THE NEED CASE AND BENEFITS OF AN AUTONOMOUSLY CONTROLLED ACTIVE DISTRIBUTION NETWORK

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ABSTRACT

This paper discusses the need case and benefits of implementing an autonomous network control system on an existing distribution network. It focusses on the significant changes in connectivity and power flow within the network caused by the large-scale proliferation of distributed generation and low carbon technologies and provides examples of the control system's implementation and wider network and customer benefits. Learning from previous innovative technology and systems' implementations is also discussed, which support the adoption of an autonomous network control system.

INTRODUCTION

As the connection of Distributed Generation (DG) in Great Britain (GB) continues to increase on distribution networks, reducing the reliance on large, centralised, generation stations connected to the transmission networks, the need to dynamically control the distribution network will be paramount. Historically the distribution network has operated in set, static conditions, which have been optimised for the transfer of loads which were predictable in both their magnitude and direction; however, with the proliferation of DG, often hugely variable in their output, the need for active and autonomous network control systems will be required.

Many distribution networks have localised areas with significant levels of DG connected, often from renewable energy sources. This means that at certain times of the day the network can operate in conditions not envisaged at the time of design, such as complete reverse power flow. Networks are reaching their traditional limits of capacity more frequently as the connection of DG continues. The network is generally limited by voltage and thermal constraints due to the static nature of distribution network operation and the need to ensure that a network remains able to supply all customers in the case of a failure of a key asset (N-1 security). The UK Government has published data [1] that sets out requirements for 85 percent of the UK electricity supply to be from 'Clean Power' by 2032, which is an increase of 40 percent based on 2015 figures. It is therefore necessary, to enable greater levels of low carbon DG to connect, to trial and demonstrate technical solutions that can dynamically control the system voltage, power flows and network connectivity to ensure that existing assets can be optimised to mitigate the need for large-scale network reinforcement.

This paper will discuss technical solutions that have been employed as part of innovative trials to enable technical network flexibility, future dynamic requirements and the benefits to network owners and customers of employing such innovations.

CURRENT PRACTICE

The act of reconfiguring the distribution network is predominantly carried out manually and in most cases, following a fault or other network issue. Under these circumstances a Control Engineer dynamically assesses the conditions of the network and the impacts of a number of potential operational decisions to re-energise or secure a customer, or number of customers, electricity supply. This action often involves both remote control of equipment, such as circuit breakers, and instructions to localised staff to manually operate network equipment.

This approach to network control has historically been appropriate as the power flow on the system has been relatively stable and predictable; whereby it has been dominated by load or load and a single DG unit. This has meant that the network could continue to be designed to accommodate the maximum credible power flow at any instant in time. This design philosophy has meant that the need to reconfigure the network for different power flow or other network conditions was not necessary.

NEED FOR AUTONOMOUSLY CONTROLLED NETWORKS

The electrification of heat and transport and the continued proliferation of DG to the network are the principal needs for having elements of autonomous network control.
The UK Government has produced the Clean Growth

Strategy [1], which identifies the need by 2032 to have 85 percent of electricity supply, and therefore generation, be from clean power sauces – these are typically wind and solar generation. The transient nature of these DG technologies, along with others, means that their maximum outputs very rarely occur, with the operating efficiency of wind and solar generation being in the region of 30%

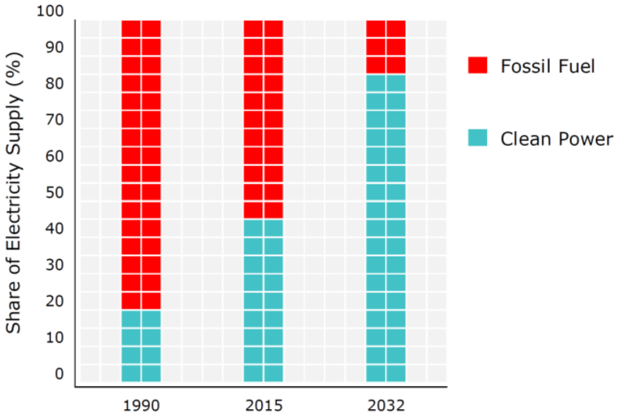

Figure 1: UK Clean Growth Strategy Electricity Supply by Energy Type

The predicted increase in the utilisation of heat pumps (HP) and electric vehicles (EV) and the transition from oil and gas to electricity for heat and transport means that a significant increase in demand on the distribution network infrastructure is likely to occur. Figure 2 shows the EV electricity demand profile for the National Grid (NG) Community Renewables scenario [2]. This indicates that as the same time, by 2032, as supplying 85 percent of UK electricity from clean power sources, there will be a UK EV demand of 31TWh. For comparison it is predicated that in 2032 the UK residential electricity demand will be 106TWh, meaning that EV demand will be equal to almost 30 percent of total domestic demand.

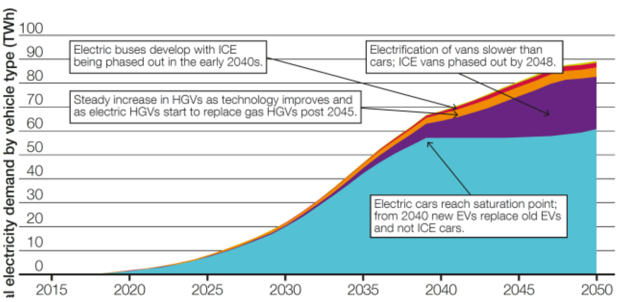

Figure 2: Electric Vehicle Demand Profile for NG Community Renewables Scenario

It is also predicted, under the Community Renewables scenario, that the total electricity demand is to reduce by 340TWh to 767TWh. Whilst this indicates an annual decrease in electricity consumption, the changing nature of the generation and utilisation of electricity, at a more localised level, means that distribution networks are more frequently going to experience operational extremes, in the form of maximum generation and minimum load conditions and vice-versa.

These projected scenarios drive the need for a network that can be frequently and autonomously reconfigured to both avoid the need for underutilised asset reinforcement and to ensure supplies are further secured as the reliance on electricity for a wider range of energy vectors continues.

AUTONOMOUS CONTROL

Currently the extent of autonomous operation on the distribution network is limited to sequence switching schemes (SQC), which operate on a condition based if system. An example of this is a two transformer substation with a bus-section that operates normally open, meaning the transformers feed their own distinct section of network, illustrated in Figure 3.

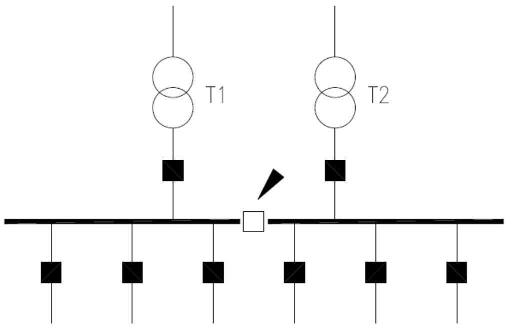

Figure 3: Substation operating pre-fault

For a fault on the transformer or the supply to that transformer, the associated circuit breakers open. The scheme will sense that a fault has occurred and make a basic assessment of the situation and determine if it is possible to close the bus-section to restore supplies (Figure 4).

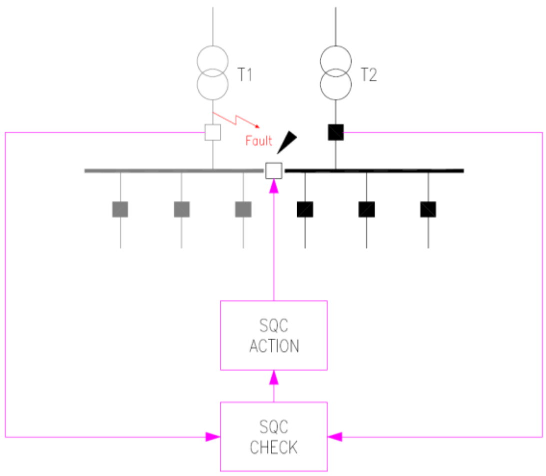

Figure 4: Sequence Switching Scheme Operation

If the basic criterion is met, the sequence scheme will perform the switching function automatically and restore all customers' supplies (Figure 5).

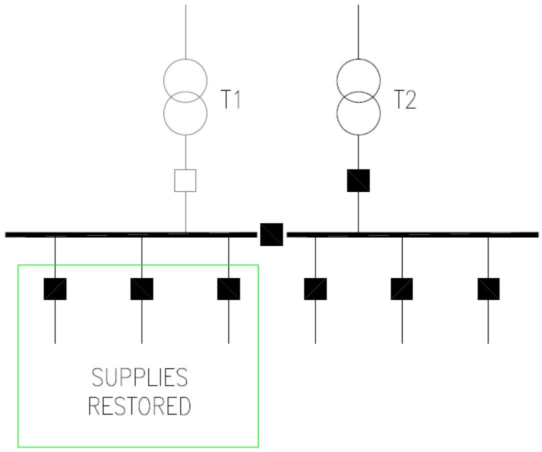

Figure 5: Restored Customers' Supplies through SQC

To optimise the operation and maximise the utilisation of the existing infrastructure real-time and dynamic automated system operation is required. This is whereby real-time power system load flows are completed and an autonomous system will be used to determine and implement the optimal configuration of the network.

The optimal configuration may be for a current instant in time or a near-future need, which has been learnt throughout a period of operational time by the system or through non-network input such as weather conditions or a national event. Learnt characteristics and behaviours would work to increase the operational performance of such a system through longevity of operation.

The flexibility of the system would mean that whilst it could and would optimise for the technical requirements and limits of the complete network it could also be configured to optimise to best suit commercial decisions integrated within the operation of a Distribution System Operator (DSO).

Example

Considering the network shown in Figure 6, where there is no autonomous control of the network, it can be seen that the mix of system loads and generation has resulted in a potential overload on one section of the network. The static normal open point (NOP) separating the two networks have been configured for one particular operating scenario. As there are thousands of NOPs on the network it is not feasible for a Control Engineer to monitor the operation of the network and make ad hoc changes to best suit the network's immediate conditions. However, the implementation of an autonomous control and operation system would mean the network would be monitored in real-time and the NOP could be closed or transferred to another location, as shown in Figure 7, thereby reducing the overload or constraint on a customer's or number of customers' output.

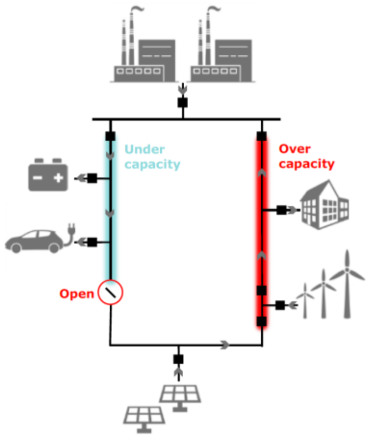

Figure 6: Non-Autonomously controlled network

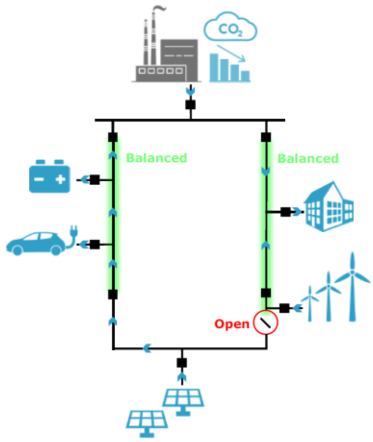

Figure 7: Autonomously controlled network

Figure 7 shows the same network equipped with autonomous control. In this instance, the configuration of the network has been optimised to allow low carbon DG to remain connected by allocating a new NOP.

This simple example demonstrates the immediate benefits of implementing an autonomous control system. Wider implementations of such a system would focus on the interconnectivity of large load and generation to balance the system, which could enable islanding of large elements of the system.

EXPERIENCE

Several technology and system trials have been undertaken that have demonstrated elements to support the implementation and rollout of an autonomous control system.

System Voltage Optimisation

The System Voltage Optimisation (SVO) enables the real-time optimisation of the voltage set-points at a

substation's Automatic Voltage Control (AVC) system, where the voltage is either reduced or increased as far as possible to facilitate additional generation or load [3].
The SVO utilises a centralised real-time load flow system, Siemen's Spectrum Power 5 (SP5) [4]. The SP5 system is integrated within the existing Network Management System (NMS), where key network data, impedance, power flow and switch positions, to enable optimised voltage settings to be determined and communicated to the on-site AVC relays.

The trialling of the SVO system has enabled the demonstration of the value and operation of a real-time optimisation tool that can enact network updates to remote network equipment.

Flexible Power Link

The Flexible Power Link (FPL) is a Medium Voltage Direct Current (MVDC) that enables the connection of two previously distinct 33kV networks and actively controls the real (P) and reactive (Q) power flows to balance the complete system [5].

The FPL is a power electronics based Direct Current (DC) system produced by ABB [6] and is controlled by a centralised Control Module (CM), which is connected to the NMS, in the same way as the SVO, to in real-time, determine the P and Q settings to be communicated to the FPL. The implementation of the FPL on to the 33kV system has released over 20MW of connection capacity.

As with the SVO the implementation of the FPL has demonstrated the capability and benefit to optimising the configuration and operation of the network in real-time.

Energy Storage Systems

The operation of Energy Storage Systems (ESS) on the network enables the balancing of excess load or generation on the network.

A number of ESSs have been implemented to enable the balancing of the network to ensure that no assets are overloaded or co-located with a generating unit to store energy produced above the exporting limit of a particular unit.

Utilising these technologies with centralised control functionality, utilised as part of the SVO and FPL applications, could facilitate significant capacity release by enabling system balancing and power-flow support.

BENEFITS

Implementing an autonomous control system as an alternative to traditional network reinforcement has the potential to deliver a number of technical and commercial benefits.

Employing a centralised control system could play a key role in reducing the level of investment required in asset reinforcement. Often asset reinforcement is required for network conditions that occur on a very infrequent basis, perhaps a few numbers of hours a year at peak winder (load) or summer (generation) conditions.

Currently the network is designed to enable the operation of the network in its worst case system conditions. The utilisation of an autonomous control system would enable the network to be optimised for a number of different drivers depending on the current state of the overall system; these could be losses optimisation, power flow minimisation or security of supply as examples.

Customer connections are increasingly contracted through the utilisation of network constraint application such as Active Network Management (ANM) schemes, whereby the output of a generating unit is limited due to conditions on the wider system. The use of an autonomous control system would enable the reconfiguration of the network rather than the reduction of output from customers to ensure the network does not enter overload conditions.

CONSIDERATIONS

Transferring the operation of a distribution network from a static operating model, which is augmented or manipulated primarily for fault and maintenance issues, to a real-time and regularly reconfigured network based on a specific or set of specific optimisation goals, means that as well as significant capacity and financial benefits there are a number of technical and commercial considerations to be understood, trialled and address prior to widespread implementation.

Technical

As the protection of the distribution network is optimised for a static system condition the consideration for how a system that is regularly being reconfigured, meaning that sections of network have different in-feed points and customers connected, is paramount. This will, from, previous studies, involve a mixture of local and centralised dynamic protection system, which in real-time can update the scheme and settings of a protection relay to ensure that assets and customers' connections are appropriately protected.

As a large section of the network assets still require local, manual operation, a significant section of key network assets would need to be made suitable for remote operation. This would, in some instances, require the replacement of assets and the installation of automation actuators to provide the network flexibility required to realise the automated control system benefits.

Commercial

All customers' connections have a specific security of supply that when the network is largely unchanged is routinely satisfied; however, as the network configuration is regularly changing understanding a customer or series of customers' security of supply must be more accurately understood. It is likely that such a system would have to incorporate an understanding of the financial and commercial potential impact of temporarily reducing or increasing a customer's security of supply.

As flexibility contracts with customers are becoming routine, whereby a customer is, for periods of time, financially incentivised to either reduce or increase their load or generation levels, the utilisation and impact of these must be considered. The inclusion of these for consideration when operating a dynamic network control system would be two fold; could they be integrated in to the decision making of how to configure the network where the flexibility contracts would support the decision making and system balancing or ensuring that an existing flexibility contract is not going to detrimentally affect a re-configuration decision.

RECOMMENDATIONS AND NEXT STEPS

This paper has discussed the need for and benefits of employing an autonomous control system, centring on the significant release of network capacity whilst minimising the need for any large-scale asset investment need. There are also a number of technical and commercial considerations to be more accurately and robustly understood to ensure that these challenges positively support the implementation of such a system.

There have been a number of technical demonstrations that have implemented key parts of what would be required for a full autonomous control system, focussing on a centralised real-time decision making tool.

Investigating and implementing a large-scale trial is now required to test and demonstrate both the technical capability of the proposed solutions and the capacity and security of supply benefits.

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