FIELD TRIAL RESULTS OF POWER ELECTRONICS IN LV DISTRIBUTION NETWORKS

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ABSTRACT

The Flexible Urban Networks – Low Voltage (FUN-LV) project has trialled three types of power electronics devices on radial and interconnected low voltage distribution networks for the first time. The aim was to assess the potential to release existing, latent spare capacity in shorter timescales as an alternative to conventional reinforcement. The project has trialled 3 Methods at 36 sites, in London and Brighton in the UK. Key findings from these trials are presented, together with a description of the challenges encountered and areas for future study.

INTRODUCTION

This paper describes some of the findings from the Flexible Urban Networks – Low Voltage (FUN–LV) project. This project was awarded funding under tier 2 of the Low Carbon Networks Fund and trialled the use of 3 methods of Power Electronics in distribution networks.

UK Power Networks led the project, with partners including Ricardo Energy & Environment, Imperial Consultants Ltd, GE Grid Solutions (UK) and CGI UK. At the heart of the project are field trials on LV distribution networks of three FUN-LV Methods;

(1) 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).

Twelve installations of each Method have been trialled in LV networks across London and Brighton in the UK. The aim of the trials is to demonstrate the extent to which these devices are able to release latent capacity in the LV network, by allowing or performing equalisation of transformer demand between secondary substations.

The benefit of equalisation is the potential for deferment of network reinforcement, particularly in areas where this would be expensive, disruptive or logistically challenging such as dense urban areas. Secondary benefits such as improvement of network voltage, harmonics and phase unbalance conditions are also possible. The SOPs also allow connections at LV across network boundaries, which previously would not have been possible, such as HV feeder, HV bus bar, Primary Substation etc.

THE FUN-LV METHODS

Method 1: LV Circuit Breakers and Link Box Switches

This Method shares capacity across two or more radial substations or between a radial embedded substation (RES) within an interconnected LV group. A RES has radial LV feeders with a LV normally open point connecting it to an interconnected network. The Method consists of (1) Power electronic (PE) assisted circuit breakers fitted into the LV circuit(s) between two or more substations which will share capacity, and (2) PE assisted switches in a link box which is currently functioning as a normal open point. Both items of equipment are remotely controllable and provide load telemetry. This method has the lowest equipment and installation cost.

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

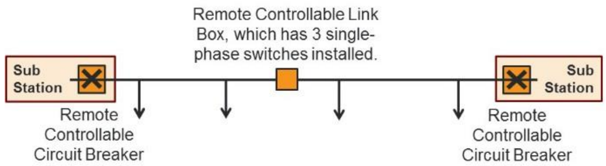

Figure 1. Schematic of a FUN-LV Method 1 installation

Figure 2. 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 the 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 SOPs have the capability to provide voltage control at its ports; to improve phase unbalance; and to allow the connection of networks without passing fault current.

The Method 2 SOP has two terminals or ports (i.e. can be connected to two feeders). The 2-terminal SOPs have been installed as street furniture and can make transfers of up to 240kVA.

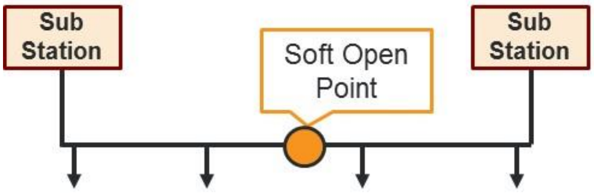

Figure 3. Schematic of a FUN-LV Method 2 installation

Figure 4. 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 was installed in secondary substations, due to its physical size, and can make transfers of up to 400kVA.

Figure 5. A FUN-LV Method 3 installation

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

Specifying the equipment in the initial stages of the project proved challenging, as this was the first of a kind use of Power Electronics on LV Distribution networks. Limited information was available with regards to the level of phase unbalance, voltage and current harmonics etc. with which the equipment should be designed to operate. Hence assumptions were made to enable a functional specification to be created, equipment designed and the trials completed within the project timeframe. Experience from the trials demonstrated the effectiveness of each of the Methods in providing the anticipated benefits, and will also allow refinement of the equipment designs based on real world application.

PROJECT FINDINGS

The 36 field trials provided valuable information on the use of each of the 3 FUN-LV Methods.

Demonstration of Equalisation

Method 1

Method 1 offers a solution for uncontrolled meshing of LV networks. The trial installations demonstrate that this Method can offer effective equalisation dependant on the network topology. In circumstances where control of the transfers and crossing of network boundaries is not required, Method 1 offers a cost effective solution.

Figure 6 below illustrates the effect of using a Method 1 solution to mesh an LV network.

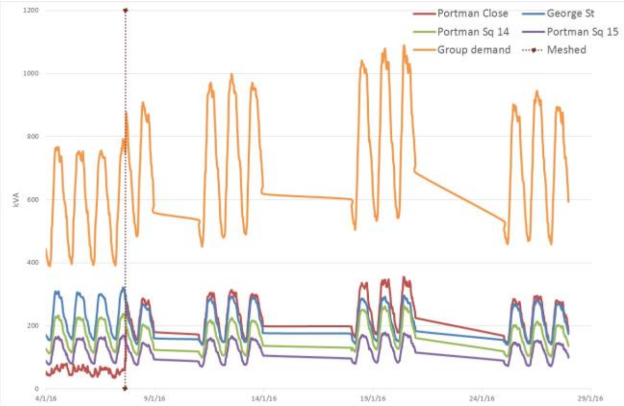

Figure 6. Example of Method 1 on substation demands.

This example installation connects a Radial Embedded Substation (RES) with the neighbouring interconnected LV network. RES often have different load profiles and/or utilisations to the neighbouring network and therefore offer significant opportunities for load sharing.

In Figure 6 the RES is not interconnected to the network on the left of the marker and is meshed on the right. The figure shows that, prior to meshing, the RES (shown in red) had a different load profile shape to the sites in the surrounding network and also a lower demand level. Upon meshing the demand at the RES increases and the profile more closely matches that of the surrounding network. Further, the increased demand at the RES reduces the demand at the three interconnected sites. Figure 7 below shows that the share of group demand for the four sites is more equally spread upon meshing.

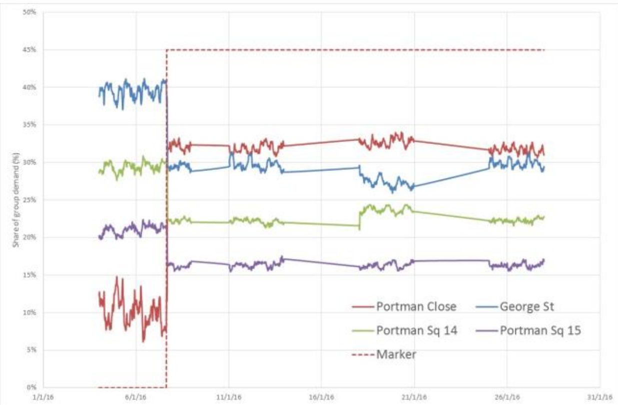

Figure 7. Effect of meshing on share of group demand.

This demonstrates the primary benefit of meshing: equalising the demand amongst the connected sites, making use of latent network capacity that can be provided for additional connections without increasing the transformer capacity. In interconnected networks the effect of meshing is seen in all of the connected sites, but is most evident in those that are electrically closest.

Figure 6 also illustrates that upon meshing of the RES the peak total group demand rises by approximately 130kVA. This is caused by an increase in the average network voltage profile after meshing and could be reduced by the adjustment of transformer taps in a permanent installation.

Method 2

Figures 8, 9 and 10 illustrate effective equalisation as seen in one of the Method 2 trial sites. This SOP was used to equalise between two sites fed from different Primary Substations and could not ordinarily be connected.

Figure 8 shows the average daily SOP transfer profile over the trial period. In this example the SOP is importing active power from port B and exporting it to port A. Low levels of active power are transferred during the night and up to approximately 90kW during the day.

Figure 8. Average real power transfers during trial period

The effect of these transfers on the substation demands is shown in Figure 9. The substation demand profiles prior to meshing are shown by the dotted lines. The real power imported by the SOP on port B is reflected by the additional demand seen at Substation B. Similarly, the power exported at port A of the SOP is reflected by the lower demand seen at Substation A.

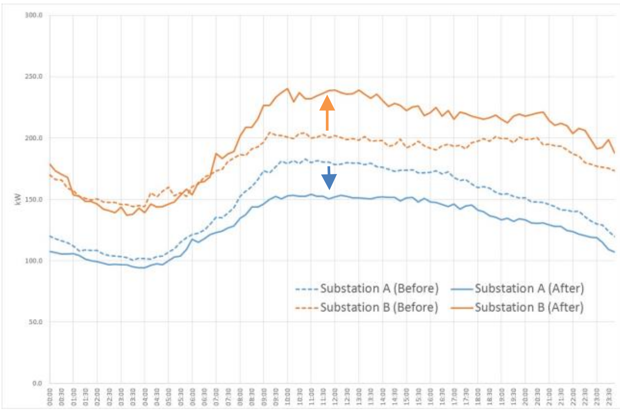

Figure 9. Effect of meshing on substation demands

The algorithm used by the SOP is based on equalisation of the substation utilisation of the connected sites to within

±10% of the average. In this instance the two connected sites have transformers of different ratings (Substation A = 500kVA and Substation B = 750kVA). Figure 10 shows that the SOP has effectively equalised the substation utilisations.

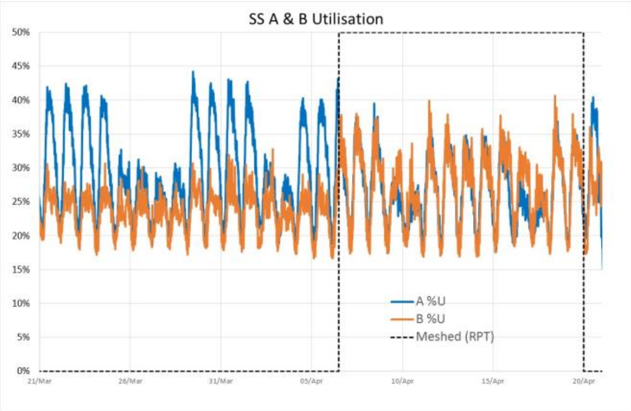

Figure 10. Effect of meshing on substation utilisation.

In some of the demonstration sites the effectiveness of the SOPs in equalising substation demands was reduced due to the impact of "Asset Guarding" settings. These settings prevent the SOP from making transfers that will cause network thermal or voltage limits to be exceeded. Also, more effective equalisation could be possible in some cases by a reduction in the ±10% utilisation dead band that was used in the trials.

Method 3

Trials of the Method 3 solution also demonstrated good examples of substation equalisation. Figure 11 illustrates the effect of meshing in an example Method 3 installation (the dotted lines show demand before meshing, and the solid lines after meshing).

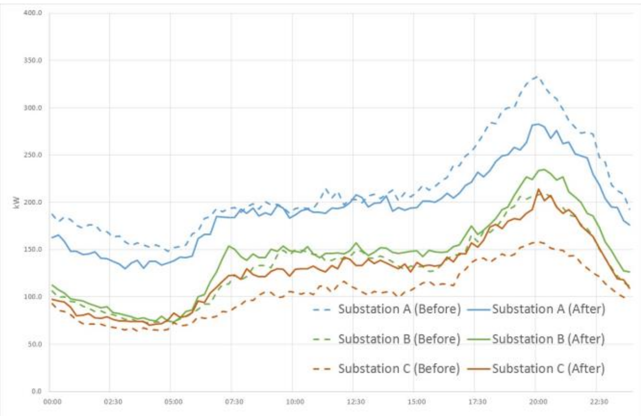

Figure 11. Effect of meshing on substation demands

In this example the SOP is importing power from Substations B and C, and exporting it to Substation A to reduce the demand at this site.

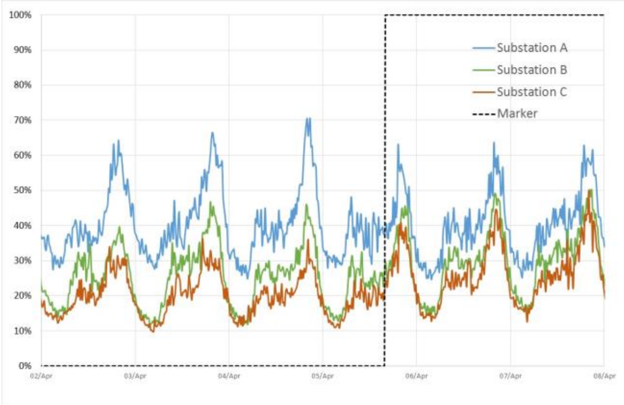

Figure 12. Effect of meshing on substation utilisation.

Figure 12 illustrates the effect of meshing on the utilisation of the connected substations. The peak demand, seen at substation A, is reduced by the action of the SOP, and the utilisations of the three substations is equalised.

As per the Method 2 solution "Asset Guarding" settings and the ±10% utilisation dead band were found to limit the effectiveness of the equalisation. The location of the SOP was also found to have an impact, as the Method 3 equipment was installed within substations. Where the SOP was located within a substation that it was directly connected to, i.e. connected via a low impedance circuit on one port, it was observed to have a greater impact on the utilisation at that site than the other two connected sites. Where the SOP was located in a substation that it was not directly connected to ("Star" connected), i.e. had a similar impedance connection circuit on each port, the impact on substation utilisations was more balanced.

Secondary benefits Demonstrated

Method 1

A secondary effect of meshing with Method 1 solutions was observed to be a flattening of the network voltage profile. The effect of equalising the demand across a number of substations is that the currents, and hence the voltage drops, in the more heavily loaded network branches is reduced. In the trials this led to increased network voltages and total demand after meshing. If this form of meshing was to be applied on a permanent basis this could be counteracted by adjusting the tap positions on the supply transformers, providing a lower but more uniform LV network voltage.

Meshing was also found to reduce the level of voltage and current phase unbalance observed in some instances, due to the aggregation of power flows and loads over a wider network area.

Methods 2 & 3

The SOPs had additional functionality included in the control software such that they were able to operate in Voltage support and Power Factor support modes. These modes were found to be effective, though the voltages and power factors observed on the trial networks were all within acceptable ranges prior to the SOP action. Further work to optimise these algorithm functions could be performed if networks with significant power quality issues were identified.

Challenges encountered

Two major challenges were encountered in the trials.

Audible Noise from the SOPs
As previously described the Method 2 SOPs were installed as Street furniture. Some of the installations received complaints from local residents and businesses due to the level of audible noise caused by the converter switching frequency. For the affected installations the resolution was to limit the periods during which the SOPs were operating by duration and/or time of day. Changes to the design of the SOP hardware could be enacted in future generations such that the switching frequency was raised outside of the audible range.

Communication network system coverage
In some of the trial installations the communications network coverage was not adequate. In particular, obtaining data from substations located in building basements, as is common in central London, was not reliable and reduced the level of detailed analysis that could be performed on these sites, as well as some of the SOP functionality. Alternative communication systems could be investigated in future installations such that reliable data is available.

FUTURE STUDY AREAS

Several areas for future investigation have been identified as a result of the FUN-LV trials. The most apparent area for future work is in the refinement of the hardware and software used in the trials. Improvements in the hardware could include optimisation of the equipment in terms of size, weight, ventilation requirements, noise levels etc., so that installation is simplified and a wider range of locations are suitable. Similarly, refinement of the control software could achieve improvements in both the primary equalisation and secondary benefit function performance. The use of alternative communication systems to ensure the availability of reliable data would also be beneficial in future.

The FUN-LV project has successfully demonstrated the use of Power Electronics in real world LV networks operating as SOPs. A further area for future investigation is in the use of Power Electronic AC/DC converters to provide alternative functionality, such as “Unified Power Flow Converters” [1]. The use of the available DC bus for electric vehicle charging could also be investigated.

A final possible area for future work would be to examine the benefits available by using the SOP’s ability to control power flows within networks, to accurately maintain the loading of network assets. This technique could be used to manage LV networks such that power flows are optimised to within the capability of the assets. This could provide benefits by safely maximising the use of existing assets, and could be particularly effective if used in conjunction with a dynamic rating process.

CONCLUSIONS

The FUN-LV project has successfully demonstrated the use of Power Electronics on LV Distribution networks and the potential benefits available through meshing. It has provided important learning on the influence of network topologies on the effectiveness of meshing, and has highlighted areas where improvements in the trial installation equipment could provide increased benefits. Finally, it has illustrated that Power Electronic converters performing alternative functions within LV networks could be investigated if expected to be beneficial.

The success of this project is due to the highly collaborative approach adopted by the project partners and suppliers in meeting the various challenges.

Additional information on the FUN-LV project can be found on the following website: http://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-2-projects/Flexible-Urban-Networks-Low-Voltage/

Acknowledgments

This project has been dependant on the valuable contributions of all of the project partners and suppliers. In particular, the contributions of Cliff Walton (Ricardo Energy & Environment), Nathaniel Bottrell and Professor Tim Green (both of Imperial Consultants) and Thazi Edwards (UK Power Networks) have been critical. Additional acknowledgement is also made of the Ofgem Low Carbon Networks Fund without which the project would not have been possible.

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