DISTRIBUTED STORAGE AND SOLAR STUDY

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ABSTRACT

Growing levels of photovoltaic (PV) penetration on the low voltage (LV) electricity network are increasingly causing reverse power flows and voltage rise issues. Battery energy storage systems (BESS) may not only provide a solution for such issues but also for those associated with the expected increase in evening peak load caused by the electrification of heat and transport. Distributed Storage and Solar Study (DS3) explores the potential for aggregator-controlled behind-the-meter BESS to address these issues by limiting reverse power flows and providing peak-shaving capability. 40 BESS have been installed in 36 homes as part of a 2 year long trial that assesses the impact they have on the network. Analysis to date shows that in general BESS have the capability to address these issues, however the extent to which they are able to do so depends on their mode of operation.

INTRODUCTION

It is expected that behind-the-meter BESS has the potential to address issues related to high PV penetration such as reverse power flows and voltage rise as well as reducing the evening peak load. However, few studies have been performed to date to verify and quantify their actual impact on the network. DS3 attempts to assess the impact BESS have on the network by monitoring a cluster of 40 domestic BESS connected alongside 27 PV systems. The households are connected to two LV distribution feeders, as is illustrated in Figure 1, and data is being recorded from all BESS as well as the distribution substation. Since there are no commercial benefits at the moment for having a BESS in a household without PV (other than those with an E7 tariff), participants without PV were offered an annual financial incentive to participate in the trial. The trial is made up of four monitoring periods, winter 2017/2018 and 2018/2019 and summer 2017 and 2018. This paper discusses the initial findings of the first winter and both summer periods and presents the trial's next steps.

NETWORK CONFIGURATION AND MONITORING

To enable this study, a total of 40 BESS were deployed in 36 premises, 27 of which were installed in homes with PV (26 systems of 2.7 kWp and 1 system of 3.78 kWp) and 9 in homes without. The capacity installed in these homes varies between 2 and 3 kWh (0.43 kW inverter). The remaining BESS were installed in 4 of the 27 properties with a PV system to double the available capacity. Monitoring systems at each property record parameters such as BESS state of charge (SoC), household consumption, generation, power flow in/out of BESS and terminal AC voltage, all of which are accessible through Moixa's web portal. It should be noted that due to installation issues and data monitoring, in some cases only a subset of the BESS fleet could be used as some units were inactive or data was unreliable due to communication issues.

Additional monitoring equipment installed at the distribution substation monitors the aggregated substation power flows and voltage. This configuration allows for high granularity disaggregated and aggregated data analysis. The distribution substation is configured as per Figure 1 and supplies a total of 119 customers. Each of the feeders feeding the area is a radial network of various known cable types and lengths.

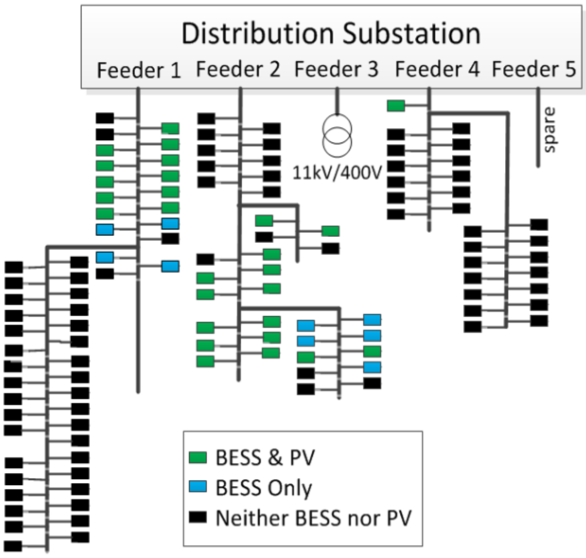

Figure 1: Network configuration

METHODOLOGY

To quantify the impact BESS have on the export profiles of the households, a number of key metrics have been defined and are calculated differently for the summer and the winter periods. The reduction parameter R represents the fraction of the total consumption that is provided by the BESS in the winter and the fraction of the excess generation that has been stored in the summer. The metric R_{time} indicates which part of the time of the peak consumption/generation the BESS is able to supply/store part of consumption or any excess generation and helps identify any systems that stop charging early due to their limited capacity. Finally, R_{peak} is used to determine whether a BESS is able to operate at peak time.

BESS OPERATING MODE

The BESS default charging scheme, threshold charging, is designed to balance consumption and generation by storing excess generation and offsetting import. The inverter has a 200 W charging threshold (the level of excess electricity demand or excess PV output at which the unit (dis)charges) and tries to minimise the house import or export. Finally, the system ensures a minimum SoC of 20%.

In addition to the default operating mode, a number of other charging schemes have been trialed to date to determine the impact BESS can have in supporting the distribution network during the evening peak demand in the winter and peak generation in the summer. The findings from the different charging schemes along with how they operate are discussed in the next section.

RESULTS

A number of charging and discharging schemes have been trialed to assess the impact BESS have on the distribution network. It should be noted that the evening peak demand of the customers in this study is relatively low compared to the evening peak demand of single family properties. Interestingly, despite the relatively low numbers in this trial, the demand profile is comparable with that of the Elderly needs in CLNR trial[1].

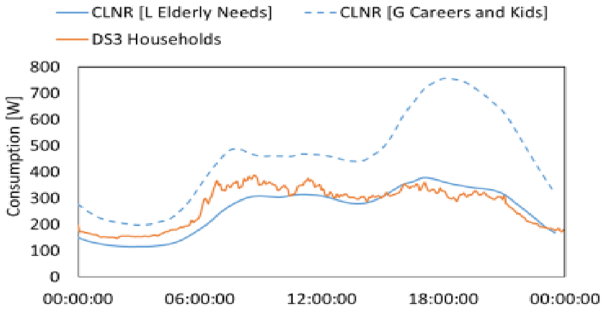

Figure 2: Average daily consumption profiles

Winter

A number of charging schemes have been tested during the 2017-2018 winter period (Sept-March) to determine the impact different operating modes have on the evening peak demand. In all of the graphs below, the blue line represents the household consumption, the yellow line the solar generation, the red line the SoC, the green line the grid import/export and the grey line the BESS charge/discharge rate, where negative indicates charging.

Threshold charging

As the default mode of operation, this scheme charges/discharges based on excess generation or demand and therefore causes no extra costs to the owner. However, due to the high default charging threshold (200 W) in combination with the low overnight consumption levels observed in these households and the limited PV generation on some days), many BESS were inactive for large periods of time. For the households with PV, the limited fluctuation in the SoC suggests that on average only a small portion of the BESS capacity was used suggesting that for consumers with a low average consumption as well as for periods of limited PV generation the threshold to start operating should be smaller to ensure the BESS is not idle when it could be active. A lower threshold level to enable discharging is particularly relevant on days when there is high solar generation, as it ensures the SoC is low in the morning, allowing more generation to be stored. Figure 3 shows a significant amount of average generation being exported at 12:00, circa 50%. Furthermore, the decreasing discharging rate at the same time suggests that some BESS become inactive, either because they are starting to get full, a result of the default inverter charging threshold as well as the high initial SoC, circa 45%, or because the excess generation is smaller than the inverter threshold.

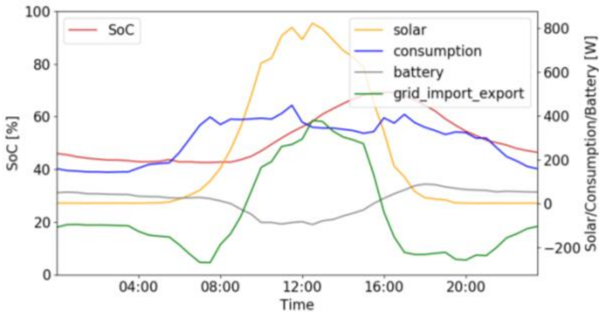

Figure 3: Average threshold charging (households with PV only)

Maximum impact

This scheme focuses on the impact BESS can have on the network, without considering the optimal performance for the owner. In the future, if such a scheme is deemed to be beneficial for distribution network operators, any costs incurred by the BESS owners may be compensated through a financial incentive (discussed in the *"conclusion and next steps"* section below). The scheme forces the batteries to charge during the day (10:00-16:00) and discharge during the evening peak (17:00-20:00). As per Figure 4, this scheme is useful during the winter when the average PV generation is low and hence the BESS might not have been charged fully unless they were forced to. The scheme therefore ensures that the BESS are charged and ready to support in the evening peak. Likewise, forcing the batteries to discharge reduces the evening peak significantly. The average discharge rate at the time of peak is about 300 W, indicating that many batteries were discharging at their maximum rate for most days. Furthermore, the grid import/export shows that none of the generated power was exported to the grid and that at the time of peak demand the electricity imported from the network is small. As opposed to the threshold charging, Figure 3, the charge rate remains the same during maximum generation, a result of both lower generation and lower initial SoC which allows for any excess generation to be captured.

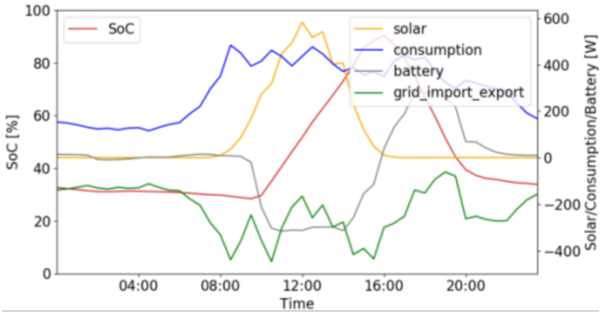

Figure 4: Average maximum impact (households with PV only)

Finally, analysis showed that forcing the batteries in all households (with and without PV) to participate in reducing the evening peak leads to a significant peak reduction *R* of circa 70%, Figure 5.

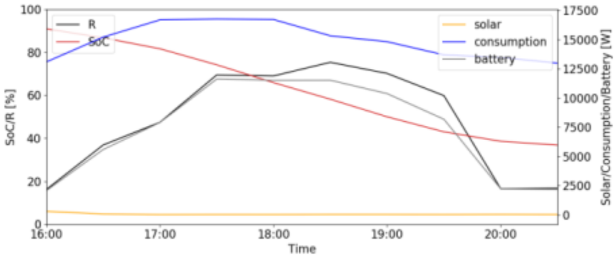

Figure 5: Total maximum impact (all households)

Demand led

The demand led scheme is a combination of the threshold charging and the maximum impact schemes in that it ensures the BESS is fully charged before the evening peak but it only discharges based on excess consumption. For the purposes of this scheme, the threshold level was reduced to 100 W to reflect the demand profile of the households in this trial. Figure 6 shows that even without forcing them to do so, due to the demand, many batteries discharge in the evening peak, reducing it by almost 40%, Figure 7 (albeit consumption was slightly lower than for the maximum impact scheme).

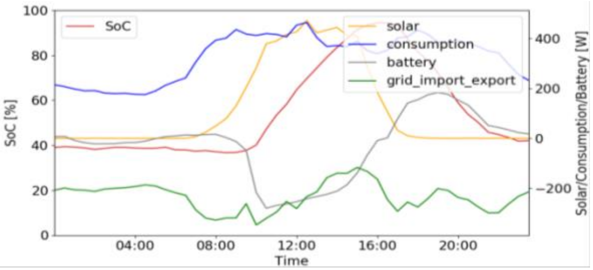

Figure 6: Average demand led (all households)

Furthermore, Figure 7 shows that despite the SoC not reaching 20%, due to the low levels of PV output experienced in the winter, there is adequate demand and available BESS capacity to ensure PV generation is not exported onto the grid, suggesting that forcing the BESS to discharge might not be necessary.

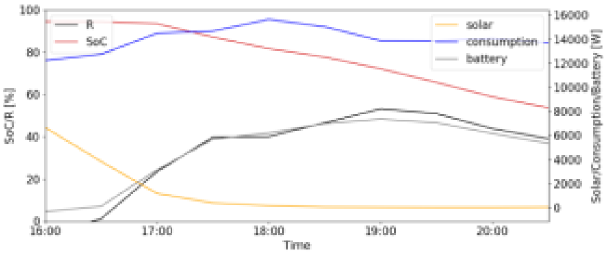

Figure 7: Total demand led (all households)

Summer

The same charging/discharging schemes were trialled in the summers of 2017 and 2018 along with a more dynamic predicted generation scheme in the summer of 2018 with a focus on reducing the generation exported to the network.

Threshold charging

Similar to the winter results, the low consumption levels do not allow the BESS to discharge, resulting in a SoC which does not go below 75%, meaning that only a portion of the excess generation is captured, making this scheme unsuitable for the summer. However, it should be noted that due to communication and BESS performance issues, the dataset analysed was only partially complete.

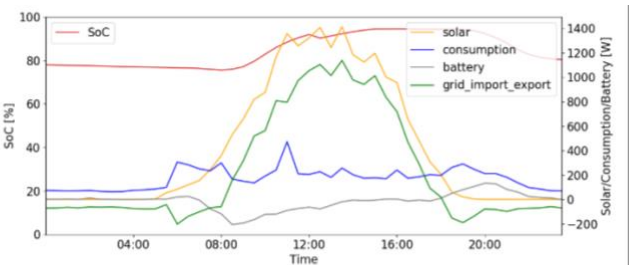

Figure 8: Average threshold charging (households with PV only)

Maximum impact

Trialling this scheme in the summer allows for the batteries to charge/discharge at nearly their maximum rate and keep charging over most of the afternoon. The batteries quickly reduce to a low SoC in the evening by discharging at 400 W for a few hours which allows them to absorb excess generation and assist the network on the next day. Furthermore, as per Figure 9, since all batteries charge at a rate over 300 W, they manage to reduce the average export significantly to approximately 600 W compared to the 1000 W in Figure 8.

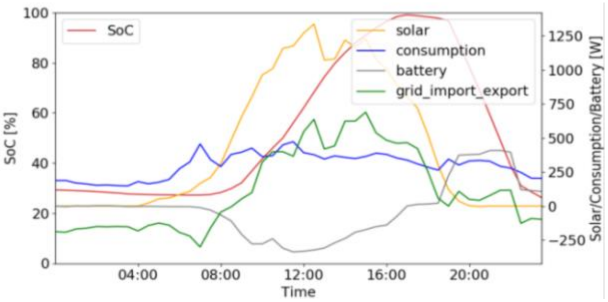

Figure 9: Average maximum impact (all households)

Finally, as per Figure 10, *R* shows that for most of the afternoon the batteries are able to reduce the excess generation by 50% until 14:00 when some of the batteries start to get full and hence reduce the impact on the network.

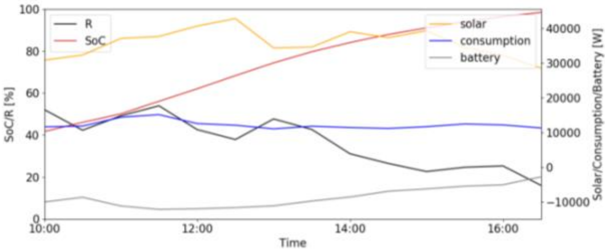

Figure 10: Total maximum impact (all households)

Demand led

Trialling this scheme in the summer has been beneficial as it showed the importance of ensuring the BESS is empty in the morning. In the winter the scheme worked well due to the low levels of generation and the higher evening peak demand, but in the summer the scheme is not suitable as the BESS reach their full capacity earlier due to the high SoC (50-60%) at the start of the next charging cycle. As such, the impact on the network is very limited, as is shown in Figure 11.

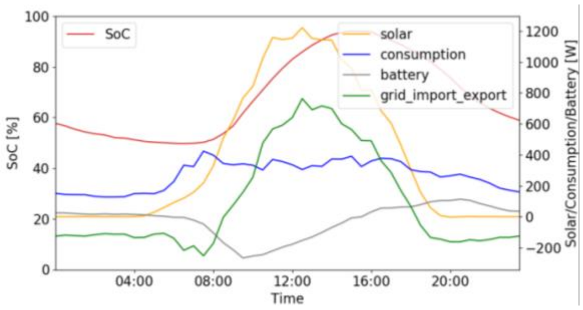

Figure 11: Average maximum impact (all households)

Finally, as per Figure 12, despite an initial 50% reduction (as in the maximum impact scheme), by 12:00 the batteries reach their maximum capacity which then leads to a 20% reduction followed by 0% before 16:00.

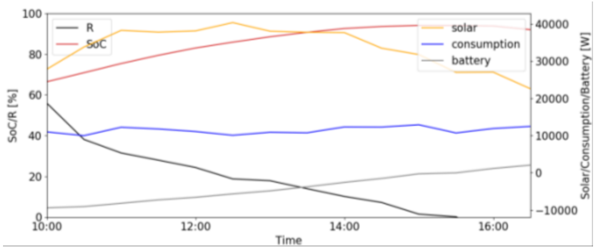

Figure 12: Total maximum impact (all households)

Predicted generation

This scheme uses weather forecasts to determine the expected cloudiness in the area a day ahead and set the BESS charging/discharging scheme accordingly. In this scheme, all units were forced to discharge overnight, and set in threshold mode throughout the day. This meant that batteries in PV homes would charge based on excess generation and batteries in non-PV homes would be inactive (hence incur no additional costs to the owner nor cause any degradation). On clear or partly cloudy days, the BESS in non-PV homes were forced to charge at their maximum rate to help out the network when the impact of PVs is expected to be the largest. The yellow lines (solar generation) in Figure 13 show that on the days for which it was predicted to be sunny (solid line), solar generation was indeed larger than on cloudy days (dashed line). As such, by forcing the non-PV BESS to assist on a sunny day the batteries reduced the exported generation at 14:00 by 10.2 kW (gray solid line) compared to 5.6 kW on a cloudy day (gray dashed line). It should be noted that due to the limited capacity of the installed batteries, the exported generation on a sunny day (green solid line) is still significantly larger than the exported generation on a cloudy day (green dashed line). However the difference is smaller than what it would have been without the assistance of the non-PV BESS.

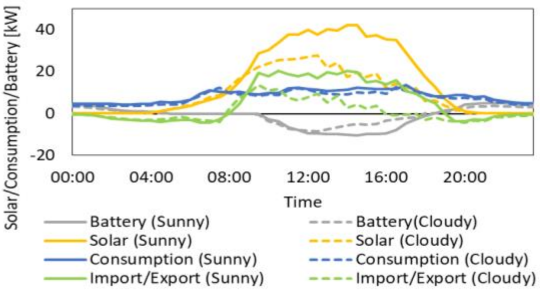

Figure 13: Total maximum impact (all households)

In addition to this, the 1-hour granularity in the cloudiness prediction allowed to predict the cloudiness level throughout the day and as such set batteries to only charge for part of those days. Although in practice this happened only in a few days within the period during which this scheme was trialed, preliminary analysis suggests that such a targeted scheme is equally useful and could be beneficial when considering aspects such as BESS degradation and owner reimbursement costs. Where predictions indicated that it would only be sunny in the afternoon, the BESS forced to charge then were able to achieve a similar impact on the network by charging in the afternoon only as opposed over the entire period (10:00-16:00).

CONCLUSIONS AND NEXT STEPS

A cluster of BESS connected alongside PV is being monitored and preliminary data analysis has shown that forcing the batteries to charge/discharge at their maximum rate during peak generation and demand is more beneficial than a threshold charging scheme and can lead up to 50% reduction in peak export and up to 70% reduction in peak demand. Furthermore, the low overall household consumption experienced in this cluster lead to a number of batteries being inactive, suggesting that the charging/discharging threshold must be set to reflect consumption. In the summer, a more dynamic predictive generation scheme was trialled which confirmed that batteries can be controlled dynamically to reflect changes in the weather and maximise the impact they have on the network. Finally, operating the batteries according to a demand led scheme (generation led in the summer) is not ideal in the summer due to the high levels of generation and low levels of demand. A scheme that forces the batteries to discharge (maximum impact) resolves this and has a much larger impact on the network.

Following the completion of the monitoring period, the data gathered will be analysed further to establish the average BESS behavior for all schemes trialed. Doing so will allow to show the export/import reduction that can be achieved by calculating R for the different schemes and discuss the difference between optimal BESS performance and 'real-life' performance (i.e. fleet availability). Furthermore, analysis of the data collected at the distribution substation will study the impact all schemes had and the extent to which they were able to help the network.

In addition to this, the network model that has already been developed will get recalibrated where necessary to increase its accuracy before simulating a range of scenarios. Various PV and BESS penetration levels as well as different demand profiles will be tested to model power flows and voltage on the distribution network and assess the thermal (demand and reverse power flow) and voltage constraints. The data analysis and network modeling will be used to assess the export reduction that can be achieved by the different charging schemes whilst taking into consideration the importance of the 'real-life' performance. The evidence developed through this project will be evaluated to determine the extent to which relevant documents (such as EREC P5) and company policies can be updated accordingly. Alternatively, additional work that may be required to draw robust conclusions will be highlighted.

The network modeling and data analysis aside, a cost benefit analysis (CBA) will performed to determine the economic feasibility of using a BESS to resolve network constraints as opposed to conventional network reinforcement solutions (e.g. increase network capacity through network upgrades). The CBA framework will include network reinforcement costs as well as information regarding BESS degradation and efficiency to calculate the costs and benefits of using BESS instead. For example, for a secondary substation constraint, the costs of traditional reinforcement will be compared against the costs and benefits of BESS connected to the distribution network (trialed in CLNR[2]) as well as the costs and benefits of BESS connected at domestic premises. For the latter, the different charging schemes trialed in this project will allow to quantify and assess the benefits for customers and DNOs under customer-led schemes (threshold charging) and DNO-led schemes (maximum impact).

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REFERENCES

[1] CLNR General Load Customers. Available at: http://www.networkrevolution.co.uk/customer-trials/domestic-customer-trials/general-load-customers/

[2] CLNR Electric Energy Storage. Available at: http://www.networkrevolution.co.uk/network-trials/electrical-energy-storage/