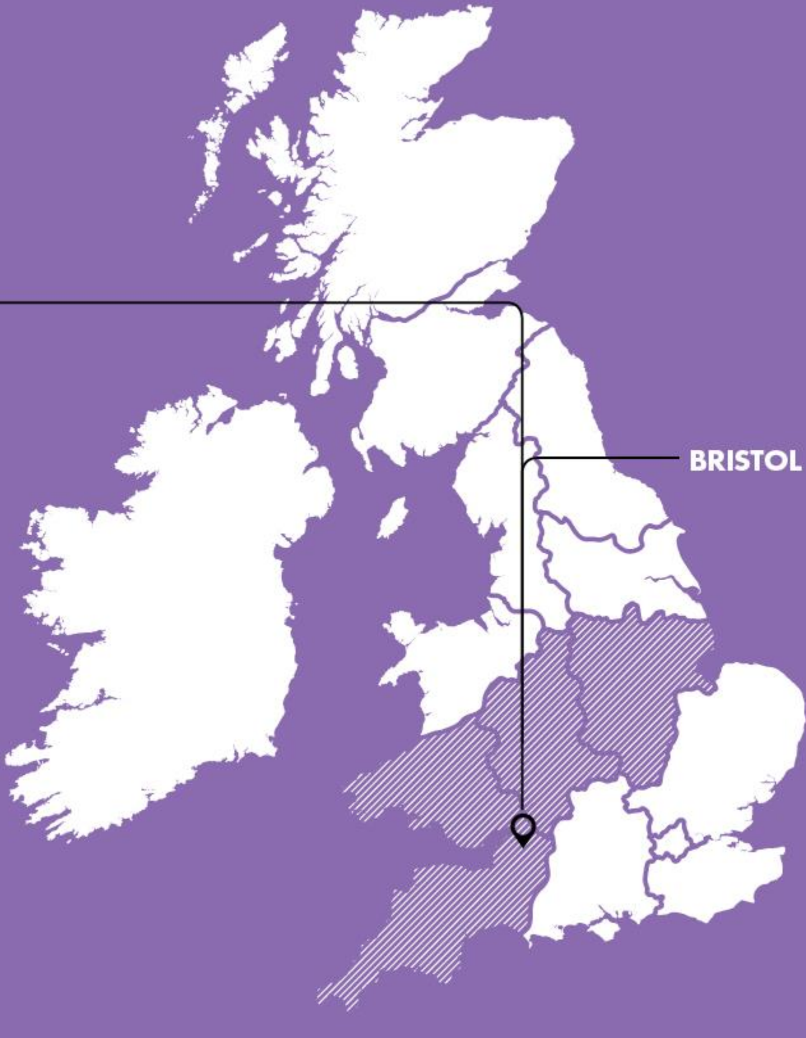
WESTERN POWER DISTRIBUTION

SOLA BRISTOL

PROJECT SOLA BRISTOL



LCN Fund Low Carbon Networks · Bristol City Council · University of Bath · Knowle West Media Centre · SIEMENS

Report Title	:	Early learning report
Report Status	:	Draft
Project Ref	:	WPDT2003 – SoLa BRISTOL
Date	:	22.12.2014

Document Control

	Name	Date
Author:	Surendra Kaushik	22.12.2014
Reviewed by:	Mark Dale	23.12.2014
Recommended by:	Roger Hey	23.12.2014
Approved (WPD):	Paul Jewell	23.12.2014

Revision History

Date	Issue	Status
22.12.2014	Issue 1	For approval
23.12.2014	Issue 2	Final for submission

Contents

Executive Summary 3
1 Introduction 4
2 Project Structure 6
3 System overview 7
4 Data Analytics 11
5 Interim Learning 14
6 Future Work 18
Appendix-1 LED Lamps 19
Appendix-2 Shadowing 21
Appendix-3 DC Only Contribution 23
Appendix-4 AC contribution 26
Appendix-5 Combined DC & AC 28
Appendix-6 Sub-station Monitoring 31
Appendix-7 Tools 32
Appendix-8 Emulator 34

Executive Summary

This interim report summarises the learning generated to-date by Western Power Distribution's (WPD) SoLa Bristol[1] Project, funded by Ofgem through the Low Carbon Network Fund (LCNF) second tier mechanism.[2]

SoLa Bristol is an alternative method to enable high density photovoltaic 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. The trial uses in-home battery storage to provide benefits to customers and aid the DNO with network management. Twenty-five houses, five 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, and a set of DC outlets will be installed to enable customers to run small appliances 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 that arise when a number of customers in a local area connect PV solar panels to their house
- investigate how a battery installed in a property 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).

During SoLa Bristol the project has worked with a range of participants, including householders, schools and office workers as well as project partners, which include charities, universities, councils and technology companies. Working with a wide range of partners has involved being flexible in the way that the project members work and communicate. In the following report we discuss some of the major stages of the project and our approaches to understanding the learning that arose from these.

[1] Buildings, Renewables and Integrated Storage, with Tariffs to Overcome network Limitations

[2] http://www.ofgem.gov.uk/Networks/ElecDist/lcnf/stlcnp/Pages/stp.aspx

1 Introduction

Project SoLa BRISTOL; Buildings, Renewables and Integrated Storage with Tariffs to Overcome network Limitations, is a Low Carbon Network Fund project, investigating the implications of investing in DC micro-grids with local battery storage within homes, schools and offices. This provides distributed storage for both the consumer and the local utility. This storage is monitored by the utility through their sub-stations and can be used to support the network when required.

The project's lead organisation is Western Power Distribution, the local electricity Distribution Network Operator. A number of partners are contributing to demonstrate the intended outcome through this consortium, contributing to various aspects of the project through their specialist knowledge and position.

The project objectives are to integrate storage-capable-renewable-distributed energy generation sites into the local electricity distribution network and to study the effect of this integration. The second objective was to introduce DC-micro grid within the properties, enabling AC-lighting loads to be shifted to DC-lighting loads, alongside providing DC device charging capability for devices types compatible with USB device charging specifications such as mobile phones, tablet computers and any other devices capable of being charged using USB sockets.

Bristol City Council is the site facilitating organisation, Siemens Ltd are the technology platform provider along with their sub-contracting organisations. Knowle west media centre's active contribution is in providing the client liaison role and the University of Bath is the academic partner.

Similar to all other partners, University of Bath has multi-faceted role within the project. Amongst these are, contributing to core technology development through to analysis of the system's operational performance and potentially post project data analysis. In another equally important role the University is engaged in creation of the next generation Tariff Structures, with the view to study the impact of tariffs on demand side reduction in the local Distribution Network. Further, the University's role also encompasses the study all aspects of Social impact of integration of new technology and to capture changes associated with user's energy outlook.

This technology demonstration project has its installed base in the city of Bristol. The installed base consists of 26 homes, 11 substations, 5 schools and 1 office. All properties are equipped with local DC-storage capability. Only the domestic properties have solar PV directly integrated into this DC-micro grid system. The larger installations including schools and office do have solar PV installed but is not directly connected to the DC-micro grid system.

As part of the project an educational aid has been developed, enabling engagement of the pupils and teachers from participating schools through delivery of web based technology. This schools engagement and interaction tool and its usage, are covered in a separate, customer focused early learning report.

This report broadly covers the electrical engineering aspects of the project from installation through to operational parameters analytics within premises. A separate report is being compiled to provide customer focused early learnings aspects.

2 Project Structure

The project management structure on the ground consists of Western Power Distribution (WPD) as the project lead organisation providing the use of their distribution network for the project and in some way the ultimate customer for equipment at the sub-stations and the operational aspects of the equipment at the installed sites. In this capacity, WPD have been actively engaging and interfacing with all project partners at frequent intervals.

Siemens Ltd are the lead technology providers and in that role are responsible for design, delivery, acceptance, commissioning and decommissioning of the entire system. Due to lack of specialist suitable equipment available off-the-shelf, Siemens had to have some external solutions provider with contributions in their specialist knowledge areas. Custom design equipment had to be specified due to the nature of operation of the system. As part of this external interface, Siemens were performing management and monitoring of design methodology, documentation, delivery schedules, product acceptance and approvals activities as well.

Bristol City Council (BCC) had primary role on three different fronts. BCC were instrumental in providing both the domestic and commercial installation sites. These properties are BCC owned properties with sitting tenants in domestic properties. The schools and Office properties are also in active use.

BCC also provided financial support for installation of the conventional PV systems in all properties. All participating households had their properties surveyed for suitability for installation of PV panels on their roofs and some associated remedial work had to be carried out to make certain properties suitable for the equipment of the project. Conventional PV installations companies were used for PV installation work. The PV panel installations were then handed over to Project SoLa Bristol without the conventional inverters.

All properties had conventional AC-lighting. BCC also had their domestic property lighting-wiring converted from AC to DC use, with new sockets and switches. The system design was conceived in 2012 and has three major components based at different locations and is covered in next section.

3 System overview

This project's prototype installation was a standalone property, the 'ecohome', which lead to the development of networked homes that have been online for some time. Presented below is an overview of the system. This distributed system comprises of sub-stations, homes, schools, office and a data repository. All these properties are attached to their allocated sub-station for dual-end performance monitoring and analysis.

A simplified view of the SoLa Bristol system, as described in the system specification, is shown in figure 1. The system comprises of three distinct sub-systems. These are geographically dispersed and are identified as the Data Repository Equipment (DRE), Sub-station Equipment (SE) and the User Premises Equipment (UPE). All three sub-systems have bidirectional communication capability utilising both the public-radio and public-IP networks.

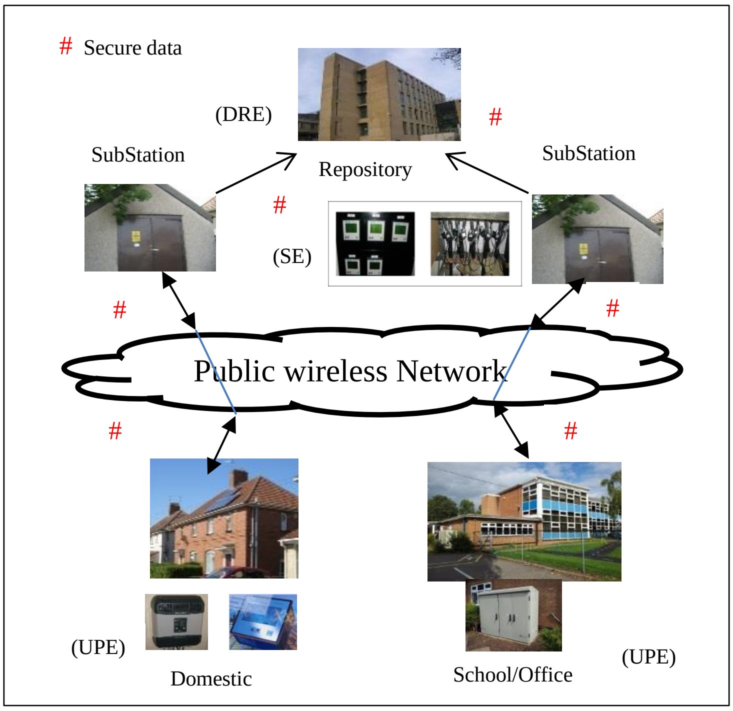


Fig. 1 SoLa Bristol distributed system

The user premises equipment (UPE) can broadly be classified into two categories, Domestic & Commercial. Though both are grid connected storage systems, the domestic UPEs are single phase units with integrated PV sub-system, and the commercial UPEs are three phase systems with PV sub-system as standalone.

The PV installations differ from site to site depending on the available roof area for solar panels and their make, model, efficiency, inclination and orientation. The domestic PV installations range from 1.5kWp to 2kWp except ecohome which is a 3.4 kWp installation. The commercial (schools and office) installations also vary in their PV plant sizes, for instance one typical school is 8.9kWp and others are larger.

All installations in this distributed energy storage system use valve regulated lead acid (VRLA) batteries. The battery storage system capacities are 4.8kWh for domestic sites and 22.5 kWh for commercial sites. All properties are wirelessly linked through sub-station equipment (SE) to the Data Repository Equipment (DRE). All inter installation communication's data contents are encrypted.

User Premises Equipment (UPE)

The domestic UPE is depicted in Fig. 2 showing the various sub systems from PV generation, meters, storage through to output to the grid. The domestic lighting has been converted to run on 24Vdc LEDs. This reduces the domestic ac-lighting load by shifting it to DC. The DC micro grid's nominal operating voltage is 24Vdc and the entire house's DC load now is sub 100 Watts which includes lighting, USB sockets and the Sola Bristol system itself with its communication and control components.

The battery charger from PV side is a custom device & Grid side inverter/charger had been specifically designed for a 24Vdc system. The domestic user has access to the generation and usage data through the tablet PC, which is updated by the system's in-home WiFi.

The system has metering capability both on the PV generation side and on the ac exporting side. The radio modem provides the link to the sub-station and supports the data encryption.

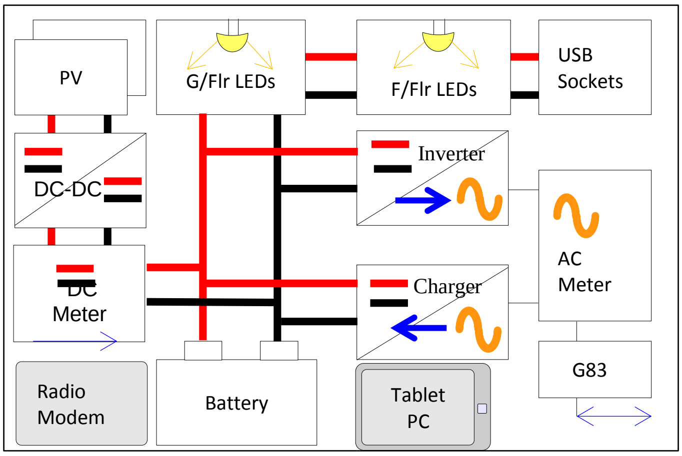


Fig.2 Domestic system details

UNIVERSITY OF BATH

As mentioned earlier, the energy storage system uses VRLA batteries, the domestic properties use four 12Vdc block batteries (12V 200 Ah each) in a combined series/parallel combination. The commercial systems use 12 cells which are series connected (2V 940 Ah) to provide the 24Vdc nominal bus voltage.

All domestic properties barring one use the same make and model of batteries. The exception is the very first installation, which uses FiAMM battery blocks. This would provide opportunity to compare battery performance from two different battery manufacturers.

Sub-station Equipment (SE)

The sub-station equipment was designed to provide monitoring and communication capabilities at the sub-station. The supply-side monitoring data at the sub-station is used for quality of supply study. The SE is a vital communication link for appropriate parameter passing to its associated sites. Each group of domestic, school and the office installation has its own associated serving sub-station.

A total of 11 sub-station monitoring sites have been installed. Substation installations provide the capability to monitor up to five feeders, with each feeder consisting of three phases. The metering equipment is as shown in Fig 3 below.

Fig. 3 Sub-station monitoring Meters

The sub-station feeder sensors are shown below.

Fig. 4 Sub Station CT Sensors

The SE also serves as communications hub for the domestic properties within the area. The user premises equipment (UPE) receives configuration and control data through SE and reports all its data through the same SE. The data repository equipment (DRE) receives this data for storage and future analysis. The lowest number of homes on a sub-station is two and the largest number of homes on a sub-station is fourteen.

Data Repository Equipment (DRE)

The data collected by this equipment is categorized as ‘high’ and ‘low’ granularity data. This data is further classified as ‘local’, ‘remote’ or ‘in-transit’ data. The high granularity data is one minute averaged data and is retained within the property and the low resolution data, sampled at fifteen minute intervals, is exported out of the property. The low resolution data provides the system’s operational status in upstream direction and remote commands to the system equipment flow in the downstream direction with reference to the sub-station.

Varying amounts of system operational data is collected within different equipment. The entire system’s operational status indicating data amounts to around 6 MB per day. The data generated can be polled or spontaneously accessed depending on the nature of the data content. In the event of a fault condition data is spontaneously provided to the substation and subsequently to the DNO.

Data Repository Equipment is currently located at Siemens Labs and is scheduled to be transferred to University of Bath in near future. The anticipated date for this transfer to take place is during first quarter of 2015. The provisions are in place to have the necessary restrictions and secure access to this machine. There is a dedicated IP path into the University of Bath for this data to be deposited.

Access to this machine is to be controlled by Siemens.

4 Data Analytics

As all external communications are based predominantly on wireless technologies, precautions are necessary to prevent unwanted access to the site data and site equipment by third parties. The communication system is based on Internet Protocol with Virtual Private Network (IP-VPN) over the public-wireless (GPRS) Wide-Area-Network.

This communication infrastructure enables the Networked-homes, schools and the offices to provide their operational data to the repository via their sub-stations. This dataset comprises of data that is sampled at fifteen minute intervals.

For user privacy and security reasons, three precautions are taken. All data transmitted out of any property is encrypted while in transit. In order to further strengthen non-infringement of user's privacy, all site data is anonymised. Only partial data is transmitted out of the premises.

For equipment security considerations, the communication system is access restricted through password and static IP addressing within the dedicated routers at each location. Each site's local area network side has exclusive and restricted access to the local data.

The current setup for the Repository access is through a VPN connection via a Private APN terminated as an interface within an application. The associated ports and protocols have restricted access as these traverse through Firewalls.

For additional in-transit security, all devices have awareness of each other's IP addresses and therefore can't be changed without considerable effort. The Repository also has persistent static routes defined for SoLa subnets that routes data through the Service providers VPN tunnels to the destination address.

The system wide data is categorised into four data-types namely In-system, In-property, In-transit and at-repository.

In-System data

This data set contains one minute averaged values of system behaviour. It always remains unencrypted. These minute by minute averaged values are retained within the equipment. This data is not remotely accessible, physical access is the only retrieval mechanism available.

In-Property data

This is the data that is consumed by the property occupier in form of system performance and usage data. This consumable data is not buffered and has time dependant lifespan. User premises are provided with a Wi-Fi setup which conveys this data to the Tablet PC. Access to WiFi data is restricted with password for the intended user. The tablet PC data delivery is encrypted.

In-Transit data

This is highly guarded data and has anonymity as well as encryption associated with it. Only the essential data traverses the property boundary. This always passes through the Sub-stations network.

At-Repository data

The data received at the Repository is considered as "historic data" and is stored in unencrypted format, still maintaining user anonymity. It is used for analysis and archiving purposes. It is anticipated that there would be around 13-15 GB of unprocessed data.

The data received at the repository is passed through a three stage process, identified as

"Merged and Sort"	A tool was developed for this operation providing 'MS data'.
"Visualise"	The same tool provides individual parameter visualisation.
"Analyse"	A second tool was developed to further process the 'MS data' that provides statistical results for individual parameter for analysis. The data is analysed from Absolute, Statistical, Limits, Envelopes, Environmental and Interdependence prospectives.

During analysis process various output file types are generated which have graphical and textural formats. Appendix-7 provides details of the data flow through the tools and the outputs generated.

Domestic Property Study

A single site's PV generation is summarised in Table 1. This table covers six days in June 2014 which was one of the highest output months. Over these six days total PV-generated output was around 30.5kWh.

The day-to-day 'perceived value' changes depending on how the generated energy is used. For instance, if entire DC energy was exported by the property a £1.22 export subsidy gain could be seen as one limit. This amount does not include the generation subsidy, which varies depending on the site's installed date and ownership of the PV plant on site.

If however, the energy was stored and utilized within the property (as DC) during peak periods, the saving could be seen as AC-import-reduction, which if calculated at 17pence per kWh would have amounted to £4.42.

The benefit due to battery usage split is likely to be somewhere between these two limits. Further analysis of the financial implications of battery usage split in relation to a proposed Time of Use tariff is underway.

H01 PV generation with battery charging and 30% export to grid.						
Property H01 June 2014	PV Output kWh	DC Value @4p/kwh pence	DC Value @17p/kWh pence	SOC range	Charge split benefits Battery	Charge split benefits AC Exported
19 June 14	2.385	9.54	40.54	67%-90%	Analysis is Ongoing	Analysis is Ongoing
20 June 14	5.902	23.60	100.34	61%-90%		
21 June 14	6.026	24.10	102.44	62%-90%		
22 June 14	5.250	21.0	89.25	62%-90%		
23 June 14	4.953	19.81	84.20	59%-90%		
24 June 14	5.989	23.95	101.81	56%-90%		
TOTAL	30.505	122 .00p	442.58p	30% Range		

Table. 1 Perceived benefits of PV generation and export to grid

The 'charge split' benefit analysis is a multipart process. The distinct elements being considered for calculation are, total PV generation, fraction used for battery charging, fraction being exported and fraction being consumed by the DC load. A further element is included which is based on utilisation of stored energy during day time generation period (day time) and its utilisation during off peak period by the DC load.

The relevant data required for this calculation has a mix of both high and low granularity data. This dataset consists of accumulated energy values at various points within the system.

5 Interim Learning

This trial has been providing and continues to provide opportunities to learn about various aspects of distributed generation and storage system. The project partners, contributors and the participants have all had learnings through the course of this project. This section primarily covers the following aspects of learning.

Planning and approvals

L1 All properties within this trial are BCC properties and during pre-installation consent stage the property insurance related issues arose and were resolved between BCC & WPD. This introduced some delay in installation of the initial trial system.

L2 A custom designed dc-dc converter had to have regulatory approvals before it could be used. In spite of streamlined processes being in place it is a lengthy process. One major obstacle was obtaining a test slot with accredited labs and that introduced some delays.

L3 Site approval was also found to be challenging. As this was the first system of its kind with battery backed storage system connected to the grid, capable of exporting to the grid. MCS approved site certification engineers were reluctant to signoff the complete installations as MCS certified. As the MCS scheme does not have a specific category of battery backed storage systems. This was resolved by providing external G83/G59 approved device controlling the system operation domestic and commercials properties respectively. Special dispensation from WPD for connection to the network as a development/demonstration system was also sought.

L4 During early product development process similar grid connectivity challenges were encountered as all grid connections of such equipment in the UK have to have a site specific certificate. This was resolved using Narec's simulated grid setup. Narec's test setup is an enhancement on a conventional Motor-Generator-Set type of grid simulators, which are utilised under lab conditions.

Installation space related

L5 The first installed property's PV panels had seen shadowing from the adjacent building. This could not be avoided as both buildings are fixed structures. Further details are provided in Appendix-2.

L6 Within the properties the lofts were identified as best compromise spaces for housing the equipment with the reason that this would reduce the unintended or accidental interference to the equipment by the occupants and non-infringement of the living space within the property. External to the building installation was also considered for domestic properties, but on the grounds of unwanted ease of access by third parties and potentially large weather proof equipment housing, this was not pursued. External equipment installation would have benefitted the project personnel to gain access to the equipment without disturbing the users.

L7 From battery operational temperature prospective alone, in-building installations are a better proposition due to the inhabitable temperatures within in the buildings. Operational temperatures of the conventional lead-acid batteries of 20-25^{O}C are closer to the inhabitable temperatures for optimum performance.

Contrary to this, from the view point of equipment with power stages within them, that generate heat during operation, on-average lower ambient temperatures are preferred, such as those found external to the buildings. Loft space was found to be the acceptable compromise with all aspects considered.

L8 During last summer, loft temperatures were observed to be as high as 35^{O}C in loft space in certain properties. No sub-zero temperatures have yet been recorded within loft space.

Majority of the equipment is installed within the loft space barring the consumer unit, which in most cases, is installed in the hallway of the properties. The inverter and the switchgear boxes, which require support of a load bearing wall, are located next to the common solid brick work walls between the adjacent properties.

L9 The batteries are loft-floor mounted on reinforced rafters. The loft space rafter Strengthening and 'equipment lift' through the access hatch took longer than expected, leading to at least one additional site visit per property than planned, staggering the work within the loft space.

L10 Within the schools and offices, location of the battery & control cabinets are external to the buildings. The locations of loads were within reasonable distance from 24Vbus, with the exception of a school, which has the highest DC load. In future this has the potential for improvement.

L11 The school with highest DC system load happens to have the longest DC cable run. During commissioning it was observed that the voltage drop along the cable had increased the lighting load current and a consequence the current increase caused the MCB to trip after a period of operation. This was resolved by splitting the DC load over multiple circuits.

Operations related

L12 During 2013 hurricane force winds, one property had developed a roof-felt damage leading to water leakage on to the inverter installed within the loft space. No risk situation developed as the system operation had stopped. The self-reporting of the system status had not been commissioned. This condition lasted for a number of days and upon request from the residents of the property a site visit was arranged, and during this site visit the water ingress problem was noticed. An immediate decision was taken, on safety grounds, to replace the equipment which could have been damaged or degraded due to water ingress, pending further investigation of the state of the equipment. Some remedial work had to be carried out, after which the property had been brought back on line.

L13 The first commercial installation, considered to be similar to an office, had had microwave motion detection installed in series with the lighting units to enable automatic switching On and delayed switching-Off of the lighting units upon motion is detection. Initial site survey showed that the usage is such that during usage of the room, at least the instructor or presenter always has some motion associated with them leading to some movement while the room is in use keeping the lights On during occupancy which turned out not to be the case while single PC user was suing the room.

Motion versus Presence detection situations arise in places such as libraries and offices, where, though the occupant is present but remains still for some considerable period which turns out to be longer than the present delay time of the motion detector.

This suggests a need for an enhanced motion detector, referred here as the Presence detector. These detectors can be seen as those that activate not only on motion detection but also remain active during detection of human presence.

User Premises Equipment (UPE) related

L14 The first two trial homes, during commissioning, had faced some intersystem communication issues. The UPE incoming message delivery path through to the destination device passes through four different devices, sourced from four different manufacturers.

The difficulties arose due to existence of multiplicity of protocols and the central translation device’s handling capability of the messages. To overcome this, two versions of modified hardware and software were used to provide consistent operation. During factory acceptance tests, the communication system operations were tested using simulated test paths.

This situation could not be averted as there were no single solutions present on the market at the time. Some high voltage (above 24Vdc) systems have come on market since then.

L15 Within domestic properties, two total battery exhaustion were encountered and remedial measures were taken using additional hardware in form of low voltage load disconnect device and user visible voltage indicator.

Both domestic and schools have had occasional disruption to operations due to low voltage detector activation.

L16 The operation associated with the first gatekeeper device, the router, is to authenticate, decrypt, accept or reject incoming messages. This equipment needed configuration changes on site due to equipment delivery mix-up.

L17 At the start of the project, 24Vdc LED lamps were not as commonly available as these are now. Some early LED failures were reported and investigation revealed less than acceptable work quality. This could not have been known at the time. Further details of the findings are presented in Appendix-1

L18 At development stage the battery status processor's (BSP) output was considered to be true reflection of the state of charge of the battery. This holds true under certain conditions, such as, the system periodically has the opportunity to fully charge the batteries and remove any accumulated measurement errors. This change is being implemented.

Voltage related

L19 The key component of the system is the combined inverter/charger which after period of operation of over three months, started to show signs of battery overvoltage. This charge leakage issue was seen as critical a fault within the system and the equipment manufacturer was contacted. After investigations by the manufacturer the recommendation was to update the system software which was completed. As a result of this major change, a second factory acceptance test had to be conducted at Narec's test labs. Current system software version is V536.

L20 Battery cable polarity identification. At one property pre-assembled battery cables were found to have incorrect polarity. This was reported to the cable manufacturer and remedial action taken by the supplier.

L21 Battery under voltage. Subsequent to introduction of low voltage disconnect, battery under voltage still occurred. This is under investigation. The current assessment is that the system's ability to instantaneously respond to excessive loading and an attempt to support this sudden large change causes the LVD trip to take place. This is specific to certain properties.

6 Future Work

The future work relates to, work that needs to be carried out during and prior to project completion before handing over to the owners in the original state, prior to commencement of the project. With the operational data at hand, certain specific domestic properties can be identified for these in-situ tests, undoubtedly adding some extra time to decommissioning process.

University's Emulation test bed and tools development based model testing work can be on going if the students are inclined to take these types of projects. The tools and Test bed details are in Appendix 7 & 8.

During project phase

Prior to completion of the project two simulated test conditions are to be applied to the system as a whole to study the following.

Concerted export effects	winter study
Concerted export effects	summer study
Simulated	Thermal pressure reaction
Simulated	Voltage sag / swell compensation.

During decommissioning

During decommissioning and removal of equipment from site, some lessons could be learnt by observation made at the site and the state of condition of the equipment. In domestic properties these pieces of equipment are located in the hallway with habitable temperature environment and the loft space, which experiences full temperature variations related to time of year fluctuations as well as system's operational temperature variations.

After a period of field operation, the study of equipment's electrical performance under Lab conditions can provide a valuable suite of information. The suggestion is to return certain custom designed equipment to the original equipment manufacturer with the view that, with their in-depth design knowledge, some additional lessons could be learnt.

During and post decommissioning, certain tests could be carried out on various pieces of equipment in-situ, which otherwise would not be possible. The batteries could be tested in Lab which can reveal comparative state of health, for future reference. These tests primarily consist of Charge acceptance capability, Charge retention capability, Thermal performance and Cable connector conditions etc.

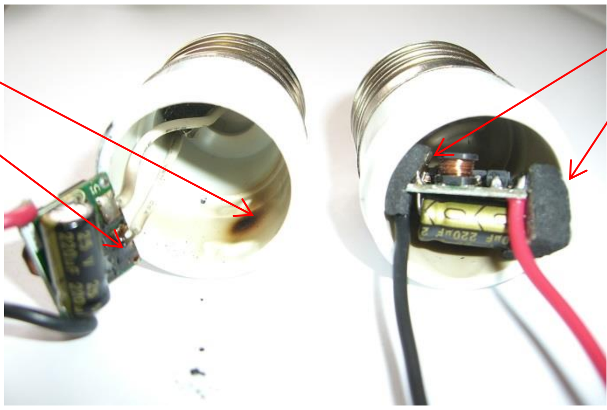
Appendix-1 LED Lamps

During the early stage of the project two domestic properties and one commercial property saw early failure of LED lamps. In all five domestic lamp failures have been reported amongst all trial properties. The time of failure was reported to be during 'in-use' operation and not on initial 'switch-on'. The samples were removed for investigation.

There are two types of lamps in use within domestic properties. The bathroom lamps are of superior IP rating to prevent moisture ingress. The rest of the domestic property has conventionally shaped lamps with E27 fitting.

On residential returned units, Initial visual inspection showed that the switch mode driver for the LED had been damage to the point of destruction with markings in surrounding areas.

Heat damage
Damaged IC

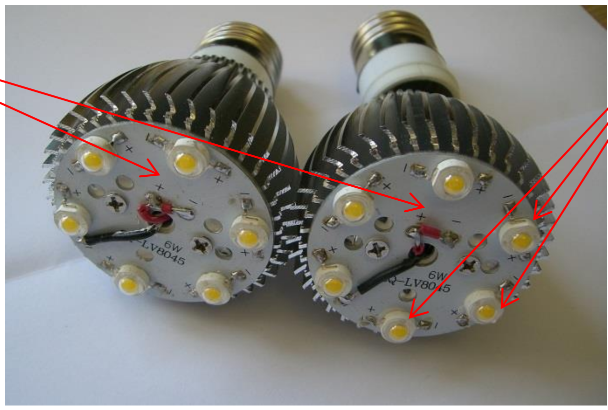


Poor board retention
Using insulating foam

Fig. A1.1 Damaged LED lamps

The driver ICs voltage ratings were checked and were found to be suitable for use within this system, so overvoltage failures mechanism was ruled out. Initial 'switch-on' failures can be caused by driver oscillator not starting up or having a slow start-up time, both of which lead to large current leading to failure. This was also later ruled out after further testing.

Poor design
(Prototype ?)

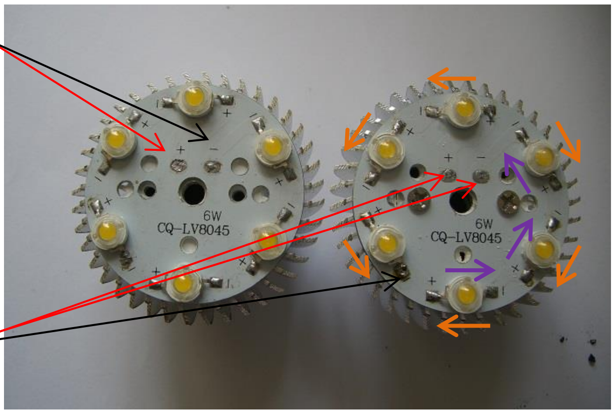


Reversed LEDs

Fig. A1.2 Incorrect silkscreen marking

The LED mounting polarity and the silkscreen polarity are visible in Fig. A1.3 below

Expected power in



LED orientation + → -
Board Marking - ← +

Actual power IN
See Fig.A2.2 above

Fig. A1.3 LED power & orientations

Visible thermal damage was caused by destruction of the driver IC. The rise of the driver IC temperature was identified to have been caused by degrading LEDs.

All six LEDs were functional, though severely degraded as shown by the measure current mismatch as shown in Fig. A1.4. Individual LEDs were driven by constant voltage of 2.9Vdc (blue) and current variations from 7mA to 22 mA (yellow) were noted.

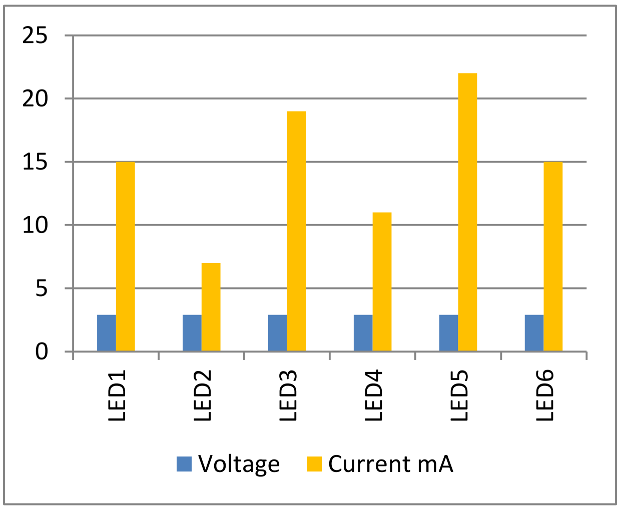


Fig. A1.4 LED degradation (current variations)

The optical performance of the LEDs still needs to be established using integrating sphere at the University Labs. The first commercial site also had LED panel malfunction after a short period. The LED panels were submitted to the supplier and a report was received indicating failure mechanism, as thermal build up within the driver housing. Remedial actions were taken by the supplier and replacement LEDs were fitted, which have been operational since replacement.

Appendix-2 Shadowing

Shadowing from nearby structure in urban environment is a known issue in PV installations, which, in some installations this cannot be avoided. This Appendix depicts the effect of the shadowing problem. During high summer, data collected showed one installation had no PV generation around 4pm even on bright sunny days. This pattern repeated itself for a period and an investigation was carried out. Site visit at that time showed that the problem was due to shadowing from the adjacent building.

Figure A2.1 below shows two traces of a twenty four hour period, starting at midnight. Purple trace has three operational states marked as Charge, Export and Idle. During Charge: Off peak charging from Mains is allowed if required. During Idle: Battery supports the DC loads and charging from PV if output is available. During Export: (9am-5pm) battery is being charged, DC loads are being supported and surplus to requirement PV energy is exported.

Fig. A2.1 blue trace shows the battery current while PV output is available, export current is marked as “Exporting” and during night same trace shows a charging attempt from the Mains side. In this case a charging attempt starts immediately stops around 11pm, as the batteries are nearly full from days PV charging activity.

The shadowing period is marked in red, the purple trace shows the operational state of the system showing no export to grid during this period. This installation suffers from shadowing effect leading to overall reduced system efficiency.

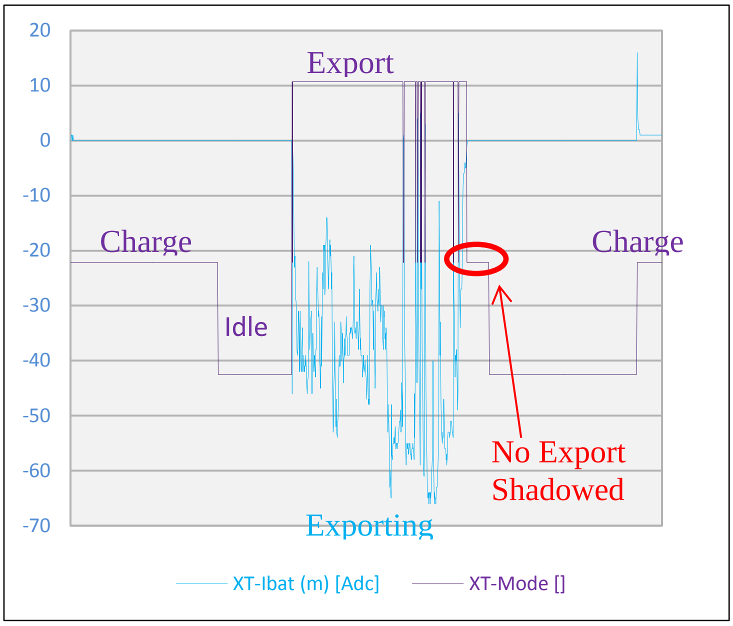


Fig. A2.1 EcoHome operational modes

From around 3:30pm onwards, shadowing starts due to scaffolding erected around the building in the background as shown in Fig. A2.2

Inappropriately designed charge controllers (DC-DC converter) known to have created catastrophic PV panel failures under partial shadowing conditions. The causes of these types of failures are localised hotspots. This system reduces the extracted current from the PV panels under shadowing conditions.

Fig. A2.2 EcoHome shadowing

These scaffolds were removed after a period of time and the normal system operation resumed.

Appendix-3 DC Only Contribution

This appendix provides system performance in DC only configuration. Benefits calculations are based on local DC usage from the battery during non-solar periods. In order to obtain unadulterated data for DC lighting usage, one property was selected where the battery charging was through the PV output only.

All DC loads were supported by the battery throughout the week. The DC loads include the self-loading of the system which is around 12 Watts. This is significant when compared to the user's DC load and has scope for improvement in future rollouts.

The plots are taken from high granularity data from property H02 for one week (9^{th} -15^{th} Jul 2014) which is one of the highest yielding months. Here only the PV generates the power to keep the batteries fully charged. The DC load support is provided by PV & Battery combination. The AC supply is not connected to the system.

Fig. A3.1 shows the Battery's 'state of charge' in green trace and the blue trace shows the battery voltage during battery charging process. The State of charge fluctuating between 95% to 100% for a 4.8kWh battery may be perceived as apparent overcapacity, it was deliberate, to keep the lights on during consecutive non-solar days and to enable battery-capacity-split-tests could be carried out which is another requirement of the project.

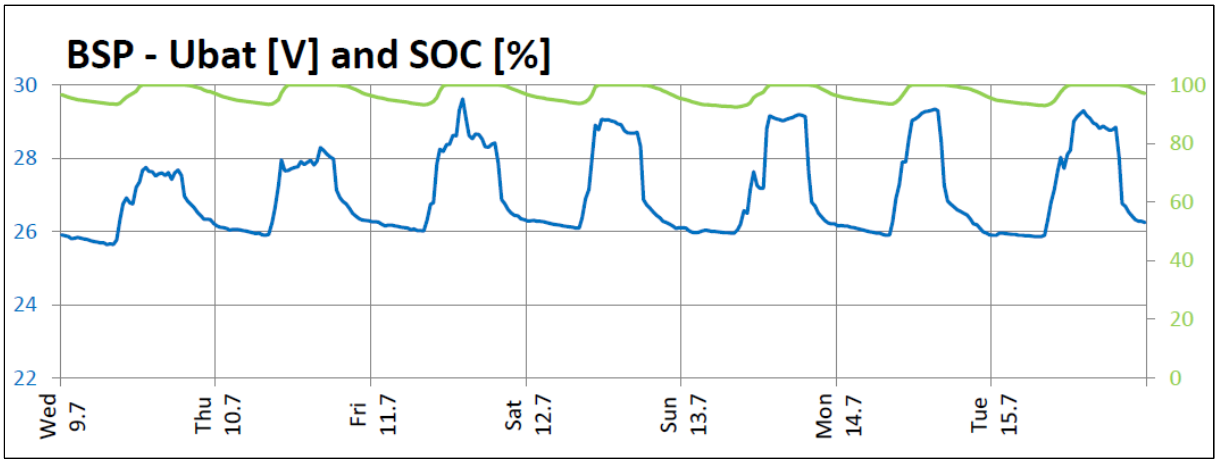


Fig. A3.1 PV only maintained Battery SOC & DC Loads

Fig. A3.2 below shows the battery currents for the same period of seven days. All positive currents are the battery charge current components derived from the PV and the negative current values are result of battery supporting the DC lighting load and the system's self-load.

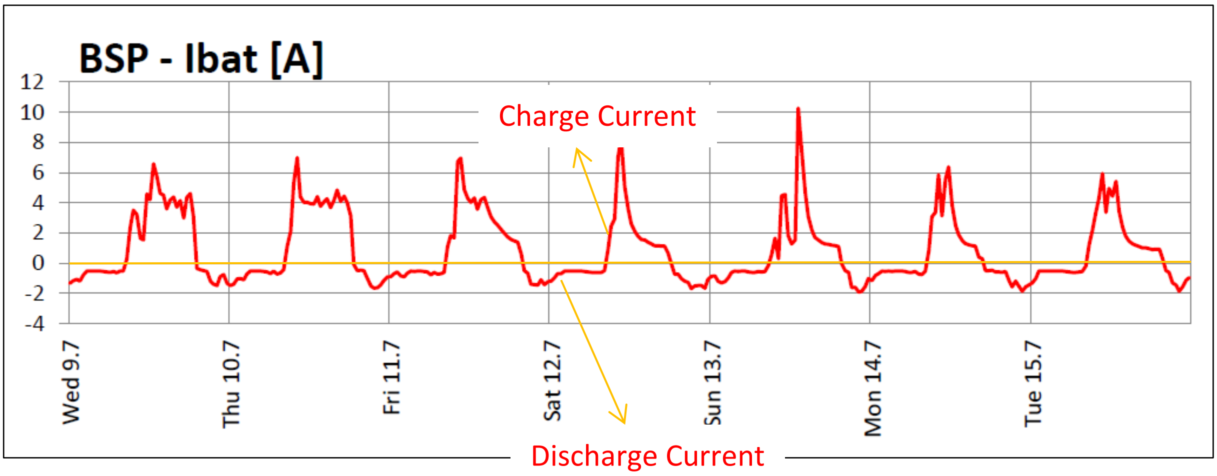


Fig. A3.2 PV charge current & Load discharge current

To keep the user anonymity, another property's DC supported load current is shown for one evening's high load period. This expanded view in Fig. A3.3 shows 6-watt lighting loads being used at various locations within the house hold. The maximum watts being consumed within entire household is below 55Watts DC from around 10:15 to 10:30pm.

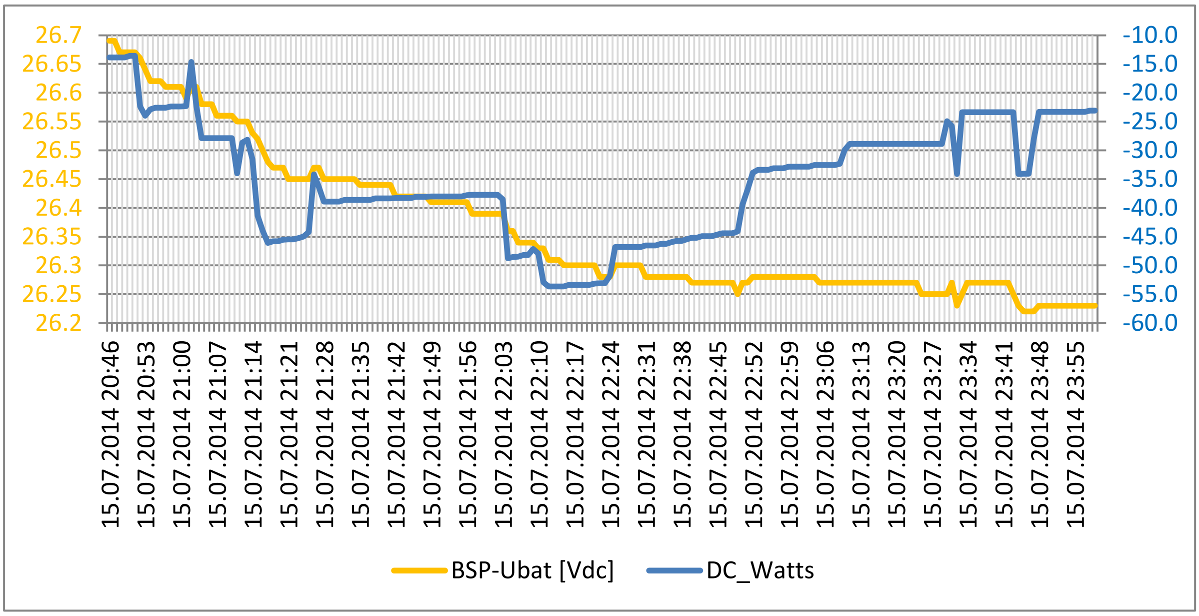


Fig. A3.3 DC only high load period of a property

Each lighting unit is rated at 6Watts DC. This indicates there are six LED lamps in use consuming 36Watts. The AC equivalent lighting load would be consuming 240Watts. (based on 9Watts LED lighting = 60 Watts AC lighting) This shows the AC load removal benefit for the DNO and reduced power consumption from the User's view point.

Plots below show a twenty four hour period for two consecutive days of April 2014 at another property. Text highlighted text (in blue) alongside the plots show the NET exported ac energy for the day. The negative value of (ac) kWh on the input port signifies energy being exported out of the system. On 14th & 15th Apr 2014 the site's export contribution towards the grid was 4.98 kWh and 5.1 kWh respectively. Taking these export figures with export tariff of for example 4.2p/kWh, without the generation subsidy, the user's net perceived gain was 20.91pence on the 14th & 21.67pence on the 15th Apr. This excludes the gains to be had by using the storage and utilising stored DC energy during peak period for DC lighting.

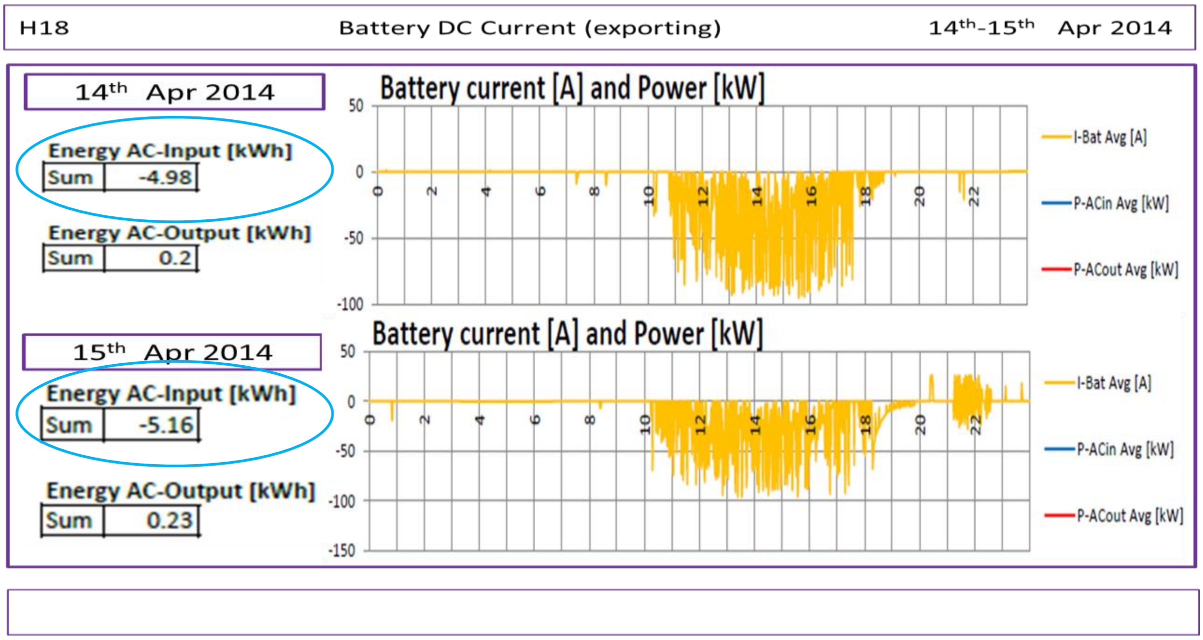


Fig. A3.4 Domestic property DC bus currents

Appendix-4 AC contribution

In this appendix, keeping user anonymity, data from two other properties are tabulated. This data is derived from high resolution data-set which is one minute averaged data. This data was obtained during site visits and represents the measured ac output to the domestic property before the incoming meter. The calculations are based on the inverter's output and not the net export to grid meter.

Table A4.1 below provides a snapshot view of the AC contribution of the system on four consecutive days in 'Spring'. This does not show the benefits discussed in appendix-4. The inverter is a bidirectional unit interfacing to the AC grid. The convention used is that the negative energy flow is towards the grid from the system and positive energy is energy imported from the grid.

The presumptions made here are independent of the parallel study dealing with variable tariffs and their impact on user behaviour. Here the simple assumptions made are that export to grid income for the household is at 4.3 pence per kWh exported and the energy import costs the consumer 17 pence per kWh. The import tariff varies from consumer to consumer and their agreement with their supplier.

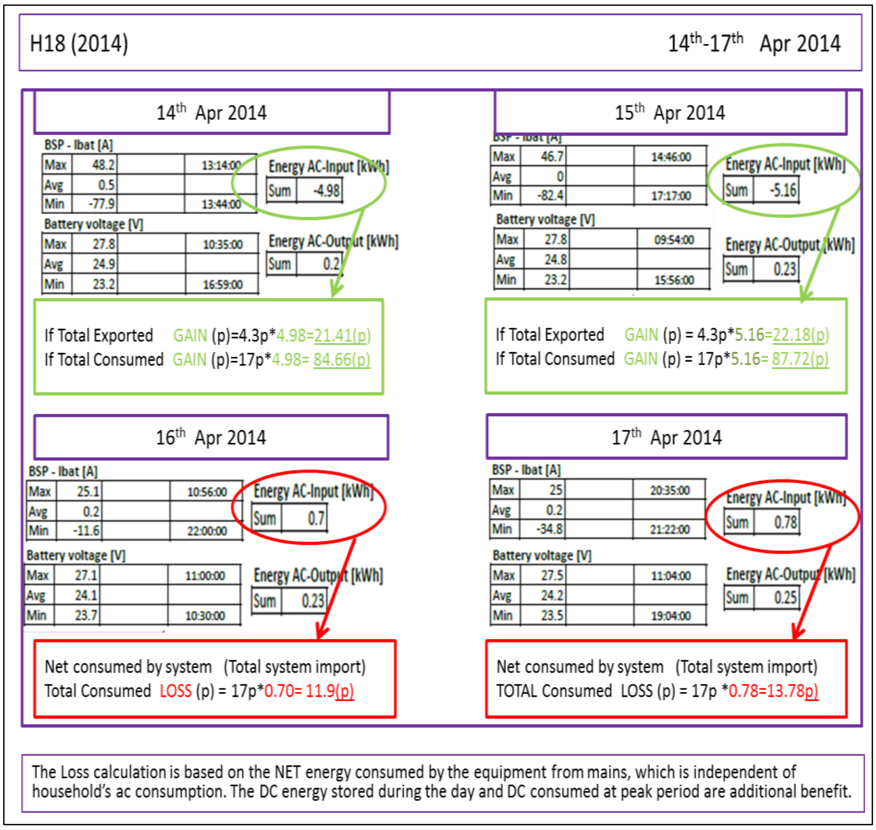


Table A4.1 PV output dependant Export to grid (spring)

On 14th 4.98 kWh was exported by the equipment on to the domestic AC lines which are before the incoming AC meter. If there were no AC loads within the house, all 4.98kWh would be contributed to the Grid, earning the consumer 21.4pence. If however, the AC base loads within the property were active, and were such that the whole of the 4.98 kWh was consumed by the user's AC base loads, then the consumer's perceived gain would be 84.66pence. (green text above). Applying same reasoning to the data of the 15th April, the consumer's perceived gains would be 22.18pence and 87.72 pence respectively.

On 16th & 17th Apr the table A5.1 shows net loss. This is effectively net result of low PV output on those days and the system had imported 0.7 & 0.78 kWh from the grid at peak rate of 17p/kWh effectively costing the consumer 11.9 & 13.78 pence respectively.

Similar to the table A4.1 above, table A4.2 below provides the data for late 'Autumn' for another property and the reductions are noticeable in output terms.

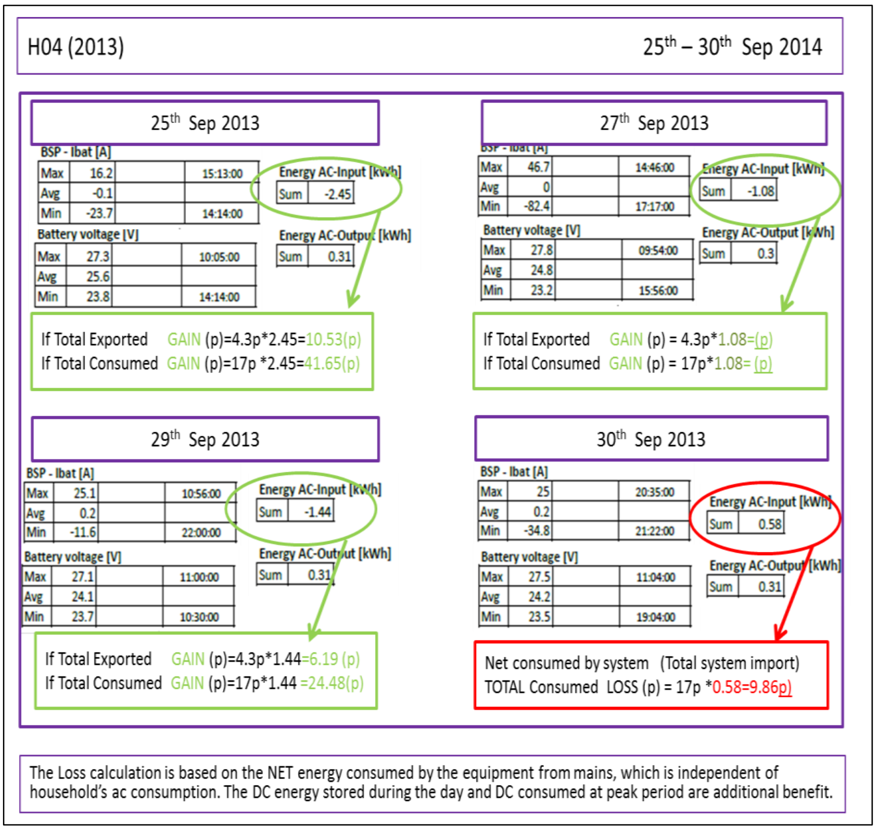


Table A4.2 PV output dependant Export to grid (autumn)

The gains and losses in both tables above show the unpredictability due to day-today fluctuations in the PV generation.

Appendix-5 Combined DC & AC

This appendix shows how the PV generated power is split between battery charging task and export to grid task. The DC load is always supported. All following plots are for the same six-day period. Fig. A5.1 shows the varying battery's state of charge from 90% to 56.5%. and the average battery state of charge is around 80%.

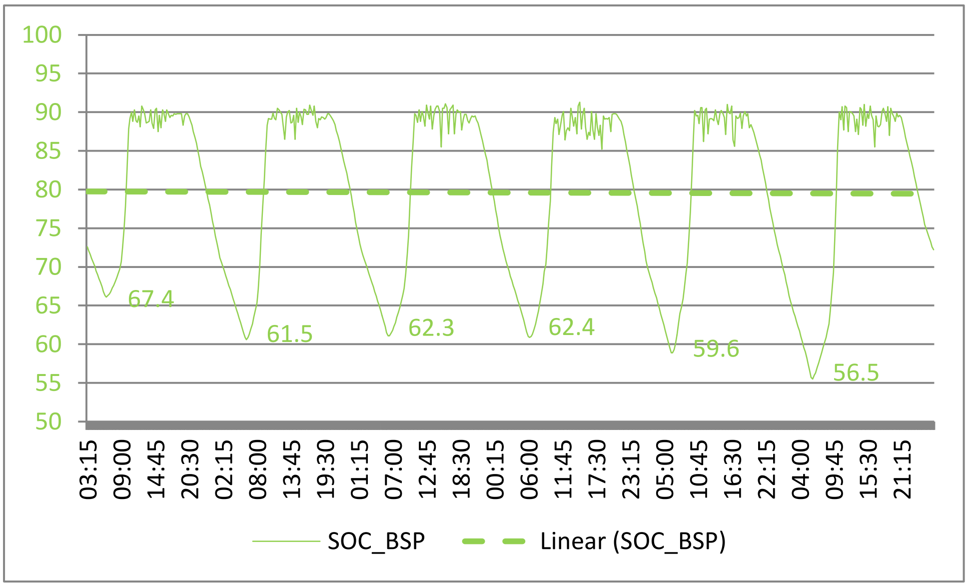


Fig. A5.1 Battery State of charge over 6 day period

Fig. A5.2 shows the PV output for the same period. The brown trace (2nd Y axis) shows daily PV output profile in Watts. The blue trace (primary Y axis) shows accumulated Watt hours over the same period. The increase in battery's state of charge above is due to one portion of this generation being used to charge the battery.

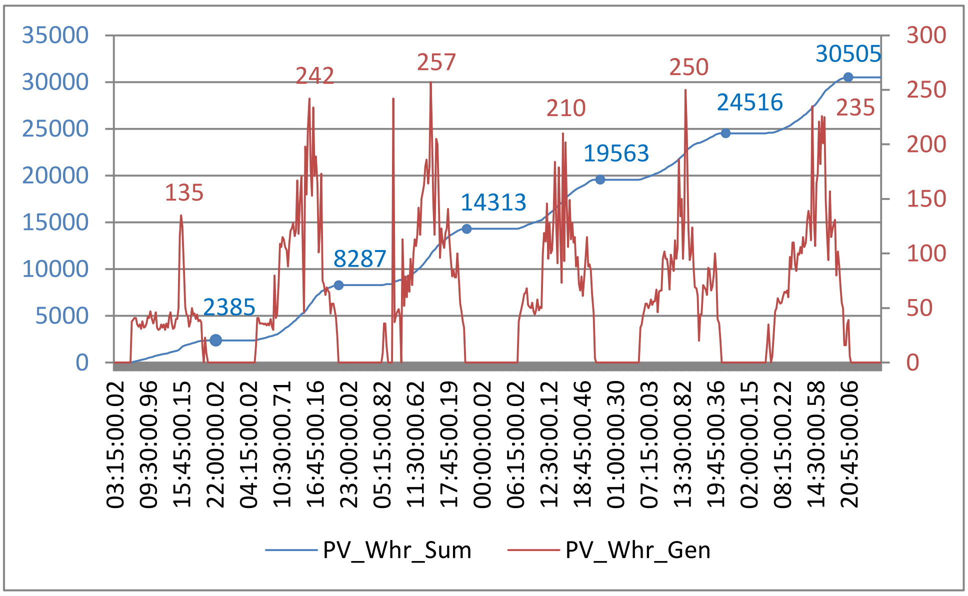


Fig. A5.2 PV output over six day period

PV output power is split between the battery charging task and grid support task. Fig. A5.3 below shows the DC current in Amps, which contributes to battery charging.

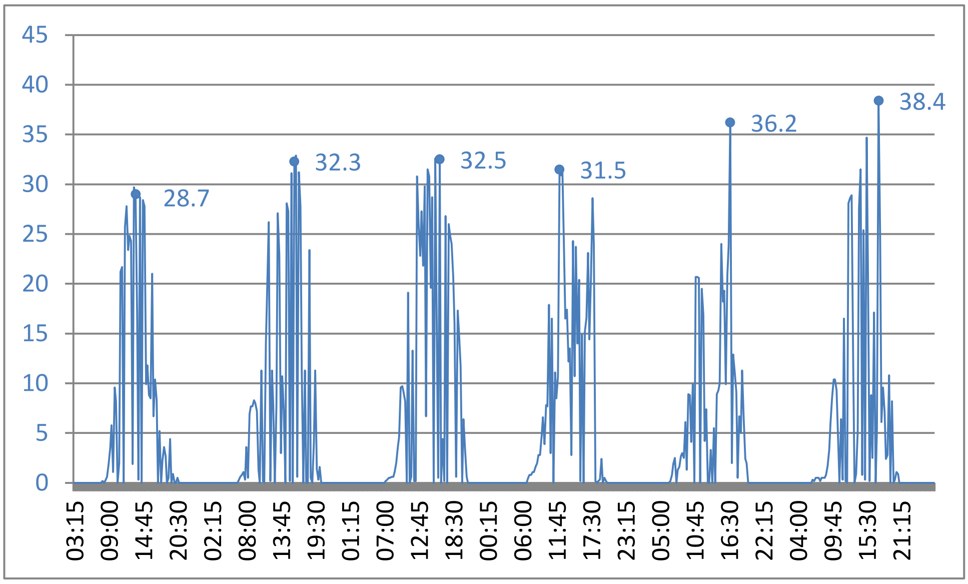


Fig. A5.3 PV Current contribution towards Battery Charging

Fig. A5.4 below shows, the remainder of the current generated by the PV. This part of the PV output current contributes towards export to grid effort.

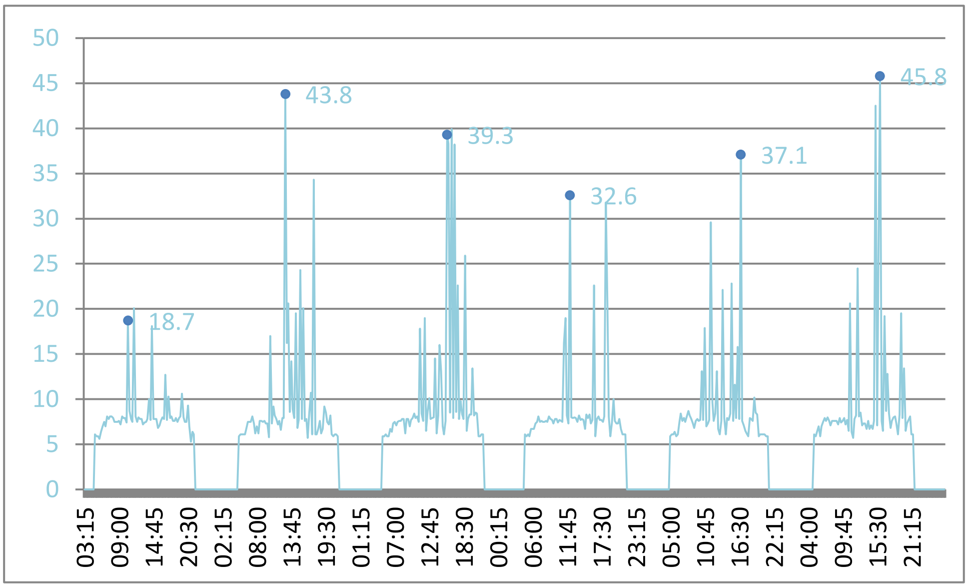


Fig. A5.4 PV Current contribution to export to grid

Fig. A5.5 below shows, the charging voltage levels that are applied to the battery terminals. The battery operates as a buffer, and has to, at times support the PV during export to grid.

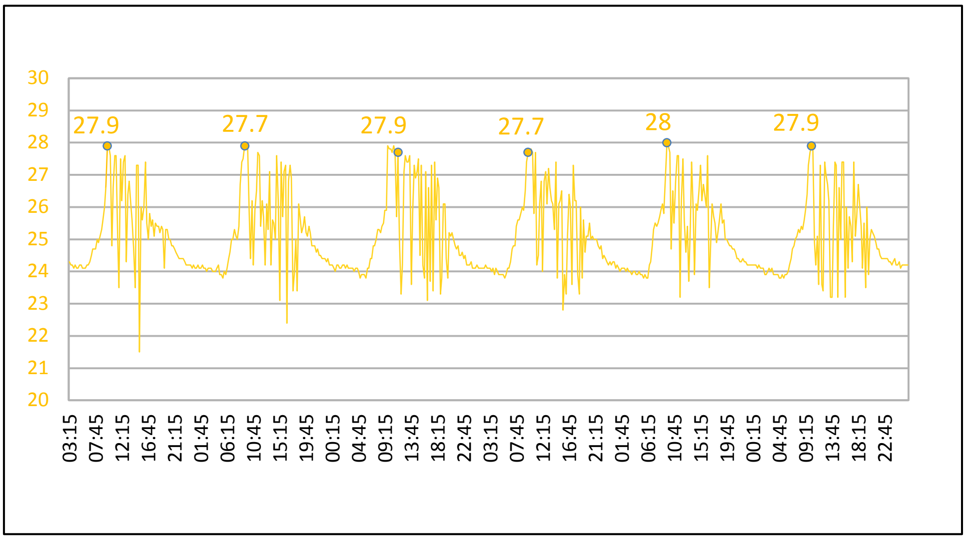


Fig A5.5 PV charging voltage at battery terminals

Financial implications and in-depth benefits calculations of 'charge-splitting' are tariff dependant and are part of on-going activity.

Alternative way to describe this operation of charge splitting is in fact battery capacity splitting between the DNO & the User. During battery discharge, battery capacity split is challenging due to active base load within the property. Due to the vicinity to the source, the user's ac base load has higher priority. In other words, the self-consumption-first within the property has an impact on grid voltage support.

Appendix-6 Sub-station Monitoring

This appendix provides sample of a Sub-station related captured data. These plots relate to the three phases of the First feeder in Substation 2 from 1st May 2014 to 1 June 2014.

In all, eleven sub-stations have been installed and commissioned. The objective of sub-station monitoring is to study the performance of the sub-station before and during the project. The equipment can generate thermal and voltage pressure messages and the objective is to study the response of the attached properties to these messages.

Figures below show the voltage variations between the three phases (A6.1) and phase current variations in (A6.2).

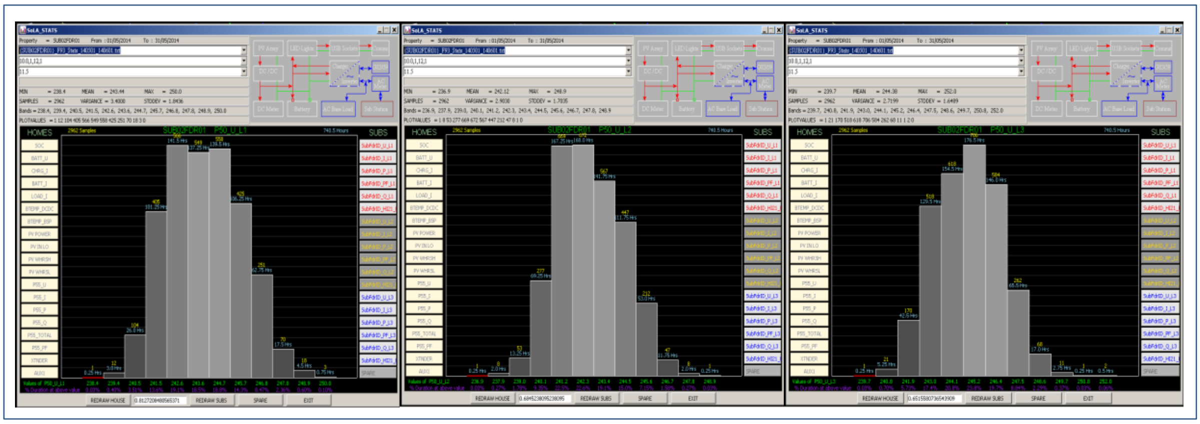


Fig. A6.1 Statistical view of single feeder phase voltages

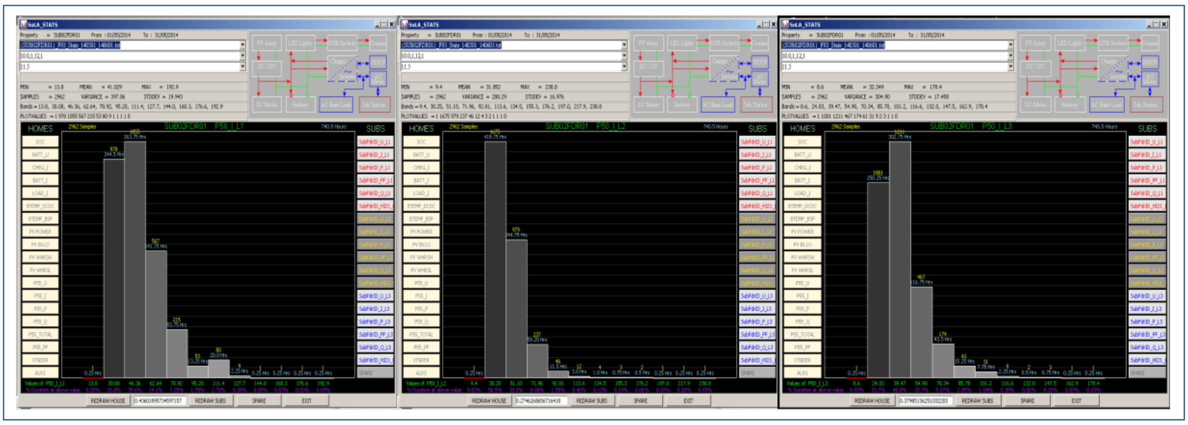


Fig. A6.2 Statistical view of single feeder phase currents

Current profiles show an asymmetry; the cause needs to be established.

Appendix-7 Tools

This appendix provides some details of data processing tools and methods. The daily data from the field arrives at the repository in three eight hour files, which need to be merged prior to any analysis. Figure A7.1 below shows the data flow through the two tools, which were developed for field data analysis. Screenshot of Merge & Sort tool is on the left and on the right is the statistical analysis tool. The outputs from the M&S tool are passed to the statistical analysis tool on the right.

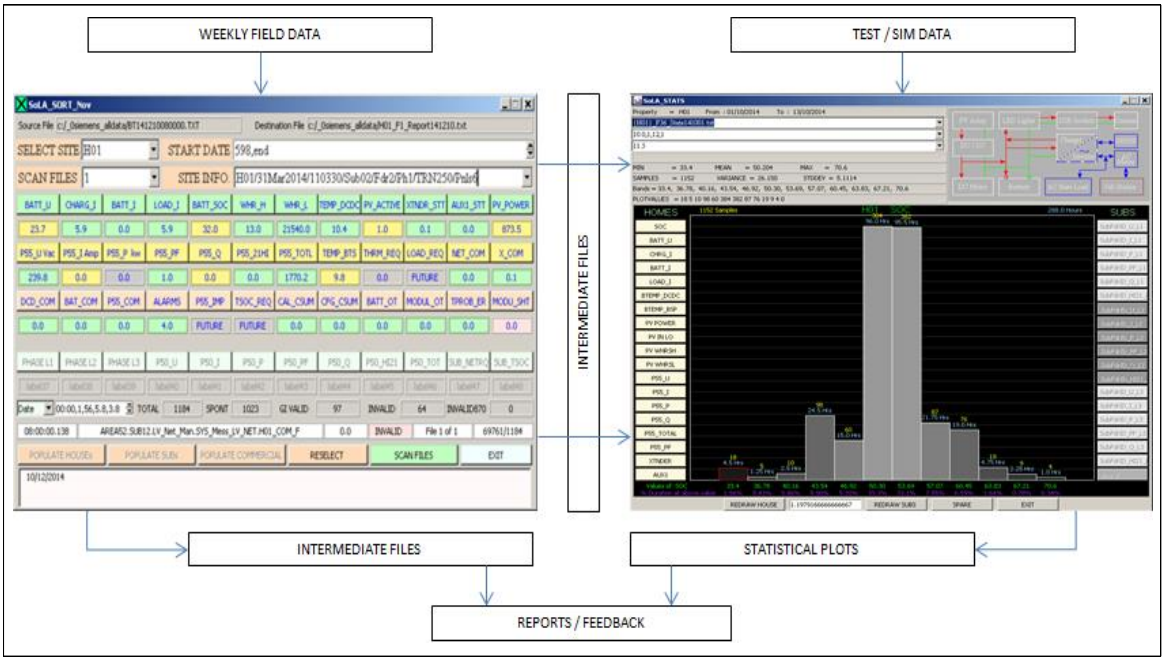


Fig. A7.1 Dataflow M&S Tool (Left) Stats Tool (Right)

Extract from the summary file from M&S tools are is shown below in Box 1.

H01 SOLA BRISTOL DOMESTIC PROPERTY SUMMARY. Generated on 27-08-14 staring from 01/08/2014 to 18/08/2014.
Total number of files scanned for this report were 45. The data counts were as follows.

Total variables	: 50400	Spont counts	: 29586
GI counts	: 18298	Invalid counts	: 2516
XTENDER STATE	: WORKING	AUX1_STATE	: WORKING
BATT_U_Max	: 28.4	BATT_U_Min	: 21.0
SOC_Max	: 90.5	SOC_Min	: 38.2
CHRG_I_Max	: 58.6	CHRG_I_Min	: 0.3
LOAD_I_Max	: 57.5	LOAD_I_Min	: 0.3
BATT_I_Max	: 38.1	BATT_I_Min	: 0.2
BSP_TMP_Max	: 35.1	BSP_TMP_Min	: 16.7
DCDC_TMP_TMax	: 31.8	DCDC_TMP_TMin	: 17.0
P55_Uac_Max	: 247.2	P55_Uac_Min	: 236.0
P55_Iac_Max	: 39.2	P55_Iac_Min	: 0.0
P55_acPWR_Max	: 139	P55_acPWR_Min	: -908
Grid Therm_REQ	: 0	Grid Load_REQ	: 0 Future

Box. 1

To aid visualisation of data, output plots are generated as shown in Fig. A7.2. These plots summarise main operational parameters such as the battery voltage, state of charge (top left), battery related currents (top right) and the DC current’s contribution towards AC export to grid (top right blue trace).

Even in well understood lead-acid battery environment, temperature monitoring is important during charging or discharging of the batteries. Sharp rises indicate higher than normal current flows or battery overcharging. As there are two charge paths within this system, one from the PV side and the other from the grid side, the system uses two separate temperature sensors. One sensor is in direct contact with the battery terminal and the other is located on the body of the battery.

Each sensor reports temperature to its respective charger (bottom left). The difference between the two temperatures is expected as the direct contact sensor has less influence from the ambient temperature and has faster response time to battery’s internal temperature, compared to the sensor located on the body of the battery as the thermal conductivity of the battery body material is much less compared to metallic contact.

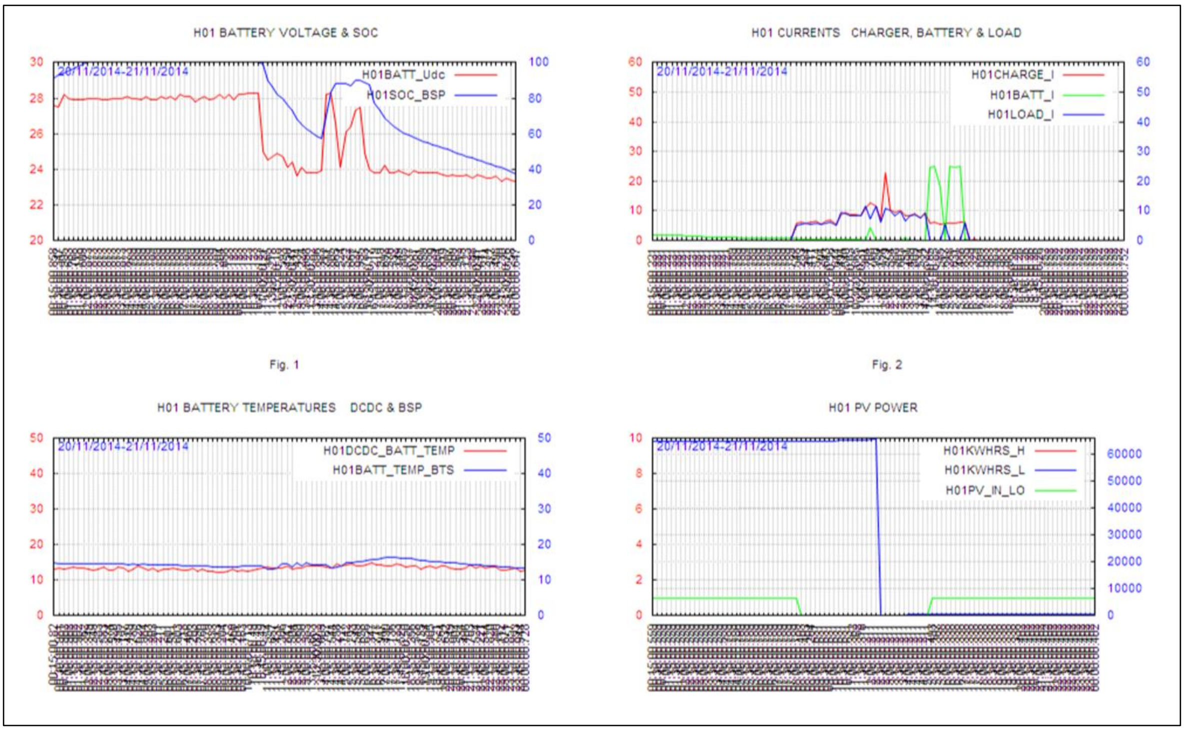


Fig. A7.2 Visualisation output from M&S tool

There are several other visualisation plots for other system parameters which aid operational analysis. Inter parameter interdependence can be seen in two left plots, as the charging current increases, the battery temperature responds.

Appendix-8 Emulator

As access to the field equipment at the domestic properties was restricted, a scaled down version of the SoLa Bristol emulator was built at the University of Bath's Labs. This emulator enables operational test scenarios to be evaluated. Figures A8.1 below shows battery charging and discharging activity. This is a twenty-four hour period plot. The charge and discharge profiles are controlled by a conventional PC, which sends half-hourly target state of charge (tSOC) commands to the system and when the tSOC is reached the system maintains that tSOC. The green trace shows the state of charge, the corresponding battery voltage is plotted in blue.

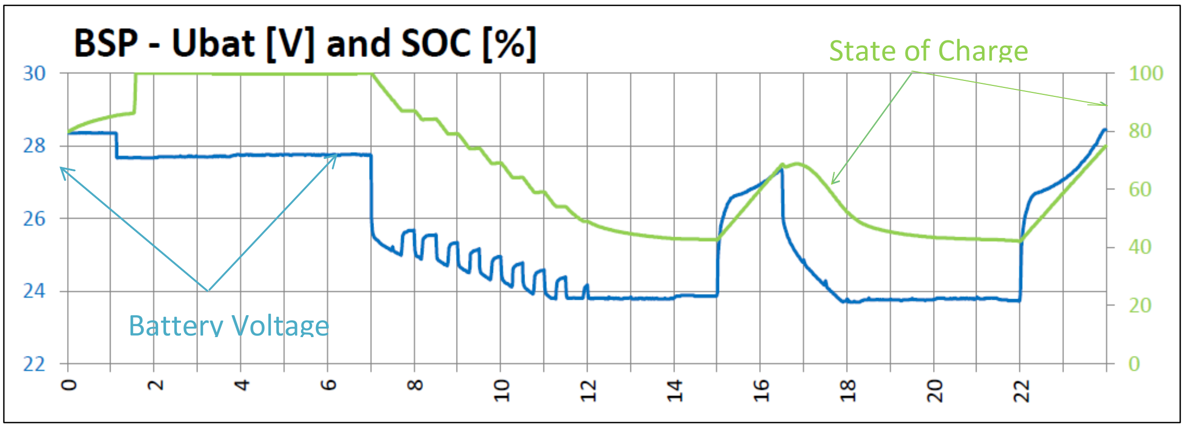


Fig. A8.1 Emulator 24 Hour test Battery Voltage and State of Charge

Fig A8.2 shows corresponding battery current trace, where positive current charges the battery and negative current discharges.

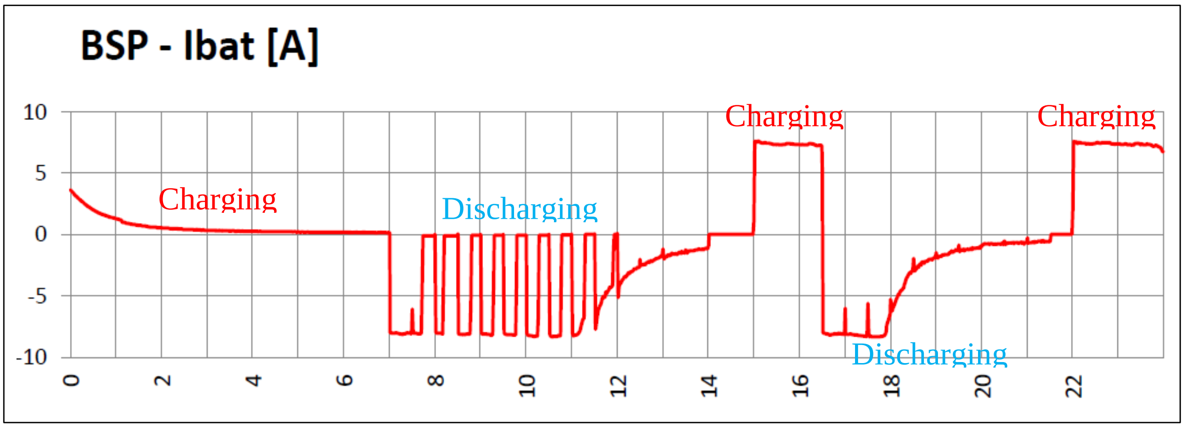


Fig. A8.2 Emulator 24 Hour test Battery Current

This emulator consists of the same subsystems which are installed in the field. The system provides the ability to validate any system modelling work that needs to be done. This test bed is available to university's students and researchers alike to understand and explore micro-grid based local energy storage system with renewables integration capability.