ACTIVE RESPONSE TO DISTRIBUTION NETWORK CONSTRAINTS

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ABSTRACT

The Active Response project will demonstrate active reconfiguration of distribution networks and the use of power electronics to create additional headroom by optimising high voltage (11 kV) and low voltage (400 V) feeders and transformer loads. The aim of the project is to reduce constraints and defer costly reinforcement; thereby supporting the growth of low carbon technologies. This paper introduces the two methods that underpin the project – Network Optimise and Primary Connect – and presents use-cases for their application. It also gives an overview of the site selection methodology for the four trials and outcomes of the site selection process.

INTRODUCTION

The Active Response project aims to demonstrate active reconfiguration of distribution networks with an advanced automation and optimisation platform and the use of power electronics to create additional headroom (defined as the capacity available for connection of new load, new generation, or load growth from low carbon technologies) by optimising feeder and transformer loads. The aim of the project is to reduce constraints and support the growth of low carbon technologies.

The £18.3 million project, led by UK Power Networks, was awarded funding by Ofgem, the energy regulator for Great Britain, through the Network Innovation Competition. The project, which started in January 2018 and will finish in 2021, will demonstrate two new methods across four independent smart grid trials.

UK Power Networks is the electricity distribution network operator for South East England, the East of England and London. It manages three licensed distribution networks which together cover an area of nearly 30,000 square kilometres and deliver electricity to over 8 million homes and businesses. Ricardo Energy & Environment is a project partner responsible for providing technical and project management support. Other partners include CGI, Turbo Power Systems and SP Energy Networks.

ACTIVE RESPONSE METHODS

The project explores two methods which together are the Active Response smart solution: Network Optimise and Primary Connect. These are discussed in the following paragraphs.

<u>Network Optimise</u>

The first method is called Network Optimise, which uses remote control switches to provide automatic reconfiguration of 11kV high voltage (HV) networks and the power electronic device (PEDs) in the 400V low voltage (LV) networks. PEDs used are *soft open points* [1], *LV circuit breakers* using thyristor switching and *link box switches* using thyristors to divert the load current for zero current switching and fault probing. Optimisation techniques will model the HV and LV networks and determine the optimal running arrangement to increase utilisation of assets and hence the amount of low carbon technologies that can be connected. This will be implemented using automatic reconfiguration and PEDs. Soft open points will be used to enable connection across LV and HV electrical boundaries to manage power flows and voltage profiles across different LV networks. The effectiveness of the advanced automation and optimisation will be demonstrated in four trials.

The Network Optimise method is comprised of three solutions as shown in Figure 1.

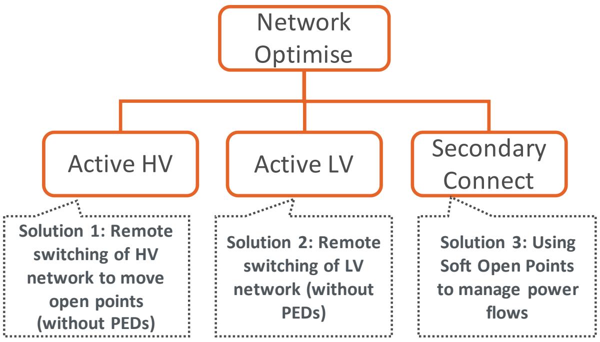

Figure 1. Diagram of the 3 solutions within Network Optimise.

Solution 1 - **Active HV** - applies the Network Optimise methodology to the HV system only (i.e. not at the LV level) without the use of PEDs.
Solution 2 - **Active LV** - uses remote control circuit breakers and link box switches to change the configuration of the LV networks as feeder loading varies.
Solution 3 - **Secondary Connect** - uses soft open points to connect or "mesh" adjacent LV networks to manage the voltage and power flow through the LV feeders.

These three solutions can be combined or used in isolation to suit each application. Four possible use-cases for Network Optimise are described in the following paragraphs. All graphs of network loadings are indicative.

Use-case 1: Active HV in isolation involves moving the location of open points within radial HV networks to optimise the loads on feeders from the primary substations. It requires ring main units (RMUs) be remotely actuated in response to instructions from the advanced automation and optimisation system. HV networks will be reconfigured automatically as feeder loading changes. A conceptual schematic diagram for use-case 1 is given in Figure 2.

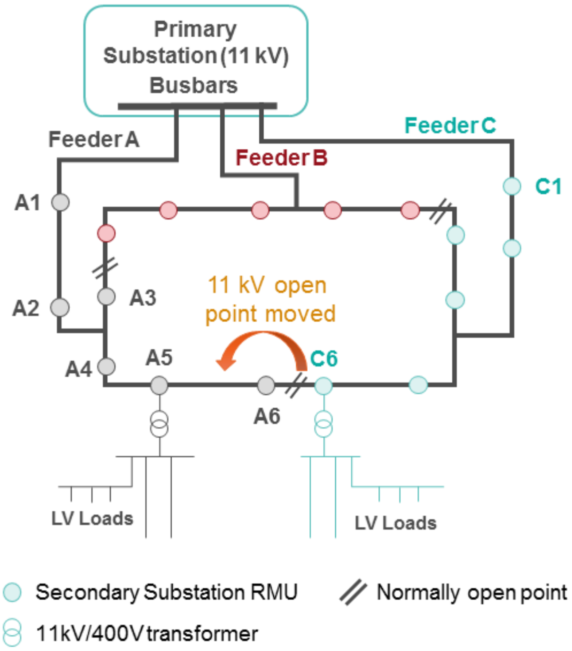

Figure 2. Network schematic for example of use-case 1.

The effect of changing the location of the open point on the feeder loads is illustrated in the graph in Figure 3.

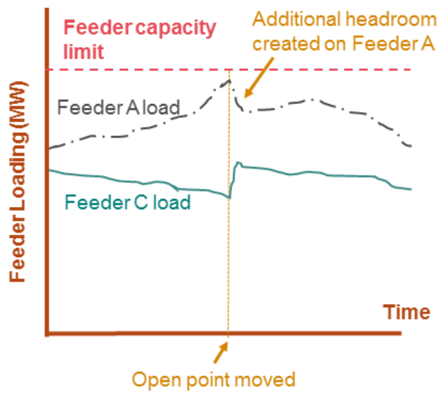

Figure 3. Indicative loading on feeders for use-case 1.

In Figure 3, the load is increasing on Feeder A while Feeder C has spare capacity, so the ring switches are operated to move the open point from between RMUs A6 and C6 to between A5 and A6. The graph shows that the effect of moving the open point is to reduce the load on Feeder A before it reaches its capacity limit, while the load on Feeder C increases by the same amount. The headroom created in Feeder A is equivalent to the load transferred from Feeder A to Feeder C.

One of the benefits of Active HV is that it does not require specialised hardware. Limited - if any - investment in additional equipment is required as it relies on switching of existing components. Some older RMUs might require retrofitting of remote actuation devices, however this is a common industry practice in the UK.

Use-case 2: Tandem reconfiguration of HV and LV open points. This use-case applies Solutions 1 and 2 in combination. It involves analysing the current and predicted loading on a network and configuring the switches to optimise the available headroom.

In Figure 4, the conceptual network diagram is extended to show details of the LV network, including link box switches to enable Active LV functionality.

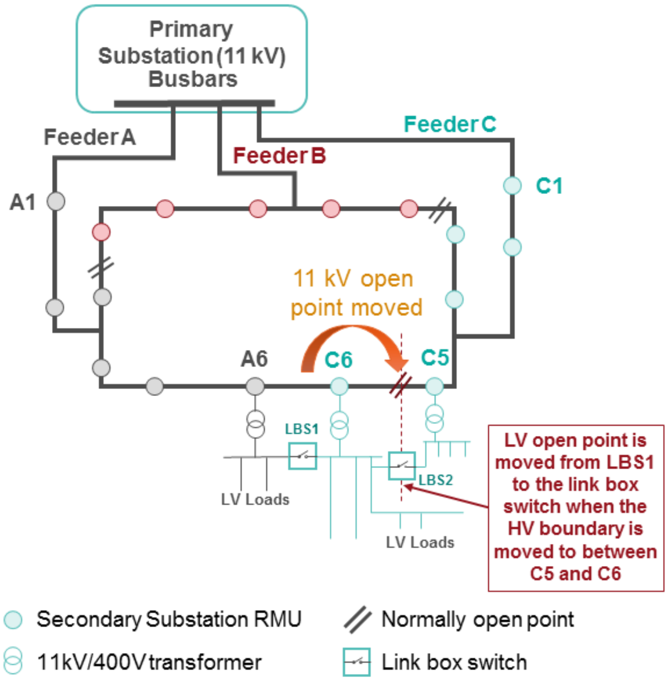

Figure 4. Network schematic for example of use-case 2.

In this example, the HV open point is moved between substations C5 and C6 as the load on Feeder C increases. Feeder A now picks up the demand at substation C6. In tandem with the movement of the HV open point, LV link box switches are used to move the open point at LV to ensure that meshing across the feeder boundary does not occur.

Use-case 3: Managed load transfer between secondary substations using a SOP. This use-case implements Solution 3 in isolation, where soft open points control power flows between secondary substations to optimise headroom available at the substations and HV feeders. An example of use-case 3 is presented in Figure 5, where a soft open point is used to transfer load between LV groups that are on different HV feeders.

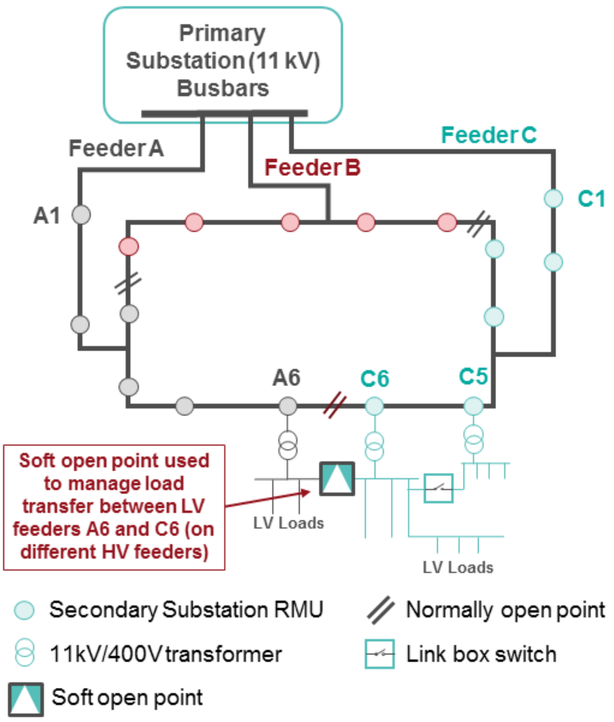

Figure 5. Network schematic for example of use-case 3.

The graph in Figure 6 shows at time T1 the load on C6 begins to increase rapidly and the soft open point is used to transfer load to group A6, which is on a different HV feeder. This might be done when there is limited headroom in C5 to accommodate the additional load from C6.

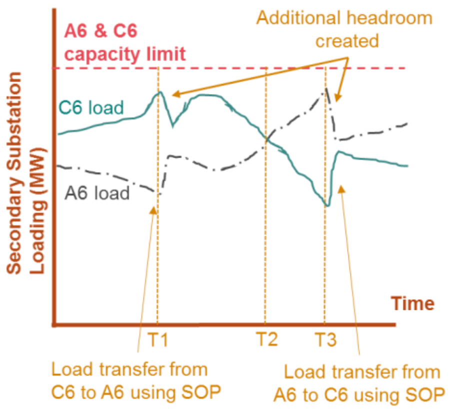

Figure 6. Indicative loading on feeders for use-case 3.

At T2 load on A6 begins to exceed that of C6. When A6 later begins to approach its capacity limit, at T3 the soft open point is used to transfer power in the opposite direction (from A6 to C6). This helps to avoid A6 reaching its capacity limit.

Use-case 4: LV meshing. This use-case implements Solution 2 in isolation to mesh LV networks so that headroom is optimised at the LV substations and HV feeders. An example schematic of this use-case is given in Figure 7.

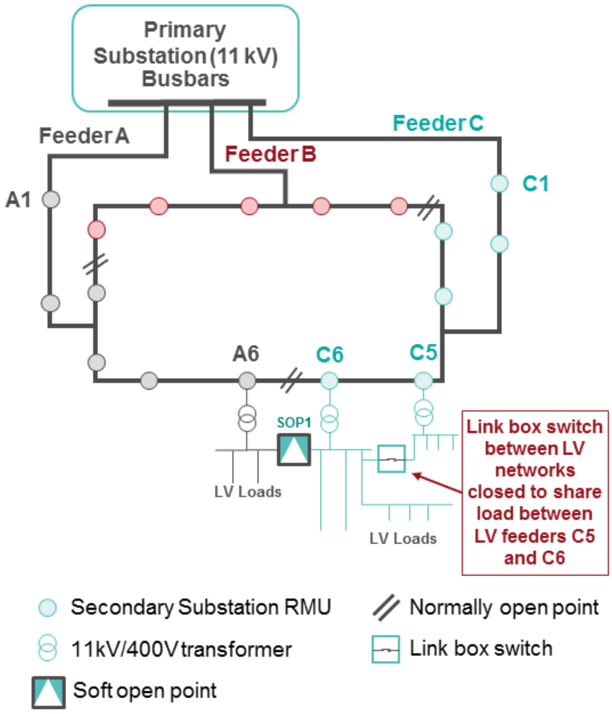

Figure 7. Network schematic for example of use-case 4.

In Figure 7, a link box switch is closed to mesh the C5 and C6 groups and thus reduce the load at substation C6.The graph in Figure 8 illustrates the loading behaviour over time. The link box switch is closed when the load on C6 begins to increase rapidly and approaches its capacity limit. This shares the load with substation C5 resulting in a decrease in load on C6 and an increase on C5.

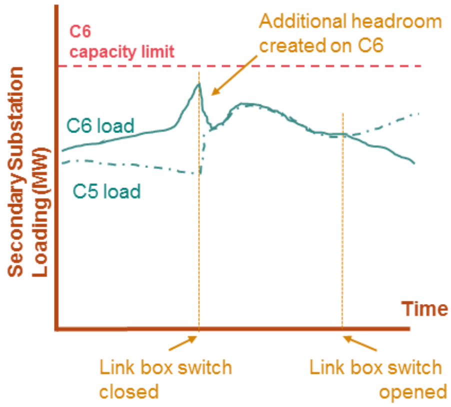

Figure 8. Indicative loading on feeders for use-case 4.

The net effect is to allow C6 to continue operating without breaching its capacity limit. When the combined load begins to decrease, the link box switch is opened again and the loads on C5 and C6 diverge.

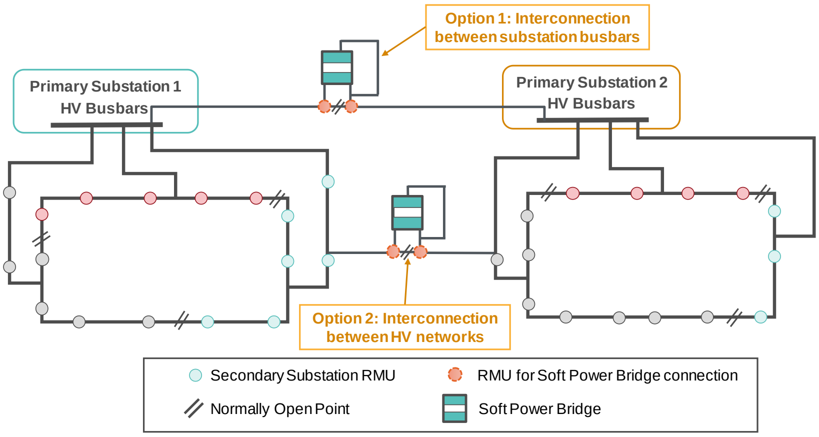

Figure 9. Network schematic for the Primary Connect method showing two options for soft power bridge connection.

Primary Connect

The second method, called **Primary Connect**, involves controlled load transfers between primary substations. A PED called a *soft power bridge* is used to share loads and optimise capacity of the primary substations and 11 kV networks. Interconnection between primary substations can offer benefits by enabling high demands at one substation to be partially met by the adjacent substation.

With increasing penetration of low carbon technologies, it is anticipated that load profiles at primary substations will become highly dynamic, with adjacent substations seeing peak demands at different times of day, depending on the type of customers they supply. Hence sharing of loads and generation between primary substations can be used to reduce peak demands, thereby deferring the need to reinforce.

The soft power bridge is a new design of PED using partially rated power electronics to provide sharing between primary substations. It is expected that the partial rating will provide a smaller, more efficient and cheaper device able to provide bi-directional power transfers. However, the device has an operational limitation on the voltage magnitude and phase angle difference across its terminals.

Interconnections between primary substations in close proximity are often provided to allow for alternative supply arrangements under outage conditions. These connections are run open because running the connection closed under normal conditions can lead to circulating currents between the networks, excessive fault levels and complex protection coordination. Moreover, in some cases the two networks may be structurally out of phase preventing parallel operation. The soft power bridge will be able to manage bi-directional power transfers without the risk of these issues.

As shown in Figure 9, the soft power bridge can provide interconnection in one of two ways: Either between the busbars of the substations (Option 1), or between the downstream supply circuits (Option 2).

THE FOUR DEMONSTRATION TRIALS

There are four trials at the heart of the Active Response project. They are intended to demonstrate the functionality and the benefits of the Network Optimise and Primary Connect methods. The trials will provide operational data on the performance of Active Response which can be used for future network planning. Demonstrations of the solutions in a live network environment are a necessary to provide confidence that the solution will deliver the anticipated benefits.

The four trials, summarised below, will build in complexity over the course of the project to minimise risk to both customers' quality of supply and the network.

Trial 1 "Active HV" - Using the advanced automation and optimisation system for remote switching of ring main switches to optimise the configuration of HV distribution networks (without the use of PEDs, or LV reconfiguration).

Trial 2 "Network Optimise" - The Network Optimise method incorporating Solutions 1, 2 and 3. The advanced automation and optimisation system will provide instructions to optimise the configuration of the network. This will be achieved by remote operation of ring switches at HV and circuit breakers, link box switches and SOP devices at LV.

Trial 3 "Primary Connect" - The Primary Connect method in isolation, using a soft power bridge to perform controlled load transfers to optimise capacity.

Trial 4 "Active Response" - Combining the Network Optimise and Primary Connect methods as a harmonised solution to prove that the technologies can operate in conjunction with each other to maximise the benefits.

TRIAL SITE SELECTION METHODOLOGY

The site selection processes for Trials 1, 2 and 3 applied filtering from the entire population of networks via four steps:

1. Select network type and configuration,
2. Loading review,
3. Equipment and network arrangement review,
4. Ranking and final considerations.

These steps were based on practical and technical considerations, so that sites displaying the necessary attributes to test the solutions were highlighted. Where several locations were shortlisted, a ranking process was applied to select the preferred option.

The selection process for Trial 4 identified common sites on the shortlists for Trials 2 and 3, as these locations have attributes suitable for testing both methods in tandem.

The following UK Power Networks data sources were used in the site selection process:

- Network and loading data from the 2017 Long Term Development Statements,
- Network load data from data historian for specific sites between the 1 October 2017 and 1 October 2018,
- Network infrastructure investment plans,
- Inspection of the network configuration from UK Power Networks' Advanced Distribution Management System.

Further details of the site selection process can be found in a project report entitled "Trial Site Selection Criteria and Process Outcome" [2].

TRIAL SITES SELECTED

Trials 1 and 2

The site selection process for Trials 1 and 2 was done simultaneously because, as variants of the Network Optimise method, the required network characteristics are similar. The London Power Network (LPN) licence area was selected for these trials for the following reasons:

- The majority of RMUs have automation,
- HV Feeder loading data was found to be of a high quality,
- Accurate data on HV feeder interconnectivity was immediately available.

Seven potential feeder groups in South London were identified as candidates for Trials 1 and 2 out of a total of 748 within LPN.

Trial 3

The Eastern Power Networks (EPN) licence area was selected for Trial 3 to demonstrate that the methods are widely applicable in multiple areas.

According to the 2017 Long Term Development Statements, there are 466 primary substations within EPN. After the site selection process, two primary substations were selected in the Stevenage area, which have complementary daily load profiles. South Stevenage exhibits a typical commercial/industrial load profile, with a peak during office hours of about 65% of its firm capacity. East Stevenage has a typical domestic profile with an evening peak of about 60%. These are shown in Figure 10.

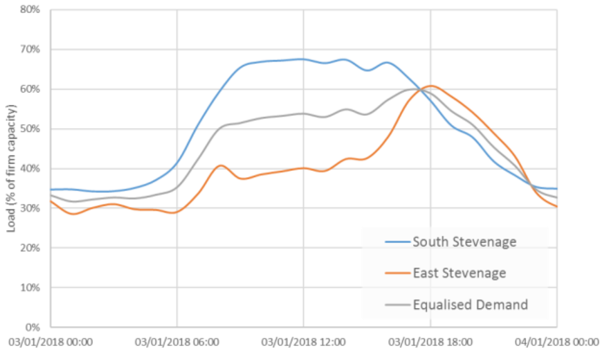

Figure 10. Typical daily load profiles for South and East Stevenage substations

It is anticipated that a soft power bridge could be used to reduce the peak loading at the first substation from 65% to 53% during the day. Analysis indicates that the equalised loading would reach a maximum of 60% at about 17.00 when the domestic load approaches its peak and the commercial/industrial load is still relatively high.

Trial 4

LPN was identified for Trial 4 for the same reasons as described for Trials 1 and 2. The site selection process identified pairs of primary substations in four networks in the South London area that would be suitable for Trial 4.

NEXT STEPS

In the next phase of the project, the shortlisted networks will be analysed in detail to select the ones that best suit the four trials. Following final site selection for each trial, the trials will be designed in detail and bills of quantities developed for hardware.

Trial 1 is planned to start in September 2019, and Trials 2 and 3 will begin in early 2020. Trial 4 will run in the first half of 2021.

REFERENCES

[1] J. M. Bloemink and T. C. Green, 2013, "Benefits of Distribution-Level Power Electronics for Supporting Distributed Generation Growth", in IEEE Transactions on Power Delivery, vol. 28, no. 2, pp. 911-919.

[2] UK Power Networks, 2019, "Trial Site Selection Criteria and Process Outcome, London" Available at URL: http://innovation.ukpowernetworks.co.uk/innovation/en