DEMONSTRATING THE CONTROL OF AGGREGATED DOMESTIC BATTERY ENERGY STORAGE SYSTEMS FOR LV NETWORK EFFICIENCY

David DALE
Nortech Management Limited – UK
david.dale@nortechonline.co.uk

Samuel JUPE
Nortech Management Limited – UK
samuel.jupe@nortechonline.co.uk

Ricky DUKE
Western Power Distribution - UK
rduke@westernpower.co.uk

ABSTRACT

The LV Connect and Manage project, delivered by Western Power Distribution (WPD) and Nortech Management Limited, has demonstrated an Active Network Management (ANM) solution to facilitate the timely connection of Low Carbon Technologies (LCTs) whilst traditional network reinforcement takes place. The results presented in this paper prove that LV ANM can be used as a short or long-term alternative to network reinforcement by demonstrating the automated control of the power output of battery storage systems in domestic properties, in response to the power flows monitored at the distribution transformer. In this way, the LV Connect and Manage solution acts as a platform for the control of aggregated distributed energy resources (DERs) and, for the first time in the UK, this has been demonstrated in live operation. This work paves the way for energy efficiencies and local markets to be introduced into the LV network (whereby peer-to-peer trading is facilitated and local demand is met by local generation and storage, rather than being sourced from remote generation).

INTRODUCTION

The LV Connect and Manage (LVCM) project has developed an Active Network Management (ANM) solution to facilitate the connection of low carbon technologies (LCT), such as electric vehicles, photovoltaic (PV) generation, battery energy storage and heat pumps on the LV network [1]. This allows customers to connect their LCTs to the LV network in a timely and managed way, in cases where network reinforcement (the traditional intervention solution) is too expensive or will take too long to deploy.

The LVCM ANM solution needed to be proven as a viable short or long-term alternative to network reinforcement. This has been achieved through trials demonstrating the control of aggregated domestic battery energy storage systems installed in customers' homes.

SYSTEM ARCHITECTURE

The solution architecture for the trials is given in Figure 1. Trials were carried out using a cluster of 16 PV-battery systems installed in customers' homes and connected to a single distribution substation in Milton Keynes, UK. Each battery inverter was connected to a Domestic Load Controller (DLC) box that provided communications from the inverter to a centralized software platform (iHost). This allowed monitoring and control of the battery export. An LV substation monitor was installed at the distribution substation and communicated the bi-directional transformer power flows to iHost.

Figure 2 shows an example installation of the DLC box in a customer's home controlling battery energy storage.

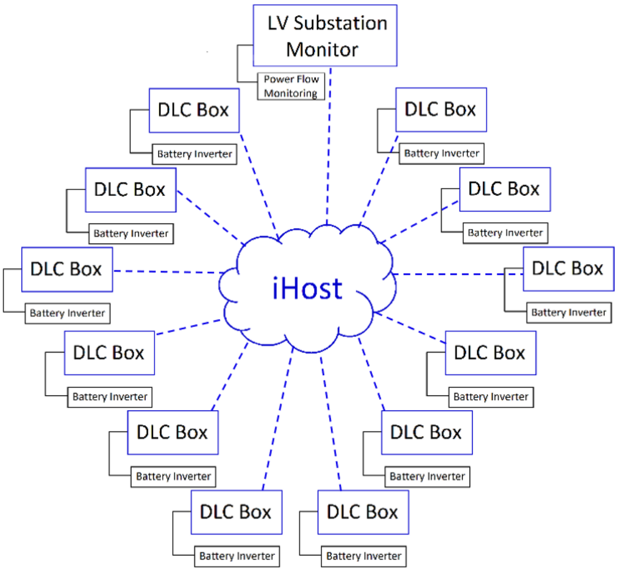

Figure 1: LVCM ANM solution trial architecture

Figure 2: Example installation of battery energy storage, smart inverter and Domestic Load Controller devices in a customer's home

CONTROL ALGORITHM FUNCTIONS

The main functions of the control algorithm are as follows:

- Set point calculation;
- Control latch;
- Enable / disable; and
- Automated / manual run mode.

Set Point Calculation

The control algorithm is designed to compare the distribution transformer power flows against a specified transformer limit and calculate set points to maximise battery export while keeping the transformer power flows compliant with this limit. The control algorithm runs once every minute to calculate new set points based on the latest monitoring data.

Control Latch

In order to provide long-term stability and avoid set point oscillations, when a set point is dispatched that further-constrains the power export, the device control becomes "latched", meaning that it will not accept relaxed set points for a pre-defined period of time.

Enable / Disable

On occasions, it can be a requirement for the Distribution Network Operator to disable the ANM scheme (for example, in the period immediately following network reinforcement but before the ANM scheme is decommissioned). This means that the control algorithm will not run and no set points will be calculated or dispatched.

Automated / Manual Run Mode

The ANM scheme runs in automatic mode as standard, continually evaluating the maximum level to which LCTs can export power. The ANM system can also operate in a manual mode, which means that the DNO can dispatch specific set points to the LCTs. For example, limiting battery export to a certain level when a network fault is in the process of being repaired.

TRIAL METHODOLOGY

The battery systems were set to discharge into the grid, coincidentally with the PV systems, creating the conditions necessary for the amount of power exported to be limited and controlled. The trial was carried out at peak PV export, maximising the likelihood of transformer reverse power flows.

Any battery systems not accepting controls due to communications failure or having been discharged too low to control remotely were excluded from the control algorithm for the trial.

Due to the level of loading on the transformer and the number of PV-battery systems available, reverse power flow at the transformer could not occur. Because of this, the reverse transformer limit was artificially raised into forward power flow values in order to test the automated control. This simply corresponded to a sign change in the calculation and does not affect the validity of the results. The reverse transformer limit was set to various values to observe the response of the control algorithm. The values used for the reverse transformer limit are listed in Table 1.

Table 1: Transformer Reverse Limits set during trial

Transformer Reverse Limit (kW)	Time after start of trial (mins)
0	0
10	9
50	13
60	19
70	24
80	29
70	34
60	39
50	44
40	49
90	64
0	69
80	74
0	79

TRIAL RESULTS

The results of the trial are shown in Figure 3. The red trace represents the power flows through the distribution transformer (kW). The green trace represents the artificial reverse transformer limit that was applied (kW). The blue trace represents the active power set point dispatched by the control algorithm to the battery systems (kW) as it responds to the transformer loading. The yellow trace represents the active power export of the battery systems (kW) as it responds to the set points issued. Positive values represent power flows in the forward direction (substation to domestic property) and negative values represent power flows in the reverse direction (domestic property to substation, e.g. battery system export).

It can be seen that when the transformer power flow is less than the reverse transformer limit, the set point is increased in the forward direction to reduce battery system export and increase the loading on the transformer. This results in the transformer power flows rising above the reverse transformer limit, until the set point reaches 0 kW and there is no more export to reduce. Likewise, when there is headroom between the transformer power flow and the reverse transformer limit, the set point is decreased in the forward direction to allow greater battery system export (without transformer power flows decreasing below the limit).

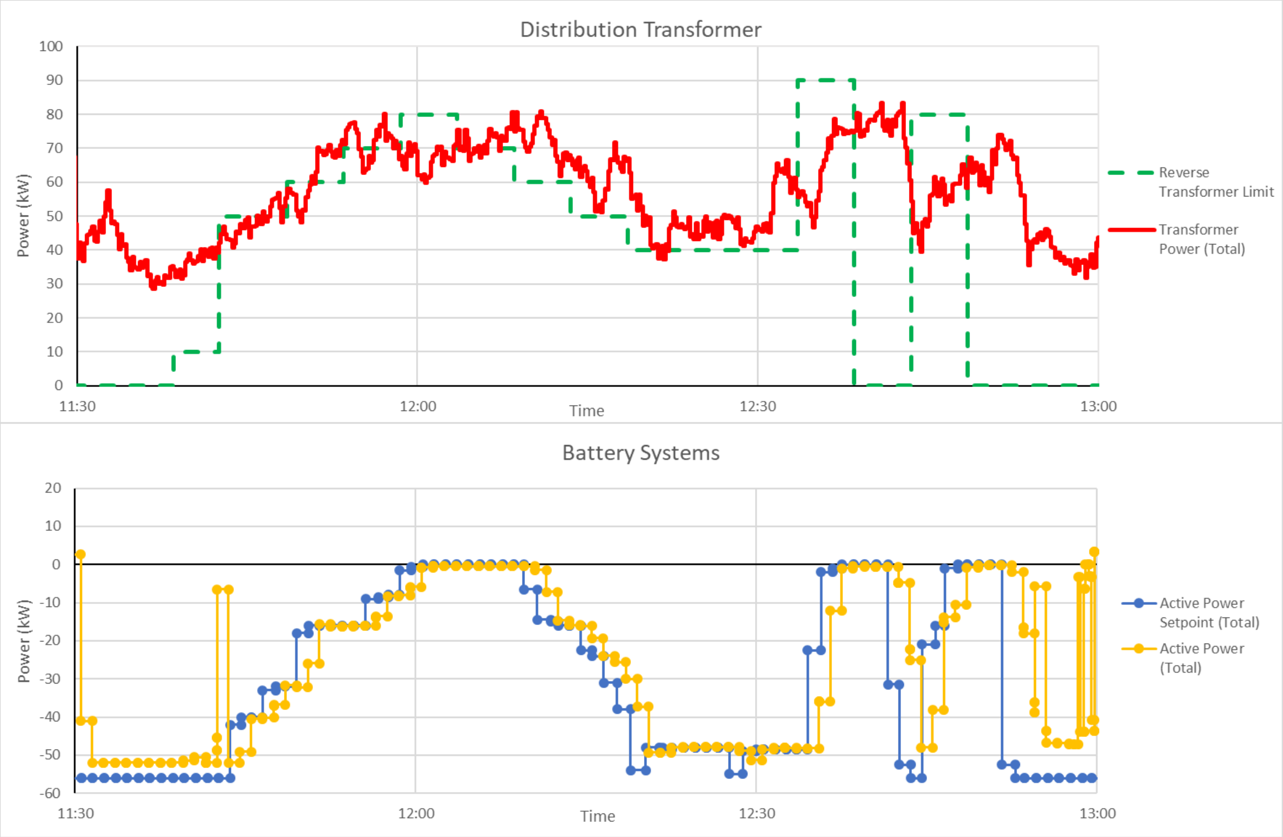

Figure 3: Trial results demonstrating the control of battery energy storage systems in customers' homes

Response Time and Reliability

Through the duration of the trial, 20 aggregated controls were sent to 16 battery systems, resulting in 320 individual controls. 317 (99.06 %) of these were successfully received by the battery systems. 2 of the unsuccessful controls were due to loss of comms between the DLC box and iHost. The other unsuccessful control was due to a new set point being calculated before the control could be communicated to the DLC box.

Of the 320 set point controls sent, 242 (75.6 %) were confirmed by readback from the inverter less than 1 minute from the end of the control algorithm run. The longest time taken for readback confirmation was between 2 and 3 minutes; this only occurred for 3 set point controls (0.9 %). The median and modal class for the set point response time were both less than 1 minute. The full set point response time data is shown in Table 2 and plotted in Figure 4.

Table 2: Active power set point response times

Time for readback confirmation of setpoint	Number of setpoint controls	Percentage out of 320
Less than 1 minute	242	75.6 %
1 - 2 minutes	75	23.4 %
2 - 3 minutes	3	0.9 %

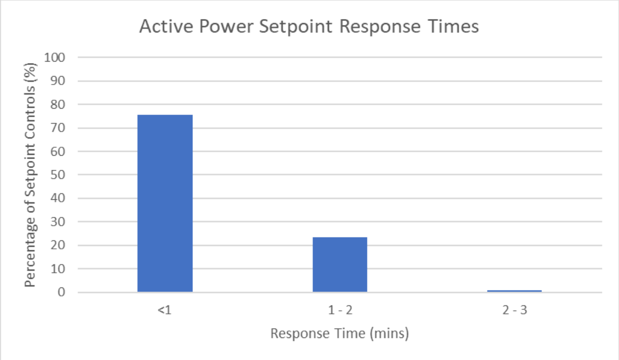

Figure 4: Active power set point response times

Of the 320 set point controls sent, 272 (85.0 %) resulted in the inverter output reaching within 0.2 kW of the new set point less than 2 minutes from the end of the ANM engine run. The longest observed time for this to occur was between 3 and 4 minutes; this occurred for 11 set point controls (3.4 %) during the trial. 7 (2.2 %) of the set point controls had an indeterminate result on the inverter output as a subsequent set point control was sent before the inverter power reached the current set point. The median and modal class for the output response time were both between 1 and 2 minutes. The full output response time data is shown in Table 3 and plotted in Figure 5.

Table 3: Inverter export response times

Time for inverter power to reach within 0.2 kW of new setpoint	Number of setpoint controls	Percentage out of 320
Less than 1 minute	58	18.1 %
1 - 2 minutes	214	66.9 %
2 - 3 minutes	30	9.4 %
3 - 4 minutes	11	3.4 %
Indeterminate	7	2.2 %

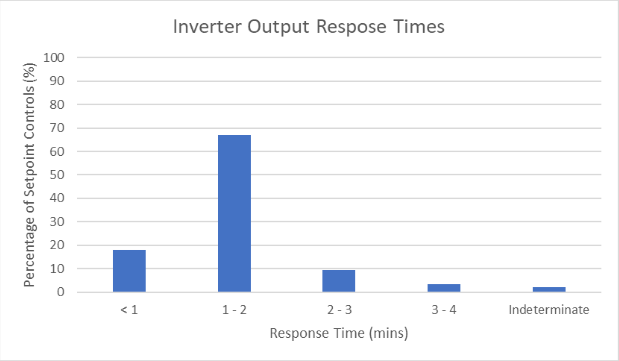

Figure 5: Inverter Output response times

DISCUSSION

Validity of Results

The results presented have been obtained from controlling 16 battery systems on a single substation, based on actual installations of equipment in customers' homes and real-time monitoring and control signals. Therefore, the results are a good indication of actual system performance (which is not always the case when the behaviour of systems are simulated in a laboratory environment).

The solution has been designed to be deployed on a larger scale, with the ANM system monitoring and controlling a larger number of devices and aggregating the monitored data for set point calculation. Due to the considered design of the system (handling each cluster of LCTs separately), the ultimate size of the system is dictated by computational power rather than a limitation in the control algorithm and the number of LCTs connected. Deploying the solution to multiple substations would not impact the validity of the results, as a separate ANM scheme would be set up for each substation and these would not interfere with each other.

The observed system performance figure (99.06 % of set point controls successfully reported back by the inverters) suggests that mobile communications are fit-for-purpose for this application, not severely impacting a network with a greater number of LCTs. For example, considering a substation with 100 3.5kW battery systems connected, 1 system may fail to accept the set point, resulting in up to 3.5 kW of uncontrolled export. This is within tolerance of the quiescent load fluctuation.

Limits versus Targets and Network Efficiency

In normal operation, the battery systems are configured in the 'self-consumption with export limitation' mode. This means that PV offsets the current load demand in the household and the net power is used to charge the battery. As the PV power reduces through the afternoon and evening, the household power consumption is delivered by the battery system and the amount of power imported from the distribution network is reduced (compared to a PV-only household). The amount of power exported into the distribution network varies, up to the limit specified by the ANM scheme, according the combination of PV generation, load demand in the household and state of charge of the battery. (For example, when the battery is fully-charged and the load demand is low, the PV system will export power into the distribution network, up to the allowable export limit).

PV-battery systems can also be configured to operate in 'target power export' mode. In this case, the systems are given a specific signal and export, constantly, at the target level required. This paves the way for DSOs to improve the energy efficiency of LV networks since the load demand on a particular substation could be fed from a number of households with PV-battery systems, rather than from the upstream distribution network. Ultimately this reduces the 'electricity miles' from source to sink, reduces losses and can, therefore, be shown to have a net-financial benefit. This forms the technological basis on which peer-to-peer markets could be established, with PV-battery households trading electricity at a local level and providing a 'network efficiency' service to the Distribution System Operator.

CONCLUSIONS

The field trials of the LV Connect and Manage solution successfully demonstrated the automated control of battery storage inverters in response to the monitored distribution transformer power flows. Set points were calculated as expected, taking into account current transformer loading, controllable generation and a pre-defined transformer limit, and then used to control the battery output with 99.06% reliability and an average 2-minute response time. This proves that the LVCM ANM solution can be used as an alternative to network reinforcement. In this way, the LVCM solution acts as a platform for the control of aggregated distributed energy resources and, for the first time in the UK, this has been demonstrated in live operation. This work paves the way for energy efficiencies and local markets to be introduced into the LV network.

REFERENCES

[1] S. Jupe, M. Prokhnich, 2018, "LV Connect and Manage: A Novel Solution for LCT Integration", *Proceedings Ljubljana Workshop*, CIRED, Paper 0192, 1-4.