storage can help to reduce curtailment of distributed generation and improve utilisation of distribution networks with ANM solutions. It evaluates and compares curtailment levels with and without energy storage technologies using the real network and wind data provided by the ARC project. In addition, the paper studies most appropriate energy storage placement points. The network under investigation includes multiple feeders with different levels of DG connections, supplied at the common Grid Supply Point (GSP). The arrangements with multiple feeders, with different levels of DGs and load, may make voltage management more challenging, so the application of energy storage in such networks may provide significant benefits.

ENERGY STORAGE

DNOs deal with network constraints under various energy system conditions, taking into account varying load demand and generation outputs and real-time network control through applying different flexible elements, etc. Energy storage devices are one of the solutions to provide additional flexibility into the constrained networks, such as the network in the ARC project.

The ARC project is looking to connect more renewable power generation in the network, which introduces challenges to the network operation due to the stochastic characteristic of the renewable energy resources. As mentioned above, the constrained ARC network is managed by the ANM system, and outputs of those non-firm DGs are curtailed under specific conditions. The curtailment of the DGs results in reduced revenue to their owner.

Energy storage could help balancing the supply and demand in the constrained network, especially during the peak load period. In addition, it could reduce the curtailment of the non-firm DGs through storing the surplus energy that would be wasted/curtailed otherwise. Furthermore, energy storage devices could be used for voltage management by injecting/exporting real power under an export/import operational mode, respectively [9].

Energy storage technologies could be classified according to the energy form stored in the storage system, containing mechanical (pumped hydro, compressed air, and flywheel), electrochemical (Lead acid, NaS, hybrid flow, etc.), chemical (electrolyser, fuel cell, etc), electrical (double layer capacitor and superconducting coil), and thermal (heat storage) [10]. The storage technologies are compared in Fig. 1. It can be seen that each technology has different features in rated power, energy, and discharging duration.

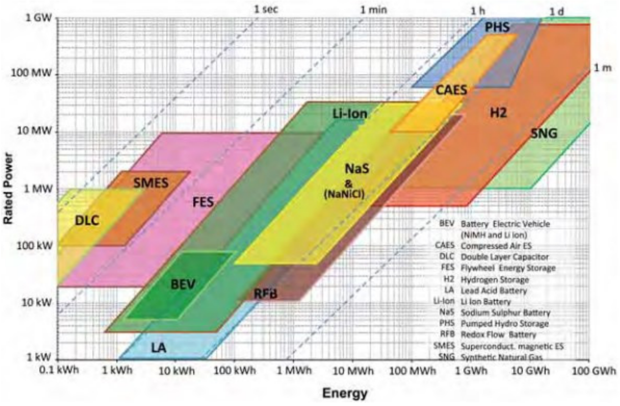

Fig. 1 Energy storage technologies comparison – rated power, energy form and discharging time [10].

The wide range of the energy storage technologies enables the storage devices to be utilised on multiple applications to the energy grid, such as provision of supply reserve, load shifting, frequency and voltage management, and integration with renewable energy.

Energy storage in the UK

Energy storage devices can participate in the UK ancillary services market, providing short term operating reserve in times when there is a shortfall of generators, responding to frequency variation and delivering frequency response services.

The Northern Isles New Energy Solutions (NINES) [11] carried out by UK Scottish & Southern Electricity (SSE) Networks installed a 1MW 3MWh Valve Regulated Lead Acid (VRLA) battery in Shetland, which is located in the north of Scotland and has no cable connection to the UK mainland energy network. The battery is aimed to reduce the peak demand at Lerwick power station so to reduce the conventional fossil fuel generation, to balance the generation and demand in such a closed network, and to integrate with the renewable distributed generators in order to lower the curtailment on renewable energies.

The Smarter Network Storage (SNS) project of UK Power Networks [12] trialled a 6MW 10MWh energy storage system at Leighton Buzzard primary substation. The SNS project is targeted to deferring traditional network reinforcement through providing load shaving during peak congestion times.

The Gigha Battery Project of Community Energy Scotland [13] will install a 1.26MWh Vanadium Redox Flow Battery (VRFB) on the Gigha island. The VRFB is a new means of energy storage; it stores energy in liquid form. The Gigha Battery Project looks to reduce curtailment on the grid constrained wind farm through applying a VRFB on the island. In addition, the additional income received because of the VRFB will benefit the Gigha community.

To summarise, energy storage could be one of the flexible solutions to help DNOs deal with grid constraints, network congestions, and curtailments of renewable DGs. The following section will investigate different case studies to show how the application of energy storage can improve the utilisation of the renewable energy and conclude the most appropriate location for placing the storage in a section of the ARC distribution network with an ANM scheme.

DESCRIPTION OF THE ANM NETWORK

Fig. 2 shows the ANM scheme model used in this paper. The scheme represents a simplification of the real ANM network operated by SPEN, although due care has been taken to match the model as closely as possible to the information available on the design of the actual network.

The scheme is connected to the transmission network via two 132kV/33kV transformers with 120MVA export capacity. At the time when this work was carried out, six DGs were assumed to be connected to the GSP. Two wind farms, Firm WF and WF 1, have already been connected to the 33kV busbars, and WF 3, 4 and 5 have been applied to connect together with an incinerator – energy from waste (EFW). Firm WF is connected through firm connection arrangements while all others are connected through non-firm connection arrangements, as well as EFW. It should be noted that this EFW is the first synchronous generator in the UK controlled by the ANM system.

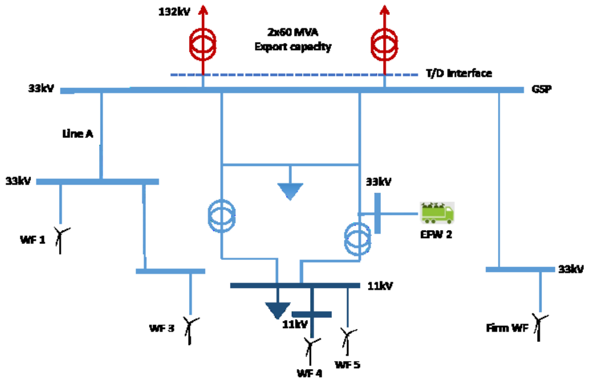

Fig. 2 ANM network model.

Assumptions about the operation of the ANM scheme, i.e the ANM stack positions of all DGs have been provided by SPEN. The 'stack' lists the priority with which each generation gains access to the distribution network during periods of constraint and is based on LIFO. Connection points for all DGs, together with their connection levels and capacities, are shown in Table 1.

Table 1 ANM scheme.

Connected generation	LIFO Priority	Connection level	Capacity (MW)
WF	Firm	33kV	62
WF	1	33kV	48
EFW	2	33kV	36
WF	3	33kV	9
WF	4	11kV	1.5
WF	5	11kV	5

ANALYSIS

In order to investigate how the application of the energy storage can help to reduce curtailment of DGs and improve utilisation of the ANM network, the analysis was carried out based on one-year half-hourly data for 2012 provided by SPEN. The data consists of historical and estimated output data for DGs and demand connected to the GSP. Data sources of uncurtailed generation outputs for all DGs are shown in Table 2. Outputs of the connected Firm WF and WF 1 are based on the historical time series, while generation for WF 3, 4, and 5 are estimated by scaling WF 1 output to the capacity of each wind farm.

The calculations are based on the following assumptions:

- WF 1 and WF 3 are connected to the GSP via the circuit with 52.17MVA capacity (Line A in Fig. 2).
- EFW is assumed to generate at full capacity at all times.

Table 2 Wind farm characteristics and data sources.

	Firm WF	WF 1	WF 3	WF 4	WF 5
State	Operational	Operational	Applied	Applied	Applied
Capacity (MW)	62	48	9	1.5	5
Data sources	Historical	Historical	Scaled WF 1	Scaled WF 1	Scaled WF 1

This analysis also takes account of network effects, including electrical losses, reactive power and voltage fluctuations.

The following 3 different case studies are considered:

1. *Base case* when no batteries are connected.
2. *Case I* when one battery is connected.
3. *Case II* when two batteries are connected.

Each of these case studies is investigated under normal conditions, when both 132kV/33kV transformers are in operation and under N-1 outage conditions, i.e. when one of them is out of operation.

CASE STUDY RESULTS

This paper presents only the case study results for one day. This day is chosen as the worst case scenario as it represents a day with the lowest demand occurred in 2012.

Base Case

Fig. 3 illustrates the levels of curtailment that each generator would experience under normal conditions. It can be seen that the curtailment levels of WF 1 and EFW 2 are zeros during the entire period, while WF 3, 4 and 5 are mostly curtailed during the off peak times.

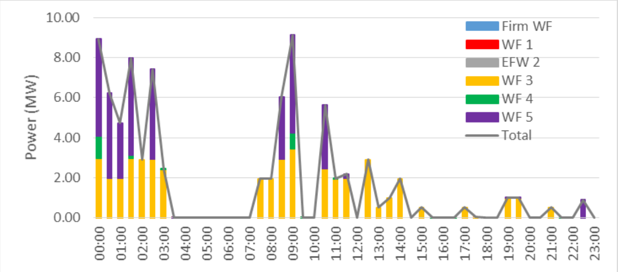

Fig. 3 Curtailment levels under normal conditions.

The curtailment levels of generators under N-1 outage condition are shown in Fig. 4. As expected, the total amount of curtailment is increased by the capacity of the transformer. In this case, all generators would experience some curtailment; EFW 2, WF 3, 4 and 5 total curtailment and WF 1 60-100%.

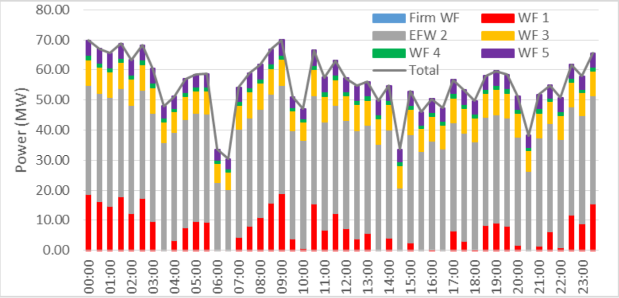

Fig. 4 Curtailment levels under N-1 outage conditions

Case I

In this case, the network is analysed with one battery connected to the network. The following locations are considered for the connection of the battery, as it can be seen in Fig. 5:

- the busbar of WF 1, behind the Line A constraint and
- the busbar of WF 4 and 5, as they are the last DGs in the 'stack' and experiencing the most curtailment.

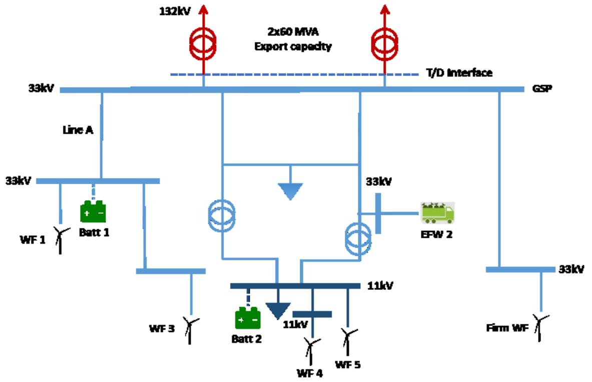

Fig. 5 ANM network with connected batteries.

Fig. 6 shows the battery activities against total curtailment when only one battery is connected per time. Both batteries are set to unlimited rated power and capacity, so to analyse capacity and location for the energy storage placement.

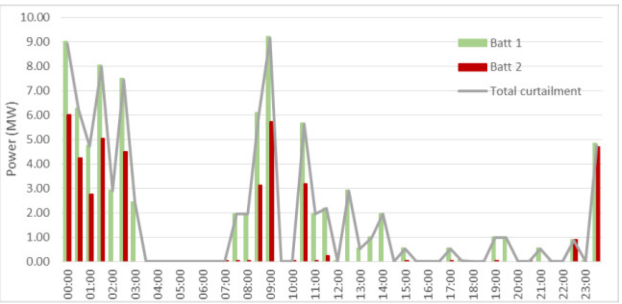

Fig. 6 Battery activities under normal conditions. One battery with unlimited rated power connected at the time.

It can be seen that for each hour, the power stored in Batt 1 is the same as the total curtailment, while Batt 2 is not able to cover all the curtailment due to line ratings and voltage limits. In particular, WF 3 would still be curtailed due to the limits of Line A.

Similarly, as in the base case, the same analysis was carried out for the outage of one transformer and these results are shown in Fig. 7. As under normal conditions, Batt 1 is able to cover all the curtailment as the flows from other busbars are lower than the Line A capacity. However, when only Batt 2 is connected both WF 3 and EFW 2 would still be curtailed.

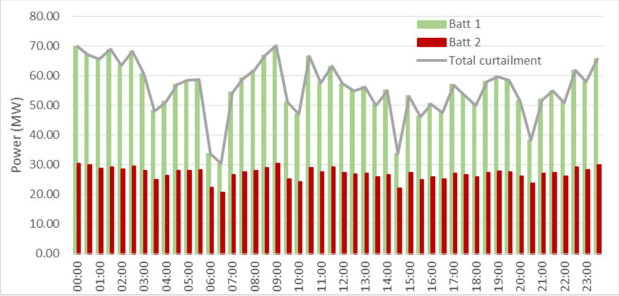

Fig. 7 Battery activities under N-1 outage conditions. One battery with unlimited rated power connected at the time.

Case II

This case analysed the network when both batteries are connected to the network and limited to charge 3MW per hour. This rated power was chosen to show the realistic case how the battery could help utilise the curtailed renewable generation. Fig. 8 shows the results of this case under normal condition.

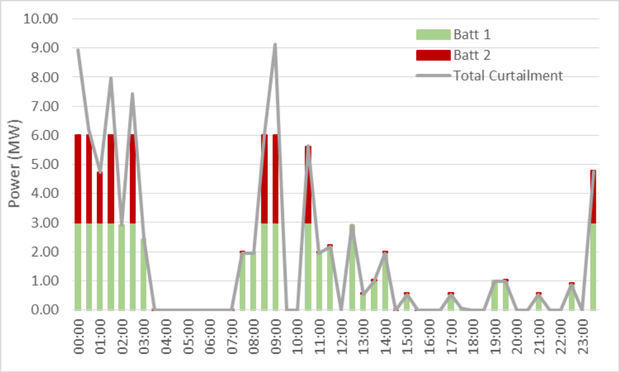

Fig. 8 Battery activities under normal conditions. Both batteries are limited to charge 3MW per hour.

It can be seen that Batt 1 would always be used first because it is closer to the GSP and Batt 2 is located in a more constrained local area with circuit line limitations. Batt 2 will be used only when WF 4 and WF 5 are curtailed, as these wind farms are located in the same local area as Batt 2. This can be observed in Fig. 8 during the period from around 12pm to 9pm. Similar behaviour occurs when one transformer is out of operation. This cannot be seen from Fig. 9 as the curtailment is much higher than the total rated power of both batteries.

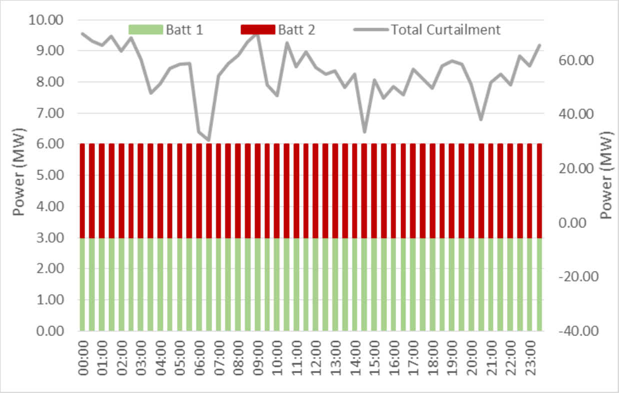

Fig. 9 Battery activities under N-1 outage conditions. Both batteries are limited to charge 3MW per hour.

When the curtailment is high under both normal and N-1 outage conditions, the two batteries operate at their full power to reduce curtailment.

CONCLUSION

The work presented in this paper presents the evaluation of energy storage size and location so to reduce curtailment and improve the utilisation of the distribution network with the ANM scheme. Simulation results for the continues evaluation within the 24h period give an insight not only in the MW size of the battery, but can help evaluate the operating regime and MWh capacity of the storage. Because it was shown that line ratings and voltage limits could affect the amount of power being absorbed by a storage device, it is still important to do this analysis in order to find the best location for placing the battery as well as its appropriate size. In addition, the following qualitative points should be considered when assessing these results:

- It is expected that during times when one of two transformers at the GSP is out of operation, there would be significantly greater curtailment.
- Geographical diversity of wind generation may affect curtailment, i.e. values of curtailment may differ when the local wind regime and a type of turbine are taken into consideration.

The analysis was illustrated using the most critical day which represents the worst case scenario when the lowest demand occurs. However, the future work will include studies based on more granular data, i.e. shorter timescales data other than half-hourly, as that would allow to carry out the analysis considering realistic network conditions rather than just the worst case scenario.

Acknowledgments

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