J – Project Methods

Background

The management of voltage is a growing concern with the integration of low carbon technologies, particularly distributed generation (DG), within electricity networks. The issue of voltage rise (during steady-state conditions) and voltage step change (during transient network conditions) were recently highlighted by the IET in their Power Network Joint Vision report “Electricity Networks – Handling a shock to the system”. There are increasing numbers of occurrences where a large amount of generation is connected to one distribution system and large amounts of demand occur on another, geographically close, distribution system. However, due to fault level issues and phase angle differences, the distribution systems cannot be coupled and power cannot be efficiently transferred from one system to the other.

Figure 1 shows a generic electricity network with generation connected along a circuit and load connected along another. At times of high generation and low load, the voltage could rise above statutory limits (in excess of 106%). At times of low generation and high load, the voltage could drop below statutory limits (lower than 94%).

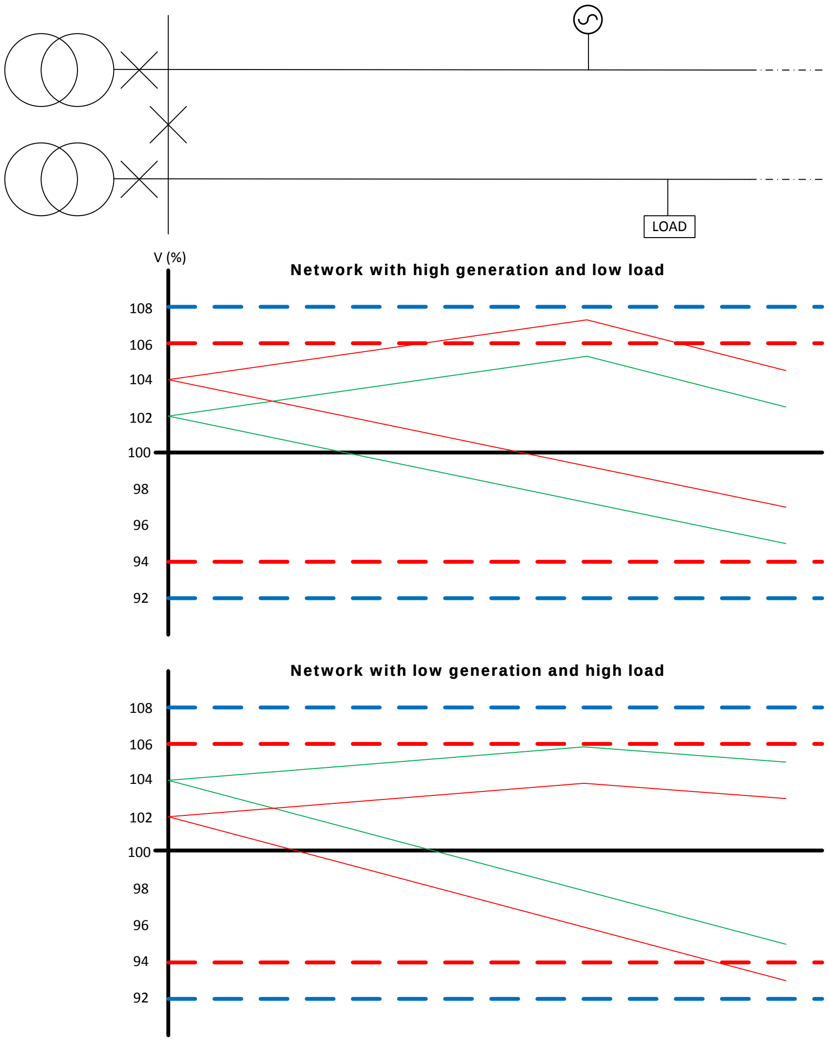

Figure 1 - Graphs of voltage along a line

J1 – Enhanced Voltage Assessment (EVA)

The Problem

At present, DNOs complete a one-off set of connection studies when a new generator applies to connect to the electricity network. The data used in these studies represents the most onerous operating conditions. The connection studies are single “snapshots” of network operating conditions (for example maximum demand coincident with minimum generation). Once the studies are completed and customers are connected to the network, they are not revisited as passive operation is assumed during normal running conditions. This can lead to underutilisation of the present network capacity, particularly for new DG connections.

Planned outages require complex studies to assess risk and decide whether or not generation customers can remain connected. As a result, abnormal (or unexpected) operation often results in existing customers being switched off until normal operation is resumed.

Current planning tools cannot represent how the system actually operates, in terms of actual power flows, due to this limitation it is extremely challenging to unlock capacity using new innovative techniques.

EVA Method

The statutory voltage limits for operating 33kV and 11kV electricity networks within ± 6% of nominal voltage were incorporated into GB’s Electricity Supply Regulations in 1937. This was based on the passive operation of the electricity network, allowing an appropriate range of voltage supplies to low voltage customers. The statutory limits also assumed that 33kV and 11kV electricity networks had no systems in place to control voltages. As seen in Figure 2, the allowable range of operation is much tighter in 33kV and 11kV electricity networks when compared to the other voltage levels.

The EVA Method will demonstrate the automation and adaption of a PSS/E model (a commercially available and common power system nodal analysis software for EHV and HV networks). It will deliver the tools to enable DNO planners to design and commission a new generation of voltage control technologies and will also establish new operating procedures. This Method will support the other two Methods, System Voltage Optimisation and Flexible Power Links, by creating PSS/E software tools for each, making them useable by WPD planning engineers.

The model will accurately calculate the effects that the System Voltage Optimisation Method and the Flexible Power Link Method will have on the distribution system under normal and abnormal network operations, at all times of the year and under all operating conditions. The Enhanced Voltage Assessment Method will also develop a forecasting and configuration tool to assist with load and generation planning, including network reconfiguration considerations. This will enable the two Methods to consider all system operating conditions, i.e. under outage and reconfiguration, rather than as previous projects have done only consider the normal operating conditions.

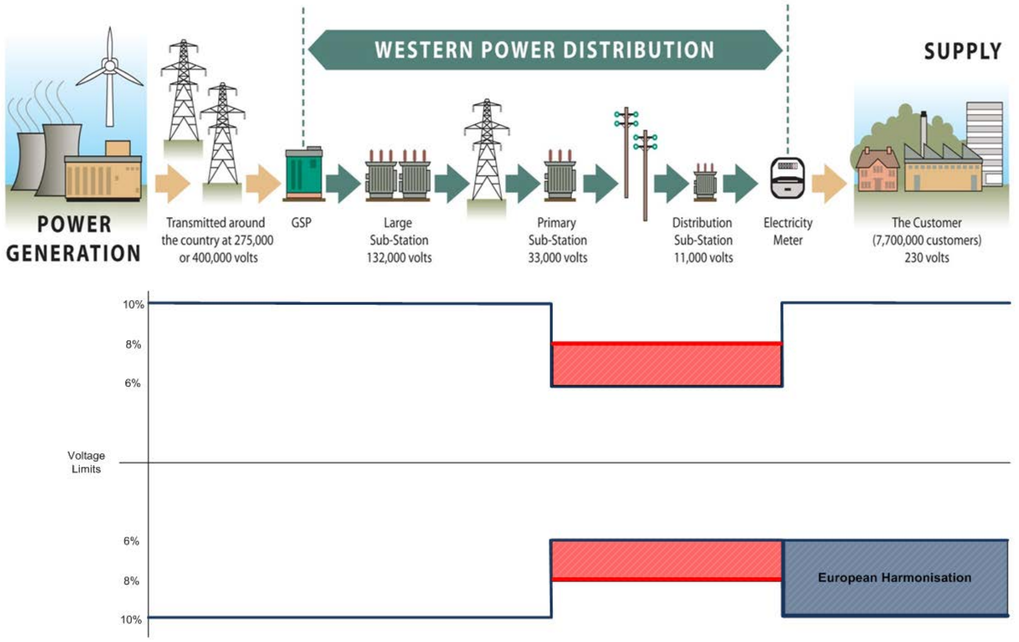

Figure 2 - Statutory voltage limits for operating GB's electricity networks

This Method will also explore and challenge the assumptions that underpin the existing voltage standards, such as percentage limits above and below nominal conditions (defined in ESQCR, P28 and P29, and DNO internal policies). This will be done to ensure they are still relevant, assessing whether modification could increase the ability to connect further generation and demand connections. A key aim is to facilitate the connection of more customers without compromising the safety of our employees and the public. Findings will be shared with DNOs and appropriate standards bodies for review and appropriate policy/standards updates.

Up to 10% connection capacity could be released through this Method. This is because current processes require the network to be studied in the most onerous condition, assuming that maximum generation output will be coincident with minimum demand and minimum generation output will be coincident with maximum demand, which will in turn result in the extreme voltage conditions being used. Actual operating conditions of the electricity network often lie well within these extremities and this can lead to conservative connection assessments for customers. By providing an enhanced model with access to additional information and data, meaning that currently essential safety margins can be reduced, this Method will establish a new operating procedure for GB distribution networks.

This Method will allow system planners to configure and operate complex distribution systems with new innovative voltage control techniques more effectively and safely.

J2 – System Voltage Optimisation (SVO)

The Problem

The voltage on a 11kV and 33kV network is currently controlled using an Automatic Voltage Control (AVC) scheme. This is where a fixed set point is determined, traditionally through the study of a network in relation to the amount of load connected, at the busbars of the substation. A system that is controlled in this manner is then limited in terms of what can be connected, downstream of the busbar controlled by the AVC, by the statutory limits imposed (±6%).

An example of the constraint is identified in Figure 1 where the voltage at the busbar, controlled by the AVC, is set at 104% of nominal voltage (either 11kV or 33kV), which means that the voltage can only increase by 2%. If the AVC scheme had the voltage set at 102% then the available voltage increase would be 4% and so on.

As generation increases the voltage on the system also increases due to the power exported at its connection point; there is a direct correlation between the available voltage headroom (the amount of voltage rise that can occur) and the size of a generator that can connect. Similarly for the connection of load, the available leg room (the amount of voltage drop that can occur) is often the limiting factor for the connection of demand.

SVO Method

The SVO Method will overcome the problem of fixed voltage points at bulk supply points and primary substation busbars through the use of a closed-loop, dynamically controlled voltage control system. This will involve monitoring key network points that will include the remote ends of network feeders and generation points connected to the substation.

In order to unlock latent capacity of the system a robust and controllable system to manage the network voltage is required. Previous innovation projects have demonstrated how monitoring key power flows and voltages across a network can be used to dynamically control the target voltage at a substation. These projects have shown that the source voltages can be configured to improve the voltage profile across multiple feeders, ensuring they’re kept within the statutory voltage limits whilst reducing the impact of DG on voltage profiles. However, previous demonstrations have not permanently unlocked conventional generation capacity as this technique needs to:

- Take account of both normal and abnormal network conditions;
- Successfully operate when there is a loss of network communications from monitoring points;
- Produce models for nodal analysis that can be rolled out to network planners to facilitate future generation and demand connections; and
- Facilitate advanced controls using existing hardware.

This project will demonstrate a complete solution and provide guidelines that can easily be rolled out at scale across a complete licence area. The learning and processes will be clearly documented on how the scheme can be applied to other DNOs licence areas.

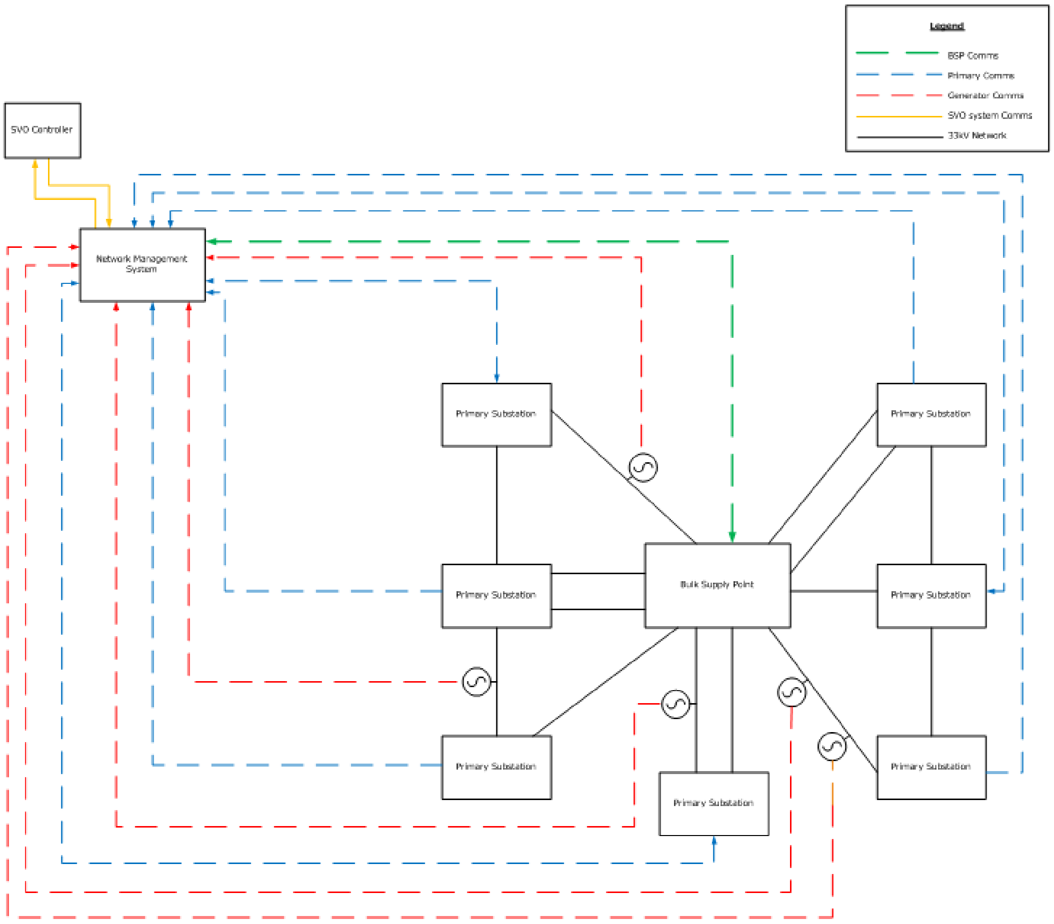

Figure 3 - System Voltage Optimisation Schematic

Figure 3 shows, schematically, the voltage and power data point requirements of a generic network architecture. This data will be communicated in to WPD's existing Network Management System (NMS) and through the use of an "SVO Controller" appropriate control signals will be generated to ensure that, under all operating conditions, the voltage profile of the system will be optimised.

The intelligence developed in the "SVO Controller" using historic data and state estimation techniques will be used to allow optimal voltage settings at the eight selected Bulk Supply Points (BSPs) and primary substations to be applied, based on real-time power flows.

This Method builds significantly on the learning generated from earlier LCNF projects, such as UKPN's Flexible Plug and Play and ENW's CLASS Tier-2 projects, and will overcome the current limitations preventing the wide scale adoption in to Business as Usual (BAU).

J3 – Flexible Power Links (FPL)

The Problem

Predominantly in the UK the areas that are most suitable for the connection of Distributed Generation (DG) are in rural locations, where there are often fewer people and at times insufficient demand locally to absorb the generation. This means that the power provided by DG on the system travels a much greater distance than in dense urban environments and due to the traditional design of rural networks (long overhead networks with a lot of inductance) the greater the distance the power must travel then the greater the voltage rise on the system will be. Also in these areas reverse power flow can occur, which is where power provided by the DG on the system is exported up the network, often through the 33kV network to the 132kV system, where it can then uncontrollably flow between DNO grid groups using the 132kV and transmission network.

Due to the levels of DG that are connecting to the existing system and the issue of reverse power flow, parts of this upstream system are now becoming the limiting factor on the connection of DG. Where, traditionally, there has been a low level of demand in an area with appropriately sized distribution networks to cater for this, an abundance of DG connections has meant that this, demand centred, network is not large enough to cope with the DG power flow requirements.

FPL Method

This Method will utilise new devices, to the distribution network, to facilitate the connection of sections of network that have previously, for issues such as fault level and phase angle, not been able to be connected. The device, a Flexible Power Link (FPL) is two back-to-back Voltage Source Converters (VSC) with a DC link connected between them, indicated in Figure 4. The VSCs facilitate the controllable transfer of both real and reactive power flows, on a dynamic basis, between previously unconnected networks. The DC link, between the two four-quadrant VSCs, removes the phase angle and fault level issues that have previously prevented these connections.

Often different substations and substation groups have significantly different demand and/or generation profiles. This is due to the varying types of load and generation connected at specific points. Often sections of network with a high demand could be physically close to a section of network with high levels of generation connected but due to engineering constraints cannot be connected. Through the use of FPLs a connection can be made that can now dynamically control the real and reactive power flow between these two previously unconnected systems.

The connection provided by the inclusion of an FPL on to the system means that DG power flows that previously travelled long electrical distances through multiple voltage levels can now be efficiently and controllably transferred to a network that is more heavily loaded. The advantage of this connection, along with the reduction of losses (through reduced power flow lengths) and the increased power flow capability by using it more effectively, locally, is the effect on voltage. Due to the reduced distances, provided by the FPL connection, between load and generation the voltage rise issue can effectively be minimised, meaning that the same network can now support the integration of additional generation. This level of integration can also be further optimised by the use of the FPL’s reactive power support functionality, where reactive power can be absorbed from or provided to the system.

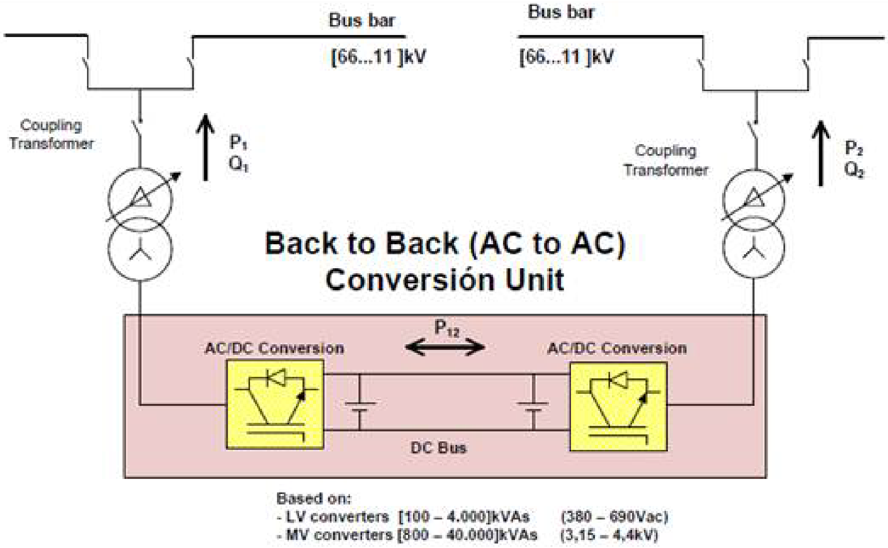

Figure 4 - Flexible Power Link Schematic (Indicative)

Along with the voltage control functionality of the FPL, a key benefit is the real power transfer capabilities of the device. This means that newly coupled networks can have their power flow more effectively controlled to ensure that, where required, excess load on one network can be transferred to a network with excess generation. This is carried out by the FPL essentially acting as a load on one side and a generator on the other. The level of load transfer from one system to the other can be controlled in order to maximise the level of additional generation and load that can permanently be connected to the system. As discussed in the Problem, networks are increasingly becoming “full” to their capacity, due to either load or generation connections. The FPL device, through the active transfer of power, allows the existing infrastructure to be optimised to accept additional load and generation.

Additional benefits, beyond that of voltage and real power control, are increased security of supply and intra and inter DNO connections. By connecting two previously separate networks an additional point of supply has been provided. This means that, much like the installation of an additional transformer at a substation, the reliability of supply to a customer is increased. This can have significant benefits in terms of CI and CML savings. Also, typically different DNO licence areas have operated and managed their systems in ways that make it very difficult for them to be connected. Through the use of an FPL device, the problem of two different systems being connected is overcome, meaning that significant advantages can be achieved through the connection of different DNOs systems, such as black-start capability and increased security of supply.

Future benefits, out of the immediate scope of Network Equilibrium, of FPLs are also active harmonic filtering and synthetic system inertia. Active harmonic filtering is used to provide control of the harmonic content on the system, often made more severe through the introduction of new demand and generation connections on to the system. ER G5/4 describes the allowable limits of harmonic content on the system and through the use of the FPL’s power electronic system harmonic content can be absorbed or supported, as required. Synthetic system inertia is the provision of system frequency support (50Hz ±1% in the UK). Traditionally large rotating plant, such as large synchronous generators at centralised power stations has provided the frequency stability required. As DG is connected to the system, often through power electronic inverters, this level of system inertia is decreased and therefore reduces the stability of the frequency. The power electronic nature of the FPL means that it can become a pseudo-rotating machine and provide a level of frequency support to ensure the stability of the system is maintained.