ARENA Knowledge Sharing Plan – Residential Solar and Storage Program Final Report

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1. Introduction

1.1 United Energy

United Energy (UE) is an electricity distribution business that supplies electricity to more than 680,000 customers across Melbourne's eastern suburbs, south eastern suburbs and the Mornington Peninsula via 13,000 kilometres of wires, 215,500 poles, 78 sub transmission lines and 47 zone substations.

The Residential Solar and Storage Program is a project funded by ARENA that has enabled UE to explore and demonstrate the viability of using Solar Storage technology as an alternative way to manage network capacity constraints and defer traditional network augmentation.

1.2 Traditional Maximum Demand Planning

UE designs and operates its electricity distribution network to facilitate there being sufficient capacity available on the network to meet customers' peak electricity demand requirements. Electricity demand of residential customers on the UE network typically peaks in the evening period over the summer months on the hottest days of the year.

Economic growth, customer number growth, and the installation of sizable load appliances (such as air conditioners) have historically driven peak demand growth on the UE network, triggering augmentation of constrained electricity distribution network assets to avoid overload. This method of reinforcing the capacity of the network is known as 'traditional network augmentation'.

Traditional augmentation solutions are often capital intensive and are typically only available in large capacity increments. Therefore, when traditional augmentation projects are undertaken by UE they are often sized with additional spare capacity to cater for forecast growth in demand. This model works well when maximum demand growth is certain.

1.3 Adapting to the Changing Energy Landscape

A number of changes over the last several years have seen growth in peak demand slow in many parts of the distribution networks across Australia. Such changes have included:

- an increased community focus on energy and the environment;
- increases in electricity retail prices;
- government policies and subsidies to support renewable energy;
- technology advances in the areas of energy efficient appliances; and
- uptake of roof-top solar photovoltaic (PV) systems.

UE recognised early that a broader range of options need to be considered to manage distribution network capacity constraints, given the impact of these changes on peak demand growth.

In an environment where future peak demand growth on constrained parts of the distribution network is uncertain, it has become increasingly difficult to plan (under all credible growth scenarios) for lump sum capacity upgrades using the traditional approach to demand planning. Uncertainty in peak demand forecasts could result in sub-optimal investment decisions being made if a broader range of alternative options are not considered to manage network capacity constraints.

Solar Storage is a technology that provides an opportunity to deliver a more incremental capacity approach to network planning. Technological advancements and ongoing price reductions in solar and storage technologies present an opportunity for industry to utilise the technology as an alternative to traditional network infrastructure for meeting peak demand. Recently, a number of studies have concluded, that Li-Ion battery prices are forecast to fall dramatically within the next few years. This is driven primarily by economies of scale achieved through an increase in manufacturing capacity (partly driven by the increased production of electric vehicles) as well as technological improvements in the energy density of batteries.

Residential rooftop solar PV systems alone do little to reduce peak demand for network assets in these residential customer areas because of the difference in time between the solar PV generation peak and the residential demand peak. However, solar PV coupled with controllable energy storage technology provides the ability to incrementally release capacity (by reducing customers' maximum demand) on the network, as required. If solar PV coupled with storage can be delivered at a lower cost in the future, Solar and Storage can be progressively targeted at capacity-constrained areas of the network to delay a capital investment in augmentation until greater certainty in peak demand growth is evident and it is established that network augmentation is required to support customer load.

Should battery prices fall in the future as forecast, Solar PV coupled with Storage is likely to become economically feasible relative to traditional augmentation at a number of locations on the UE distribution network. UE has estimated that by 2025, Storage could be a cost effective solution for some distribution substation and low-voltage (LV) circuit constraints on the UE distribution network.

1.4 ARENA and UE Residential Solar and Storage Systems (Project)

UE sought as a deliverable for this ARENA-funded project, to undertake a targeted deployment of solar PV and storage at customers' premises that are connected to constrained (overloaded) distribution substations on the UE distribution network. The Project aligned with multiple ARENA priority areas for new investments including "Integrating renewables and grids" and "fringe-of-grid and network constrained areas" [1].

UE demonstrated through the Project that multiple Solar Storage units installed on a constrained distribution substation can be controlled in concert to defer investment in traditional substation augmentation projects.

Solar PV coupled with storage-based systems are an emerging technology in the electricity supply industry. Solar PV installers and energy retailers are now offering solar PV systems coupled with storage as prices become increasingly competitive with grid-connected energy. The residential solar PV and storage-based system market is developing rapidly and maturing.

The key objectives of this Project were to:

- validate the ability of solar PV and storage technology to defer or eliminate the requirement for traditional network augmentation. This could be undertaken by controlling and scheduling the residential Solar and Storage systems during the hotter summer months to reduce summer peak demand across constrained substations thus deferring network augmentation;
- evaluate and report on the commercial and operational viability of the solar PV and storage technology and its ability to be integrated into business-as-usual (BAU) network operations;
- quantify the magnitude of the different benefits generated through the installation of solar PV and storage for utilities and customers; and
- demonstrate and provide data on the success of operation of the solar and storage systems and associated control algorithms.

Recognising the potential opportunities of residential energy storage, UE and ARENA initiated the Project in mid-2017. The trial was aimed primarily to investigate the potential of residential battery storage coupled with solar PV to:

- demonstrate the capability of the technology as an alternative to traditional augmentation;
- flatten residential customer demand profiles;
- manage the peaks in network demand on constrained distribution network assets that were driven by residential customers;
- improve the integration of residential solar PV generation into the distribution network; and
- assess the financial benefits of battery storage to the network and customers.

2. Substation Identification

Aggregated smart meter data over the 2016/17 summer was analysed to identify substation assets which had been constrained (or overloaded). Subsequently, UE identified traditional augmentation projects to alleviate constraints on the substations identified. UE compared the cost of these augmentation projects with the net cost of Solar Storage solutions (subsidised by ARENA and by customer contributions). Table 1 shows these distribution substations where the use of Solar Storage systems was *'more economically viable'* than the traditional augmentation solution. Analysis revealed a requirement to have a total of 42 Solar Storage systems installed to bring the substations to their design rating to deliver benefits that were effectively equivalent to a network augmentation. Progressive recruitment of customers then allowed some level of augmentation deferral.

Table 1: Constrained Substations, Total and Recruited (Actual and Target) Customers

No	Substation	Suburb	Total Customers	Target Customers	Actual Customers
1	ACHERON KOETONG	Mount Eliza	107	3	4
2	ENTRANCE NEPEAN	Seaford	73	3	1
3	FLORENCE-GERALD	Blackburn Nunawading	82	3	2
4	HYPERNO LAYTON	Mount Martha	141	4	4
5	KARRAKATTA-BLUFF	Black Rock	99	3	1
6	MILLGROVE GEORGE	Scoresby	104	2	2
7	PRINCETON STANFORD	Keysborough	84	6	11
8	TRENTBRIDGE MANCHESTER	Mulgrave	86	3	4
9	WINDSOR-ST JAMES	Bentleigh	167	4	5
10	AMETHYST DIAMOND	Glen Waverley	133	2	2
11	BRIGGS CHLORIS	Caulfield	73	3	2
12	CASTLEWOOD MARLBOROUGH	Bentleigh East	156	2	2
13	WARATAH WARRIGAL	Bentleigh East and Oakleigh South	93	3	1
14	MT PLEASANT LORIKEET	Nunawading	98	1	1
TOTAL	–	–	**1,496**	**42**	**42**

Figure 1 shows the geographic locations of the Solar Storage systems installed under the ARENA-funded Program.

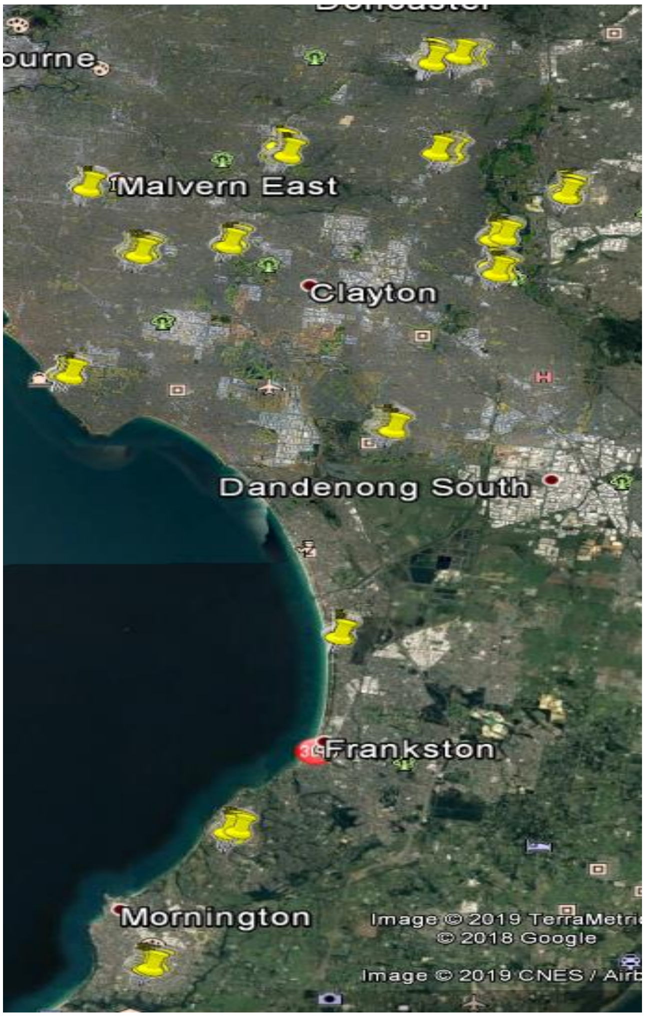

Figure 1 Solar Storage Systems Installed under the ARENA-Funded Program

3. Installation and Operation of Solar Storage Systems

3.1 Technology Selection

UE undertook a comprehensive investigation to identify and understand the state of technology that would be suitable for this Project. The following hardware was recommended for procurement and installation as the least-cost lifecycle option for the Project:

- Solar PV system with optimisers (15 Jinko Solar Panels × 270W = 4kW);
- LGChem RESU10 battery (9.8kWh);
- Sungrow SH5k (5kW) inverter; and
- Reposit Power control.

3.2 Customer Identification

With suitable distribution substations for the Project identified by UE, the next phase of the project was to identify appropriate customers on the substation to target for the installation. It may not be economically viable to install Solar PV and Storage for the customers at all these sites. UE then sought to install solar PV and storage at customers that provided good value for the network but also good economic return for their investment. In order to identify and target these *'high value'* customers along an overloaded substation, UE used a combination of smart meter data, demographic profiling and market research to assist in the analysis and selection of suitable customers on each substation subsequent to customers registering.

Customers that provided the best network benefits were strategically targeted by UE for having the Solar and Storage systems installed. Initially, UE did not consider customers who already had solar PV installed. A key reason for this was to avoid interfacing and potential warranty issues which may arise from existing solar PV panels.

3.3 Installation and Operation

A marketing plan was developed for the Project and deployed to recruit potential customers supplied by the nominated distribution substations. UE undertook marketing to approximately 1,500 customers targeted across the identified constrained substations. 150 customers registered with 85 proposals prepared and submitted to customers. A preferred installer was engaged for procuring hardware and undertaking installation works. The preferred installer completed site assessments for the 150 registered customers. 27 Solar and Storage systems were installed by 15 December 2017, ready for dispatch during the 2017/2018 summer with the remaining 15 Solar and Storage systems installed by 31 May 2018. As a result, a customer uptake of 2.8% was achieved.

Site visits were undertaken to customer premises and included technical representatives to ensure the customer fully understood the product technology and how it would be controlled by UE, as well as a sales representative that communicated the benefit of the offer being presented to the customer via marketing collateral. Once a customer agreed to participate in the project, the customer entered into a legal agreement with UE.

UE controls the multiple solar PV and storage units on a substation as an aggregated fleet for network benefits (i.e. shaving the customers demand and exporting to the network) on peak demand days when the ambient temperature exceeds 35°C. All other times, the solar PV and energy storage units are used for the financial benefit of the customer (i.e. to maximise their self-consumption of solar).

After commissioning, UE tested and demonstrated the operation of the systems over the 2017/2018 and 2018/2019 summers. UE currently has the capability of monitoring the performance of the customers' solar PV and storage units remotely, as well as providing all maintenance and repair services required for customers in the event of a fault or mal-operation with the systems. UE plans to continue to implement a number of adjustments to the control algorithms in order to optimise the operation of the Solar and Storage systems for the next summer.

3.4 Transition to Business-As-Usual

Testing was undertaken over summer 2017/18 for 27 systems and over summer 2018/2019 for 42 systems. This report documents the full set of results and analysis.

An important part of this Project was to establish the appropriate plans and business systems in order to integrate the systems installed as part of this project into BAU processes. This included the development of asset management plans as well as the establishment of procedures for ongoing customer support of the units.

UE also intended to provide this knowledge sharing report to ARENA to communicate the project outcomes and learnings within the industry.

With recent ring-fencing guidelines prohibiting UE from owning any further behind-the-meter installations, it is now planned to expand the learnings generated from this Project and those from the earlier Virtual Power Plant (VPP) pilots to an LV grid-side battery trial. This LV grid-side battery trial will continue to develop the technology in a way that it can be used as an incremental approach to address immediate capacity shortfalls and defer traditional network augmentation solutions. A pilot is currently underway, being supported by UE's 2016-2020 Regulatory Control Period Demand Management Innovation Allowance (DMIA), set by the AER. Public reporting on this trial is expected to be available on the AER's website during 2020.

4. Benefits and Economic Value

The main benefit arising out of this Project was the confirmation that residential Solar and Storage systems can be successfully used as a viable network augmentation alternative to address real network capacity constraints. It was also confirmed that Solar and Storage systems are likely to become economically competitive (if battery prices continue to fall as predicted) against the cost of traditional augmentation solutions in certain constrained areas of the distribution network within the next several years.

While the Project identified that network capacity constraints could be addressed at localised levels, if Solar and Storage systems are deployed at a greater scale, aggregating the systems within a geographic location could achieve peak demand reductions. These reductions would be sufficient to economically defer larger upstream network augmentation projects. That is, the systems can be used to coincidentally address more than one network constraint at a time, further improving the economics of the systems.

This Project has familiarised participants with the technology and helped spread knowledge of the benefits of combining both Solar and Storage systems for customers. This will lead to increased customer adoption of Solar and Storage in the market and will also allow greater customer recruitment for these types of projects in the future. This Project highlights to regulators and policy makers, the value that Solar and Storage systems can deliver.

The Project provided significant benefits for the participating customers. Given the peaky nature of residential load, systems are typically only required to operate to reduce demand on the hottest days of the year. On non-peak demand days, the Solar and Storage systems operate to maximise the customers' own economic benefits from significantly lower grid consumption with savings realised through electricity bills.

By undertaking this project with ARENA, UE has been able to share its key learnings which will be invaluable for the industry for implementation of similar projects moving forward.

This Project aligns with multiple ARENA priority areas for new investments including "integrating renewables and grids" and "fringe-of-grid and network constrained areas". This project has demonstrated the value that renewable energy systems when combined with storage can play in alleviating network constraints.

In relation to ARENA's Advancing Renewables Programme, the objectives this Project has demonstrated are:

Increased the Value delivered by Renewable Energy Sources

Despite the rapid uptake of rooftop solar PV systems over the last decade, there has been a relatively small impact on peak demand. Particularly in residential areas, network peak demand tends to occur in the evening as people arrive home from work, when the generation of solar PV systems is quickly subsiding. Hence, residential solar PV systems alone do not necessarily reduce peak demand.

Residential solar PV systems have low network value as the same level of network infrastructure is still required to meet peak demand for just a few days of the year. Batteries alone can reduce peak demand, but are expensive and rely on charging from the grid.

Energy storage coupled with solar PV systems work together to solve this problem and has the potential to play a key role in supporting future energy infrastructure. Solar PV paired with batteries is a more optimal solution to supply power in times of peak demand rather than solar PV or batteries alone as solar energy helps fill the first part of the residential peak period (typically 4:00 - 5.30 pm) and batteries can be used for the remaining part of the peak (5.30 – 7:00 pm).

This Project demonstrated to the industry, the capability and value of the role that renewable energy systems with storage can increasingly play as a potential economic alternative to traditional network augmentation. In the future, as costs reduce and more customers take up solar PV and/or storage systems, networks could potentially procure and utilise Solar and Storage systems at very low cost across its network delivering benefits for all users.

Reduced the Barriers to Renewable Energy Sources Uptake

This Project has provided investors, the industry and the regulator with an understanding of the value that renewable energy systems combined with energy storage can play in the future, enabling them to establish appropriate conditions and frameworks for entry into the market. Successful demonstration of economics and technology provides a stepping stone for investment in solar and storage.

1. *Increase skills, capacity and knowledge relevant to renewable energy sources*

This Project has helped broaden the knowledge base and capability for many stakeholders including distributors, equipment suppliers, retailers and customers. Key learnings from this Project for the industry included:

- Introduction of a new commercial model to the market that can facilitate investment in Solar and Storage by utilities.
- Technical ability of Solar and Storage to be collectively controlled to shave peak demand and add capacity to the network during high temperature days.
- Value streams that can be generated through the installation of the technology were quantified including augmentation deferral for the network and increased self-utilisation of solar PV systems for the customer.
- Customer behaviour was explored including response to technology, ownership, installation and operation by the distributor.

2. *Reducing the cost of renewable energy sources*

Successful demonstration of the Project has enabled the reduction in cost of renewable energy technologies as below:

- Investment in Solar and Storage is presently economically unviable for the majority of customers due to the high capital costs of battery technology, however the ability to use the systems for network support improves the economics of such systems.
- The business model is also scalable to larger augmentation deferral projects, thereby increasing the number of locations and applications for which renewable energy systems could be used.
- The developing market for the installation of Solar and Storage systems at residential customers' premises can be facilitated by initiatives like this. It is expected that additional competition, supply chain efficiencies, etc. will develop and lead to a reduction in cost of renewable energy sources for customers.
- This Project has demonstrated the value that renewable energy sources including storage systems can have in reducing network costs, which can enable regulators and policy-makers to establish appropriate frameworks to encourage customer uptake.

Network Benefits

For UE, residential Solar and Storage systems have the potential to help reduce network costs by reducing peaks in demand, and managing the impact on the network from standalone solar PV systems. Reducing customers' use of electricity at peak times or shifting the usage to off-peak times is desirable because it reduces the risk of the network becoming overloaded with the associated asset risks. In the long term, this can reduce or defer the need for networks to invest in new capacity that may only rarely be used (i.e. during periods of peak demand), and that would be paid for by customers through their electricity bills.

By storing excess solar PV generation that would otherwise be exported to the grid, storage systems help mitigate technical issues for the network such as the voltage rise that can be caused by high penetration levels of solar PV generation. In this way, storage systems will help facilitate a higher uptake of solar power whilst maintaining network power quality and reliability for all customers.

The network cost reduction benefits are as below:

- The network upgrade solution can be deferred for a number of years depending on the growth rate being experienced. In areas of very high demand growth, it may not be possible to defer an upgrade for long due to the large numbers of storage systems that must be deployed. Storage viability and requirements need to be assessed and implemented according to the peak demand growth in the area.
- The network upgrade solution for a constrained site could be high in cost in some cases. In practice, this can be the case for long rural power lines where an upgrade would require the replacement of many kilometres of line, or where capacity is limited by underground cables that are expensive to replace. In other cases however, a low-cost network solution may exist which would reduce the attractiveness of the

battery storage option. Storage viability and requirements need to be assessed and implemented according to the comparative costs of the traditional network solution on a case by case basis.

- The Solar and Storage systems installed across constrained substations were successfully controlled to act in concert on days of peak demand. The financial value of voltage-rise management through reducing solar exports was assessed to be small in most cases given that low-cost alternative responses such as transformer tap changing can often alleviate the issues. As solar PV penetration increases over time, traditional responses such as this may be less effective, and the relative value of alternative approaches such as battery storage may increase. Options to adjust power factor settings or Volt-VAr modes on solar PV inverters provide a transitional solution to address voltage-rise issues until storage uptake increases which would enable further increases in solar PV penetration.

Customer Benefits

For customers, solar PV and storage systems offer a potential means to reduce electricity bills and to better utilise their solar PV generation. Storage can also be used to provide a backup power supply during times of network outage, however backup functionality was not considered part of this Project.

There are three primary ways a customer can lower their energy costs using a storage system.

1. ***Time-of-use tariff arbitrage:*** When a customer's tariff includes different rates for different times of the day (time-of-use pricing), the customer can charge the storage system during off-peak times when the cost is lower and discharge during peak times, when the cost is higher.
2. ***Feed-in tariff arbitrage:*** When a customer's solar PV generation exports excess energy to the grid at a feed-in-tariff rate lower than the import tariff, the customer can use a storage system to store the excess energy for re-use later when customer energy demand exceeds supply from the customer's solar PV system. This is the default offset control algorithm implemented across all the Solar and Storage systems.
3. ***Demand charge minimisation:*** When a customer's tariff includes a charge for the maximum customer demand, the customer can operate the storage system so as to minimise the maximum electricity demand from the network. The demand charge is typically calculated during peak periods only.

A key finding was the importance of storage capacity for use in demand management. While peak demand periods can vary across a range of networks, a solution which provides a short-term reduction in the peak demand on a network asset should ideally have the potential to provide 3 to 5 hours of demand reduction. The storage systems were discharged across 3 to 4 hours. Where a solution is only capable of shorter dispatch periods, networks would typically combine demand reductions from multiple sources staged in time windows to achieve the required reduction.

The energy storage capacity can be optimised by using automated battery management functions which better utilise the available storage capacity by only discharging at partial power output to maintain network demand to a pre-set threshold. The use of remote measurement devices along with smart control algorithms could be investigated in the future.

4.1 Economic Assessment – Solar and Storage versus Augmentation

In this section a high level economic assessment of Solar and Storage versus augmentation is presented. Table 2 shows a comparison of costs for the 14 constrained substations where installations were completed.

Table 2: Economic Assessment

No	Substation	Total Number of Installed Solar Storage System	Customer Benefits ($k)	Solar Storage Systems Cost ($k)[1]	Network Benefits ($k)	Economic Gap ($k)
1	ACHERON KOETONG	4	12	104	55	37
2	ENTRANCE NEPEAN	1	3	26	55	-32
3	FLORENCE-GERALD	2	6	52	55	-9
4	HYPERNO LAYTON	4	12	104	55	37
5	KARRAKATTA-BLUFF	1	3	26	55	-32
6	MILLGROVE GEORGE	2	6	52	55	-9
7	PRINCETON STANFORD	11	33	285	55	197
8	TRENTBRIDGE MANCHESTER	4	12	104	55	37
9	WINDSOR-ST JAMES	5	15	130	55	60
10	AMETHYST DIAMOND	2	6	52	55	-9
11	BRIGGS CHLORIS	2	6	52	55	-9
12	CASTLEWOOD MARLBOROUGH	2	6	52	55	-9
13	WARATAH WARRIGAL	1	3	26	55	-32
14	MT PLEASANT LORIKEET	1	3	26	55	-32
TOTAL	**–**	**42**	**126**	**1,089**	**770**	**193**
AVERAGE	**–**	**–**	**9**	**78**	**55**	**14**

[1] Excludes In-Kind Contribution from United Energy.

Key observations from Table 2 are noted below:

- The network benefits associated with the installed Solar Storage systems were the costs of network augmentation for the constrained distribution substations. The total costs were $770k across the 14 constrained distribution substations.
- Since the customers could benefit from the installed Solar Storage systems via tariff arbitrage, the customer benefits were the contributions that they made to this Project. The total customer benefits were $126k from 42 customers across 14 constrained distribution substations.
- The economic gap is calculated using the below formula:

$$Economic\ Gap = \ Cost\ of\ Solar\ Storage\ System - Network\ Benefit - Customer\ Benefit$$

  This economic gap could be filled by contributions from third parties via using the installed Solar Storage systems for participating in energy and Frequency Control Ancillary Services (FCAS) markets during non-network support days which would be the majority of the year.

- According to the calculated economic benefits, for some constrained distribution substations, network augmentation cost was less than the Solar and Storage cost. However, the duration of demand deferral achieved from traditional augmentation achievable would be larger compared with Solar and Storage systems.
- In comparison, for some constrained distribution substations, network augmentation cost was much higher compared to the Solar and Storage cost because the incremental demand deferral obtained from the installed systems was small. This analysis demonstrates how Solar and Storage systems can be deployed incrementally compared to investing high upfront capital augmentation costs.
- Gross Solar and Storage costs were on average 42% higher than network augmentation costs across the 14 constrained distribution substations.
- Solar and Storage system costs would need to fall in the future to be considered an economically viable option compared to augmentation unless customers were to contribute a higher customer contribution.

5. Lessons Learnt

The lessons learnt are detailed below under the respective headings of marketing, planning/installation, operations and customers.

5.1 Marketing

- Customers were enrolled for the Project using a combination of direct mail-outs, web-based promotion and outbound calling. Customers registering interest were screened to assess site suitability.
- The initial round of marketing included a brochure detailing the offer of the Solar and Storage system by UE, customer contribution, benefits the customers would receive and a high-level overview of the Solar and Storage system.
- Due to the slow rate of uptake, the marketing material was revised in the next marketing campaigns to include the above and details on benefits of renewable energy sources, environmental benefits and cost savings.
- In addition, existing customers who had installations undertaken were contacted to determine whether they would be willing to provide testimonials and become a point of reference for new customers deciding to sign onto the Project.

5.2 Planning and Installation

- During implementation, a site visit was undertaken to every customer who sought to participate in the Project, to confirm the suitability of their site, considering criteria such as space, surface types and potential hazards.
- Insufficient roof space and shading were the two most common criteria resulting in elimination of ineligible sites. The evaluation process was streamlined by undertaking assessments using Google Maps data.
- Installers needed to assess types of roof tiling and the need to source spare roof tiles (roof tiles being cracked as part of the installation was common). UE ensured installers pre-arranged a supply of tiles prior to commencing installation.
- Wi-Fi connectivity at some sites posed issues. During site visits, details on Wi-Fi connections were gathered to ensure installation proceeds smoothly.
- Initial installations took 2 days to complete with subsequent installations undertaken in a day as the installers became more familiar with equipment and installation requirements. The plan was to utilise the existing installers to complete additional installations.
- Some installations required installation of concrete slabs which increased the installation time. Installers were advised of this immediately after the site visit to fast track installation.
- Ideal sites were those with a West or North facing roof with no shading from surrounding trees. The evaluation ensured the roof was clear of flu pipes, antennas or satellite dishes on the face where panels were to be installed. Such aspects were assessed during the site visit.
- The batteries were installed close to the switchboard and solar PV panels to minimise the length of the Alternating Current (AC) and Direct Current (DC) cable runs.
- The evaluation ensured the switchboard had sufficient spare terminals to accommodate the critical load and Voltage Transformer (VT) / Current Transformer (CT) reference Master Control Circuit Breakers (MCCBs).
- Other technical risks were mitigated by a rigorous product selection process and using initial installations to identify potential installation, integration and telecommunications issues and develop mitigations.

- It was essential to engage a reliable installer to ensure installations were completed in a timely manner and any issues identified were rectified quickly.

5.3 Operation

- Batteries were discharged as expected during peak demand times.
- The control strategy implemented included customer benefit self-maximisation for days when the temperature was less than 35°C. On days, when the temperature was forecast to exceed 35°C, the network support control algorithm ensured the battery was charged prior to the 35°C exceedance day. On the 35°C exceedance day, the batteries were discharged between a selected duration (for example, 5:00 – 8:00 pm or 4:00 – 7:00 pm to align with the peak period of the constrained network asset) with due consideration to limits on battery State of Charge (SOC).
- The network support control algorithm discharged a set output for the specified time, and guaranteed a set reduction during that time. One of the considerations for using this type of operation is that the batteries only have a certain amount of storage capacity at full power output. For this type of battery, there was only a nominal 3 hours of storage capacity at full power output, so the peak load would need to be predicted within a 3-hour window to reduce the peak demand by the full power output of the battery. Alternatively, a larger time window could be specified at a reduced rate of power output.
- When considering the value to networks of using battery storage systems for peak demand reduction, the limit of stored energy is a significant consideration as a battery may exhaust stored energy during a peak reduction event if it is not sized appropriately. The two main battery storage system specifications to consider when selecting the size of the battery for this application are the usable energy storage capacity (kWh) and peak power output (kW). By sizing a larger battery storage capacity for a given power output, any limitation would be alleviated, but the battery system cost is likely to increase for a given power output as the majority of battery system costs are currently related to the battery costs. As battery prices continue to decrease, this may make larger battery systems more affordable such that this concern may be less of an issue. To ensure battery discharge accurately meets peak demand, it is necessary to forecast the occurrence of the peak demand with greater accuracy.
- Reliability of components (i.e. inverter as power conversion equipment typically has a high rate of failures at the beginning - 2 installations had to have their inverters replaced due to failure).
- A safe and reliable control of the Solar Storage system is crucial for an economically viable operation. The control system needs to coordinate the data from the battery management system, the power conversion systems and external requests.
- Extensive monitoring of the battery systems such as voltage, temperature, current as well as redundant monitoring and control in terms of a fail-safe battery management system is crucial for a safe operation of the System to minimise the risk of a thermal run-away.
- A control challenge in most applications is the accuracy of the SOC value. Since the SOC value is the result of a nonlinear state estimation involving current integration and voltage measurements, large deviations from the real value and transient time behaviour of the SOC estimate are possible. The uncertainty in SOC estimation therefore needs to be considered in all control strategies which aim at managing SOC. The typical limited storage capacity needs careful management of SOC levels.
- Losses do not only occur within the batteries, the additional losses of the inverters, transformers, cables, switchgear, etc. need to be taken into account.
- It is necessary to implement a Life Cycle Strategy to address the operations and maintenance of the Solar Storage systems over the contract period.
- It is clear that there is room for improvement in technical performance. In particular, degradation, design, life and availability are considered areas where battery storage performance could improve. In addition, there is a need for better understanding of battery storage technical characteristics. This includes the

relationship between charging regime and degradation rates (which may influence the choice of battery storage applications), SOC accuracy, warranties and their limitations, availability of test data, and the standardisation of technical specifications.

5.4 Customer Lessons

- Duration of Contract: The contract offered to the customers was for a period of 10 years and many customers were deterred to sign up to the Project. In future, a potential model should be considered to offer customers a short duration contract such as for 3 or 5 years.
- Ownership of the System: The ownership of the system was also a concern expressed by many customers. The 10-year contract in effect binds the customer to provide ownership to UE.
- Unfamiliarity with technology: Many customers were unable to appreciate the way the Solar and Storage system would operate and benefit them. In subsequent rounds of marketing, UE modified the marketing material to present the benefits to customers in a simple manner.
- Upfront payment: Many customers were deterred to pay the upfront payment. In future, flexible finance offerings should be considered for customers.
- Motivation: The primary investment driver for customers was a reduction in their electricity bill. A desire for energy independence was also a key factor as well as having a source of back-up power.

5.5 Outcomes

- This Project involved recruiting a large base of customers across a number of constrained substations to reduce such constraints on the selected substations. This has allowed UE to halt growth in demand and defer network augmentation across the selected constrained substations.
- Results have shown Solar and Storage systems can be a viable solution for managing network demand once the product matures along with lower energy storage prices.
- Reducing the peak demand on an asset can enable significant savings for networks by facilitating the avoidance or deferral of network investments to build additional network assets. These savings are ultimately passed on to customers in the form of lower bills.
- Ideally, battery installations should be undertaken in an incremental manner to relieve constraints on selected constrained substations to defer the required network augmentation. Such an approach will be more prudent, cost effective and efficient allowing incremental deferral of network augmentation.
- When considering the potential application of using a battery system as a demand management solution to defer a network augmentation, other solutions should also be considered. Such other solutions may include customer demand response that could be viable to meet network needs.
- Although battery storage systems are currently more expensive than other similar demand management solutions. As battery costs decline, this technology may offer a cost effective alternative to other forms of demand management such as residential demand response.
- The Project has shown that centralised control of batteries can provide network support without materially reducing the primary customer benefit of bill reduction through solar PV shifting.
- In the longer term, the Project has also shown the potential for residential batteries to mitigate emerging system-wide challenges in maintaining network reliability, quality and security of supply as the penetration of rooftop solar PV continues to increase.

6. Control Strategy

The following control strategy was implemented for the duration of the Project across all Solar and Storage systems installed at the selected constrained substations.

6.1 Temperature Less than 35°C

For days when forecast maximum temperature is less than 35°C, the offset demand control strategy as demonstrated in Table 3 has been implemented across the selected constrained substations.

Table 3: Offset Demand Strategy Deployed in UE Solar Storage Systems

Time	Control	Description
All Day	Offset Demand	Offset demand control is the typical customer mode which seeks to limit exports to the network and maximise self-consumption of solar PV systems. The batteries and solar PV systems are used to firstly offset customer usage. The batteries only charge from excess solar PV generation which is not used by the customer.

The default algorithm is the offset demand control strategy.

6.2 Temperature Greater than or Equal to 35°C

For days when forecast maximum temperature is greater than or equal to 35°C, the network support control strategy demonstrated in Table 4 has been implemented across the selected constrained substations.

Table 4: Demand Response Strategy Deployed in UE Solar Storage Systems

Time	Control	Description
All Day	Demand Response	Ensure battery is charged prior to the weather event condition. On the weather event condition day, ensure battery is discharged between a selected duration (5:00 – 8:00 pm or 4:00 – 7:00 pm) with due consideration to limits on Battery SOC. For Solar PV systems, limit export to network and maximise self-consumption.

An event is set up in the Solar and Storage systems Fleet to discharge the battery between a selected duration when the temperature is forecast to be greater than or equal to 35°C.

The current system utilises the Fleet software which can be deployed as follows:

1. Offset demand control is the typical customer mode which seeks to limit exports to the network and maximise self-consumption of solar PV systems. The batteries and solar PV systems are used to firstly offset customer usage. The batteries will only charge from excess solar PV generation which is not used by the customer. This is the default control algorithm.
2. A manual discharge event can be scheduled for a selected day in the future. This also allows the flexibility of discharging the battery over a selected duration.

Implementation of the above control strategies is demonstrated through the analysis documented in the following section.

An option is to automate dispatch by programming a user specific dispatch control algorithm. For example, a 3, 5 or 7 day forward temperature forecast check would be performed. If the temperature is forecast to be greater than or equal to 35°C on a particular day, the network support control algorithm would ensure the battery is charged prior to that day and available to discharge between selected hours on the greater than 35°C. UE is working with the controller supplier to implement such a dispatch algorithm.

The customer load profile which presents the best economic value for the network from a Solar Storage perspective is one which meets the following criteria:

- Relatively consistent over a given peak period; and
- Not lumpy in nature.

7. Network Peak Demand Reduction

7.1 Summer 2017/2018 and 2018/2019 Dispatch Events

Hot Days

This section presents the load profiles for Demand Response dispatch events executed on the Solar and Storage systems on 6 January 2018 (41°C) and 14 January 2019 (35°C) for the Princeton Stanford constrained distribution substation. Table 5 provides a summary of the hot dispatch events.

Table 5: Summary of 2017/2018 and 2018/2019 Summer Dispatch Events – Princeton Stanford Distribution Substation

Date	Forecast Temperature (°C)	Maximum Substation Demand (kW)	Consumption Reduced (kWh)	Number of Solar and Storage systems operational
6-Jan-2018	41	282	39	5
14-Jan-2019	35	298	61	7

Princeton Stanford had 5 Solar and Storage systems operational on 6 January 2018 and 7 systems operational on 14 January 2019. Figure 2 shows the distribution substation demand with and without the battery contribution, and also plots the contribution from the battery for 6 January 2018.

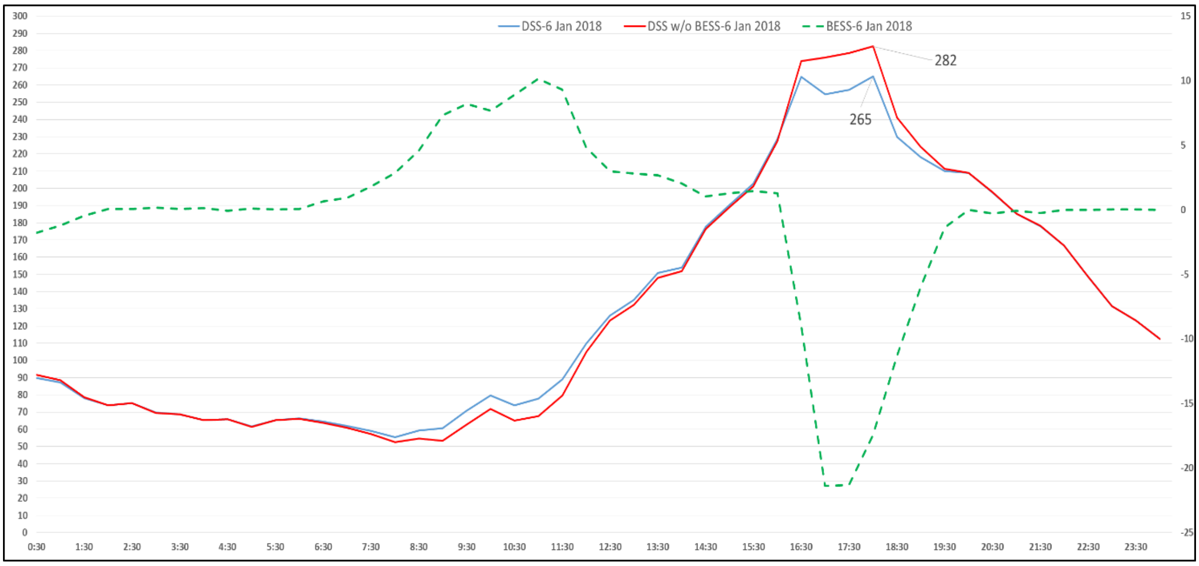

Figure 2 Constrained Substation Demand with Multiple Solar and Storage Systems on a Hot Day – 6 January 2018

Figure 3 shows the distribution substation demand with and without the battery contribution, and also plots the contribution from the battery for 14 January 2019.

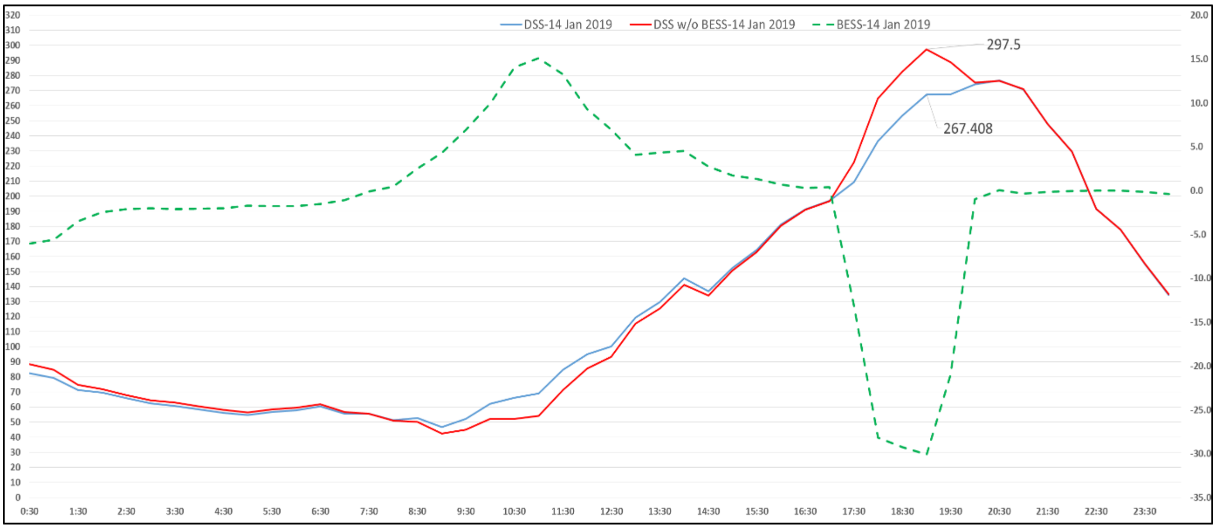

Figure 3 Constrained Substation Demand with Multiple Solar and Storage Systems on a Hot Day – 14 January 2019

The key observations to note from the above figures are:

- Given Network Demand is growing at less than 1% growth rate, dispatch on 6 January 2018 achieved a 7% reduction in demand which in effect will defer augmentation by 7 years. While, on 14 January 2019 the substation demand reduced from **297.5kW to 267.4kW, which is a reduction of approximately 10.1%, suggesting the ability to defer network augmentation by 10.1 years.**
- The batteries only began charging at approximately 8 am and used the Solar PV generated on the day to do so. This has highlighted an issue with the controller algorithm, as the batteries were to charge to 100% overnight, drawing energy from the grid to do so. UE is currently working on optimisation of the dispatch algorithm to ensure the battery achieves maximum SOC prior to the dispatch event and is able to discharge over the complete duration of the dispatch event.
- Advantage of Solar and Storage systems is the ability to incrementally add to the network to continue achieving deferral of augmentation.
- For network support mode, battery pre-charged to allow solar PV energy to support the network during the day.
- The batteries exported full capacity in the early evening during peak demand when solar output reduced.
- The dispatch events on 6 January 2018 and 14 January 2019 demonstrated that Solar and Storage systems can address network constraints.

<u>Normal Day</u>

This section presents the load profiles for normal dispatch days on the Solar and Storage systems on 7 January 2018 (21°C) and 3 January 2019 (25°C) for the Princeton Stanford constrained distribution substation. Table 6 provides a summary of the hot dispatch events.

Table 6: Summary of 2017/2018 and 2018/2019 Normal Dispatch Days – Princeton Stanford Distribution Substation

Date	Forecast Temperature (°C)	Maximum Substation Demand (kW)	Consumption Reduced (kWh)	Number of Solar and Storage systems operational
7 Jan 2018	21	107	4	5
3-Jan-2019	25	205	7	7

Figure 4 shows the demand on a selected constrained substation on 7 January 2018 with the multiple Solar and Storage systems in operation on a normal day.

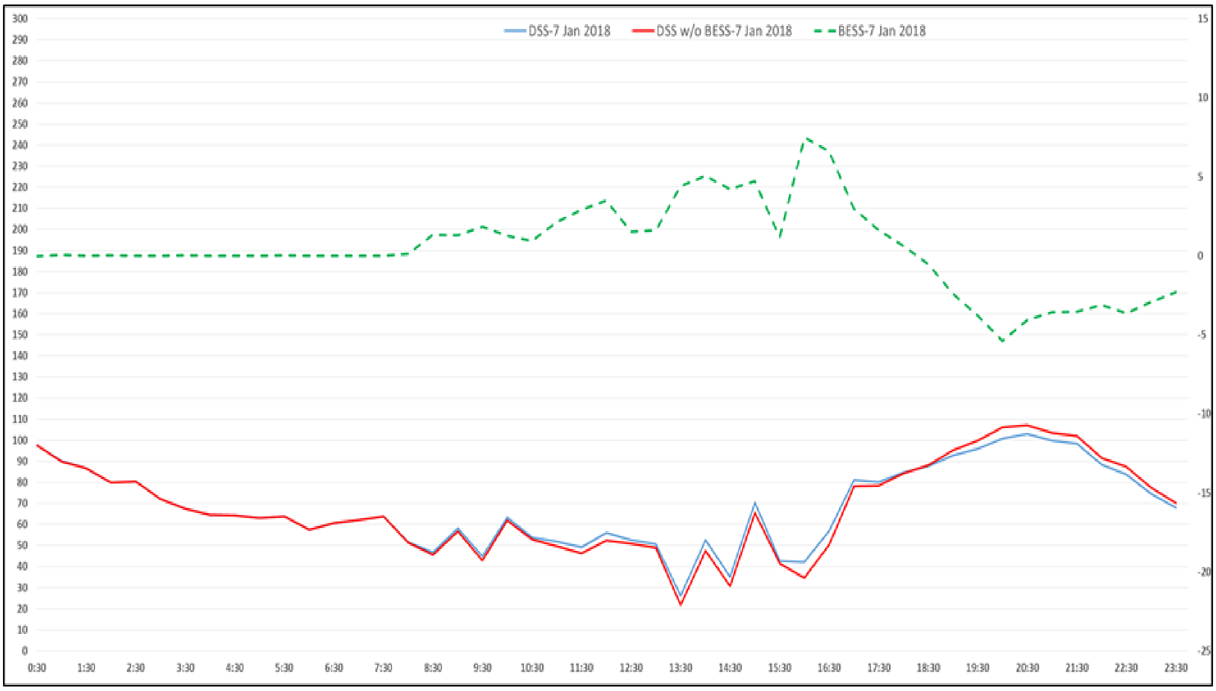

Figure 4 Constrained Substation Demand with and without Multiple Solar and Storage Systems on a Normal Day – 7 January 2018

Figure 5 shows the demand on the Princeton Stanford constrained distribution substation on 3 January 2019 with the multiple Solar and Storage systems in operation on a normal day.

Figure 5 Constrained Substation Demand with Multiple Solar and Storage Systems on a Normal Day – 3 January 2019

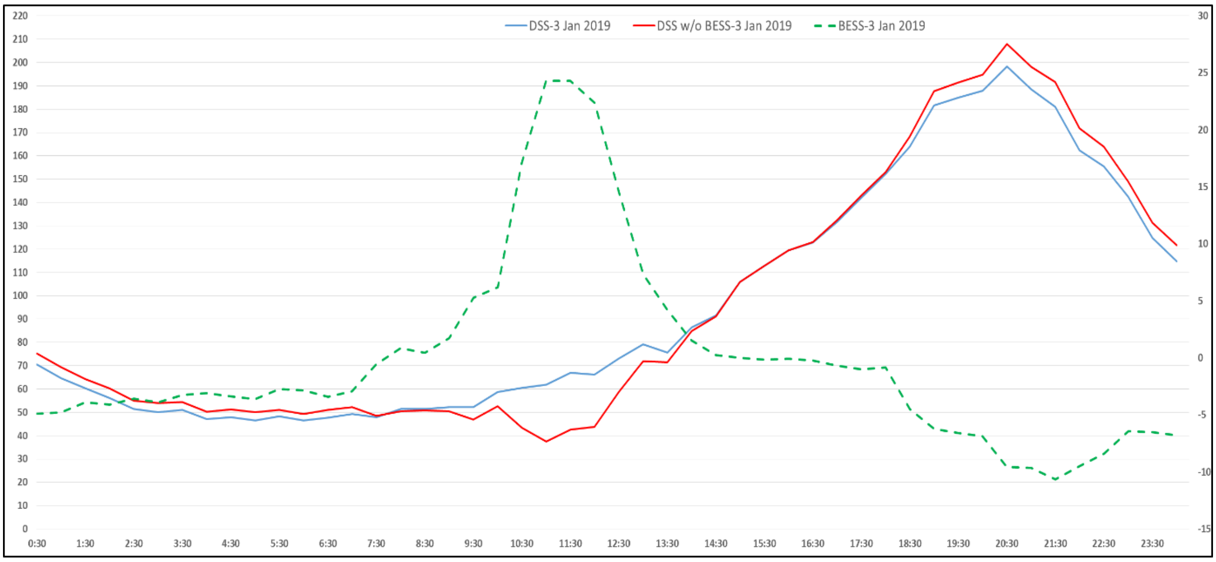

Figure 5 Constrained Substation Demand with Multiple Solar and Storage Systems on a Normal Day – 3 January 2019

The key observations to note from Figure 4 and Figure 5 are:

- The impact of Solar PV systems should be noted during the middle of the day.
- When Solar PV generation was high, demand was reduced and excess solar generation was used to charge the batteries.
- When demand increased in the evening, the batteries commenced discharging to support the increased demand maximising customer benefits.
- For energy arbitrage mode, battery charged from solar PV energy during the middle of the day.
- On a normal day (03 January 2019), a maximum reduction in demand of up to 6.1% was achieved (172.9kW down to 162.3kW).
- When in Offset Demand mode, the solar generation was used firstly to meet household consumption, with excess generation used to charge the battery, with any additional excess generation being exported to the grid.
- On 03 January 2019, the peak demand (which occurred at 8 pm) was successfully reduced by 6.88kW, as the battery was automatically discharged to meet demand. Peak demand reduced by approximately 3.31% (205.2kW to 198.4kW).

7.2 2018/2019 Summer Dispatch Event Summaries

This section documents a high-level summary of the dispatch events for summer 2018/2019. Table 7 shows the Demand Response dispatch events UE activated over the 2018/2019 summer. Detailed dispatch event analysis are included as Appendices.

Table 7: Demand Response Dispatch Events – Summer 2018/2019

Date	Start Time	End Time	Forecast Temperature (°C)	Detailed Dispatch Event Analysis
04-Jan-2019	4:00 PM	7:00 PM	39.4	See Appendix A
14-Jan-2019	5:00 PM	8:00 PM	35.4	See Appendix B
24-Jan-2019	5:00 PM	8:00 PM	37.4	See Appendix C
25-Jan-2019	4:00 PM	7:00 PM	37.4	See Appendix D
03-Feb-2019	4:00 PM	7:00 PM	36.3	See Appendix E
01-Mar-2019	4:00 PM	8:00 PM	36.4	See Appendix F
02-Mar-2019	5:00 PM	9:00 PM	35.4	See Appendix G

Table 8 summarises the outcomes of the Demand Response dispatch events UE activated over the 2018/2019 summer.

Table 8: Summer 2018/2019 Events – Augmentation Deferral

Date	Start Time (PM)	End Time (PM)	Forecast Temperature (°C)	Deferral across all constrained distribution substations (years)	Deferral across Princeton Stanford distribution substation (years)	Average Battery Energy Discharged (kWh)
4/1/2019	4:00	7:00	37.4	7	13.9	6.4
14/1/2019	5:00	8:00	33.2	4	10	6.3
24/1/2019	5:00	8:00	37.3	4	6	6.3
25/01/2019	4:00	7:00	38.8	4	11.2	6.5
3/02/2019	4:00	7:00	34.4	5	9	6.5
1/03/2019	4:00	8:00	36.2	4	7.2	6.9
2/03/2019	5:00	9:00	33.2	5	7.1	7.7
Average				**4.7**	**9.2**	**6.7**

The key observations to note from Table 8 are:

- Solar and Storage systems can provide network augmentation deferral ranging **from 4 to 14 years**. Individual constrained substations can have augmentation deferred **up to 14 years**.
- Average network augmentation deferral of 4.7 years should be achieved across all 14 constrained distribution substations.
- Average network augmentation deferral of more than 9.2 years should be achieved for Princeton Stanford distribution substation. The reason for the higher augmentation deferral duration is Princeton Stanford has 11 Solar and Storage systems installed whilst the required target was 6 systems. As only 7 Systems were operational on 14 January 2019, a greater network augmentation deferral duration should be achieved when all 11 systems are operational.
- Average battery energy discharge of 6.7kWh was achieved across all 14 constrained distribution substations. The useable capacity of each LG Chem battery is 8.8 kWh. The useable battery efficiency is 6.7kWh / 8.8kWh = 76%. This has highlighted the following:
  - Losses need to be accurately accounted for and addressed when sizing battery systems.
  - An issue with the controller algorithm, as the batteries are to charge to 100% overnight, drawing energy from the grid to do so. UE is working on optimisation of the dispatch algorithm to ensure the battery achieves maximum SOC prior to the dispatch event and is able to discharge over the complete duration of the dispatch event.
- Augmentation deferral periods can vary depending on the kWh demand to be reduced. The kWh demand will vary depending on the temperature experienced at the constrained distribution substation.
- Greater network benefit can be achieved by ensuring the event period is centred on the peak demand. This can be achieved if forecasting is used to better predict customer demand profiles, which can be used to align when the dispatch events take place.
- If all 42 Solar and Storage systems had been available during the above dispatch events, network benefit would have been greater resulting in a higher duration of augmentation deferral. UE will be implementing a life cycle strategy in 2019 to optimise the availability of all 42 systems to maximise the augmentation deferral. This will include optimisation of the dispatch algorithm to ensure the battery achieves maximum SOC prior to the dispatch event and is able to discharge over the complete duration of the dispatch event.
- UE successfully tested varying durations of discharge from the batteries i.e. 3 hours (4:00 pm to 7:00 pm; 5:00 pm to 8:00 pm) and 4 hours (4:00 pm to 8:00 pm; 5:00 pm to 9:00 pm). The varying durations of discharge successfully demonstrated the capability of the control algorithm in implementing different discharge rates.

Table 9 summarises the performance outcomes of the Demand Response dispatch events UE activated over the 2018/2019 summer.

Table 9: Summer 2018/2019 Dispatch Events – Performance Statistics

Date	Start Time (PM)	End Time (PM)	Forecast Temperature (°C)	Solar Generation (kWh)	Battery Contribution (kWh)	Number of Solar and Storage Systems operational
4/1/2019	4:00	7:00	37.4	117	182	31
14/1/2019	5:00	8:00	33.2	103	172	30
24/1/2019	5:00	8:00	37.3	105	183	32

Date	Start Time (PM)	End Time (PM)	Forecast Temperature (°C)	Solar Generation (kWh)	Battery Contribution (kWh)	Number of Solar and Storage Systems operational
25/01/2019	4:00	7:00	38.8	137	183	31
3/02/2019	4:00	7:00	34.4	121	125	25
1/03/2019	4:00	8:00	36.2	118	177	29
2/03/2019	5:00	9:00	33.2	82	201	32
Average				**112**	**175**	**30**

The key observations to note from Table 9 are:

- Solar generation (average 112kWh) and contribution of energy from the batteries (average 175kWh) were consistent across majority of the summer 2018/2019 dispatch events.
- On 3 February 2019, only 25 Solar and Storage systems were online, resulting in a lower contribution of energy from the batteries.
- On average 30 Solar and Storage systems were operational across the summer 2018/2019 dispatch events. This is 71% of the fleet. If the remaining 12 Solar and Storage systems were operational, clearly a larger network benefit would have been achieved. UE will be implementing a life cycle strategy in 2019 to optimise the availability of all 42 systems to maximise the augmentation deferral.
- UE successfully tested varying discharge event durations of 3 and 4 hours across the 14 constrained distribution substations.

8. Installation Requirements

For the installation of all systems, UE ensured that the Service Provider met the following requirements:

- Ensure the personnel installing the solar PV and energy storage unit had the required licences, certifications and qualifications required to perform installations, including a certificate as an A-Grade Registered Electrical contractor and Clean Energy Council (CEC) accreditation for the design and installation of solar PV systems. A copy of the relevant licences, certifications and qualifications were to be provided to UE on request.
- Install the solar PV and energy storage system in accordance with relevant Australian Standards and Regulatory codes and standards, including but not limited to the CEC guidelines and requirements and other reasonable directions by UE.
- Comply with HS&E (Heath, Safety and Environmental) requirements of the site and manage site safety as required. The Service Provider prepared Job Safety Assessment (JSA) before commencing the installation.
- Install the solar PV and energy storage system in line with installation guidelines and requirements from the manufacturer.
- Install the solar PV and energy storage system in a presentable and aesthetically pleasing manner where possible.
- Install the solar PV and energy storage system without causing damage to the property.
- Install the solar PV and energy storage system in a manner in which it is secured from theft.
- Install all necessary safety and warning signs, and any additional signage as required to comply with standards.
- Provide all required tools, equipment, hardware and software required to successfully install the solar PV and energy storage system at the Customer Site.
- Review the structural capability of the wall to support the weight of the battery and inverter (even if the hardware is installed on a uni-strut).
- The solar PV and energy storage system (including solar optimisers, inverter and the energy storage units) was commissioned by the Service Provider in line with manufacturer's requirement. The inverter and battery came pre-programed with default settings however, some of the default settings needed to be altered in line with the manufacturers commissioning requirements.
- For the purpose of the scope of works, it can be assumed that a standard installation includes:
  - The switchboard and customer modem are 40m away from the Solar Storage installation.
  - The switchboard has sufficient room to house peripheral hardware i.e. MCCB's.
  - Battery and inverter are installed next to each other.
  - The installation is a standard install i.e. no tilt frames, single story, single array, no switchboard replacement required.

At the conclusion of the installation phase, the Service Provider prepared paperwork to be submitted to the retailer/UE (UE Inverter-Based Micro Embedded Generator Connection form, CEC installation and commissioning form, Electrical Works Request form, other CEC forms as required for residential PV installation, etc.).

The Service Provider ensured the following documents were submitted to UE at the completion of the installation:

- Job Safety Assessment at the customer's site.
- UE Inverter-Based Micro Embedded Generator Connection form.
- Clean Energy Council's installation and commissioning checklist.

- Array frame installation declaration.
- Electrical Works Request form.
- Pictures of installation.
- Written record of all assets installed i.e. serial numbers of solar PV, solar optimisers, DC disconnect switch, AC disconnect switch, check meter, inverter and battery.
- Prescribed Certificate of Electrical Safety.
- The Service Provider supplied a copy of maintenance manuals to the customer for all plant and equipment supplied and/or installed, together with manufacturers printed matter related to the component parts including drawings, illustrations, data sheets, photographs, hazard identification lists and manuals.
- As built mark-up of aerial drawing showing location of equipment on the customer's premises.

The Service Provider organised for an independent Licenced Electrical Inspector to inspect the installation for defects post installation. The Service Provider ensured any defects identified by the Licenced Electrical Inspector were remedied by the installer. The Service Provider obtained a CES certificate for the installation signed by Licenced Electrical Inspector for submission to UE.

9. Operational Requirements

9.1 Customer Control

In this section, documented are the findings of the extent to which customers were willing to give over control of the Solar and Storage systems to the UE network.

Initially, there was hesitation by customers to provide control of the Solar and Storage systems to UE. However, customers were briefed on the following:

- UE would be deploying the Solar and Storage Systems for provision of network support on peak demand days.
- Network support on peak demand days would be required only when temperatures exceeded 35°C and such events would be limited to between 4 and 5 per year.
- Customers would be reimbursed when the batteries were charged from the grid to provide network support on peak demand days.

The briefing above assisted in customers feeling at ease with allowing UE to control the assets for network support over the summer periods of 2017/2018 and 2018/2019.

9.2 Model Rollout

The model employed in the Project can now be formalised for application to other locations in the UE network. The process to be followed is as below:

- Identify the constrained substation.
- Determine the volume of network support required to alleviate the constraint.
- Calculate the costs of alleviating the constraint using traditional augmentation and Solar and Storage systems.
- Assess the costs and benefits of traditional augmentation versus Solar and Storage systems.
- Recommend traditional augmentation or Solar and Storage systems.

10. Knowledge Sharing Activities

This section documents the Knowledge Sharing Activities completed over the duration of this project. Presentations on the Solar Storage Program and lessons learnt delivered as below:

- Progress update to ARENA at United Energy offices on 18 January 2018.
- Tokyo Electric Power Company (TEPCO), Kansai Electric and Mitsubishi Research Institute on 24 May 2018.
- SA Power Networks Future Networks Distribution Forum in Adelaide on 25 October 2018.
- RMIT University Smart Energy Systems Industry Forum on 22 November 2018.
- Australia Solar + Energy Storage Congress & Expo 2018 in Sydney on 5-6 December 2018.
- UE and AGL Knowledge Sharing Workshops on 6 February 2019, 26 March 2019 and 9 May 2019.
- UE and SA Power Networks Knowledge Sharing Workshop on 7 February 2019.
- UE and Powershop Knowledge Sharing Workshop on 14 February 2019.
- TasNetworks Future Networks Distribution Forum in Hobart on 4-6 April 2019.
- RMIT Industry Lecture for Advanced Power System on 27 May 2019.
- Australian Solar Storage Conference and Exhibition in Sydney on 13-14 June 2019.
- Updated the knowledge sharing webpage on the UE website for the purposes of sharing our project performance reports and provided input into the ARENA knowledge sharing insights website content.

UE has received significant positive feedback from the Knowledge Sharing activities undertaken above. A number of the participants who attended these Knowledge Sharing activities have contacted UE to share lessons learnt from the Solar and Storage Program.

11. Conclusions and Recommendations

The Residential Solar and Storage Project has successfully demonstrated a reduction in peak demand as an alternative solution for deferring network augmentation. Aspects that UE investigated during 2017/2018 and 2018/2019 are as below:

- Developed operating modes for the systems including automated control algorithms.
- Investigated business models that could facilitate the deployment of storage to address network issues.
- The outcomes from the dispatch events were complemented by ongoing market research in order to facilitate the provision of non-network solutions to system planners where network constraints are identified, and to feed into ongoing asset strategy development regarding the application of energy storage in a network context.

Augmentation deferral periods can vary depending on the magnitude of the demand that can be reduced by the Solar Storage systems. Greater network benefit could have been achieved if the dispatch events had covered the entire duration of peak demand times. The default control algorithm deployed was charging the battery prior to the dispatch event from only excess solar energy resulting in the batteries not being at 100% SOC prior to the dispatch event. UE is working to optimise the dispatch algorithm to ensure the battery achieves maximum SOC prior to the dispatch event and is able to discharge over the complete duration of the dispatch event. The algorithm will then ensure the batteries are charged from excess solar energy and supplemented by grid energy to achieve a 100% SOC prior to the dispatch event.

The 2018 and 2019 dispatch results show augmentation deferral between 4 to 14 years can be achievable using the installed Solar Storage systems.

The primary reason for all Solar and Storage systems being unavailable was loss of communication due to Wi-Fi issues as many sites were affected by the rollout of NBN. It is expected that by completing the NBN rollout, all of the systems will be available for network support services.

If all 42 Solar and Storage systems had been available during the above dispatch events, network benefit would have been greater resulting in a higher duration of augmentation deferral. UE will be implementing a life cycle strategy in 2019 to optimise the availability of all 42 systems to maximise the augmentation deferral.

12. Glossary of Terms

The following terms are referenced within this document:

Term	Description
ARENA	Australian Renewable Energy Agency
AC	Alternating Current
BAU	Business As Usual
BESS	Battery Energy Storage System
CEC	Clean Energy Council
CES	Certificate of Electrical Safety
CT	Current Transformer
DC	Direct Current
MCCBs	Master Control Circuit Breakers
SOC	State of Charge
UE	United Energy
VT	Voltage Transformer

13. Appendix A – 2019 Dispatch Event 1

13.1 Event Overview

Event 1 occurred on Friday, 04 January 2019, with the dispatch set between 4:00 pm and 7:00 pm for the Solar Storage systems. From the 42 systems installed, operational data was available for 31 systems, with the remaining units being offline at the time of the event, or unable to record the operational battery usage for the day.

Figure 6 shows the performance of the Solar Storage systems on the network during the dispatch event. Specifically, it shows the solar generation, energy exported to the grid, energy discharged by the battery and household consumption during the 3-hour dispatch event. Also, shown are graphs of these measures along with the net effect on all distribution substations (i.e. substation demand with and without the contribution from Solar Storage systems).

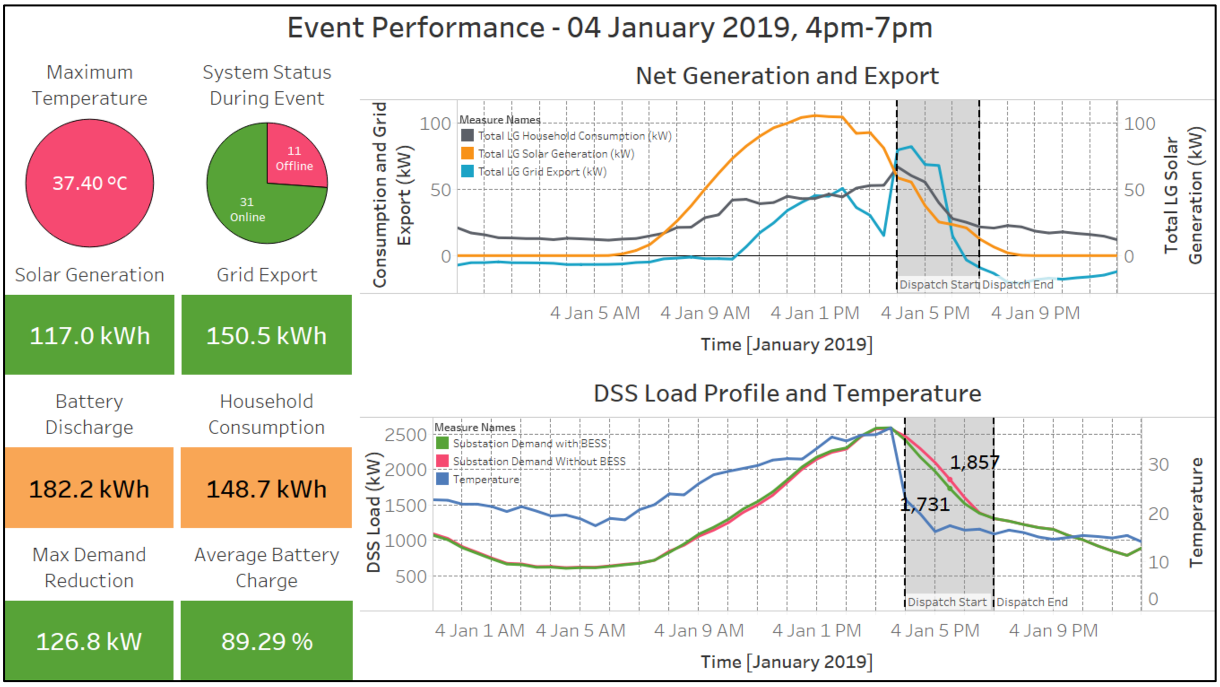

Figure 6: Summary of Event 1 (04 January 2019)

Key observations worthy of note are as below:

- The Solar PV systems installed at households generated 117kWh during the event period.
- 151kWh was exported to the grid reducing overall demand at constrained distribution substations.
- The operational batteries discharged 182kWh of energy.
- Of the households with online systems during the event, the total (gross) consumption was 149kWh over the 3-hour period.

The forecast maximum temperature at Moorabbin weather station was 39.4°C. The actual recorded maximum temperature was 37.4°C at 3:30 pm (refer to Table 10) whilst the overnight minimum temperature was 17.5°C.

Table 10: Maximum Temperatures at Various Locations on the UE Network

Location	Maximum Temperature (°C)	Time of Maximum Temperature
Moorabbin	37.4	15:30 pm
Viewbank	38.7	16:00 pm
Scoresby	38.9	16:00 pm
Cerberus	36.6	14:00 pm

Figure 7 depicts the temperature for different locations of the UE distribution network.

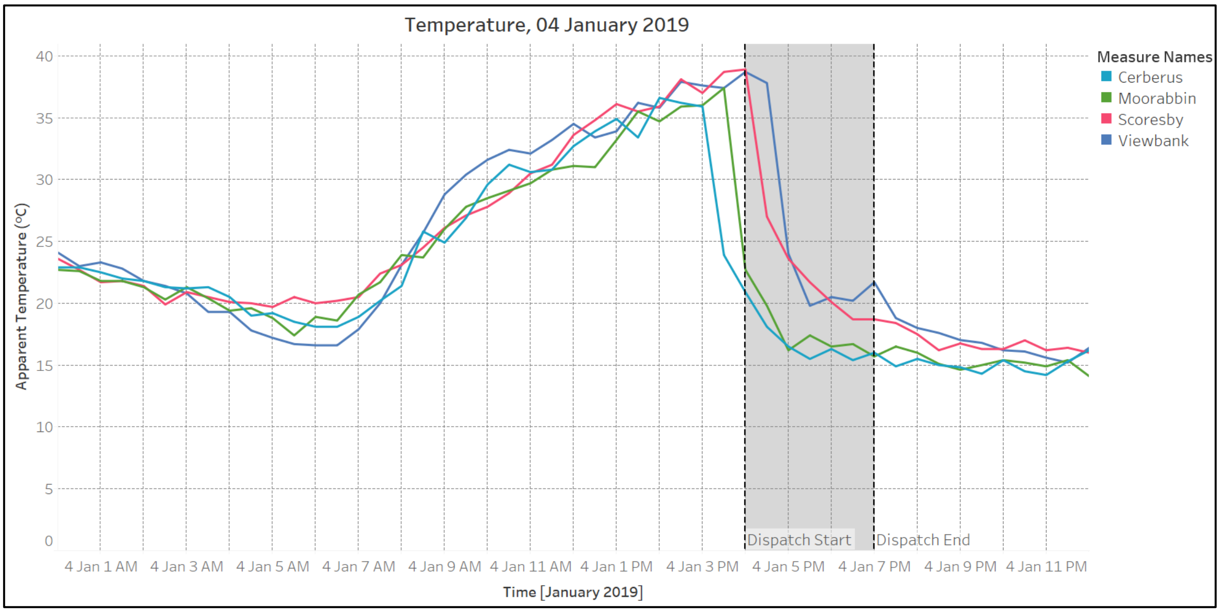

Figure 7: Temperatures at Different Locations in the United Energy Distribution Network on 04 January 2019

The apparent temperature exceeded 30°C from 11:09 am and remained above this temperature until 3:45 pm. A temperature above 35°C was maintained between 2:08 pm and 3:34 pm. While the day was considerably hot, the cool change came through earlier than expected, resulting in cooler temperatures during the event period. At the start of the event, the temperature was 22.7°C, which further dropped to 15.7°C by 7:00 pm.

13.2 Network Impact

Figure 8 depicts the load profile of the 14 substations on the day of the event (Green). For comparison, the amount of contribution from the Solar Storage systems was subtracted and the resultant curve (Red) shows the resultant load had the Solar Storage systems not contributed to reducing demand. Total contribution during the event is shown in Blue with Solar Generation shown in Orange.

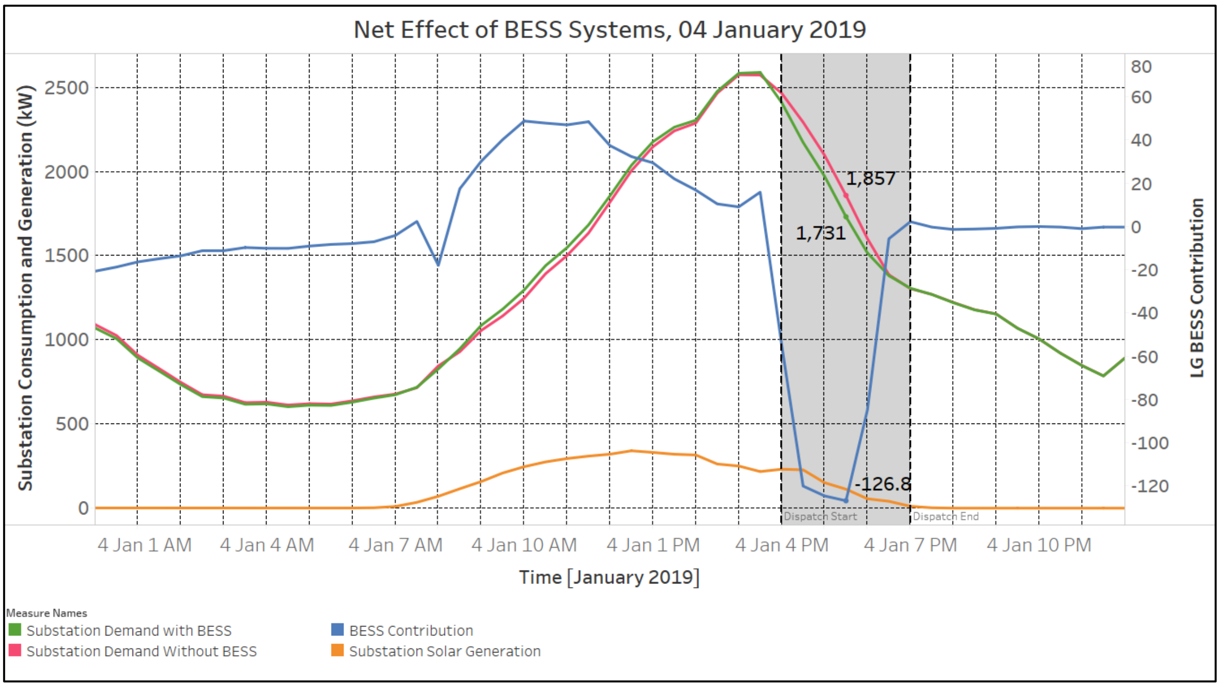

Figure 8: Total Substation Demand With (Green) and Without (Red) Solar Storage on 04 January 2019 – Battery Contribution (Blue) and Solar Generation (Orange)

Figure 8 shows the load on constrained substations decreased from 1,857kW to 1,731kW. This represents a 6.8% (126.8kW) maximum reduction in demand. As network demand is growing at less than 1% per year, the resulting reduction suggests that UE can defer network augmentation by 6.8 years.

As the cool change hit the region earlier than expected, the peak demand across these substations occurred at around 3:00pm, an hour before the dispatch event began. Greater network benefit could have been achieved had the event period been centred on the peak demand. This could be achieved if forecasting was used to better predict customer demand profiles, which could be used to align when the dispatch events take place.

Table 11 depicts the consumption in kWh at each of the 14 distribution substations with and without the Solar Storage systems. This allows for the impact to be measured, and in all, consumption was reduced by approximately 257kWh, which is a reduction of 3.95%.

Table 11: Substation Consumption during Dispatch Event (4-7 pm) on 04 January 2019

Substation Name	Number of Systems Online	Substation Consumption without systems during Dispatch Period (kWh)	Substation Consumption with systems during Dispatch Period (kWh)	Consumption Reduced (kWh)	Percentage Reduced (%)
ACHERON KOETONG	4	470.67	444.79	25.87	5.50
AMETHYST DIAMOND	2	430.48	413.93	16.56	3.85
BRIGGS CHLORIS	2	370.93	354.07	16.86	4.55
CASTLEWOOD MARLBOROUGH	1	378.35	369.58	8.78	2.32
ENTRANCE NEPEAN	1	195.06	186.90	8.16	4.18
FLORENCE-GERALD	1	425.67	416.87	8.80	2.07
HYPERNO LAYTON	2	608.49	591.24	17.25	2.83
KARRAKATTA-BLUFF	0	661.97	661.97	0.00	0.00
MILLGROVE GEORGE	2	491.18	474.01	17.17	3.50
MT PLEASANT LORIKEET	1	456.00	447.33	8.67	1.90
PRINCETON STANFORD	7	700.62	639.34	61.28	8.75
TRENTBRIDGE MANCHESTER	3	607.23	582.19	25.04	4.12
WARATAH-WARRIGAL	1	261.31	252.76	8.55	3.27
WINDSOR-ST JAMES	4	442.38	408.28	34.11	7.71
TOTAL	**31**	**6500.34**	**6243.26**	**257.09**	**3.95**

13.3 System Performance

As a comparison, the dispatch performance on Thursday, 03 January 2019 was assessed. This allowed for the pre-event analysis of the Solar Storage systems. The maximum temperature on the day was 29.4°C.

13.3.1 Performance on 03 January 2019

The State of Charge (SOC) is the percentage level of charge remaining within the batteries at a particular point in time. Figure 9 depicts the average performance of the batteries. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plotted next to the Discharge Rate, with the Battery SOC and Temperature of the day plotted in the final graph.

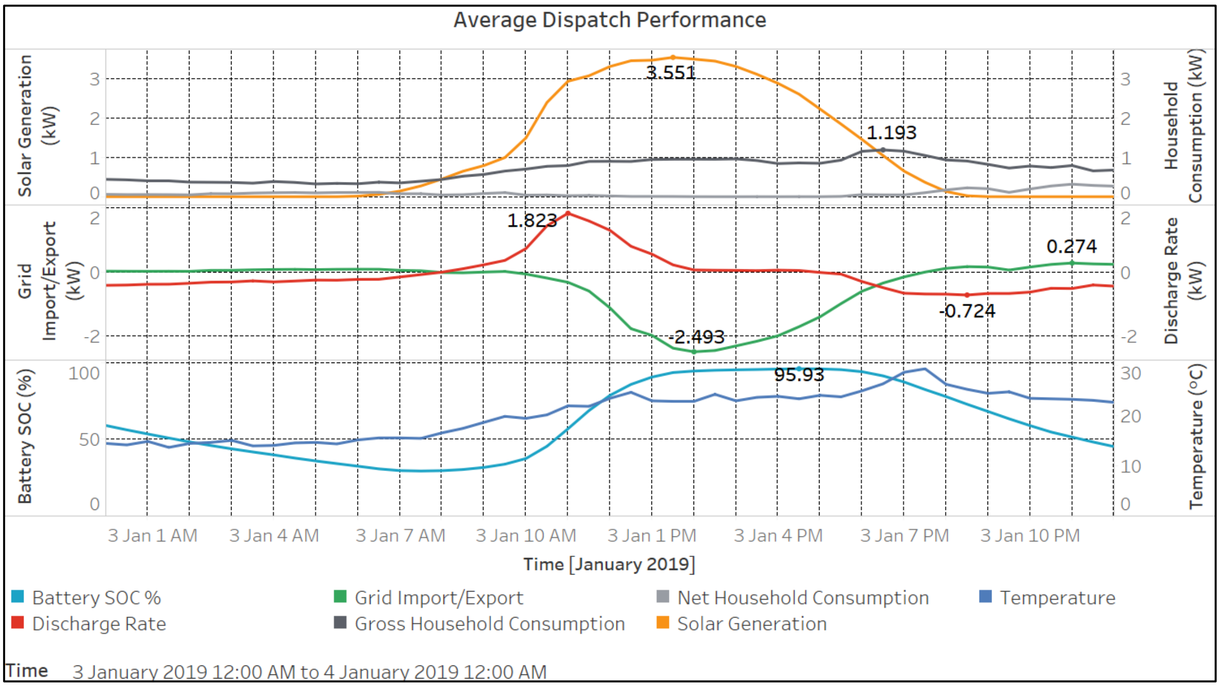

Figure 9: Average Dispatch Performance for 03 January 2019

The day commenced with zero Solar Generation with the households drawing power from the batteries. Consequently, the batteries were discharging to meet demand during the early hours of the day. This is visible between the hours of 12am to 8am, where the Average Battery SOC steadily decreased as the Discharge Rate was still negative.

The households began to draw power from the solar panels as Solar Generation commenced, and the excess solar generation was used to charge the battery. This is visible in Figure 9 as the Discharge Rate turned positive (batteries were charging), and the Battery SOC started to increase rapidly. During this period (8:00 am to 6:30 pm), the average Gross Household Consumption rose from approximately 0.439kW to 1.193kW. However, the Net Consumption as seen by the network was close to zero for this period. By 5:30 pm, as solar generation began to reduce, the batteries began to discharge to meet the increasing household demand.

It must be noted that during a typical day, the Battery SOC is almost sinusoidal in nature when keeping up with customer demand. While this is an ideal scenario to offset the customer's demand for an average day, this control method will be unable to help the network (and especially constrained substations) during days of peak demand.

13.3.2 Performance on 04 January 2019

Similarly to the comparison for the non-event day, Figure 10 depicts the average performance of the batteries on the event day. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plotted next to the Discharge Rate, with the Battery SOC and Temperature of the day plotted in the final graph.

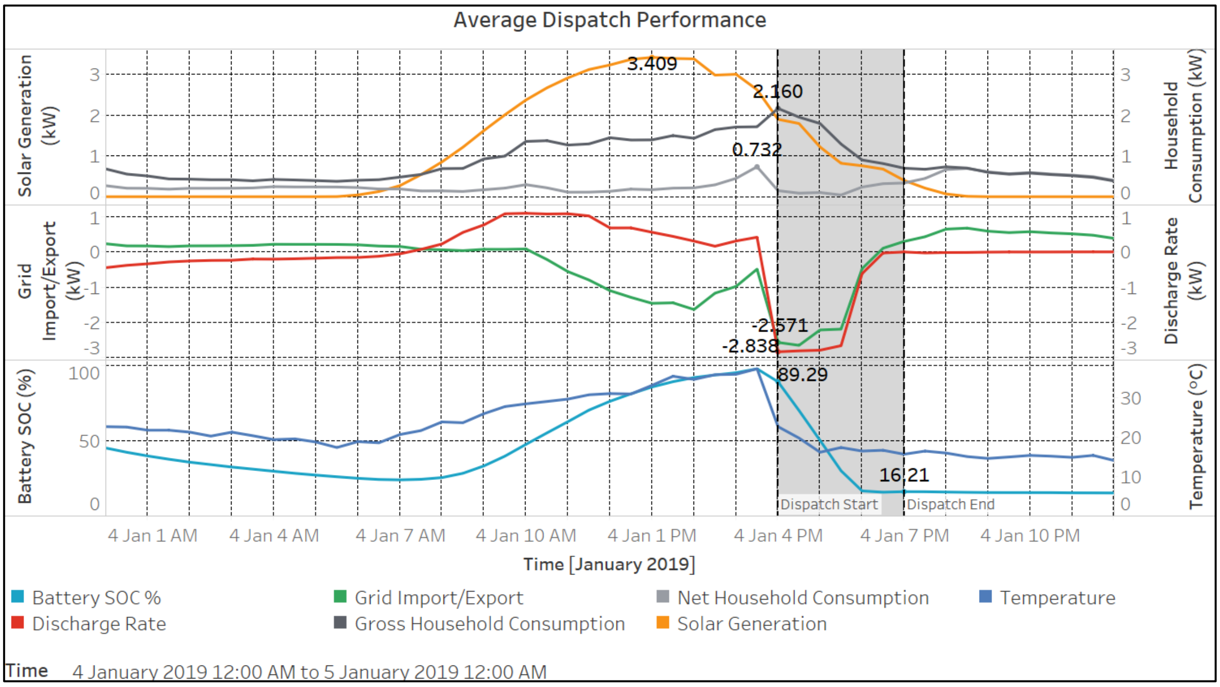

Figure 10: Average Dispatch Performance for 04 January 2019

As with 03 January 2019, in the early hours of the day on 04 January 2019, there was no solar generation occurring. As a result, the household was powered partly by the stored energy in the battery. It was not until 7:30 am that the battery stopped supplying power to the household, and started pre-emptively charging in anticipation for the dispatch event later in the day.

Figure 10 depicts the Demand Response control strategy in operation. It is important to note the difference in the battery Discharge and actual energy being exported to the grid at the time of the event.

By comparing Figure 9 and Figure 10, it can be noted that the maximum average Gross Household Consumption nearly doubled from 1.19kW to 2.16kW due to the extreme weather experienced. However, during the event on 04 January, net consumption fell from 0.732kW to nearly 0kW at the beginning of the event. This could be attributed to the fact that at 4:00 pm, the Solar Generation fell below Gross Consumption and in response to this, a small part of the battery discharge was being used by the household. This explains why the amount of energy dispatched onto the network was less than the discharge amount of the battery.

As mentioned previously, it was also during this time the cool change swept through the UE Network. Customer demand would have fallen regardless of the battery dispatch.

13.3.3 Dispatch Performance by Distribution Substation

Table 12 shows the dispatch performance of the Solar Storage systems by Distribution Substation.

Table 12: Dispatch Performance by Distribution Substation on 04 January 2019

Substation Name	Battery Size (Usable Capacity) (kWh)	Number of Systems Online	Total Usable Battery Capacity (kWh)	Percentage of Battery Discharged (%)	Total Energy Discharged (kWh)	Total Solar Generation (kWh)	Household Consumption (kWh)	Net Grid Export (kWh)
ACHERON KOETONG	9.8 (8.8)	4	35.20	58.85	19.72	16.84	18.43	18.13
AMETHYST DIAMOND	9.8 (8.8)	2	17.60	77.46	12.70	6.51	13.84	5.37
BRIGGS CHLORIS	9.8 (8.8)	2	17.60	76.94	12.61	6.31	7.67	11.25
CASTLEWOOD MARLBOROUGH	9.8 (8.8)	1	8.80	78.42	6.24	3.59	4.27	5.56
ENTRANCE NEPEAN	9.8 (8.8)	1	8.80	78.13	6.39	4.33	12.11	-1.39
FLORENCE-GERALD	9.8 (8.8)	1	8.80	39.36	6.43	1.83	2.56	5.70
HYPERNO LAYTON	9.8 (8.8)	2	17.60	39.57	12.80	11.08	11.63	12.25
MILLGROVE GEORGE	9.8 (8.8)	2	17.60	77.30	11.87	7.25	6.60	12.52
MT PLEASANT LORIKEET	9.8 (8.8)	1	8.80	78.32	6.32	2.90	2.89	6.33
PRINCETON STANFORD	9.8 (8.8)	7	61.60	50.91	37.67	26.24	26.96	36.95
TRENTBRIDGE MANCHESTER	9.8 (8.8)	3	26.40	55.90	18.93	10.65	20.90	8.68
WARATAH-WARRIGAL	9.8 (8.8)	1	8.80	78.64	6.51	3.57	3.01	7.07
WINDSOR-ST JAMES	9.8 (8.8)	4	35.20	62.41	23.99	15.92	17.83	22.08
TOTALS	**-**	**31**	**272.80**	**60.87**	**182.18**	**117.02**	**148.70**	**150.50**

13.3.4 Performance Summary

For this Project, 42 LG Chem RESU10 batteries have been installed at 14 at-risk distribution substations. Each LG Chem Battery has a total energy capacity of 9.8kWh, of which 8.8kWh is actually usable. The maximum discharge rate of the LG Chem batteries is 5kW.

The following comparisons only take into account the performance of the 31 systems that were operational throughout the entire dispatch period.

Table 13 shows the online status of the 42 LG Chem batteries installed at the various sites on the UE network.

Table 13: Breakdown of Online Status during Event 1

Distribution Substation	Solar Storage Customers	No. of Systems Online
ACHERON KOETONG	4	4
AMETHYST DIAMOND	2	2
BRIGGS CHLORIS	2	2
CASTLEWOOD MARLBOROUGH	2	1
ENTRANCE NEPEAN	1	1
FLORENCE-GERALD	2	1
HYPERNO LAYTON	4	2
KARRAKATTA-BLUFF	1	0
MILLGROVE GEORGE	2	2
MT PLEASANT LORIKEET	1	1
PRINCETON STANFORD	11	7
TRENTBRIDGE MANCHESTER	4	3
WARATAH-WARRIGAL	1	1
WINDSOR-ST JAMES	5	4
TOTAL	**42**	**31**

In Demand Response mode, the Fleet software monitors the batteries to ensure they are charged fully (or as high as possible) by Solar PV prior to the dispatch event. On the dispatch day, the Fleet software ensures the batteries are discharged between the selected duration with due consideration to limits on Battery SOC. Solar PV systems are set to limit export to the network and maximise self-consumption.

In Figure 11, the Average Battery SOC (%) is plotted. This shows the aggregated Battery SOC performance of the LG Chem batteries.

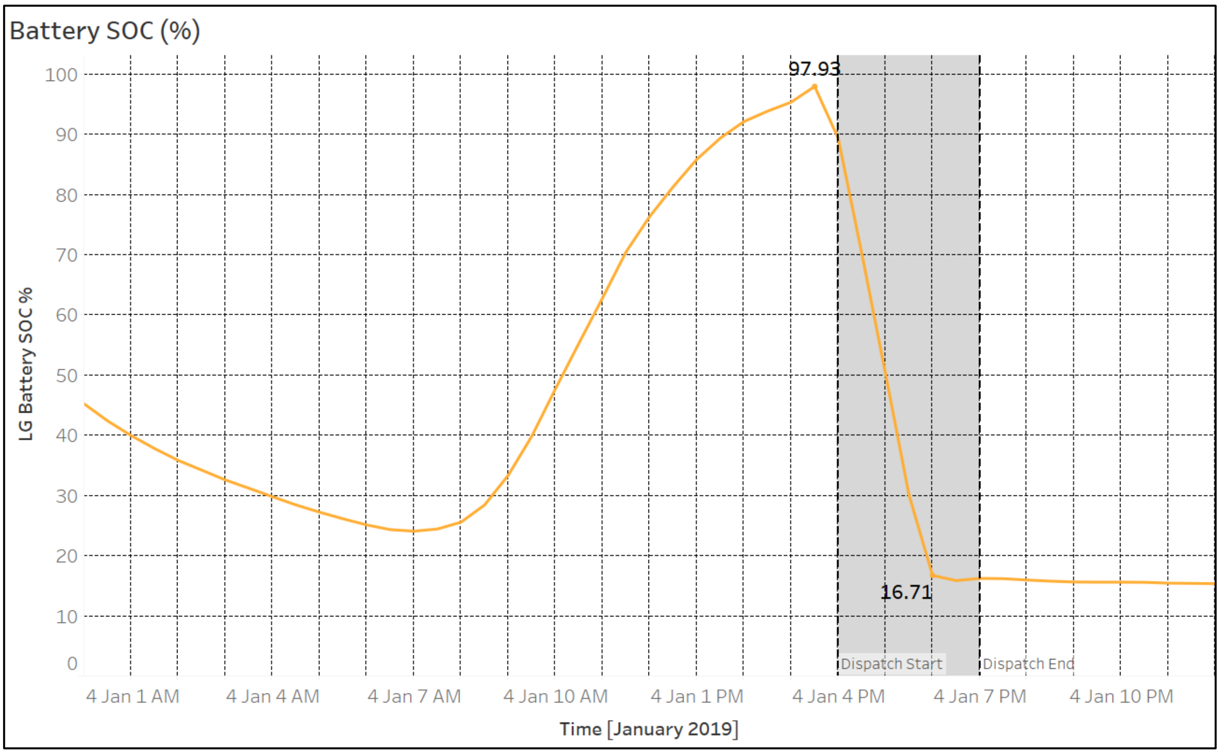

Figure 11: State of Charge (%) for batteries on 04 January 2019

From around 7:00 am until the time of the event, Figure 11 clearly shows the batteries in a state of charge in anticipation of the eventual discharge during the event period. While the Fleet is set to ensure the batteries are charged to 100% prior to the dispatch, when the data is aggregated, the batteries were charged to 97.93% on average.

Figure 11 also shows that at around 6:00 pm, the batteries stopped discharging, with an average SOC of 16.71%. This is an acceptable figure as the LG Chem batteries installed, while rated to 9.8kWh, only have 8.8kWh of usable energy, allowing a minimum SOC of approximately 10.2%. The batteries should not discharge below this point to maintain battery integrity and life. It seems that greater network benefit could have been achieved if the battery capacity was higher, as while the Discharge Rate was certainly adequate, the batteries effectively run out of charge 2 hours into the event.

Table 14 shows a comparison of the SOC for the batteries. All data is obtained from Figure 11.

Table 14: Battery State of Charge Comparison for 04 January 2019

Parameter	LG (%)
Maximum	97.93
Dispatch Start	89.29
Dispatch End	16.21
Minimum	15.34

The percentage of charge used during the dispatch event is summarised in Table 15.

Table 15: Percentage of Charge Used during Dispatch Event 1

Battery Type	Charge at Dispatch Start (%)	Charge at Dispatch End (%)	Percentage of Charge Used (%)	Average Energy Discharged (kWh)
LG	89.29	16.21	73.08	6.43

The LG Chem RESU10 9.8kWh batteries have a maximum discharge rate of 5 kW.

Figure 12 depicts the average discharge rate for the LG Chem batteries. The batteries discharged with a peak value of 2.8kW at 4:00 pm.

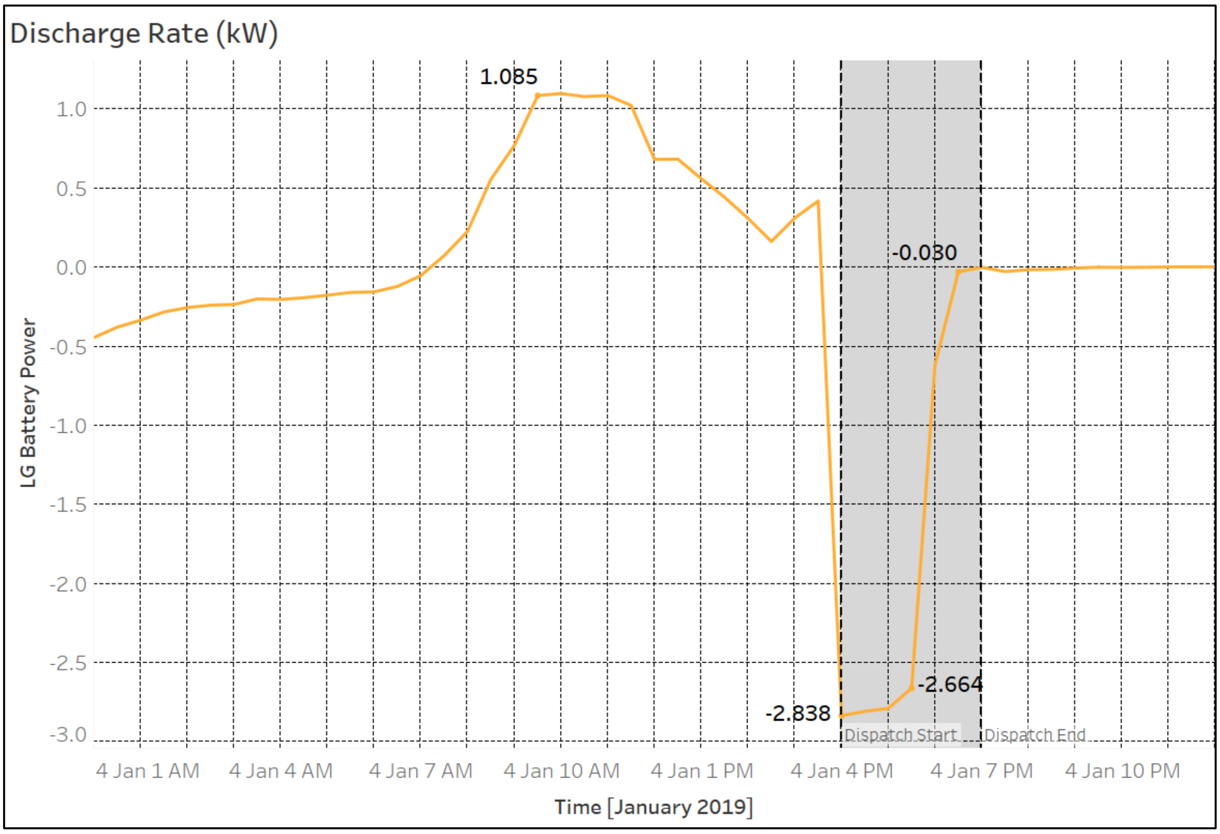

Figure 12: Average Discharge Rate of Batteries on 04 January 2019

The sloping curve at the beginning and end of the event in Figure 12 is an artefact of the level of granularity of the averaged performance data. This is also effected by the half-hourly data collected from the controller.

With a usable charge of 8.8kWh, the LG battery should have been able to discharge for approximately 3.76 hours at an average discharge rate of 2.34kW. However, as the LG batteries were only charged to 89.29% prior to the dispatch event, and were left with 16.21% at the end of the event (from Table 14), the average percentage of charge used for an LG battery was 73.08%. This equates to approximately 6.43kWh of charge.

At an average discharge rate of 2.34kW, it would have taken 2.74 hours for the battery to discharge. As the data collected is half-hourly, it is not feasible to determine exactly how long the discharge duration was, but as per Figure 12, it was during the last half hour (2.5-3 hours) that the discharge of the LG battery fell from 0.03kW to 0kW.

Table 16 breaks down the discharge characteristics of the battery as seen on 04 January 2019.

The Average Energy Discharged was calculated as the product of the Average Discharge Rate (kW) and Average Discharge Duration (Hours). Here a simple kW to kWh conversion was applied in the form of:

$$Energy\ (kWh) = Power\ (kW) * Time\ (hours)$$

Table 16: Average Discharge Performance of Online battery Systems for 04 January 2019

Battery Type	Average Discharge Rate (kW)	Average Discharge Duration (Hours)	Average Energy Discharged (kWh)
LG	2.34	2.74	6.43

Table 15 and Table 16 use two different measures in order to calculate the Average Energy Discharged, with both resulting in near identical results. Table 15 uses the Battery's SOC, whilst Table 16 uses the Battery's Discharge Rate.

14. Appendix B – 2019 Dispatch Event 2

14.1 Event Overview

Event 2 occurred on Monday, 14 January 2019, with the dispatch set between 5:00 pm and 8:00 pm for the Solar Storage systems. From the 42 systems installed, operational data was available for 30 systems, with the remaining units being offline at the time of the event, or unable to record the operational battery usage for the day.

Figure 13 shows the performance of the Solar Storage systems on the network during the dispatch event. Specifically, it shows the solar generation, energy exported to the grid, energy discharged by the battery and household consumption during the 3-hour dispatch event. Also, shown are graphs of these measures along with the net effect on all distribution substations (i.e. substation demand with and without the contribution from the Solar Storage systems).

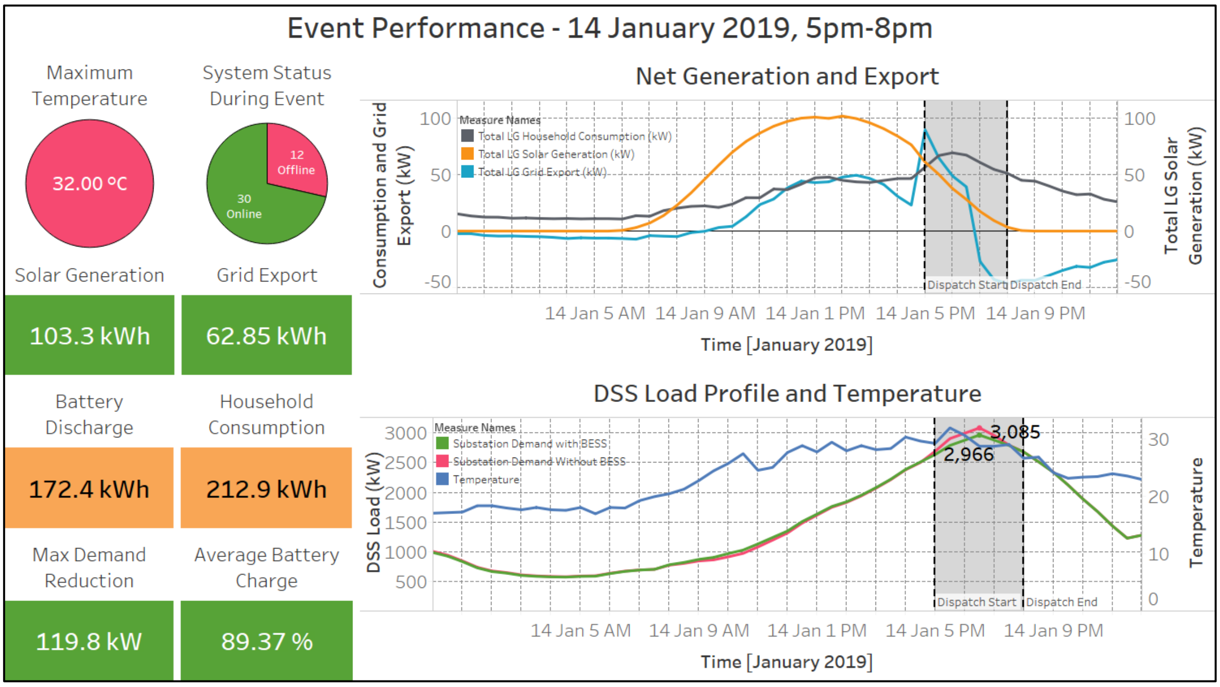

Figure 13: Summary of Event 2 (14 January 2019)

Key observations worthy of note are as below:

- The Solar PV systems installed at households generated 103kWh during the event period.
- 63kWh was exported to the grid reducing overall demand at constrained distribution substations.
- The operational batteries discharged 172kWh of energy.
- Of the households with online systems during the event, the total (gross) consumption was 213kWh over the 3-hour period.

The forecast maximum temperature at Moorabbin weather station was 35.4°C. The actual recorded maximum temperature was 32°C at 5:30pm whilst the overnight minimum temperature was 17°C (refer to Table 17).

Table 17: Maximum Temperatures at Various Locations on the UE Network

Location	Maximum Temperature (°C)	Time of Maximum Temperature
Moorabbin	32.0	17:30
Viewbank	39.9	15:30
Scoresby	38.6	15:30
Cerberus	33.1	13:00

Figure 14 depicts the temperature for different locations of the UE distribution network.

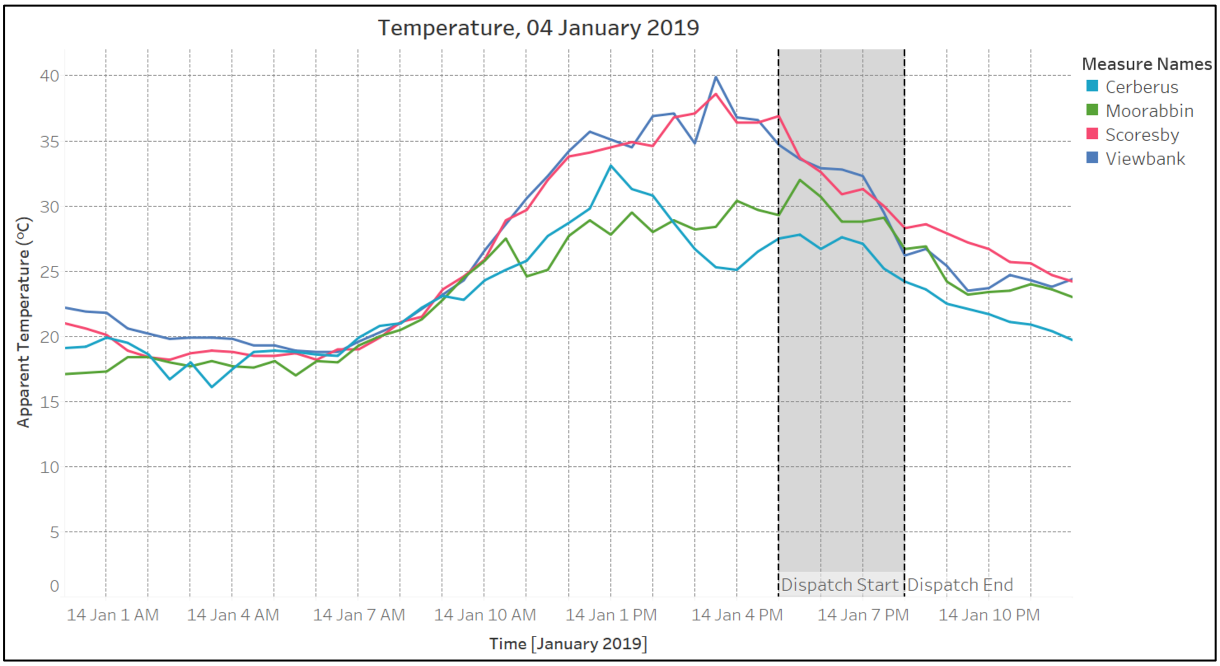

Figure 14: Temperatures at Different Locations in the United Energy Distribution Network on 04 January 2019

The apparent temperature exceeded 30°C from 04:00 pm and remained above this temperature until 3:45 pm. The temperature was stable during the event at an average of 29.0°C. At the start of the event, the temperature was 29.3°C which further dropped to 26.7°C by 8:00 pm. There was no cool change present on the day.

14.2 Network Impact

Figure 15 depicts the load profile of the 14 substations on the day of the event (Green). For comparison, the amount of contribution from the Solar Storage systems was subtracted and the resultant curve (Red) shows the resultant load had the Solar Storage systems not contributed to reducing demand. Total contribution during the event is shown in Blue with Solar Generation shown in Orange.

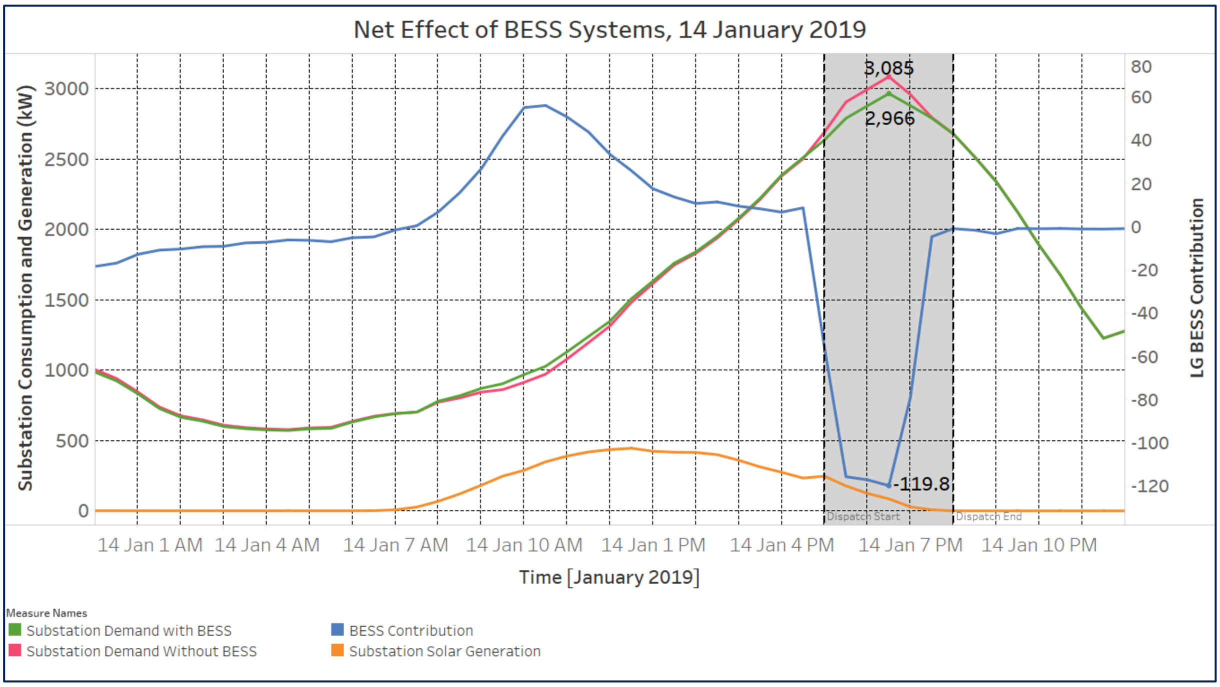

Figure 15: Total Substation Demand With (Green) and Without (Red) Solar Storage on 04 January 2019 – Battery Contribution (Blue) and Solar Generation (Orange)

Figure 15 shows the load on constrained substations decreased from 3,085kW to 2,966kW. This represents a 3.88% (119.8kW) maximum reduction in demand. As network demand is growing at less than 1% per year, the resulting reduction suggests that UE can defer network augmentation by 3.88 years.

As there was no cool change present on the day of the event, the peak demand occurred at 6.30 pm, right in the middle of the dispatch period. As a result of the batteries having only a set amount of charge, the network benefit did not increase as demand increased, and as such, the percentage reduction observed here was nearly half of Event 1.

Table 18 depicts the consumption in kWh at each of the 14 distribution substations with and without the Solar Storage systems. This allows for the impact to be measured, and in all, consumption was reduced by approximately 247kWh, which is a reduction of 2.45%.

Table 18: Substation Consumption during Dispatch Event (5-8 pm) on 14 January 2019

Substation Name	Number of Systems Online	Substation Consumption without systems during Dispatch Period (kWh)	Substation Consumption with systems during Dispatch Period (kWh)	Consumption Reduced (kWh)	Percentage Reduced (%)
ACHERON KOETONG	4	680.74	645.73	35.02	5.14
AMETHYST DIAMOND	2	676.86	659.37	17.48	2.58
BRIGGS CHLORIS	2	547.67	530.54	17.13	3.13
CASTLEWOOD MARLBOROUGH	1	542.51	533.72	8.79	1.62
ENTRANCE NEPEAN	1	342.57	333.79	8.78	2.56
FLORENCE-GERALD	1	668.13	659.94	8.19	1.23
HYPERNO LAYTON	2	880.46	863.19	17.27	1.96
KARRAKATTA-BLUFF	0	760.98	760.98	0.00	0.00
MILLGROVE GEORGE	2	750.58	733.43	17.15	2.29
MT PLEASANT LORIKEET	1	635.74	627.06	8.68	1.37
PRINCETON STANFORD	7	953.69	892.52	61.17	6.41
TRENTBRIDGE MANCHESTER	3	933.02	914.59	18.43	1.98
WARATAH-WARRIGAL	1	422.83	420.75	2.09	0.49
WINDSOR-ST JAMES	3	1261.01	1234.39	26.63	2.11
TOTAL	**30**	**10056.78**	**9809.97**	**246.81**	**2.45**

14.3 System Performance

As a comparison, the dispatch performance on Sunday, 13 January 2019 was assessed. This allowed for the pre-event analysis of the batteries. The maximum temperature on the day was 25.6°C.

14.3.1 Performance on 13 January 2019

Figure 16 depicts the average performance of the batteries. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plot next to the Discharge Rate, and the Battery SOC and Temperature of the day plotted in the final graph.

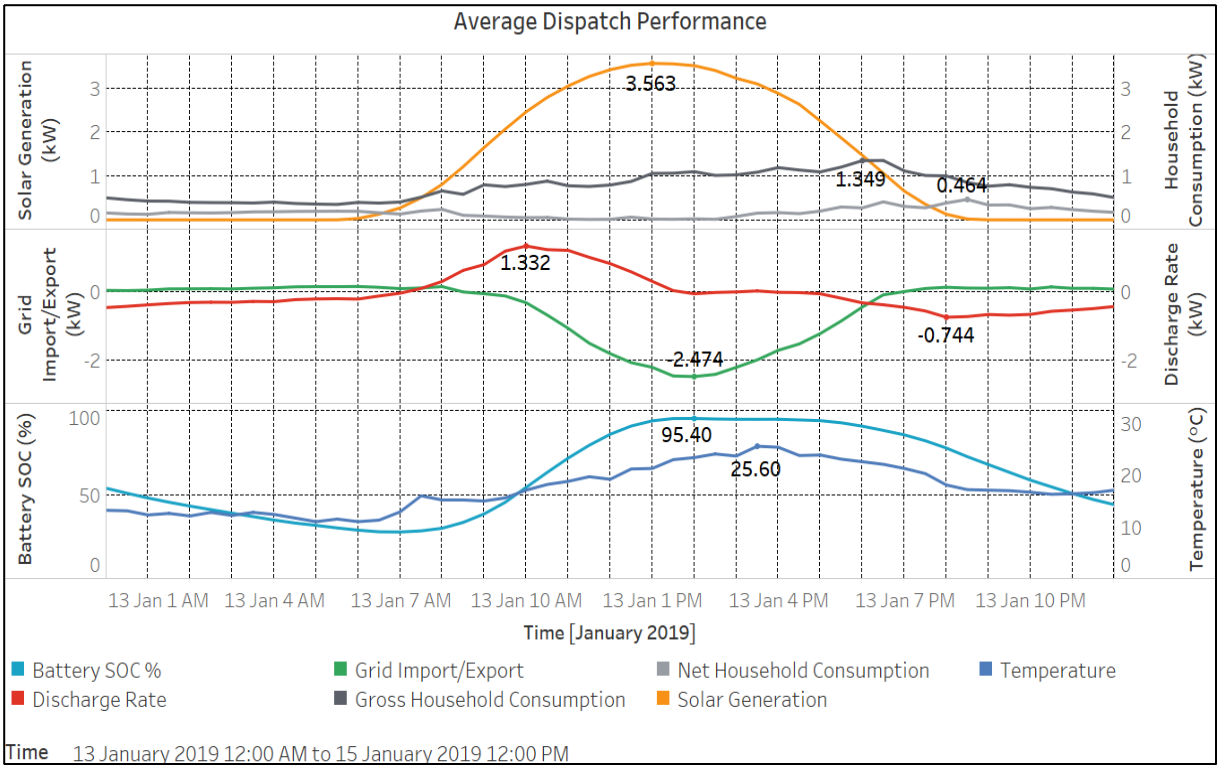

Figure 16: Average Dispatch Performance for 13 January 2019

During the period of 7:00 am to 5:00 pm, the average Gross Household Consumption rose from approximately 0.406kW to 1.349kW, however the Net Consumption as seen by the network was close to zero for this period (Net Consumption increases to 0.2kW at the end of this period).

14.3.2 Performance on 14 January 2019

Similar to the comparison for the non-event day, Figure 17 depicts the average performance of the batteries on the event day. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plotted next to the Discharge Rate, with the Battery SOC and Temperature of the day plotted in the final graph.

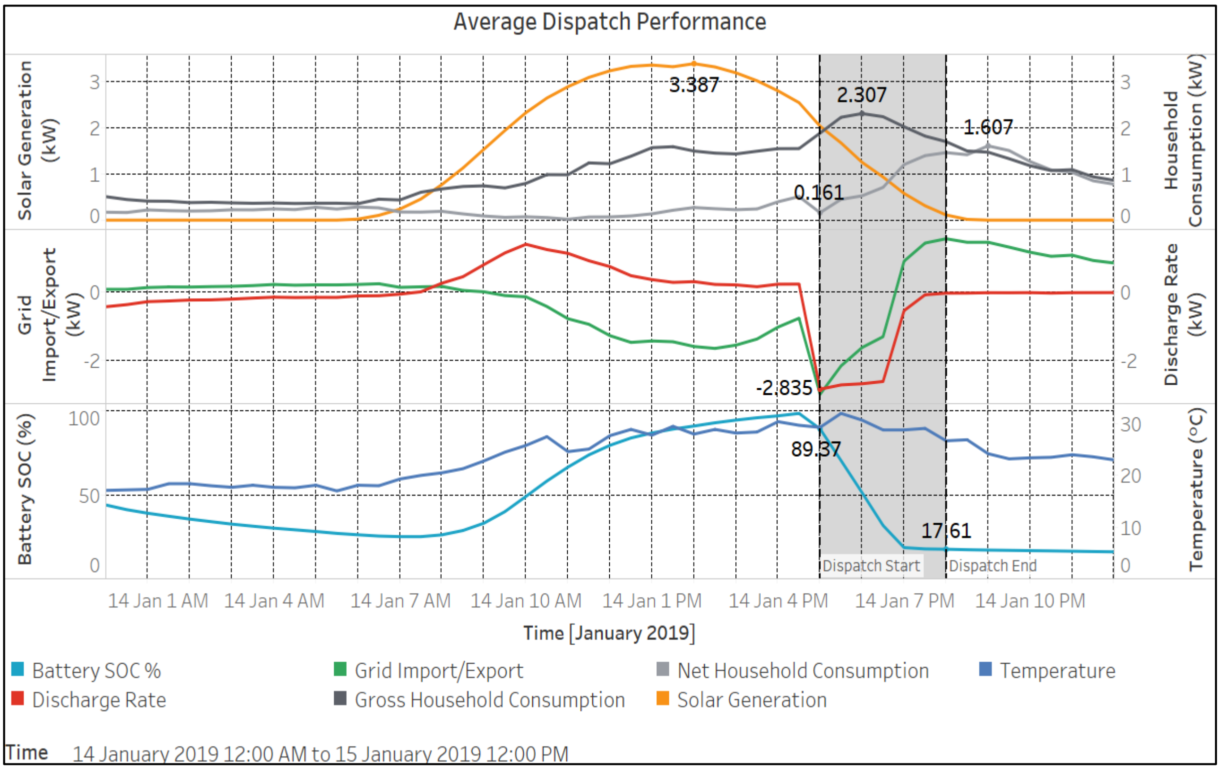

Figure 17: Average Dispatch Performance for 14 January 2019

By comparing Figure 16 and Figure 17, it can be noted that the maximum average Gross Household Consumption nearly doubled from 1.349kW to 2.307kW due to the extreme weather experienced. However, during the event on 14 January, Net Consumption fell from 0.51kW down to nearly 0kW at 5:00 pm. As the batteries were discharged, Net Household Consumption fluctuated around the 2kW mark. This can be attributed to the fact that at 7:00 pm, the Solar Generation fell below Gross Household Consumption and in order to cope with the excess demand, the household was required to draw power from the grid. This can be seen when the Grid Import/Export curve went positive at this time. This also explains why the amount of energy dispatched onto the network was less than the discharge amount of the battery.

14.3.3 Dispatch Performance by Distribution Substation

Table 19 shows the dispatch performance of the systems by Distribution Substation.

Table 19: Dispatch Performance by Distribution Substation on 04 January 2019

Substation Name	Battery Size (Usable Capacity) (kWh)	Number of Systems Online	Total Usable Battery Capacity (kWh)	Percentage of Battery Discharged (%)	Total Energy Discharged (kWh)	Total Solar Generation (kWh)	Household Consumption (kWh)	Net Grid Export (kWh)
ACHERON KOETONG	9.8 (8.8)	4	35.20	78.90	25.44	15.53	26.35	14.61
AMETHYST DIAMOND	9.8 (8.8)	2	17.60	78.63	12.59	5.64	13.60	4.63
BRIGGS CHLORIS	9.8 (8.8)	2	17.60	78.21	12.84	4.91	4.98	12.77
CASTLEWOOD MARLBOROUGH	9.8 (8.8)	1	8.80	78.45	6.24	2.68	7.72	1.20
ENTRANCE NEPEAN	9.8 (8.8)	1	8.80	78.93	6.32	2.98	19.67	-10.37
FLORENCE-GERALD	9.8 (8.8)	1	8.80	39.26	6.49	0.74	17.24	-10.01
HYPERNO LAYTON	9.8 (8.8)	2	17.60	39.44	12.70	11.54	17.25	6.99
MILLGROVE GEORGE	9.8 (8.8)	2	17.60	76.90	11.87	7.39	7.95	11.32
MT PLEASANT LORIKEET	9.8 (8.8)	1	8.80	78.25	6.25	1.54	4.61	3.18
PRINCETON STANFORD	9.8 (8.8)	7	61.60	50.72	44.05	28.52	45.96	26.61
TRENTBRIDGE MANCHESTER	9.8 (8.8)	3	26.40	42.35	13.25	9.77	22.21	0.81
WARATAH-WARRIGAL	9.8 (8.8)	1	8.80	11.14	1.57	2.39	4.68	-0.72
WINDSOR-ST JAMES	9.8 (8.8)	3	26.40	47.79	12.80	9.70	20.67	1.83
TOTALS	**-**	**30**	**264**	**55.64**	**172.41**	**103.33**	**212.89**	**62.85**

14.3.4 Performance Summary

The following comparisons only take into account the performance of the 30 systems that were operational throughout the entire dispatch period.

Table 20 shows the online status of the 42 LG Chem batteries installed at the various sites on the UE network.

Table 20: Breakdown of Online Status during Event 2

Distribution Substation	Solar Storage Customers	No. of Systems Online
ACHERON KOETONG	4	4
AMETHYST DIAMOND	2	2
BRIGGS CHLORIS	2	2
CASTLEWOOD MARLBOROUGH	2	1
ENTRANCE NEPEAN	1	2
FLORENCE-GERALD	2	1
HYPERNO LAYTON	4	1
KARRAKATTA-BLUFF	1	2
MILLGROVE GEORGE	2	0
MT PLEASANT LORIKEET	1	2
PRINCETON STANFORD	11	1
TRENTBRIDGE MANCHESTER	4	7
WARATAH-WARRIGAL	1	3
WINDSOR-ST JAMES	5	3
TOTAL	**42**	**30**

In Figure 18, the Average Battery SOC (%) is plotted. This shows the aggregated Battery SOC performance of the LG Chem batteries.

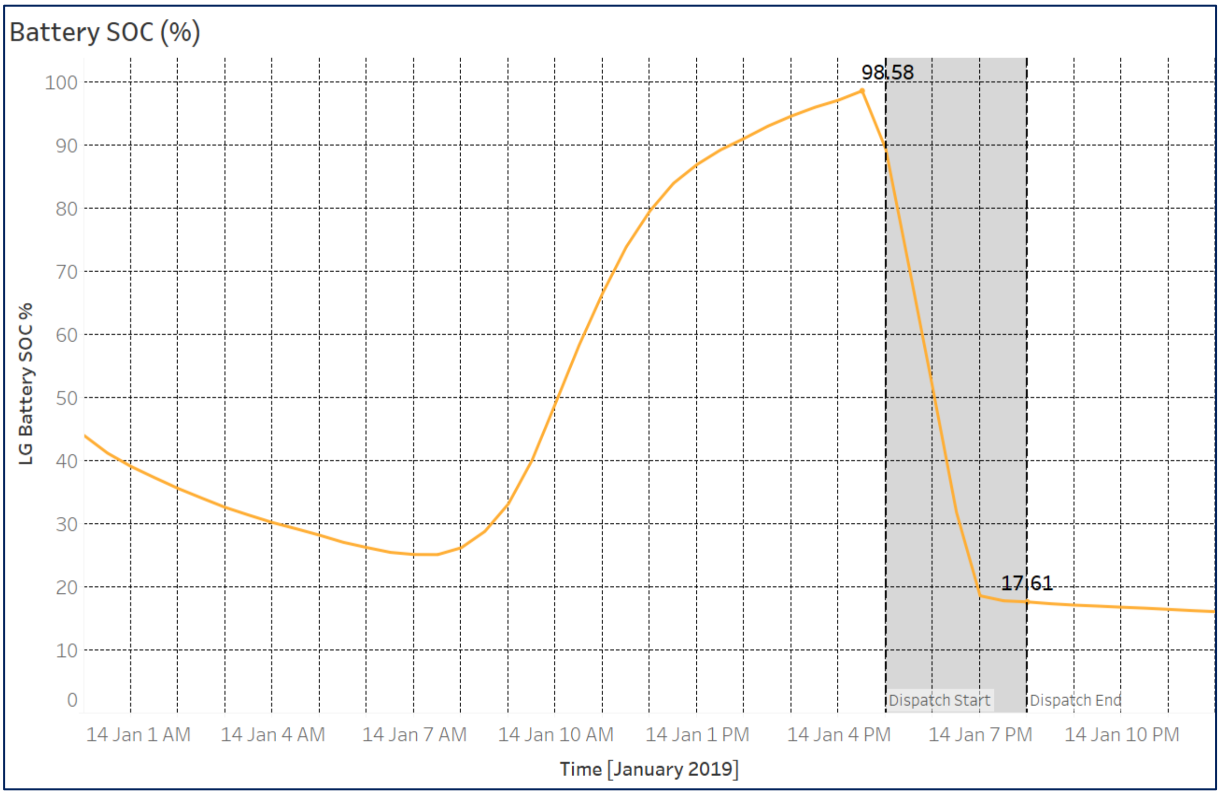

Figure 18: State of Charge (%) for Batteries on 14 January 2019

From Figure 18, the LG Chem batteries only began to charge at 7:30 am, the day of the dispatch event. From a minimum charge of 25.1%, with the aid of the solar generation during the day, the batteries charged to a maximum of 98.58%. Upon discharging when the event began, the LG Chem batteries went down to 18.58% at 7:00 pm and essentially stop discharging after this point. By 8:00 pm, the SOC was 17.61%.

This is an acceptable figure as the LG Chem batteries installed, while rated to 9.8kWh, only have 8.8kWh of usable energy, allowing a minimum SOC of approximately 10.2%. The batteries should not discharge below this point to maintain battery integrity and life. It seems that greater network benefit could have been achieved if the capacity of the batteries was to increase, as while the Discharge Rate was certainly adequate, the batteries effectively run out of charge 2 hours into the event.

Table 21 shows a comparison of the SOC for the batteries. All data is obtained from Figure 18.

Table 21: Battery State of Charge Comparison for 14 January 2019

Parameter	LG (%)
Maximum	98.58
Dispatch Start	89.37
Dispatch End	17.61
Minimum	16.06

The percentage of charge used during the dispatch event is summarised in Table 22.

Table 22: Percentage of Charge Used during Dispatch Event 2

Battery Type	Charge at Dispatch Start (%)	Charge at Dispatch End (%)	Percentage of Charge Used (%)	Average Energy Discharged (kWh)
LG	89.37	17.61	71.76	6.31

Figure 19 depicts the average discharge rate for the LG Chem batteries. The batteries discharged with a peak value of 2.8kW at 5:00 pm.

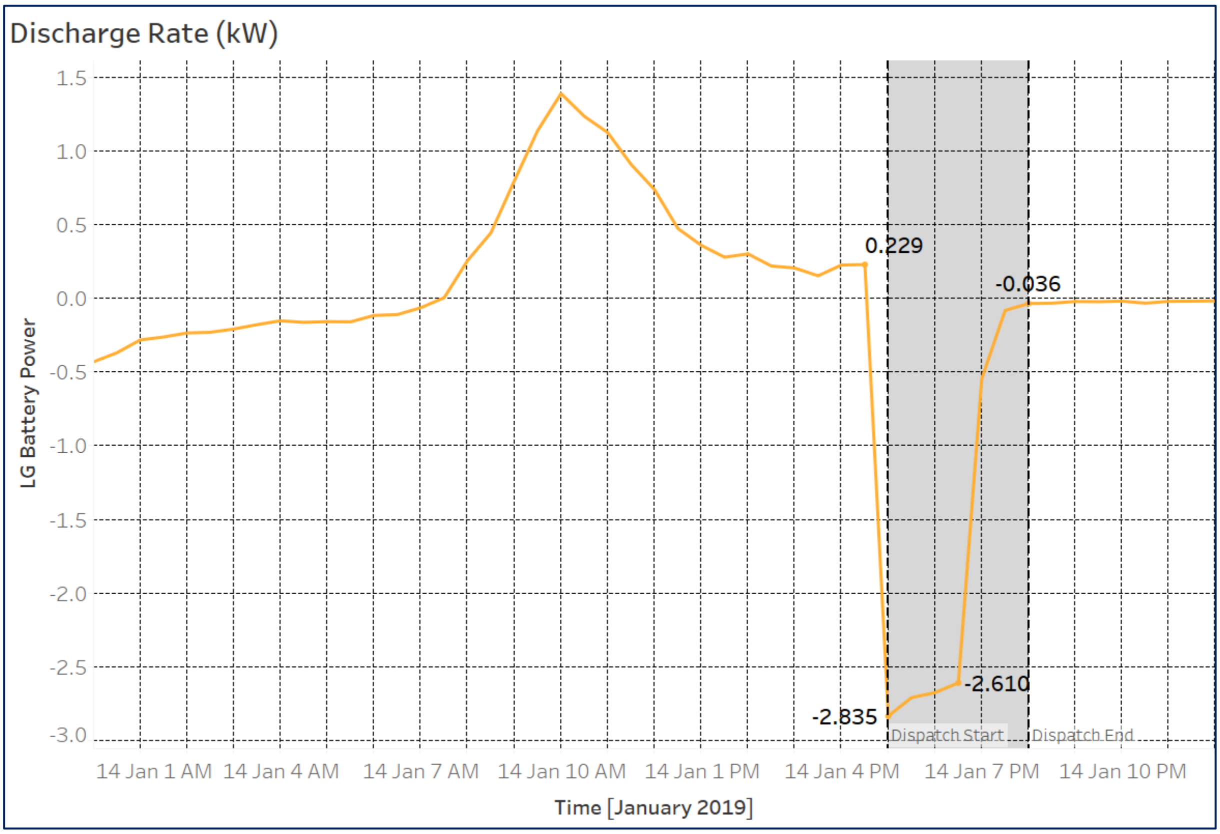

Figure 19: Average Discharge Rate of Battery Systems on 04 January 2019

The sloping curve at the beginning and end of the event in Figure 19 is an artefact of the level of granularity of the averaged performance data. This is also effected by the half-hourly data collected from the controller.

With a usable charge of 8.8kWh, the LG battery should have been able to discharge for approximately 3.86 hours at an average discharge rate of 2.28kW. However, as the LG batteries were only charged to 89.37% prior to the dispatch event, and were left with 17.61% at the end of the event (from Table 21), the average percentage of charge used for an LG battery was 71.76%. This equates to approximately 6.31kWh of charge.

At an average discharge rate of 2.28kW, it would have taken 2.77 hours for the batteries to discharge. As the data collected is half-hourly, it is not feasible to determine exactly how long the discharge duration was, but as per Figure 19, it was during the last half hour (2.5-3 hours) that the discharge of the LG batteries fell from 0.08kW to near 0kW.

Table 23 breaks down the discharge characteristics of the batteries as seen on 14 January 2019.

Table 23: Average Discharge Performance of Online Systems for 14 January 2019

Battery Type	Average Discharge Rate (kW)	Average Discharge Duration (Hours)	Average Energy Discharged (kWh)
LG	2.28	2.77	6.31

Table 22 and Table 23 use two different measures in order to calculate the Average Energy Discharged, with both resulting in near identical results. Table 22 uses the Battery's SOC, whilst Table 23 uses the Battery's Discharge Rate.

15. Appendix C – 2019 Dispatch Event 3

15.1 Event Overview

Event 3 occurred on Thursday, 24 January 2019, with the dispatch set between 5:00 pm and 8:00 pm for the Solar Storage systems. From the 42 systems installed, operational data was available for 32 systems, with the remaining units being offline at the time of the event, or unable to record the operational battery usage for the day.

Figure 20 shows the performance of the systems on the network during the dispatch event. Specifically, it shows the solar generation, energy exported to the grid, energy discharged by the battery and household consumption during the 3-hour dispatch event. Also, shown are graphs of these measures along with the net effect on all distribution substations (i.e. substation demand with and without the contribution from the Solar Storage systems).

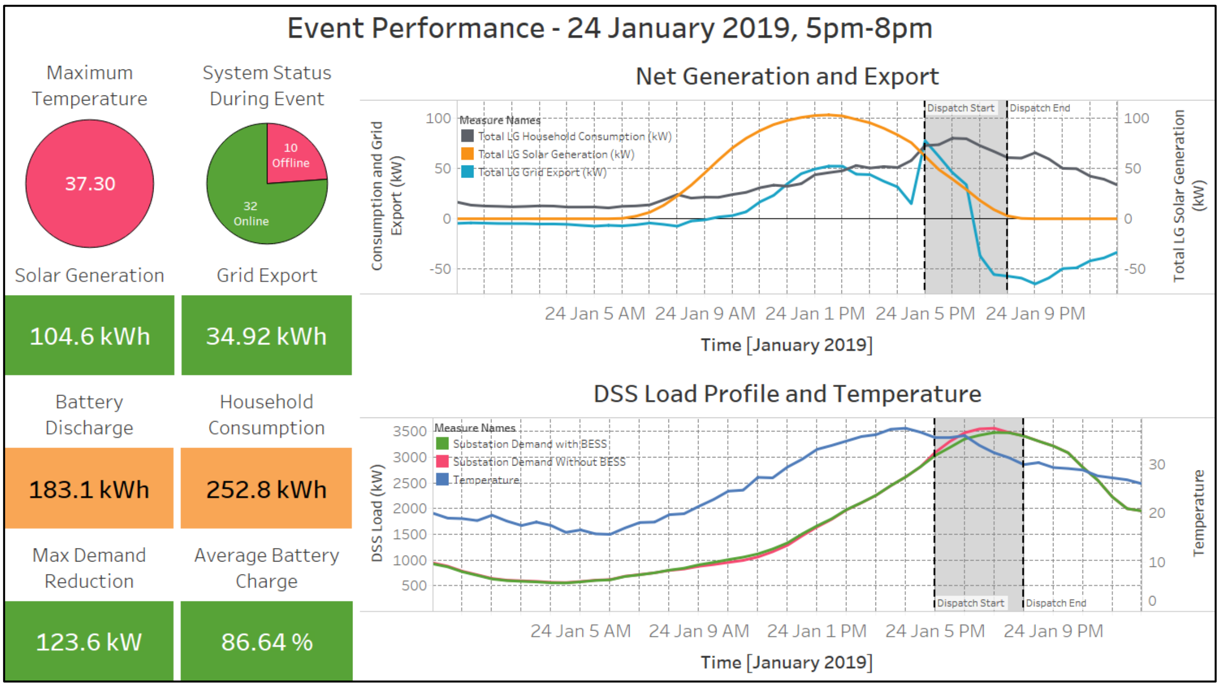

Figure 20: Summary of Event 3 (24 January 2019)

Key observations worthy of note are as below:

- The Solar PV systems installed at households generated 105kWh during the event period.
- 35kWh was exported to the grid reducing overall demand at constrained distribution substations.
- The operational batteries discharged 183kWh of energy.
- Of the households with online systems during the event, the total (gross) consumption was 253kWh over the 3-hour period.

The actual recorded maximum temperature at Moorabbin weather station was 37.3°C at 4:00pm whilst the overnight minimum temperature was 16°C (refer to Table 24).

Table 24: Maximum Temperatures at Various Locations on the UE Network

Location	Maximum Temperature (°C)	Time of Maximum Temperature
Moorabbin	37.3	16:00
Viewbank	39.8	16:30
Scoresby	39.9	17:00
Cerberus	35.6	18:00

Figure 21 depicts the temperature for different locations of the UE distribution network.

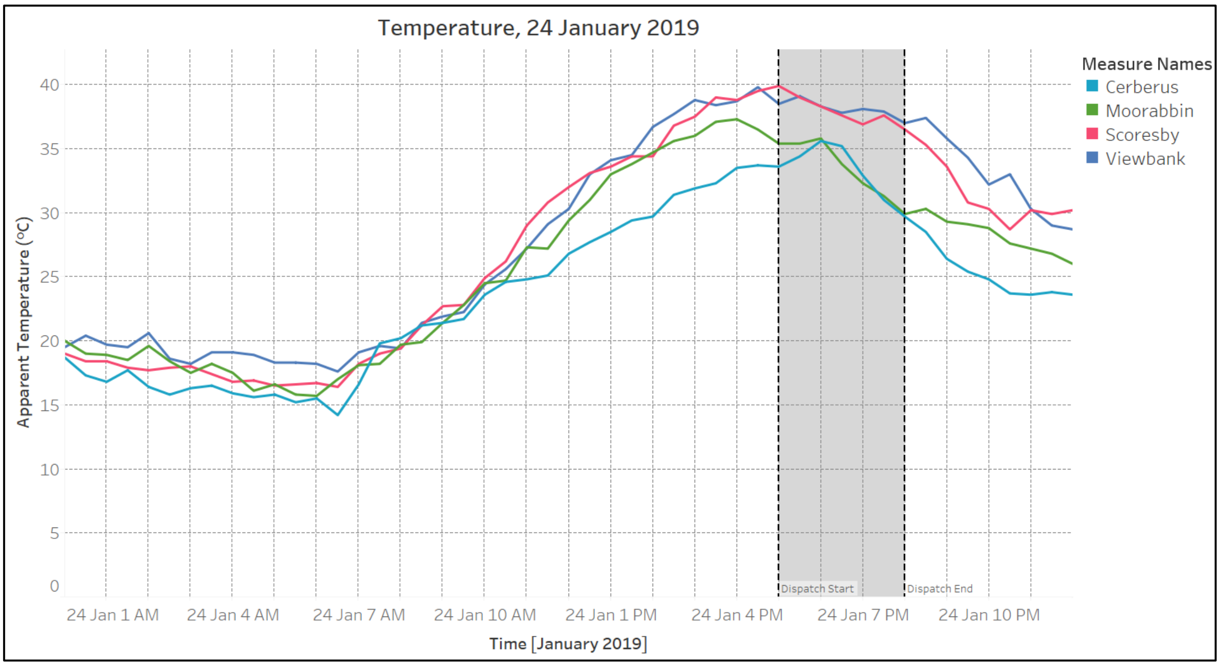

Figure 21: Temperatures at Different Locations in the United Energy Distribution Network on 24 January 2019

The apparent temperature exceeded 30°C from 11:30 am. The temperature was stable during the event at an average of 33.4°C. At the start of the event, the temperature was 35.4°C which further dropped to 29.9°C by 8:00 pm. There was no cool change present on the day.

15.2 Network Impact

Figure 22 depicts the load profile of the 14 substations on the day of the event (Green). For comparison, the amount of contribution from the Solar Storage systems was subtracted and the resultant curve (Red) shows the resultant load had the Solar Storage systems not contributed to reducing demand. Total contribution during the event is shown in Blue with Solar Generation shown in Orange.

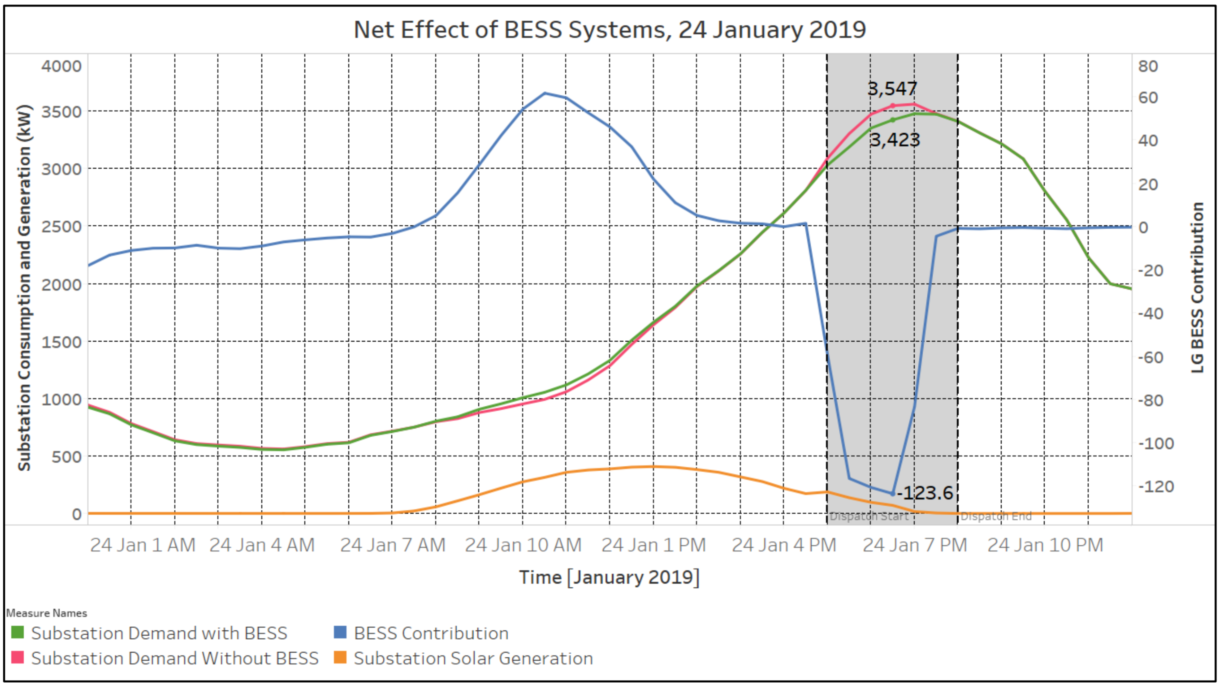

Figure 22: Total Substation Demand With (Green) and Without (Red) Solar Storage on 24 January 2019 – Battery Contribution (Blue) and Solar Generation (Orange)

Figure 22 shows the load on constrained substations decreased from 3,547kW to 3,423kW. This represents a 3.5% (124kW) maximum reduction in demand. As network demand is growing at less than 1% per year, the resulting reduction suggests that UE can defer network augmentation by 3.5 years.

As there was no cool change present on the day of the event, the peak demand occurred at 7:00 pm. As a result of the batteries having only a set amount of charge, the network benefit did not increase as demand increased.

Table 25 depicts the consumption in kWh at each of the 14 distribution substations with and without the Solar Storage systems. This allows for the impact to be measured, and in all, consumption was reduced by approximately 254kWh, which is a reduction of 2.13%.

Table 25: Substation Consumption during Dispatch Event (5-8 pm) on 24 January 2019

Substation Name	Number of Systems Online	Substation Consumption without systems during Dispatch Period (kWh)	Substation Consumption with systems during Dispatch Period (kWh)	Consumption Reduced (kWh)	Percentage Reduced (%)
ACHERON KOETONG	4	746.91	712.03	34.88	4.67
AMETHYST DIAMOND	2	812.14	794.65	17.48	2.15
BRIGGS CHLORIS	2	660.69	643.32	17.37	2.63
CASTLEWOOD MARLBOROUGH	1	708.60	699.80	8.79	1.24
ENTRANCE NEPEAN	1	382.28	373.79	8.49	2.22
FLORENCE-GERALD	1	779.50	771.00	8.51	1.09
HYPERNO LAYTON	2	1053.83	1036.48	17.35	1.65
KARRAKATTA-BLUFF	1	1139.81	1131.05	8.76	0.77
MILLGROVE GEORGE	1	715.20	706.81	8.39	1.17
MT PLEASANT LORIKEET	1	699.70	690.88	8.82	1.26
PRINCETON STANFORD	8	1109.45	1046.94	62.52	5.63
TRENTBRIDGE MANCHESTER	4	1061.69	1034.57	27.13	2.55
WARATAH-WARRIGAL	1	497.79	497.67	0.12	0.02
WINDSOR-ST JAMES	3	1561.97	1536.19	25.78	1.65
TOTAL	**32**	**11929.56**	**11675.18**	**254.38**	**2.13**

15.3 System Performance

As a comparison, the dispatch performance on 23 January 2019 was assessed. This allowed for the pre-event analysis of the battery. The maximum temperature at Moorabbin on the day was 24.8°C.

15.3.1 Performance on 23 January 2019

Figure 23 depicts the average performance of the battery. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plot next to the Discharge Rate, and the Battery SOC and Temperature of the day plotted in the final graph.

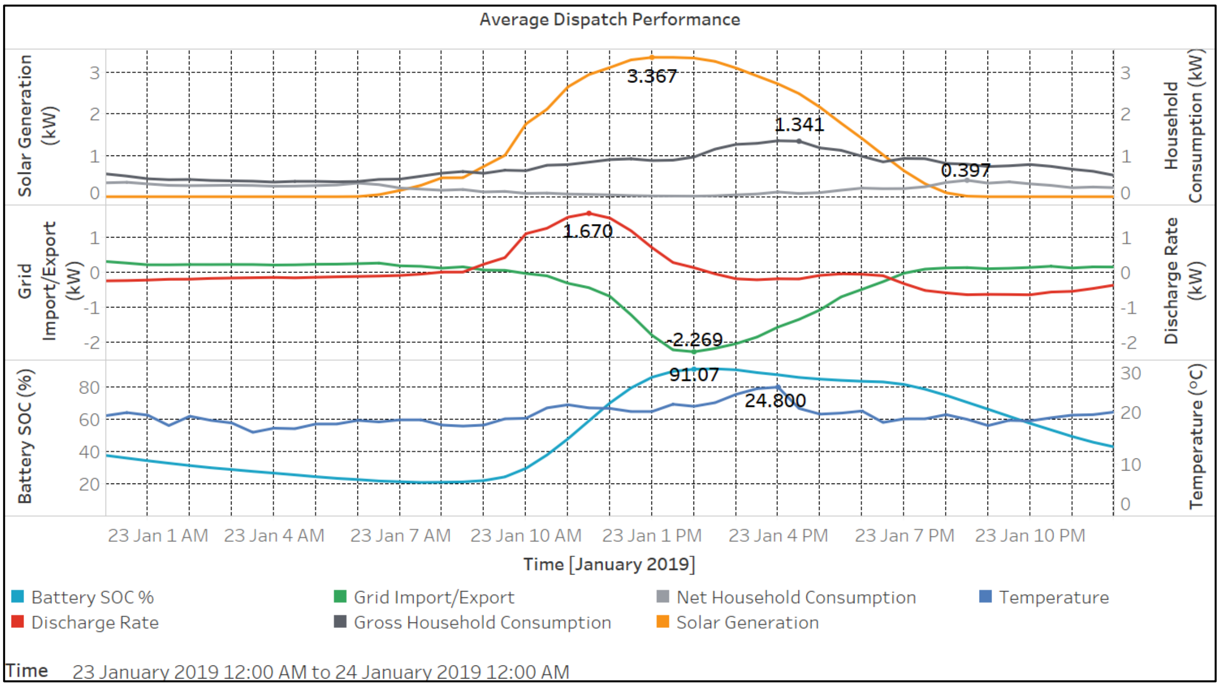

Figure 23: Average Dispatch Performance for 23 January 2019

During the period of 7:00 am to 4:30 pm, the average Gross Household Consumption rose from approximately 0.425kW to 1.341kW, however the Net Consumption as seen by the network was close to zero for this period (Net Consumption increases to 0.078kW at the end of this period).

15.3.2 Performance on 24 January 2019

Similar to the comparison for the non-event day, Figure 24 depicts the average performance of the batteries on the event day. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plotted next to the Discharge Rate, with the Battery SOC and Temperature of the day plotted in the final graph.

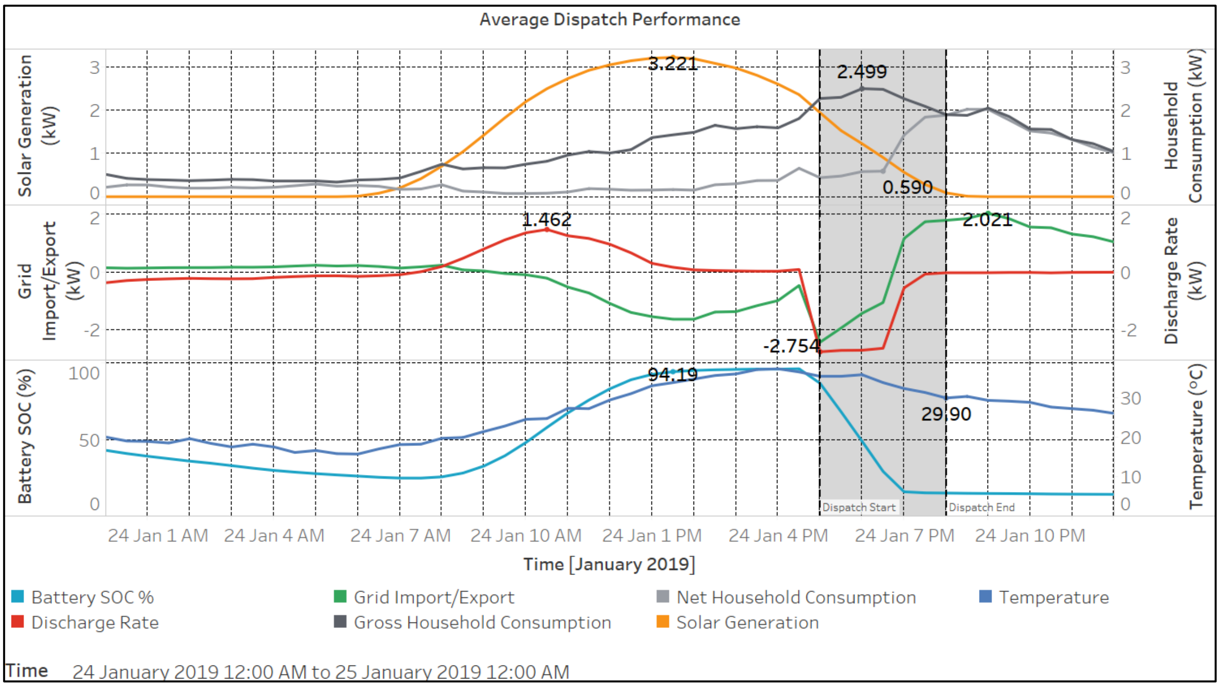

Figure 24: Average Dispatch Performance for 24 January 2019

By comparing Figure 23 and Figure 24, it can be noted that the maximum average Gross Household Consumption nearly doubled from 1.341kW to 2.499kW due to the extreme weather experienced. As the batteries are discharged, Net Household Consumption fluctuated around the 2kW mark. This can be attributed to the fact that by 7:00 pm, Solar Generation fell below Gross Household Consumption and in order to cope with the excess demand, the household was required to draw power from the grid. This can be seen when the Grid Import/Export curve went positive at this time. This also explains why the amount of energy dispatched onto the network was less than the discharge amount of the batteries.

15.3.3 Dispatch Performance by Distribution Substation

Table 26 shows the dispatch performance of the Solar Storage systems by Distribution Substation.

Table 26: Dispatch Performance by Distribution Substation on 24 January 2019

Substation Name	Battery Size (Usable Capacity) (kWh)	Number of Systems Online	Total Usable Battery Capacity (kWh)	Percentage of Battery Discharged (%)	Total Energy Discharged (kWh)	Total Solar Generation (kWh)	Household Consumption (kWh)	Net Grid Export (kWh)
ACHERON KOETONG	9.8 (8.8)	4	35.20	78.98	25.45	14.63	32.50	7.58
AMETHYST DIAMOND	9.8 (8.8)	2	17.60	78.30	12.59	5.55	18.25	-0.10
BRIGGS CHLORIS	9.8 (8.8)	2	17.60	78.13	12.66	4.73	5.68	11.71
CASTLEWOOD MARLBOROUGH	9.8 (8.8)	1	8.80	78.64	6.25	2.60	5.34	3.51
ENTRANCE NEPEAN	9.8 (8.8)	1	8.80	78.04	6.26	2.98	23.20	-13.96
FLORENCE-GERALD	9.8 (8.8)	1	8.80	39.07	6.49	0.98	20.31	-12.84
HYPERNO LAYTON	9.8 (8.8)	2	17.60	39.27	12.62	10.95	20.21	3.36
KARRAKATTA-BLUFF	9.8 (8.8)	1	8.80	77.95	6.23	5.46	4.89	6.81
MILLGROVE GEORGE	9.8 (8.8)	1	8.80	38.07	6.14	2.53	1.15	7.52
MT PLEASANT LORIKEET	9.8 (8.8)	1	8.80	78.84	6.30	1.39	4.10	3.59
PRINCETON STANFORD	9.8 (8.8)	8	70.40	50.87	44.69	26.84	66.27	5.26
TRENTBRIDGE MANCHESTER	9.8 (8.8)	4	35.20	61.20	19.37	12.72	21.01	11.09
WARATAH-WARRIGAL	9.8 (8.8)	1	8.80	1.19	0.00	0.00	5.39	-5.39
WINDSOR-ST JAMES	9.8 (8.8)	3	26.40	46.78	18.09	13.25	24.57	6.77
TOTALS	**-**	**32**	**281.6**	**58.95**	**183.14**	**104.62**	**252.85**	**34.92**

15.3.4 Performance Summary

The following comparisons only take into account the performance of the 32 systems that were operational throughout the entire dispatch period.

Table 27 shows the online status of the 42 LG Chem batteries installed at the various sites on the UE network.

Table 27: Breakdown of Online Status during Event 3

Distribution Substation	Solar Storage Customers	No. of Systems Online
ACHERON KOETONG	4	4
AMETHYST DIAMOND	2	2
BRIGGS CHLORIS	2	2
CASTLEWOOD MARLBOROUGH	2	1
ENTRANCE NEPEAN	1	1
FLORENCE-GERALD	2	1
HYPERNO LAYTON	4	2
KARRAKATTA-BLUFF	1	1
MILLGROVE GEORGE	2	1
MT PLEASANT LORIKEET	1	1
PRINCETON STANFORD	11	8
TRENTBRIDGE MANCHESTER	4	4
WARATAH-WARRIGAL	1	1
WINDSOR-ST JAMES	5	3
TOTAL	**42**	**32**

In Figure 25, the Average Battery SOC (%) is plotted. This shows the aggregated Battery SOC performance of the LG Chem batteries.

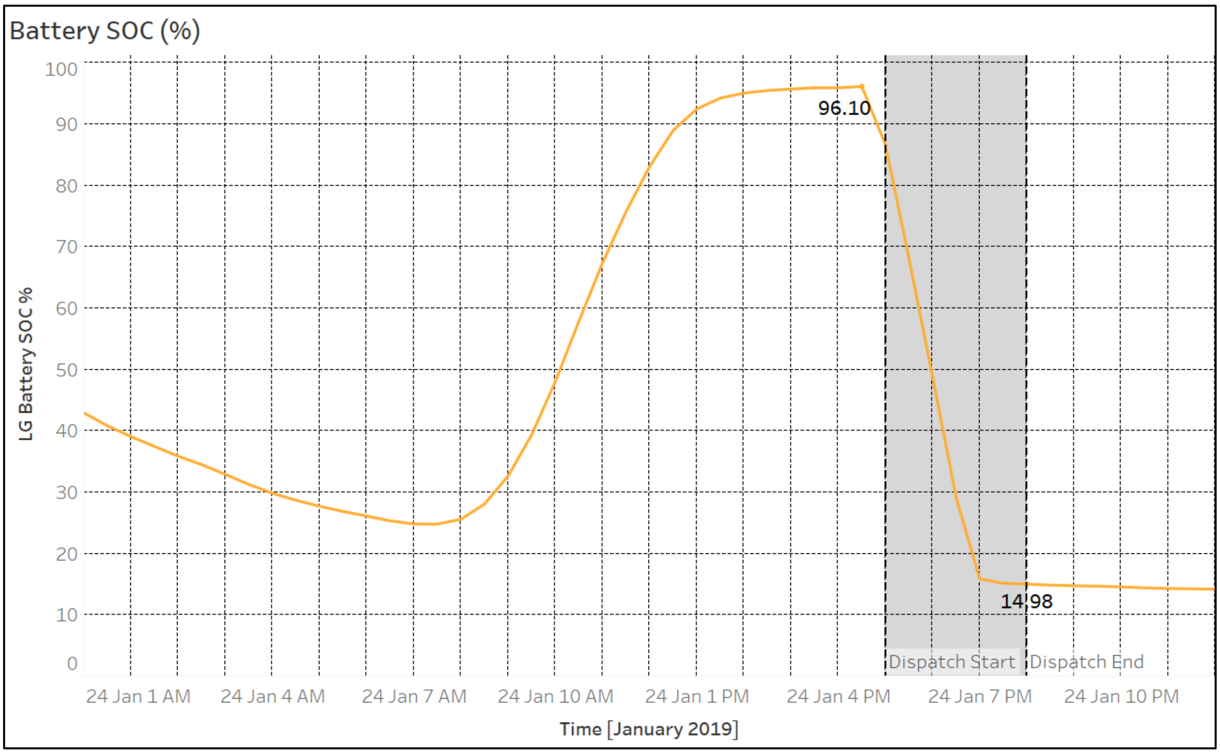

Figure 25: State of Charge (%) for Batteries on 24 January 2019

From Figure 25, the LG Chem batteries only begin to charge at 7:30 am, the day of the dispatch event. From a minimum charge of 24.75%, with the aid of the solar generation during the day, the batteries charged to a maximum of 96.1%. Upon discharging when the event began, the LG Chem batteries went down to 15.83% at 7:00 pm and essentially stopped discharging after this point. By 8:00 pm, the SOC was 14.98%.

This is an acceptable figure as the LG Chem batteries installed, while rated to 9.8kWh, only have 8.8kWh of usable energy, allowing a minimum SOC of approximately 10.2%. The batteries should not discharge below this point to maintain battery integrity and life. It seems that greater network benefit could have been achieved if the capacity of the batteries was to increase, as while the Discharge Rate was certainly adequate, the batteries effectively run out of charge between 2.5 and 3 hours into the event.

Table 28 shows a comparison of the SOC for the batteries. All data is obtained from Figure 25.

Table 28: Battery State of Charge Comparison for 24 January 2019

Parameter	LG (%)
Maximum	96.1
Dispatch Start	86.64
Dispatch End	14.98
Minimum	14.16

The percentage of charge used during the dispatch event is summarised in Table 29.

Table 29: Percentage of Charge Used during Dispatch Event 3

Battery Type	Charge at Dispatch Start (%)	Charge at Dispatch End (%)	Percentage of Charge Used (%)	Average Energy Discharged (kWh)
LG	86.64	14.98	71.66	6.31

Figure 26 depicts the average discharge rate for the LG Chem batteries. The batteries discharged with a peak value of 2.8kW at 5:00 pm.

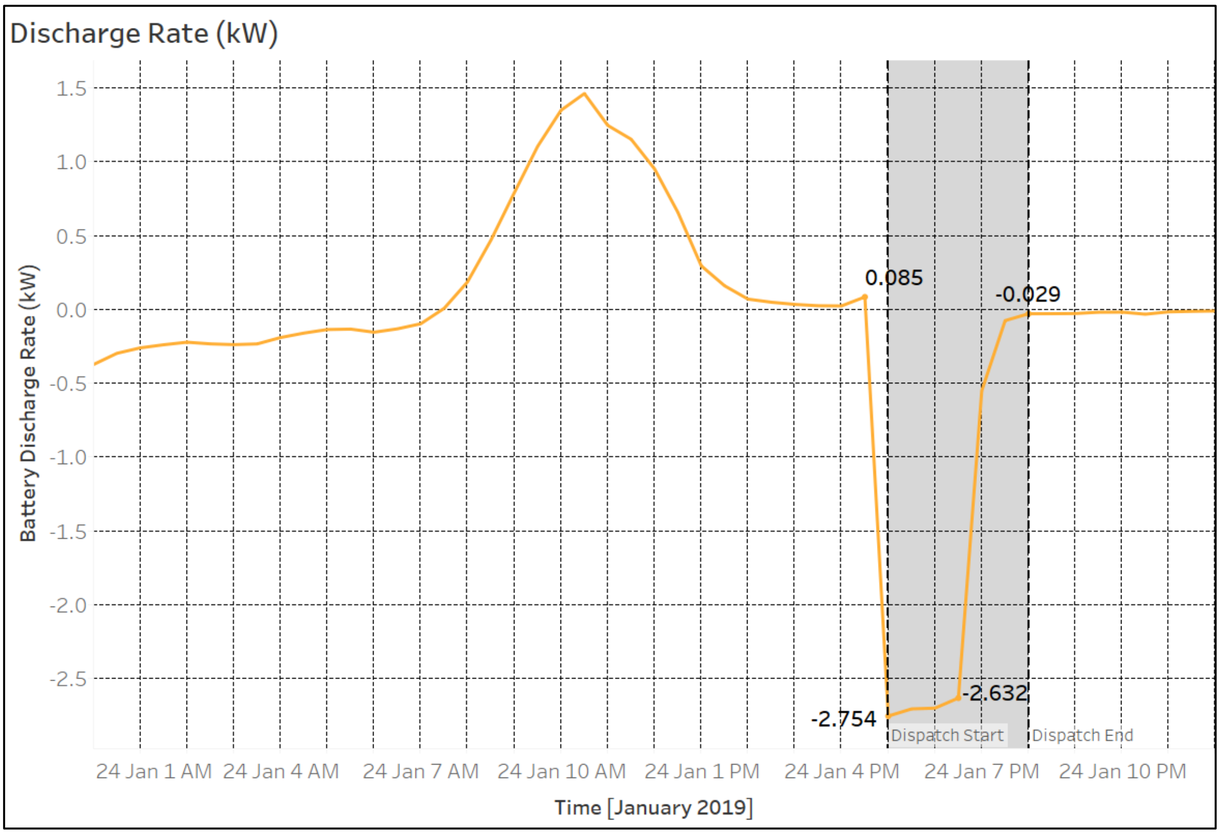

Figure 26: Average Discharge Rate of Battery Systems on 24 January 2019

The sloping curve at the beginning and end of the event in Figure 26 is an artefact of the level of granularity of the averaged performance data. This is also effected by the half-hourly data collected from the controller.

With a usable charge of 8.8kWh, the LG batteries should have been able to discharge for approximately 3.8 hours at an average discharge rate of 2.34kW. However, as the LG batteries were only charged to 86.64% prior to the dispatch event, and were left with 14.98% at the end of the event (from Table 28), the average percentage of charge used for an LG battery was 71.66%. This equates to approximately 6.31kWh of charge.

At an average discharge rate of 2.34 kW, it would have taken 2.7 hours for the batteries to discharge. As the data collected is half-hourly, it is not feasible to determine exactly how long the discharge duration was, but as per Figure

26, it was during the last half hour (2.5-3 hours) that the discharge of the LG batteries fell from 0.08 kW to near 0kW.

Table 30 breaks down the discharge characteristics of the batteries as seen on 24 January 2019.

Table 30: Average Discharge Performance of Online Systems for 24 January 2019

Battery Type	Average Discharge Rate (kW)	Average Discharge Duration (Hours)	Average Energy Discharged (kWh)
LG	2.34	2.7	6.31

Table 29 and Table 30 use two different measures in order to calculate the Average Energy Discharged, with both resulting in near identical results. Table 29 uses the battery's SOC, whilst Table 30 uses the Battery's Discharge Rate.

16. Appendix D – 2019 Dispatch Event 4

16.1 Event Summary

Event 4 occurred on Friday, 25 January 2019, with the dispatch set between 4:00 pm and 7:00 pm for the Solar Storage systems. From the 42 systems installed, operational data was available for 31 systems, with the remaining units being offline at the time of the event, or unable to record the operational battery usage for the day.

Figure 27 shows the performance of the systems on the network during the dispatch event. Specifically, it shows the solar generation, energy exported to the grid, energy discharged by the battery and household consumption during the 3-hour dispatch event. Also, shown are graphs of these measures along with the net effect on all distribution substations (i.e. substation demand with and without the contribution from Solar Storage systems).

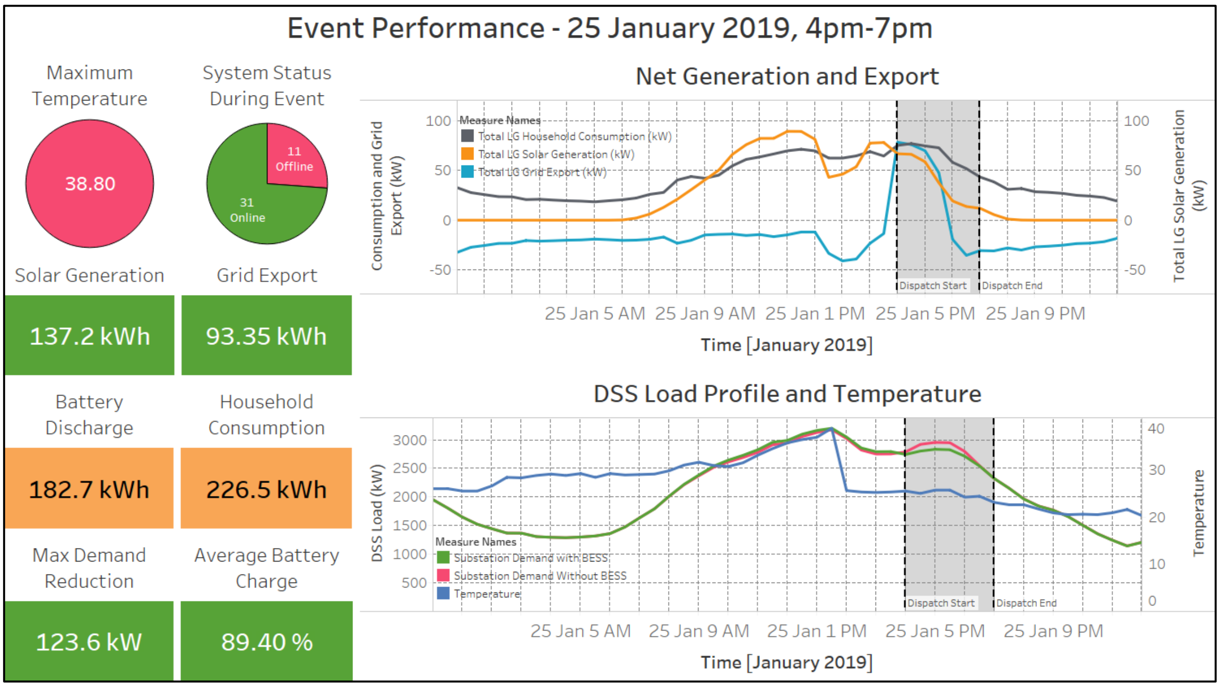

Figure 27: Summary of Event 4 (25 January 2019)

Key observations worthy of note are as below:

- The Solar PV systems installed at households generated 137kWh during the event period.
- 93kWh was exported to the grid reducing overall demand at constrained distribution substations.
- The operational batteries discharged 183kWh of energy.
- Of the households with online systems during the event, the total (gross) consumption was 227kWh over the 3-hour period.

The actual recorded maximum temperature at Moorabbin weather station was 38.8°C at 1:30 pm whilst the overnight minimum temperature was 20.5°C (refer to Table 31).

Table 31: Maximum Temperatures at Various Locations on the UE Network

Location	Maximum Temperature (°C)	Time of Maximum Temperature
Moorabbin	38.8	13:30
Viewbank	40.6	14:00
Scoresby	39.8	14:00
Cerberus	37.8	12:30

Figure 28 depicts the temperature for different locations of the UE distribution network.

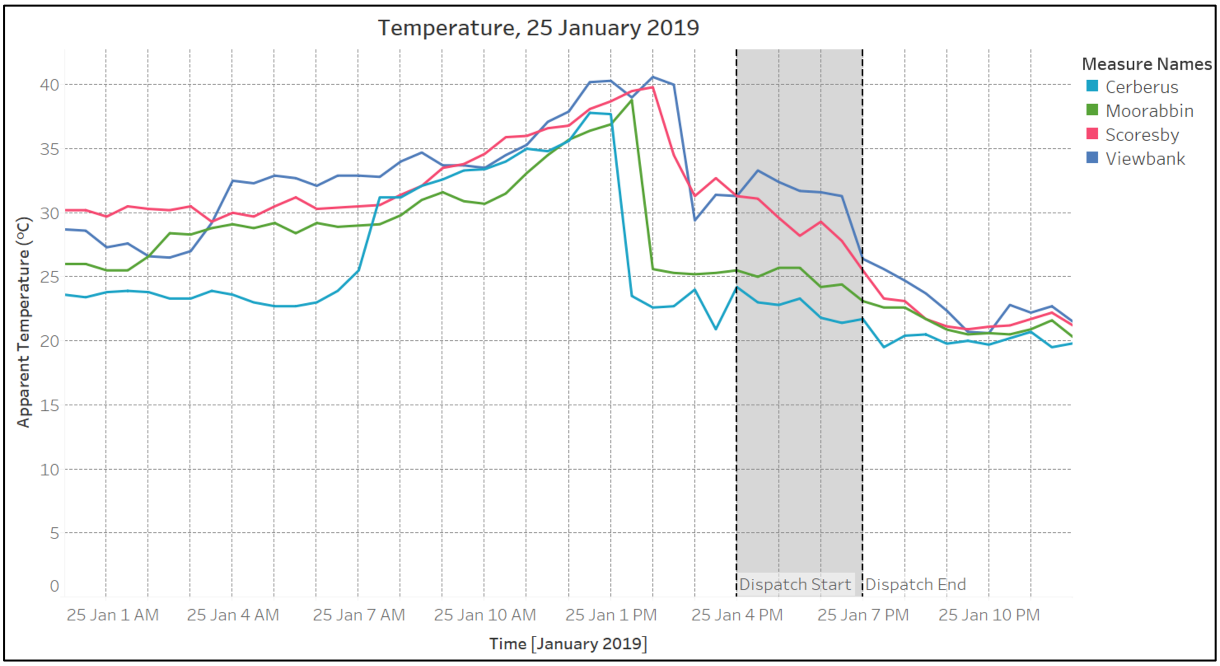

Figure 28: Temperatures at Different Locations in the United Energy Distribution Network on 25 January 2019

The apparent temperature exceeded 30°C from 8:30 am. The temperature was stable during the event at an average of 24.8°C. At the start of the event, the temperature was 25.5°C which further dropped to 23.1°C by 7:00 pm. A cool change commenced from 2:00 pm onwards.

16.2 Network Impact

Figure 29 depicts the load profile of the 14 substations on the day of the event (Green). For comparison, the amount of contribution from the Solar Storage systems was subtracted and the resultant curve (Red) shows the resultant load had the Solar Storage systems not contributed to reducing demand. Total contribution during the event is shown in Blue with Solar Generation shown in Orange.

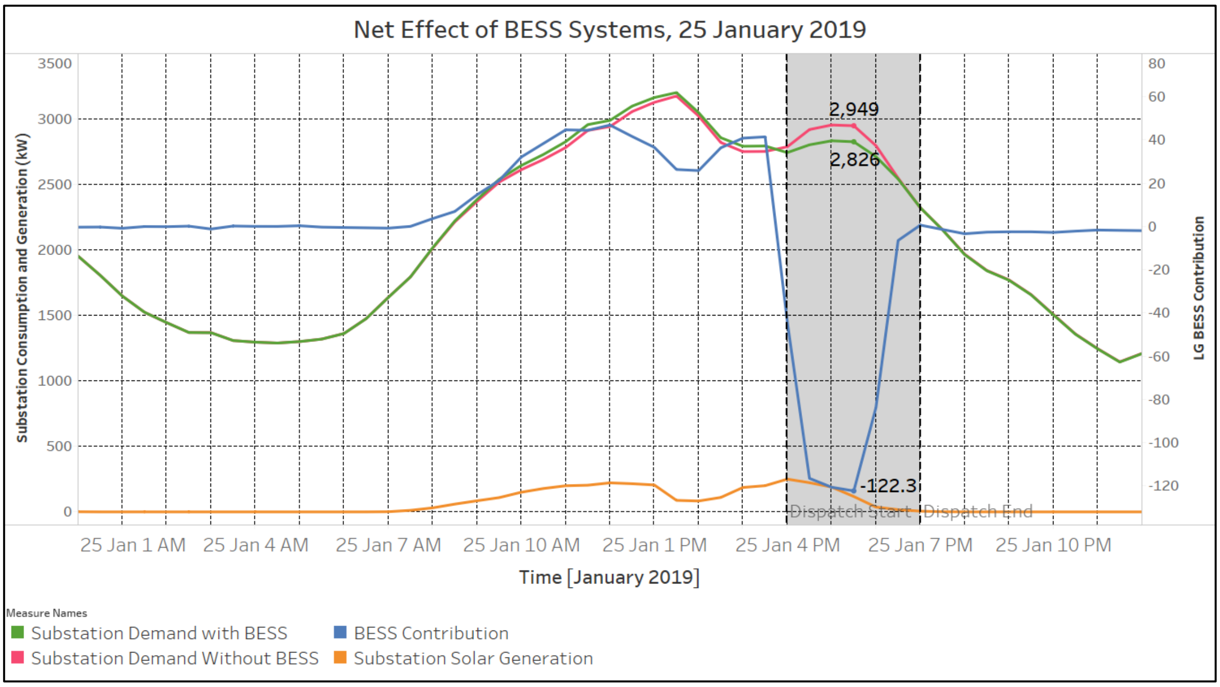

Figure 29: Total Substation Demand With (Green) and Without (Red) Solar Storage on 25 January 2019 – Battery Contribution (Blue) and Solar Generation (Orange)

Figure 29 shows the load on constrained substations decreased from 2,949kW to 2,826kW. This represents a 4.2% (123kW) maximum reduction in demand. As network demand is growing at less than 1% per year, the resulting reduction suggests that UE can defer network augmentation by 4.2 years.

As there was a cool change present on the day of the event, the peak demand occurred at 1.30 pm. As a result of the batteries having only a set amount of charge, the network benefit did not increase as demand increased.

Table 32 depicts the consumption in kWh at each of the 14 distribution substations with and without the Solar Storage systems. This allows for the impact to be measured, and in all, consumption was reduced by approximately 246kWh, which is a reduction of 2.56%.

Table 32: Substation Consumption during Dispatch Event (4-7 pm) on 25 January 2019

Substation Name	Number of Systems Online	Substation Consumption without systems during Dispatch Period (kWh)	Substation Consumption with systems during Dispatch Period (kWh)	Consumption Reduced (kWh)	Percentage Reduced (%)
ACHERON KOETONG	4	627.30	601.35	25.95	4.14
AMETHYST DIAMOND	2	681.14	664.24	16.90	2.48
BRIGGS CHLORIS	2	569.74	552.24	17.50	3.07
CASTLEWOOD MARLBOROUGH	1	513.07	504.35	8.72	1.70
ENTRANCE NEPEAN	1	285.83	277.31	8.52	2.98
FLORENCE-GERALD	1	638.50	630.17	8.32	1.30
HYPERNO LAYTON	2	760.56	743.23	17.33	2.28
KARRAKATTA-BLUFF	1	876.94	868.94	8.01	0.91
MILLGROVE GEORGE	1	627.81	619.33	8.47	1.35
MT PLEASANT LORIKEET	1	613.78	604.96	8.82	1.44
PRINCETON STANFORD	8	946.94	880.21	66.73	7.05
TRENTBRIDGE MANCHESTER	4	930.83	904.55	26.28	2.82
WARATAH-WARRIGAL	0	387.55	387.55	0.00	0.00
WINDSOR-ST JAMES	3	1179.33	1154.47	24.86	2.11
TOTAL	**31**	**9639.32**	**9392.90**	**246.42**	**2.56**

16.3 System Performance

As a comparison, the dispatch performance on 26 January 2019 was assessed. This allowed for the pre-event analysis of the batteries. The maximum temperature at Moorabbin on the day was 25°C.

16.3.1 Performance on 26 January 2019

Figure 30 depicts the average performance of the batteries. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plot next to the Discharge Rate, and the Battery SOC and Temperature of the day plotted in the final graph.

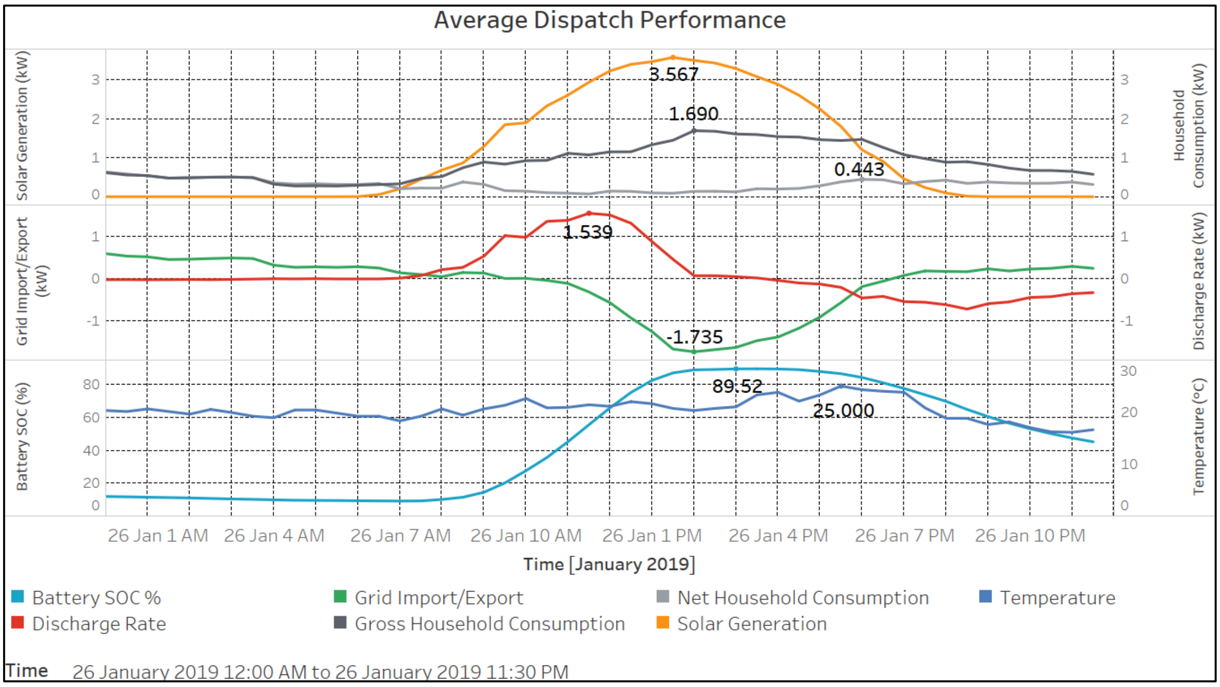

Figure 30: Average Dispatch Performance for 26 January 2019

During the period of 7:00 am to 2:00 pm, the average Gross Household Consumption rose from approximately 0.33kW to 1.69kW, however the Net Consumption as seen by the network was close to zero for this period (Net Consumption increases to 0.136kW at the end of this period).

16.3.2 Performance on 25 January 2019

Similar to the comparison for the non-event day, Figure 31 depicts the average performance of the batteries on the event day. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plotted next to the Discharge Rate, with the Battery SOC and Temperature of the day plotted in the final graph.

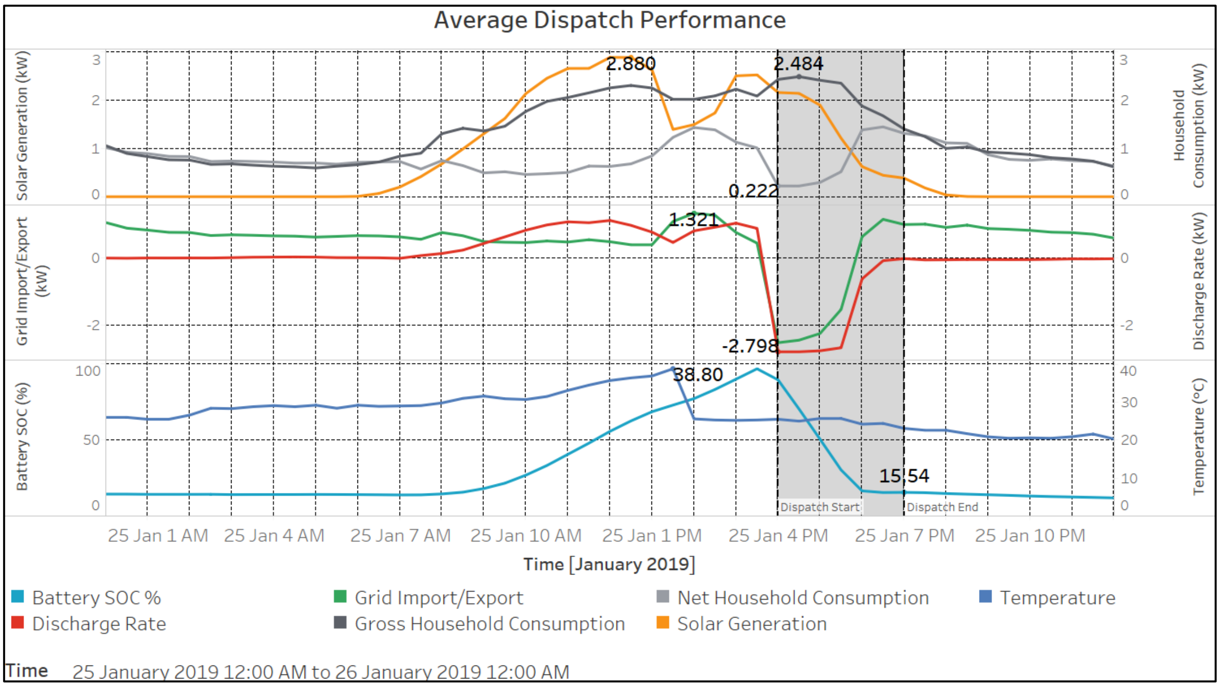

Figure 31: Average Dispatch Performance for 25 January 2019

By comparing Figure 30 and Figure 31, it can be noted that the maximum average Gross Household Consumption increased from 1.69kW to 2.484kW due to the extreme weather experienced. As the batteries are discharged, Net Household Consumption fluctuated around the 1kW mark. This can be attributed to the fact that at 7:00 pm, the Solar Generation fell below Gross Household Consumption and in order to cope with the excess demand, the household was required to draw power from the grid. This can be seen when the Grid Import/Export curve went positive at this time. This also explains why the amount of energy dispatched onto the network was less than the discharge amount of the batteries.

16.3.3 Dispatch Performance by Distribution Substation

Table 33 shows the dispatch performance of the Solar Storage systems by Distribution Substation.

Table 33: Dispatch Performance by Distribution Substation on 25 January 2019

Substation Name	Battery Size (Usable Capacity) (kWh)	Number of Systems Online	Total Usable Battery Capacity (kWh)	Percentage of Battery Discharged (%)	Total Energy Discharged (kWh)	Total Solar Generation (kWh)	Household Consumption (kWh)	Net Grid Export (kWh)
ACHERON KOETONG	9.8 (8.8)	4	35.20	61.73	20.00	17.44	19.08	18.37
AMETHYST DIAMOND	9.8 (8.8)	2	17.60	78.63	12.68	8.38	15.73	5.32
BRIGGS CHLORIS	9.8 (8.8)	2	17.60	78.26	12.77	8.36	11.66	9.48
CASTLEWOOD MARLBOROUGH	9.8 (8.8)	1	8.80	79.00	6.28	4.47	6.06	4.70
ENTRANCE NEPEAN	9.8 (8.8)	1	8.80	78.52	6.25	4.20	23.78	-13.33
FLORENCE-GERALD	9.8 (8.8)	1	8.80	39.00	6.50	2.58	21.01	-11.93
HYPERNO LAYTON	9.8 (8.8)	2	17.60	39.80	12.89	8.59	18.58	2.89
KARRAKATTA-BLUFF	9.8 (8.8)	1	8.80	77.63	6.14	4.96	4.66	6.43
MILLGROVE GEORGE	9.8 (8.8)	1	8.80	38.31	6.22	4.13	1.28	9.08
MT PLEASANT LORIKEET	9.8 (8.8)	1	8.80	79.27	6.33	3.58	3.93	5.98
PRINCETON STANFORD	9.8 (8.8)	8	70.40	56.80	49.58	35.84	51.58	33.84
TRENTBRIDGE MANCHESTER	9.8 (8.8)	4	35.20	60.49	19.00	18.79	21.70	16.08
WARATAH-WARRIGAL	9.8 (8.8)	0	0.00	0.00	0.00	0.00	0.00	0.00
WINDSOR-ST JAMES	9.8 (8.8)	3	26.40	46.81	18.06	15.86	27.48	6.44
TOTALS	**-**	**31**	**272.8**	**58.16**	**182.71**	**137.17**	**226.53**	**93.35**

16.3.4 Performance Summary

Table 34 shows the online status of the 42 LG Chem batteries installed at the various sites on the UE network.

Table 34: Breakdown of Online Status during Event 4

Distribution Substation	Solar Storage Customers	No. of Systems Online
ACHERON KOETONG	4	4
AMETHYST DIAMOND	2	2
BRIGGS CHLORIS	2	2
CASTLEWOOD MARLBOROUGH	2	1
ENTRANCE NEPEAN	1	1
FLORENCE-GERALD	2	1
HYPERNO LAYTON	4	2
KARRAKATTA-BLUFF	1	1
MILLGROVE GEORGE	2	1
MT PLEASANT LORIKEET	1	1
PRINCETON STANFORD	11	8
TRENTBRIDGE MANCHESTER	4	4
WARATAH-WARRIGAL	1	0
WINDSOR-ST JAMES	5	3
TOTAL	**42**	**31**

In Figure 32, the Average Battery SOC (%) is plotted. This shows the aggregated Battery SOC performance of the LG Chem batteries.

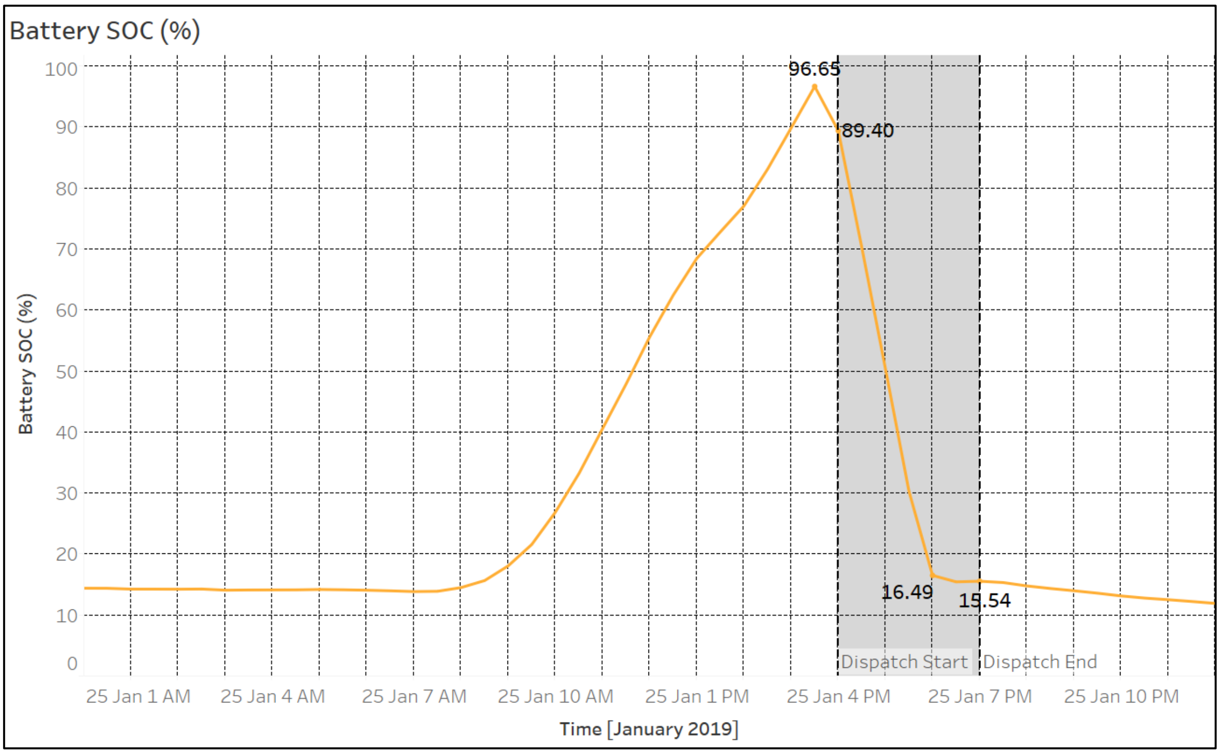

Figure 32: State of Charge (%) for Batteries on 25 January 2019

From Figure 32, the LG Chem batteries only began to charge at 7:30 am, the day of the dispatch event. From a minimum charge of 13.9%, with the aid of the solar generation during the day, the batteries charged to a maximum of 96.65%. Upon discharging when the event began, the LG Chem batteries went down to 16.49% at 6:00 pm and essentially stop discharging after this point. By 8:00 pm, the SOC was 14.77%.

This is an acceptable figure as the LG Chem batteries installed, while rated to 9.8kWh, only have 8.8kWh of usable energy, allowing a minimum SOC of approximately 10.2%. The batteries should not discharge below this point to maintain battery integrity and life. It seems that greater network benefit could have been achieved if the capacity of the batteries was to increase, as while the Discharge Rate was certainly adequate, the batteries effectively run out of charge between 2.5 and 3 hours into the event.

Table 35 shows a comparison of the SOC for the batteries. All data is obtained from Figure 32.

Table 35: Battery State of Charge Comparison for 24 January 2019

Parameter	LG (%)
Maximum	96.65
Dispatch Start	89.4
Dispatch End	15.54
Minimum	11.9

The percentage of charge used during the dispatch event is summarised in Table 36.

Table 36: Percentage of Charge Used during Dispatch Event 4

Battery Type	Charge at Dispatch Start (%)	Charge at Dispatch End (%)	Percentage of Charge Used (%)	Average Energy Discharged (kWh)
LG	89.4	15.54	73.86	6.5

Figure 33 depicts the average discharge rate for the LG Chem batteries. The batteries discharged with a peak value of 2.8kW at 4:00 pm.

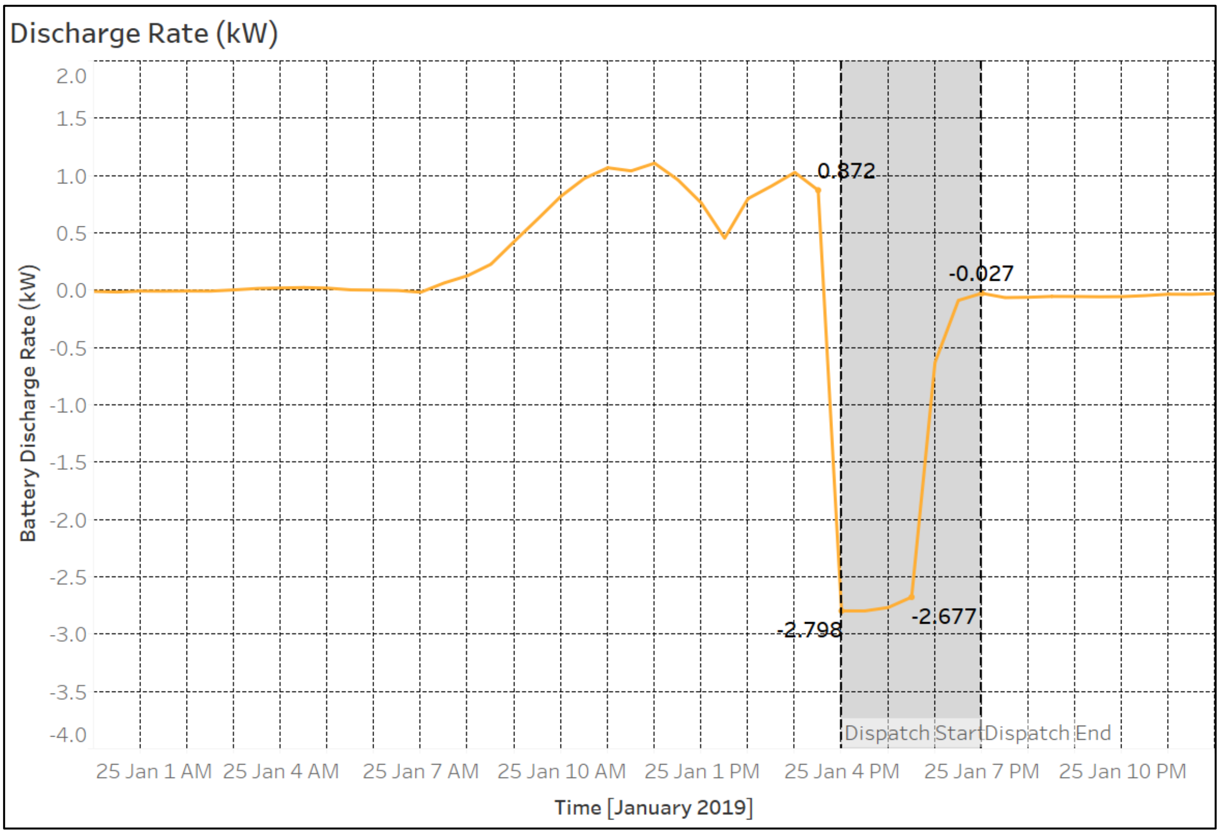

Figure 33: Average Discharge Rate of Battery Systems on 25 January 2019

The sloping curve at the beginning and end of the event in Figure 33 is an artefact of the level of granularity of the averaged performance data. This is also effected by the half-hourly data collected from the controller.

With a usable charge of 8.8kWh, the LG batteries should have been able to discharge for approximately 3.8 hours at an average discharge rate of 2.34kW. However, as the LG batteries were only charged to 89.4% prior to the dispatch event, and were left with 15.54% at the end of the event (from Table 35), the average percentage of charge used for an LG battery was 73.86%. This equates to approximately 6.5kWh of charge.

At an average discharge rate of 2.34kW, it would have taken 2.77 hours for the batteries to discharge. As the data collected is half-hourly, it is not feasible to determine exactly how long the discharge duration was, but as per Figure 33, it was during the last half hour (2.5-3 hours) that the discharge of the LG batteries fell from 0.05kW to near 0kW.

Table 37 breaks down the discharge characteristics of the batteries as seen on 25 January 2019.

Table 37: Average Discharge Performance of Online Systems for 25 January 2019

Battery Type	Average Discharge Rate (kW)	Average Discharge Duration (Hours)	Average Energy Discharged (kWh)
LG	2.34	2.77	6.5

Table 36 and Table 37 use two different measures in order to calculate the Average Energy Discharged, with both resulting in near identical results. Table 36 uses the battery's SOC, whilst Table 37 uses the Battery's Discharge Rate.

17. Appendix E – 2019 Dispatch Event 5

17.1 Event Summary

Event 5 occurred on Sunday, 3 February 2019, with the dispatch set between 4:00 pm and 7:00 pm for the Solar Storage Systems. From the 42 systems installed, operational data was available for 25 systems, with the remaining units being offline at the time of the event, or unable to record the operational battery usage for the day.

Figure 34 shows the performance of the systems on the network during the dispatch event. Specifically, it shows the solar generation, energy exported to the grid, energy discharged by the battery and household consumption during the 3-hour dispatch event. Also, shown are graphs of these measures along with the net effect on all distribution substations (i.e. substation demand with and without the contribution from the Solar Storage systems).

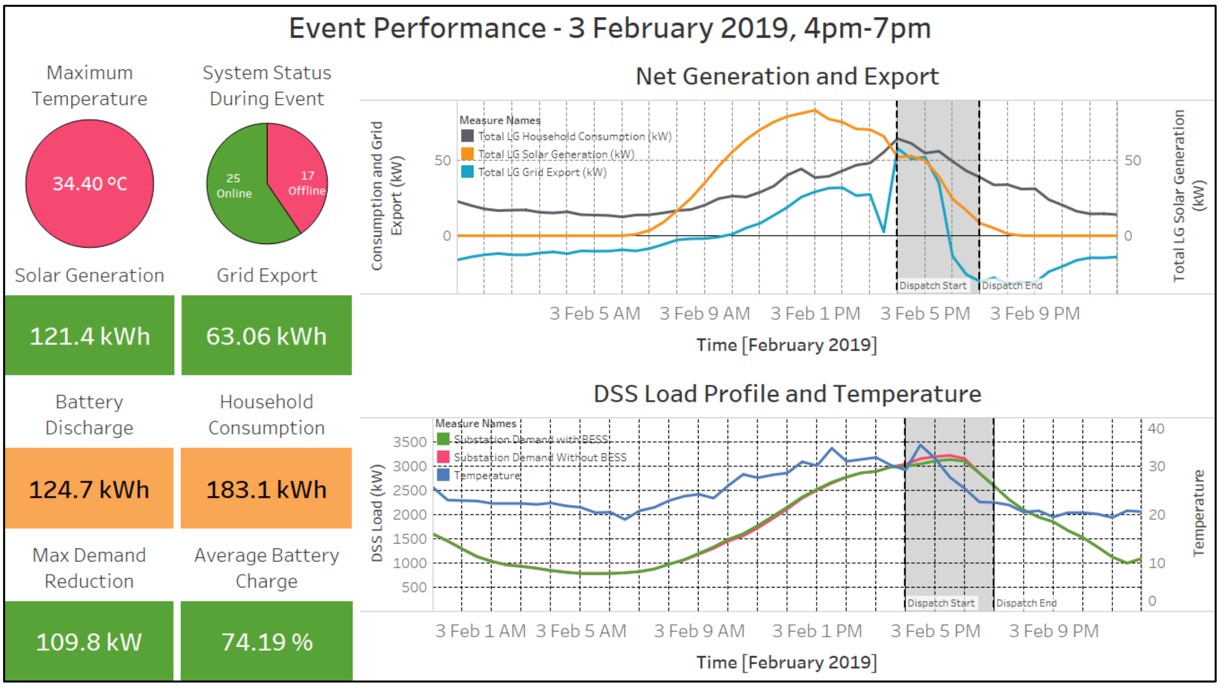

Figure 34: Summary of Event 5 (3 February 2019)

Key observations worthy of note are as below:

- The Solar PV systems installed at households generated 121kWh during the event period.
- 63kWh was exported to the grid reducing overall demand at constrained distribution substations.
- The operational batteries discharged 125kWh of energy.
- Of the households with online systems during the event, the total (gross) consumption was 183kWh over the 3-hour period.

The actual recorded maximum temperature at Moorabbin weather station was 34.4°C at 4:30 pm whilst the overnight minimum temperature was 19°C (refer to Table 38).

Table 38: Maximum Temperatures at Various Locations on the UE Network

Location	Maximum Temperature (°C)	Time of Maximum Temperature
Moorabbin	34.4	16:30
Viewbank	36.9	16:00
Scoresby	38.4	16:30
Cerberus	30.9	12:00

Figure 35 depicts the temperature for different locations of the UE distribution network.

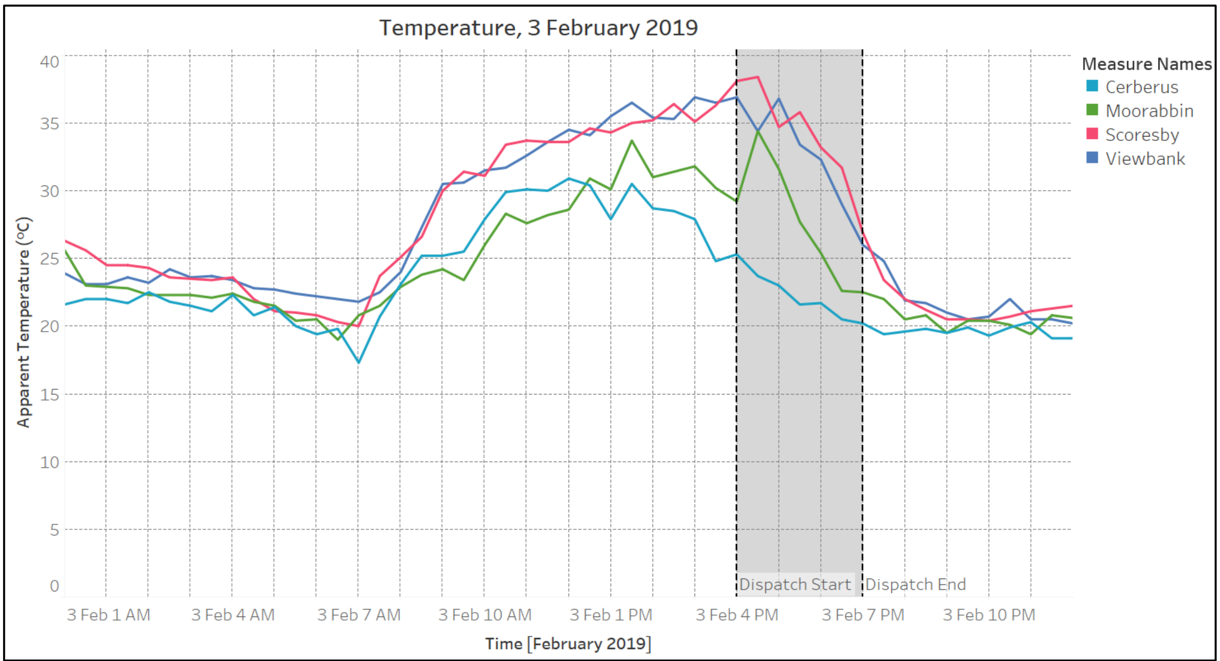

Figure 35: Temperatures at Different Locations in the United Energy Distribution Network on 3 February 2019

The apparent temperature exceeded 30°C from 12:30 pm. The temperature was stable during the event at an average of 27.7°C. At the start of the event, the temperature was 29.2°C which further dropped to 22.5°C by 7:00 pm.

17.2 Network Impact

Figure 36 depicts the load profile of the 14 substations on the day of the event (Green). For comparison, the amount of contribution from the Solar Storage systems was subtracted and the resultant curve (Red) shows the resultant load had the Solar Storage systems not contributed to reducing demand. Total contribution during the event is shown in Blue with Solar Generation shown in Orange.

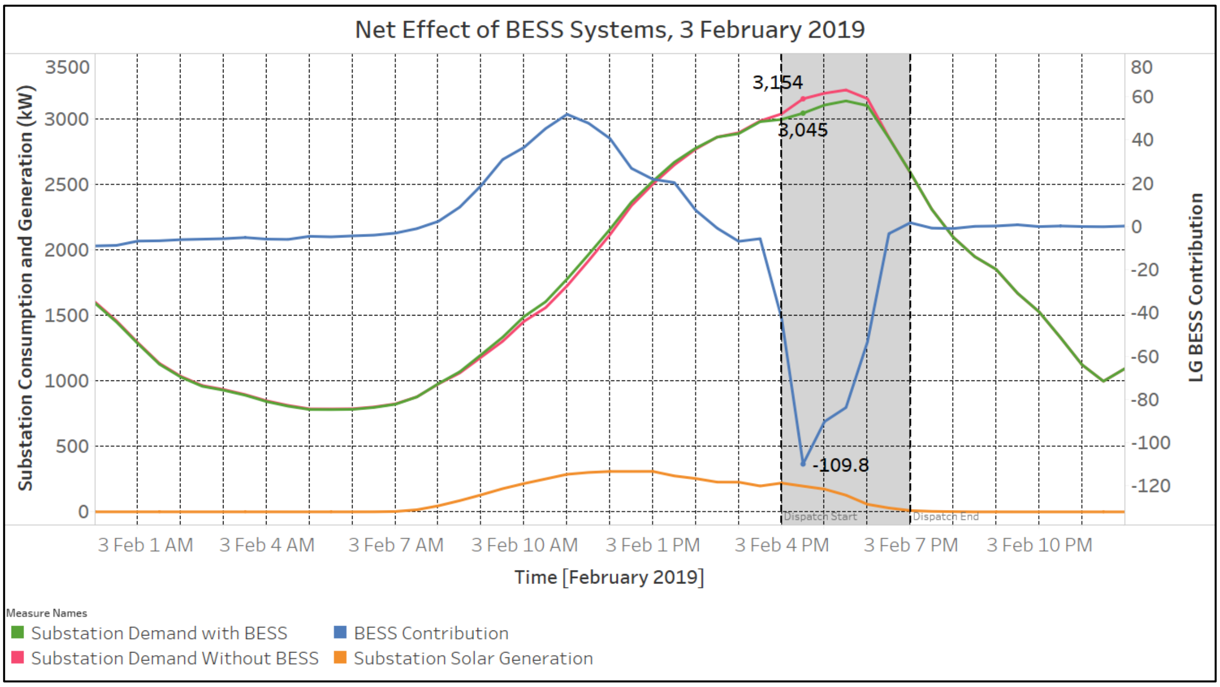

Figure 36: Total Substation Demand With (Green) and Without (Red) Solar Storage on 3 February 2019 – Battery Contribution (Blue) and Solar Generation (Orange)

Figure 36 shows the load on constrained substations decreased from 3,154kW to 3,045kW. This represents a 3.5% (109kW) maximum reduction in demand. As network demand is growing at less than 1% per year, the resulting reduction suggests that UE can defer network augmentation by 3.5 years.

As there was no cool change present on the day of the event, the peak demand occurred at 5.30 pm, right in the middle of the dispatch period. As a result of the batteries having only a set amount of charge, the network benefit did not increase as demand increased, and as such, the percentage reduction observed here was nearly half of Event 1.

Table 39 depicts the consumption in kWh at each of the 14 distribution substations with and without the Solar Storage systems. This allows for the impact to be measured, and in all, consumption was reduced by approximately 191kWh, which is a reduction of 1.8%.

Table 39: Substation Consumption during Dispatch Event (4-7 pm) on 3 February 2019

Substation Name	Number of Systems Online	Substation Consumption without systems during Dispatch Period (kWh)	Substation Consumption with systems during Dispatch Period (kWh)	Consumption Reduced (kWh)	Percentage Reduced (%)
ACHERON KOETONG	2	635.48	618.59	16.88	2.66
AMETHYST DIAMOND	1	852.39	838.50	13.89	1.63
BRIGGS CHLORIS	2	627.78	618.67	9.11	1.45
CASTLEWOOD MARLBOROUGH	0	651.36	642.58	8.78	1.35
ENTRANCE NEPEAN	1	287.01	282.86	4.16	1.45
FLORENCE-GERALD	1	790.25	789.42	0.83	0.11
HYPERNO LAYTON	3	741.20	724.30	16.90	2.28
KARRAKATTA-BLUFF	1	931.45	922.74	8.71	0.93
MILLGROVE GEORGE	1	662.24	645.99	16.26	2.45
MT PLEASANT LORIKEET	1	679.18	670.36	8.82	1.30
PRINCETON STANFORD	6	953.01	900.92	52.10	5.47
TRENTBRIDGE MANCHESTER	3	975.57	956.59	18.99	1.95
WARATAH-WARRIGAL	0	409.38	409.38	0.00	0.00
WINDSOR-ST JAMES	3	1411.52	1396.35	15.17	1.07
TOTAL	**25**	**10607.82**	**10417.23**	**190.59**	**1.80**

17.3 System Performance

As a comparison, the dispatch performance on 2 February 2019 was assessed. This allowed for the pre-event analysis of the batteries. The maximum temperature at Moorabbin on the day was 32°C.

17.3.1 Performance on 2 February 2019

Figure 37 depicts the average performance of the battery. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plot next to the Discharge Rate, and the Battery SOC and Temperature of the day plotted in the final graph.

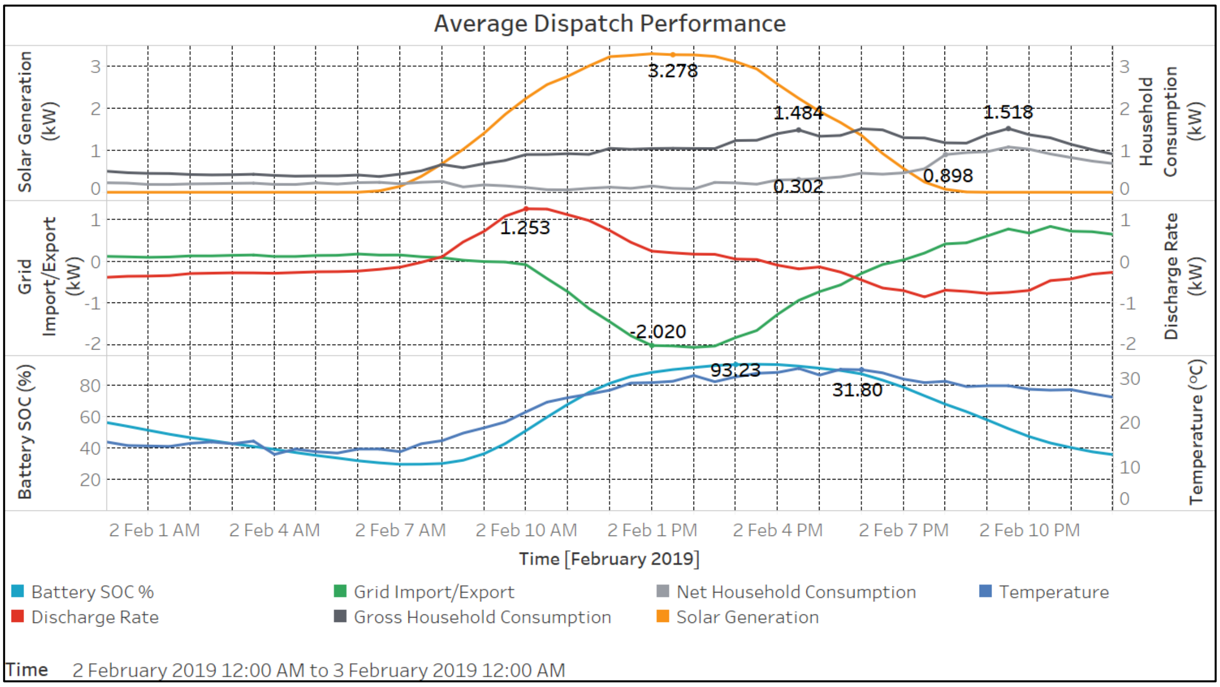

Figure 37: Average Dispatch Performance for 2 February 2019

During the period of 7:00 am to 4:30 pm, the average Gross Household Consumption rose from approximately 0.432kW to 1.484kW, however the Net Consumption as seen by the network was close to zero for this period (Net Consumption increases to 0.302kW at the end of this period).

17.3.2 Performance on 3 February 2019

Similar to the comparison for the non-event day, Figure 38 depicts the average performance of the batteries on the event day. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plotted next to the Discharge Rate, with the Battery SOC and Temperature of the day plotted in the final graph.

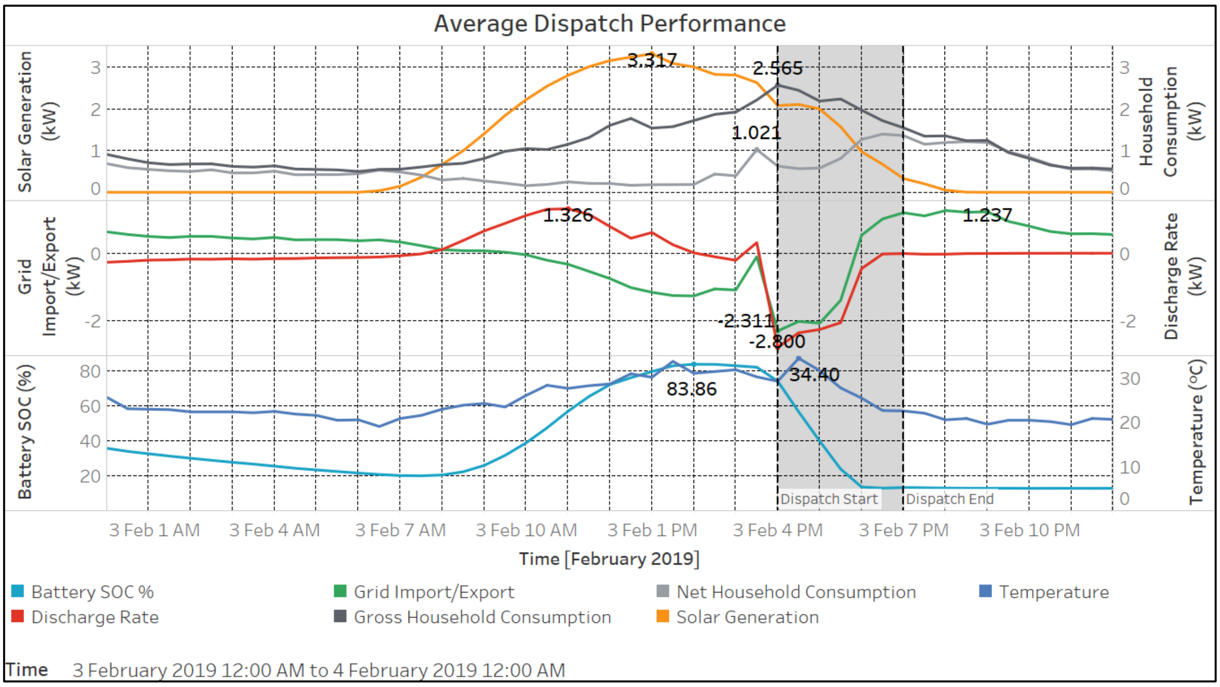

Figure 38: Average Dispatch Performance for 3 February 2019

By comparing Figure 37 and Figure 38, it can be noted that the maximum average Gross Household Consumption increased from 1.518kW to 2.565kW due to the extreme weather experienced. As the batteries are discharged, Net Household Consumption fluctuated around the 1kW mark. This can be attributed to the fact that at 7:00 pm, the Solar Generation fell below Gross Household Consumption and in order to cope with the excess demand, the household was required to draw power from the grid. This can be seen when the Grid Import/Export curve went positive at this time. This also explains why the amount of energy dispatched onto the network was less than the discharge amount of the battery.

17.3.3 Dispatch Performance by Distribution Substation

Table 40 shows the dispatch performance of the Solar Storage systems by Distribution Substation.

Table 40: Dispatch Performance by Distribution Substation on 3 February 2019

Substation Name	Battery Size (Usable Capacity) (kWh)	Number of Systems Online	Total Usable Battery Capacity (kWh)	Percentage of Battery Discharged (%)	Total Energy Discharged (kWh)	Total Solar Generation (kWh)	Household Consumption (kWh)	Net Grid Export (kWh)
ACHERON KOETONG	9.8 (8.8)	2	17.60	39.22	12.63	10.56	13.04	10.15
AMETHYST DIAMOND	9.8 (8.8)	1	8.80	63.62	6.36	3.92	6.21	4.07
BRIGGS CHLORIS	9.8 (8.8)	2	17.60	40.88	7.10	6.84	8.44	5.51
CASTLEWOOD MARLBOROUGH	9.8 (8.8)	0	0.00	78.82	0.00	0.00	0.00	0.00
ENTRANCE NEPEAN	9.8 (8.8)	1	8.80	37.65	3.26	5.22	24.75	-16.27
FLORENCE-GERALD	9.8 (8.8)	1	8.80	2.55	0.95	4.07	13.57	-8.55
HYPERNO LAYTON	9.8 (8.8)	3	26.40	39.55	13.41	18.71	22.67	9.46
KARRAKATTA-BLUFF	9.8 (8.8)	1	8.80	77.56	6.24	5.60	1.78	10.06
MILLGROVE GEORGE	9.8 (8.8)	1	8.80	77.07	6.13	4.38	1.29	9.22
MT PLEASANT LORIKEET	9.8 (8.8)	1	8.80	79.14	6.39	3.22	3.68	5.93
PRINCETON STANFORD	9.8 (8.8)	6	52.80	42.63	37.52	29.54	37.34	29.71
TRENTBRIDGE MANCHESTER	9.8 (8.8)	3	26.40	41.17	13.99	15.47	12.10	17.36
WARATAH-WARRIGAL	9.8 (8.8)	0	0.00	0.00	0.00	0.00	0.00	0.00
WINDSOR-ST JAMES	9.8 (8.8)	3	26.40	27.65	10.77	13.85	38.19	-13.57
TOTALS	**-**	**25**	**220**	**46.25**	**124.74**	**121.38**	**183.06**	**63.06**

17.3.4 Performance Summary

The following comparisons only take into account the performance of the 25 systems that were operational throughout the entire dispatch period.

Table 41 shows the online status of the 42 LG Chem batteries installed at the various sites on the UE network.

Table 41: Breakdown of Online Status during Event 5

Distribution Substation	Solar Storage Customers	No. of Systems Online
ACHERON KOETONG	4	2
AMETHYST DIAMOND	2	1
BRIGGS CHLORIS	2	2
CASTLEWOOD MARLBOROUGH	2	0
ENTRANCE NEPEAN	1	1
FLORENCE-GERALD	2	1
HYPERNO LAYTON	4	3
KARRAKATTA-BLUFF	1	1
MILLGROVE GEORGE	2	1
MT PLEASANT LORIKEET	1	1
PRINCETON STANFORD	11	6
TRENTBRIDGE MANCHESTER	4	3
WARATAH-WARRIGAL	1	0
WINDSOR-ST JAMES	5	3
TOTAL	**42**	**25**

In Figure 39, the Average Battery SOC (%) is plotted. This shows the aggregated Battery SOC performance of the LG Chem batteries.

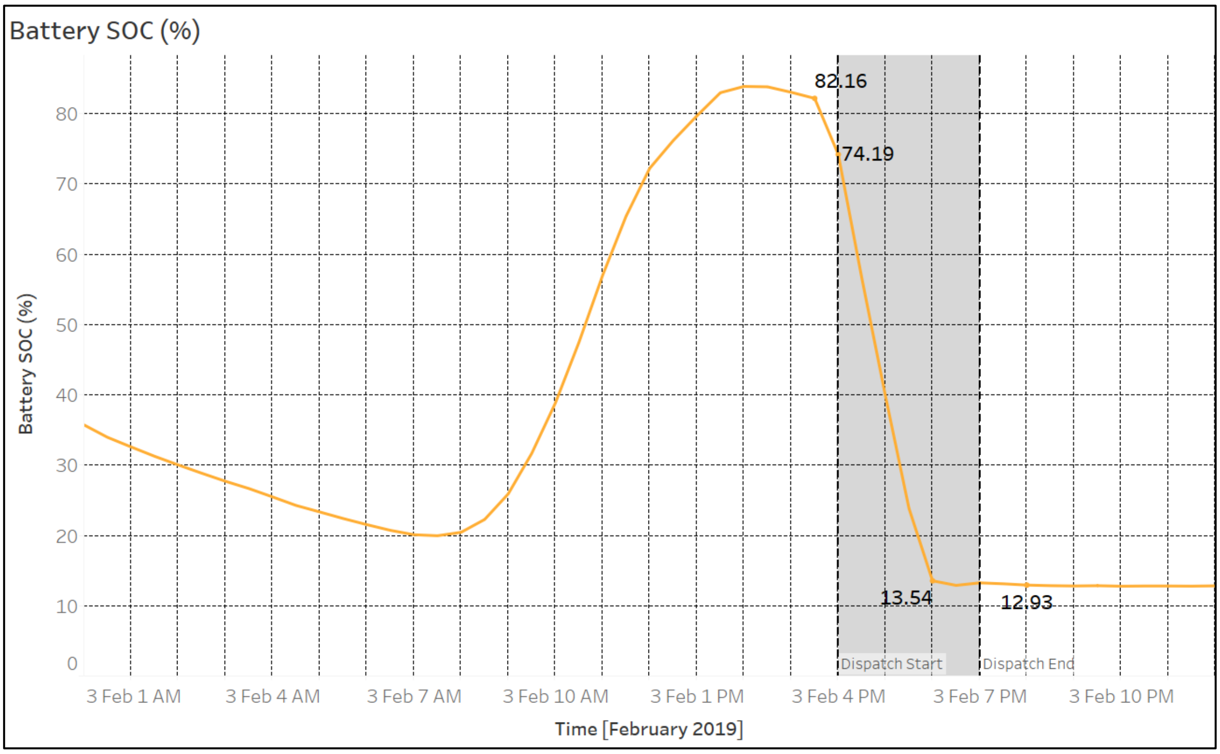

Figure 39: State of Charge (%) for Batteries on 3 February 2019

From Figure 39, the LG Chem batteries only began to charge at 7:30 am, the day of the dispatch event. From a minimum charge of 20.4%, with the aid of the solar generation during the day, the batteries charged to a maximum of 83.9%. Upon discharging when the event began, the LG Chem batteries went down to 13.54% at 6:00 pm and essentially stopped discharging after this point. By 8:00 pm, the SOC was 12.93%.

This is an acceptable figure as the LG Chem batteries installed, while rated to 9.8kWh, only have 8.8kWh of usable energy, allowing a minimum SOC of approximately 10.2%. The batteries should not discharge below this point to maintain battery integrity and life. It seems that greater network benefit could have been achieved if the capacity of the batteries was to increase, as while the Discharge Rate was certainly adequate, the batteries effectively run out of charge between 2.5 and 3 hours into the event.

Table 42 shows a comparison of the SOC for the batteries. All data is obtained from Figure 39.

Table 42: Battery State of Charge Comparison for 3 February 2019

Parameter	LG (%)
Maximum	83.9
Dispatch Start	74.19
Dispatch End	13.54
Minimum	12.93

The percentage of charge used during the dispatch event is summarised in Table 43.

Table 43: Percentage of Charge Used during Dispatch Event 5

Battery Type	Charge at Dispatch Start (%)	Charge at Dispatch End (%)	Percentage of Charge Used (%)	Average Energy Discharged (kWh)
LG	74.19	13.54	73.86	5.34

Figure 40 depicts the average discharge rate for the LG Chem batteries. The batteries discharged with a peak value of 2.8kW at 4:00 pm.

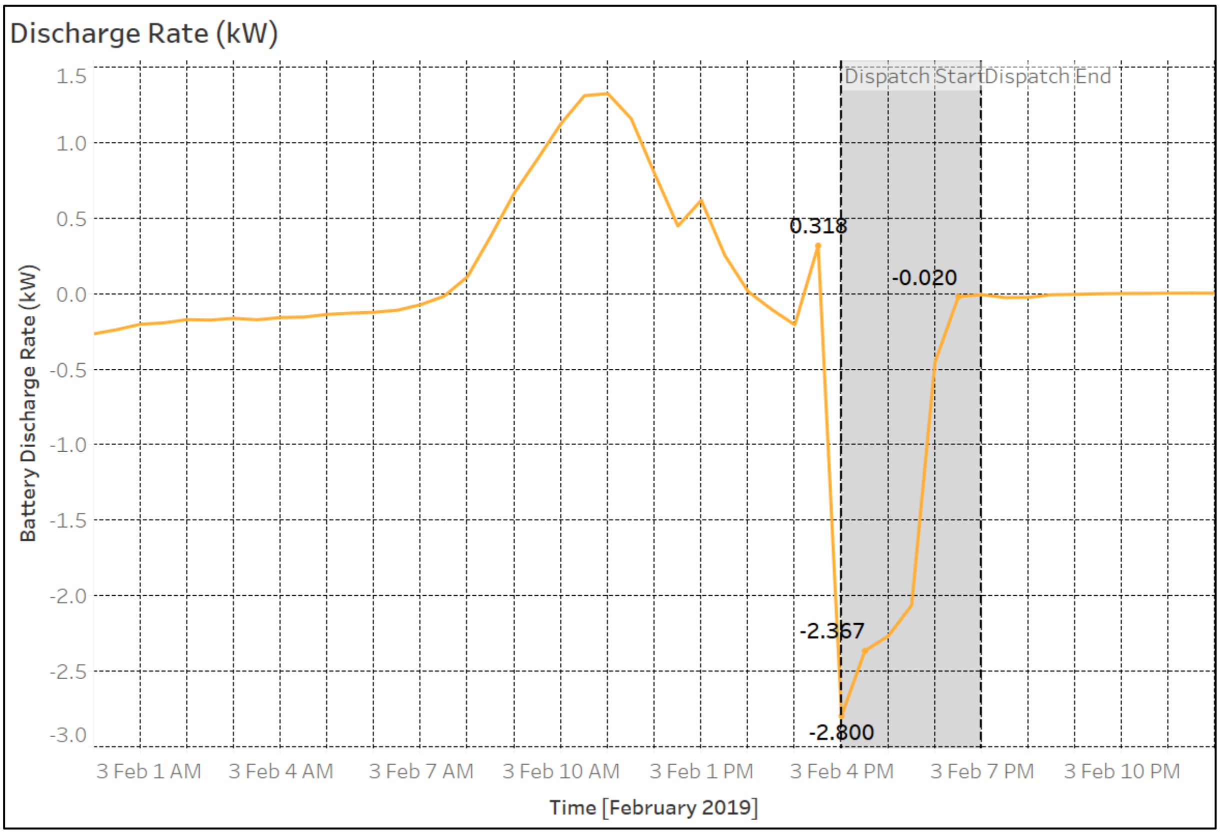

Figure 40: Average Discharge Rate of Battery Systems on 3 February 2019

The sloping curve at the beginning and end of the event in Figure 40 is an artefact of the level of granularity of the averaged performance data. This is also effected by the half-hourly data collected from the controller.

With a usable charge of 8.8kWh, the LG batteries should have been able to discharge for approximately 3.7 hours at an average discharge rate of 2.4kW. However, as the LG batteries were only charged to 74.19% prior to the dispatch event, and were left with 13.54% at the end of the event (from Table 42), the average percentage of charge used for an LG battery was 73.86%. This equates to approximately 6.5kWh of charge.

At an average discharge rate of 2.4kW, it would have taken 2.7 hours for the battery to discharge. As the data collected is half-hourly, it is not feasible to determine exactly how long the discharge duration was, but as per Figure 40, it was during the last half hour (2.5-3 hours) that the discharge of the LG batteries fell from 0.05kW to near 0kW.

Table 44 breaks down the discharge characteristics of the batteries as seen on 3 February 2019.

Table 44: Average Discharge Performance of Online Systems for 3 February 2019

Battery Type	Average Discharge Rate (kW)	Average Discharge Duration (Hours)	Average Energy Discharged (kWh)
LG	2.4	2.7	6.5

Table 43 and Table 44 use two different measures in order to calculate the Average Energy Discharged, with both resulting in near identical results. Table 43 uses the Battery's SOC, whilst Table 44 uses the Battery's Discharge Rate. The slight difference between the two calculations can be attributed to rounding error.

18. Appendix F – 2019 Dispatch Event 6

18.1 Event Summary

Event 6 occurred on Friday, 1 March 2019, with the dispatch set between 4:00 pm and 8:00 pm for the Solar Storage systems. From the 42 systems installed, operational data was available for 29 systems, with the remaining units being offline at the time of the event, or unable to record the operational battery usage for the day.

Figure 41 shows the performance of the systems on the network during the dispatch event. Specifically, it shows the solar generation, energy exported to the grid, energy discharged by the battery and household consumption during the 4-hour dispatch event. Also, shown are graphs of these measures along with the net effect on all distribution substations (i.e. substation demand with and without the contribution from the Solar Storage systems).

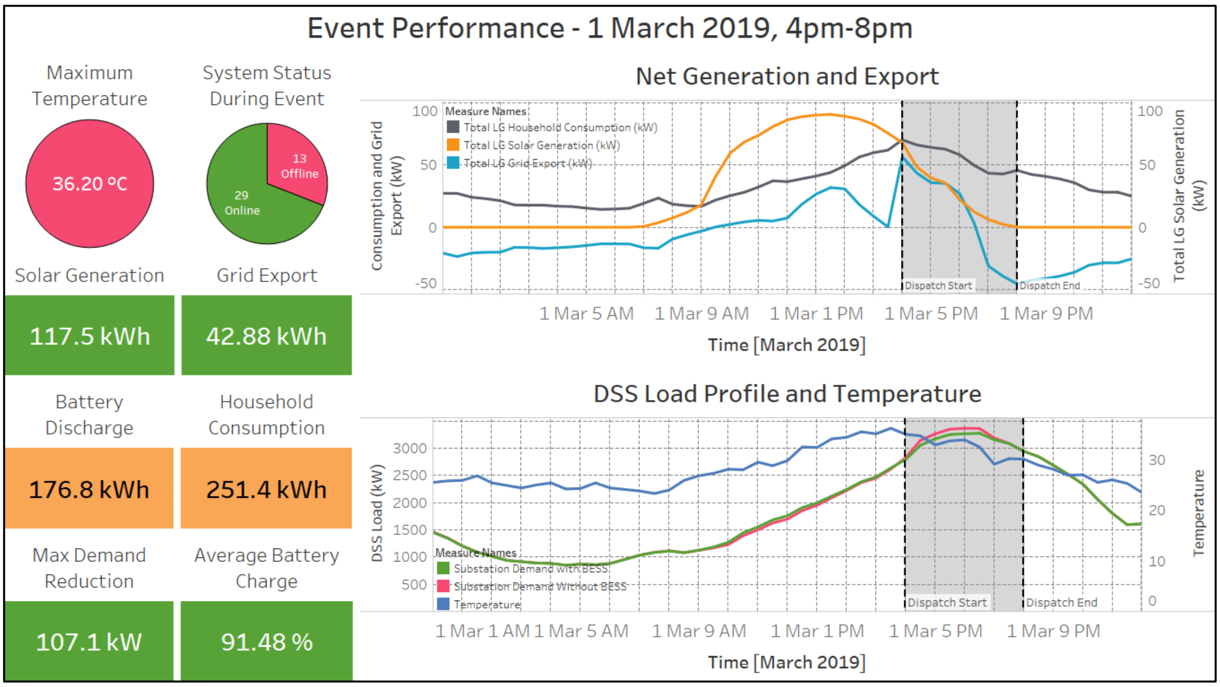

Figure 41: Summary of Event 6 (1 March 2019)

Key observations worthy of note are as below:

- The Solar PV systems installed at households generated 118kWh during the event period.
- 43kWh was exported to the grid reducing overall demand at constrained distribution substations.
- The operational batteries discharged 177kWh of energy.
- Of the households with online systems during the event, the total (gross) consumption was 251kWh over the 4-hour period.

The actual recorded maximum temperature at Moorabbin weather station was 36.2°C at 3:30 pm whilst the overnight minimum temperature was 23.3°C (refer to Table 45).

Table 45: Maximum Temperatures at Various Locations on the UE Network

Location	Maximum Temperature (°C)	Time of Maximum Temperature
Moorabbin	36.2	15:30
Viewbank	35.7	17:30
Scoresby	37.2	17:30
Cerberus	35.4	15:00

Figure 42 depicts the temperature for different locations of the UE distribution network.

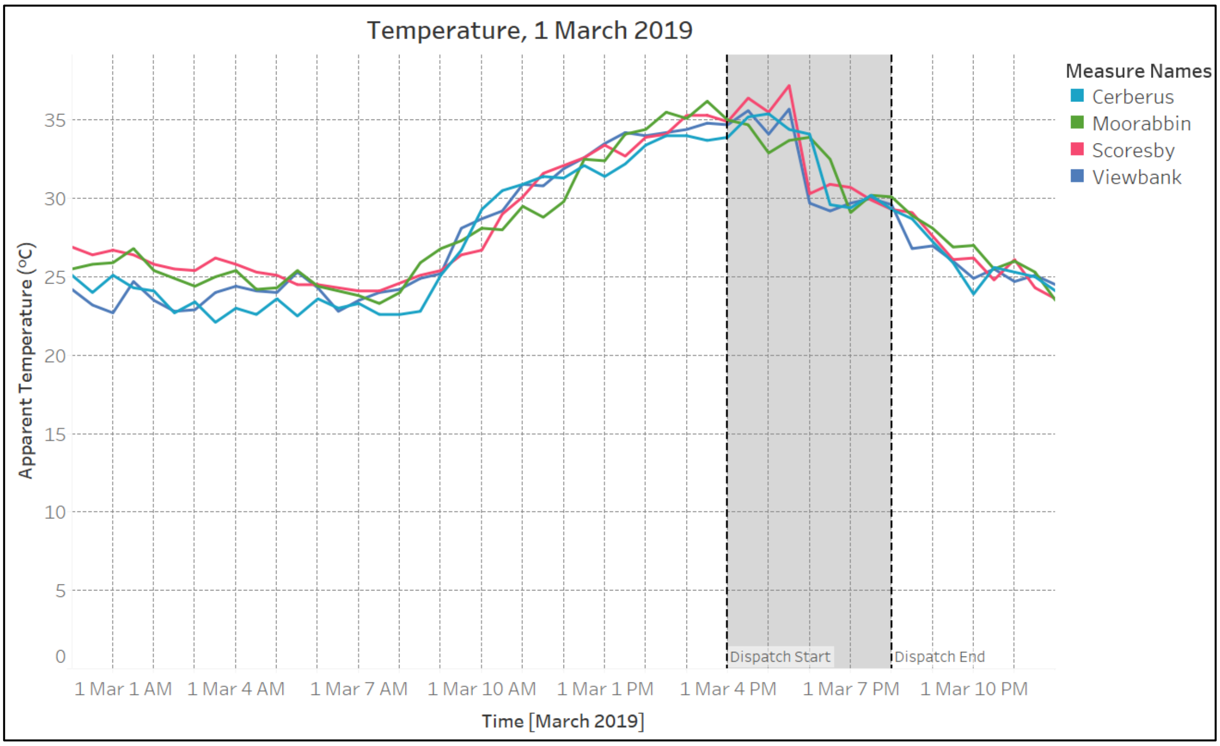

Figure 42: Temperatures at Different Locations in the United Energy Distribution Network on 1 March 2019

The apparent temperature exceeded 30°C from 12:30 pm. The temperature was stable during the event at an average of 32.5°C. At the start of the event, the temperature was 35°C which further dropped to 30.1°C by 8:00 pm.

18.2 Network Impact

Figure 43 depicts the load profile of the 14 substations on the day of the event (Green). For comparison, the amount of contribution from the Solar Storage systems was subtracted and the resultant curve (Red) shows the resultant load had the Solar Storage systems not contributed to reducing demand. Total contribution during the event is shown in Blue with Solar Generation shown in Orange.

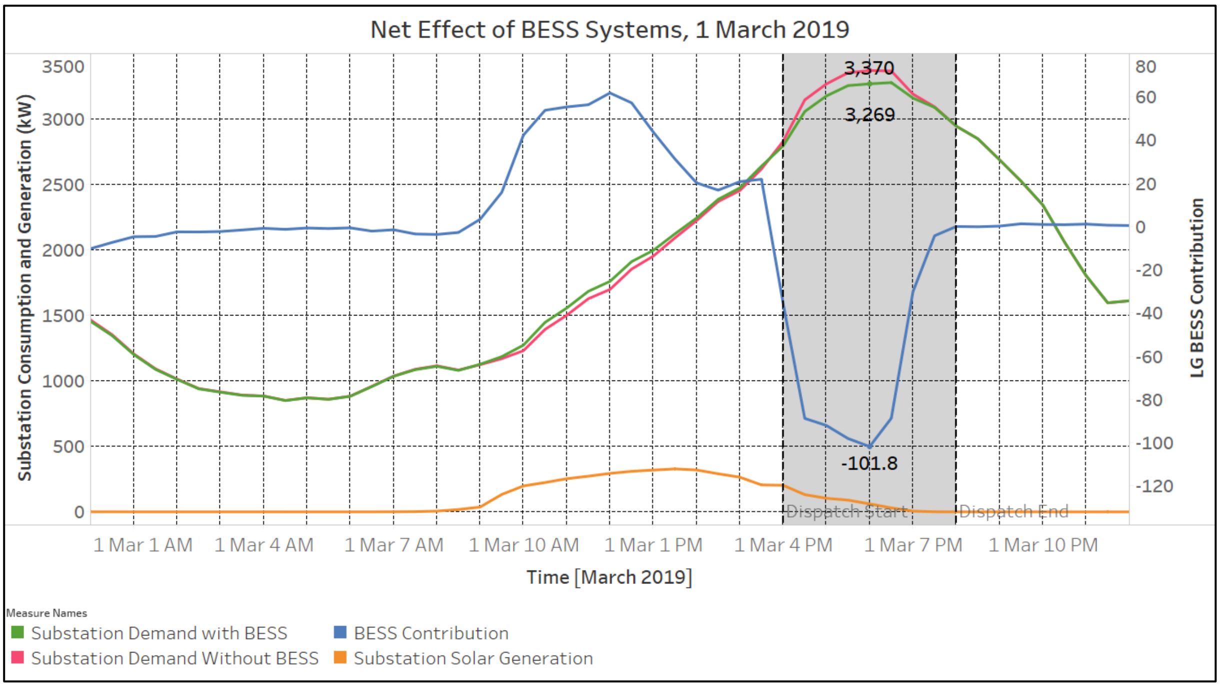

Figure 43: Total Substation Demand With (Green) and Without (Red) Solar Storage on 1 March 2019 – Battery Contribution (Blue) and Solar Generation (Orange)

Figure 43 shows the load on constrained substations decreased from 3,370kW to 3,269kW. This represents a 3% (101kW) maximum reduction in demand. As network demand is growing at less than 1% per year, the resulting reduction suggests that UE can defer network augmentation by 3 years.

As there was no cool change present on the day of the event, the peak demand occurred at 6:00 pm. As a result of the batteries having only a set amount of charge, the network benefit did not increase as demand increased.

Table 46 depicts the consumption in kWh at each of the 14 distribution substations with and without the Solar Storage systems. This allows for the impact to be measured, and in all, consumption was reduced by approximately 270kWh, which is a reduction of 1.89%.

Table 46: Substation Consumption during Dispatch Event (4-8 pm) on 1 March 2019

Substation Name	Number of Systems Online	Substation Consumption without systems during Dispatch Period (kWh)	Substation Consumption with systems during Dispatch Period (kWh)	Consumption Reduced (kWh)	Percentage Reduced (%)
ACHERON KOETONG	1	1068.16	1047.80	20.36	1.91
AMETHYST DIAMOND	2	1013.61	996.00	17.61	1.74
BRIGGS CHLORIS	2	916.17	898.56	17.61	1.92
CASTLEWOOD MARLBOROUGH	1	932.47	923.69	8.79	0.94
ENTRANCE NEPEAN	1	460.16	451.73	8.43	1.83
FLORENCE-GERALD	2	1002.39	986.62	15.77	1.57
HYPERNO LAYTON	2	1277.20	1259.60	17.60	1.38
KARRAKATTA-BLUFF	1	1430.62	1422.19	8.44	0.59
MILLGROVE GEORGE	2	840.04	823.01	17.04	2.03
MT PLEASANT LORIKEET	1	855.31	846.50	8.81	1.03
PRINCETON STANFORD	6	1435.85	1376.00	59.85	4.17
TRENTBRIDGE MANCHESTER	3	1322.16	1297.41	24.76	1.87
WARATAH-WARRIGAL	1	558.63	549.85	8.78	1.57
WINDSOR-ST JAMES	4	1168.76	1133.07	35.69	3.05
TOTAL	**29**	**14281.54**	**14012.00**	**269.54**	**1.89**

18.3 System Performance

As a comparison, the dispatch performance on 28 February 2019 was assessed. This allowed for the pre-event analysis of the batteries. The maximum temperature at Moorabbin on the day was 33°C.

18.3.1 Performance on 28 February 2019

Figure 44 depicts the average performance of the batteries. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plot next to the Discharge Rate, and the Battery SOC and Temperature of the day plotted in the final graph.

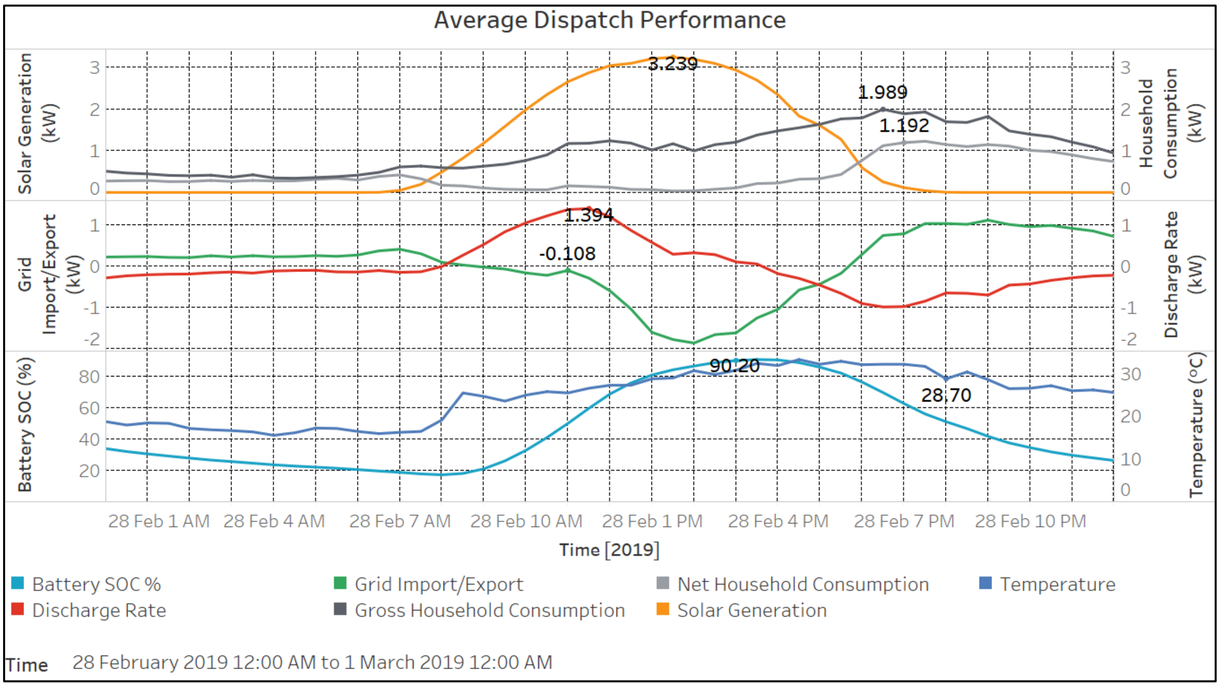

Figure 44: Average Dispatch Performance for 28 February 2019

During the period of 7:00 am to 6:30 pm, the average Gross Household Consumption rose from approximately 0.610kW to 1.989kW, however the Net Consumption as seen by the network was close to zero for this period (Net Consumption increases to 1.119kW at the end of this period).

18.3.2 Performance on 1 March 2019

Similar to the comparison for the non-event day, Figure 45 depicts the average performance of the batteries on the event day. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plotted next to the Discharge Rate, with the Battery SOC and Temperature of the day plotted in the final graph.

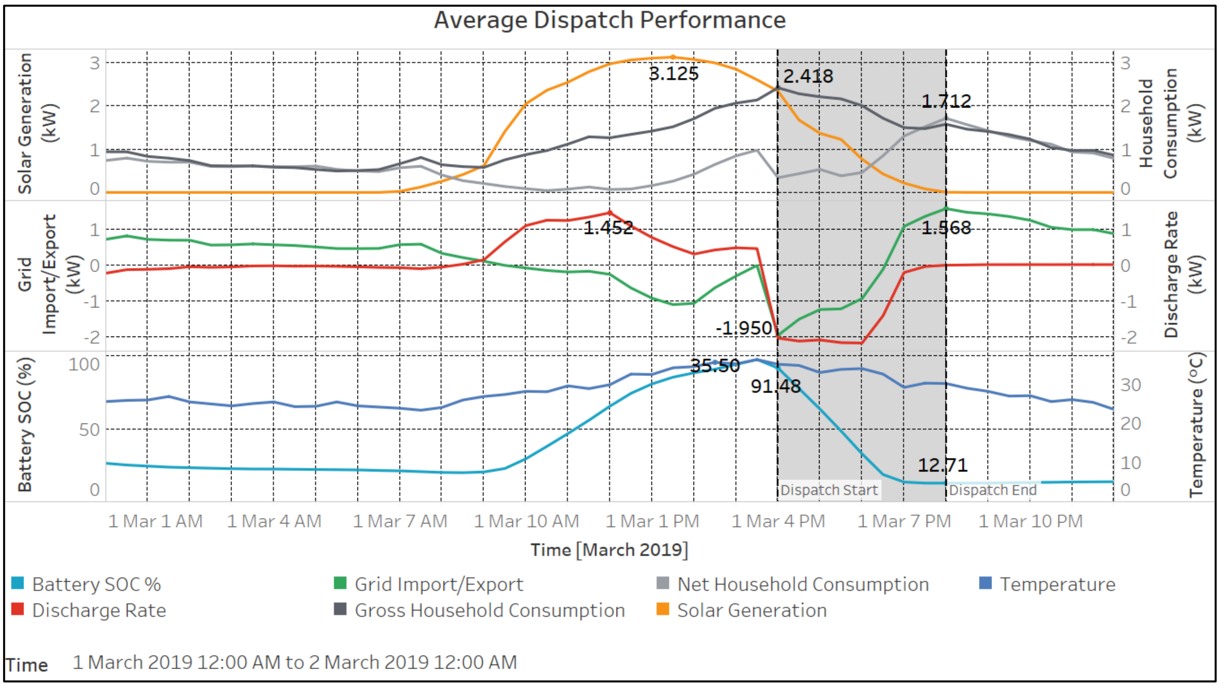

Figure 45: Average Dispatch Performance for 1 March 2019

By comparing Figure 44 and Figure 45, it can be noted that the maximum average Gross Household Consumption increased from 1.989kW to 2.418kW due to the extreme weather experienced. As the batteries were discharged, Net Household Consumption fluctuated around the 1kW mark. This can be attributed to the fact that at 7:00 pm, the Solar Generation fell below Gross Household Consumption and in order to cope with the excess demand, the household was required to draw power from the grid. This can be seen when the Grid Import/Export curve went positive at this time. This also explains why the amount of energy dispatched onto the network was less than the discharge amount of the batteries.

18.3.3 Dispatch Performance by Distribution Substation

Table 47 shows the dispatch performance of the Solar Storage systems by Distribution Substation.

Table 47: Dispatch Performance by Distribution Substation on 1 March 2019

Substation Name	Battery Size (Usable Capacity) (kWh)	Number of Systems Online	Total Usable Battery Capacity (kWh)	Percentage of Battery Discharged (%)	Total Energy Discharged (kWh)	Total Solar Generation (kWh)	Household Consumption (kWh)	Net Grid Export (kWh)
ACHERON KOETONG	9.8 (8.8)	1	8.80	50.41	6.30	4.65	6.68	4.27
AMETHYST DIAMOND	9.8 (8.8)	2	17.60	81.30	12.65	6.32	19.72	-0.76
BRIGGS CHLORIS	9.8 (8.8)	2	17.60	82.52	12.85	7.97	7.96	12.86
CASTLEWOOD MARLBOROUGH	9.8 (8.8)	1	8.80	81.06	6.26	4.20	8.18	2.28
ENTRANCE NEPEAN	9.8 (8.8)	1	8.80	81.76	6.36	4.72	33.20	-22.11
FLORENCE-GERALD	9.8 (8.8)	2	17.60	77.47	12.23	4.17	25.74	-9.34
HYPERNO LAYTON	9.8 (8.8)	2	17.60	41.71	12.71	12.32	20.04	4.99
KARRAKATTA-BLUFF	9.8 (8.8)	1	8.80	80.91	6.33	5.97	9.43	2.88
MILLGROVE GEORGE	9.8 (8.8)	2	17.60	81.57	12.05	7.16	8.69	10.53
MT PLEASANT LORIKEET	9.8 (8.8)	1	8.80	83.59	6.31	2.29	3.45	5.15
PRINCETON STANFORD	9.8 (8.8)	6	52.80	51.31	37.07	27.13	52.13	12.07
TRENTBRIDGE MANCHESTER	9.8 (8.8)	3	26.40	58.86	19.69	10.65	23.31	7.03
WARATAH-WARRIGAL	9.8 (8.8)	1	8.80	86.31	6.44	4.84	5.79	5.49
WINDSOR-ST JAMES	9.8 (8.8)	4	35.20	68.34	19.53	15.06	27.05	7.54
TOTALS	**-**	**29**	**255.2**	**71.94**	**176.81**	**117.46**	**251.39**	**42.88**

18.3.4 Performance Summary

The following comparisons only take into account the performance of the 29 systems that were operational throughout the entire dispatch period.

Table 48 shows the online status of the 42 LG Chem batteries installed at the various sites on the UE network.

Table 48: Breakdown of Online Status during Event 6

Distribution Substation	Solar Storage Customers	No. of Systems Online
ACHERON KOETONG	4	1
AMETHYST DIAMOND	2	2
BRIGGS CHLORIS	2	2
CASTLEWOOD MARLBOROUGH	2	1
ENTRANCE NEPEAN	1	1
FLORENCE-GERALD	2	2
HYPERNO LAYTON	4	2
KARRAKATTA-BLUFF	1	1
MILLGROVE GEORGE	2	2
MT PLEASANT LORIKEET	1	1
PRINCETON STANFORD	11	6
TRENTBRIDGE MANCHESTER	4	3
WARATAH-WARRIGAL	1	1
WINDSOR-ST JAMES	5	4
TOTAL	**42**	**29**

In Figure 46, the Average Battery SOC (%) is plotted. This shows the aggregated Battery SOC performance of the LG Chem batteries.

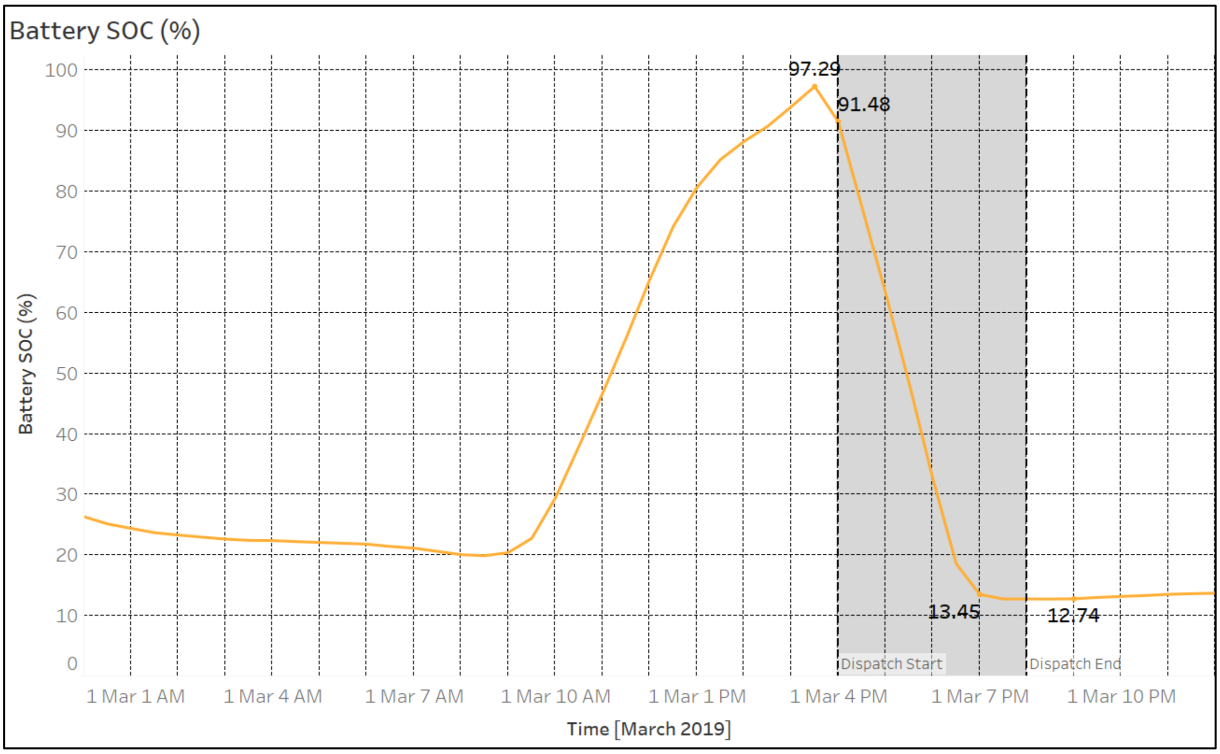

Figure 46: State of Charge (%) for Batteries on 1 March 2019

From Figure 46, the LG Chem batteries only began to charge at 9:00 am, the day of the dispatch event. From a minimum charge of 20.3%, with the aid of the solar generation during the day, the batteries charged to a maximum of 97.29%. Upon discharging when the event began, the LG Chem batteries went down to 13.45% at 7:00 pm and essentially stopped discharging after this point. By 8:00 pm, the SOC was 12.7%.

This is an acceptable figure as the LG Chem batteries installed, while rated to 9.8kWh, only have 8.8kWh of usable energy, allowing a minimum SOC of approximately 10.2%. The batteries should not discharge below this point to maintain battery integrity and life. It seems that greater network benefit could have been achieved if the capacity of the batteries was to increase, as while the Discharge Rate was certainly adequate, the batteries effectively run out of charge between 3.5 and 4 hours into the event.

Table 49 shows a comparison of the SOC for the batteries. All data is obtained from Figure 46.

Table 49: Battery State of Charge Comparison for 1 March 2019

Parameter	LG (%)
Maximum	97.29
Dispatch Start	91.48
Dispatch End	13.45
Minimum	12.7

The percentage of charge used during the dispatch event is summarised in Table 50.

Table 50: Percentage of Charge Used during Dispatch Event 6

Battery Type	Charge at Dispatch Start (%)	Charge at Dispatch End (%)	Percentage of Charge Used (%)	Average Energy Discharged (kWh)
LG	91.48	13.45	78.03	6.9

Figure 47 depicts the average discharge rate for the LG Chem batteries. The batteries discharged with a peak value of 2.165kW at 6:00 pm.

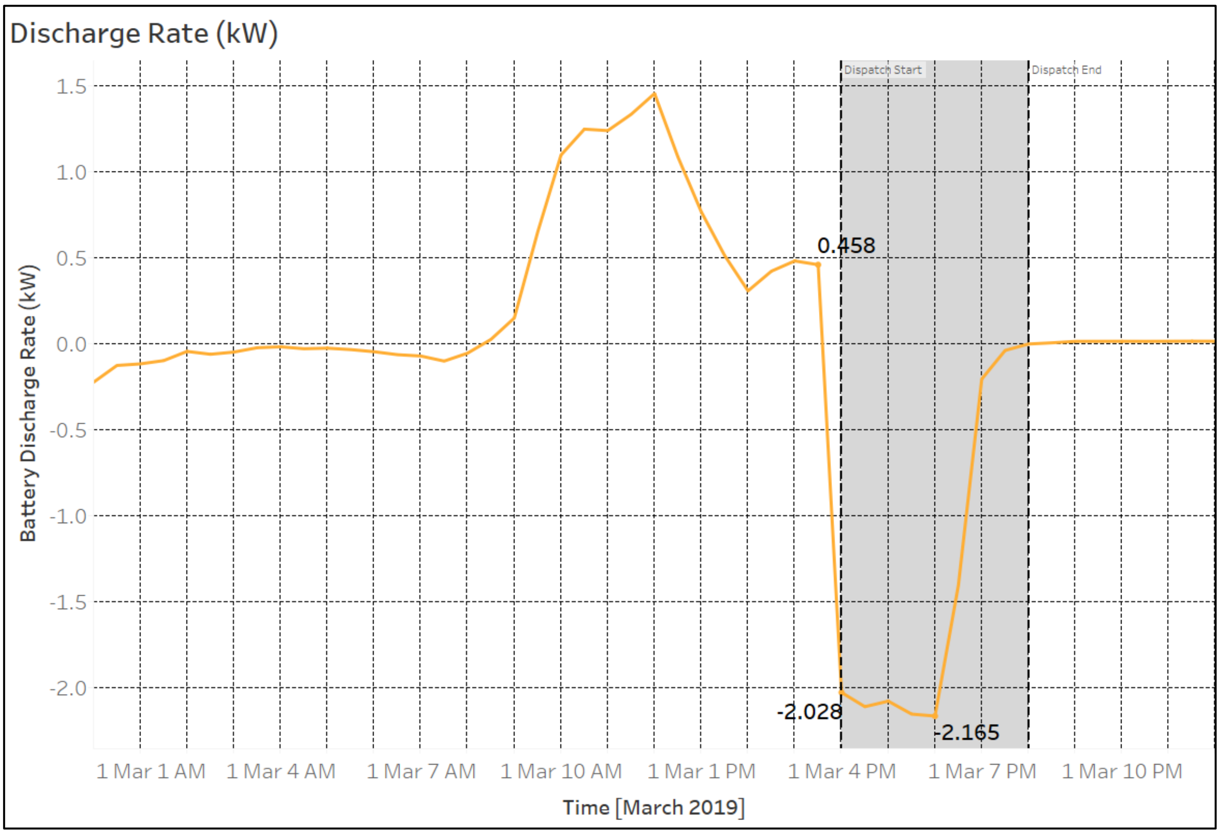

Figure 47: Average Discharge Rate of Battery Systems on 1 March 2019

The sloping curve at the beginning and end of the event in Figure 47 is an artefact of the level of granularity of the averaged performance data. This is also effected by the half-hourly data collected from the controller.

With a usable charge of 8.8kWh, the LG batteries should have been able to discharge for approximately 4.4 hours at an average discharge rate of 2kW. However, as the LG batteries were only charged to 91.48% prior to the dispatch event, and were left with 13.45% at the end of the event (from Table 49), the average percentage of charge used for an LG battery was 73.86%. This equates to approximately 6.9kWh of charge.

At an average discharge rate of 2kW, it would have taken 3.45 hours for the batteries to discharge. As the data collected is half-hourly, it is not feasible to determine exactly how long the discharge duration was, but as per Figure 47, it was during the last half hour (3.5-4 hours) that the discharge of the LG batteries fell from 0.05kW to near 0kW.

Table 51 breaks down the discharge characteristics of the batteries as seen on 25 January 2019.

Table 51: Average Discharge Performance of Online Systems for 25 January 2019

Battery Type	Average Discharge Rate (kW)	Average Discharge Duration (Hours)	Average Energy Discharged (kWh)
LG	2	3.45	6.9

Table 50 and Table 51 use two different measures in order to calculate the Average Energy Discharged, with both resulting in near identical results. Table 50 uses the battery's SOC, whilst Table 51 uses the battery's Discharge Rate.

19. Appendix G – 2019 Dispatch Event 7

19.1 Event Summary

Event 7 occurred on Saturday, 2 March 2019, with the dispatch set between 5:00 pm and 9:00 pm for the Solar Storage systems. From the 42 systems installed, operational data was available for 32 systems, with the remaining units being offline at the time of the event, or unable to record the operational battery usage for the day.

Figure 48 shows the performance of the system on the network during the dispatch event. Specifically, it shows the solar generation, energy exported to the grid, energy discharged by the battery and household consumption during the 4-hour dispatch event. Also, shown are graphs of these measures along with the net effect on all distribution substations (i.e. substation demand with and without the contribution from the Solar Storage system).

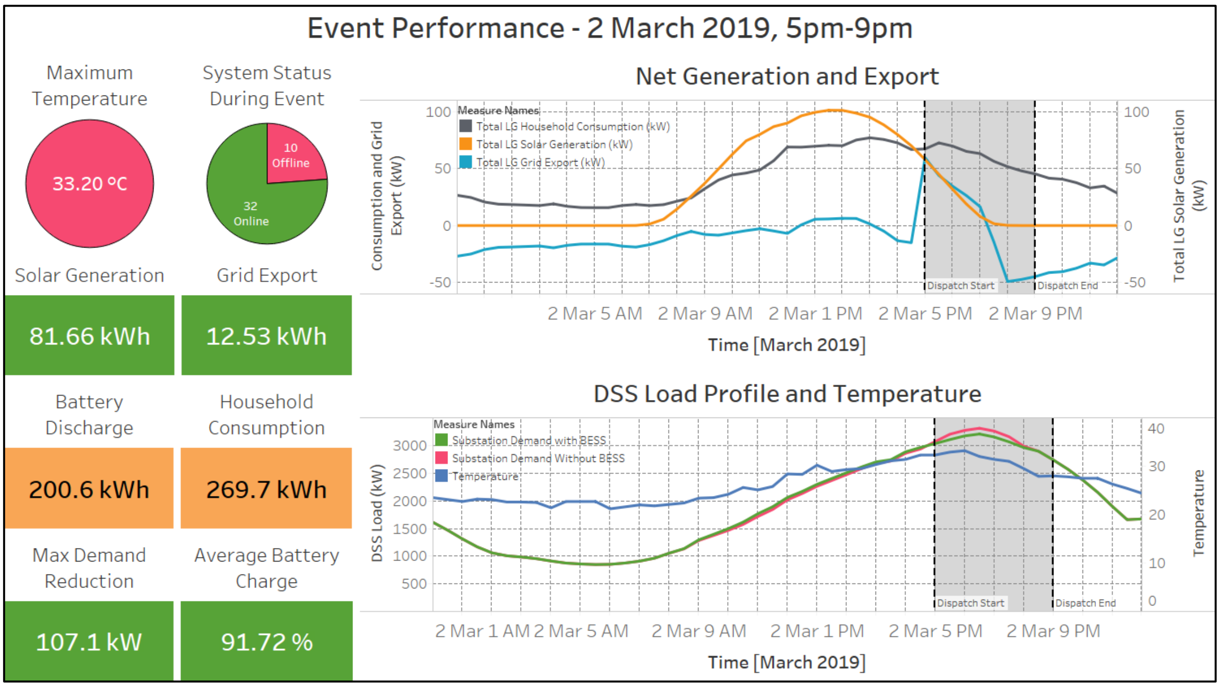

Figure 48: Summary of Event 7 (2 March 2019)

Key observations worthy of note are as below:

- The Solar PV systems installed at households generated 82kWh during the event period.
- 13kWh was exported to the grid reducing overall demand at constrained distribution substations.
- The operational batteries discharged 201kWh of energy.
- Of the households with online systems during the event, the total (gross) consumption was 270kWh over the 4-hour period.

The actual recorded maximum temperature at Moorabbin weather station was 33.2°C at 3:30 pm whilst the overnight minimum temperature was 23.3°C (refer to Table 52).

Table 52: Maximum Temperatures at Various Locations on the UE Network

Location	Maximum Temperature (°C)	Time of Maximum Temperature
Moorabbin	33.2	18:00
Viewbank	34	17:30
Scoresby	33.5	17:00
Cerberus	33.4	19:00

Figure 49 depicts the temperature for different locations of the UE distribution network.

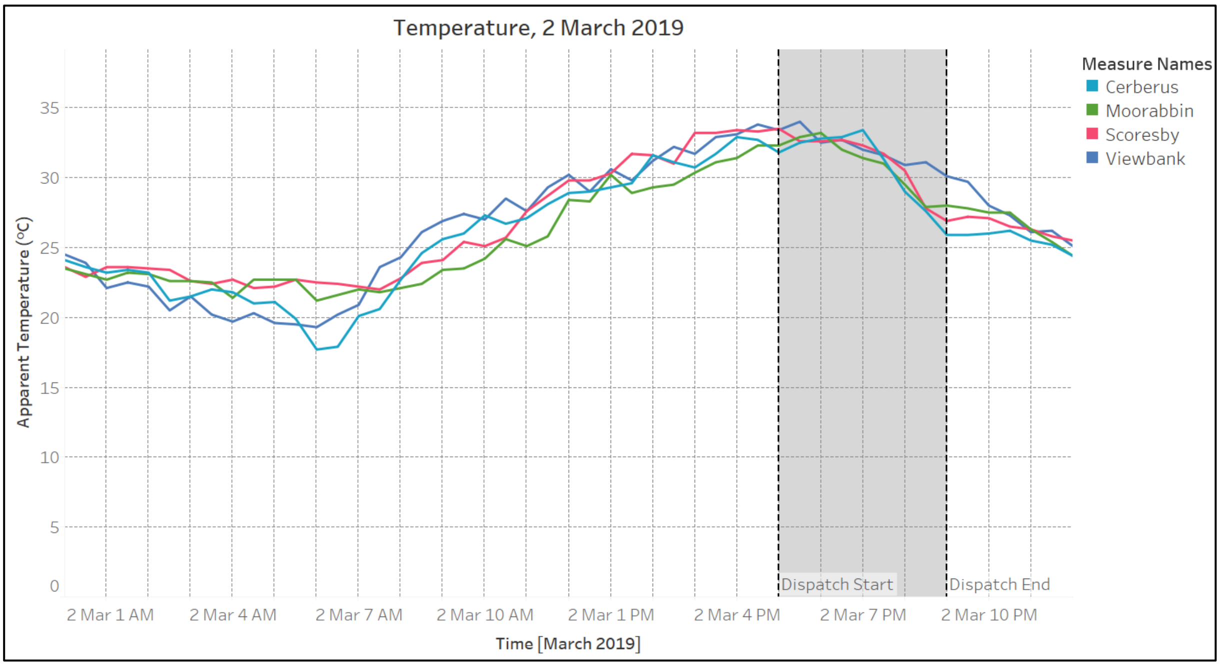

Figure 49: Temperatures at Different Locations in the United Energy Distribution Network on 2 March 2019

The apparent temperature exceeded 30°C from 3:00 pm. The temperature was stable during the event at an average of 30.9°C. At the start of the event, the temperature was 32.3°C.

19.2 Network Benefit

Figure 50 depicts the load profile of the 14 substations on the day of the event (Green). For comparison, the amount of contribution from the Solar Storage systems was subtracted and the resultant curve (Red) shows the resultant load had the Solar Storage systems not contributed to reducing demand. Total contribution during the event is shown in Blue with Solar Generation shown in Orange.

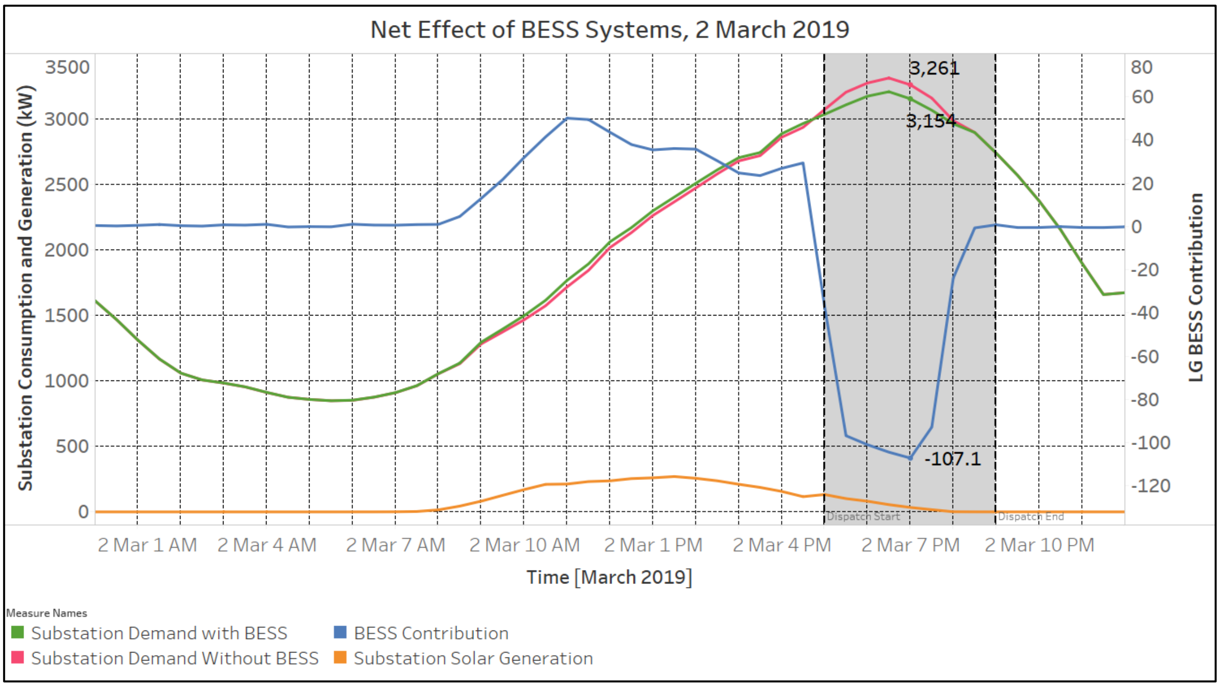

Figure 50: Total Substation Demand With (Green) and Without (Red) Solar Storage on 2 March 2019 – Battery Contribution (Blue) and Solar Generation (Orange)

Figure 50 shows the load on constrained substations decreased from 3,261kW to 3,154kW. This represents a 3.3% (107kW) maximum reduction in demand. As network demand is growing at less than 1% per year, the resulting reduction suggests that UE can defer network augmentation by 3.3 years.

As there was no cool change present on the day of the event, the peak demand occurred at 6.30 pm. As a result of the batteries having only a set amount of charge, the network benefit did not increase as demand increased.

Table 53 depicts the consumption in kWh at each of the 14 distribution substations with and without the Solar Storage systems. This allows for the impact to be measured, and in all, consumption was reduced by approximately 281kWh, which is a reduction of 2%.

Table 53: Substation Consumption during Dispatch Event (5-9 pm) on 2 March 2019

Substation Name	Number of Systems Online	Substation Consumption without systems during Dispatch Period (kWh)	Substation Consumption with systems during Dispatch Period (kWh)	Consumption Reduced (kWh)	Percentage Reduced (%)
ACHERON KOETONG	2	1002.23	977.45	24.79	2.47
AMETHYST DIAMOND	2	956.04	939.16	16.88	1.77
BRIGGS CHLORIS	2	864.64	847.38	17.26	2.00
CASTLEWOOD MARLBOROUGH	1	916.67	908.12	8.55	0.93
ENTRANCE NEPEAN	1	410.90	402.58	8.32	2.03
FLORENCE-GERALD	2	885.14	868.46	16.68	1.88
HYPERNO LAYTON	2	1188.05	1170.48	17.57	1.48
KARRAKATTA-BLUFF	1	1439.37	1430.55	8.82	0.61
MILLGROVE GEORGE	2	897.06	879.96	17.11	1.91
MT PLEASANT LORIKEET	1	816.54	807.72	8.82	1.08
PRINCETON STANFORD	7	1419.04	1359.21	59.82	4.22
TRENTBRIDGE MANCHESTER	3	1421.58	1397.10	24.48	1.72
WARATAH-WARRIGAL	1	563.04	554.24	8.79	1.56
WINDSOR-ST JAMES	5	1174.93	1131.69	43.24	3.68
TOTAL	**32**	**13955.23**	**13674.09**	**281.14**	**2.01**

19.3 System Performance

19.3.1 Performance on 3 March 2019

Figure 51 depicts the average performance of the battery. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plot next to the Discharge Rate, and the Battery SOC and Temperature of the day plotted in the final graph.

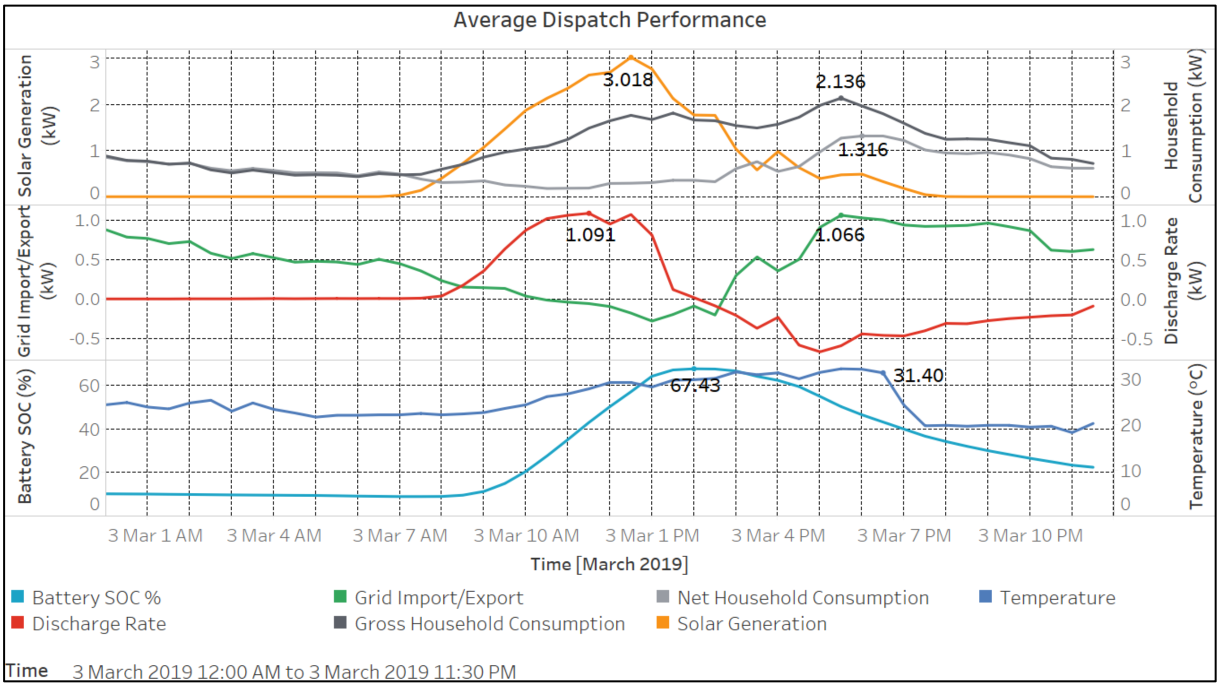

Figure 51: Average Dispatch Performance for 3 March 2019

During the period of 7:00 am to 5:30 pm, the average Gross Household Consumption rose from approximately 0.474kW to 2.136kW, however the Net Consumption as seen by the network was close to zero for this period (Net Consumption increases to 1.269kW at the end of this period).

19.3.2 Performance on 2 March 2019

Figure 52 depicts the average performance of the systems on the event day. In particular, the average Solar Generation is compared to Household Consumption (Net and Gross). The average Grid Import/Export is plotted next to the Discharge Rate, with the Battery SOC and Temperature of the day plotted in the final graph.

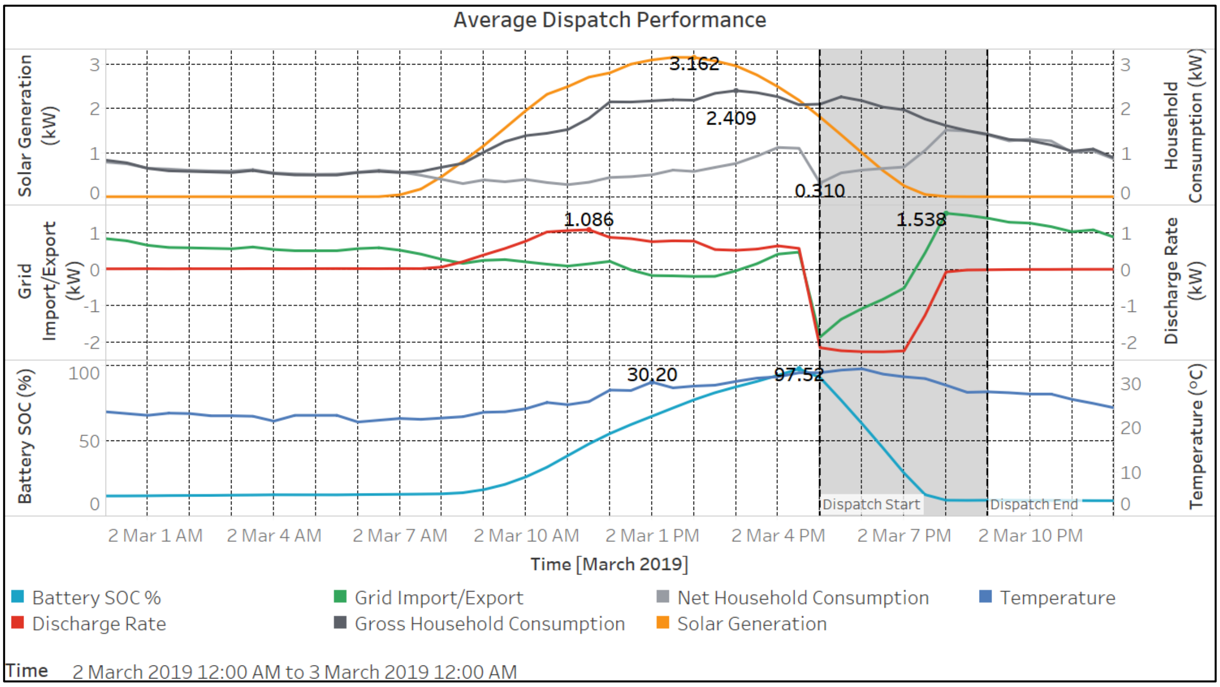

Figure 52: Average Dispatch Performance for 2 March 2019

By comparing Figure 51 and Figure 52, it can be noted that the maximum average Gross Household Consumption increased from 2.136kW to 2.409kW due to the extreme weather experienced. As the batteries were discharged, Net Household Consumption fluctuated around the 1kW mark. This can be attributed to the fact that at 7:00 pm, the Solar Generation fell below Gross Household Consumption and in order to cope with the excess demand, the household was required to draw power from the grid. This can be seen when the Grid Import/Export curve went positive at this time. This also explains why the amount of energy dispatched onto the network was less than the discharge amount of the batteries.

19.3.3 Dispatch Performance by Distribution Substation

Table 54 shows the dispatch performance of the Solar Storage systems by Distribution Substation.

Table 54: Dispatch Performance by Distribution Substation on 2 March 2019

Substation Name	Battery Size (Usable Capacity) (kWh)	Number of Systems Online	Total Usable Battery Capacity (kWh)	Percentage of Battery Discharged (%)	Total Energy Discharged (kWh)	Total Solar Generation (kWh)	Household Consumption (kWh)	Net Grid Export (kWh)
ACHERON KOETONG	9.8 (8.8)	2	17.60	61.85	12.74	4.99	18.94	-1.20
AMETHYST DIAMOND	9.8 (8.8)	2	17.60	80.70	12.63	4.60	21.48	-4.25
BRIGGS CHLORIS	9.8 (8.8)	2	17.60	81.70	12.85	3.82	7.05	9.62
CASTLEWOOD MARLBOROUGH	9.8 (8.8)	1	8.80	79.20	6.20	2.18	11.47	-3.09
ENTRANCE NEPEAN	9.8 (8.8)	1	8.80	81.85	6.38	2.56	32.58	-23.65
FLORENCE-GERALD	9.8 (8.8)	2	17.60	80.69	12.82	2.88	26.02	-10.33
HYPERNO LAYTON	9.8 (8.8)	2	17.60	41.38	12.79	6.80	15.47	4.12
KARRAKATTA-BLUFF	9.8 (8.8)	1	8.80	81.97	6.33	4.22	9.01	1.54
MILLGROVE GEORGE	9.8 (8.8)	2	17.60	83.32	12.19	5.34	12.73	4.80
MT PLEASANT LORIKEET	9.8 (8.8)	1	8.80	81.86	6.32	0.99	3.93	3.38
PRINCETON STANFORD	9.8 (8.8)	7	61.60	51.42	43.65	18.04	47.80	13.89
TRENTBRIDGE MANCHESTER	9.8 (8.8)	3	26.40	58.72	19.64	7.55	13.77	13.43
WARATAH-WARRIGAL	9.8 (8.8)	1	8.80	84.32	6.45	3.45	4.07	5.83
WINDSOR-ST JAMES	9.8 (8.8)	5	44.00	81.21	29.57	14.23	45.37	-1.57
TOTALS	**-**	**32**	**281.6**	**73.58**	**200.56**	**81.66**	**269.69**	**12.53**

19.3.4 Performance Summary

The following comparisons only take into account the performance of the 32 systems that were operational throughout the entire dispatch period.

Table 55 shows the online status of the 42 LG Chem systems installed at the various sites on the UE network.

Table 55: Breakdown of Online Status during Event 7

Distribution Substation	Solar Storage Customers	No. of Systems Online
ACHERON KOETONG	4	2
AMETHYST DIAMOND	2	2
BRIGGS CHLORIS	2	2
CASTLEWOOD MARLBOROUGH	2	1
ENTRANCE NEPEAN	1	1
FLORENCE-GERALD	2	2
HYPERNO LAYTON	4	2
KARRAKATTA-BLUFF	1	1
MILLGROVE GEORGE	2	2
MT PLEASANT LORIKEET	1	1
PRINCETON STANFORD	11	7
TRENTBRIDGE MANCHESTER	4	3
WARATAH-WARRIGAL	1	1
WINDSOR-ST JAMES	5	5
TOTAL	**42**	**32**

In Figure 53, the Average Battery SOC (%) is plotted. This shows the aggregated Battery SOC performance of the LG Chem batteries.

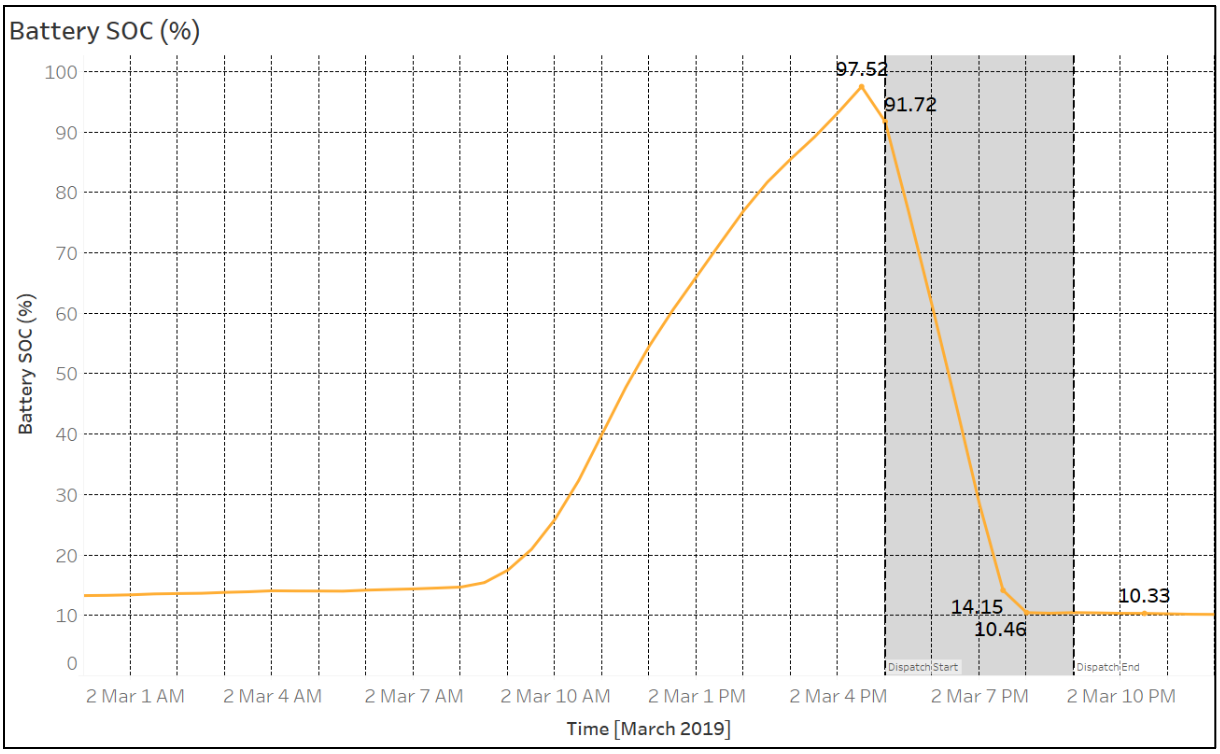

Figure 53: State of Charge (%) for Batteries on 2 March 2019

From Figure 53, the LG Chem batteries only began to charge at 8:00 am, the day of the dispatch event. From a minimum charge of 14.7%, with the aid of the solar generation during the day, the batteries charged to a maximum of 97.52%. Upon discharging when the event began, the LG Chem batteries went down to 10.46% at 8:00 pm and essentially stopped discharging after this point. By 9:00 pm, the SOC was 10.46%.

This is an acceptable figure as the LG Chem batteries installed, while rated to 9.8kWh, only have 8.8kWh of usable energy, allowing a minimum SOC of approximately 10.2%. The batteries will not discharge below this point to maintain battery integrity and life. It seems that greater network benefit could have been achieved if the capacity of the batteries was to increase, as while the Discharge Rate is certainly adequate, the batteries effectively run out of charge 3 hours into the event.

Table 56 shows a comparison of the SOC for the batteries. All data is obtained from Figure 53.

Table 56: Battery State of Charge Comparison for 2 March 2019

Parameter	LG (%)
Maximum	97.52
Dispatch Start	91.72
Dispatch End	10.46
Minimum	10.33

The percentage of charge used during the dispatch event is summarised in Table 57.

Table 57: Percentage of Charge Used during Dispatch Event 7

Battery Type	Charge at Dispatch Start (%)	Charge at Dispatch End (%)	Percentage of Charge Used (%)	Average Energy Discharged (kWh)
LG	97.52	10.46	87.1	7.66

Figure 54 depicts the average discharge rate for the LG Chem batteries. The batteries discharged with a peak value of 2.24kW at 7:00 pm.

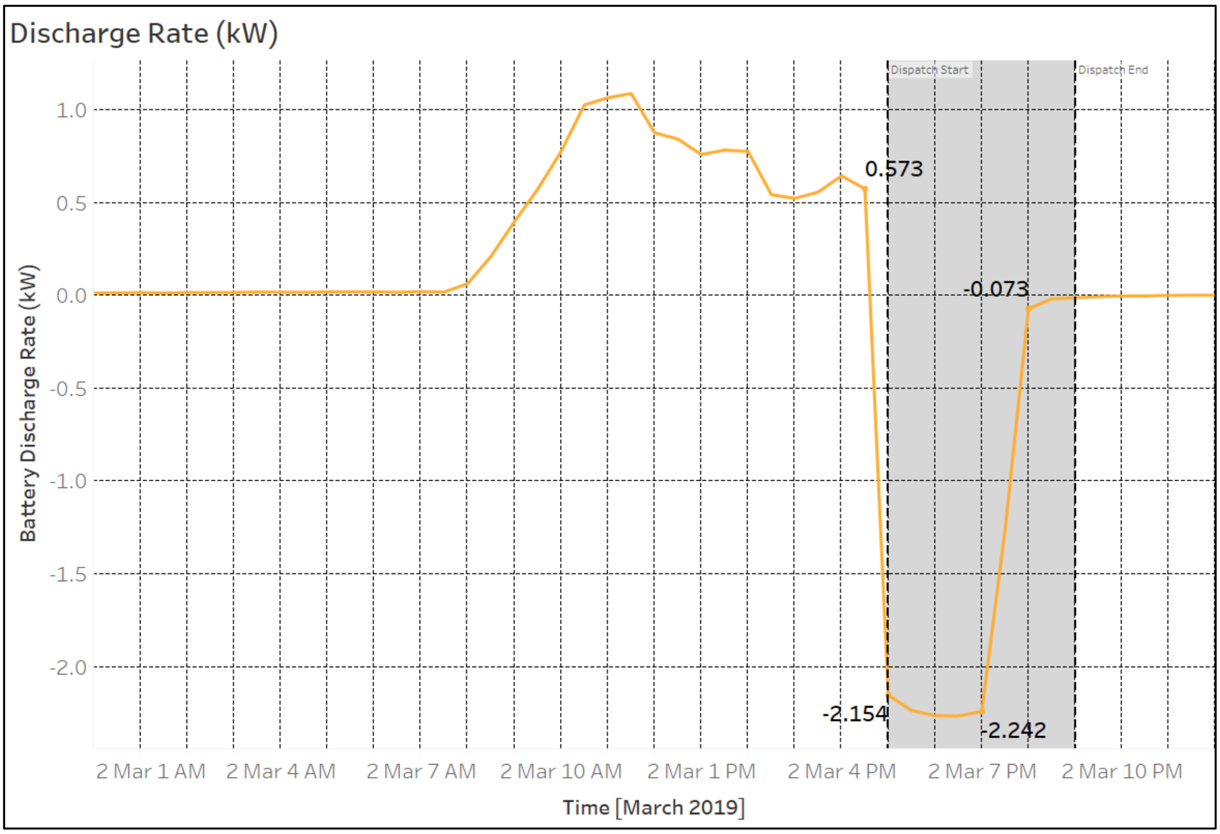

Figure 54: Average Discharge Rate of Battery Systems on 2 March 2019

The sloping curve at the beginning and end of the event in Figure 54 is an artefact of the level of granularity of the averaged performance data. This is also effected by the half-hourly data collected from the controller.

With a usable charge of 8.8kWh, the LG batteries should have been able to discharge for approximately 4.2 hours at an average discharge rate of 2.1kW. However, as the LG batteries were only charged to 97.52% prior to the dispatch event, and were left with 10.46% at the end of the event (from Table 56), the average percentage of charge used for an LG battery was 87.1%. This equates to approximately 7.66kWh of charge.

At an average discharge rate of 2.1kW, it would have taken 3.65 hours for the batteries to discharge. As the data collected is half-hourly, it is not feasible to determine exactly how long the discharge duration was, but as per Figure 54, it was during the last hour (3.5-4 hours) that the discharge of the LG batteries fell from 0.07kW to near 0kW.

Table 58 breaks down the discharge characteristics of the batteries as seen on 2 March 2019.

Table 58: Average Discharge Performance of Online Systems for 2 March 2019

Battery Type	Average Discharge Rate (kW)	Average Discharge Duration (Hours)	Average Energy Discharged (kWh)
LG	2.1	3.65	7.66

Table 57 and Table 58 use two different measures in order to calculate the Average Energy Discharged, with both resulting in near identical results. Table 57 uses the battery's SOC, whilst Table 58 uses the battery's Discharge Rate.

20. References

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