SELECTING SITES FOR FUN-LV FIELD TRIALS

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ABSTRACT

Flexible Urban Networks – Low Voltage (FUN-LV) is a project that aims to trial power electronics devices on low voltage distribution networks for the first time, to assess the potential to release existing, latent spare capacity in shorter timescales as an alternative to conventional reinforcement. In order to demonstrate the business case for the FUN-LV solutions, it is important to select sites that will demonstrate the full range of benefits expected for the three different methods that will be trialled. Selection criteria have been developed for selecting sites, noting differences between radial and interconnected networks. Transformer load data has been obtained and analysed, including in Brighton where there was previously limited substation monitoring and data available, and tools developed to simulate the transfer potential between substations. As a result, 36 trial sites have been proposed, in London and Brighton. Key challenges and lessons from this process have been identified.

INTRODUCTION

Flexible Urban Networks – Low Voltage (FUN-LV) is a project that was awarded funding under Tier 2 of Ofgem's Low Carbon Networks Fund (LCNF). The aim of the project is to explore how LV networks could be used in a more flexible way as an alternative to traditional reinforcement. The project will trial the use of a combination of power electronics (circuit breakers, switches and soft open points), informational tools and network reconfiguration to facilitate the increase in the demand for electricity resulting from the connection of low carbon technologies at Low Voltage (LV). The role of power electronics in future distribution networks is described in [1].

UK Power Networks is leading the project with PPA Energy, a practice area of Ricardo-AEA, as a project partner. Other partners include CGI UK, GE Digital Energy Services (UK) and IC Consultants Ltd.

At the heart of the project are field trials on LV distribution networks of three FUN-LV methods;
(1) Remotely controllable Circuit Breakers and Link Box switches (provided by EA Technology Ltd);
(2) 2-port Soft Open Points (SOP); and
(3) 3-port SOPs (both SOP Methods provided by Turbo Power Systems).

The primary aim and benefit of the Methods is to allow load transfers and equalisation across secondary substations, by connecting parts of the network that were previously not connected, to make use of latent capacity. Other expected benefits, primarily associated with the SOP, include improvements to voltages, harmonics, and phase unbalance; and the ability to connect across network boundaries. The SOP is also considered to have the potential to increase the penetration of Distributed Generation [2].

In order to demonstrate the business case for the FUN-LV solutions, as well as understanding the costs associated with the different solutions, it is important to select sites that will demonstrate the full range of benefits expected [3]. The challenge is to select suitable trial sites, in some cases with limited LV network data, and for devices which have not been tried on LV networks before (SOPs). This paper describes the selection criteria to select trial sites, the methods employed, the expected benefits, and the challenges associated with the activity and what has been learnt.

THE FUN-LV METHODS

FUN-LV is aiming to trial three methods, which are described in this section.

Method 1: LV Circuit Breakers and Link Box Switches

This basic method shares capacity across two or more substations and is the lowest cost to install. The method consists of (1) Circuit breakers being fitted into the LV circuit(s) between two or more substations which will share capacity, and (2) Fitting link box switches into a link box which is currently functioning as a normal open point. Both items of equipment are remotely controllable and provide load telemetry.

Capacity sharing is uncontrolled, i.e. power flows according to network impedance. Method 1 typically can allow a transfers of up to 200kVA.

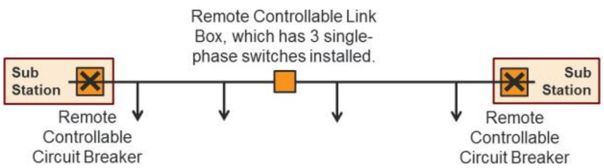


Figure 1. Example of a FUN-LV Method 1 installation

Method 2: Two terminal Soft Open Point (SOP)

A Soft Open Point (SOP) is a Power Electronics (PE) device, comprising back-to-back DC converters. The SOP allows the control of real and reactive power flows on connected circuits. It can be installed in place of a normally open point or between separate LV circuits. As well as controlled power flows for capacity equalisation, the SOP will have the capability to provide voltage control at the end of traditional LV feeders; to improve phase unbalance; to reduce harmonics; and to allow the connection of networks without passing fault current.

The method 2 SOP has two terminals or ports (i.e. can connected to two feeders). It is intended that the 2-terminal SOP will be installed as a piece of street furniture, in a cabinet. The device can make a transfer of up to 240kVA.

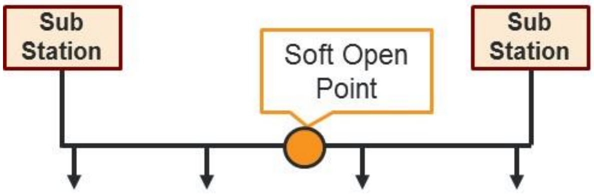


Figure 2. Example of a FUN-LV Method 2 installation

Method 3: Three terminal SOP

The Method 3 solution is as above, but has three terminals or ports. The method 3 SOP will be installed in secondary substations, due to its physical size. The device can make a transfer of up to 400kVA.

Method	Technology	Transfer rating
1	Circuit Breakers and Link Box switches	Up to 200kVA
2	SOP (2-port)	240 kVA
3	SOP (3-port)	400 kVA

Table 1. Summary of FUN-LV Methods

THE TRIALS

The FUN-LV field trials have been selected to demonstrate:

- 12 solutions in Brighton;
- 12 solutions in radial London networks; and
- 12 solutions in interconnected London networks.

comprising four of each of Methods 1, 2 and 3 in each area.

Brighton is in the UK Power Network's licence area called SPN (South Eastern Power Networks) and London is in the licence area called LPN (London Power Networks). As SPN and LPN were historically owned by different companies, and as parts of the networks have different characteristics, there are some differences between the selection criteria and approach.

SELECTION CRITERIA

The general criteria for identifying pairs and triplets for FUN-LV solutions in radial networks in Brighton were:

Transfer Potential

Sites should have the potential to demonstrate sufficient load transfer / sharing capabilities between pairs and triplets of substations, whereby:

- At least one of the selected sites should be heavily loaded and / or,
- The substations should exhibit different times of peak and minimum loading (different load profile types, e.g. residential, commercial or industrial).

Boundaries

Method 1 can only cross HV feeder boundaries; Method 1 circuits cannot cross primary substation, group or bus-bar boundaries where voltages may be out of phase.

Method 2 and 3 sites can cross all network boundaries but it is essential that each LV circuit is also supplied from a separate fused LV infeed in order that existing conventional customer circuit overcurrent protection is maintained at all times.

Space Requirements

Specific requirements for the SOP equipment are as follows.

For Method 2 sites: identification of a suitable space on the pavement (or elsewhere) to install a 2-port SOP along the existing circuits between the two substations using Google Street View. Validation with on-site investigations, based on preliminary device size and detailed consideration of LV connection arrangements.

For Method 3 sites: evaluation of SOP installation feasibility in one of the connected substations, including potential for SOP space and weight, cable and plant access, heat exchanger, inlet and outlet ventilation. Layout allowing clearances sufficient to enable transformer(s) and other plant to be replaced without having to move the SOP.

Close and Connectable

LV circuit diagrams were reviewed to evaluate suitable, and existing, LV circuits to effectively connect a pair or triplet of substations. The distance between the substations is taken into account, as it would not be practical from a voltage drop and losses point of view to select substations that are geographically too far apart. Equally, substations that are too close together could incur fault level constraints that may impact the performance of Method 1 Remote Control Circuit Breakers (RCCB).

LPN Radial Networks

The same general criteria has been applied for identifying pairs and triplets for London as in Brighton.

In addition, the presence of Remote Terminal Unit (RTU) data enabled wider benefits to be considered, including the opportunity to address power quality issues, e.g. voltage unbalance, harmonic distortion and fault level.

LPN Interconnected Networks

The interconnected area in Central London poses some additional challenges and opportunities to demonstrate the capabilities of all the Methods. Since the 1930s LV networks in central London have used various forms of LV interconnection to supply large and diverse LV customer loads. As most LPN interconnected LV circuits already run as fused spine circuits between two or three distribution transformers, the opportunities to improve load sharing and equalisation between transformers and release of capacity is limited, and very different in nature from that of networks that are currently run radial.

Some specific differences in the selection criteria for interconnected networks are based upon the need to focus on those parts of networks where there are significant opportunities for releasing capacity by equalisation. This involves identifying target zones, including:

- Network boundaries
- Positions of normal open points on LV spine circuits and between LV blocks / "clunches" (groups of connected secondary substations)
- Radial Embedded Substations (those substations supplying customers that, whilst having usually one LV network cable for maintenance purposes, are not at present normally run connected to interconnected networks)
- Larger substations and LV only sites (substations that do not contain transformers) with potential space for 3-port SOPs

APPROACH

Obtaining Load Profile Data in Brighton

At the beginning of the project there was no data on secondary substation utilisation available in Brighton (SPN); the only information available was the MDI (Maximum Demand Indicator) reading, which needs to be read at the substation, and is an analogue dial that shows the peak demand recorded since it was last reset. An alternative means of establishing transformer utilisation and load profile type was required in order to select trial sites. 65 secondary substations in central Brighton were selected to be monitored for initial site investigations.

These substations were fitted with non-invasive, low cost, easy to install monitoring devices, which measured transformer temperature. This data, along with ambient temperature data, was used to estimate transformer load, and therefore load profile.
These non-invasive sensors, provided by Ash Wireless, are mounted on the transformers at the hottest spot possible (in line with the top-oil level). They measure the instantaneous temperature every half-hour, store the measurement, and send the last 24 hours of data every day (at the time that the sensor was first commissioned) using the 2G GSM Network to a server managed by Ash Wireless. As of October 2014, 41 sensors are monitoring 41 transformers of interest to the project in Brighton (sensors at substations that were no longer of interest were decommissioned and transferred to cable monitoring).

The process for estimating load profiles from temperature sensor data is as follows:

- Collect and gather all sets of temperature data and perform data quality cleansing.
- Calculate an average daily temperature profile, based on the period of time that the temperature data was available (which has ranged from 3 to 8 months).
- Normalise the average daily temperature profile (where 0 is the minimum and 1 the maximum) (Figure 3).
- Estimate the average daily load profile, a time delay could be introduced between the temperature profile and the load profile to account for the thermal characteristics of the transformer (thermal inertia). However, as it was estimated that the thermal inertia factor (delay) was similar in all sites in central Brighton, and estimating the maximum transfer potential was of more interest for site selection, rather than defining a schedule of transfer flows, shifting the temperature profiles was omitted for this purpose.
- Convert the normalised temperature data to an estimated load profile, based on temperature and load data taken at the time of commissioning.

An example of normalised load profiles for a number of substations in Brighton, based on data available in January 2014, is shown below.

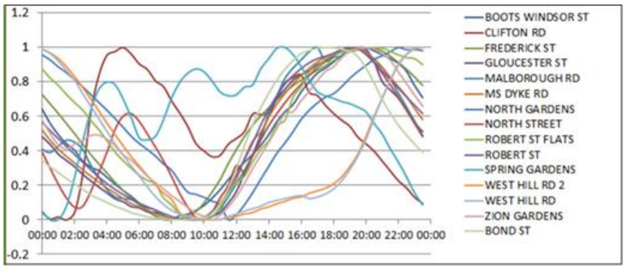


Figure 3. Normalised load profiles for Brighton substations based on temperature sensor data

Data Analysis and Ranking

Once the load profiles had been estimated, potential pairs and triplets were identified by looking at circuit diagrams, MDI readings and load profiles. Load profile types were characterised according to a classification process that was developed as part of the Distribution Network Visibility project, a Tier 1 project funded by the Low Carbon

Networks Fund. The load profiles types were visualised geographically, with different load profile types represented by different colours, e.g. orange is commercial, green is residential, red has a predominant night demand and blue is mixed (Figure 4).

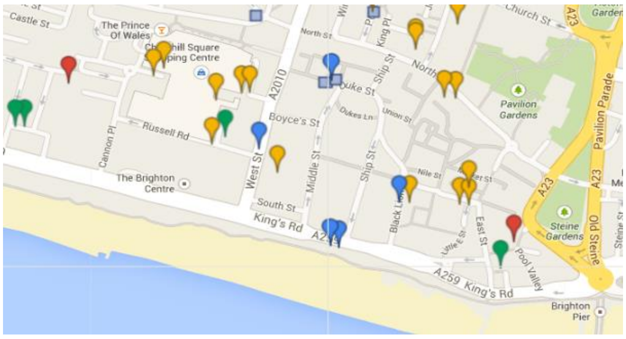
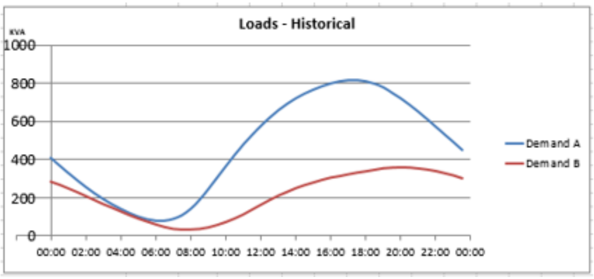


Figure 4. Visualisation of substation load profile types

A tool was developed in Excel to assess the potential transfer between sites, based on the estimated load profiles. This tool was only used to calculate transfer potential for sites where there are SOPs, i.e. Methods 2 and 3, where power flows are controlled. For Method 1 sites, load flow studies are required to estimate expected capacity transfer. The tool determined the ideal kVA load transfer profile from substation A to substation B, such that the utilisation is the same for transformers A and B at any time (half hourly periods). The approach is similar for triplets A-B-C, where transfer potentials were estimated between transformers A and B and between transformers A and C (providing that the SOP would be located in A) such that all three substations have the same utilisation profile. This gives an initial view on the potential for transfers; it does not take account of load flows, cable ratings or any operational dead-band that the SOP may have programmed.

The pairs and triplets were then prioritised according to the selection criteria, i.e.:

- Substations are geographically close and easily connectable;
- Substations do not cross group or MSS boundaries for Method 1; and
- The load profiles and/or utilisation are different and show potential for transfers.



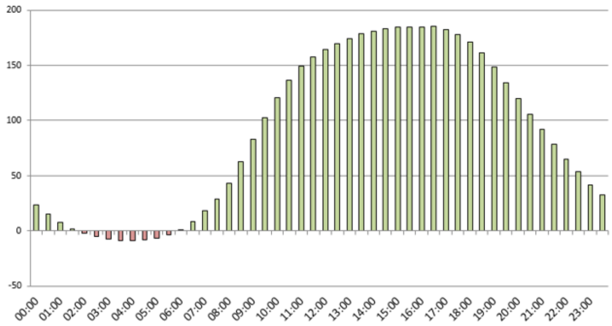


Figure 5. Original estimated load profiles (top) and simulated transfer in kVA (bottom) from Frederick Street (Substation A) to North Gardens (Substation B)

Approach for Radial LPN

Due to the availability of RTU data in LPN, the approach for selecting sites differed to that of Brighton, although the principals are the same. RTU load data is available for most of the selected sites in LPN, and was analysed to shortlist and prioritise heavily loaded substations. In LPN, the load transfer potential was considered under a range of scenarios defined by the load profiles used as inputs to the simulation model:

- Transfer potential based on average load profiles during week days;
- Transfer potential based on average load profiles during weekends; and
- Transfer potential based on load profiles for the day where the most overloaded substation of the pair or triplet has reached its maximum utilisation.

Transfer potential calculations are based on 12 months of kVA data.

Approach for LPN Interconnected

As noted in the Selection Criteria section, the interconnected networks in the central London area posed additional and different challenges and opportunities for the FUN-LV methods compared with radial networks. Key differences with the approach for selecting sites in the interconnected area of LPN included:

- Network areas of interest, which were identified in the original project proposal, were prioritised, concentrating primarily on the Leicester Square West and Hyde Park B Main Substation Groups, where DPlan network data was available. DPlan is a distribution planning tool that is being enhanced by CGI and IOA to be able to support additional functionality required for FUN-LV.
- LV diagrams from GE PowerOn were used to identify network boundaries and scope potential connections.
- GE Smallworld was used to identify larger substation sites as potential Method 3 sites (to house the SOP).
- It became clear that many of the Radial Embedded Substations (RES) had different profiles or utilisation from that of their surrounding networks and therefore

represented key targets for the release of capacity, and that there were significant numbers of these in the Leicester Square West and Hyde Park B target areas.

- DPlan was used to assess existing and proposed Prospective Short Circuit Current (PSCC) levels. DPlan outputs were used to drive an Excel based fault level analytics system in the target areas. This was particularly key for Method 1 sites, as Method 1 equipment does not limit fault current from being passed on when connecting feeders, unlike the SOPs.

EXPECTED BENEFITS

As the data available for secondary substations in SPN is limited, the assessment of benefits for FUN-LV installations in Brighton are currently limited to consideration of load transfers and transformer equalisation. The following chart shows the present maximum utilisation of three substations in a Method 3 site, and the potential utilisation following the installation of a SOP (Figure 6).

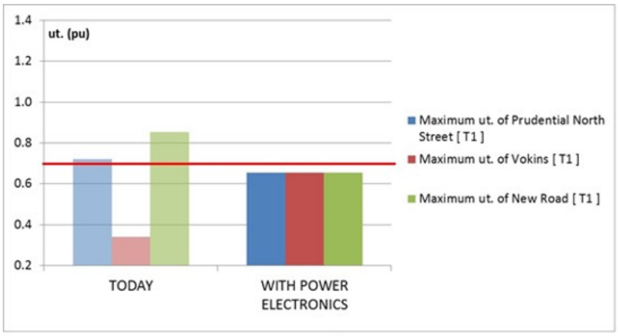


Figure 6. Maximum recorded utilisation (left) and simulated utilisation with Power Electronics (right) for a Method 3 site in SPN (Prudential North Street, Vokins and New Road).

During the field trials capacity released (e.g. at New Road in Figure 6) will not be made available to customers. However, in the longer term, capacity released could be made available to customers, for example where demand increases due to increased penetration of Low Carbon Technologies (e.g. heat pumps and electric vehicles).

In London, the availability of RTU data also gives the opportunity to identify other issues that could be addressed by the use of SOPs, including:

- Voltage correction
- Phase current and voltage unbalance
- Harmonics correction
- Power Factor correction
- Transferring generation
- Constraining and reducing fault level
- Integrating radial embedded networks (interconnected only)

Each LPN site has been assessed for opportunities to demonstrate these benefits.

CHALLENGES, LESSONS AND NEXT STEPS

To our knowledge, the process of selecting sites for SOPs has not been considered or undertaken before, and there was significant learning in undertaking this activity. Key challenges and lessons include:

- Network boundaries are key in the consideration of sites and the different Methods. The ability of SOPs to connect across boundaries is seen as a significant benefit, and a capability not previously available to Distribution Network Operators.
- There are significant differences in the opportunities for substation equalisation for radial and interconnected networks. In radial networks, the key opportunity is equalisation between neighbouring substations that have different load profiles / utilisations. In interconnected networks, there are opportunities to connect "clunches" (groups of connected secondary substations), and Radial Embedded Substations, which can have significantly different profiles and utilisation to the surrounding network.
- Load flow data and studies are required to validate initial views of potential transfers. Tools to undertake these studies still need to be developed.
- Important practical aspects have been identified for consideration for 3-port SOP installations in substations. Site visits are required to assess the suitability of substations for SOP installations.

Installation and commissioning of equipment is due to take place between February and June 2015. Data from the trials will then be collected and analysed, and the business case for the use of power electronics in Low Voltage distribution networks considered. Proving the Soft Open Point concept at LV will facilitate the development and demonstration of Equalisation Networks at higher voltage levels.

REFERENCES

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