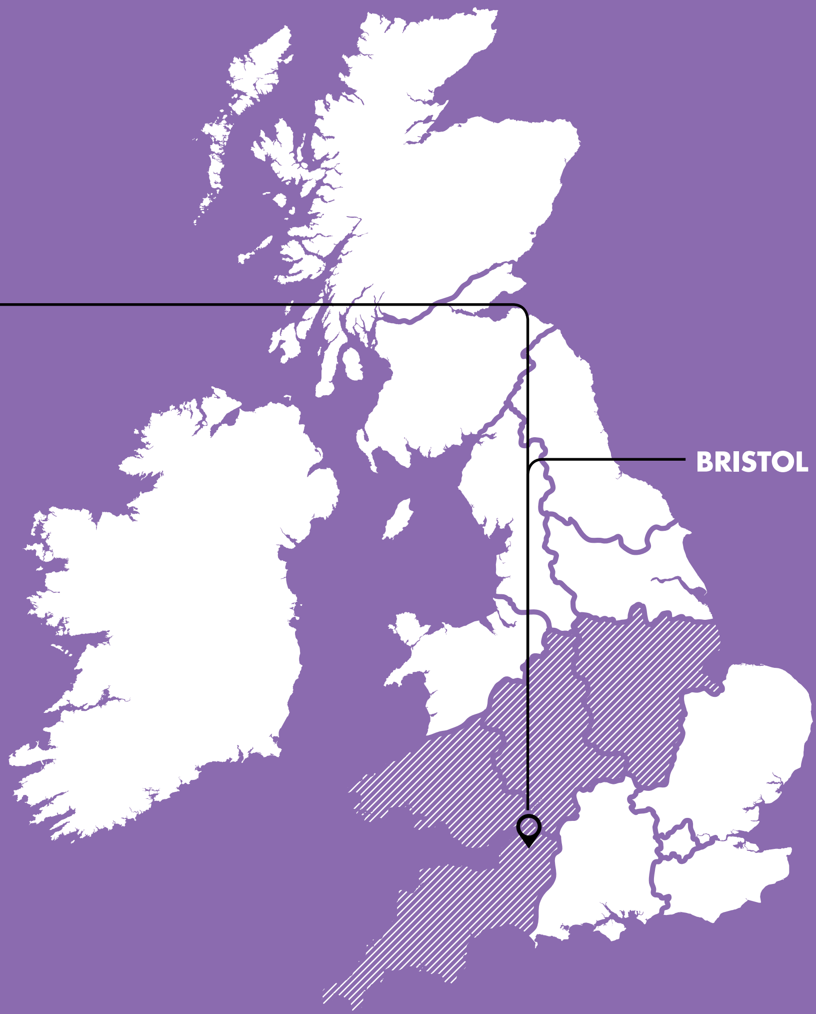
WESTERN POWER DISTRIBUTION

SOLA BRISTOL

# PROJECT SOLA BRISTOL

## PROJECT PROGRESS REPORT
## REPORTING PERIOD: DECEMBER 2012 TO MAY 2013



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## 1. EXECUTIVE SUMMARY

This report details the progress of the Low Carbon Network Fund project focussing on the progress in the last six months, December 2012 to June 2013.

### 1.1 Project Background

BRISTOL is an alternative method to enable high density photo voltaic solar generation to connect to the low voltage network more efficiently through using an in home battery and variable tariffs. The project aim is to address the technical constraints that DNOs expect to arise on Low Voltage networks as a result of the adoption of solar PV panels. The trial uses in-home battery storage to provide benefits to customers and aid the DNO with network management. Thirty houses, ten schools and an office will have solar PV and a battery installed. The solar PV will be connected directly to the battery using a DC connection. The AC lighting circuits in the premises will also be converted to DC to enable customers to run small appliances on DC directly from the PV/battery. The battery will be "shared" between the customer and the DNO. The customer will be provided with a variable tariff to encourage electricity use at times of high PV generation and to use electricity stored by the battery when the network is heavily loaded. The DNO will be able to communicate with the battery to charge and discharge it to help with network management.

**The project will aim to:**

- solve the network problems which arise when a number of customers in a local area connect PV solar panels to their house
- investigate how a battery installed in the home can help customers to manage their energy usage and save money on their bills
- test how customers respond when offered different electricity tariffs throughout the day
- explore the benefits of utilising direct current (DC) in the home, rather than the traditional alternating current (AC).

### 1.2 Project Progress Highlights

In the third reporting period (December 2012-June 2013) SoLa BRISTOL has focused on the Installation of equipment in the Bristol City Council (BCC) EcoHome, and the recruitment of the trial homes for property 2 & 3. The following is a summary of the key activities and project updates during this reporting period.

### EcoHome Installation

The Initial installation in the BCC EcoHome was undertaken on the 12th – 14th December 2012. Following a brief training refresher, six BCC electricians installed the equipment using the detailed installation guide provided by Siemens. There were issues with the Studer Inverter and the DC/DC Converter, that resulted in further delays before the solar panels could be incorporated into the system, and these issue are explained within the Project Managers report. The batteries were connected and the DC system has been running since this installation date. The Studer unit was replaced on 21st March 2013, but further problems were encountered with the DC/DC converter. This required further testing by PE and Siemens. An updated DC/DC converter was installed on 29th April and from this date the full system has been working without any problems.

**Property 2 & 3 recruitment**
2 customers have expressed an interest in becoming the next trial homes for the project. They were invited to the EcoHome on 2nd May for a guided tour of the installation and to experience the DC lighting. The system was explained as was the expected works that would be required within their properties. Following this both customers agreed to participate in the next phase. Detailed surveys of their properties, both electrical and structural are now underway.

**Dissemination of information**
During the last six months of the project, greater exposure has been achieved. Details of the SoLa Bristol project have been shared through conferences, the websites, magazine articles and meetings with interested parties. The SoLa Bristol design information is also accessible through both the www.westernpowerinnovation.co.uk and www.LowCarbonUK.com websites. Our external website has been updated, to ensure that elements relating to our future networks programme and the BRISTOL project can be easily found by a range of stakeholders. For further details please see www.westernpowerinnovation.co.uk/So-La-Bristol.aspx.

**Risks**
The main areas of risk to the project are listed below.

- Recruitment risks
  Property 2 & 3 have agreed to take part in phase 2, but until these installations are complete, and an installation report approved, the further 27 properties cannot be signed up. The schools engagement is only now getting underway, with the initial parties being re engaged to confirm their continued interest.

- Installation risks
  Detailed surveys of the office and the schools are only just starting, and as each installation will be unique, there is a risk that the equipment design and space available on some premises may be restrictive. Due to the delays mentioned above, and in the previous report, timescales for the school installation are very restricted. The target being to complete all 10 during the 6 week summer break that starts in mid-July.

**Learning**
The problems encountered in the EcoHome installation have highlighted the implications of working with new equipment and innovative systems. More time needs to be built into projects for unforeseen problem solving.

Although it is understood that customer engagement can only come after the initial system has been tested and approved, some form of pre survey access, particularly in the schools and office would have been an advantage.
The initial installation in the EcoHome environment was a real advantage, as the issues encountered had little effect on customers, as the EcoHome is a demonstration property only with no residents.

## 2. PROJECT MANAGER'S REPORT

This is the third reporting period for the SoLa Bristol project that received £2.2m funds from Ofgem's Tier 2 Low Carbon Network Fund. During this reporting period the project management has transferred from Philip Bale to Mark Dale.

**2.1 Project Background**
BRISTOL is an alternative method to enable high density photo voltaic solar generation to connect to the low voltage network more efficiently through using an in home battery and variable tariffs.

The project aim is to address the technical constraints that Distribution Network Operators (DNOs) expect to arise on Low Voltage networks as a result of the adoption of solar Photo Voltaic (PV) panels. The trial uses in-home battery storage to provide benefits to customers and aid the DNO with network management. Thirty houses, ten schools and an office will have solar PV and a battery installed. The solar PV will be connected directly to the battery using a Direct Current (DC) connection. The Alternating Current (AC) lighting circuits in the premises will also be converted to DC to enable customers to run small appliances on DC directly from the PV or the battery.

The battery will be "shared" between the customer and the DNO. The customer will be provided with a variable tariff to encourage electricity use at times of high PV generation and to use electricity stored by the battery when the network is heavily loaded. The DNO will be able to communicate with the battery to charge and discharge it to help with network management.

The project aims to solve a number or the key network problems which arise when a number of customers in a local area connect PV solar panels to their house. Through SoLa Bristol we will investigate how a battery installed in the home can help customers to manage their energy usage, save money on their bills and how this can provide network benefits. We will test how customers respond when offered different electricity tariffs throughout the day and the impact this has on the distribution network. And finally explore the benefits of utilising direct current (DC) in the home, rather than the traditional alternating current (AC) and the positive impacts this could have on the distribution network.

**2.2 Project & Techniques Progress Highlights**
Over the first year of the project, the SoLa Bristol project focussed on recruiting interested parties, designing the three techniques, DC Networks, Battery storage and Variable Tariffs that will be demonstrated together in 30 homes, 10 schools and an office. At the end of the last reporting period we were preparing the first installation of the SoLa Bristol installation in Bristol City Councils (BCC) EcoHome.

**2.2.1 EcoHome Installation – progress**

The EcoHome installation commenced on Wednesday 12th December, the installation progressed as planned over three days. The domestic equipment has been designed to take two days with a team of three electricians, the EcoHome installation was extended by one day as this was the first time the Bristol City Council electricians had installed the equipment and additional steps were required in the EcoHome that would not need to be replicated in the remaining domestic properties.

The first installation was used as further reinforcement to the training provided to the BCC Electricians. Whilst the SoLa Bristol equipment has been designed, and guides created, so it could be installed by standard electricians, the SoLa Bristol equipment is a little different to their normal day to day activities.

**Day 1 – Installation of equipment in the Loft area**

A refresher session was held, consisting of a run through of the installation guide with the BCC electricians and Siemens, with a question and answer session to ensure everyone was confident of what was expected.

The SoLa Bristol consumer unit, Studer Inverter and DC/DC converter were installed along with the battery box.

**Day 2 – Installation of DC Fittings**

All DC light fittings and switches were installed along with the USB charging box. This included time to trace circuits of outside lights which were discovered to be on the desired lighting circuit.

**Day 3 – Final system testing & G59 testing**

Issues with the Studer inverter are reported in the next section. These did not impact on the successful G59 testing.

The equipment was successfully installed by Bristol City Council electricians following the installation guide and wiring plans provided.

**Lessons learnt from the EcoHome installation**

- **Electricians training** – It was good practice to run through the installation guide to ensure the BCC Electricians understanding. Once the second phase of installations is underway and the electricians are more familiar with the equipment, this should not be necessary.
- **Importance of pre survey** – Having an understanding of potential installation issues, such as outside lights/smoke alarms etc. on the proposed DC circuits along with a plan for trunking and cable routes would save time on install days. This is particularly relevant with respect to the schools and office installations where each building will be unique.
- **Working with new equipment** – When installing new equipment extra time needs to be allowed for overcoming potential issues. Any changes to planned works must be approved by all relevant parties and recorded
- **Requirement for strategic spares** – Spares of strategic equipment need to be available at each installation in case of individual failures or damage.
- **Heat shrinking wire** – The requirement to fit heat shrink colour coded sleeving on all DC wired light fittings and switches required considerably more time than anticipated, as each existing termination needed to be remade individually.

**Installation issues**

SoLa Bristol is a collaborative project combining the expertise from Siemens employees, their sub-contractors and the University of Bath professors and employees. Whilst the majority of the project design and testing was carried out by Siemens, a dedicated University of Bath Post Doctorial Research Associate (PDRA) supported Siemens by leading the battery inverter, Studer inverter, programing and testing. The detailed design work was fed into Siemens to be incorporated into the entire system.This section of the design included the setting of parameters and the compliance with G59[1] testing, a requirement as the Studer inverter is not approved for G.83[2]. The Studer inverter being used for the EcoHome installation was a new device and did not have the required settings as demonstrated in both the Siemens and UoB labs. This required the UoB to upload the settings.

[1]G.59 – covers generation at more than 16A per phase for operation in parallel with the public electricity supply, and all connections made at HV. The settings required are usually drawn up by the appropriate DNO on a site specific basis. Full witness testing of each installation is usually a requirement at the first time of connection.

[2]G.83 - covers generation at 16A per phase or less for operation in parallel with the public electricity supply. The connection will be at LV. The settings are standard, and a compliance certificate is usually provided with the inverter. However not all inverters are compliant for G.83, these are treated like G.59 installations. The Studer inverter is not G.83 approved.

The installation was carried out by BCC electricians in accordance with the installation guide and the drawings provided by Siemens. This effectively replicated the setup demonstrated through the Siemens Factory Acceptance Tests (FAT) and how the normal domestic installation would be made. When the PDRA programmed the settings in the Studer in preparation for the G59 tests they modified the small wiring from the installation guide and wiring diagram to match that in their lab environment.
The result of this modification was the cross polarity of Studer inverter control circuitry. The issue was investigated and rectified immediately; the Studer was replaced, as a precautionary measure, wired as indicated in the Siemens FAT. Following a review between WPD, Siemens and the University of Bath, systems have been put in place to ensure this could not happen again and all parties were reminded that changes must not be made without formal agreement and testing in a lab environment.

In the future the Studer inverter will not be programmed onsite but instead arrive pre-programmed.

**Lessons learnt**

- A formal change request system has been put in place to ensure before any modifications can be made to the equipment it can be carefully considered, with the agreement of WPD, Siemens and the University of Bath.
- All of the people working on the project were reminded that they must follow the directions and drawings. If the installation needs to be different then the formal change request must be followed.
- Any changes to the design requires the system to be re tested in a factory environment, this included both hardware and software modifications.
- Except in exceptional circumstances the equipment should arrive pre-programmed to reduce the requirements during the installation.

### 2.2.2 CE Marking

The SoLa Bristol was designed to use off the shelf components to reduce the risk of delays on the project. The project was forced to deviate from this when it became apparent that the use of off the shelf charge controllers would not be sufficient due to the high voltage associated with Solar PV installations.
An alternative to charge controllers was found and Siemens sourced a DC/DC converter that would provide two functions.

1. Provide an Isolation Transformer between the PV panels and the domestic property for lighting protection, allowing the PV panel frame to operate floating without a direct earth connection. This is in line with Photovoltaic in Buildings, Guide to the installation of PV Systems 2nd Edition written by the DTI.

2. Transform the PV input from 150-600V DC to a steady 27.8V DC.
The DC/DC converter being supplied to the project is part of an existing component used as part of a larger piece of equipment. The component has been operating in larger systems since 2008, had been CE marked and was selected as it would perform a number of functions for the SoLa Bristol project.

The DC/DC converter had additional communications ports added to improve control, monitor performance and measure how much power was being created by the PV panels. During the first day of the installation, 12th December 2012 Siemens informed WPD that the DC/DC converter did not have the required CE markings for domestic installations due to the modifications made.

In order to CE mark the equipment it must pass the Low Voltage Directive (LVD) and Electromagnetic compatibility (EMC) tests.

The DC/DC converter had been included in the system tested in Siemens laboratory. As a project the partners carried out a risk assessment including PE Systems, Siemens, WPD and BCC. Whilst the risk associated with the installation was very small as the EcoHome is open to the public the decision was made not to connect the DC/DC converter until it was CE marked. The property was left without the Solar PV connected to the DC/DC converter, replicated a School and commercial installation, providing a DC network and battery storage using the Studer battery inverter.

The DC/DC converter passed the CE marking in early February 2013 and a new DC/DC converter was shipped and installed in the EcoHome on 21st March 2013

**Lessons learnt**

- The project team had a knowledge gap regarding equipment required for domestic installations.
- Even with risk registers and mitigation – this was unforeseen.
- Sub-contractors can be pivotal to the success of the project; this visibility of this can be reduced due no direct contact with the sub-contractor.
- Even with excellent partner and sub-contractor engagement, some issues cannot always be solved immediately.

### 2.2.3 DC/DC converter Installation

Bristol City Council electricians replaced the entire DC/DC box containing the CE marked DC/DC converter with a unit that had been CE marked. During the CE marking process PE systems re-evaluated the DC/DC converter and associated protection and realised they could make the installation process more streamlined by using bus bars instead of cable connections.

This will further speed up the installation process, leading to with the swapping out of the DC/DC converter installed in December 2012 with a second version. This replaced a number of cable connections with Bus Bar connections, making the installation process easier and quicker.

This unit underwent a FAT at Heburn before being installed in the EcoHome. When installed it was quickly apparent the DC/DC converter was not performing as designed or how it performed when tested by both PE and Siemens.

The testing within labs used advanced DC power packs to replicate the voltage and current contribution from solar PV. When the input conditions changed, both voltage and current, the DC/DC converter responded accordingly to modify power being supplied by the PV panels.

During installation of the SoLa Bristol equipment at the Ecohome on 21st March it was determined that the DC-DC converter was performing poorly; in particular it was determined that the input voltage was collapsing due to poor load regulation by the DC-DC converter

The property was again left without the Solar PV connected to the DC/DC converter, replicated a School and commercial installation, providing a DC network and battery storage using the Studer battery inverter

**Lessons learnt**

- The FAT must appropriately replicate the environment the equipment is being installed in to provide greater certainty the equipment will perform as intended.
- The importance of having mitigation plans for when projects do not follow the expected plans.

**2.2.4 Problem solving DC/DC converter**

The DC/DC converter was again removed from the EcoHome to allow Siemens and PE systems to conduct further tests to rectify the issues with the DC/DC converter. These further tests confirmed that the DC/DC was still operating poorly. The first solution investigated was a review of the system software used to control the DC/DC converter. This was not able to speed up the control loop satisfactory as the latency of voltage measurements via Modbus is identified as a factor in the instability. Following this result a telephone conference call was immediately scheduled with Siemens to explore the potential solutions open to the project. Four options were discussed:

- Re investigate the use of an alternative off the shelf component that could provide the same function as the DC/DC converter.
- Re investigate the use of an alternative custom DC/DC converter from another manufacturer.
- Add an additional DC/DC converter to provide additional high speed transducers into the Modbus unit and update the DC/DC control algorithm to accept the new voltage input.
- Modify the DC/DC converter hardware to provide additional high speed transducers without using the Modbus connection and update the DC/DC control algorithm to accept the new voltage input.

Due to the time constraints the decision was taken to investigate using an external transducer with the Modbus connection in parallel with connecting the external transducer modification to the DC/DC Hardware. Weekly conference calls were also scheduled to ensure a solution was progressing.

Siemens procured such a transducer and PE Systems carried out some preparatory modifications to the DC-DC converter regulation algorithm prior to testing the modified system.

Durham Energy Institute (DEI) (part of Durham University) provided access to their Smart Grid Laboratory, which included a DC source able to simulate the dynamic response of a PV Panel, using a Labview control environment.

On Thursday 4th and Friday 5th April Siemens and PE Systems carried out testing on the modified SoLa Bristol hardware, particularly the DC-DC converter. The tests were supported by DEI researchers and PE Systems provided an employee able to carry out algorithm adjustments during the test programme.

The tests established the following:

- Regulation of the input voltage has improved the performance of the inverter, however it remains operating in an instable manner, with frequent voltage collapses.
- The latency of voltage measurements via Modbus is identified as a factor in the instability.
- The simulated PV source has an I-V characteristic which, while close to a real characteristic, displays an overly steep gradient which reduces the ability of the DC/DC converter to regulate the voltage effectively.
- A simple input voltage regulation method has been applied which, could be improved by regulating the I-V slope to avoid collapses in input voltage.

A low latency method of measuring voltage was required. Following consultation with PE Systems, Siemens proposes to make use of an off the shelf transducer but feed the resulting signal directly in to the DC-DC converter. This will require hardware modification to the converter design, PE Systems confirmed this would not require re-testing for CE certification.

PE Systems modified the converter hardware design to accept a direct signal from the voltage transducer and Siemens worked with DEI to create an I-V profile closer to that for the SoLa Bristol PV panels.

The modified DC-DC converter required informal testing by PE Systems to confirm that the current algorithm modifications with the new voltage measurement will deliver the required stability. The algorithm was adjusted to take into account the slope of the I-V curve to avoid voltage collapse

The modified DC-DC converter was then retested at the DEI Smartgrid Laboratory to ensure all instabilities have been removed.

This solution provided a satisfactory operation of the DC/DC converter in the DEI Smartgrid Laboratory. The modifications were made to the EcoHome DC/DC converter on 29th April 2013 and the system has operated as intended since that date with no further issues.

**Lessons learnt**

- The use of advanced DC power supplies was not an appropriate equivalent for Solar PV panels.
- The effort and risk in developing a new piece of equipment or modifying an existing piece of equipment should not be under estimated.

**Technique Progress**

During the last reporting period, the project has continued to develop the three techniques, DC Networks, Battery storage and a Variable Tariff. Domestic properties will have all DC Networks, Battery Storage and a Variable Tariff. Schools and offices will have DC Networks and battery storage.

**2.2.5 Battery storage**

SoLa Bristol will install 4.8kWh of battery storage within homes and up to 19.2kWh of battery storage in schools and the office. The control methodology of the battery storage has been designed by the University of Bath.

For this project, ‘charging envelopes’ will be used to manage the state of charge of the battery, this includes, the charge / discharge start time, duration and charging / discharging slope. Theoretically, the battery will be “shared” between the customer and the Distribution Network Operator (DNO) through the use of the charging envelope. The DNO will be able to communicate with the intelligent control, modifying the charging envelope to aid network management. Therefore, as well as the physical constraints of the battery, network constraints are also taken into consideration when determining the charging envelope.

The effect of using battery storage to absorb excess PV, peak lopping and reducing network constraints leads to financial savings across the whole of the energy system. Combining with variable tariffs this leads to greater savings in electricity tariffs. Therefore, the charging envelopes are expected to provide an approach determining charging/discharging period of storage battery together with a variable tariff. They are defined by predicted AC/DC loads, PV outputs, energy price variations and network pressures. Moreover, the charging envelopes are reserved for the integrated energy management system to call upon for unscheduled distribution demands.

The design of the charging envelopes aims to maximise the use of battery storage for both properties and DNOs. The battery charging profile is restricted when it is required to relieve network pressure, at other times the battery is available to the customer for PV charging and economy (Peak Lopping) charging.

Battery charging envelopes are collections of minimum and maximum state of charge within the battery. Using PV generation, DC demand and AC demand, the LV Connection manager will optimise the use of the batteries within the charging envelopes.

The battery charging envelopes are characterised by charging /discharging start time, duration and rate, indicating how much energy is available for charging and discharging at a given rate in the local energy storage. The battery optimisation for minimising energy cost will be operated between the upper and lower limits dictated by the charging envelope. Figure 1 illustrates the relationship between battery's real-time state of charge and charging envelope for demonstration purpose.

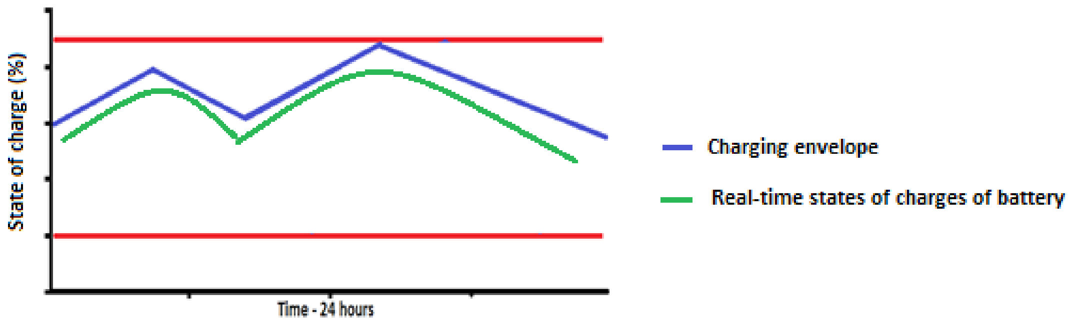


*Figure 1 Relationship between charging envelope and real-time state of charge*

The most important components of the battery charging envelops are the initial state of charge for charging/discharging, charging/discharging start time, duration and slopes. For different types of network constrains with varying strength and duration, the key parameters of charging envelope will be modified to reflect them.

Charging envelopes have an upper and lower charge window, and battery's state of charge is limited within the range defined by it. From the perspective of the physical basis of storage battery, the maximum and minimum state of charge depend on the basic attributes of storage battery. On one hand, battery charging is expected to be conducted in charging linear region which is from 0% to 90% of battery capacity. On the other hand, fully discharging a battery may lead to damage, or a reduction in its life. Therefore, the maximum and minimum state of charges proposed for charging envelope design are defined as 90% and 20% of storage capacity for the purposes of this project.

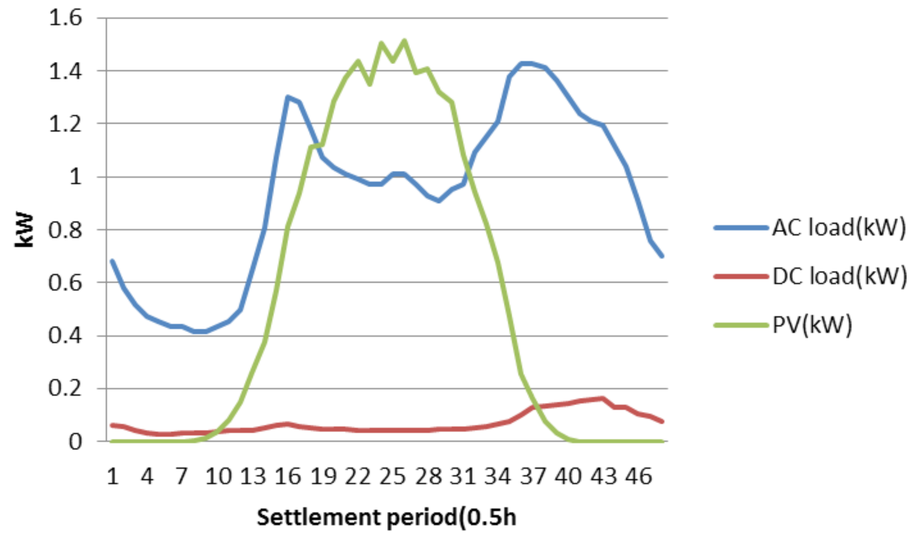


*Figure 2 Household load and PV output profiles in a summer day*

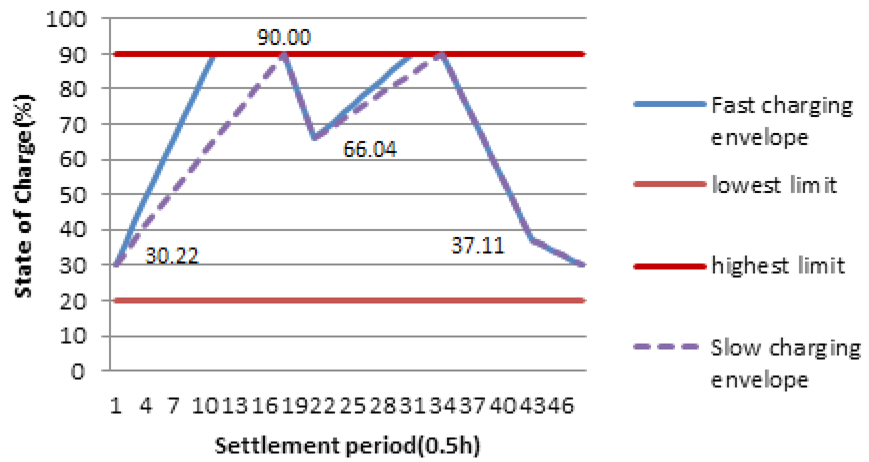


*Figure 3 Summer charging envelope for customers on Ilminster avenue substation*

In order to avoid unacceptable voltage violation caused by large distributed generation, battery storage is essential for charging from PV around the middle of the day. Based on the approach introduced in Section 3, the over voltage situations lasting from 10:00 to 14:00 require battery capacity reservation for charging

Therefore, both charging and discharging slopes in charging envelopes are linked to the degree of network stresses and the level of solar generation. In general, the discharging envelops are mainly designed for peak demand reduction during winter periods, and the charging envelops are designed to absorb high PV generation during high summer. Through rough estimation, a property would store from 967 to 1,282.96 kWh of energy per year.

**2.2.6 Variable Tariff**

The intelligent use of Battery storage combined with SoLa PV will reduces a customer's true electricity costs through a reduction in demand, especially during peak energy demand. Therefore the University of Bath have created a dynamic tariff that: Focus on whole system charges, is simplicity for customers to understand, transparent whilst providing stability.

**Introduction**

Household flat-rate electricity tariffs have been in existence for decades in the UK. At present, the vast majority of consumers purchase their electricity from suppliers at flat-rate tariffs, with no price variations throughout the day or throughout the year. In addition to the traditional flat-rate tariffs, a number of suppliers offer Economy 7 or Economic 10 tariffs, although these have significantly less customer volume, at around 9.7%. These tariffs feature a cheaper night or afternoon rate, in order to shift load from peak to trough, thus reducing energy consumption during the peak period. These patterns and their respective customer volume are generally used for settlement and tariffs.

The fitness of these flat-rate and Economy 7/10 tariffs is challenged in the application of the SoLa BRISTOL project, where high density photo voltaic (PV) generation is connected to the low voltage network. The present tariff structure is not sufficiently dynamic to reflect the inherent uncertainties in the supply system, hence, is not effective in following intermittent generation, or shaving peaks. The need for further development in electricity tariffs is analysed with an aim to support suppliers undergoing innovations to provide various tariffs for different types of customers to maximize their participation. The customer participating in this Project will be provided with a variable tariff to encourage electricity use at times of high PV generation and to use electricity stored by the battery when the network is heavily loaded.

SoLa BRISTOL proposes an alternative tariff coordinated with the LV connection manager to enable efficient usage of the in-home PV and battery. The variable tariff will be trialled on the domestic installations to incentivise customers to alter their demand profile, flattening their demand, reducing their peaks using the PV and battery storage. in cooperation with charging envelopes, the variable tariff will reflect energy price variation and will realise cost savings in energy generation, transmission, distribution and supply.

In general, variable tariffs enable price setting for each settlement period easily, and they are expected to encourage energy storage charging/discharging at appropriate time slots. However, tariffs with time varying prices are difficult for customers to understand. Therefore, in addition to the variable tariff supplied to the storage battery, a fixed tariff with discount is directly offered to the end users in the Project. It is not only easier for customers to understand, but also guarantees returns for the participants of the Project.

**Variable tariffs Types**

**Variable tariffs considered for this project**

The variable tariffs considered in this project are directed to real-time prices (RTP), with the support of charging/discharging envelopes, where real-time prices vary on a half-hour interval. Other tariffs that have been examined include time-of-use (TOU) tariff and critical-peak pricing (CPP) tariff.

In TOU tariff, a day is separated into several peak and off-peak prices for certain fixed time periods that are defined from historical supply conditions, which is an essential extension to Economy 7. CPP is an improved TOU tariff that traces critical supply period over time, and determines a number of critical peak rate, non-critical peak rate, and off-peak rates that are more reflective of real-time supply conditions. In contrast to the two tariffs described above, the price of RTP tariffs vary every half-hour, generally following the energy price variation effectively.

**Pros and Cons for Variable Tariffs**

Among the variable tariffs mentioned above, each type of tariff has its own benefits and drawbacks. These can be summarised as follows. A summary of the features of each type of tariff are given in Table I.

- TOU tariffs are simple for customers to understand, but are not closely linked to real-time energy price variation and therefore relatively inefficient and ineffective compared to a CPP or RTP tariff.
- As an improvement of TOU tariff, CPP tariffs with their critical peak periods are often associated with an extremely high unit price which reflects the critical peak energy price or network congestion. However, they require relatively accurate energy price prediction.
- Real time pricing provides the most direct way of reflecting dynamics of wholesale price variations throughout the day and throughout the year.

Compared with TOU and CPP, the RTP tariff would provide flexibility in an energy management system, so that there is total freedom to develop optimisation algorithms to either trace the few critical periods or optimise energy use throughout the day. Therefore, for this project, the RTP tariff is proposed, to take advantage of low energy price in wholesale market.

**TABLE I COMPARISONS OF EACH OF THE TARIFF TYPES**

| | TOU Tariff | CPP Tariff | RTP Tariff |
|---|---|---|---|
| Simple for understanding | x | | |
| Reflect real-time supply | | x | x |
| Efficient for responses | | x | x |
| Reflect dynamic energy price variation | | | x |

### Proposed variable tariff for the project

As mentioned in last section, the proposed tariffs have been selected as RTP tariffs in the Project implementation, and they will be categorised by seasons throughout a year. For each season, two types of tariffs will be designed for weekdays and weekends separately. Eventually, there will be 8 classes of variable tariffs for a whole year, to encourage energy consumption at appropriate times in different seasons.

### Benefits from PV and energy storage implementation

The benefits in terms of energy cost savings and network investment deferral need to be investigated in order to justify its usage. The quantification reflects the characteristics of LV networks through space and over time.

1. Wholesale Energy Saving: The energy bills paid by customers are calculated by their electricity use in each settlement period and the corresponding energy prices. The benefits in terms of energy cost savings as the result of introducing the integrated energy management system are calculated as the amount of energy consumption shifted from high energy price periods to low energy price periods.
2. Network Investment Deferral: The benefit in network investment deferral is determined by examining the peak demand reduction and the time delay in network assets' future investment, and then translating the time delays into network benefits.
3. Other saving: such as the saving from environmental charges.
4. Total Benefits: The total financial benefits are the sum of savings from the wholesale energy costs, network investment and so forth.

The breakdown of the cost of electricity for household electricity bills is shown in Figure 4. Each part of the cost in energy supply chain has been quantified in the illustration.

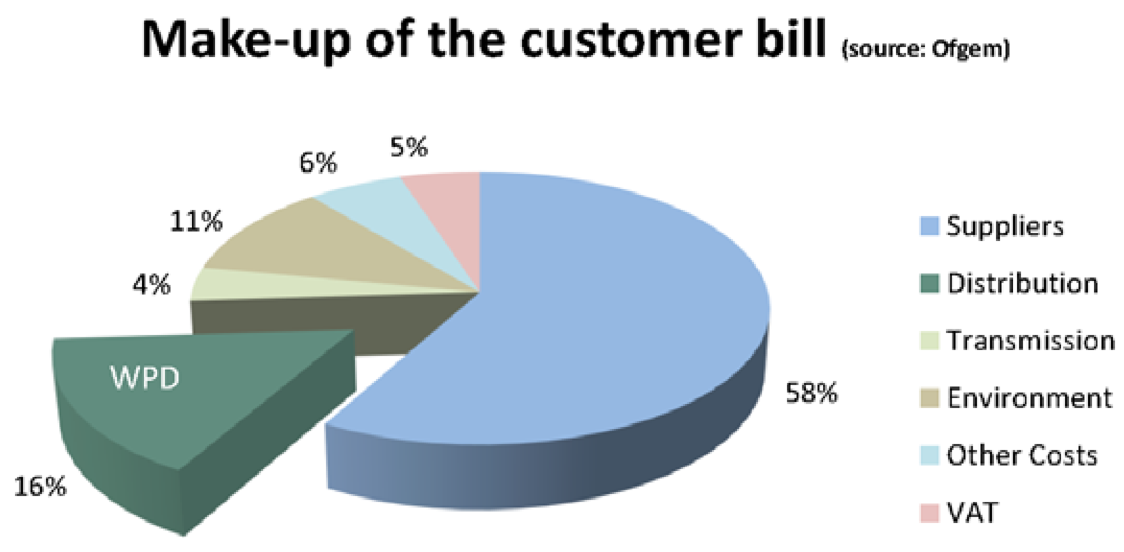


*Figure 4 Breakdown for household electricity bills*

### Variable tariff for storage battery

Since the load management is based on load forecasting and predicted PV outputs, short-term energy price information from APX Power UK has be used for the tariff design. The energy prices collected in half-hour periods in n weekdays/ weekends of a season.

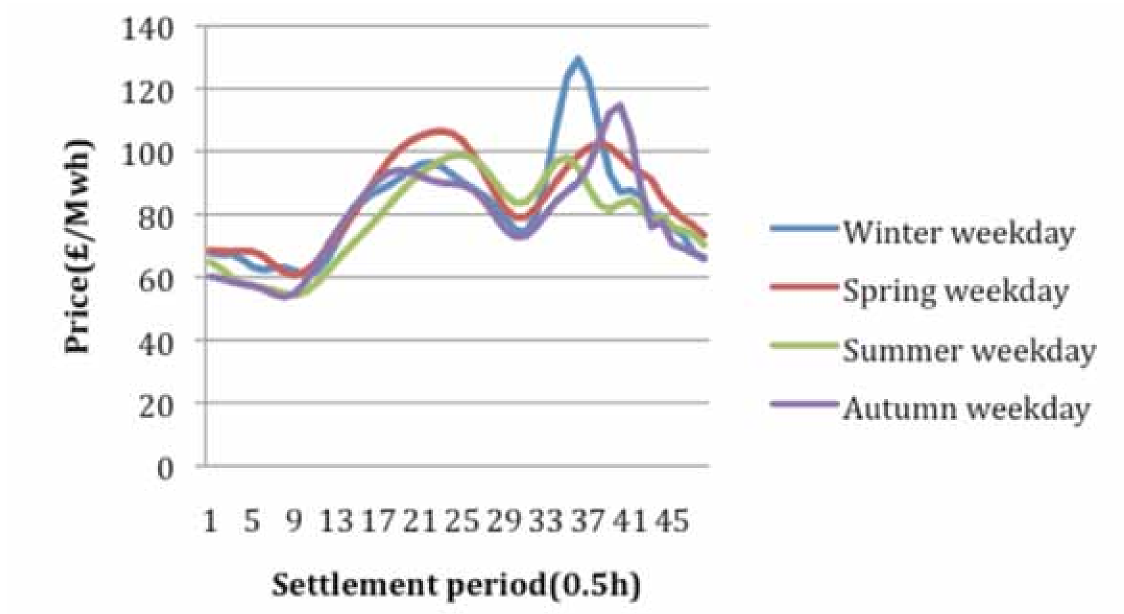


*Figure 5 Variable prices for weekdays in different seasons*

Once the energy price in each settlement period is determined, the energy price profile for a specific season in weekdays or weekends will be plotted. Moreover, as shown in Figure 1, the spending on energy occupies 55% of the total cost in the tariff. Therefore, the final tariff will be determined by scaling up the real-time energy prices. The eventual variable prices for weekdays and weekends in different seasons are shown in Figure 5 and 6.

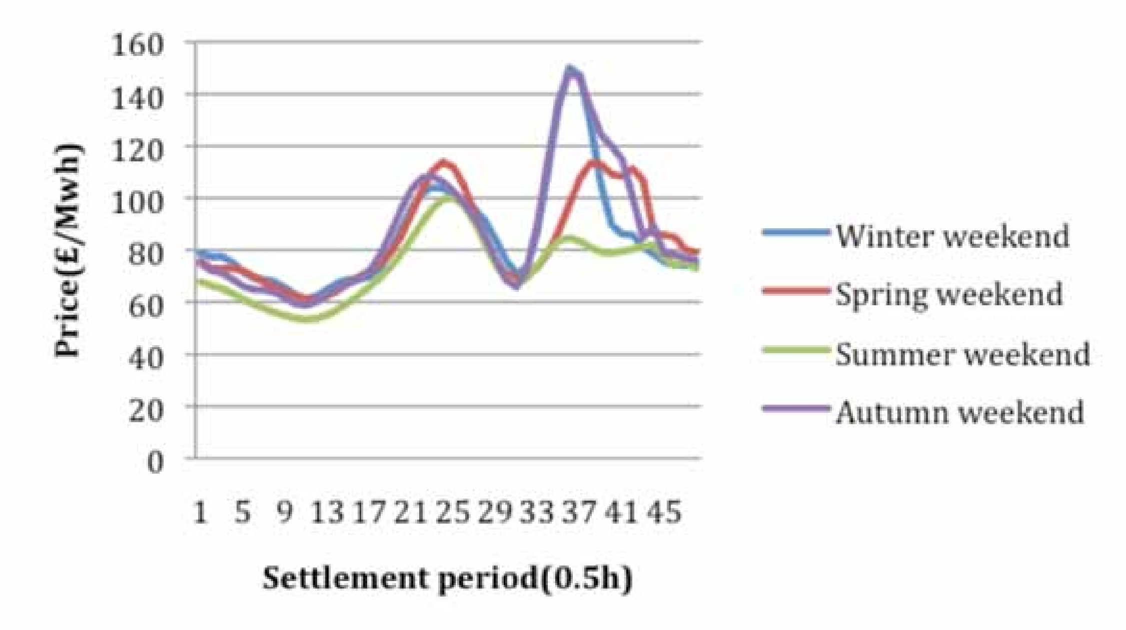


*Figure 6 Variable prices for weekends in different seasons*

**Fixed tariff for customers**
For storage with shared ownership between customers and DNOs, the benefits from energy shift with applying the variable tariffs will be combined with benefits from network usage, and together form the level of discount to customer's trialling the SoLa BRISTOL solution. Battery charging envelopes that force the system to absorb the solar PV, charge and discharge the battery during peak periods will provide a benefit on the use of system cost.

The benefit calculations are based on predicted AC/DC loads and PV outputs, and their consequential impacts on the network. According to the load demand and PV output information of real network data. The total benefit could be converted as the discount of price rate for users adopting the SoLa BRISTOL solution is a 17.2% discount. Unit rate (which is the quotient of total electricity bill and energy consumption from grid) will drop from 17p/kWh to 14.5p/kWh as shown in Table III. The amount of discount that customers will benefit is directly related to the benefits of the SoLa BRISTOL solution.

**TABLE III COST AND TARIFF RATE COMPARISON AT ILLMINISTER AVENUE SUBSTATION LEVEL**

| | Annual energy from grid (MWh) | Energy cost (£) | Use of system cost (£) | Others (£) | Total electricity bill (£) | Tariff (p/kWh) |
|---|---|---|---|---|---|---|
| No PV & storage | 1450 | 135609 | 56709 | 54244 | 246562 | 17 |
| With PV & storage | 933 | 74410 | 31117 | 29764 | 135292 | 14.5 |
| Cost saving | | 61199 | 25592 | 24479 | 111270 | |

The discount has been predicted using good engineering principles, If there are large deviations between the predicted and monitored, then the original benefit will be re calculated and the envelope design will be modified.

**Conclusions**
The SoLa BRISTOL project utilises an innovative combination of energy storage in customers' premises, coupled with new variable tariffs and integrated network control to overcome generation or load related constraints at key times of the day. Following a review of the main types of variable tariff available, a Real-Time Pricing (RTP) tariff was selected and the method by which the tariff will be developed was discussed. However, it was noted that such tariffs are difficult for customers to understand. Therefore, the total benefit obtained from PV generation and battery charging will be expressed to customers as a discount on a fixed tariff, which could be as much as 2.5p/kWh.

**1.5 DC Networks**
The DC Network has been successfully demonstrated in the EcoHome since the 14th December 2012, supplying DC lighting and DC sockets. Through the installation it has been demonstrated that that the load and voltage drop across the DC network is not an issue. The power consumption of the DC lighting is approximately 50% of the datasheet.

There have been no adverse comments from the EcoHome volunteers regarding the DC lighting quality and the second and third trial property participants were also happy with the EcoHome installation.

#### 2.2.7 SoLa Bristol Domestic Installations

The SoLa Bristol installation will only be progressed from the EcoHome to domestic installations after completion of the following criteria:

- Second and third property recruitment
- Following the EcoHome demonstration. Property 2 & 3 are now selected.
- Second and third property surveys
- The structural survey of the loft area is now complete, and the electrical surveys are underway. It is anticipated that the installs will commence before the end of June 2013.

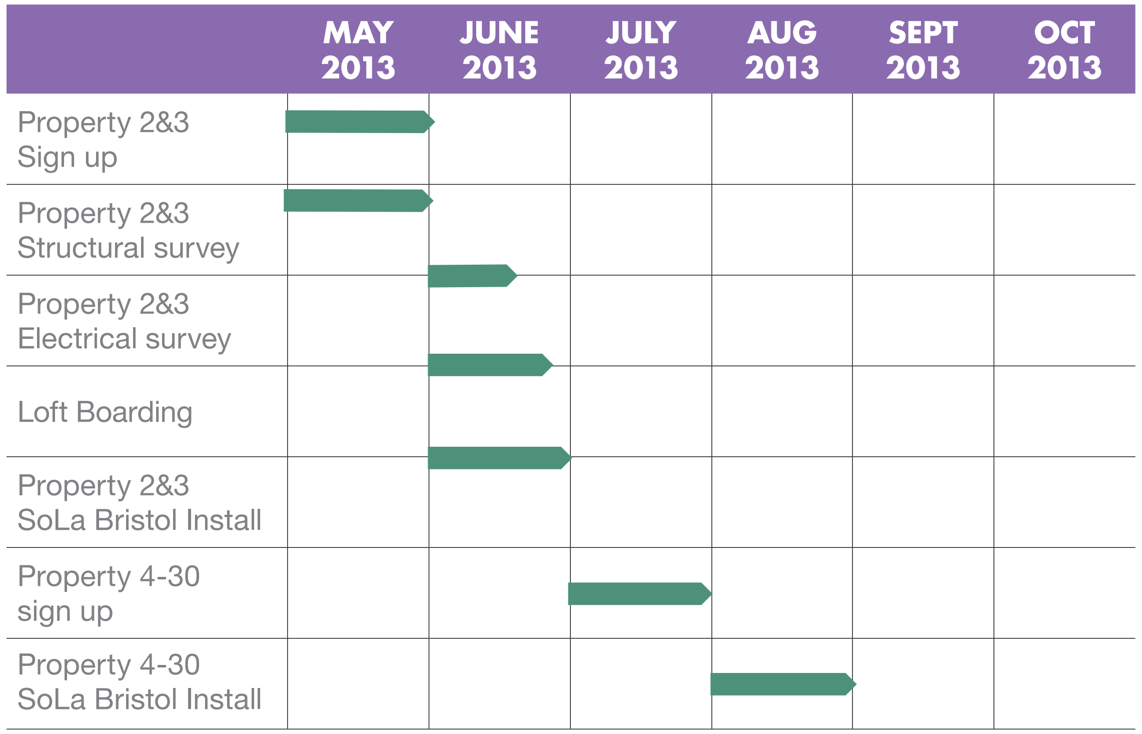


*Figure 7 – Project Plan for SoLa Bristol roll out – domestics*

#### 2.2.8 SoLa Bristol Office and Schools Installation

In order to attempt to complete the schools installations within the summer break. The schools engagement has started with preliminary surveys underway. The intention is to complete all surveys by end of June to enable installations to commence in July

#### Key Issues

Delivery has been delayed by the issues with DC/DC converter. The program now is to have the domestic installs progressing in parallel with the commercial ones throughout the July and August 2013.

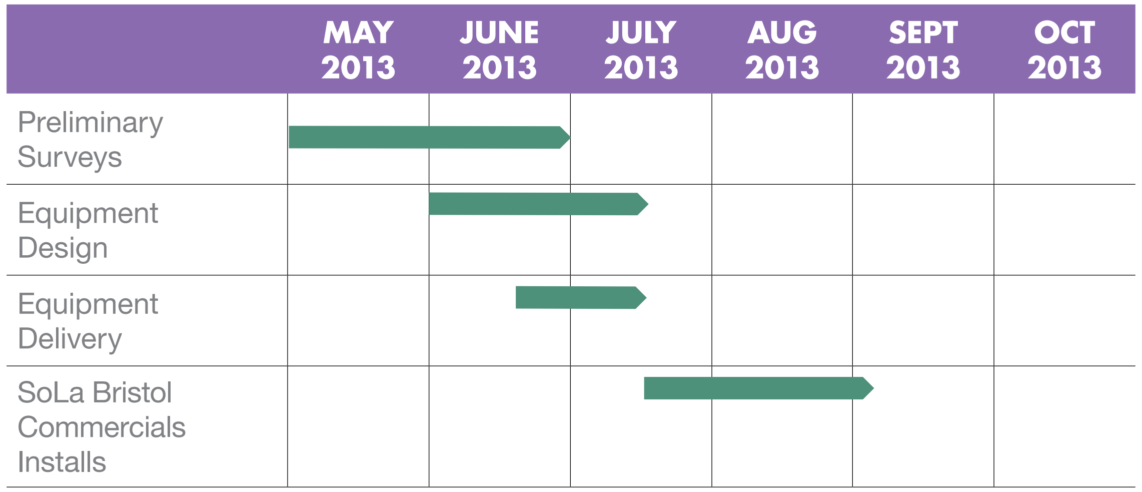


*Figure 8 – Project Plan for SoLa Bristol roll out – Office and Schools*

## 3. DISSEMINATIONS EVENTS

- **Disseminated to EcoHome volunteers**
  On the 2nd May 2013 a dissemination/ training session was held for all the EcoHome volunteers.
- **ESOF group**
  WPD hosted the February Energy Storage Operators Forum in Bristol. After the forum, members, the six GB DNOs and the GB TSO; namely Electricity North West (ENW), Northern Power Grid (NPG), Scottish Power - Energy Networks (SPEN), Scottish & Southern Energy Power Distribution (SSEPD); UK Power Networks, (UKPN), Western Power Distribution (WPD) and National Grid (NG) were all invited to visit BCC's EcoHome to view the SoLa Bristol equipment.
- **Business Plan stakeholder events**
  During this time we presented on the domestic equipment, how the design has evolved, the steps taken to ensure a safe installation, the installation procedure and the issues still facing the project.
- **Sustainability Live Event NEC Birmingham**
  The SoLa Bristol project was presented on 17th April at the Sustainability Live Event in Birmingham
- WPD met with Ian Borthwick, Portfolio Development Manager for the IET. The IET are investigating creating a standard/guide on the integration of electrical energy storage systems into buildings beyond the meter. WPD disseminated all the steps and considerations that had been taken regarding electrical, structural and fire safety. We explained the areas investigated, the areas discounted and the decisions that had been taken around the siting and sizing of battery storage, the circuit integration into the home and system intelligence, control, conversion and communications integration.
- **Future Events**
  The project will be presented at the Energy Institute Conference in Bristol in October 2013 and at the LCNF conference in November 2013

The proposal is for a standard/guide on the integration of electrical energy storage systems into buildings (i.e. 'south of the meter' applications, covering electrical/structural/fire safety, siting/sizing, circuit integration, control/inverter/comms integration).

- **Outlook to next period**
  In the next reporting period the project will be heavily involved in the installation phase of both the domestic and commercial properties, as well as the Sub-Station cabinet installations. In addition to this the communication and data transfer protocols will be finalised and implemented.

## 4. BUSINESS CASE UPDATE

No changes to the business case have been forecast at this stage. However, the increasing interest in energy storage beyond the meter has led to the IET investigating the requirement for standards / guides. This will significantly help the adoption of energy storage beyond the meter.

## 5. PROGRESS AGAINST BUDGET

BRISTOL remains on target to be delivered within the available project budget; delays in project delivery and where the payments schedules detailed in the collaboration agreements have not all reflected the expected spend during the 18 months of the project. The spend profile will be closer to the expected spend after the completion of the installations due to milestone payments dependent on the completion. Project outturn is not expected to exceed the 5% set out in the LCNF Governance document.

| | TOTAL BUDGET £K | EXPECTED SPEND TO END NOVEMBER 2012 £K | ACTUAL | VARIANCE £K OVER PERIOD | VARIANCE % OVER PERIOD |
|---|---|---|---|---|---|
| **BCC Project Management** | £60.00 | 28.33 | 16.70 | 11.63 | 41%[1] |
| **Detailed Installation Survey and Planning** | £57.00 | 57.00 | 0.05 | 56.95 | 100%[2] |
| **Training and Installations** | £203.00 | 42.50 | 40.90 | 1.60 | 4%[3] |
| **Trial Property Recruitment, Equipment Maintenance & Ongoing Support** | £177.00 | 48.33 | 35.05 | 13.28 | 27%[2] |
| **Equipment Decommissioning (including battery disposal)** | £198.00 | - | - | | - |
| **Scope change Contingency (Survey results)** | £49.00 | 39.83 | 20.90 | 18.93 | 48%[2] |
| **Data Communications (LV Connection Manager & LV Network Manager)** | £20.00 | 11.00 | 9.90 | 1.10 | 10%[2] |
| **Distribution Sensing Equipment** | £11.00 | 11.00 | 12.15 | -1.15 | -10%[4] |
| **Customer Sensors Equipment** | £2.00 | 2.00 | 2.14 | -0.14 | -7% |
| **Overall Project Manager** | £151.20 | 72.75 | 49.59 | 23.16 | 32%[5] |
| **Substation installation (including any civil modifications)** | £29.00 | 29.00 | - | 29.00 | 100%[2] |
| **Battery Charging Costs** | £9.00 | 1.00 | - | 1.00 | 100%[2] |
| **Variable Tariffs - Payments to users for changes in behaviour** | £9.00 | 1.00 | - | 1.00 | 100%[2] |
| **DC Meters** | £5.00 | 5.00 | 4.00 | 1.00 | 20%[2] |
| **SIEMENS** | £1,295.81 | 141.11 | 68.23 | 72.88 | 52%[2] |
| **System Design and Engineering** | £173.19 | 312.25 | 141.18 | 171.06 | 55%[2] |
| **Domestic premises equipment (supply)** | £358.37 | 271.43 | 118.98 | 152.45 | 56%[2] |
| **School equipment (supply)** | £302.02 | 28.17 | 12.34 | 15.83 | 56%[2] |
| **Office equipment (supply)** | £31.33 | 133.69 | 63.46 | 70.22 | 53%[2] |

| | | | | | |
|---|---|---|---|---|---|
| **Substation equipment (supply)** | £161.09 | 79.15 | 38.67 | 40.47 | 51%[2] |
| **Data archiving and access equipment (supply)** | £98.17 | 90.85 | 55.80 | 35.05 | 39%[2] |
| **Installation, commissioning and operation support** | £141.64 | 5.00 | - | 5.00 | 100%[2] |
| **Smart Appliances & ICT Equipment** | £30.00 | 51.71 | 38.96 | 12.75 | 25%[2] |
| **University of Bath** | £507.55 | 129.13 | 73.03 | 56.10 | 43%[6] |
| **Input to smart tariffing** | £122.91 | 38.58 | 37.49 | 1.10 | 3%[6] |
| **Input to network design** | £230.39 | 4.67 | 3.80 | 0.86 | 18%[6] |
| **Dissemination planning** | £118.25 | 9.33 | 7.61 | 1.73 | 18%[6] |
| **Workshops** | £12.00 | 28.33 | 16.70 | 11.63 | 41%[6] |
| **School engagement** | £24.00 | 57.00 | 0.05 | 56.95 | 100%[6] |

[1] *Awaiting recite of an invoice from Bristol City Council.*
[2] *Delayed in the spend profile due to the delay in the installation of the SoLa Bristol solution*
[3] *Payment of GPRS communications required for testing of the SoLa Bristol solution,*
[4] *Additional sensors purchased to reduce risk and increase learning generated by the project.*
[5] *The Project manager was shared with other T2 projects for extended period resulted in lower Project manager costs.*
[6] *The payments schedules are as detailed in the collaboration agreements*

## 6. SUCCESSFUL DELIVERY REWARD CRITERIA (SDRC)

Successful initial engagement with customers – KWMC is leading the domestic engagement; they visited customers identified from desk top analysis as suitable for solar PV and the BRISTOL solution. Interested households were left with the project leaflet (Appendix 1) and Frequently Asked Questions (Appendix 2). All customers were invited to the drop in sessions to speak to the project team and answer any questions. Two drop in sessions where run on 26th April 2012, hosted by KWMC and supported by BCC, Siemens and WPD. Two, two hour sessions where held between 11am – 1pm and between 6pm – 8pm. 22 people attended from 11 homes.

- 60 homes registered an interest in the project before 12th May 2012. Bristol City Council is leading the schools and office engagement; project details were sent to the head teachers of schools with solar PV already installed and a suitable office. In order to meet the target to install equipment during the summer break, the schools engagement and survey work commenced in June 2013.
- 12 schools and an office registered interest in the project before 12th May 2012.

**Initial Installation –** Due to the delays in the EcoHome installation with the DC/DC converter and the reluctance to install equipment in customers' homes until system confidence was high. The 2 trial homes have been delayed. The target is now the end of June 2013

**Confirmation of the BRISTOL design –** The Bristol Design was approved during the last reporting period.

**Installation and commissioning of equipment –** Due to the delays with the DC/DC converter issues in the EcoHome there have been considerable delays in the domestic and commercial installs. It is now proposed to run both programs together, over the summer of 2013, and complete all installations by September 2013.

**Early Operational Performance of BRISTOL,** the project is still on track to meet this successful delivery reward criteria.

**Measured the impact on the LV network,** the project is still on track to meet this successful delivery reward criteria.

**Customer Opinion**, the project is still on track to meet this successful delivery reward criteria

**Keeping the lights on during power outages**, the project is still on track to meet this successful delivery reward criteria.

**Suitability of solution for mainstream adoption**, the project is still on track to meet this successful delivery reward criteria.

## 7. LEARNING OUTCOMES

1. Having an area like the EcoHome has been essential to allow the project to get to roll out.It has also helped to overcome installation and equipment performance issues without disrupting customers.
2. The realisation that the FAT cannot always adequately simulate the real installation scenario and some issues are not spotted.
3. Although it is understood that customer engagement can only come after the initial system has been tested and approved, some form of pre survey access, particularly in the schools and office would have been an advantage.
4. When installing new equipment extra time needs to be allowed for overcoming potential issues. Any changes to planned works must be approved by all relevant parties and recorded

## 8. INTELLECTUAL PROPERTY RIGHTS (IPR)

No Intellectual Property Rights have been generated or registered during this period. It is not anticipated that any IPR will be registered over the next reporting period.

## 9. RISK MANAGEMENT

Report any risks highlighted in box 26 of the full submission pro forma plus any other risks that have arisen in the reporting period, and describe how you are managing the risks it has highlighted and how it is learning from the management of these risks.

| | RISK | UPDATE |
|---|---|---|
| **R002** | Energy efficient smart appliances used for demand response are not available in the UK when required or appliances cannot be retrofitted (making them smarter) | Due to the limited development of smart appliances in Europe, there is no viable product we can offer domestic properties, further analysis will be completed to understand if smart appliances can be used in the schools and office. |
| **R004** | When surveying properties, the BRISTOL scope of works must change, resulting in unanticipated cost variations. | The condition placed on the project through the project direction prevents the project from visiting participants' properties. This has required a more generic design, with increased risk of variations in the project delivery. This risk now has an increased probability and impact. The scope of works has increased to include a G59 relay and commissioning for the project as detailed above. |
| **R006** | Thirty homes do not volunteer to participate in BRISTOL in one area, connected to one distribution substation. | 30 domestic customers have had solar PV fitted to their homes in Knowle West. When these customers had their solar PV fitted by BCC it stated that having solar PV installed would allow them to be considered for the SoLa solutions (but did not commit them to it) The risk participants drop out or do not commit to the project after the initial installation is still live. |
| **R007** | Ten schools do not volunteer to take part in the project. | We have engaged with 26 schools that have had solar panels connected, 12 have registered interest as well as KWMC. We are continuing to review the possibility of installing a BRISTOL type solution into schools that have temporary class rooms with PV panels, increasing the number of eligible schools. Schools' applying for academy status has placed an increased risk on the project as an increasing number of schools no longer use Bristol City Council for maintenance and IT. |
| **R009** | Bristol City Councils M&E teams or normal qualified electrical contractors are unable to install and maintain the premises BRISTOL equipment | Bristol City Council will install the DC network and batteries in homes, six BCC electricians have been successfully trained on the installation of the SoLa Bristol equipment. The electricians picked up the installation process very quickly and had no issues with the equipment assembly and installation during training.<br>An electrical contractor will be contracted for the schools and office installation. They have commenced preliminary surveys to assess the suitability of selected schools. |

| | | |
|---|---|---|
| **R013** | The equipment is too heavy to be stored in the roof space. | BCC have reviewed the risk for domestic properties, surveying empty properties of the same construction. The equipment must be spread over a minimum of 3 roof trusses by boarding out the loft. The project will spread the 5 loft trusses; The structural survey has been completed and there are minor modifications to the roof supports required.This will not impact on the project installations.<br>The risk of the equipment being too heavy to be stored in the roof space has been decreased. |
| **R014** | There is no suitable location to store the equipment in homes, schools and an office | This risk is on-going as we are currently surveying the schools |
| **R023** | Bristol City Council are unable to support the customer engagement and installations | WPD and BCC are ready to start the domestic properties installations. The arrangements for the schools and office installations will be started July 2013 in order to complete during the summer break |

## APPENDIX 1

### BATTERY CHARGING ENVELOPE DETERMINATION

Once battery capacity reserved for discharging is determined, the corresponding charging process will be decided in the charging envelope design, so as to store enough energy for discharging. When the battery charging process is conducted from the grid to the storage device overnight, charging current can be selected from a series of charging slopes. In the study cases, 25Amps and 14Amps charging current are selected to represent fast charging and slow charging processes which are shown as the first non-coincident slope between blue solid and violet dash lines in Figure 4 and 5.

Following economy charging overnight, the second discharging period occurs to free more capacity in battery for PV charging. This period lasts for an hour from 8:00 to 9:00, corresponding to the morning peak in domestic energy consumption. As shown in Figure 3, the daily output of a typical PV is 4.48 kWh from 10:00 to 17:00 in winter. If the whole PV output is supplied to

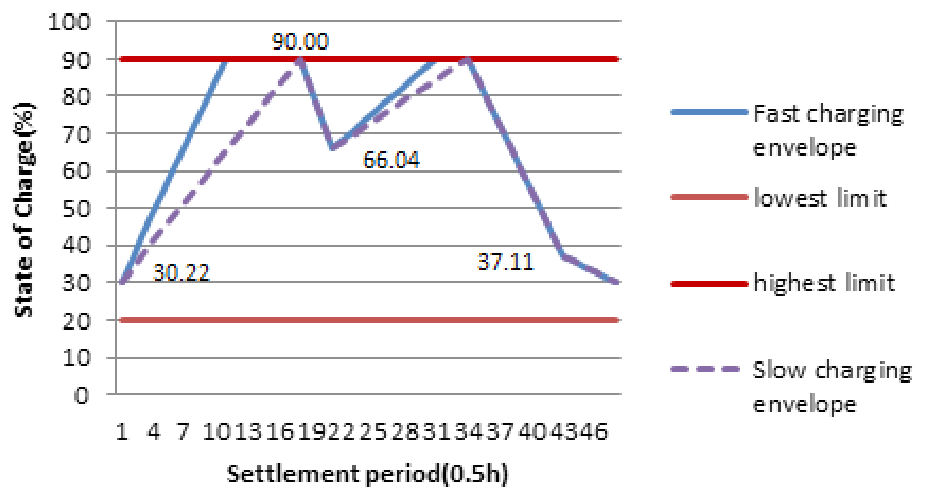


*Figure 4 Winter charging envelope for customers along feeder 0011 and 0012*

the battery, it has to be deeply discharged for present power release. Besides, due to the uncertainty of PV generation, the daily output is not guaranteed and, indeed, may vary significantly.. Thus, with the assumption of 25% of the typical output as the minimum distributed generation, 23.96% of stored energy is required to be discharged to cover this amount of PV generation and the state of charge limit will decrease to 66.04%. Then, the fast or slow battery charging limit will be represented by the second non-coincident slope between blue solid and violet dash lines in Figure 4 and 5. Excess electricity generated from the PV can return to the main grid.

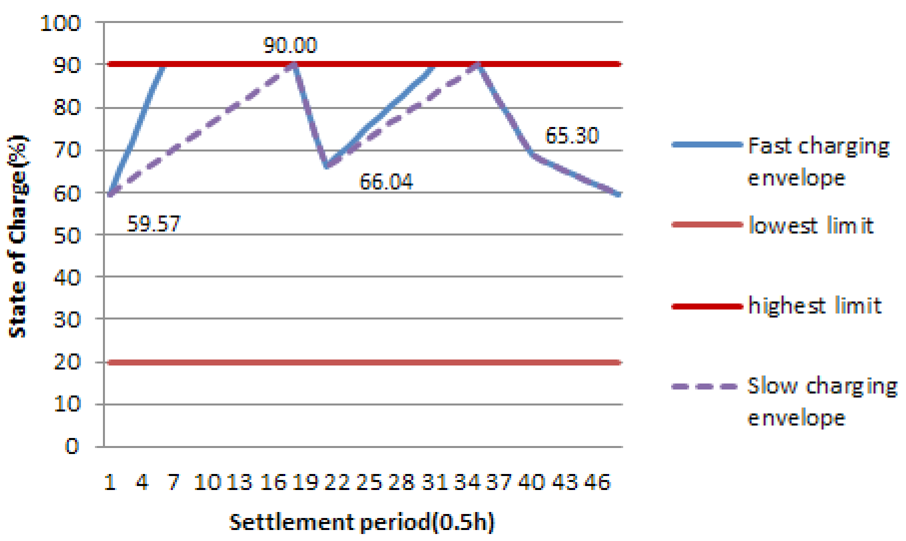


*Figure 5 Winter charging envelope for customers along feeder 0021*

To summarise, winter charging envelopes for domestic customers along Feeder 0011, 0012 and 0021 in Illminster Avenue are illustrated in Figure 4 and 5. The peaks of charging envelopes generally occur at the end of off-peak charging in the morning and the end of PV charging period in the afternoon. The peak value could reach 90% which is determined by the characteristics of storage battery. In a typical winter day, 4.32 kWh of energy is estimated to be stored for a household in Feeder 0011 and 0012. Customers under Feeder 0021 only store around 2.59kWh energy per day.

In different seasons and networks, charging envelopes for storage battery will change following variations on demand and PV generation, and their consequential impacts on network thermal and voltage constraints. In highly stressed network driven by thermal limits, the energy required is higher for the same time period. This requires steeper discharging slopes to release the network stresses, and is associated with the upper envelop limit. However, when solar generation is strong in summer, charging envelope will be impacted on lower envelop limit. In this case, storage charging capacity will be reserved for periods with strong solar irradiation for potential voltage violation mitigation, and the charging slope is dictated by the strength of predicted solar irradiation.

Under the same network condition, the daily load profile [2] with morning and evening peaks, and PV output [3] for each typical household in summer is shown in Figure 6. Compared with winter scenario, peak demand drops slightly but PV output is nearly five times as much as that shown in Figure 3.

## GLOSSARY OF TERMS

| TERM | DEFINITION |
|---|---|
| **DNOs** | Distribution Network Operators |
| **PV** | Photo Voltaic |
| **DC** | Direct Current |
| **AC** | Alternating Current |
| **BCC** | Bristol City Councils |
| **PDRA** | Post Doctorial Research Associate |
| **FAT** | Factory Acceptance Tests |

# NOTES