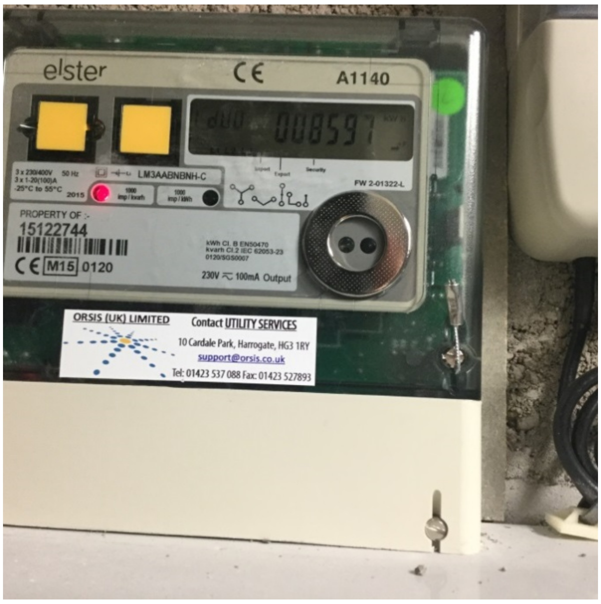
CP755

Battery storage, Bridgend, Wales
Valleys to Coast

Technical Evaluation Report



Tomos Davies, Nick Backhouse, Paul Rogers and Michael Hamer
September 2017

CP755

Battery Storage, Bridgend, Wales Valleys to Coast

Number of properties assisted	7 (containing 173 individual flats)
Number of properties monitored	7

Background

About National Energy Action

National Energy Action is the national fuel poverty charity working across England, Wales and Northern Ireland, and with sister charity Energy Action Scotland (EAS), to ensure that everyone can afford to live in a warm, dry home. In partnership with central and local government, fuel utilities, housing providers, consumer groups and voluntary organisations, it undertakes a range of activities to address the causes and treat the symptoms of fuel poverty. Its work encompasses all aspects of fuel poverty, but in particular emphasises the importance of greater investment in domestic energy efficiency.

About the Technical Innovation Fund

NEA believes that there is huge potential for new technologies to provide solutions for some of the 4 million UK households currently living in fuel poverty, particularly those residing in properties which have traditionally been considered too difficult or expensive to include in mandated fuel poverty and energy efficiency schemes. However, more robust monitoring and evaluation is needed to understand the application of these technologies and assess their suitability for inclusion in future schemes.

The Technical Innovation Fund (TIF) which was designed and administered by NEA, formed part of the larger £26.2m Health and Innovation Programme along with the Warm Zone Fund and Warm and Healthy Homes Fund.

TIF facilitated a number of trials to identify the suitability of a range of technologies in different household and property types and had two strands: a large measures programme to fund the installation and evaluation of technologies costing up to a maximum £7,400 per household, and a smaller measures programme with up to the value of £1,000 per household. It launched in May 2015, with expressions of interest sought from local authorities, housing associations, community organisations and charities wishing to deliver projects in England and Wales.

Over 200 initial expressions of interest were received and NEA invited 75 organisations to submit full proposals. Applications were assessed by a Technical Oversight Group, chaired by Chris Underwood, Professor of Energy Modelling in the Mechanical and Construction Engineering Department at Northumbria University who is also a trustee of NEA. In total, 44 projects were awarded funding to trial 19 different types of technologies and around 70 products (although this number reduced slightly as some products proved not to be suitable and were withdrawn).

More than 2,100 households have received some form of intervention under this programme that has resulted in a positive impact on either their warmth and wellbeing, or on energy bill savings. Of course the amount of benefit varies depending on the household make up and the measures installed. In a small number of instances we removed the measures and took remedial action.

Technical monitoring and evaluation

NEA has been working with grant recipients to monitor the application of these technologies and assess performance, as well as understand householder experiences and impacts.

A sample of households from each TIF project was selected for monitoring purposes. Participation was entirely voluntary and householders were free to withdraw at any time. This involved the installation of various monitoring devices within the home which collected data for analysis by NEA's technical team. Some residents were also asked to take regular meter readings. In some instances, a control group of properties that had not received interventions under TIF were also recruited and monitored.

The technical product evaluation was conducted alongside a social impact evaluation to inform our understanding of actual energy behaviour changes, perceived comfort levels and energy bill savings, as well as any other reported benefits. Householders were asked to complete a questionnaire both before and after the installation of the measures which captured resident demographic data including any health conditions. Small incentives in the form of shopping vouchers were offered to maintain engagement over the course of the evaluation period.

The HIP fund was principally designed to fund capital measures to be installed into fuel poor households. A small proportion of the funding enabled NEA to conduct limited research and monitoring of products installed, and was restricted to ensure that the majority of funds were spent on the products. All products included in the trials were deemed to offer costs savings and energy efficient solutions as proposed by the delivery partners. The research and monitoring aimed to provide insights to inform future programme design and interested parties of the applicability of the product to a fuel poor household. We recognise that due to the limited number of households involved in the monitoring exercises and the limited period we were able to monitor a product's performance, we may recommend that further research is needed to better understand the application of these products in a wider range of circumstances over a longer period of time.

The research was conducted according to NEA's ethics policy, which adopts best practice as recommended by the Social Research Association (SRA) Ethical Guidelines 2002.

An accompanying programme of training and outreach work was also delivered to 292 frontline workers to increase local skills and capacity.

Individual project reports are being compiled and will be made available publicly on NEA's website from September 2017, along with a full Technical Innovation Fund Impact Report.

Acknowledgements

With thanks to our project partners:

Valleys to Coast
Alun Roberts, Project Manager, Raymonde De-Schoolmeester, Electrical Works Supervisor and Kathy Hopes, Housing Officer
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Tomorrow's Energy

Manufacturer
SolaX Power – Hybrid inverter and battery management system

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Legal limitations and disclaimer

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Executive summary

Project overview

This project assessed the performance of solar PV battery storage at sheltered housing properties owned by Valleys to Coast Housing Association. The aims of the project were;

- To test the performance of solar PV battery storage in sheltered housing settings.
- To improve understanding of the benefits of adding battery storage to existing solar PV installations in different settings and assess whether installing battery storage successfully shifted energy demand and made energy savings, potentially saving fuel poor tenants money on the service charge element of their rent, part of which pays for the energy consumed in the communal areas of the building.

Context

According to research, there were 26,863 sheltered housing units in Wales in 2015[1]. Sheltered housing comprises a significant proportion of the social housing stock in the UK. Many of these properties have communal areas used by the residents with the cost of energy and heating in these areas paid for by older vulnerable tenants to their social housing providers.

The annual energy consumption for the communal areas of the Valleys to Coast sheltered housing properties studied ranged from just over 30,000 kWh per annum to about 185,000 kWh per annum. The costs associated with this electricity consumption are passed on to residents through their service charge.

Solar PV combined with battery storage is a relatively new but fast developing technology. The aim is to store excess power generated by the solar PV system which would otherwise be exported to the grid. When the electricity consumption of the property is greater than any power generated by the solar array then at least some of the extra demand can be supplied from the charged batteries.

Communal areas in sheltered properties and other shared properties such as flats use low level energy for lighting, heating and the running of communal washing machines. The installations could help lower shared energy bills of sheltered properties, saving them money and potentially contributing to the alleviation of fuel poverty in these households. This evaluation could potentially be used to provide evidence for the investment in solar PV and battery storage in other settings such as privately owned flats.

The technology

The first rechargeable battery was a lead acid battery, invented in 1859. Maintenance free lead-acid batteries were developed from the 1970s such as Gel lead acid batteries and the AGM or Absorbed Glass Mat lead acid battery. A rechargeable battery goes through cycles of charge and discharge. A measure of the level of charge of the battery prior to recharging is the Depth of Discharge (DOD). This is the percentage of the maximum battery capacity that has been

[1] https://www.housinglin.org.uk/_assets/Resources/Housing/Regions/Wales/HLIN_Table_OSH_and_ECH_in_Wales_2015.pdf

discharged. A lead acid battery for starting cars only has a small DOD. Those used to provide power over a period of hours have a larger DOD and are known as 'Deep Cycle' batteries. They have thicker plates (anodes and cathodes) than the starter batteries used in cars to extend their lifespan as high levels of discharge damages the plates. These batteries are generally more expensive to purchase.

A maintenance free deep cycle lead acid battery such as an AGM might have a life span of 1000 charge and discharge cycles if the Depth of Discharge (DOD) is 50%. The lifespan decreases to about 500 cycles if the depth of discharge (DOD) increases to 80% of full charge[2]. Although lead acid batteries have a lower cost, they are heavy, have a relatively short lifespan, charge slowly and are not environmentally friendly.

Lithium is an attractive material for batteries due to its low weight. Due to the instability of metallic Lithium, rechargeable batteries were developed from the 1990s using non-metallic compounds with Lithium ions. There are various compositions of Lithium-ion battery. These include oxides of Lithium with other metals such as Cobalt, Nickel and Manganese as well as Lithium Iron Phosphate[3].

The batteries used in this project were Lithium Iron Phosphate manufactured by Pylontech. As with other Lithium ion batteries, these have a better energy density (Wh per litre) and specific energy (Wh per kg) than lead acid batteries. All Lithium-ion batteries are 'deep cycle' and have a longer lifespan than lead acid batteries. Lithium ion batteries are more expensive than lead acid batteries, but their costs have been falling as the technology develops and production increases.

The solar PV inverter used in this project used a 5kW hybrid inverter manufactured by SolaX. As well as converting direct current (DC) electricity from the solar panels to alternating current (AC) electricity which could be used in the building, the hybrid inverter also included a management system and charge controller for the batteries.

The hybrid inverter measures the level of generation from the solar PV system and the consumption from the building. The SolaX energy management system prioritises self-consumption of electricity generated by the PV system and any surplus which can't be used on site at the time is diverted to charge the batteries. When the building electricity demand exceeds generation from the solar PV system, power is supplied by the batteries to meet demand. Electricity is only exported to the grid if the generation from the solar panels meets all electricity demand and the batteries are fully charged.

[2] A Comparison of Lead Acid to Lithium-ion in Stationary Storage Applications, AllCell Technologies (2012) http://www.batterypoweronline.com/main/wp-content/uploads/2012/07/Lead-acid-white-paper.pdf (Accessed 21 August 2017)

[3] BU-205: Types of Lithium-ion, Battery University http://batteryuniversity.com/learn/article/types_of_lithium_ion (Accessed 21 August 2017)

The project

Valleys to Coast Housing Association is a social housing provider based in Bridgend County Borough Council. It owns and rents 5,800 properties to tenants throughout Bridgend including sheltered accommodation.

Battery storage was installed in 7 of Valley to Coast's sheltered housing complexes, which ranged in size from 14 to 39 flats. These properties already had solar PV arrays installed up to about 11kW in size. There were a total of 173 flats in the properties which were home to vulnerable and older residents. These tenants contributed, via a central service charge, to the electrical costs of communal areas and facilities. The majority of residents were on welfare benefits.

An assessment of the performance of the solar PV and battery systems was conducted as part of this evaluation, along with some detail about the effectiveness of shifting energy demand from the grid was made using meter readings and data from the monitoring portal for the SolaX X-hybrid inverter.

The project funded the installation of SolaX X-hybrid inverters and Pylontech Lithium-ion batteries to existing solar PV systems at sheltered housing properties owned by Valleys to Coast. The partner had originally planned to install a wider range of measures including heat pumps with thermal stores but these trials did not go ahead.

Summary of findings and insights

Installations

- Analysis of the performance of the battery installations was carried out using data from the SolaX web portal. Poor WIFI connections at some sites limited the data that was available.
- Examination of historic performance graphs from the SolaX portal showed that at 2 of the 7 sites, the batteries were not charging or discharging due to a fault with the system. This may be due to a loose connection to the battery or current sensor. A further 2 sites showed some anomalous plots on the portal which suggested there might be a loose connection or the current sensor was installed on the wrong cable.

Performance of systems

- In January the output from the batteries was low, typically being about 0.3 kWh/day. This was due to low solar generation in winter.
- There was a significant increase in battery output from March as the solar generation improved. At the Llys Ton Extra Care Scheme, the average battery output was in the range 2.66 kWh/day to 3.05 kWh/day between April and August 2017.
- At the Dinam Close sheltered housing scheme the battery output was up to 4.79 kWh/day. This may be due to lower electricity demand and great solar export allowing greater charging and discharging of the battery during the day.
- The batteries at Dinam Close were able to supply power late into the evening so that the site was able to avoid grid import until early the next morning. At Llys Ton the battery reached maximum discharge by about 8.30pm on a sunny day.
- The annual battery output from the system at Llys Ton was estimated to be 686kWh, producing an annual energy cost saving of £76.80 at the site. Based on this energy saving, the payback time for installing batteries to an existing system was estimated to be 27 years.

- Between 1 March 2017 and 31st July 2017, the electricity saving at Dinam Close was estimated to be £65.20. This would provide a saving of £3.62 per household on the electricity cost for the communal area at the site over this period.

Conclusions and recommendations

- Care should be taken when comparing quotations for battery storage systems. Batteries are not currently a technology which is covered under the Microgeneration Certification Scheme (MCS). There are no standards for quotes that must be used and estimates of the financial benefit may vary between installers for the same system.
- Web portals for batteries allow the performance of solar PV and battery systems to be monitored. WIFI connections can be an issue for installations and good quality power line adapters may help improve the connection between the inverter and the WIFI router.
- Installers and Energy Managers should make good use of web portals for battery systems as these can allow faults with the battery or solar system to be detected early. Although the performance graphs may initially look complex, being able to identify the characteristics of a correctly performing system is important.
- The current project installed single phase inverters including a SolaX X-hybrid inverter on each of the phases of a 3-phase supply. A new 3-phase X-Hybrid inverter is being released in September 2017 which would be a better option for similar installations. Advantages include lower costs, the batteries being connected to all the solar panels on the array as well as powering all the appliances on the 3-phase supply.
- The payback time for the current generation of battery systems is long and the system may not pay for itself in the battery lifetime. The cost of battery and solar PV systems is continuing to fall. Battery manufacturers are developing new income streams for systems such as grid balancing and frequency response. There may also be opportunities for greater savings with ‘time of use’ tariffs for the electricity supply.
- The current project estimated the battery output using data from the SolaX web portal. In a future project it would be beneficial to include additional monitoring equipment to confirm the data from the portal. This could include Direct Current (DC) loggers on the connection between the SolaX hybrid inverter and the batteries.

1. Project overview

1.1 Introduction

Valleys to Coast Housing Association is a social housing provider based in Bridgend County Borough Council. It owns and rents 5,800 properties to tenants throughout Bridgend including sheltered accommodation.

The project involved the installation of battery storage in 7 Valleys to Coast-owned sheltered and extra care housing properties throughout Bridgend County Borough Council. The properties had solar PV systems fitted prior to the installation of the battery storage. The location and details of the properties are shown in Figure 1.1 and Table 1.2.

The number of flats in the properties ranged from 14 to 39. The 173 flats across the 7 sheltered properties contribute, via a central service charge, to the electrical costs of communal areas and facilities; the vast majority being on welfare benefits. Installing battery storage aimed to shift energy demand from the grid and make cost savings, and thereby reduce the tenants' service charge bills.

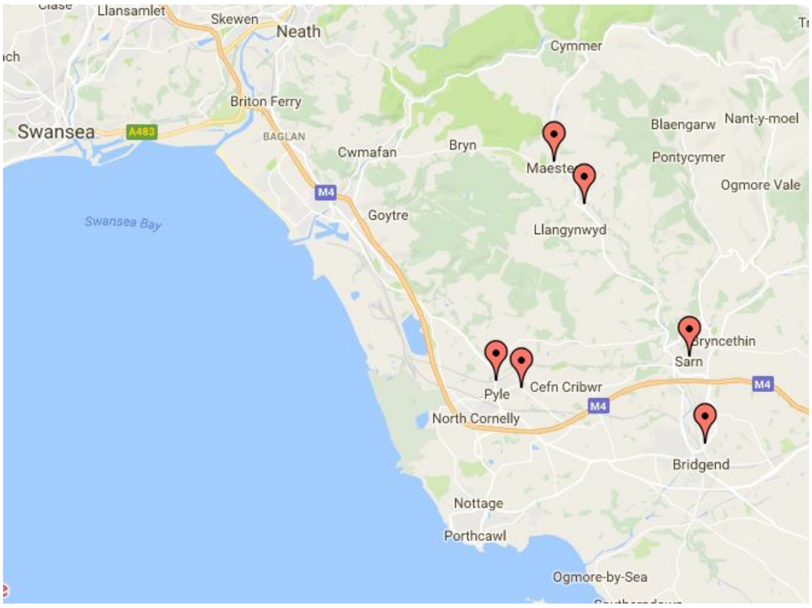

Figure 1.1 Site locations

Property	Number of flats	Further details
Dinam Close, Nantymoel	18	Sheltered housing, over 60 years
Ger Y Nant, Bridgend	14	Sheltered housing, over 60 years
Hafan Deg, Maesteg	32	Sheltered housing, over 60 years
Llys Cynffig, Pyle	30	Sheltered housing, over 60 years
Lys Ton, Bridgend	39	Extra care scheme, over 50 years
Merfield House, Sarn, Bridgend	22	Sheltered housing, over 60 years
Treharne Row, Maesteg	18	Sheltered housing, over 60 years

Table 1.2 Details of Valleys to Coast properties where battery storage systems were installed

1.2 Project timeline

The project was approved in September 2015. Battery storage units were installed across all participating sheltered housing properties between January and November 2016.

NEA was limited to using historical and monthly energy meter readings provided by Valleys to Coast along with data obtained from the SolaX monitoring portal. The partner had originally planned to install a wider range of measures including heat pumps with thermal stores but these trials did not go ahead. It was not possible to install additional monitoring equipment at the sites with battery storage due to late changes in the project.

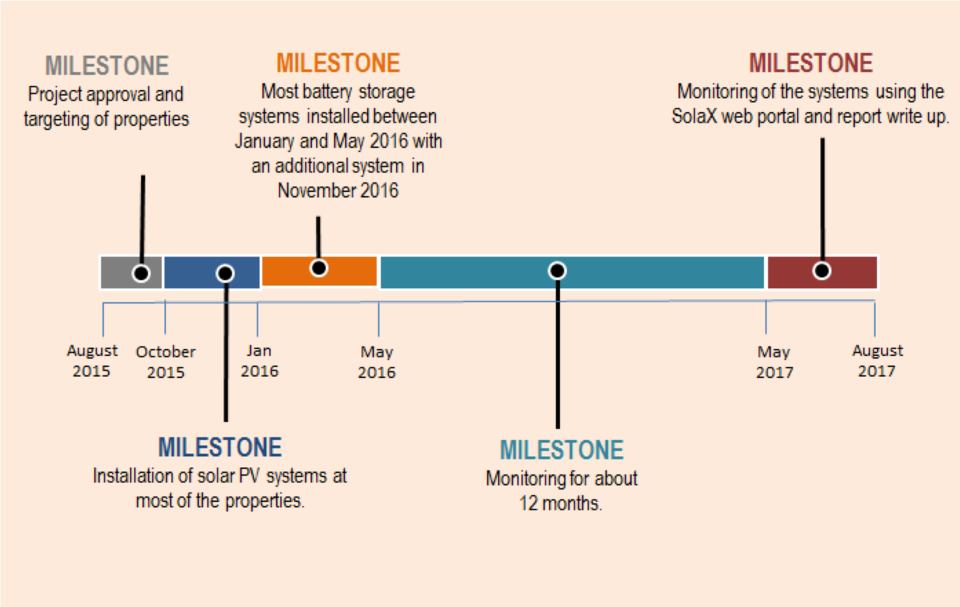

Figure 1.3 Project timeline

1.3 Battery technology

The first battery was invented by Alexander Volta in 1800 with pairs of dissimilar metal discs separated by an electrolyte placed in a pile. The lead acid battery was the first rechargeable battery and was invented in 1859 by Gaston Planté[4]. Maintenance free lead-acid batteries were developed from the 1970s such as Gel lead acid batteries, where the electrolyte is suspended in a silica gel. Another is the AGM or Absorbed Glass Mat lead acid battery, which has fine fibre glass matting soaked in acid electrolyte placed between plates of the battery which are compressed.

A rechargeable battery goes through cycles of charge and discharge. A measure of the level of charge of the battery prior to recharging is the Depth of Discharge (DOD). This is the percentage of

[4] BU-201: How does the Lead Acid Battery Work?, Battery University http://batteryuniversity.com/learn/article/lead_based_batteries (Accessed 21st August 2017)

the maximum battery capacity that has been discharged. A lead acid battery for starting cars only has a small DOD. Those used to provide power over a period of hours have a larger DOD and are known as ‘Deep Cycle’ batteries. They have thicker plates (anodes and cathodes) than the starter batteries used in cars to extend their lifespan as high levels of discharge damages the plates.

A maintenance free deep cycle lead acid battery such as an AGM might have a life span of 1000 charge and discharge cycles if the Depth of Discharge (DOD) is 50%. The lifespan decreases to about 500 cycles if the depth of discharge (DOD) increases to 80% of full charge[5]. Although lead acid batteries have a lower cost, they are heavy, have a relatively short lifespan, charge slowly and are not environmentally friendly.

Lithium is an attractive material for batteries due to its low weight. Due to the instability of metallic Lithium, rechargeable batteries were developed from the 1990s using non-metallic compounds with Lithium ions. There are various compositions of Lithium-ion battery. These include oxides of Lithium with other metals such as Cobalt, Nickel and Manganese as well as Lithium Iron Phosphate[6].

The batteries used in this project were Lithium Iron Phosphate. As with other Lithium ion batteries, these have a better energy density (Wh per litre) and specific energy (Wh per kg) than lead acid batteries. All Lithium-ion batteries are ‘deep cycle’ and have a longer lifespan than lead acid batteries. Lithium ion batteries are more expensive than lead acid batteries, but their costs have been falling as the technology develops and production increases. A review from 2012 comparing lead acid batteries with Lithium ion noted that a Lithium Iron Phosphate battery ($LiFePO_4$) had a life of 3000 cycles at 80% depth of discharge[5].

1.4 SolaX X-hybrid inverter

The solar PV systems in this project used a 5kW hybrid inverter manufactured by SolaX (Figures 1.4 & 15). This acted as an inverter for the solar panels and provided a management system and charge controller for the batteries. DC (direct current) electricity from the solar panels is fed into the hybrid inverter (connection 1 on Figure 1.3). The hybrid inverter supplies AC (alternating current) to the building (2) which can be used by appliances.

The hybrid inverter monitors the level of generation from the solar PV system and the consumption from the building. The SolaX energy management system prioritises self-consumption of electricity generated by the PV system and any surplus is diverted to charge the batteries (3). When the building electricity demand exceeds generation from the solar PV system, power is supplied by the batteries (4) to meet demand. Electricity is only exported to the grid (5) if the generation from the solar panels meets all electricity demand and the batteries are fully charged. The SolaX X-hybrid

[5] A Comparison of Lead Acid to Lithium-ion in Stationary Storage Applications, AllCell Technologies (2012) http://www.batterypoweronline.com/main/wp-content/uploads/2012/07/Lead-acid-white-paper.pdf (Accessed 21 August 2017)

[6] BU-205: Types of Lithium-ion, Battery University http://batteryuniversity.com/learn/article/types_of_lithium_ion (Accessed 21 August 2017)

inverter includes built-in WIFI communication and when linked to the internet, data from the system can be uploaded to the Xcloud (6) and can be accessed via the SolaX web portal.

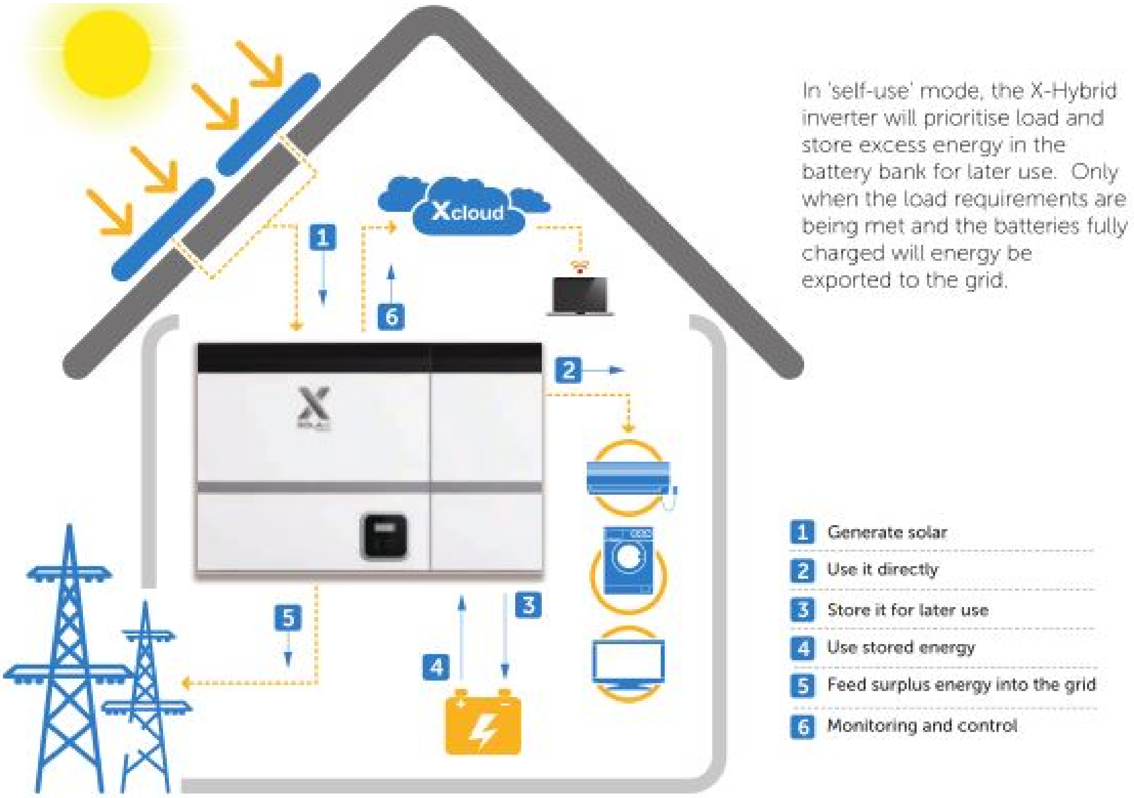

Figure 1.4 Connections to SolaX hybrid inverter[7]

Figure 1.5 SolaX SK-SU5000E 5kW hybrid inverter (Dinam Close)

Figure 1.6 Pylon Tech US2000B batteries (Battery storage unit at Llys Ton)

[7] http://www.solaxpower.com/wp-content/uploads/2017/02/SolaX-Portal-User-Guide.pdf

Figure 1.7 Pylon Extra 2000 Lithium Iron Phosphate battery (2.4kWh)

Batteries are DC devices and are sometimes retrofitted to an existing solar PV system. Since the output to the home from the solar PV system is AC, the battery system added requires a further inverter to switch back from AC to DC. There are energy losses as a result of the system using 2 inverters. The SolaX X-hybrid inverter is a DC-coupled system, where the battery is connected before the output from the solar panels is converted from DC to AC and avoids the need for a second inverter. This should be more efficient than an AC-coupled system.

The Pylontech batteries fitted in this project had an expected life of between 8 and 10 years depending on storage temperature, hence they were provided with an environmentally controlled cabinet with cooling fans (Figure 1.6). Lithium Iron Phosphate ($LiFePO_4$) is a stable medium and not as prone to runaway temperature rise[8] which can be a concern with some Lithium ion batteries. Most of the batteries installed were Pylontech Extra 2000 batteries (Figure 1.7) and the data sheet gave the number of charge and discharge cycles for the battery life as >4000 at 80% depth of discharge (DOD). A newer version of the battery, the USB2000B, was released by Pylontech in late 2016 where the number of life cycles is >6000 with an 80% DOD[9]. This battery was fitted at Lys Ton (Figure 1.6), which had a later installation data than the other sites.

The periods of greater electricity demand in a dwelling tend to be in the morning and the late afternoon/evening. However with a solar PV system, electricity generation is greatest in the middle of the day when demand from the building tends to be lower. As a result a lot of the electricity generated by the solar PV system is exported to the grid (upper diagram in Figure 1.8). When a battery is added to the system (lower diagram in Figure 1.8), as the solar generation increases at the start of the day, the energy management system sends power to meet the electricity demand of the building first and then sends any excess to charge the battery. When the battery is fully charged and if there is no further demand from the building, only then will the energy management system export power to the grid. Later in the day as the solar generation falls and fails to meet all

[8] Battery University BU-205:Types of Lithium-ion http://batteryuniversity.com/learn/article/types_of_lithium_ion (Accessed 17 August 2017)

[9] Pylontech US2000B data sheet, low voltage energy storage for X-Hybrid http://www.solaxpower.com/wp-content/uploads/2017/01/Pylontech_US2000B_cn.pdf (Accessed 24 August 2017)

the electricity demand of the building, the battery discharges and reduces the need for electricity import.

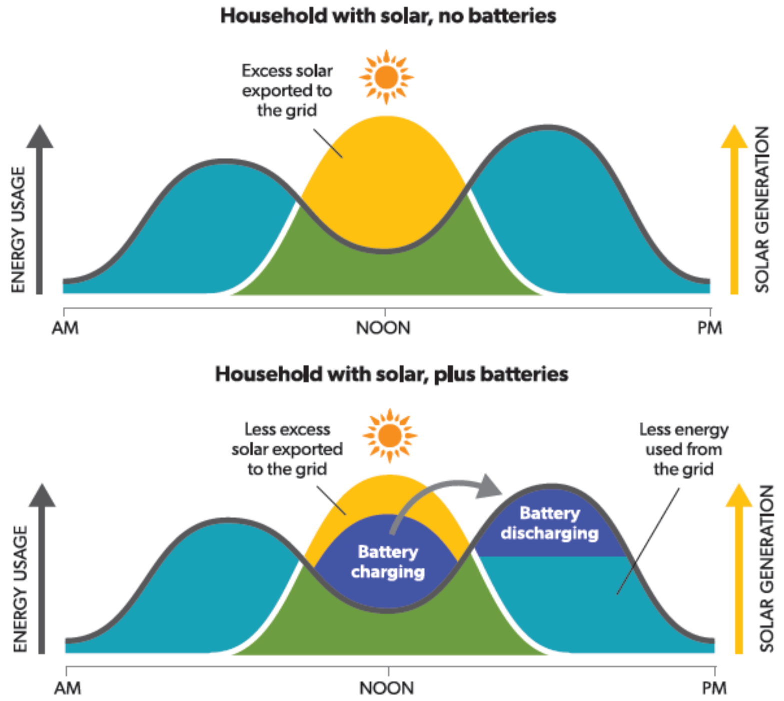

Figure 1.8 Illustration of the benefits of energy storage on a solar PV system[10]

The use of on-site generated electricity is highly beneficial and should not be understated either in terms of pure cost or environmental impact. Drawing electricity through the grid results in losses as it travels across the country and through the many step-down transformers. Losses between the power plant and the consumer are in the range 8 to 15%[11]. This equates to a large waste of resources and has environmental impact if fossil fuels are used in that generation. This wastage is not experienced when electricity is generated on-site using renewables as the losses on locally generated electricity are minimal.

[10] NSW Home Solar Battery Guide (2017), http://www.resourcesandenergy.nsw.gov.au/__data/assets/pdf_file/0005/728816/NSW-Home-Solar-Battery-Guide_WEB.pdf (Accessed 24 August 2017)

[11] How big are Power line losses (2013), http://blog.schneider-electric.com/energy-management-energy-efficiency/2013/03/25/how-big-are-power-line-losses/ (Accessed 24 August 2017)

2. Technical evaluation methodology

2.1 Installation of the technologies

Figure 2.1 11KW Solar PV installation (Merfield House)

Figure 2.2 Sofar Solar 3000TL Mass Energy Inverter (Llys Cynffig)

Property	Solar PV installation date	Solar panels	System Size (kW)	Inverters	Battery Installation date	Battery	Battery Size
Dinam Close	12-Jan-16	Seraphim SRP-265-6PB	11.14	2 x Growatt 3000MTL + 1 x SolaX SK-SU5000E	15-Mar-16	Pylontech Extra 2000	2 x 2.4kWh
Ger Y Nant	22-Oct-12	BRLD 240	11	2 x Trannergy 2700 + 1 x SolaX SK-SU5000E	15-Apr-16	Pylontech Extra 2000	2 x 2.4kWh
Hafan Deg	22-Oct-15	Canadian Solar CS6P250P	11	2 x Sofar Solar 3000TL + 1 x SolaX SK-SU5000E	15-Jan-16	Pylontech Extra 2000	2 x 2.4kWh
Llys Cynffig	15-Oct-15	Canadian Solar CS6P250P	11	2 x Sofar Solar 3000TL + 1 x SolaX SK-SU5000E	23-Mar-16	Pylontech Extra 2000	2 x 2.4kWh
Lys Ton	17-Oct-11	Sharp ND-220E1F	2.2 *	1 x SolaX SK-SU5000E	15-Nov-16	Pylontech USB2000B	2 x 2.4kWh
Merfield House	29-Oct-15	Seraphim SRP-250-6PB	11	2 x Sofar Solar 3000TL + 1 x SolaX SK-SU5000E	15-Feb-16	Pylontech Extra 2000	2 x 2.4kWh
Treharne Row	12-Jan-16	Seraphim SRP-265-6PB	11.14	2 x Growatt 3000MTL + 1 x SolaX SK-SU5000E	21-Mar-16	Pylontech Extra 2000	2 x 2.4kWh

* Solar PV system expanded to 5.6kW and inverter replaced 1 to 25 Nov 2016

Table 2.3 Details of solar PV and battery storage installations at Valleys to Coast properties

Table 2.3 shows installation details for the solar PV and battery systems in the sheltered housing properties. The installation dates were approximate values. Solar PV systems, about 11kW in size, were installed a few months before the battery systems at 5 of the properties. Normally a single 3-phase inverter would have been installed with the solar PV systems. Since it was known that battery storage was to be subsequently fitted, 2 single phase inverters and a SolaX single phase X-hybrid inverter were used with the solar PV system. This was because a suitable 3-phase hybrid inverter was not available at the time of installation, although SolaX are releasing models in September 2017. Figure 2.1 shows the 11kW solar PV system at Merfield House, while Figure 2.2 shows the 2 x Sofar Solar 3000TL Mass Energy single phase 3kW inverters which were installed as part of the solar PV system at Llys Cynffig.

An 11kW solar PV system was installed at Ger Y Nant in 2012 and this included a 3-phase inverter. At the time of the battery installation in May 2016, the 3-phase inverter was replaced by 2 Trannergy 2700 single phase inverters and the SolaX SK-SU5000E X-hybrid inverter. For Lys Ton, there was only a 2.2kW PV system fitted in October 2011. At the time of the battery installation, the solar PV system was extended to make a total of 5.6kW and the original single phase inverter was replaced with a SolaX SK-SU5000E X-hybrid inverter.

While all the solar panels at Lys Ton fed the SolaX X-hybrid inverter which was connected to the batteries, this was not the case at the other sites. Here the panels were split between the different inverters in a ratio of 5:3:3, where the SolaX X-hybrid inverter was supplied by about 5kW of panels.

The batteries installed at most of the sites were Pylontech Extra 2000 Lithium Iron Phosphate batteries. Each of these had a capacity of 2.4kWh and 2 were installed with each solar PV system. When both fully charged batteries provided power down 80% DOD, the system provided a total of 3.84kWh. At Lys Ton, the more recent USB2000B battery from Pylontech was fitted.

Other battery systems are being tested as part of the Technical Innovation Fund and these include systems from Growatt, Moixa, Powerflow, Powervault, Sonnen and Victron. These were installed at domestic properties with solar PV systems and used smaller batteries than in the current study, with a total battery size of typically 2 or 3kWh.

2.2 Technical assessment methods

Meter readings

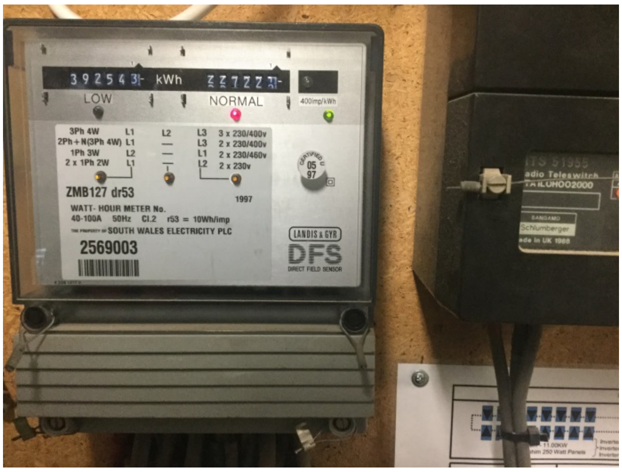

Fig 2.4 Economy 7 meter (Treharne Row)

Fig 2.5 Solar PV meter (Llys Cynfig)

Electricity consumption data for the communal areas was provided by Valleys to Coast and meter readings were also taken (Figure 2.4).The latest data available for some sites was from November 2016, which did not provide a full 12 month monitoring period.

For most of the sites, the batteries were installed soon after the solar PV systems. While the benefit of the solar PV systems was likely to be significant, the impact from the battery storage system was smaller. This made it difficult to separate any benefit of the batteries from the solar PV system by comparing electricity consumption data before and after the installation.

The total generation meter installed with the solar PV system supported remote monitoring by Orsis (Figure 2.5), this measured the generation from the whole solar PV array and the output from all 3 inverters. The meter transmitted half-hourly readings and the data could be obtained via the Orsis web portal. Data was provided by Valleys to Coast up to June 2017.

Assessment of solar PV generation

The annual solar PV generation at each of the sites was calculated from the Orsis meter readings. These values were compared with estimates for annual generation made by different methods commonly used in the solar industry. Each of these methods takes into account system size as well as angles of orientation and inclination. These angles were estimated for the calculations from satellite and other site photos. Normally account is taken for shading, but this was not possible from the photographs.

MCS method:
This is used by installers to provide the estimated annual generation on a MCS Certificate[12].

PVGIS method:
Photovoltaic Geographical Information System, produced by the European Commission Joint Research Centre. There are two databases which can be used for estimates: the 'Classic' PVGIS, based on interpolation of ground station measurements and the more recent Climate SAF, using satellite data[13].

PV Sol:
Solar PV industry software which takes into account the model of solar panels and inverters[14].

As well as the annual generation for the whole solar PV arrays, a value for the annual generation for the SolaX inverter in that array was also provided where there was data available from the SolaX portal.

Although the PV systems will generate electricity with diffuse light all year round, the output is severely reduced when the sun is low in the winter sky. From April through to around October, there is normally more direct sunlight and with the sun being higher in the sky the solar radiation levels are higher, leading to greater PV generation.

Figure 2.6 illustrates for how the solar radiation levels build-up and drop-off over a year[15]. The chart also illustrates that weather patterns have a marked effect on the output of solar systems, for example showing the large differences between May 2014 and May 2015. However the annual variation in solar radiation (and PV generation at a site) will vary less between years than for individual months.

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[12] Guide to the Installation of Photovoltaic Systems http://www.microgenerationcertification.org/images/PV%20Book%20ELECTRONIC.pdf (Accessed 30 August 2017)
[13] Photovoltaic Geographical Information System, http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php# (Accessed 30 August 2017)
[14] PV Sol, The Solar Design Company http://www.solardesign.co.uk/pvsol.php (Accessed 30 August 2017)
[15] Calculating Solar Panel Output, Exeo Energy https://www.exeoenergy.co.uk/solar-panels/solar-panel-output/ (Accessed 30 August 2017)

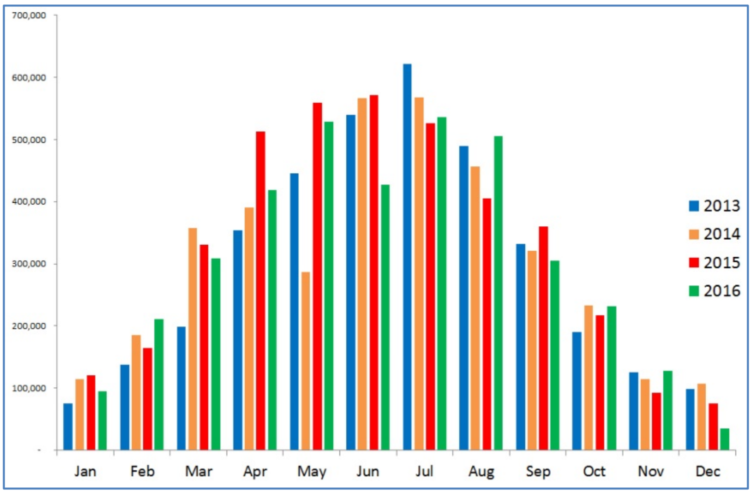

Figure 2.6 Variation in annual solar irradiation

Analysis using data from the SolaX web portal

The SolaX X-hybrid inverter includes built-in WIFI communication. Data on the performance of the solar PV and battery system is collected every 5 minutes and this operational data can be uploaded to the Xcloud (the brand name for the SolaX server) where it is processed. It is possible to monitor the data by logging into a registered account via the SolaX web portal or apps for Apple or Android devices[16].

The SolaX X-Monitoring system can provide current and historic data in the form of graphs or the raw data which can be downloaded. Figure 2.6 shows part of the overview screen for Llys Ton, while figure 2.7 shows the Power graph for Llys Ton on 11th April 2017. The blue line is the 'feed-in power'. When electricity is being imported from the grid, this is a negative number, while it is positive when electricity is being exported to the grid. The green line is the 'solar power' and is the amount of power produced by the solar panels which were connected to the SolaX X-hybrid inverter. The orange line is the output power, which illustrates the power output by the inverter.

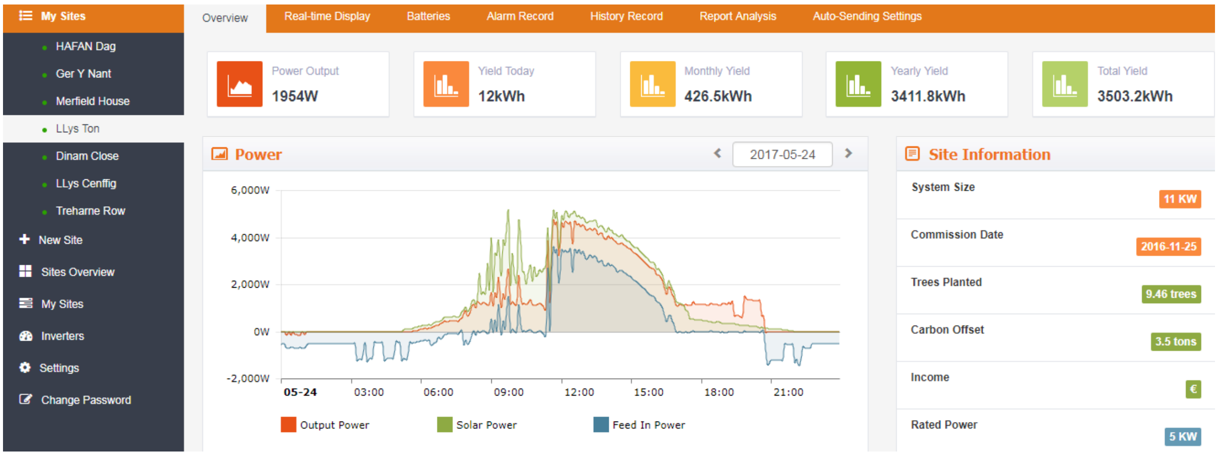

Figure 2.7 Overview screen from the SolaX X-Monitoring portal

[16] SolaX Power WIFI monitoring user guide http://www.solaxpower.com/wp-content/uploads/2017/02/SolaX-Portal-User-Guide.pdf (Accessed 25th August 2017)

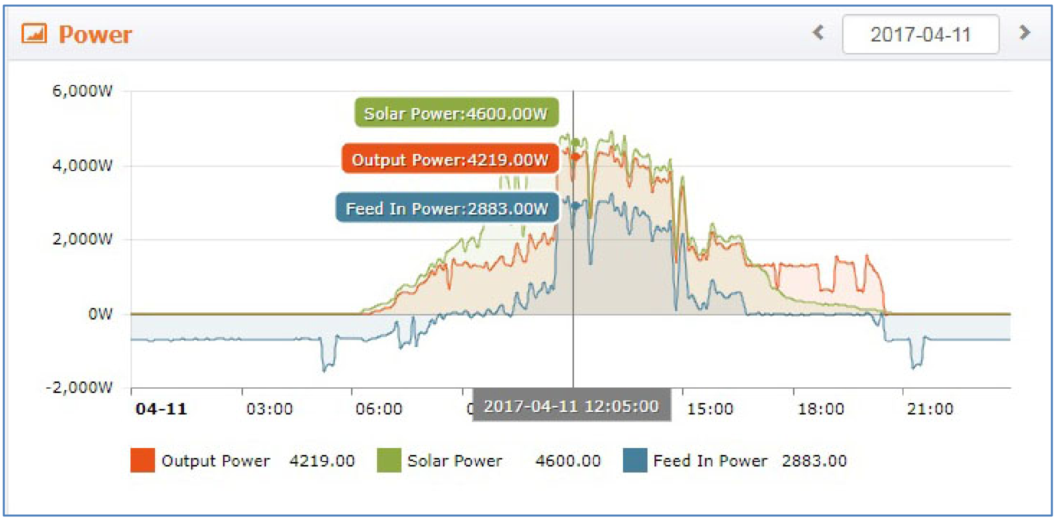

Figure 2.8 Power graph from the Overview screen for Llys Ton on 11th April 2017

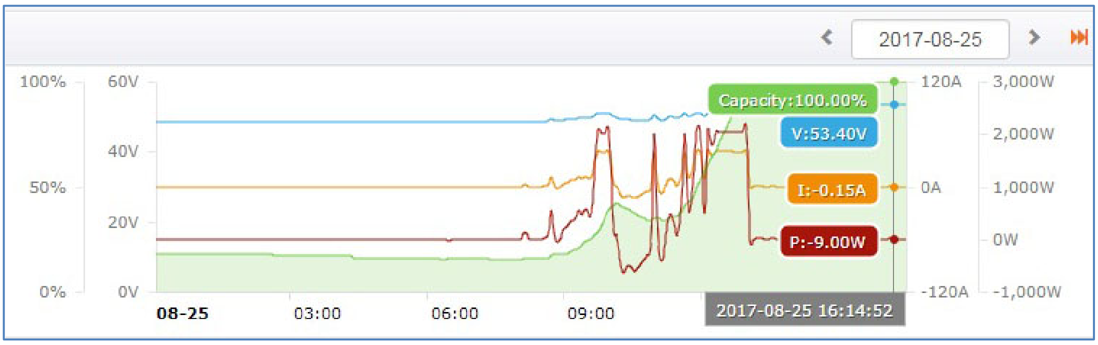

Figure 2.9 Battery performance from the 'Batteries' section on the SolaX monitoring portal on 25 August 2017

When the 'Solar Power' is larger than the 'Output Power', the batteries are charging and when the 'Output Power' is greater than the 'Solar Power', the batteries are discharging. It can be seen that in Figure 2.8, the batteries are charging during late morning. The batteries discharged from about 17:15 and by about 20:30 reached maximum discharge (just over 80% DOD). After that the overnight demand from the grid for the communal area was typically just over 700W.

The 'Batteries' section of the SolaX monitoring portal allows the charge and discharge cycles of the battery to be monitored (Figure 2.9). The charged capacity of the battery is show in green, starting at 16% overnight and increasing to 100% by 1pm after charging from the solar panels. The power into and out of the battery in watts (W) is shown in red. When it is charging it is positive (e.g. peaks at 09:00 – 10:00 and 12:00 to 13:00), when it is discharging it is negative (e.g. minima at 10:15 to 11:00). The voltage in blue is normally fairly consistent at 48 to 51V, while the current in orange broadly follows the power and is negative when discharging and positive when charging.

Among the data recorded by the SolaX X-hybrid inverter is:

- PV current, voltage and power for both strings of the solar array
- Feed-in power (electricity grid import or export)
- 'Power Now' – the output from the inverter at that time
- 'Today's Energy' - energy output by the inverter that day (in kWh)
- 'Total Energy' – energy output by the inverter since installation

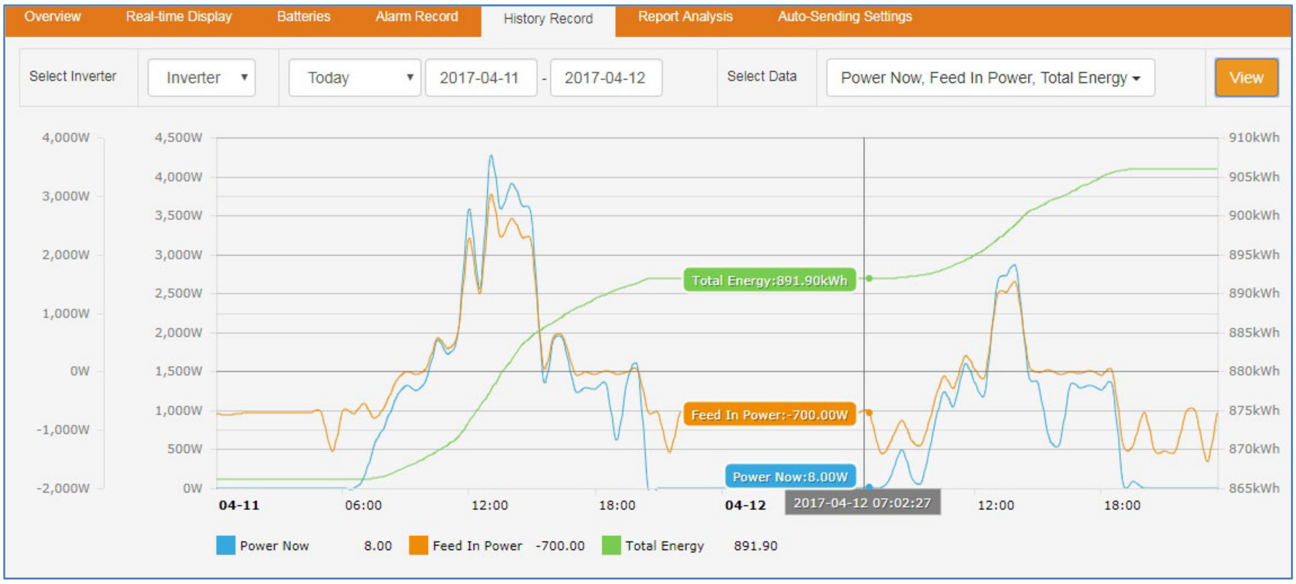

Figure 2.10 ‘History Record’ section on the SolaX monitoring portal – 11 April – 12 April 2017

Using the ‘History Record’ section on the portal it is possible to generate plots from the raw data for each of these variables. Figure 2.10 shows a plot with ‘Power Now’, ‘Feed-in Power’ and ‘Total Energy’.

Using the ‘Report Analysis’ section, it is possible to download raw data from the portal in the form of a CSV file. In addition to all the variables which can be plotted on the ‘History Record’, the data available includes information about the battery such as the voltage, current, power, inner temperature and remaining capacity.

The data provided does not include the cumulative charge and discharge from the battery in kWh. When the battery is discharging the battery power is negative and when it is charging it is positive. An approximate value for the total discharge over a period can be obtained by multiplying the battery power by the time interval between readings (5 minutes) and summing all the negative values. Likewise the cumulative power that has charged the battery can be obtained by summing all the positive values after multiplying the battery power by the time interval.

The above technique was used for determining the battery charge and discharge in kWh during the monitoring period. The ‘Feed-in Power’ data stream from the SolaX inverter provides the electricity import or export on the phase of the electricity supply that the inverter is connected. The analysis method used for the battery charge and discharge was also used on the ‘Feed-in Power’ data stream to obtain the cumulative import and export over the monitoring period.

At most of the sites there was a poor WIFI signal between the hybrid inverters and the router and it was necessary to install WIFI extenders to expand the signal. As a result of these WIFI problems, there were gaps in the data available.

2.3 Factors affecting the evaluation methodology

Project scope variation	The original scope of the project was wider but this scaled back trial was agreed and the evaluation methodology revised.
Delays in scheduled installation dates	The first battery unit was installed in January 2016 and the last in November 2016. The later installation at Llys Ton limited the duration of the study and reduced the data available.
Solar array shut down	The solar array at Hafan Deg was taken offline between 8th March and 8th May 2017, while an external refurbishment project was undertaken.
WIFI connection for SolaX inverters	The WIFI connection between the hybrid inverters and the routers at all sites was poor and it was necessary to install WIFI extenders to expand the signal.
Reduced data from the SolaX portal	Data was not available from the SolaX web portal for the periods when arrays were off line, WIFI routers were turned off or when there was no connection between the SolaX hybrid inverter and the WIFI router. This meant that data was only available for Dinam Close, Llys Cynffig and Treharne Row from March 2017 and a few days of data per month might be missing for some sites.
Measurement of charge and discharge of battery	It was only possible to estimate the charge and discharge of the batteries based on the input/output power of the battery recorded every 5 minutes in data uploaded to the SolaX web portal. This could not be done over periods where no data was available.
Analysis of charge and discharge of battery	While the inverter transmitted data every 5 minutes, occasionally data points were not recorded on the portal or there was a duplicate reading with the same time or the time period between data points changed. Although it was not possible to compensate for occasional missing data points, duplicate lines where the same time and data was recorded were deleted.
Charge and discharge cycle	The batteries had a typical charge and discharge pattern during the day. To ensure the calculations included the full charge and discharge of the battery, only days where there was data from midnight to midnight were assessed. Also days where more than 10% of the data points were missing during the day were typically ignored in the assessment.

3 Technical evaluation and results

3.1 Dinam Close

Figure 3.1 Satellite photo of Dinam Close showing the 11.14 kW solar PV array

A satellite photo of the property at Dinam Close is shown in Figure 3.1. There were 33x 265W panels on the roof facing south east and a further 9 on an adjacent roof facing south west. The annual generation from 1 Feb 2016 to 1 Feb 2017 was 7807 kWh. Although most of the solar PV arrays in the study were of a similar size, the annual generation was the second lowest of the sites in the study due to shading from other parts of the building, trees and the building across the courtyard. It was not possible to make a worthwhile estimate of expected annual generation due to complications of assessing the shading from photographs.

Although the solar PV system was installed in January 2016 and the battery unit in March 2016, the system was not connected to the SolaX monitoring portal until 9th March 2017. Detailed data was therefore only available from when the portal was up and running. The WIFI connection was good and so few data points were lost during this monitoring period.

Values of the grid import and export as well as the battery charge and discharge in kWh were calculated from the SolaX monitoring portal data assuming that the instantaneous value was constant for the 5 minute duration until the next reading (as discussed in section 2.2). In practice the time interval between data points occasionally differed from 5 minutes. The error due to this was reduced by taking into account the number of data points when calculating the values of kWh / day. Table 3.2 shows values of grid import and export which were obtained from the ‘Feed In Power’ data stream from the SolaX monitoring portal.

Month	Grid import (kWh/day)	Grid export (kWh/day)	Average grid import, 12am - 6am (Watts)	SolaX inverter generation (kWh/day)	Full PV system generation (kWh/day)
Mar-17	10.25	4.45	733.3		18.3
Apr-17	5.58	9.13	604.4	17.8	34.7
May-17	5.15	10.30	462.5	18.4	36.3
Jun-17	4.60	7.06	369.5	15.1	
Jul-17	4.19	8.06	372.7	15.9	

Table 3.2 Grid import/export and solar generation at Dinam Close

There were different solar PV inverters connected to each of the 3-phases of the mains supply for the communal area at Dinam Close. The SolaX X-hybrid inverter was one of these and generated about half of the total electricity from the full system (as seen in April and May 2017). The electricity exported to the grid on the phase connected to the SolaX X-hybrid inverter was between 46.6% and 55.9% of that generated by that inverter.

The mains supply for the communal area mainly powered the laundry and communal lighting. The consumption for appliances connected to the same phase as the SolaX X-hybrid inverter decreased from 10.25 kWh / day in March to 4.19 kWh / day in July 2017.

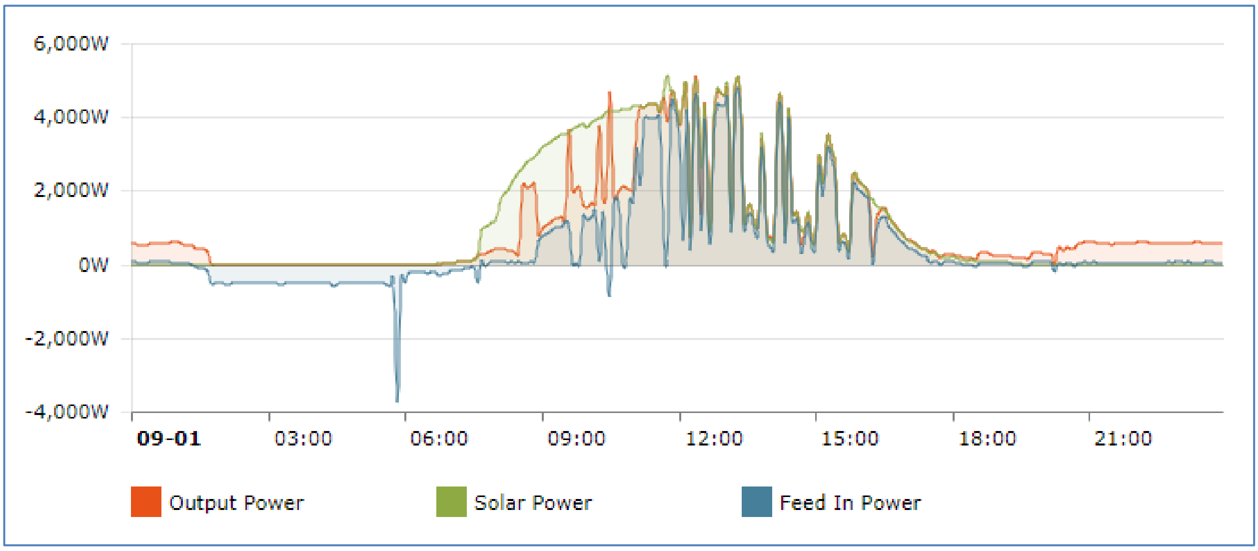

Figure 3.3 Plot showing data from the SolaX portal for the system at Dinam Close on 1 September 2017

A plot showing data from 1st September 2017 for the SolaX X-hybrid inverter system at Dinam Close is shown in Figure 3.3. When the Feed In Power (blue line) is negative, the phase of the mains supply connected to the SolaX X-hybrid inverter is importing electricity and when it is positive it is exporting. The green line shows the generation from the solar panels connected to the SolaX X-hybrid inverter. When the Output Power (orange line) is less than the solar power, the battery is charging and when the output power is greater than the solar power, the battery is discharging.

On 1st September nearly all the electricity import occurred overnight with a baseload of about 500 to 550W. There was also a spike in consumption at 05:50 where the demand increased to 3.75kW. During the day, nearly all the demand for the communal supply is provided by the solar PV system.

The morning of September 1st was a particularly sunny and this enabled the battery to charge up. At 10.30, there was an increase in electricity demand which required just over 800W of electricity to be supplied by the grid. However at this time the battery was also supplying about 550W, which reduced the amount required from the grid. In the evening as the generation from the solar PV system decreased, the battery supplied 550 – 600W from about 20.30 to 01:30, ensuring that electricity did not have to be supplied by the grid over this period.

During the evaluation, NEA staff noticed that the portal for Dinam Close had been set up with the incorrect time zone and the time was out of synchronisation by 12 hours. This issue was corrected by SolaX technical support during August 2017. Figure 3.4 shows a plot from the SolaX portal with data for 17 April 2017. It can be seen that the graphs have been displaced by 12 hours due to the time zone issue. Apart from this, the graph has the same characteristics as Figure 3.3. There is charging of the battery in the morning. Peaks in electricity demand were reduced during the day and early evening due to output from the battery. The battery discharged at a fairly steady rate until about 11pm, ensuring there was little or no import required from the electricity supply. In the late afternoon and early evening there were periods where demand was higher and the battery supplied up to 2 kW. As a result, the battery was depleted earlier in the evening that on 1st September. It should be noted that the maximum charge or discharge rate between the battery and SolaX hybrid inverter is 2.5 kW.

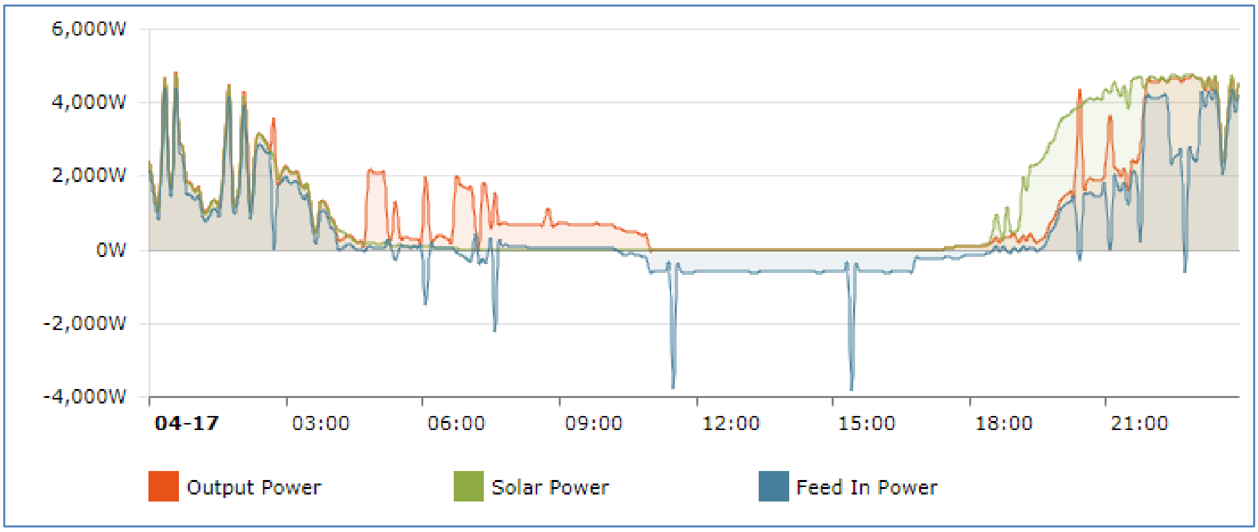

Figure 3.4 Plot showing data from the SolaX portal for the system at Dinam Close on 17 April 2017

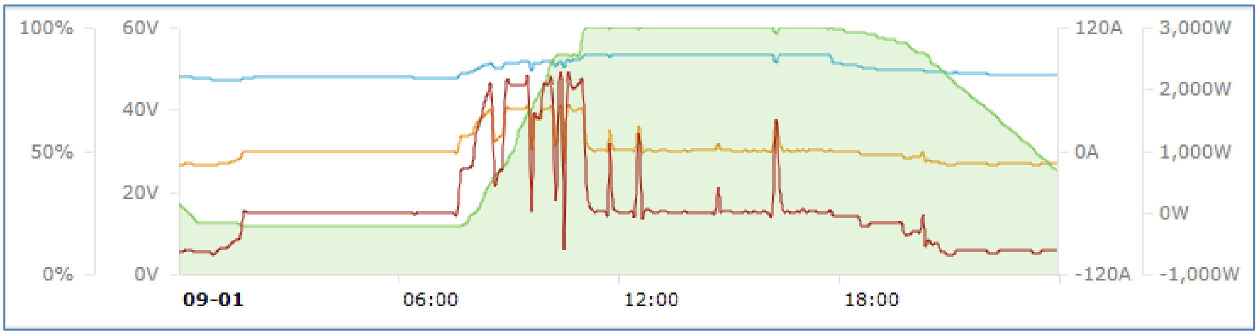

Figure 3.5 Plot showing performance of the battery at Dinam Close on 1st September 2017

The performance of the battery on 1st September 2017 is shown in Figure 3.5. The state of charge of the battery is shown in green, the battery power in red, the current in orange and the battery voltage in blue. In the morning the battery had 19% charge remaining (near 80% depth of discharge, DOD). The battery began charging at 7.45am and the battery charge capacity increased steadily until about 10.30 am when it was fully charged. During this period, the power input to the battery went up to about 2 kW and the current input was up to nearly 40A. The battery started discharging from about 7pm, with an output of about 175 W. The power line in red, dropped further to an output of about 600 W from about 8.30 pm. There was 48% of the charge remaining in the battery at 11.30 pm. Over-night, while the battery was at about 80% DOD, the voltage was approximately 47.8 V and this increased to about 53.4V when fully charged.

Table 3.6 shows the battery output and input determined from the battery power readings provided by the data from the SolaX web portal. The readings for March were based on data between 9th and 31st March 2017. In practice, the interval between readings was sometimes less than 5 minutes. The values in kWh /day compensated for the number of data points per month.

The battery output determined from the SolaX data ranged from 2.94 kWh per day in March 2017 to 4.79 kWh per day in April 2017. There are some losses when charging a battery and the charging efficiency is indicated by the ratio of the battery output divided by the battery input. For Lithium Iron Phosphate batteries, the round trip efficiency is normally about 92%[17] [18].

On a sunny day, a battery storage system using Lithium ion batteries will normally fully charge during the day and supply power back to the household in the afternoon/evening down to about 80% depth of discharge. For a 4.8 kWh battery going from fully charged to 80% depth of discharge and taking into account the battery efficiency, the system might output 3.53 kWh based on a single charge and discharge cycle. On cloudy days, the battery may not fully charge and so the average kWh/day is likely to be less.[19] However, where there is suitable demand and generation, the batteries can charge during the morning and discharge at times during the day when generation drops and recharge when it increases again. A final discharge would occur later in the afternoon / evening after the solar generation dropped off. This allows more than 1.0 charge / discharge cycles per day and may account for the high battery outputs in Table 3.6.

Month	Battery output (kWh)	Battery input (kWh)	Output / input (%)	Battery output (kWh/day)	Battery input (kWh/day)
Mar-17	67.5	75.9	88.9%	2.94	3.30
Apr-17	143.8	158.3	90.8%	4.79	5.27
May-17	131.3	146.3	89.8%	4.22	4.70
Jun-17	137.6	140.4	98.0%	4.47	4.56
Jul-17	146.7	156.5	93.8%	4.63	4.94

Table 3.6 Battery input and output for the SolaX / Pylontech system at Dinam Close

[17] Lithium Iron Phospate battery data sheet, Wattstor, http://wattstor.com/wp-content/uploads/2016/03/Lithium-Iron-Datasheet.pdf (Accessed 4 September 2017)

[18] Lithium Batteries – a technical overview, Energy Solutions http://energy-solutions.co.uk/news/article/lithium-batteries-a-technical-overview-of-lithium-batteries-and-the-benefit (Accessed 4 September 2017)

[19] Carbon Commentary (2014), https://www.carboncommentary.com/blog/2014/10/17/domestic-batteries-to-store-excess-pv-and-reduce-peak-demand-loads (Accessed 4 September 2017)

3.2 Ger Y Nant

Figure 3.7 Satellite photo of Ger Y Nant showing the south facing 11 kW solar PV array

The 2 south facing solar PV arrays at Ger Y Nant are shown in Figure 3.7. A comparison of the annual generation from the system with estimates of the generation produced by different methods is shown in Table 3.8. Between 1 January and 31 December 2015, the solar PV array generated 8,876 kWh. During April 2016 the original 3 phase inverter at Ger Y Nant was replaced with 2 x Trannergy 2700 single phase inverters and the SolaX X-hybrid inverter. The different inverters may partly explain the decrease in annual generation to 7,939 kWh between June 2016 and June 2017, but natural variation in generation between years is likely to also be a factor

The impact of shading was not assessed when making the estimates for annual generation as this was difficult to judge based on just photographs. There is likely to be shading on the more northerly array from the roof to the south and both will be affected by shading from the roof to the west. This is likely to explain why the estimates were significantly greater than the actual generation.

Between 1 August 2016 and 1 August 2017, the 5kW SolaX inverter generated 3988 kWh, making up about 50% of the generation from the system.

Dates	Annual generation for full array (kWh)	Annual generation MCS method (kWh)	Annual generation PV Sol (kWh)	Annual generation PVGIS Classic (kWh)	Annual generation PVGIS Climate SAF (kWh)
		10,439	-	9,950	11,900
1 Jan 15 - 1 Jan 16	8,876				
1 Jun 16 - 1 Jun 17	7,939				

Table 3.8 Annual solar generation and estimates for annual solar generation at Ger Y Nant

Stable data was obtained from the SolaX portal for the period from the mid-April 2016 until the end of September 2016. Over this period there were negligible gaps in the data. After that the data quality deteriorated with no full days of data in October and only 3 and 7 in November and December. In January and July there were 18 full days of data in each, with fewer than 10% of the data points missing for each day.

Table 3.9 shows the grid import and export for the phase of the mains supply to which the SolaX X-hybrid inverter was connected. It is apparent that the electricity demand was considerably higher than at Dinam Close (Table 3.2). Although the generation from the solar PV system was comparable to Dinam Close, the grid export was negligible due to the high electricity demand. The electricity supply to the communal area powered a lift, laundry and communal lighting.

Figure 3.7 shows a plot from the SolaX monitoring portal for Ger Y Nant on 4 May 2016, which was a particularly sunny day. Overnight, the electricity demand was between 2750 and 2925 W. The solar PV generation increased in the morning and by 09:00 no electricity import was required and the excess solar demand could charge the battery. At 16:45, the solar generation began to drop off and the battery discharged until about 19:00, reducing the grid import required. Figure 3.7 shows the performance of the battery which discharged more rapidly than in figure 3.4 at Dinam Close.

Month	Grid import (kWh/day)	Grid export (kWh/day)	Average grid import, 12am - 6am (Watts)	SolaX inverter generation (kWh/day)	Full PV system generation (kWh/day)
Apr-16	85.0	0.2	3,892.6		19.6
May-16	43.1	0.6	2,311.0	18.8	38.3
Jun-16	33.7	0.7	2,178.2	15.8	32.2
Jul-16	28.8	1.2	1,437.8	16.0	32.7
Aug-16	31.0	1.4	1,605.6	15.5	31.3
Sep-16	32.5	0.7	2,358.9		23.3
Jan-17	52.3	0.01	2,139.6		6.4
Jul-17	31.1	0.9	1,588.3		

Table 3.9 Grid import/export and solar generation at Ger Y Nant

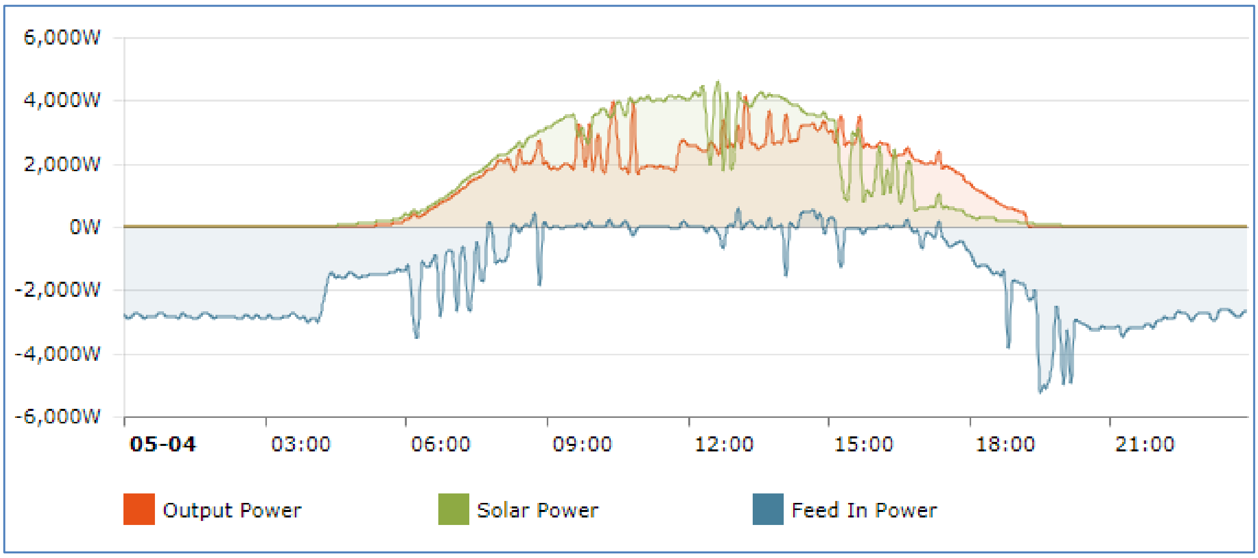

Figure 3.10 Plot showing data from the SolaX portal for the system at Ger Y Nant on 4 May 2016

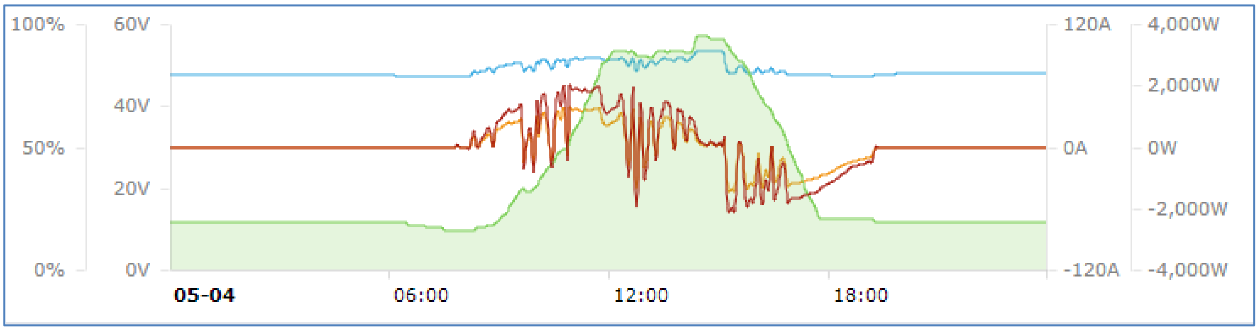

Figure 3.11 Plot showing performance of the battery at Ger Y Nant on 4 May 2016

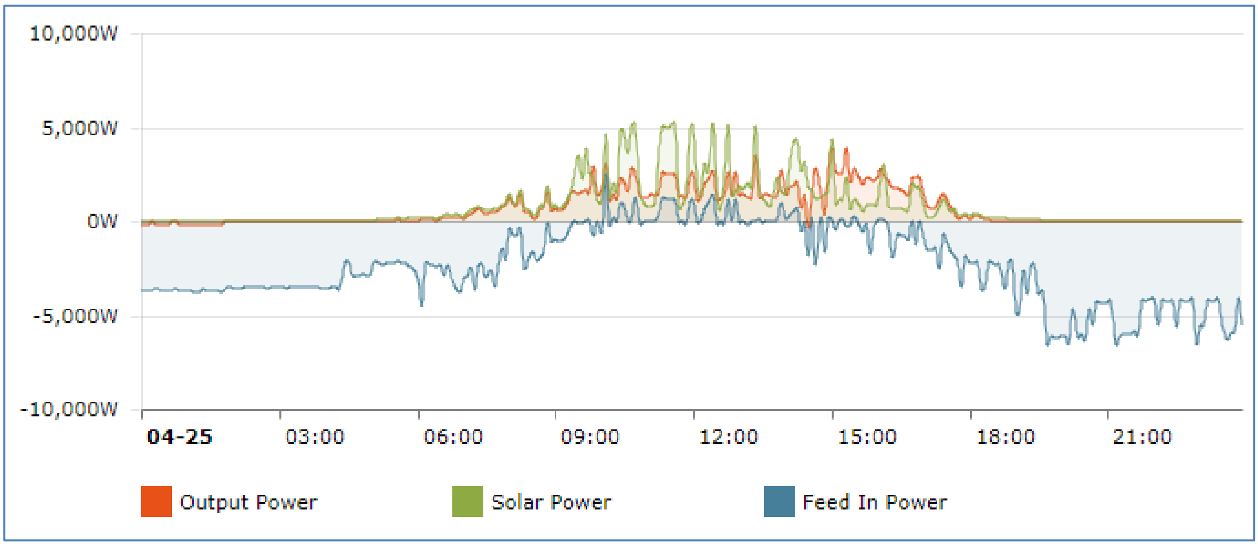

Figure 3.12 Plot showing data from the SolaX portal for the system at Ger Y Nant on 25 April 2016

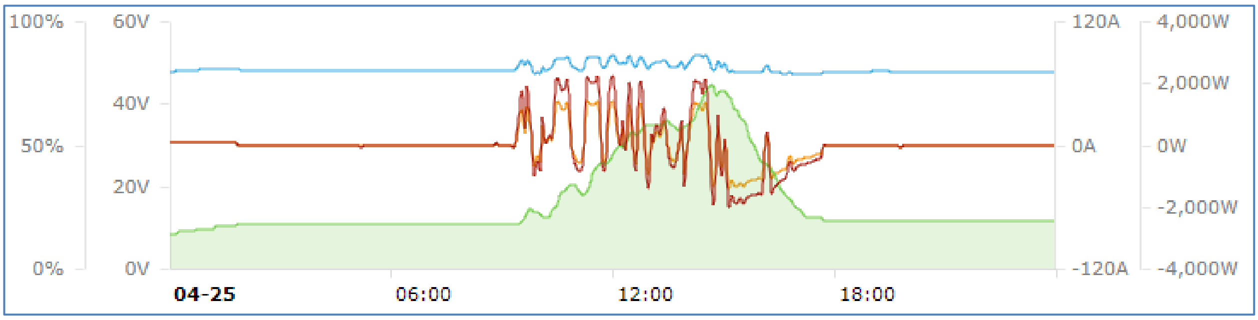

Figure 3.13 Plot showing performance of the battery at Ger Y Nant on 25 April 2016

Figure 3.12 shows a plot from the SolaX portal from 25 April 2016. The grid import baseload overnight was 3,550W to 3,750W (see blue line). The PV generation increased during the day, which reduced the grid import and allowed the battery to charge. However there were times when the solar generation dropped during the day and the battery switched from charging to discharging to avoid the need for electricity import from the grid. This occurred from 15:00 to 17:30 and it was necessary for the battery to discharge to limit grid imports. The battery had only charged to 72% of capacity by 14:30 and subsequently discharged to about 20% of capacity (80% DOD) at 17:30.

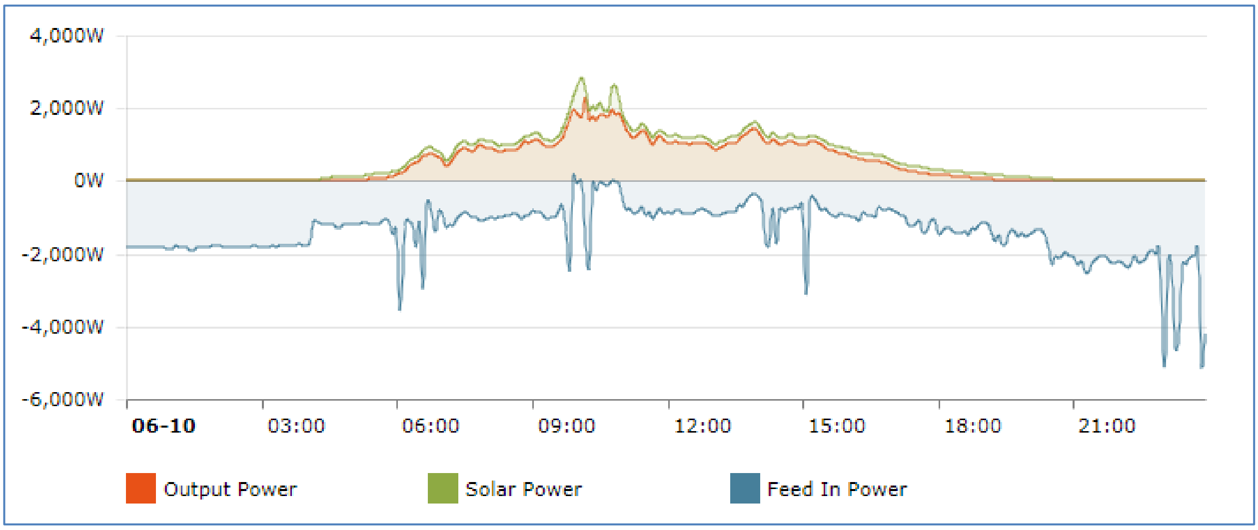

Figure 3.14 Plot showing data from the SolaX portal for the system at Ger Y Nant on 10 June 2016

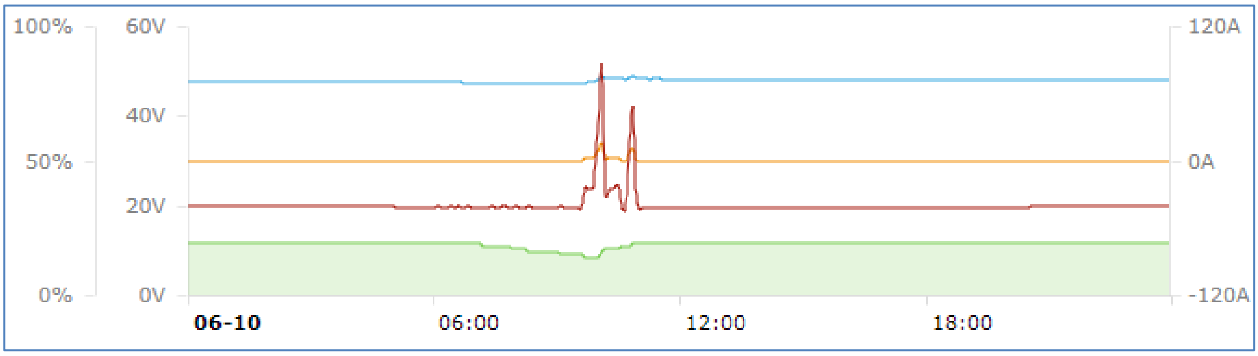

Figure 3.15 Plot showing performance of the battery at Ger Y Nant on 10 June 2016

Figure 3.14 shows that on 10th June 2016, there was less generation from the solar PV system than in the previous 2 examples. The generation was only sufficiently high for a short period at 10:00 that there was export to the grid and the battery was charging (Figure 3.15). The previous day had been sunnier and the battery was depleted in the evening to 80% DOD. On the morning of 10th June it had a charge level of about 20% and it was not possible to recharge the battery during the day as the demand from the appliances was at or greater than the generation from the solar PV system.

Table 3.16 provides details of the performance of the batteries at Ger Y Nant as determined from the SolaX web portal data. The round trip charge and discharge efficiency determined by this method was again typically of the order of 92% as would be expected. In January 2017 it was 77.5%, but there was little charging of the battery that month and there were losses due to the charge decreasing over time and consumption by the Pylontech battery management system.

In January 2017, when the solar generation was very low, there was rarely enough generation to meet demand let alone charge the battery. As a result the average battery output per day was low. For the period April to September 2016, the lowest battery output (in kWh/day) was in April 2016, which had the lowest solar generation out of these months (Table 3.9). For the other months, there was not a simple relationship between solar generation, grid import and battery output.

Month	Battery output (kWh)	Battery input (kWh)	Output / input (%)	Battery output (kWh/day)	Battery input (kWh/day)
Apr-16	18.7	20.0	93.77%	1.26	1.34
May-16	101.2	113.6	89.04%	3.25	3.65
Jun-16	71.1	77.5	91.77%	2.35	2.57
Jul-16	104.7	112.9	92.66%	3.36	3.62
Aug-16	103.4	112.8	91.68%	3.33	3.63
Sep-16	75.9	83.8	90.54%	2.61	2.89
Jan-17	5.3	6.9	77.48%	0.30	0.39
Jul-17	47.2	51.9	91.02%	2.64	2.91

Table 3.16 Battery input and output for the SolaX / Pylontech system at Ger Y Nant

3.3 Hafan Deg

Figure 3.17 Satellite photo of Hafan Deg showing the south west facing 11.0 kW solar PV array

The Hafan Deg sheltered housing scheme is shown in the satellite photo in Figure 3.17, with the solar PV array apparent on the south west facing roof. Table 3.18 shows values for the annual generation from the solar PV array and estimates of the generation. The measured generation between 2016 and 2017 ranged from 9,330 kWh to 9,507 kWh. This is significantly higher than for Dinam Close and Ger Y Nant. Despite the PV array at Hafan Deg being orientated further away from south than those for Dinam Close and Ger Y Nant, the generation was higher due to a lack of shading on the PV array.

Since there was no shading of the PV array at Hafan Deg, it made estimating the annual generation easier and more accurate. The MCS method used the size of the array (in kW) and a value of kWh/kW_p taken from a table for South Wales with different values for different angles of orientation and inclination. The estimate with the PV Sol software used details of the inverters and panels installed and climate data for Severn-Wales (SAP 2012).

Dates	Annual generation for full array (kWh)	Annual generation MCS method (kWh)	Annual generation PV Sol (kWh)	Annual generation PVGIS Classic (kWh)	Annual generation PVGIS Climate SAF (kWh)
		9,581	9.893	9,080	10,100
1 Jan 16 - 1 Jan 17	9,459				
1 Feb 16 - 1 Feb 17	9,507				
1 Mar 16 - 1 Mar 17	9,330				

Table 3.18 Annual solar generation and estimates for annual solar generation at Ger Y Nant

While the MCS method was the simplest, it produced the most accurate estimates for this system in Maesteg near Bridgend. The estimate using the PVGIS 'Classic' database based on ground station measurements was too low. Using the more recent PVGIS Climate SAF database based on satellite data produced too high an estimate. The estimate from PV Sol was in between that made using the MCS method and PVGIS Climate SAF database.

The solar PV system was installed in October 2015 and the battery system fitted in January 2016. The system was connected to the SolaX portal from 23rd March 2016. An example of how the system was performing on a sunny day is shown in Figure 3.13 with data from 4 May 2016. The baseload power consumption overnight was about 1,100 W. The solar PV system began generating electricity after 06:00 and by 09:00 the solar array was supplying the appliances and charging the batteries. By 13:00 the batteries were fully charged (Figure 3.20). The output from the solar PV system dropped off from 18:45 and the batteries were supplying up to 1,100W until 23:50 when they had reached 80% DOD.

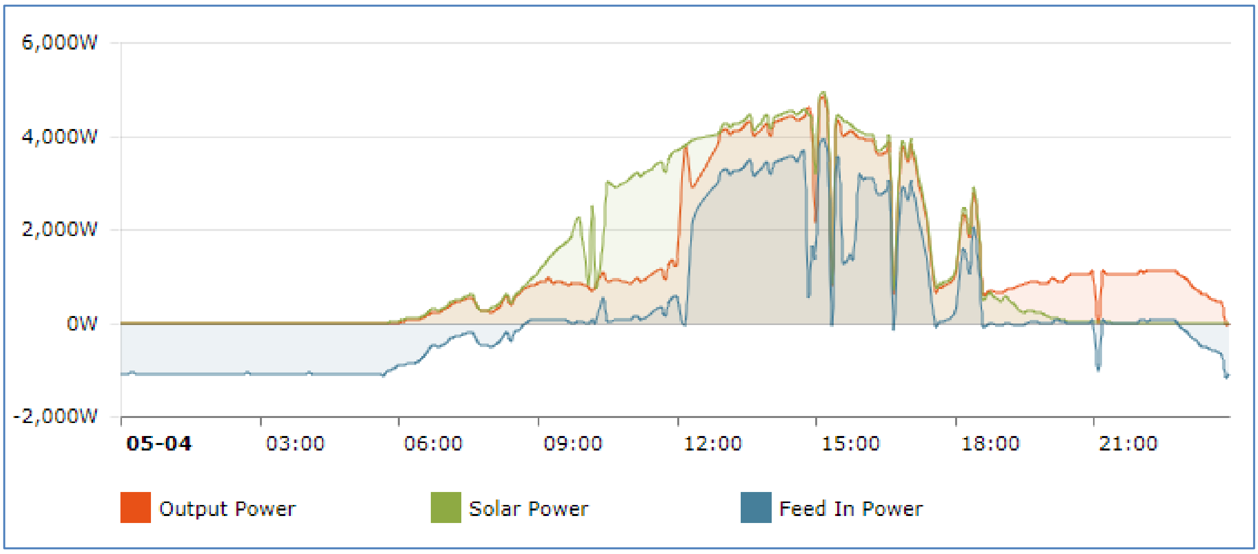

Figure 3.19 Plot showing data from the SolaX portal for the system at Hafan Deg on 4 May 2016

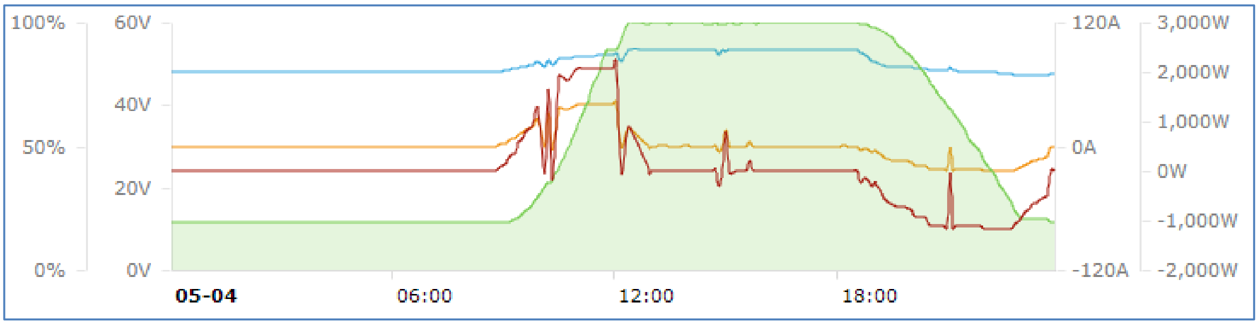

Figure 3.20 Plot showing performance of the battery at Hafan Deg on 4 May 2016

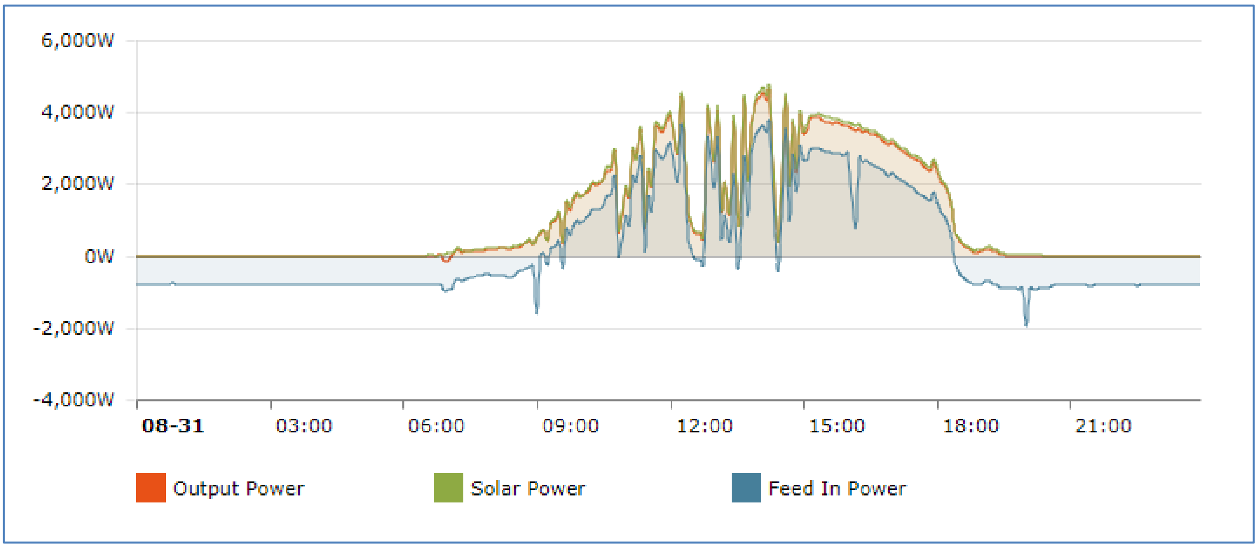

Figure 3.21 Plot showing data from the SolaX portal for the system at Hafan Deg on 31 August 2017

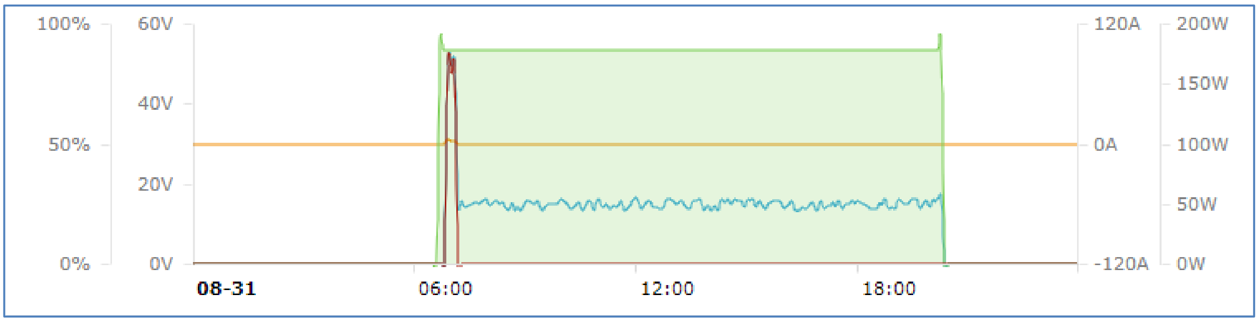

Figure 3.22 Plot showing measurements from the battery at Hafan Deg on 31 August 2017

The system developed a fault on 20th May 2016. Figure 3.21 shows the plot from the SolaX portal for 31 August 2017. Since there was no difference between the line for the output power (in orange) and the solar power (in green) throughout the day, it showed that the battery was not charging or discharging.

The plot with the battery performance was also anomalous after 20th May 2016. In the example from 31 August 2017 in Figure 3.22, the battery charge was at 0% when the solar PV array was not generating and at 89% at other times. The battery power showed a small spike in power to 182 W just after the solar PV array started generating and was at 0 W at other times. For comparison, in Figure 3.14, the battery power varied between 2,081 W and -1,166 W. After the fault, the battery current remained at 0 A, apart from a small increase to 3.7 A when the battery power increased after the solar array started generating. On 4 May 2016, the battery voltage was between 48 V and 53.5 V. On 31 August 2017, after the fault developed, the battery voltage was between 13.5 and 16 V when the solar array was generating and at 0 V at other times.

Although the solar PV system continued to generate after the fault developed, the battery system was of no benefit to the building. As a result, further analysis of the battery system at the site was not carried out.

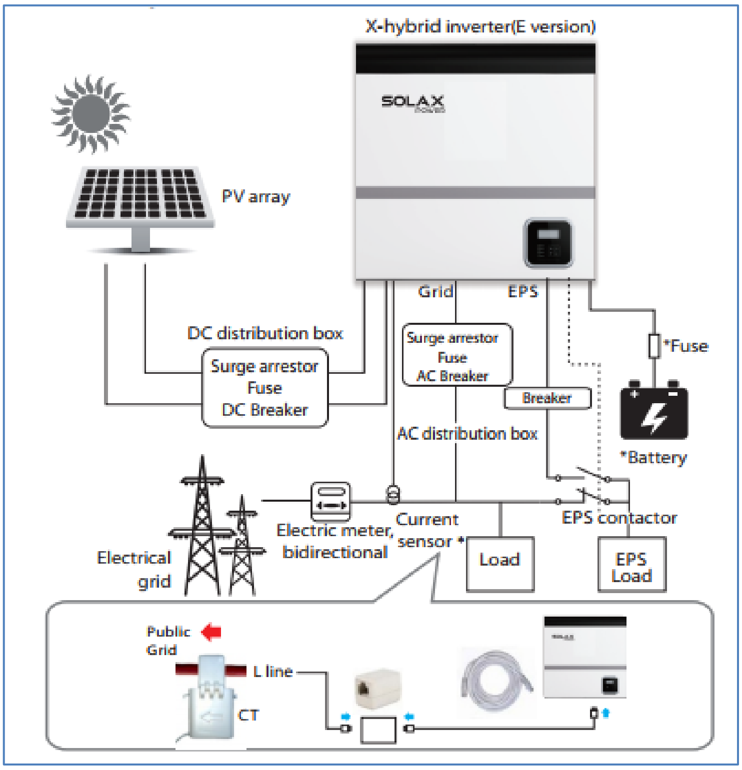

Figure 3.23 Schematic diagram showing the connections for the SolaX X-hybrid inverter[20]

It is possible that the fault that developed with the Hafag Deg system was due to a loose connection for sensor cabling to the battery or for the current sensor monitoring the grid input. (Figure 3.23). While there would be errors if the current sensor failed, it is rare for such failures to occur, making a loose connection or moved cable more likely.

3.4 Llys Cynffig

Figure 3.24 Satellite photo showing the south facing 11.0 kW solar PV array at Llys Cynffig

[20] SolaX X-Hybrid Series User Manual http://www.solaxpower.com/wp-content/uploads/2017/01/X-Hybrid-Install-Guide.pdf (Accessed 4 September 2017)

The solar PV array at Llys Cynffig is shown in Figure 3.24. It is south facing and there was no shading. Accurate estimates of the annual generation could be made from photographs and these are shown in Table 3.25. Once again the value calculated by the MCS method was the most accurate. Figure 3.26 shows a plot of monthly generation from the whole PV array at Llys Cynffig during 2016 and 2017, compared to the prediction by PVSol.

Dates	Annual generation for full array (kWh)	Annual generation MCS method (kWh)	Annual generation PV Sol (kWh)	Annual generation PVGIS Classic (kWh)	Annual generation PVGIS Climate SAF (kWh)
		10,439	10,787	9,970	11,900
1 Jan 16 - 1 Jan 17	10,573				
1 Mar 16 - 1 Mar 17	10,507				
1 Jun 16 - 1 Jun 17	10,175				

Table 3.25 Annual solar generation and estimates for annual solar generation at Llys Cynffig

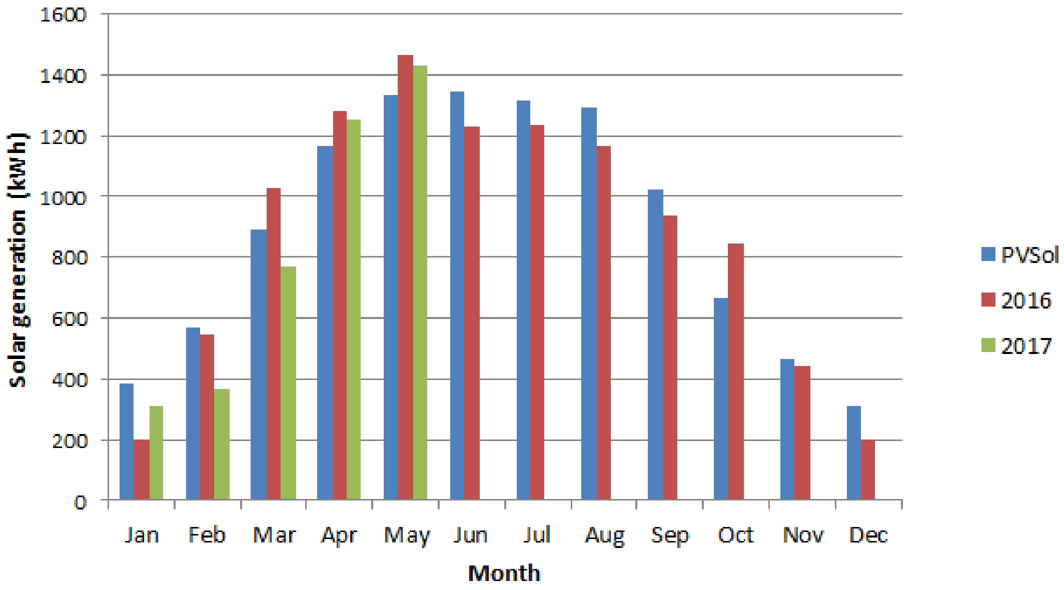

Figure 3.26 Monthly solar generation for 11kW solar PV array at Llys Cynffig

The solar PV system was installed in October 2015 and the battery system was installed in April 2016. The system was connected to the SolaX monitoring portal in March 2017. The system had been set up with the incorrect time zone, which led to the same problem as for Dinam Close where plots of data were displaced by 12 hours. NEA staff informed the SolaX technical team about this problem and this setup error was corrected.

Figure 3.27 shows a plot of data from the SolaX inverter for Llys Cynffig on 2 September 2017. There was a base load of about 4,000 to 4,100 W overnight, with a couple increases in demand which took consumption to about 6,300 W. As generation from the solar PV system increased, import from the grid decreased. For much of the time between 11:00 and 14:00 the solar generation was sufficiently high that electricity was exported to the grid. As for Hafan Deg after the fault developed, there was no difference between the lines for Output Power and Solar Power throughout the day. This indicated that the battery was not charging or discharging despite there being grid export in the middle of the day.

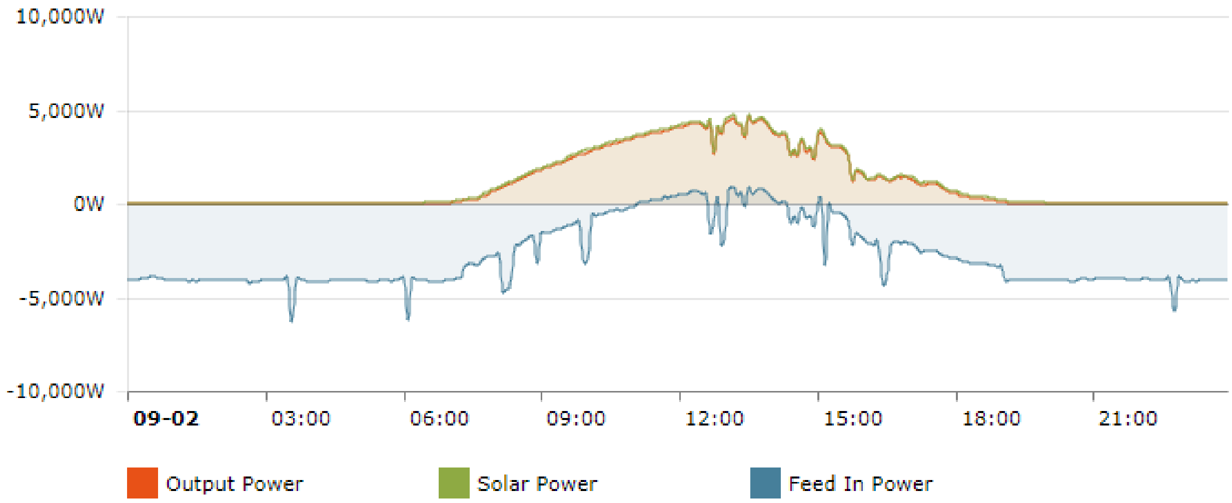

Figure 3.27 Plot showing data from the SolaX portal for the system at Llys Cynffig on 2 September 2017

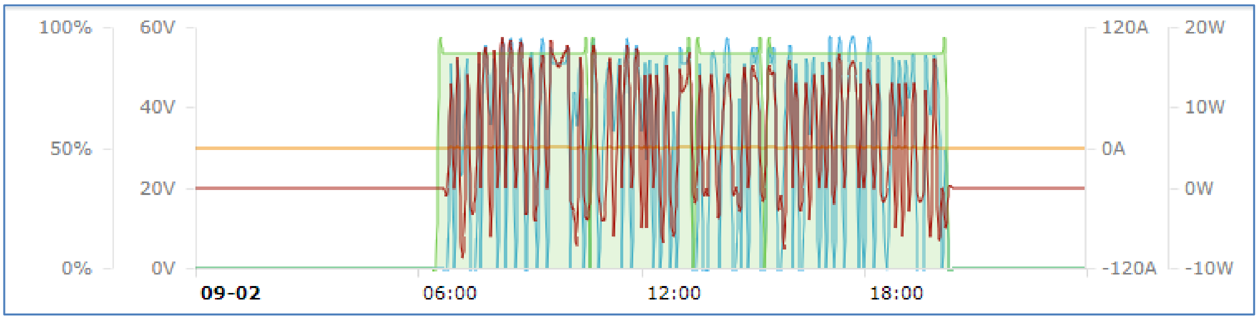

Figure 3.28 Plot showing measurements from the battery at Llys Cynffig on 2 September 2017

Figure 3.28 shows a plot of readings from the batteries at Llys Cynffig on 2 September 2017. Here the Power output varied between about 16 W and -6 W when the solar PV array was generating and was zero when it was not. In a similar manner, the battery voltage varied between 0V and 51V while the array was generating. Although such a graph was typical for plots of battery readings at Llys Cynffig, it was quite different to the normal performance of batteries shown in Figures 3.5, 3.8 and 3.15.

It is likely that there was another connection fault with this system which meant the SolaX inverter was not receiving the appropriate inputs for the energy management system to operate correctly. It is possible that this issue occurred during installation and that the battery system has never operated correctly at Llys Cynffig. As a result no further assessment of the performance of the batteries at the site will be included.

3.5 Llys Ton

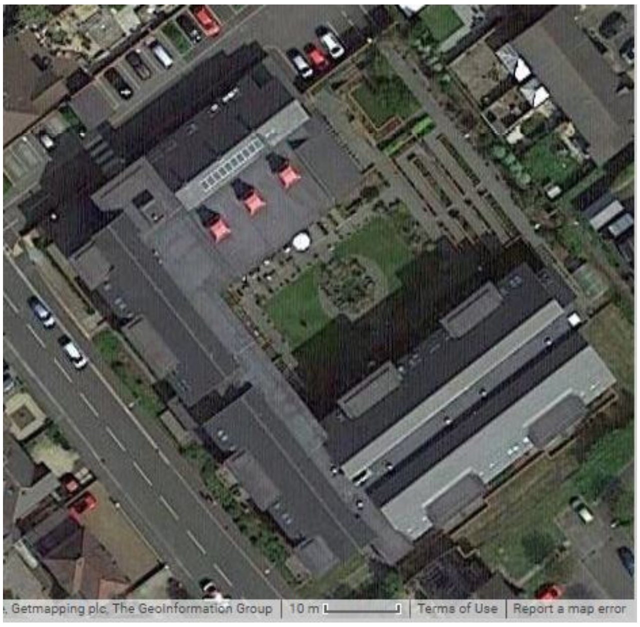

Figure 3.29 Satellite photo of Llys Ton Extra Care Scheme showing the original 2.2kW solar PV array

The original 2.2 kW solar PV array at Llys Ton can be seen in Figure 3.29 on the pitched roof near the 3 red features on the flat roof. The annual generation between June 2015 and June 2016 was 2,098 kWh and between August 2015 and August 2016 it was 2,000kWh.

During November 2016, the array was extended to 5.6kW and the previous inverter was replaced with a SolaX SK-SU5000E X-hybrid inverter. The system was operational again on 25th November 2016. Further details on the PV extension were not available and so it was not possible to make an estimate of the annual generation. The extended system had not been operating for more than a year at the time of writing and so a value for the annual generation based on meter readings could not be provided.

Table 3.30 shows that between 1 Dec 2016 and 1 Jun 2017 the extended array generated 1799.46 kWh as measured by the Orsis generation meter. Since the extended array used only a SolaX hybrid inverter, readings of the total generation recorded by the inverter and available on the SolaX portal could be compared with the Orsis generation meter. Between 1 Dec 2016 and 1 Jun 2017 the SolaX inverter recorded a generation of 1852.5 kWh, a difference of 2.95%. The generation recorded by the SolaX X-hybrid inverter between 1 December 2016 and 1 September 2017 was 3638.7 kWh. It should be noted that the SolaX SK-SU5000E was a single phase inverter and so the solar PV array and battery storage system was fitted to just 1 of the 3-phases of the mains supply.

Dates	Solar generation Orsis meter (kWh)	Solar generation SolaX inverter (kWh)
1 Dec 2016 - 1 Jun 2017	1799.46	1852.5
1 Dec 2016 - 1 Sep 2017		3638.7

Table 3.30 Recorded generation from the 5.6 kW solar PV array at Llys Ton

Month	Grid import (kWh/day)	Grid export (kWh/day)	Average grid import, 12am - 6am (Watts)	SolaX inverter generation (kWh/day)	Full PV system generation (kWh/day)
Jan-17	20.6	0.0	610.2	3.11	2.93
Feb-17	17.1	0.2	595.0	4.96	
Mar-17	14.7	1.8	694.9	10.10	
Apr-17	11.2	4.6	743.8	18.30	18.20
May-17	10.0	8.6	795.4	21.23	21.05
Jun-17	10.0	6.5	682.8	19.73	
Jul-17	10.9	7.3	827.8	20.58	
Aug-17	10.1	5.9	769.1	18.60	

Table 3.31 Grid import/export and solar generation at Llys Ton

Good quality data was transmitted to the SolaX monitoring portal from the inverter at Llys Ton from the date of the installation. Table 3.31 shows details of the grid import and export and SolaX generation determined using data from the monitoring portal.

While the average grid import was 20.6 kWh/day in January 2017, during April to August 2017 it was between 10 and 11 kWh/day. The electricity demand for the phase of the electricity supply where the solar PV system was connected at Llys Ton was lower than for Ger Y Nant, but higher than for Dinam Close. The period of lower grid import at Llys Ton corresponded with the months with higher solar generation. At Ger Y Nant there was less than 10% export from the solar PV system during the summer due to the high electricity demand. In contrast the maximum export from the solar PV system at Llys Ton was 40.5% and 55.9% at Dinam Close in May 2017.

Figure 3.32 shows a plot from the SolaX monitoring portal for the system at Llys Ton on a fairly sunny day on 28 February 2017. Between midnight and 07:00, the electricity import was about 560W. By 07:20 the demand had increased to 1,265W. However the solar generation increased from 07:00 and by 08:30 it sufficiently high that the battery was charging and electricity was briefly exported to the grid. The battery was also charging at 10:45 and between 13:30 and 14:30 when there were higher levels of solar generation. From 13:00 to 17:00 there was little import for the grid due to solar generation, and when that dropped, due to discharge of the battery.

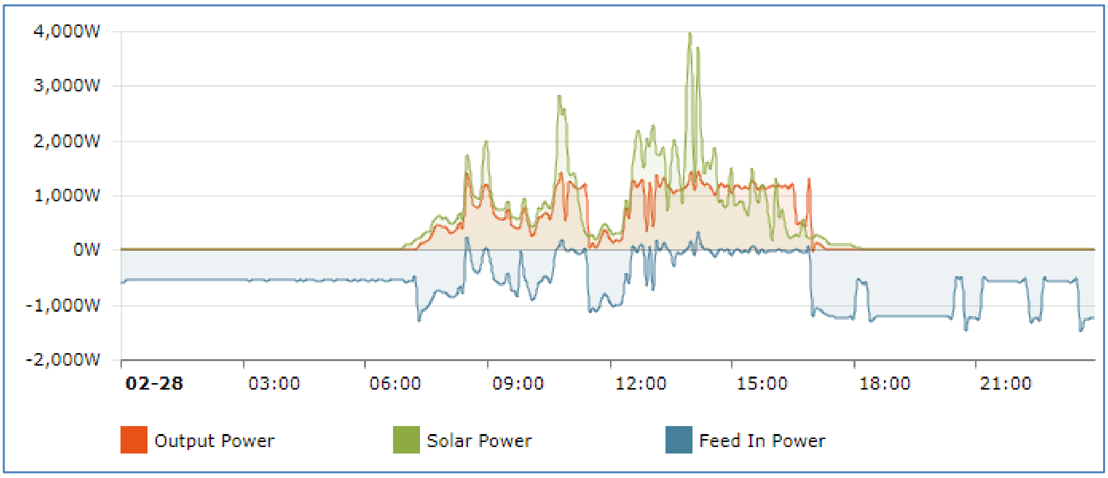

Figure 3.32 Plot showing data from the SolaX portal for the system at Llys Ton on 28 February 2017

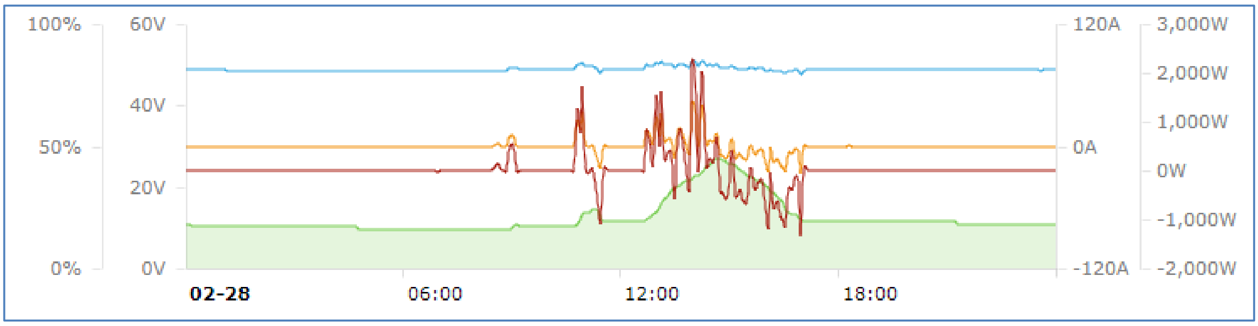

Figure 3.33 Plot showing performance of the battery at Llys Ton on 28 February 2017

The batteries had a charge level of 16% at 08:00 on 28 February 2017. Significant charging of the battery occurred from 12:30 (Figure 3.33) and the battery reached 45% capacity at 14:45. The battery had discharged back to 20% capacity by 17:00. The battery only charged to 45% capacity that day due to the solar generation not being significantly larger than the grid demand during the day.

Figure 3.34 shows a graph from the SolaX monitoring portal for Lys Ton for 6 May 2017, which was a sunnier day. The solar generation met demand from 06:30 and as the solar output increased, the additional power was used to charge the battery. The output was sufficiently high that from 09:30 electricity was exported to the grid. The solar generation was able to power the demand from appliances until 17:45 when the battery was required to provide additional power. The battery discharge ensured that there was no electricity import required until after 21:00.

The performance of the batteries on 6 May 2017 is shown in Figure 3.35. The battery was under 20% capacity until after 07:00 when it began charging. It was fully charged by 10:15 and remained so until 17:45. By 21:30 the battery charge had fallen to under 20%.

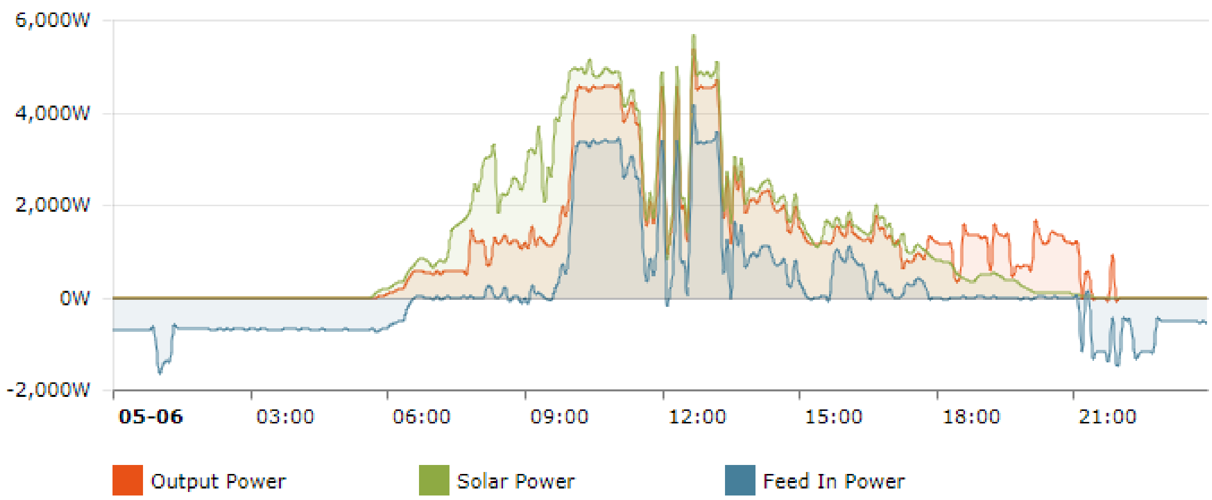

Figure 3.34 Plot showing data from the SolaX monitoring portal for the system at Llys Ton on 6 May 2017

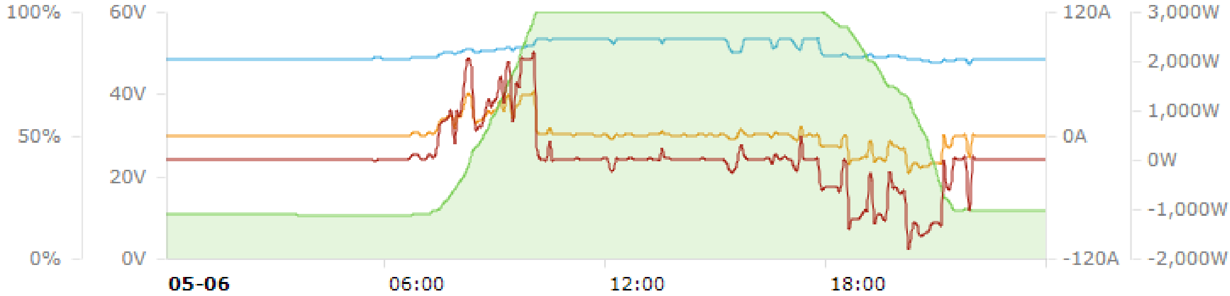

Figure 3.35 Plot showing performance of the battery at Llys Ton on 6 May 2017

Month	Battery output (kWh)	Battery input (kWh)	Output / input (%)	Battery output (kWh/day)	Battery input (kWh/day)
Jan-17	8.6	13.5	63.78%	0.28	0.43
Feb-17	22.1	29.2	75.67%	0.80	1.05
Mar-17	53.8	62.8	85.60%	1.74	2.04
Apr-17	91.6	100.1	91.46%	3.05	3.34
May-17	86.3	94.8	91.02%	2.79	3.06
Jun-17	79.5	86.3	92.07%	2.66	2.89
Jul-17	85.5	95.6	89.44%	2.79	3.12
Aug-17	93.0	102.2	90.97%	2.99	3.29

Table 3.36 Battery input and output for the SolaX / Pylontech system at Llys Ton

The average battery output in kWh/day calculated from the SolaX monitoring portal data for the system at Llys Ton is shown in Table 3.36. The battery output was limited in January and February due to the low solar generation. There was little or no grid export from the system in those months and nearly all the power generated was used to meet the demand of appliances. The round trip efficiency of the battery was poor during these months. This was due to there being little charge and discharge of the battery, consumption by the battery management system and discharge of the battery over time.

There was greater benefit from the battery from April to August with the system supplying on average between 2.66 and 3.05 kWh per day during those months. The battery efficiency for these months was around the value of 91 to 92% and comparable to what might be expected.

3.6 Merfield House

Figure 3.37 Satellite photo showing the south east facing 11.0 kW solar PV array at Merfield House

There was little or no shading of the 11.0 kW south east facing solar array at Merfield House (Figure 3.37). The annual generation between 2016 and 2017 ranged from 9,285 kWh to 9,735kWh. Table 3.38 shows that the most accurate estimate again was produced using the MCS method with a value of 9,592 kWh.

The annual generation recorded by the SolaX inverter in this system was 4321 kWh between 1 May 2016 and 1 May 2017 and 4338 kWh between 1 August 2016 and 1 August 2017. The figure for May 2016/17 represents 46.1% of the total generation. It should be noted that the 5 kW of solar panels connected SolaX hybrid inverter is 45.5% of the total array.

The solar PV system at Merfield House was installed in October 2015 and the battery system in February 2016. The system was connected to the SolaX web portal at the end of April 2016. The quality of the WIFI connection was poor and sometimes as few as 10 days of data per month were received from the system.

Figures 3.38 and 3.40 show data from the SolaX monitoring portal for Merfield House on 9 May 2016. It can be seen that the battery capacity registered 100% throughout the day. This fault continued until the end of September 2016. Other unusual characteristics to the graphs were noted by SolaX technical support and it was suggested that a potential cause was a loose connection to the current sensor or battery. As a result of potential issues with data from this system, no further detailed analysis for this site is included in the report.

Dates	Annual generation for full array (kWh)	Annual generation MCS method (kWh)	Annual generation PV Sol (kWh)	Annual generation PVGIS Classic (kWh)	Annual generation PVGIS Climate SAF (kWh)
		9,592	10,140	9,230	10,100
1 Jan 16 - 1 Jan 17	9,735				
1 May 16 - 1 May 17	9,367				
1 Jun 16 - 1 Jun 17	9,287				

Table 3.38 Annual solar generation and estimates for annual solar generation at Merfield House

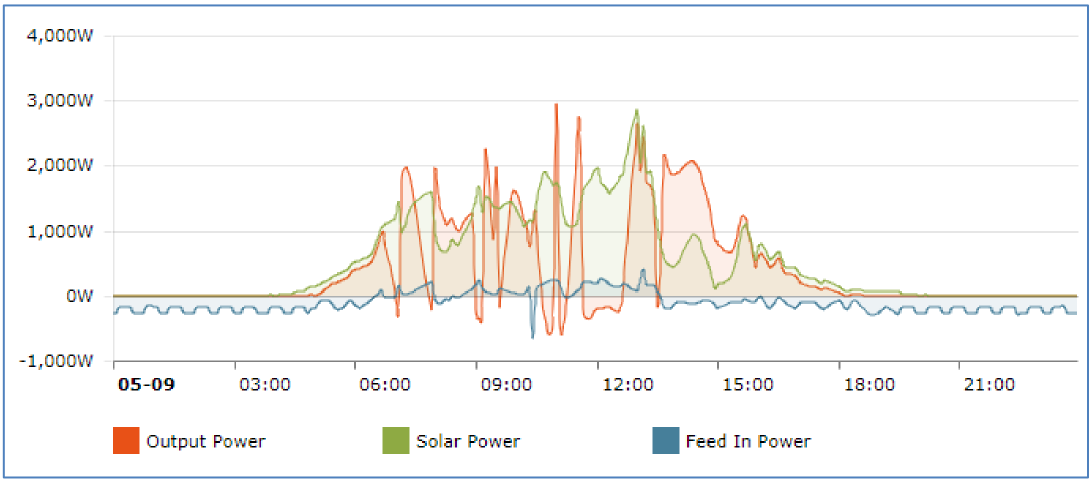

Figure 3.39 Plot showing data from the SolaX portal for the system at Merfield House on 9 May 2016

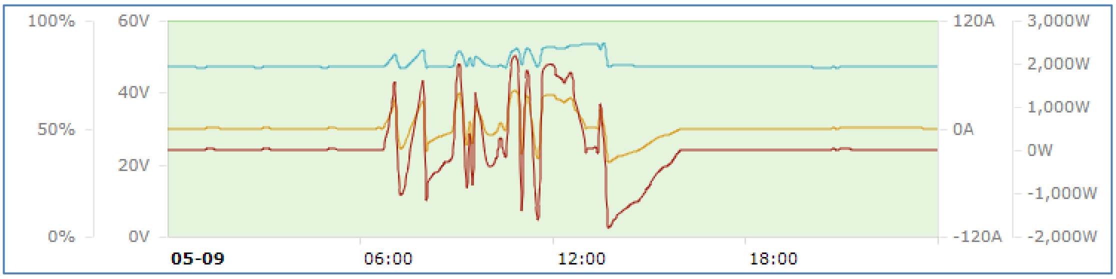

Figure 3.40 Plot showing measurements from the battery at Merfield House on 9 May 2016

3.7 Treharne Row

Figure 3.41 Satellite photo showing the west facing 11.14 kW solar PV array at Treharne Row

The solar PV system at Treharne Row can be seen in Figure 3.41. The PV array is west facing and there is likely to be shading from the row of trees to the west. Estimates for the annual generation from the PV system are shown in Table 3.42. As it was difficult to assess shading based on photographs, the estimates did not take shading into account. All the estimates were significantly greater than the annual generation from the system which was between 7,106 kWh and 7,169 kWh. This illustrates the problem of installing solar PV on roofs with significant shading and why it is important to properly take into account shading when making estimates for annual generation. Out of the 6 PV installations of comparable size, the generation at Treharne Row was the lowest.

Dates	Annual generation for full array (kWh)	Annual generation MCS method (kWh)	Annual generation PV Sol (kWh)	Annual generation PVGIS Classic (kWh)	Annual generation PVGIS Climate SAF (kWh)
		8,132	8,410	7,750	8,480
1 Feb 16 - 1 Feb 17	7,169				
1 Mar 16 - 1 Mar 17	7,165				
1 Jun 16 - 1 Jun 17	7,106				

Table 3.42 Annual solar generation and estimates for annual solar generation at Treharne Row

The solar PV array at Treharne Row was installed in January 2016 and the battery system in March 2016. The SolaX X-Hybrid inverter was connected to the SolaX monitoring portal on 16 March 2017. The WIFI connection at the site was not good and in April and June 2017, 5 days of data in the month were not recorded, while in July more than 15 days of data were missing.

Figure 3.43 shows a plot from the SolaX web monitoring portal for the system at Treharne Row on 4 July 2017. It can be seen that there was apparently negligible power consumption throughout the day on the phase of the mains supply where the SolaX inverter was installed. As the solar generation increased in the morning, the power was initially used to charge the battery and later most of the solar generated electricity was exported. Examining the raw data showed that after 20:30 the system typically exported 100 to 150 W overnight until charging the next morning.

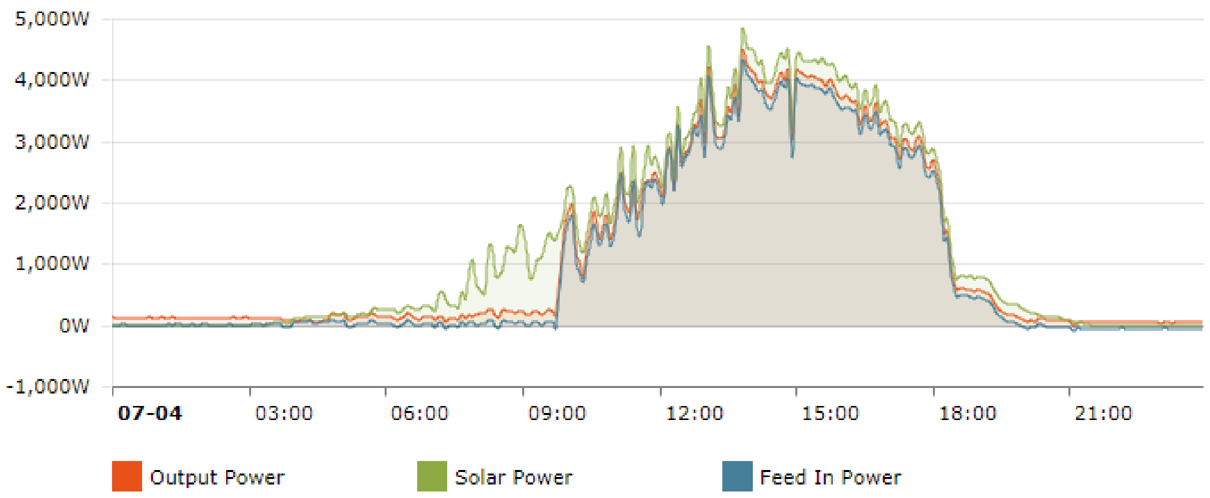

Figure 3.43 Plot showing data from the SolaX portal for the system at Treharne Row on 4 July 2017

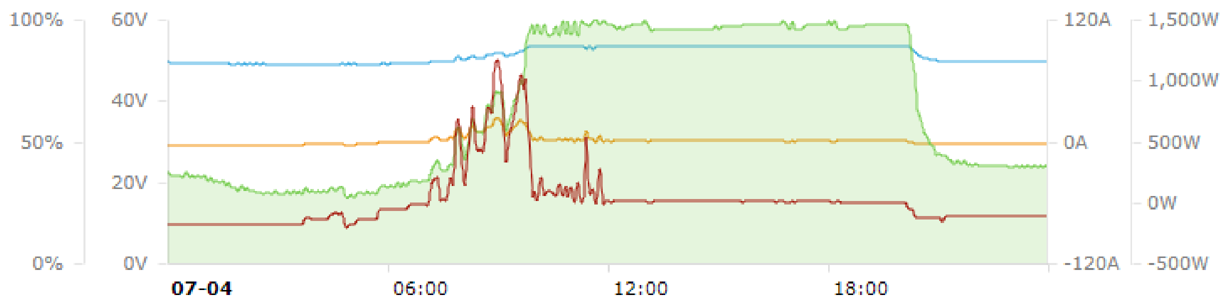

Figure 3.44 Plot showing measurements from the battery at at Treharne Row on 4 July 2017

The variation in battery charge on 4 July 2017 can be seen in figure 3.32. Overnight the charge in the battery had fallen to a minimum of 27% at 05:00 where it started recharging, reaching 98% capacity at 10:00. The battery started to discharge from 20:10 and fell to 39% capacity by midnight.

For the months with more than 20 days of data, the output from the battery was between 1.46 and 1.60 kWh / day. The negligible demand could account for the low battery output and the battery only partially discharging during the daily charge discharge cycle. It is possible that the SolaX inverter was connected to a phase of the supply where few if any appliances were connected. However it is more likely that the current sensor for the inverter (see Figure 3.19) was connected to the wrong cable of had a loose connection. As a result of the limited data and potential technical problems with the installation, further discussion of the results at the site is not included.

3.8 Analysis of savings at the different sites

The battery systems stored excess solar generation which would otherwise have been exported to the grid. When the solar generation could no longer supply the electricity demand of the building, the battery discharged and reduced the electricity import. The battery output in kWh/day from Dinam Close, Ger Y Nant and Llys Ton was used to obtain a value of the battery output over a period of months (table 3.13).

The electricity tariffs at the different sites were used to calculate the savings from the battery output. For Dinam Close, the day rate was 10.857p/kWh and at night it was 9.417p/kWh. At Llys Ton, the day rate was 11.2p/kWh and at night it decreased to 6.964p/kWh. There was a single rate tariff of 10.256p/kWh at Ger Y Nant. Since the battery at Dinam Close discharged overnight, it was assumed that 50% of the savings were at the day rate and 50% at the night rate. The discharge at Llys Ton was more rapid and it was assumed the savings were all made at the day rate. Savings were also calculated per household using the number of flats in the building.

Property	Period	Battery output (kWh)	Savings	Saving per household
Dinam Close	1 Mar 17 to 31 Jul 17	643.1	£65.20	£3.62
Ger Y Nant	1 Apr 16 to 30 Sep 16	494.9	£50.76	£3.63
Llys Ton	1 Jan 17 to 31 Aug 17	522.3	£58.50	£1.50

Table 3.45 Assessment of the savings from the battery storage at different sites

3.9 Performance comparison against manufacturers claims

Manufacturers of battery systems have been careful not to overstate claims about the length of time required before payback could occur. This is because each installation is very specific in terms of location, alignment and local features. It is very difficult to predict precise performance values without carefully placed and accurate data-loggers and a full set of regular meter reading data. Therefore expressions such as ‘make the most of your solar energy’ and that the solution ‘makes it possible to utilise solar power by using it time-independently by storing it’ are used by the manufacturers. These are certainly true to some degree and there is no doubt that the ability to do this is of benefit to the household as well as the environment, but the precise values are unclear.

What is not made clear is that the electricity stored in the battery must not be allowed to fall below a pre-selected level and if it does, the management system will draw current from the grid to recharge it to a level above the critical level if there is no solar power available at that particular time. This needs further investigation through more intensive monitoring.

Battery output data was obtained for the Llys Ton Extra Care Scheme site between January and August 2017. For an approximate calculation, it is assumed that the battery output between July and December is the same as that from January to June. Using that assumption the battery system annual output was 686 kWh. Using the day rate for electricity at Llys Ton, the annual saving was £76.80

Measure	Annual energy cost saving from NEA study	Annual cost saving claimed by manufacturer	Assumptions
SolaX inverter and battery management system with 2 x 2.4kWh Pylontech batteries plus storage cabinet	£76.80	-	Annual battery output of 686kWh Electricity savings made at 11.2p/kWh This does not take into account any savings resulting from the solar PV system or the Feed-in tariff

Table 3.46 Estimate of annual energy cost saving for the battery storage system

3.10 Economic business case for the installation of measures

The economic business case for installation of solar PV is known to be attractive, but the benefits of adding battery storage to a system are less clear. At present, for most battery systems, the financial benefit is due to storing solar generated electricity during the day to allow it to be used in the evening, reducing the amount of electricity imported from the grid. In future, additional income streams for battery systems are likely to be available by providing grid balancing or frequency response. With greater adoption of time of use tariffs, savings could also be made if a battery system enables a site to avoid importing electricity during times of peak consumption. Additional benefits such as powering at least some appliances during a power cut could add to the attraction of battery storage.

The simple assessment in Table 3.47 uses the savings determined from storing solar generated electricity at Llys Ton for later consumption. No account is taken for inflation of energy prices in later years. It is assumed that the SolaX X-hybrid inverter is installed as part of the solar PV system and the costs associated with that are covered with the payback from solar generation and the feed-in tariff. Pylontech US2000B 2.4kWh batteries are now available for under £800 each, but there are additional costs of about £200 for a cabinet.

The indicative payback time calculated is 27 years based on the savings from reduced consumption. The additional income streams discussed earlier should reduce the payback time for future installations and battery prices are falling at a high rate. It should be noted that the Pylontech US2000B battery has a warranty for 5 years and an advertised lifespan of 10 years.

Measure	Capital Cost	Indicative installation costs	Total	Annual energy savings from study	Indicative annual payback	Assumptions
SolaX inverter and battery management with 2 x 2.4kWh Pylontech batteries plus storage cabinet	£1,800	£300	£2,100	£77	27.3	Savings as for the Llys Ton site in this study Financial benefit only from stored solar generated electricity for later consumption

Table 3.47 Assessment of the payback time from adding batteries to a SolaX X-hybrid inverter

4. Conclusions and recommendations

4.1 Conclusions

The project installed battery storage at 7 sheltered housing properties

- Battery storage was added to existing solar PV systems connected to the power supplies for the communal areas at 7 sheltered housing properties owned by Valleys to Coast housing in the Bridgend District.
- The installations used 5kW single phase SolaX X-hybrid inverters with DC coupled Pylontech Lithium Iron Phosphate batteries.
- The storage capacity for the 2 Pylontech batteries was 4.8 kWh.
- During the evaluation, it was determined that out of the 7 systems fitted, 2 had problems where the batteries were not charging or discharging correctly, which may be due to loose connections or an incorrectly located or faulty current sensor.
- A further 2 systems showed unusual behaviour and may have problems with loose connections or an incorrectly located sensor.
- The evaluation aimed to create data to improve understanding of the benefits of adding battery storage to existing solar PV installations in different settings and assess whether installing battery storage successfully shifted energy demand from the grid and made energy savings, potentially saving tenants money on their ‘service charge’, part of which pays for the energy consumed in the communal areas of the building.

The evaluation assessed the battery performance using data from the SolaX web portal

- The SolaX X-hybrid inverter provided a wide range of performance data in 5 minute intervals which was transmitted to a monitoring portal via WIFI.
- The WIFI connection at some sites was poor, which reduced the quality of the data and period it was available over for the evaluation.
- It was not possible to use additional monitoring equipment to assess the charge and discharge of the batteries, however values of the battery input or output power from the SolaX monitoring portal was used to estimate the battery input and output in kWh per day.

For the installation at Dinam Close, the battery output ranged from 2.94 kWh/day in March 2017 to 4.79 kWh/day in April 2017

- At Dinam Close, the SolaX SK-SU5000E X-hybrid inverter was connected to 5kW of an 11.14kW solar PV array.
- Out of the 3 sites studied in depth, the battery output at Dinam Close was the highest and it also had the highest grid export and lowest demand from appliances.
- The battery output at Dinam Close ranged from 2.9 kWh/day in March 2017 to 4.79 kWh/day in April 2017.
- With the Pylontech battery system installed, an output of greater than about 3.53 kWh/day would require more than 1 charge and discharge cycle per day.
- The high level of electricity export due to excess solar generation and lower consumption leads to charging and discharging during the day and may explain the high output figures for the batteries at Dinam Close.

- The batteries at Dinam Close were able to supply power late into the evening so that the site was able to avoid grid import until early the next morning.
- The savings per household resulting from the lower electricity bill for the communal area at Dinam Close was £3.62 for the period 1st March to 31st July 2017.

The battery output for the installation at Ger Y Nant ranged from 0.30 kWh/day in January 2017 to 3.36 kWh/day in July 2016

- A SolaX X-hybrid inverter was connected to 5kW of an existing 11kW solar PV system at the Ger Y Nant sheltered housing scheme.
- The electricity demand for the communal area at Ger Y Nant was high and there was little export of excess generation from the solar panels connected to the SolaX X-hybrid inverter.
- The battery output ranged from 0.30 kWh/day in January 2017 to 3.36 kWh/day in July 2016.
- The percentage of the solar generation from the SolaX X-hybrid inverter at Ger Y Nant that was exported to the grid was less than 10%.
- The battery at Ger Y Nant reached maximum discharge by early evening and only tended to reduce the grid import during the period of discharge.
- The savings per household for the battery installation at Ger Y Nant was £3.63 between 1st April and 30th September 2016.

At Llys Ton Extra Care Scheme, the average output from the battery installation ranged from 0.43 kWh/day in January 2017 to 3.05 kWh/day in April 2017

- At the Llys Ton Extra Care Scheme, the SolaX SK-SU5000E X-hybrid inverter was fitted to an existing solar PV array which was extended to 5.6kW.
- The values for the grid import and export at the site were in between those for Ger Y Nant and Dinam Close.
- In January 2017, the battery output was 0.28 kWh/day and the round trip efficiency for the battery charge and discharge was 64%.
- The average battery output was in the range 2.66 kWh/day to 3.05 kWh/day between April and August 2017.
- For most months, the battery round trip efficiency was between 91% and 92%.
- On some summer evenings, the combination of the solar and battery enabled the system to avoid electricity imports until after 8.30pm.
- The savings per household from the battery storage system at Llys Ton over the period 1st January to 31st August 2017 was about £1.50.
- Based on storage of excess solar generation by the batteries which is used later in the evening, the payback time for the battery system at Llys Ton was about 27 years.

4.2 Recommendations for potential future installations

- Battery storage is a fast evolving technology and many installers have limited experience with installations. There is currently no MCS standard for battery storage which can make comparing quotations a challenge. However battery systems are now included under the Renewable Energy Consumer Code (RECC), who have produced guidance for sellers/installers which is also beneficial for those considering purchasing a system[21].
- Online monitoring portals for battery systems are useful for installers and Energy Managers. There can be challenges in ensuring a good WIFI connection to the battery system. Good quality power-line adapters may help with this.
- It is important that the installer and owner of the system understand the outputs from the monitoring portal. An installer can confirm in the days following the installation that the system is operating correctly and if there is a problem, deal with it early on. Use of the portal by the owner can ensure nothing is missed by the installer.
- Energy Managers and owners should consider recording performance of the solar PV system and battery on a monthly basis. Comparison with a benchmark figure can ensure that faults with the solar PV or battery system are detected early and the benefits of the system are not lost for an extended period. Solar inverters usually have a lifespan of 5 to 10 years, but some fail after a shorter period
- In the current study, 3 single phase inverters, including a SolaX X-hybrid inverter were installed on the different phases of a 3-phase supply as a suitable 3-phase hybrid inverter was not available at the time.
- An X-Hybrid 3-phase inverter is being released by SolaX in September 2017. The benefits of an installation using the X3-Hybrid inverter include lower installation costs and the batteries being charged by the whole solar PV array. A 10kW X3-Hybrid inverter could potentially charge 4 x 2.4kWh Pylontech batteries. Appliances on all 3-phases of the mains supply would be powered by the batteries rather than just those connected to the phase where the single phase X-hybrid inverter was attached.

4.3 Impact on fuel poverty

- A house with a solar PV system can benefit from a battery storing excess solar generation which can be used later in the evening. Many domestic battery installations are about 2 to 3kWh in size and the system on average goes through less than 1 charge and discharge cycle per day. Over a year, a 2kWh battery system in a home might store on average 1.2kWh per day[22]. Assuming an electricity tariff of 15p/kWh, this could save residents about £65.70 per year.
- In future, 'time of use' tariffs will become more common. Residents with larger battery systems will be able to benefit from lower tariffs at times of low demand and will be able to supply their appliances with power from the battery during times of high demand when the tariff is high.

[21] Battery storage for solar power: guidance for sellers/installers (RECC,2015) https://www.recc.org.uk/pdf/guidance-on-battery-storage.pdf (Accessed 5 September 2017)

[22] Domestic batteries to store excess PV and reduce peak demand loads, Carbon Commentary (2014), https://www.carboncommentary.com/blog/2014/10/17/domestic-batteries-to-store-excess-pv-and-reduce-peak-demand-loads (Accessed 5 September 2017)

- In the current project, batteries powered appliances in communal areas of sheltered housing. Savings on electricity due to the battery storage could lead to a smaller service charge for residents. In the current study, the reduction in the electricity bill for the communal area at Dinam Close sheltered housing scheme was about £3.62 per household over a 5 month period.
- The financial benefit from battery storage systems is likely to improve in the coming years. Prices for solar installations and battery systems are continuing to fall, improving the payback time. New income streams like grid balancing, frequency response and operation with 'time of use' tariffs are likely to improve the economics further for battery installations. Batteries can also provide added value such as an Emergency Power Supply during power cuts. Such a feature is particularly beneficial for vulnerable residents.

Appendix 1: Glossary of Terms

AC	Alternating Current
DOD	Depth of Discharge
DC	Direct Current
EPC	Energy Performance Certificate
$LiFePO_4$	Lithium Iron Phosphate
FiT	Feed in Tariff
MCS	Micro-generation Certification Scheme
NEA	National Energy Action – the National Fuel Poverty Charity
OFGEM	Office of Gas and Electricity Markets (the Energy Regulator)
PV	Photovoltaic
RECC	Renewable Energy Consumer Code

Appendix 2:Technologies installed

SolaX Power 5kW X-hybrid inverter – SK-SU5000E

http://www.solaxpower.com/wp-content/uploads/2017/08/Gen2-X-hybrid.pdf

Pylontech Extra2000 and US2000B – 2.4kWh Lithium Iron Phosphate batteries

http://www.greenengineering.com.au/pdf/LithiumBatteryInformation.pdf

http://www.solaxpower.com/wp-content/uploads/2017/01/Pylontech_US2000B_cn.pdf

Appendix 3: Monitoring portal

Solax web portal

http://www.solax-portal.com/

Appendix 4: Health and Innovation Programme 2015 – 2017

The Health and Innovation Programme (HIP) was a £26.2 million programme to bring affordable warmth to fuel poor and vulnerable households in England, Scotland and Wales.
The programme launched in April 2015 and was designed and administered by fuel poverty charity National Energy Action as part of an agreement with Ofgem and energy companies to make redress for non-compliance of licence conditions/obligations. To date, it remains the biggest GB-wide programme implemented by a charity which puts fuel poverty alleviation at its heart.

The programme comprised 3 funds

- **Warm and Healthy Homes Fund (WHHF)**: to provide heating, insulation and energy efficiency measures for households most at risk of fuel poverty or cold-related illness through health and housing partnerships and home improvement agencies

- **Technical Innovation Fund (TIF)**: to fund and investigate the impact on fuel poverty of a range of new technologies

- **Warm Zones Fund (WZF):** to install heating and insulation and provide an income maximisation service to households in or at risk of fuel poverty, delivered cost-effectively through partnership arrangements managed by NEA's not-for-profit subsidiary Warm Zones Community Interest Company

What it involved

- **Grant programmes** to facilitate the delivery of a range of heating and insulation measures and associated support. Grant recipients were encouraged to source match and/or gap funding to increase the number of households assisted and to enhance the support provided to them
- **Free training** to equip frontline workers with the skills needed to support clients in fuel poverty
- **Outreach work and community engagement** to provide direct advice to householders on how to manage their energy use and keep warm in their homes

In addition we undertook substantial **monitoring and evaluation** work, to assess the effectiveness and measure the performance of the technologies, and to understand the social impacts of the programme. Our **communications programme** helped partners to promote their schemes locally as well as share best practice with others. The programme generated a considerable amount of **knowledge and insight** which will be made freely available to help support future policy and delivery.

Proper investment of advanced payments allowed us to generate interest which, along with efficiency savings, was reinvested back into the programme in the form of additional grants and support which helped us further exceed our targets.

For more information see www.nea.org.uk/hip

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