Accelerating Renewable Connections (ARC)

Learning Report 1

Designing and Operating Alternative Connection Solutions Across Voltage Levels

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Abbreviations

AD	Anaerobic Digester	DNO	Distribution Network Operator
ADMD	After Diversity Maximum Demand	DSR	Demand Side Response
ANM	Active Network Management	ER	Engineering Recommendation
ARC	Accelerating Renewable Connections	EMS	Energy Management System
AVC	Automatic Voltage Control	ERF	Energy Recovery Facility
BAU	Business as Usual	FiT	Feed In Tariff
BELLA	Bilateral Embedded Licence Exemptible Large Power Station Agreement	GIS	Geographical Information System
BHA	Berwickshire Housing Association	GPRS	General Packet Radio Service
CES	Community Energy Scotland	GSP	Grid Supply Point
CUSC	Customer Use of System Code	ICP	Independent Connections Provider.
CT	Current Transformer	kV	Kilo-Volt
DG	Distributed Generation	kW	Kilo-Watt
DER	Distributed Energy Resource	LCNF	Low Carbon Network Fund
DMS	Distribution Management System	LAN	Local Area Network

LCT	Low Carbon Technology	PLC	Programmable Logic Controller
LDC	Line Drop Compensation	POC	Point of Connection
LIFO	Last In First Off	P.u.	Per Unit
LMS	Load Management Scheme	PV	Photovoltaic
LV	Low Voltage	RLM	Reset Less Margin
MP	Measurement Point	RPZ	Regional Power Zone
MPAN	Metering Point Authority Number	RTS	Real Time Systems
MV	Medium Voltage	RTU	Remote Terminal Unit
MW	Mega-Watt	SO	System Operator
MWh	Mega-Watt Hour	SoW	Statement of Works
NGET	National Grid Electricity Transmission	SPT	Scottish Power Transmission
OCAT	Online Curtailment Assessment Tool	TO	Transmission Operator
OFGEM	Office of Gas and Electricity Markets	UoS	University of Strathclyde
OLTC	On Load Tap Changer	VPW	Virtual Private Wire
PCC	Point of Common Coupling		

1. Executive Summary

Accelerating Renewable Connections (ARC) was developed in response to a significant uptake in customers wishing to connect embedded renewable generation to SP Energy Networks' distribution system across our electricity network licence area. The aim of the project was to inform the development of a suite of new alternative technical and commercial solutions to facilitate a greater penetration of distributed generation (DG) accessing the network. Traditional network solutions often led to delays in time to connect, expensive connection costs and challenges in managing the connection application process against a significant volume of applications, while ensuring that all users of the system were provided with access to a safe, secure and reliable distribution network.

The suite of learning reports developed from the ARC Project seek to create a positive step change through improved information provision, creation of new technical and commercial options for customers seeking connection to the network, promote a review of the methodology deployed to develop existing design assumptions being applied by network planners and designers and facilitate across all the UK DNOs, the adoption of new innovative approaches around design and operating new alternative connection solutions across voltage levels.

At the time of project inception, the concepts of managed connections and Active Network Management were relatively unproven, Scottish and Southern Energy Networks had previously undertaken work demonstrating managed connections within the Orkney Registered Power Zone, and was continued more recently by UK Power Networks Flexible Plug and Play and Western Power Distribution's Low Carbon Hub. The ARC project sought to build on this learning, helping to move managed connections, Active Network Management, and other innovations, detailed in Figure 3, out of the commercial and technical trial phase and into business as usual. ARC focused on planning standards, the transmission and distribution boundary, customer service, community engagement and network investment signals, as well as addressing new network use cases.

Three learning reports cover the main areas of new knowledge generated for the industry;

- ✓ Technical Innovations,
- ✓ Commercial Innovation across the Transmission and Distribution Boundary,
- ✓ New Business Processes and Investment Mechanisms.

This report, first in a series of three, looks at the suite of alternative connection solutions deployed within the trial area to help accelerate new generation projects gain network access through the various case studies implemented. The report details the technical solutions deployed to overcome both transmission and distribution constraints and includes customer service innovations that complemented the technical approach. This report has been written to allow a wide range of stakeholders to understand current design and process methodologies, the nature of the technical issues were being witnessed through the connection of greater levels of DG and how the ARC project delivered new solutions to address them.

The fundamental challenge, as already identified in previous Active Network Management projects, is that conventional network planning methodologies are normally undertaken with limited, or no real time network visibility, that leads to conservative network planning assumptions with respect to potential network capacity. Current network modelling is undertaken based upon a static view of network limits, limited to the theoretical scenarios of maximum generation/minimum demand and considers only the nameplate capacity of the technology seeking to connect rather than its operational characteristics and the overall contribution to the system, typically expressed in MWh.

A transition towards a probabilistic planning methodology based on real network flows accounting for diversity between load, generation and seasons is necessary. However, in order to achieve this DNOs require access to enhanced network planning tools, more detailed datasets, modified standards and policies, supported by new commercial agreements. Moreover this transition needs to be complemented with a shift in general culture to embrace the adoption of new network management techniques, built upon confidence that modern network control technology is reliable, can optimise and operate a range of customer assets, is interoperable with existing network infrastructure and continues to provide a safe, secure and reliable network operating environment.

This report shares our experience in creating the connections toolbox to inform on new commercial and technology solutions to facilitate a range of DG connections and in time facilitate not only generation, but also demand and storage across distribution and transmission voltage levels.

The ARC toolbox included:

- ✓ managed connections using wide area and local Active Network Management schemes;
- ✓ static and dynamic export limiting solutions;
- ✓ community energy schemes;
- ✓ voltage reduction including dynamic voltage reduction across LV and MV networks; and
- ✓ local demand side response.

The community energy schemes were implemented onto the network within the confines of the existing market and regulatory structure. However, the project studied and demonstrated, using a simulated network, how new models, such as Virtual Private Wire, could be adopted – proving technically how local energy balancing could be implemented. The results of the community energy element were disseminated through a dedicated workshop at the Power Networks Demonstration Centre in September 2016 and separate paper detailing the learning and outcomes from the event.

In addition to providing customers with technical solutions that were both economic and technically deliverable, the ARC project tackled the issue of reducing the number of aborted DG connection applications through customer service engagement pre-application. Over the last few years the volume and quality of information being provided by DNOs to DG customers has improved immensely. The purpose and aim of these improvements have been to assist developers in understanding where they may be able to connect. It is now common practice across UK DNOs to provide both Long Term Development Statements and network heat maps. However, again these are relatively static and do not reflect the day to day changes in connected, contracted, and offered positions. Most developers therefore feel the most efficient way to understand if a connection is possible in a given area is simply to submit a connection application following which the DNO has a licence obligation to provide a connection quote against as part of its distribution licence obligations. To improve the ability of DG developers to self-serve, and avoid making speculative applications, we trialled through ARC, an online portal to examine the potential of being able to regularly update and which could complement the existing online heat maps. The principle behind the online portal would be to permit DG developers to select a generation technology, identify a preferred network location to connect, specify the size of the proposed development and through an online portal be able to receive a high level view of estimated time and cost to connect either under conventional connection arrangements, which considers the impact of know transmission upgrades or via a managed connection. Feedback from the DG developers was overwhelmingly positive to explore the introduction and potential use of such a tool, which would not only aid exchange of network information but hopefully directly reduce the volume of aborted connection applications being made in future.

Finally, none of the technical innovations considered could have been implemented in the absence of complimentary commercial innovation. Here the ARC project has broken new ground within the existing industry structure, implementing new ways for DNOs to manage DG behind transmission constraints through the implementation of an agreed two-stage connection agreement that not only enabled accelerated access to the network for developers behind transmission constraints but also provided robust economic signals for future network reinforcement across both distribution and transmission voltage levels.

With lower transmission voltages in Scotland and many Grid Supply Points already exporting, the ARC project sought to address existing constraints at the interface between transmission and distribution networks. The project demonstrated that managed connections can be enduring solutions, or where necessary, can be temporary measures to mitigate the impact of transmission reinforcement delays. They can also be used where the customer’s choice is to fund a firm connection in the long term but can benefit from accelerated grid access in the shorter term. They can also enable customer choice, to accept a level of curtailment in exchange for a reduced cost of the grid connection. Both models were demonstrated through the project with the implementation of a two-stage commercial agreement for interim solutions trialled under Dunbar Grid Supply Point.

In the end, the innovations applied across the ARC project have accelerated the connection of approximately 133MW of Distributed Generation (DG), reduced aborted connections, deferred or mitigated the cost of connection for customers by circa £33M and paved the way forward for future DG customers to be managed against local and wider transmission constraints. The project has identified the need for further investment in key enablers including data management, communications and network modelling tools. The project also demonstrated that improved network visibility will enhance network modelling and represents a significant enabler to releasing greater network capacity for DG customers. Furthermore customer service innovation and regular engagement is as equally important to delivery as technical or commercial innovations.

Table 1: Overview of Applied Connection Techniques and Potential Cost Savings

Technique	Description	Capacity	Cost Saving (Estimate)	Time Accelerated
Wide Area ANM Deployment	Multiple Generator, Multiple Constraint Active Network Management Scheme	110MW	£32m	2-5 Years
Local Area ANM Connection	Single Generator, Single Constraint Active Network Management Scheme	280kW	£0.85m	Unfeasible without alternative solution
Voltage Reduction	Lower of local Distribution Network Voltages creating additional capacity for DG	400kW	£0.82m	Unfeasible without alternative solution
Virtual Private Wire	Matching New Embedded Generation with Local Demand creating ‘Protected Capacity’	200kW	-	4 Years
Enhanced Monitoring, Advanced Modelling, and Secondary Substation on-load Tap Changers	Use of enhanced network monitoring and modelling techniques to create additional DG capacity on LV Networks	2.2MW	£1.9m*	Unfeasible without alternative solution

* Represents forecast saving in home energy costs that will be realised by tenants living in social landlord homes over the 20 year life of the PV installation

2. Introduction

The Accelerating Renewable Connections (ARC) project was a four year project that concluded at the end of December 2016. Building on previous LCNF projects, which had started to prove the technical and commercial feasibility of managed connections and alternative connection arrangements, the ARC project sought to prove new use cases, tackle the interaction of Distributed Generation (DG) with the transmission system, empower customers through customer service engagement, and deliver business case and business model information to allow UK Distribution Network Operators (DNO) to adopt similar techniques and processes.

The ARC project was focused within the trial area of East Lothian and the Scottish Borders. The characteristics of this area are mainly rural with a number of market towns forming hubs of population. There are few large demand centres however in some areas large manufacturing facilities exist, including a cement plant which can draw a significant load under Dunbar GSP. Generation already exists in the area in the form of the Torness nuclear power station and a number of early transmission and distribution connected renewable wind farm projects. The local geography includes upland areas making it a rich resource for wind development. The area also benefits from having some of the highest solar irradiation levels in Scotland making it equally as attractive for photovoltaic (PV) development. A large portion of the Scottish Borders network was substantially rebuilt following storms in 2001. Generally the network in the ARC trial area is a mix of overhead lines and underground cables serving a customer base of approximately 77,000 customers. Prior to the commencement of the ARC project there was approximately 300MW of renewable generation connected in across the area, however as discovered during the project, this is likely a conservative estimate due to the significant penetration of domestic G83 PV connections.

The Learning Outcomes from the ARC project have been summarised into three independent but inter-related reports:

1. Designing and Operating New Alternative Connection Solutions Across Voltage Levels
2. The Changing Nature of the Transmission-Distribution Boundary
3. The Business Case for Top Down Investment in Smart Solutions

Each report has been written to allow a range of stakeholders to be able to understand and adopt the various technical and commercial approaches trialled through the project.

This report focuses on the technical aspects of the project and the methods applied to accelerate customer connections. It provides the background context to the local network, existing policies and practices and the solutions implemented to resolve conventional technical constraints. A number of the solutions build on work from other projects, such as the use of and learning from monitoring equipment trialled during SP Energy Networks Flexible Networks project. Instead of focusing specifically on the solution we instead focus on the policies, standards and methods used to analyse and adopt these solutions; delivering learning that we hope will make it easier for other network operators to adopt going forward.

Many of the solutions considered by ARC required a deeper understanding of the existing network, with consideration of power flows and voltages over a much wider range of operational conditions as opposed to the conventional deterministic planning studies. However, a more probabilistic approach to planning requires a greater resolution of network data, modified tools and improved methods to be able to assess the level of network capacity that is actually available and enable customer choice in how it should be used. This report will focus on the challenges associated with obtaining this level of insight.

The Electricity Network Association (ENA), through the Active Network Management (ANM) working group, sought to address some of the issues associated with the advent and implementation of ANM throughout the UK and the published Good Practice Guide was an excellent first step. The early adoption and implementation of ANM systems has been to date specifically for the real-time control of DG to provide actively managed connections where the export can be flexible in response to the availability of real-time network capacity. It should not be confused with protection based systems or inter-tripping arrangements which are in general limited to only on/off control. Issues associated with this form of control are specifically highlighted as a case study.

The report is structured into technical, commercial and customer service innovations, with a series of case studies detailing how each solution was applied in practice. Our aim is that anyone reading this report will be able to understand technically how to plan, design and adopt the smart solutions trialled.

3. Connections planning and processing

This section discusses the tools and techniques used during the ARC project to address the challenges of connecting DG across distribution voltage levels, starting with an overview of the existing connections process and tools used by network planners. These tools are available to all DNOs and they can be used on their own or in combination to engineer new solutions to connect future DG customers. This section describes the limitations of the current planning approach, tools and data and describes the key enablers for smarter network planning and connections processing.

3.1. Existing Tool Box

3.1.1. The Connections Process

Figure 1 provides a summary of the current connection process followed generally by UK DNOs. UK regulation requires DNOs to provide DG connection applicants with an offer no later than 65 working days following receipt of a valid connection request. If the DG application received is not accompanied by other necessary information (e.g. a completed ENA application form) then the DNO is only obliged to provide a budgetary estimate of a potential Point of Connection (POC). If a completed ENA application form is received then a formal connection offer must be issued. Note that this process only assumes that distribution works are required, and does not account for any wider works associated with transmission infrastructure.

Where the registered capacity of the DG is above a certain size e.g. subject to transmission connection agreements with National Grid Electricity Transmission (NGET) or is considered to potentially contribute to wider transmission network constraints, additional steps and potential cost implications will impact the applicant. The DNO must make an application to the System Operator (SO), National Grid, who will undertake additional studies working with the incumbent transmission operator to detail the cost and timescales for any associated transmission system reinforcement.

For SP Energy Networks planners, the location of the proposed DG site is identified on schematics and the closest Point of Connection (POC) established. The DG location and the POC are then incorporated into the power systems network model for analysis. A more detailed description of the screening tests applied in the analysis can be found in section 3.1.4. If, through this process, the proposed POC does not meet pre-scripted network design limits then the location is deemed not technically feasible and another solution or POC is modelled until a viable connection location is identified. Through this technical analysis process, the DNO has an obligation to provide the least-cost technically-competent connection. Once the most economic and technically competent POC is identified, non-contestable and contestable costs associated with sole use and reinforcement costs are calculated and entered into the connection offer.

3.1.2. Planning Tools

DNO planners have a number of tools available at their disposal to assist with the connection process. To ensure consistency, efficiency and connection timescales are met there are also a number of internal standards, policies and processes that are followed. There have been relatively few substantial changes to these tools, standards, policies and processes over recent years. Changes have tended to be limited to refinements to improve efficiency and reduce the costs of application processing. Continuous development in process efficiency and refinement is valuable and has the aim of improving the experience for customers.

Before considering the process for handling DG connections, it is worth highlighting how demand is treated. For demand customers, the network is not planned on the basis of worst case operating conditions instead it takes account of diversity between customers through a load diversity factor or after diversity maximum demand (ADMD). The justification being that load profiles are more predictable and slow to change. In contrast, DG connections are typically intermittent and can be subject to a step changes in export over time which makes applying similar diversity factors more challenging. However, like demand there is diversity amongst varying DG technologies such as Wind and PV, as well as changes to the characteristics of expected wind generation output based upon geographical locations. This diversity however is not currently accounted for to the same degree during the network design and planning phase.

This design philosophy with diversity has been appropriate to facilitate new demand customers connecting to a traditionally passive network. However, as the current network is becoming more active and will have a greater requirement to accommodate increased levels of DG as well as facilitate various forms of low carbon technologies, conventional design and planning methodology need to evolve to exploit and make best use of existing and future network capacity.

The implication is that anything other than simplistic analysis using worst case scenarios, such as the analysis required for more innovative connection solutions, requires enhanced network data which takes greater account of dynamic and real-time network conditions. The existing analytical tools and processes are insufficient for more probabilistic analysis based on actual network conditions. This means that DG connections are planned with an inherent level of engineering conservatism built in and the full availability of the existing network for hosting capacity new connections is not realised.

Table 2: Existing Design & Planning Systems

Tool	Details	Strengths	Weakness
Connections Database	Each DNO has a database with details of each connection application. Applications are assigned a unique identifier used to track the connection through the process.	This is an effective way of tracking applications and ensuring regulatory obligations are met.	Deadlines for the offers can provide blocks to undertaking anything other than simplistic conservative analysis. Also can lead to interactivity between developers.
Geographic Information System (GIS)	The GIS software allows viable POCs to be identified for power systems screening analysis. An extract is	This provides an accurate way of presenting the connection	Network models cannot be automatically generated from GIS data, although this is

	provided in connection offers to show the proposed location of the site and POC.	information to the customer.	possible and has been demonstrated by other network operators in Europe for 11kV networks.
Network Characteristics and Equipment	Each DNO holds various databases that hold characteristics of network assets and equipment. This data is used to populate and validate the Power Systems Software network model.	Central location and 'Single Point of Truth' for all circuit information and a good reference source for planners.	It is a manual database that requires regular updating. There is no way to validate the information without physical field inspection.
Power Systems Software	Each DNO has computational models that represent the network as implemented. The software allows them to perform analysis and determine if the connection is technically feasible.	Fast and effective way to understand some of the technical issues which may be caused by a new connection.	These tend to be desktop tools and parallel connections processing can be laborious and inefficient. The analysis is also limited to the data that is available.
Cost Database	Each DNO has a database of preferred equipment suppliers and costs used to price sole use assets and any required reinforcements.	Consistencies in pricing as all planners use the same equipment costs and suppliers.	The database includes costs for conventional reinforcements and does not typically include smart solution alternatives.
Template letters	Each DNO has standard templates for connection offer letters and connection agreements. This allows efficient population of offers using the output from the other tools.	Consistent approach to all customers and presentation of data. Ensures policies and standards are met.	Can limit the ability to incorporate any deviation from existing standard terms and conditions

3.1.3. Data Sets

For the existing process the most important dataset for any DNO is access to an up to date network model that accurately represents the state of the network as constructed. This must include all connected, accepted and offered generation where the contractual position is constantly varying. There is also a requirement to identify the relevant network parameters in respect of minimum and maximum load. The customer must also provide accurate fault level information and site design. All of this data is targeted at being able to facilitate the deterministic, extreme conditions on the network.

Conventional planning tools and network models therefore require very little network information about the day to day or seasonal profiles actually observed across voltage levels. Instead they rely on simplified versions and network modelling relies upon identification of outlying parameters of maximum ratings in respect of existing network equipment and assets. However, the true energy flows across the existing network, and hence availability of existing capacity, is dependent on how customers actually use energy once connected to the network, not what the potential for maximum output is. Developing a more accurate view of the network is dependent upon the availability of a greater granularity of network information and access to such improved data will permit greater scope for more informed network design but which is unfortunately not consistently available across the entire network at present.

3.1.4. Analysis of the Network

There are three types of power systems study required to analyse any POC. This analysis provides network planners with a view of the impact of the new DG connection to the network. The three screens applied to all connections are:

- ✓ Impact on the network and transformer ratings under outage/worst case scenarios;
- ✓ Fault level analysis to check switchgear ratings; and
- ✓ Voltage step change studies to ensure statutory limits are maintained at all times.

This traditional approach to modelling and analysis focuses on worst case scenarios. This usually requires the modelling of minimum network demand with maximum generator output, under N-1 conditions (for example, the loss of a single network element such as a circuit or a transformer at the primary/grid substation). The purpose of this analysis is to ensure that the network continues to operate in a safe, secure and reliable manner.

Different network configuration scenarios are investigated to determine if the generator can export its maximum rated proposed connection capacity while certain circuits are intact or under outage. This determines the operational conditions for the generator and what additional reinforcement schemes may be required to accommodate its connection to the network.

3.2. Enablers of Smarter Network Design

To enable adaption of the approach to connection design, network planners require access to a suite of enhanced data sets to support connection studies.

Without accurate network data, network planners seek to design out risk at the planning of a new connection by designing to and understanding the potential worst case network scenario – an occurrence of maximum export of generation coupled with a minimum circuit load, accounting for minimum/maximum ratings of relevant network equipment. By installing enhanced monitoring at key network locations, this will enable the implementation of enhanced network planning and give rise to consideration of a wider suite of connection solutions based upon the reality of how the network operates day to day across network voltage levels and various periods of the year. By implementing a monitoring strategy within the ARC trial area, building upon the learning from SP Energy Networks Flexible Networks project[1], this provided evidence and development of analysis that supported a view of how infrequently the worst case scenario is realised and through this evidence based knowledge combined with the implementation of real-time control of connecting technology, greater network capacity for new generation was released.

Improved, more granular data, time-stamped over shorter timescales (i.e. 10 mins max) other than traditionally half-hourly, allows for a connection assessment to be undertaken considering realistic network conditions, the true median of network operation can be considered rather than worst case maximum generation, minimum demand conditions and which will facilitate connections where it may not be possible under conventional network planning and modelling connections process. The opportunity therefore to realise greater availability of network capacity within the existing network, demonstrated in Figure 2 below, is through the use of improved network data enabling an enhanced network modelling methodology.

The solid line shows the maximum value recorded over a half hour period (worst case scenario), while the variable line below shows the true level of circuit demand witnessed on the same 33kV feeder over a 90 second cycle. Over the period measured we can see that the gap between the maximum recorded thermal power flow across the half hourly period is just below 4MW, however the maximum flow of energy ranges during the shorter window from 3.8MW down to 2.2MW representing latent network capacity of 0.2MW and 1.8MW that with real-time control and application of Active Network Management can release greater network capacity for new generators especially if the same pattern is experienced over the course of a year.

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[1] http://www.spenergynetworks.co.uk/pages/flexible_networks_for_a_low_carbon_future.asp

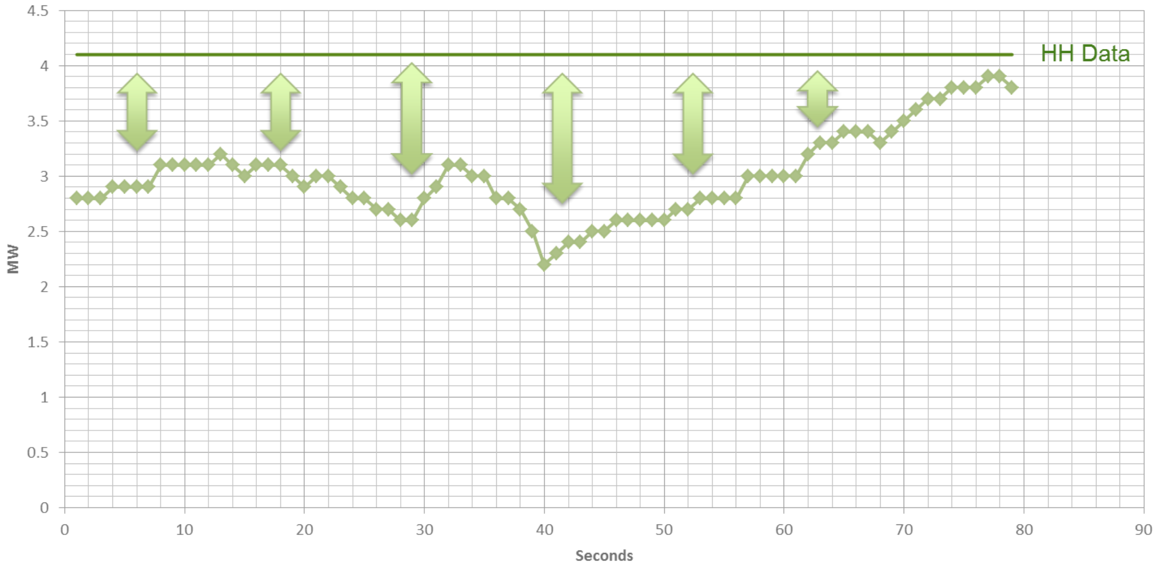


Figure 1: Real-time Data vs. Design Assumption

Additional network monitoring, communication and IT infrastructure to support the collection, storage and access to this data, is a fundamental enabler and 'no-regret investment' of smarter network design and rollout of alternative connection solutions. There are also efficiencies to be gained from the deployment of robust and secure communication infrastructure across DNO networks that can enable the application of additional network technology including operational control (e.g. restoration schemes) and operational management (e.g. remote site security) and which ultimately will represent a critical component of the transition to the smart and intelligent network.

In conclusion, the enablers essential for smarter network design are:

- ✓ Improved monitoring and data acquisition;
- ✓ Foundation of robust communication platform to support sensing and data acquisition;
- ✓ IT systems, subject to appropriate cyber security provision, to support the handling and analysis of larger data sets; and
- ✓ New tools to allow enhanced modelling of smart grid solutions using time stamped data at more granular intervals, typically 10 minutes max.

Improved data sets and analysis tools will enable DNOs to move away from deterministic studies to a more probabilistic view of the network. This will release additional hosting capacity for DG and other low carbon technologies and complement the requirement for additional network reinforcement.

4. Technical Innovations across Distribution Voltage Levels

This section describes the technical solutions that have been implemented and the operational learning captured as part of the ARC project. It lists different scenarios and voltage levels supported by accompanying case studies related to specific customer connections.

As part of the ARC project we developed and demonstrated innovations in the following two categories:

- ✓ The deployment and demonstration of new technologies and control approaches, i.e. smart interventions which offer an alternative to conventional reinforcement; and
- ✓ Alternative approaches to connection design which draw on:
    - a different way of dealing with customers connecting to the network; and
    - learning from the Flexible Networks project, which illustrates that, in the right circumstances, there is more capacity available to connecting customers than conventional design studies may suggest.

Listed below are the technical innovations developed and demonstrated through ARC that cover various network scenarios and across the voltage level including the interface with the transmission network and standalone LV generation customers.

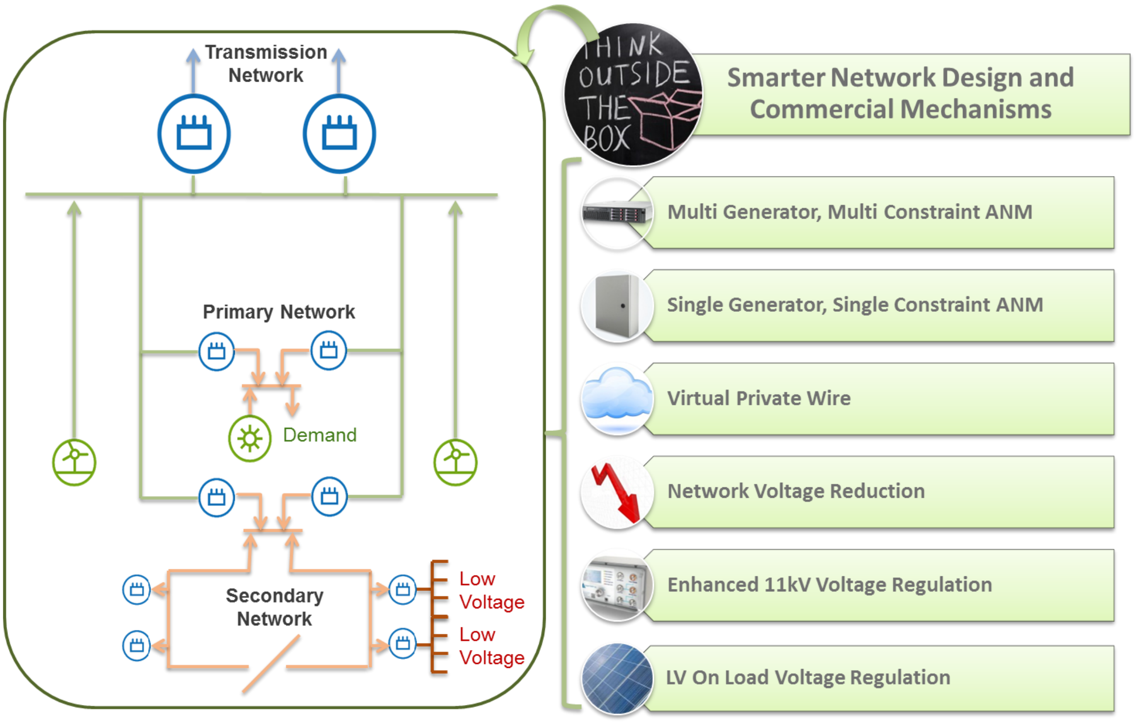


Figure 2: ARC Smarter Network Design and Commercial Mechanisms Toolbox

These technical innovations and smart design techniques form a toolbox available to network designers and system planners to help connect customers faster and ultimately reduce long term investment in network reinforcement schemes where smart intervention can be demonstrated as a more cost effective solution. Each innovation that is detailed above has at least one real demonstration case study that can be found in this report.

Table 3 provides a list of the tools deployed during the ARC trial and cross references the solution with the applicable voltage levels and relevant case studies.

Table 3: Overview of Tools Deployed During ARC Project

<table>
<tr><th>Tool</th><th>Description</th><th>33kV</th><th>11kV</th><th>LV</th></tr>
<tr><td>Multi Generator, Multi Constraint ANM</td><td>Devices are installed to control multiple generators against single or multiple network constraints. The device can regulate generator real power export to mitigate voltage and thermal constraints. Voltage and current can be measured at the site, or at remote measurement points.</td><td colspan="2">Dunbar GSP
Berwick GSP</td><td></td></tr>
<tr><td>Single Generator, Single Constraint ANM</td><td>Devices are installed sited next to the generator and regulates real power export against local voltage and/or thermal constraints.</td><td colspan="3">Ruchlaw Mains PV
Penmanshiel Piggery Wind/PV</td></tr>
<tr><td>Virtual Private Wire</td><td>Virtual Private Wire is where increases in demand at a particular site are translated into increases in the export capacity afforded to a generator site via a community energy system, creating a virtual connection between the two sites, known as ‘Protected Capacity’.</td><td colspan="3">PNDC
Bowhill AD</td></tr>
<tr><td>Network Voltage Reduction at AVC</td><td>Through the use of enhanced monitoring at key points on the network, Network Voltage Reduction can be applied to create voltage headroom on the network to facilitate quicker and cheaper connection of more generation to the distribution network.</td><td></td><td>Standhill Farm AD
Bassendean Farm AD</td><td></td></tr>
</table>

LV OLTC	Control relays that regulate voltage through automatically changing the windings ratio when the voltage varies by a certain amount from a target voltage as a result of clustered uptake on LCT			**BHA**
Advanced Automated Voltage Control	Advanced Automated Voltage Control (AVC) relay which has functions to handle parallel transformers, remotely embedded generation, dynamically changing substation and network switch configuration, variable load power factors and dynamic changes to voltage targets.			**BHA**
Smart Network Design	Using enhanced data sets from improved network visibility monitoring, to enable enhanced network modelling will permit network and system planners to deviate from a conventional design approach and enable adoption of smarter connection solutions.	**Dunbar GSP** **Berwick GSP**	**Bowhill AD** **Standhill Farm AD** **Ruchlaw Mains PV** **Penmanshiel Piggery Wind/PV**	**BHA**

4.1. The Exporting GSP

The ARC project set out to directly tackle the technical and commercial challenges associated with the contribution to power flow transfer of distributed generation across the transmission and distribution boundary. The original submission to Ofgem drew on a case study known as "The Exporting GSP" and which has proven to be a case study rich in drawing out learning associated with:

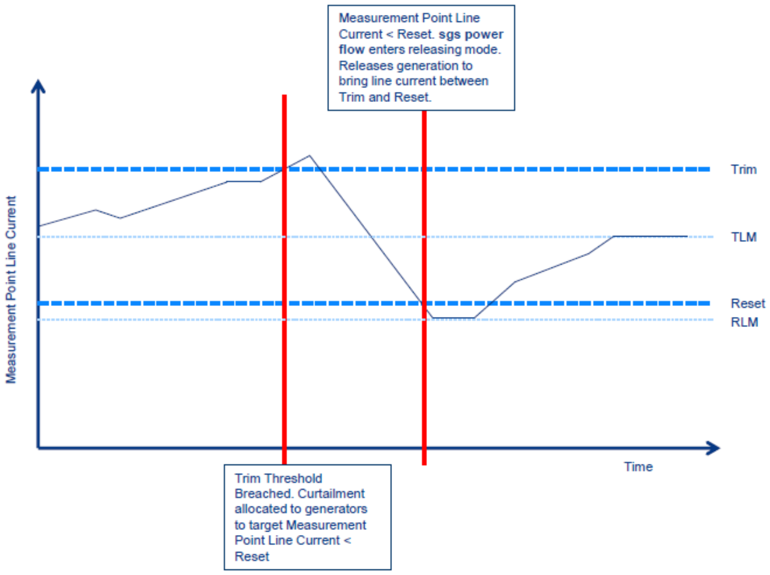
- ✓ The commercial agreements for generators connecting to distribution networks which are subject, via the Statement of Works process, to transmission constraints (details of which are included within learning report 2, The Changing nature of the Transmission Distribution boundary);
- ✓ The grouping and interdependency between customer projects subject to network reinforcement when sitting behind common network constraints on transmission networks;
- ✓ Technical considerations at the boundary of transmission and distribution; and
- ✓ The technical and commercial issues that follow from areas where ANM could allow additional generation to connect but where embedded generators are already connected under bilateral contracts with NGET.

At the outset of the project, and in our original submission to Ofgem, we set out to:

- ✓ Develop and demonstrate technical approaches to managing generators under both system intact and N-1 conditions.

4.1.1. ANM Enablement of a Grid Supply Point

Nearly all of the ANM schemes deployed in the UK to date that manage thermal network constraints rely upon the same basic approach for managing generators. These schemes take measurement of current or voltages at the identified constraint location(s) on the network and based upon that measurement, curtail or releases generation capacity accordingly. The graph below details a typical response of the ANM system to a breach of an ANM Trim threshold. After the current breaches the Trim margin, generation is curtailed until the current reaches the Reset Less Margin (RLM). Generation is then released up to the Trim Less Margin (TLM).



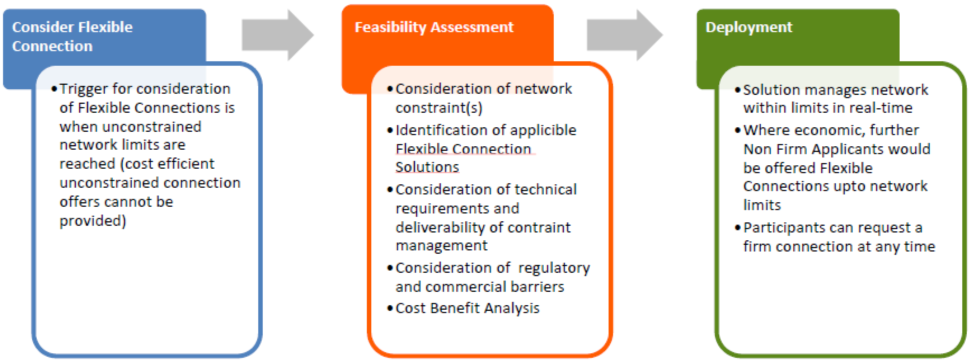
Measurement Point Line Current < Reset. sgs power flow enters releasing mode. Releases generation to bring line current between Trim and Reset.

Trim Threshold Breached. Curtailment allocated to generators to target Measurement Point Line Current < Reset

Figure 3: Example of Trim to Reset Margin and then Release.

The ANM scheme deployed at Dunbar GSP manages a commercially bound merit order of access to the network using Last in First Off (LIFO) principles. This means that the last generator to enter the LIFO stack is the first to be curtailed. The position of the generator within the LIFO stack was, during the ARC project, secured based on the date planning permission was granted for the project. This differs from other schemes, where other DNOs have granted positions in the stack based on the date that the connection offer was accepted. The advantage of using planning permission in order to set the LIFO stack position was that it prevented generators from blocking out access to those generators who were ready and willing to connect in the shortest possible timescales and negates the opportunity of creating a secondary network access queue.

As we move to implement similar schemes as part of our wider network roll-out we recognise that securing the position in the LIFO stack based on planning permission grant date may not be a sustainable approach. The SPEN BaU policy, developed towards the end of 2016, implements a staged connections process for flexible connections. This ensures that customers connecting to the network are clear as to when their position in the LIFO stack will be secured and that capacity which could productively be used by others is not tied up when projects stall.



Consider Flexible Connection

- Trigger for consideration of Flexible Connections is when unconstrained network limits are reached (cost efficient unconstrained connection offers cannot be provided)

Feasibility Assessment

- Consideration of network constraint(s)
- Identification of applicible Flexible Connection Solutions
- Consideration of technical requirements and deliverability of contraint management
- Consideration of regulatory and commercial barriers
- Cost Benefit Analysis

Deployment

- Solution manages network within limits in real-time
- Where economic, further Non Firm Applicants would be offered Flexible Connections upto network limits
- Participants can request a firm connection at any time

Figure 4: Flexible Connection Solution Offer Process

4.1.2. ANM GSP Measurement Points

Unlike previous LNCF projects, where network benefits of ANM have been realised, the ARC project has successfully demonstrated that the same technology can also be applied to overcome Transmission-Distribution constraint issues, such as thermal transmission constraints caused by the connection of distributed generation. However, to deploy such a scheme requires access to accurate and reliable measurement data from the transmission owner. This requires being co-ordinated with the transmission owner as effectively the distribution ANM system has been deployed to offer load management to mitigate thermal overload of existing transmission assets.

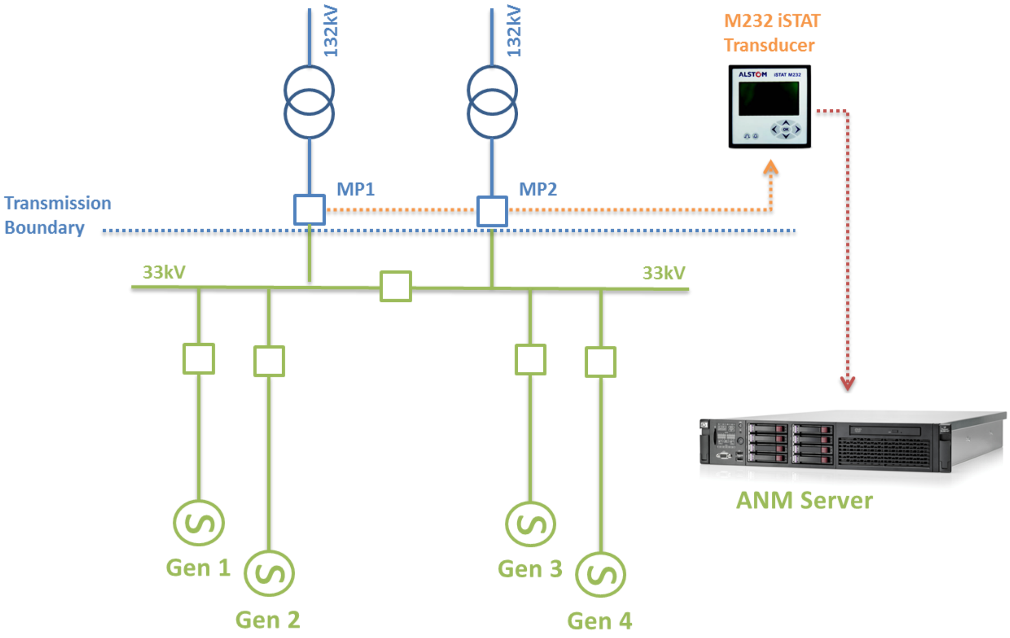


Figure 5: T/D Interface Measurement Points at Transformers

4.1.3. Hardware Platforms for Substation ANM Deployments

The original Orkney RPZ system design was implemented on industrial Programmable Logic Controllers (PLCs). As generators were added to that system, it became apparent that, even with modern PLC hardware, the system would not scale beyond the level of generators connected. It was recognised that any proposed solution must be capable of operating in the same time-bounded way but which could be targeted onto different hardware environments allowing flexibility for DNOs preferring substation or centralised deployments. As part of the ARC project, both approaches were trialled to understand the pros and cons of each.

For the Dunbar GSP we trialled actively managing generators under system intact and N-1 conditions with the ANM system deployed on commodity computer hardware (e.g. HP DL-series servers) and for the Berwick GSP the same technology was deployed on ruggedized substation computers (e.g. Amplicon). This reflects that substations are different environments to control centres and as such ANM systems deployed can be delivered using different operating platforms depending on the availability of communications and data. Table 4 provides a summary of the considerations, relative benefits of each approach and when each is best employed. Substation solutions form part of the overall SP Energy Networks Operational Data Network (ODN) while the centralised solution requires a combination of management across both the existing IT and ODN infrastructure. Therefore there are ownership, skills and cost implications for both types of deployment that will be relevant to individual network operators deploying similar approaches.

Table 4: Pros and Cons of Substation vs Centralised Deployment of ANM

	Pros	Cons
Substation	Local constraint management system, can be operated as a local or network wide scheme	Non-sterile environment that typically is not suited to commodity based server hardware solutions. Access for installation of vendors who must be accredited/authorised by DNO. More onerous on existing SPEN staff
Centralised	Easier access for repair, upgrade or maintenance	Potential single point of failure for all generators connected to multiple ANM schemes Potential RTU sampling rate restrictions, as all data must pass through RTU and full capability of ANM equipment is not realised Communications failure leads to total shutdown of generation under ANM control

4.1.4. Case Study A: Dunbar 132/33kV GSP

Dunbar Grid Supply Point

In 2003, an existing 62.5MW wind farm connected to the 33kV busbar at Dunbar GSP. This was followed by a second 48MW wind farm in 2008. Network access was provided to the second wind farm on a non-firm basis against the transmission network subject to implementation of a Bilateral Embedded Licence Exemptible Large Power Station Agreement (BELLA)[2] commercial contract with NGET. In addition, non-firm access required the implementation of an overload intertrip scheme that would protect the existing network against a potential thermal overload during an N-1 condition as shown in Figure 7.

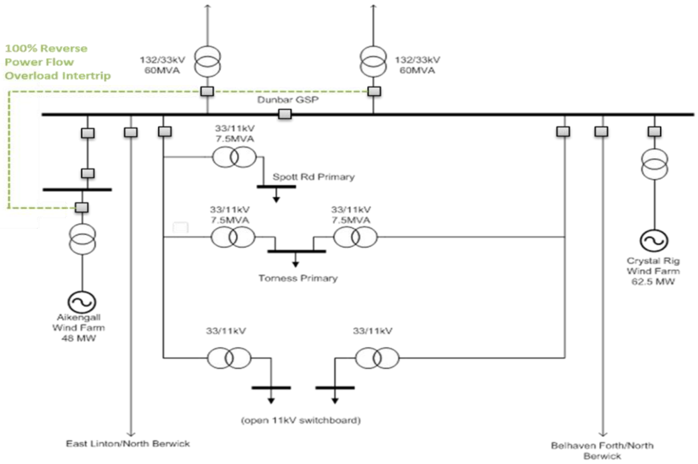


Figure 6: Dunbar GSP Constraint Management Scheme Pre ANM Enablement

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[2] http://www2.nationalgrid.com/UK/Services/Electricity-connections/New-connection/New-BELLA-Agreement/

In line with the timing and commencement of the ARC project, three additional distribution generation projects sought to move forward and connect to the SP Distribution network under the Dunbar GSP. In the absence of an alternative connection solution, each project was provided with a distribution connection offer that would not permit network access before 2021 and following completion of transmission reinforcements.

As part of conventional design modelling across the transmission network to ensure compliance with SQSS and continued operation of the network in a safe and secure manner, it was confirmed that the existing assets could not accommodate the proposed generation capacity that was seeking to connect under both system intact and system outage conditions. Therefore the three generators were provided with a connection offer that required payment of a distribution/transmission connection charge to upgrade the existing network infrastructure to increase the capacity available at the Grid Supply Point, and provide security towards wider transmission reinforcement costs to upgrade two 132kV circuits within the transmission network. The transmission reinforcement asset costs for these upgrades was estimated at approximately £6M for localised works and £14M for upgrading of the existing transmission 132kV overhead line and associated wider transmission works.

As part of understanding the customer journey, it is important to understand the objectives and drivers of each generator in developing their three individual projects:

- ✓ Hoprigshiels Wind Farm is a 7.5MW community project whereby all profits generated will be used to invest in new affordable housing stock and wider community benefit schemes
- ✓ Kinegar 5MW wind farm was being developed by an experienced development group looking to expand their existing generation portfolio
- ✓ Dunbar Energy Recovery Waste Centre is a 31MW energy recovery facility being taken forward by national waste disposal company Viridor who have been working with Zero Waste Scotland in building a modern waste incineration plant. The purpose of the plant is to convert waste to energy sourced from several local authorities across the central belt of Scotland and which is estimated will divert 4.75M tons of waste from landfill across the lifetime of the project.

A key element of this project was to implement both an innovative technical solution as well as an equally innovative commercial agreement. The advancement of both these objectives would facilitate an early connection through the use of Active Network Management but also provide a clear investment signal for the requirement to reinforce the transmission network. Working with each of the developers, incumbent TO and national system operation, National Grid, the ARC project coordinated the development and implementation of a two-stage commercial agreement that satisfied both the current industry connection process and enabled the advancement of generation to connect through implementation of Active Network Management. This enabled the distribution network owner to control, in real-time, the generation assets managed against a constraint on the transmission system.

This represented a significant step change from the conventional solution deployed in respect of the earlier transmission constraint management i.e. implementation of an overload protection scheme, by coordinating the connection of all three generators and allowing them to enter into an agreement whereby they all received a non-firm managed connection in the short-term (Stage 1), and then following the completion of the planned reinforcement works they will transition to a firm connection in circa 2021, Stage 2. The transition to a firm connection requires each generator to contribute towards the local cost for transmission reinforcement works to upgrade the GSP transformers.

By working together as a co-ordinated group and each generator committing to the staged connection agreement, each generator has been able to accelerate access to the network and a clear signal is now in place to commence the wider transmission reinforcement investment works.

The ANM system is shown below in Figure 8. This is in situ within the Dunbar GSP substation and actively controls the three generators in real-time by issuing a maximum export limit when the power flow across the Dunbar GSP constraint location breaches a prescribed network limit.

Figure 7: Dunbar 132/33kV GSP ANM Core Platform

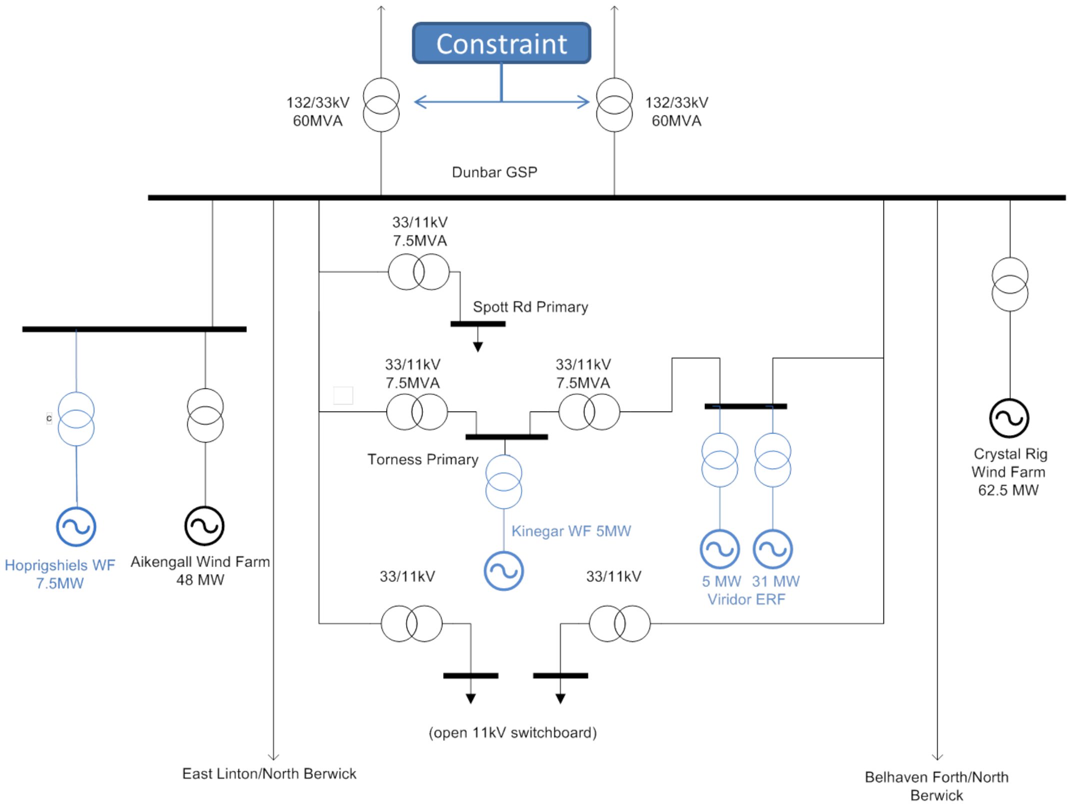


Figure 8: Network Diagram Showing the Location of Constraints

SP Energy Networks used equipment supplied from project partner Smarter Grid Solutions to facilitate the managed connections. In this instance ANM has been implemented as an interim solution prior to the completion of local and wider transmission network reinforcement works scheduled to complete in 2021. This allows developers to connect to the network in the short term, secure project finance and generate income, while awaiting and contributing towards the cost of the wider reinforcements. This provides a real and secure network reinforcement investment signal.

For the first time in the UK, as part of the Dunbar ANM scheme, the technology was retro-fitted to an existing generator to improve their ability to export from their existing wind farm during planned and unplanned network constraints. The Aikengall Wind Farm connected to the network and energised during 2008 and as part of their connection solution an overload protection scheme was commissioned that was designed to disconnect the generator during an unplanned outage at Dunbar GSP. The real-time control offered by the new ANM system complemented this arrangement with a curtailment signal, whereby instead of being disconnected, the ANM monitors the limits on the network and allocates the maximum amount of capacity to all customers managed by the scheme. Furthermore, the ANM control has facilitated connection of the three additional windfarms under Dunbar GSP. These have connected without increasing the risk of Aikengall Wind Farm being curtailed as these subsequent connections have a lower priority in the LIFO stack and are therefore curtailed before the existing Aikengall Wind Farm.

There were a number of aspects which make the Dunbar ANM scheme different from other existing schemes implemented to date across the UK, including the technology of the generation seeking to connect and interaction with existing overload protection arrangements. The Dunbar Energy Recovery Facility (ERF) site is the first synchronous generator to be controlled as part of any ANM system. The steam generator that will form the basis of the generation unit has differing operational characteristics to that of a wind turbine or PV array and response times in respect of response to curtailment instruction is significantly longer than either a wind turbine or PV array which can reduce power output in seconds as opposed to a number of minutes. Furthermore, to overcome the ability of the ERF facility to comply with a curtailment instruction, it would be easy to simply trip the generator and de-energise it from the network however this course of action and forecast frequency of curtailment event could lead to conflicts with existing commercial agreements in place between the manufacturer and supplier of the new generator turbine and the customer.

4.1.5. Case Study B: Berwick 132/33kV GSP

The geography of the Berwickshire area makes it an attractive location for onshore wind development. In 2012, a 28.6MW wind farm connected to the 33kV distribution network under Berwick GSP. This was followed in 2014 by connection of a 15MW wind farm. SP Energy Networks subsequently received connection requests, all with planning consents, from further wind farm developers seeking to connect under the Berwick GSP. The transmission system supplying Berwick was unable to accommodate all the proposed generation prior to completion of local grid reinforcements.

Wider system analysis by the System Operator and incumbent Transmission Operator identified deeper additional transmission constraints. Berwick GSP operates as part of a group of three GSPs under Eccles 400/132kV supergrid substation. Due to the level of connected DG under all three GSPs, as well as considering the contribution from transmission connected wind farms within the area, under low demand high generation conditions a possible second overload constraint was identified at Eccles 400/132kV supergrid substation.

To mitigate risk of an overload condition arising at Berwick GSP or at Eccles supergrid substation, the transmission operator implemented a new multiple layered transmission load management intertrip scheme, whereby a sequence of generator disconnections would take place in the event of an overload condition being witnessed at either constraint location.

To complement this requirement for a wide area Load Management Scheme (LMS), the ANM solution deployed under Berwick GSP was implemented with the aim of minimising the risk of disconnection associated with the LMS, whereby distribution connected generators would be managed in real-time and curtailed as a first line of defence prior to the last line of defence being physical disconnection from the system via a trip signal, as detailed in figure 10.

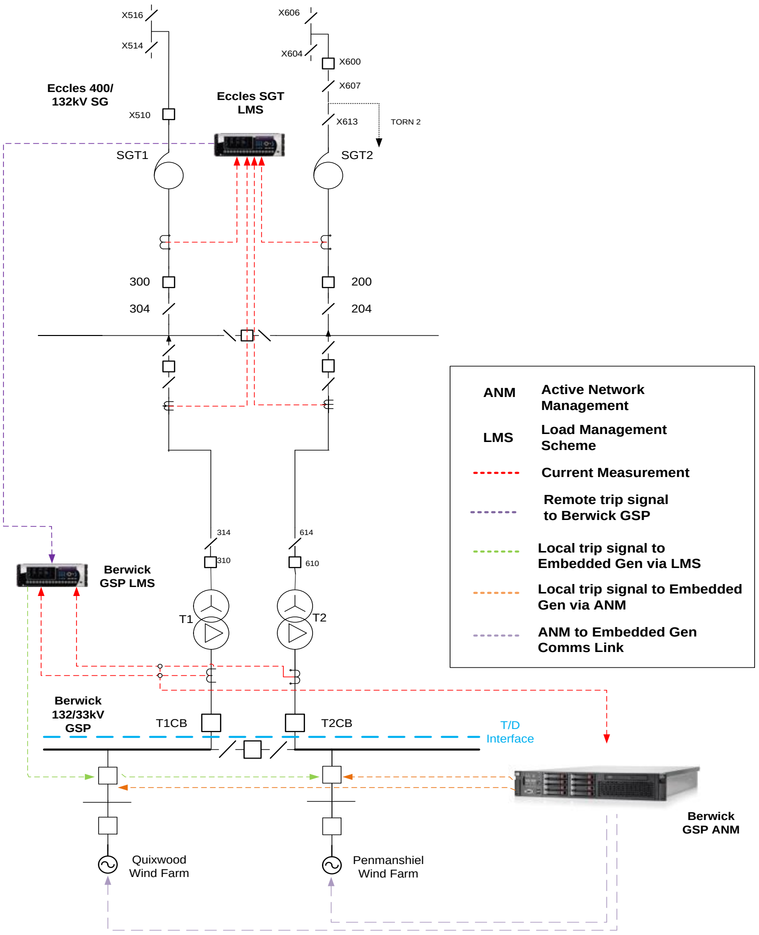


Figure 9: Eccles/Berwick GSP LMS & ANM Scheme

A specific improvement from the Dunbar GSP ANM scheme was a change in the original method used to acquire the constraint point measurements, which provide the system data to decide any actions taken by the ANM system. At Dunbar GSP, measurements were originally taken from the bulk metering point at the GSP and transferred to the ANM system via the GSP Remote Terminal Unit.

There were two specific issues discovered with this method. Firstly the sample rate and dead-banding of data from the bulk metering point resulted in a more conservative calculation of network capacity headroom being available for use by generators connected to the ANM system. Secondly, it introduced an additional point of failure of the overall system in that if there was a fault with the existing Remote Terminal Unit (RTU), this would result in loss of network measurement data being received by the ANM system, resulting in the issuing of a fail-safe set point to each generator managed by the scheme, which in most cases would be 0kW export.

To mitigate this potential weakness of the overall system, at Berwick GSP, dedicated transducers were installed to gather network measurement data from the existing transmission infrastructure overcurrent protection CT and VT's (voltage to obtain power flow direction) installed at both the 33kV grid incomer circuit breakers within Berwick GSP. This provided the ANM System with direct network information and removed the potential weakness of an RTU failure causing the potential for generators to be curtailed to 0kW export.

The original studies undertaken at Berwick GSP showed that reinforcement would be required to comply with existing industry design standards to accommodate the potential for full export of the proposed generation under N-1 conditions. Therefore, ANM has been implemented as an enduring solution at Berwick GSP to mitigate this constraint and will work alongside SPT's wide area LMS scheme to ensure customers continue to get access to the network whilst providing network security against overload events. As more generators wish to connect to the network using the ANM system, the need for investment may be triggered in future as constraints are likely to appear under system intact conditions, similar to that experienced under Dunbar GSP, however at this stage the investment signal for new reinforcement is absent and generators are willing to connect to the network under an enduring ANM scheme.

There are currently two generators connected to the network and managed via the Berwick ANM scheme - Penmanshiel Wind Farm (28.7 MW) and Quixwood Wind Farm (24 MW), both of which connected at 33kV and during early 2018, two further wind farm projects will connect at 11kV via Eyemouth primary.

To facilitate the connection of these connections and inform on the overall objectives of the ARC project, over the course of the project a number of workshops were held with developers and wider industry stakeholders to explain the benefits of connection via the ANM system. These workshops considered the likely positive impact on each developers overall business case. Evaluation of each site was a bespoke task for each developer and there was a significantly enhanced level of customer engagement provided to each developer by the ARC project team beyond what a normal level of interaction would be for a similar size of connection. This was necessary however to help explain both the technical and operational benefits of being part of the ANM system. Key learning from the project has been that when deploying an ANM solution, the relationship and level of engagement required between the DNO and project developer is significantly enhanced. Going forward, to be able to deliver such connections successfully, this has to be a key factor of the overall business case.

The two further wind farm projects are due to connect to the 11kV network fed from Eyemouth Primary, and is subject to the same transmission thermal constraint issues as Penmanshiel and Quixwood Wind Farms, however, the distribution connection offer to mitigate against voltage rise resulted in a cost of around £2.8M for an 11km POC. Through deployment of alternative connection proposal involving a voltage reduction scheme that has been possible to remodel through the deployment at Eyemouth Primary of enhanced network monitoring. This permitted a revised connection cost of £1.1M, based on learning detailed in section 5.2.3.

Curtailment assessments were provided for all generators connecting to the network and considered a wide range of scenarios and network configurations to understand the sensitivity and range of curtailment that may be experienced by each developer. The ANM scheme deployed at Berwick GSP employs the LIFO principle where the last generator to connect is the first to be curtailed.

4.2. Facilitating Connections for the Community

4.2.1 Active Control against Voltage and Thermal Constraints

Network planners are required to make a number of assumptions when planning 11kV connections, as discussed more fully in Section 3. Studies seek to design any potential risk out of future operation of the network therefore design solutions tend to focus upon the potent worst case conditions to establish if the generator may contribute to a voltage rise constraint at the Point of Common Coupling (PCC), that could result in forcing both the generator and other users of the system outside statutory voltage limits.

It is recognised that for the majority of the time the characteristics of the load distributed through the network is likely to be above that of minimum design values therefore this presents the opportunity through greater visibility and real time control of assets connecting to the system, to make greater use of the inherent latent capacity available across the network in real time. In a similar manner to the managed connections offered for thermally congested networks, a generator could be offered a managed connection where their output is managed against a measurement of the voltage at the PCC. Should the voltage breach a predefined limit, the generator can be instructed to curtail such that the voltage at the PCC is maintained within a pre-defined limit.

Traditionally distribution networks have been designed to serve load. The conductor sizes and feeder lengths have been chosen to accommodate a voltage drop along the feeder at peak demand. There are a number of technical strategies that can be used to manage voltage at the PCC. One strategy is to connect generators in voltage control mode where the network is monitored in real time and the reactive power import/export of the generator is regulated around a predefined voltage set point. This often requires the installation of additional control and or reactive compensation equipment at the generator. As with any actively managed connection, measures have to be deployed to deal with failure of the measurement equipment and failure of the generator to respond to control instructions issued by that local management system; the generation cannot be allowed to push network voltages above statutory limits.

Voltage control mode can and has been used successfully across various networks but can have the disadvantage that hunting between different generators can occur if those generators are electrically close to one another. If a generator is connecting in a fixed power factor mode at unity power factor, it will push up the voltage at the point of connection. That voltage rise will limit how much power the generator can export. It is currently SP Energy Networks policy to connect generation at 11 kV with a fixed power factor range, of 0.95 lead to lag.

Therefore a number of techniques were explored to accelerate the connection of generators onto the local distribution network who were previously facing lengthy and expensive connections.

- ✓ Single Constraint, Single Generator Local ANM Connection
- ✓ Network Voltage Reduction

4.2.1. Case Study – Ruchlaw Mains Farm PV Scheme

Generally network planners undertake studies using potential worst case network conditions (typically the occurrence of maximum generation correlated with low demand) to mitigate potential adverse effects that a proposed generator may have on voltage rise across a specific network location that may lead to the operation of the network out with statutory voltage limits. It is recognised that most of the time however real-time operating characteristics of network power flow mean that those instances of when the network may operate at worst case scenario will be few and far between. This therefore leads to the possibility of new generation being able to make use of that latent capacity to connect to the existing network.

In a similar manner to the managed connections offered for thermally congested networks, a generator may also be offered a managed connection whereby their output is managed against a measurement of the voltage at the PCC or potential impact upon a secondary network location. Should the voltage breach a predefined limit, the generator is then instructed to curtail such that the voltage at the PCC, or relevant network location, is maintained within a pre-defined limit.

Ruchlaw Mains farm is located in East Lothian and which is the Headquarters of pig enterprise Ruchlaw Produce Ltd. The business has a high annual energy demand. To that end the management of the company have embarked upon the development and installation of a range of renewable energy technologies in order to not only secure but attempt to stabilise their future energy costs.

During 2014, Ruchlaw Mains Farm applied for the connection of an additional 250kVa demand that would supply power to a new Milling Shed and sought a generation connection that would enable the installation of a new 80kW roof mounted PV array. The coincidence of customer demand and generation was not considered when the original applications were made and this resulted in both offers being taken forward separately leading to an offer to connect the proposed PV generation that included the construction of a new 1.3km overhead line at a cost estimated at £160k, across land not owned by the business. This led to the management of Ruchlaw Produce Limited advising that the proposed connection solution offered was both unfeasible and uneconomic.

As part of the project we carried out a site survey to consider if an alternative connection solution could be developed. Part of this process was to undertake analysis to better understand the balance between the onsite demand, and its correlation with the PV and an existing 275kW wind turbine connected nearby onto an existing 11kV overhead line. The original network modelling identified an existing voltage constraint in the area which was based on the assumption that the 275kW wind turbine already connected further down the line operated at full capacity 24 hours, 7 days per week.

Again learning was applied from the SP Energy Networks Flexible Networks project and subsequently network monitoring at the 11/.433 kV transformer was installed. This showed that the actual line voltage issue was not as high as originally calculated because the maximum wind export at the site had never reaches the agreed export capacity. The network monitoring enabled the analysis for the connection to consider a more realistic export profile for each of the various onsite generation units and incorporated the diversity between the different technologies.

Engagement with the customer aided understanding of how new demand to serve a new milling facility would be utilised. Based upon this greater understanding of the sites use of energy further network analysis was undertaken. This applied a more realistic capacity factor to the proposed PV array (15% annually) and a feasible connection was established where the network could continue to operate within statutory voltage limits subject to a local standalone ANM control system being installed to manage against a potential voltage constraint during extreme energy use scenarios. This could arise where generator diversity is less than expected, or the milling facility not drawing demand as expected especially at the weekend when production is suspended. In practice, the new 80kW PV array generator may have its export constrained to some extent on windy, sunny, weekend afternoons when there may be high generation export and low demand. The expected number of occurrences of this scenario throughout the year was however considered negligible.

To control the generation, a local ANM solution was developed provided by Smarter Grid Solutions. This device monitors up to one local and one remote thermal or voltage constraint on the network and manages the real power export of the generator to resolve constraints.

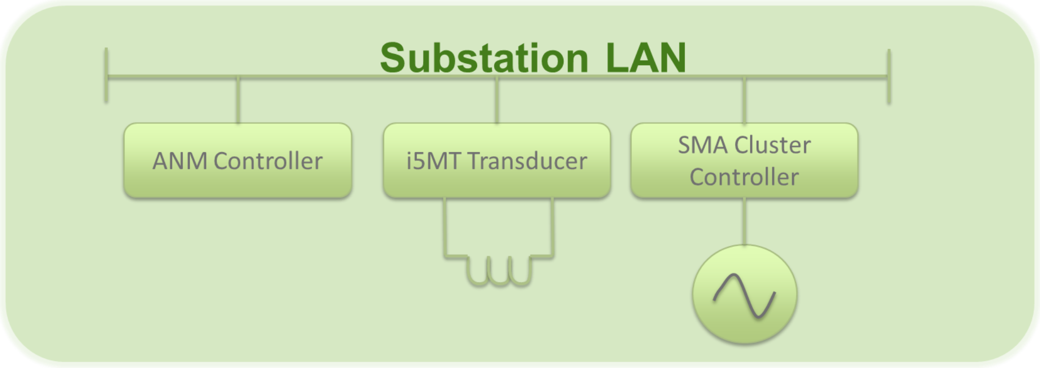


Figure 10: Ruchlaw Mains Substation LAN

The local ANM connect device was installed on the customer side of the Ruchlaw Mains secondary substation. Receiving voltage measurement data from the local 11kV transformer and if required sends a curtailment set point to the PV arrays if the voltage breaches limits specified by SP Energy Networks. When a curtailment set point is issued, the PV generation is curtailed to match the local load.

The ANM solution is connected to the relevant network device controllers, and timers set appropriately to ensure control does not over-ride or interfere with network protection. The connection was developed and commissioned within 12 months. A review of the curtailment data has shown that the requirement to limit the export of the PV has been limited to a few occasions. This supports the view that real-time monitoring and control action can release greater capacity that is available within the existing network.

4.2.2. Case Study - Penmanshiel Piggery Farm Wind/PV Scheme

Penmanshiel Piggery is located within the Berwickshire area and is fed via the Berwick GSP. The customer applied for the connection of 100kW of PV and a 100kW wind generator. The customer had already received planning permission for both the PV and wind generation. The nearest point of connection was identified as Ayton Primary based on standard network planning analysis, as voltage constraints were identified locally. The cost of an unmanaged connection was uneconomic for the customer, with a connection quote likely to be in the order of £740,000 based on a new overhead line back to the primary substation.

Following engagement with the customer, the project reviewed as part of ARC. Similarly to the Ruchlaw Mains case study again the team first stage engaged with the customer to understand his overall energy requirements and used this information to develop a potential solution along with agreeing a period of network monitoring to understand the real-time actual load across the relevant network.

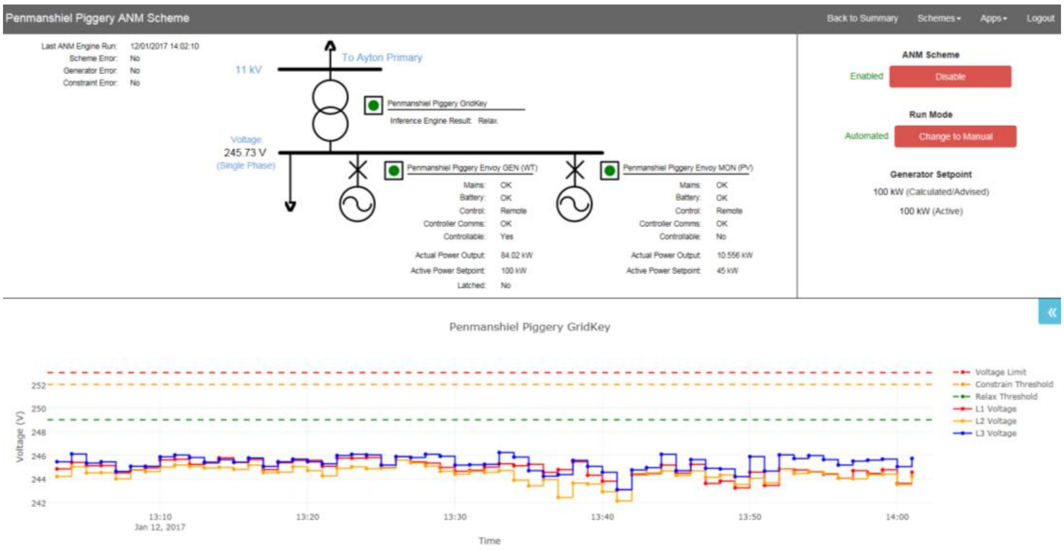
Monitoring undertaken over the summer months identified that minimum demand at the piggery ran at a minimum load of 50kW. Based upon this information it was agreed that an initial 50kW PV array could be permitted to connect to the existing network without any constraint. However, monitoring also confirmed that the proposed 100kW wind turbine and additional 50kW solar array would require being subject to a local standalone ANM control scheme.

A non-firm connection offer was issued in summer 2015 that proposed an enduring managed connection that would permit both the 100kW wind turbine and additional 50kW solar array. The ANM scheme deployed would manage either the wind turbine or solar array dependent upon the contribution each made to a potential excursion of the voltage limits along the feeder circuit. This design solution recognised the diversity between different generation technologies connecting behind a single connection point. The revised connection offer was accepted by the customer and the 50kW PV array was connected during winter 2015. The additional 50kW PV array and 100kW wind turbine was commissioned in spring 2016.

The total connection cost for the required distribution connection and associated local ANM control equipment did not exceed £20k, representing a saving over ~98% in connection costs from the original quote.

A different control solution was deployed at Penmanshiel Piggery than the one deployed at Ruchlaw Mains. The voltage constraint (or measurement) points are monitored using GridKey devices installed on pole-mounted transformers, allowing the voltages and current of individual LV feeders to be monitored with a 1-minute granularity. This data is collated and reported via a Nortech supplied iHost platform using General Packet Radio Service (GPRS).

The platform was located in a centralised data centre location. Voltages at the constraint points are compared to pre-determined thresholds. When the voltages exceed the 'constrain threshold', a constraint signal is dispatched via Nortech's Envoy Generation Controller to either the wind turbine or PV array, dependent upon which system is contributing to the breech of the constraint threshold at that particular point in time, and power output is reduced in discrete intervals until the wider voltage level is brought back within statutory limits. When the voltages fall below the 'release threshold' the power output of the generation is released, allowing the generation to return to an unconstrained output, when the headroom allows. The system is configurable and is accessible via a secure dashboard, as seen below. To date the system has not had to issue any curtailment instruction to either the wind turbine or PV array.



Last ANM Engine Run: 12/01/2017 14:02:10
Scheme Error: No
Generator Error: No
Constraint Error: No

Voltage: 245.73 V (Single Phase)

Penmanshiel Piggery GridKey
Inference Engine Result: Relax

Penmanshiel Piggery Envoy GEN (WT)
Mains: OK
Battery: OK
Control: Remote
Controller Comms: OK
Controllable: Yes
Actual Power Output: 84.02 kW
Active Power Setpoint: 100 kW
Latched: No

Penmanshiel Piggery Envoy MON (PV)
Mains: OK
Battery: OK
Control: Remote
Controller Comms: OK
Controllable: No
Actual Power Output: 10.556 kW
Active Power Setpoint: 45 kW

ANM Scheme
Enabled Disable

Run Mode
Automated Change to Manual

Generator Setpoint
100 kW (Calculated/Advised)
100 kW (Active)

Figure 11: ANM LV Dashboard

Further monitoring of the PV at this site post installation has shown to date that the annual capacity factor of PV solar sits between 12-15% with the maximum export at any single point in the year not exceeding 90% of the rated installed capacity.

The key learning from this case study is that the monitoring, implemented for a period prior to developing the final connection design allowed visibility of real-time network characteristics and the development of a design that reflected the true state of the network and available capacity rather than reliance upon a deterministic static network model. Furthermore the coupling of two different generation technologies behind one connection point demonstrates that that there is significant diversity between wind and PV and that both can co-exist without having a detrimental effect upon one another or the surrounding network. This however can only be managed with implementation of a real-time control system which is backed up with real-time reliable network monitoring data.

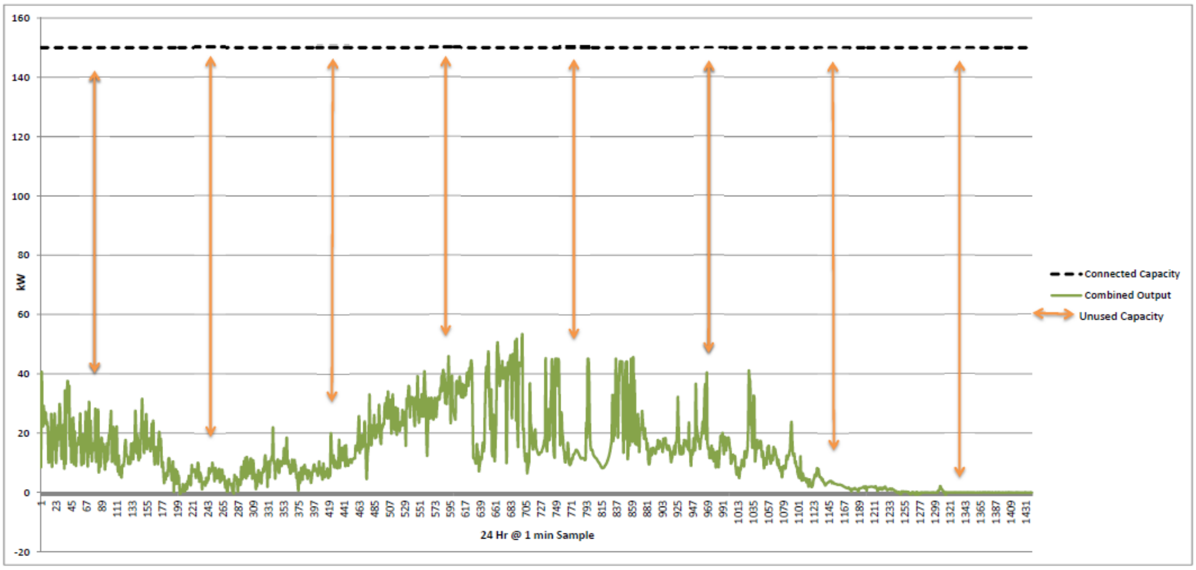


Figure 12: Single Line Diagram of the Penmanshiel Piggery Network and Control Solution.

4.2.3. Network Voltage Reduction

Traditionally target voltage and Line Drop Compensation (LDC) settings are used to manage the voltage levels at a Primary substation (33 kV/11 kV). These are set to account for a voltage drop along the length of an 11 kV circuit. This ensures that all customers, whether close to the Primary substation, or at the end of the relevant feeder circuit, receive voltages at all times of day within the statutory limits.

With increasing amounts of DG connected at lower voltage levels, coupled with an increase in energy efficiency measures (such as home insulation) and the acceleration of low energy devices in the home and business, the traditional assumption of the profile of network voltage being higher at the beginning of the circuit and decreasing as the circuit progresses as a static rule is no longer valid for a modern network. It is true however that exporting DG can raise the voltage level locally at the point of connection.

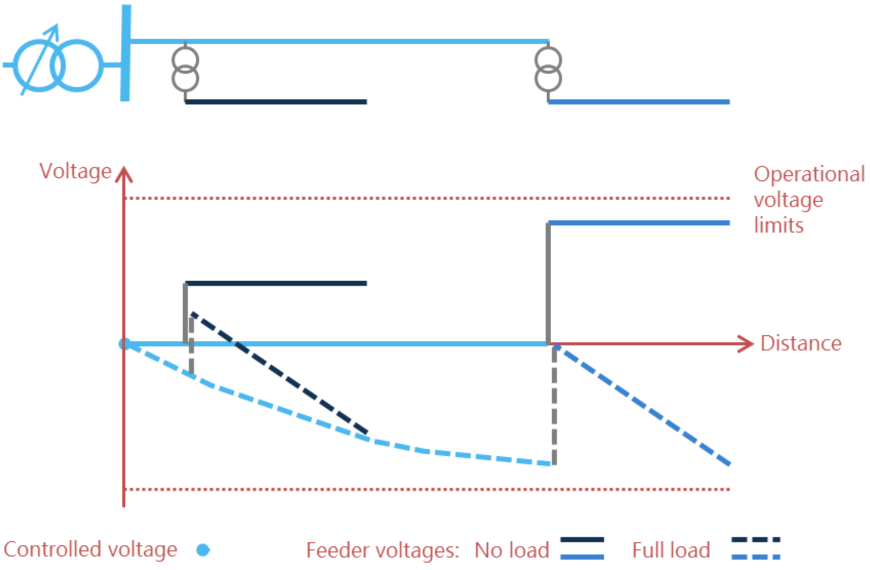


Figure 13: Graph Demonstrating the Drop in Voltage along a Feeder

Voltage reductions require careful consideration. It is essential that all customers along a feeder still receive a supply voltage that is within statutory limits. From the perspective of network design, this involves studying credible running arrangements. It is imperative that the voltage at a primary substation is set at a high enough level to ensure that no customers experience a supply voltage below the lower statutory limit in all network running arrangements.

To undertake detailed studies, the DNO requires accurate voltage data from a number of key measurements points along the circuit, especially at points that are the greatest distance from the primary point of supply. Installation of enhanced network monitoring and recovery of real-time data is therefore essential to inform the decision making process, providing a better general understanding of the network.

Following installation of monitoring and recovery of network data over a nine-month period on circuits within trial area, the project investigated the impact that a voltage reduction would deliver in allowing an increased export capacity for customers wishing to connect distributed generation. The revised network study using real-time data modelled the implications of reducing the target voltage at several primary substations from 11.2 to 11.0kV, a reduction in voltage of 1.02pu to 1.00pu. Examples of which are included in Case Study: Standhill Farm AD

4.2.4. Case Study: Standhill Farm AD

Standhill Farm is located in Denholm, Scottish Borders, and is a diverse agricultural business which consists of a dairy farm, a cheese factory, vegetable growing facility, and tenant housing as well as the annual production of arable crops. The owner had previously sought connection for a 500kW wind turbine and 200kW Anaerobic Digester (AD) plant on the farm however planning permission was subsequently rejected for the wind turbine. The customer then decided to progress with the construction of the 200kW Anaerobic Digester and subsequently made an application to export onto the distribution network.

The site is located approximately 10 miles from St Boswell's primary substation. The initial system planning studies that informed the first standard connection offer was based upon modelling that assumed a minimum on-site demand of 20kW and used existing records of conductor type on the radial 11kV circuit. These studies found that exporting the maximum generation at a time of minimum demand would risk an excessive voltage rise at the customer point of connection. Therefore the full export capacity of 200kW could not be accommodated without significant network reinforcement. Designing the network against the worst case conditions, the site was offered an export capacity of 70kW. A 200kW connection would have required reinforcement of the existing 11kV network at a cost to the developer of £821,000.

Following a challenge by the customer to SP Energy Networks regarding the level of onsite demand used on site, a more detailed on-site survey was conducted. This identified a data error in the 11kV conductor records. The circuit had a larger cross-section than was shown on historical records. Additional system planning studies using revised conductor impedance provided a new connection export capacity of 153kW and this was offered and accepted by the customer.

Although this was still short of the 200kW maximum export capability of the plant, the customer was provided with a connection offer under an agreed site export limit of 153kW with standard connection terms. The site was subsequently energised in 2014.

As part of the ARC project alternative connection solutions were considered that could facilitate the maximum 200kW export of the plant. A current and voltage monitoring device was installed at the pole-mounted transformer at the point-of-connection to observe the actual site demand and network voltage profile prior to the energisation of the plant. The outcome of this monitoring trial provided detailed energy profile information to determine if the site export capacity could be increased to 200kW.

After nine months of monitoring the site, including a period post-energisation, it was confirmed that the original design assumptions were correct and that a voltage rise constraints still existed. The site was, on occasion, subject to the G59 protection relay tripping due to over-voltage measurements within the first 6 months post energisation. The monitoring data confirmed that in all cases of G59 protection tripping, the generator had exceeded the 153kW export limit (which for the purposes of the ARC trial had been agreed with the customer and Network Operational teams).

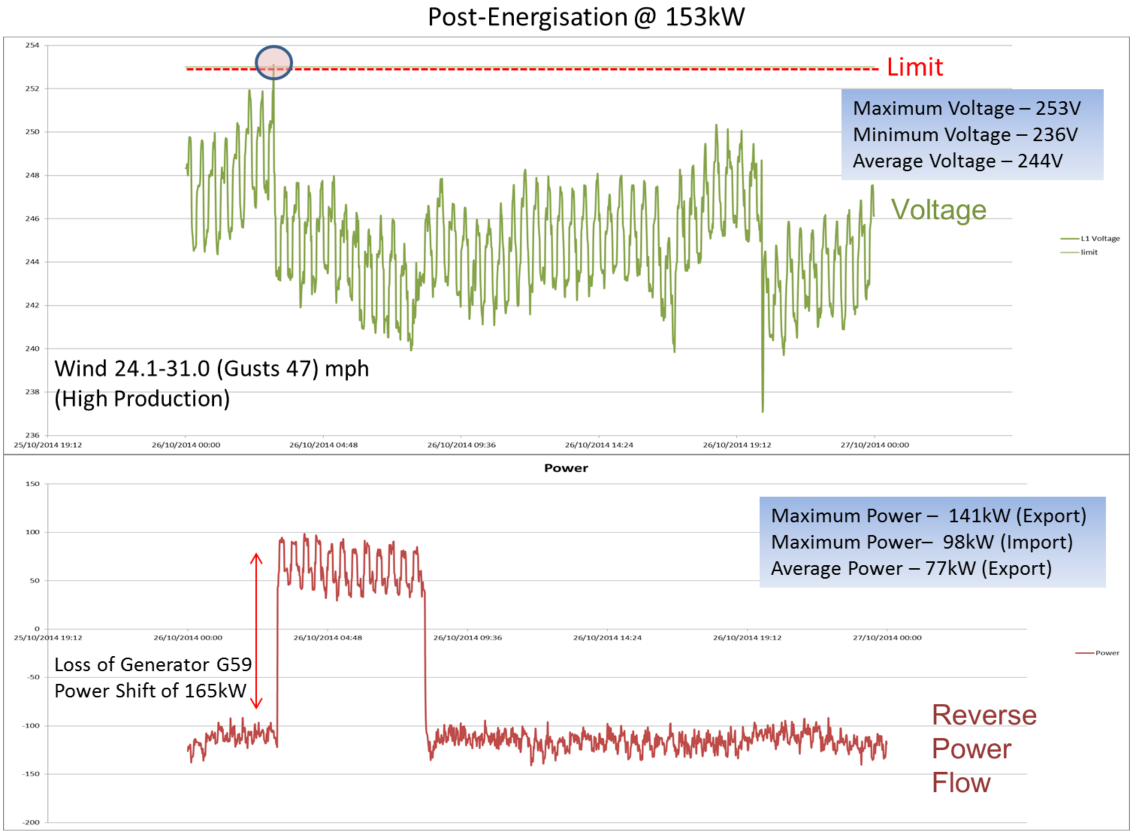


Figure 14: Standhill Farm Post Energisation Voltage Profile (pre VR Reduction)

In order for the ARC project to facilitate the additional 47kW of export capacity, a number of alternative connection solutions were explored. These included advanced export limiting through control of the onsite generator gas turbine or demand side response (DSR). However, neither of those solutions was viable due to technical limitations of the AD plant to accept a curtailment instructions and lack of controllable demand behind the meter to limit network export. The implementation of the monitoring had confirmed a site minimum demand of 20kW.

Additional network capacity was therefore sought through adjustments to the voltage on the 11kV network. A reduction in the 11kV network voltage at St Boswell's primary substation allowed the anaerobic digester plant to export its full capacity of 200kW without risk of excessive voltage rise at the point of connection for any other customer supplied via the same network.

St Boswells primary network supplies approximately 2,500 customers across a rural area via predominantly 11kV overhead feeders. A number of key points on the network were monitored, including the customer supply points furthest from the primary. Using real-time data demonstrated that the voltage drop along these long, rural feeders was not as great as suggested by desktop network modelling due to the diversity of demand and generation and the modelling being reliant upon a static view of the network in the absence of real-time data. The monitoring studies found that a voltage reduction to 11.0 kV at the St Boswells primary substation would adequate network capacity to accommodate the additional 47kW export requirement for the Standhill site, without adversely affecting voltage levels to other customers.

The reduction of voltage at a primary substation was in breach of our current network design policy and standards. However, based on the monitoring data, the Design Authority and the Technical Review Panel within SP Energy Networks authorised an innovation solution to reduce the voltage at this primary substation. This enabled the release of additional network capacity and allowed the customer to realise the full export from his distributed generation plant.

We have now implemented this same innovative solution at a number of locations during the course of the ARC project, each time presenting to and obtaining approval from the Distribution System Review Group, to reduce the target voltage at a substation to release greater headroom of network capacity. This tool is acceptable when it can be verified either through direct measurement or appropriate analysis that the minimum voltage along the circuit will remain above the statutory limit under all network conditions. It is also, where applicable, is a relatively low cost solution to facilitate additional renewable generation in most cases allowing a generator to connect at a point on the network relatively close to the proposed generation site.

The adoption of such a solution to accommodate additional distributed generation not only has a direct customer benefit in respect of reduced costs and accelerating access to the network, there may also be wider benefits for the network operator. These include softer benefits through the mitigation of new infrastructure that both has an economic and environmental benefit, this however can be applied to most of the solutions developed as part of the ARC connection solutions toolkit. By negating the requirement to new overhead lines or cabling, we now no longer have to construct, in most cases, a new overhead line over rural landscape that following connection is adopted and required to be operated and maintained by the network. Furthermore by not impacting upon the landscape with new infrastructure there are wider social and environmental benefits for those stakeholders living and working in and around the location of the proposed generation project.

In addition to increased revenues from energy exports, the connection of the anaerobic digester plant provides the capability to off-set energy demand on the site, including the provision of heat energy from the Combined Heat and Power system that supports vegetable production on the farm. The customer, Jim Shanks, commented, *"SP Energy Networks got on board and really helped"* and *"I cannot stress enough that, without them, it just would not have happened. I believe in the benefits that renewables can bring to a farm and I've fought like a dog to get what I've got; but it was SP Energy Networks who, in the end, got me a viable grid offer to make this project work."*

Furthermore, as the farm seeks to diversify its business in future, the construction of a 4 acre greenhouse has also commenced at the site which will be used to grow tomatoes for the Scottish market. This will overall increase the demand at the site above the current 20kW and will be served from the on-site generation plant. By working with the customer and knowing their current and future business plans and how this would impact upon the proposed generation plant in the longer term, it enabled the ARC project to develop and implement the most suitable and economic connection solution for that customer.

Standhill Farm Visit by HRH The Princess Royal

4.2.5. Virtual Private Wire

A significant number of connections undertaken as part of the ARC project have been directly linked to the increase in the number of communities wishing to own and operate their own generation projects. The links with local communities during the project was strengthened through our collaboration with ARC project partner Community Energy Scotland. This partnership proved very successful leading during the project and has enabled several generation projects to gain network access through the deployment of alternative connection solutions to realise delivery of their project.

When communities or organisations wish to obtain a connection for new generation they are in many cases willing to explore alterations to their own energy demand profile to offset excess generation. If demand and generation are behind the same connection point then this can be easily incorporated into an export limited connection. However, when the demand and generation do not share a common network connection point this is more difficult. It requires a “private wire”, either physical or virtual. A physical private wire would ensure generation is routed directly to the demand similar to the case of a shared network connection point, however this is usually a prohibitively expensive solution. A Virtual Private Wire (VPW) is where increases in demand at a particular site are translated into permitted increases in the export capacity afforded to a linked generator using a wide Active Network Management system creating a virtual connection between the two sites.

A VPW solution may be achievable in many cases and may offer the most cost effective connection solution, but only if certain criteria is met. Firstly, the demand and generation must both be downstream of the same constraint, i.e. the demand must be able to influence the level of the constraint that the generator is contributing to. This is not always the case due to network connectivity, even when sites are close in proximity. Secondly, there must be a way to reconcile changes in power flow at the constraint with increases in demand at a particular site so that this is then accurately allocated as export capacity to the generator through ANM. This requires additional measurement at the demand site and analysis of its influence on power flows, similar to the analysis performed for the generators themselves.

As part of the project learning reports we have produced a separate paper that provides further detail around the key considerations and implementation of Virtual Private Wire solutions.

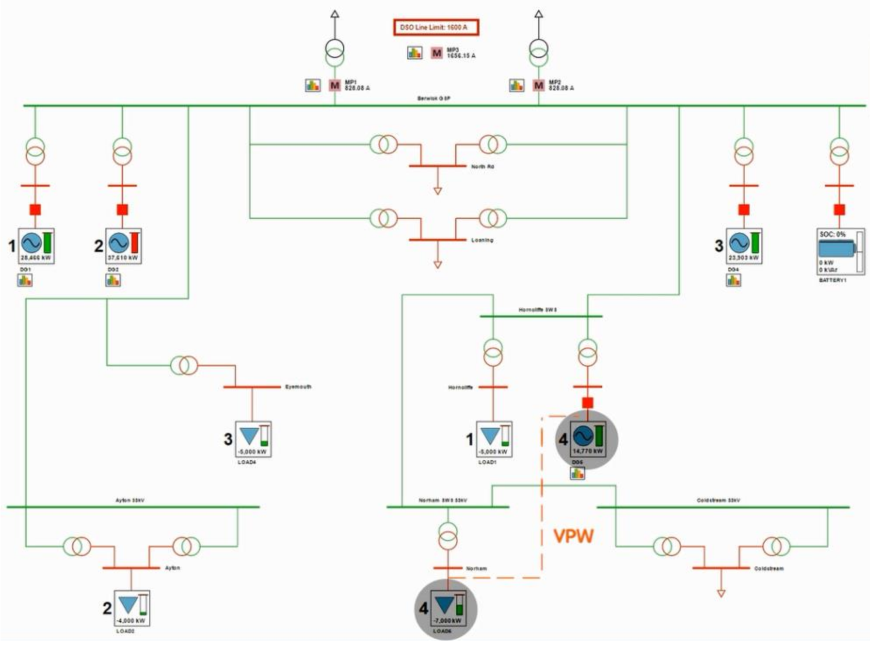


Figure 15: Modified ANM Scheme with VPW Arrangements

4.2.6. Case Study: Power Networks Demonstration Centre - Desktop Trial

As part of our original submission to Ofgem we committed to delivering a community energy scheme and also demonstrating another whereby a community project in an ANM-enabled area could create additional capacity for itself by accommodating linked demand.

If a community or generator wishes to connect a local energy scheme under an ANM-enabled GSP there may already be several generators connected through ANM, each taking its contractual position within the LIFO stack. Community-owned, which for the purposes of this document includes businesses and individuals who are both generators and consumers of energy, generation joining the stack later in the process will be subject to same network access rights and curtailment instructions of the existing generators.

There are a number of reasons why a community energy group may wish to link their community owned generation to demand consumed. This could be to reduce curtailment if part of an ANM scheme or it could be to leverage commercial benefit via net metering of locally dispersed load and generation. From a technical perspective, under a LIFO arrangement, any new demand added to the system benefits the generators who connected first. The last generator to connect will only see benefit after additional non-firm capacity created by the demand has been added to the generators ahead of it in the LIFO stack.

Working with project partners Smarter Grid Solutions and Community Energy Scotland, we created a demonstration system to show technically how an ANM system could match associated load with generation and manipulate the LIFO stack such that a generator further down the stack could benefit from matching their own new demand. This exercise required the development and configuration of an ANM system that could measure demand and allocate capacity and curtailment differently from current practice in the UK. In doing so, we have demonstrated that such an approach is technically feasible.

However, as part of the project we have only been able to demonstrate certain technical requirements when considering the use of VPW or virtual net metering under ANM arrangements as an alternative connection solution. A further development to take this learning forward will be to analyse how communities are able to use their local networks to develop community energy schemes where load and generation are linked for technical and commercial benefits which will involve a holistic review by network companies, suppliers, ELEXON, aggregators and other interested industry stakeholders. To provide some insight into this work Community Energy Scotland (CES) have lead work looking at the commercial and technical arrangements for such schemes.

4.2.7. Case Study: Bowhill AD Plant

Bowhill Estate is located outside Selkirk, in the heart of the Border region and part of the ARC project trial area. It is a large estate with a working farm and a number of properties that include: estate offices, small industrial units, animal housing, and residential homes. In 2015 the Estate made an application to SP Energy Networks to install a 200kW anaerobic digestion plant at Bowhill. The original offer issued provided for a connection at distribution voltage level, however due to the cumulative effect of a number of existing and planned generation applications in the area, this offer was subject to application for a Statement of Works from National System Operator National Grid.

Following review, it was considered that the proposed development would have an impact upon the transmission network due to the contribution it would make to increase the reverse power flow across the transmission/distribution boundary. Following an initial network study by the transmission network owner and NGET, it was considered that the impact of this new generation would increase reverse power flow across Galashiels GSP and therefore the connection would be limited to an export 100kW if transmission upgrades were not performed. This would have represented a significant cost and would have delayed connection until 2019 at the earliest. The cost and timescales of these upgrades were prohibitive for the developer.

Engagement with the developer permitted a more detailed desktop study to be carried out and a site visit was undertaken which identified substantial existing load on the Estate. It was established during this visit that demand of the various Estate properties was split across three separate metering points. The onsite demand is not identified during the standard design process to complete a connection offer. The summation of the total minimum demand across all three MPANs was greater than that of the entire proposed AD plant's forecast export capacity assuming that it was running at 100% capacity factor. By coupling the demand connections from the various properties around the estate, full export of the generator could be achieved. Coupling local demand with the generator ensured that the net export did not exceed the 100kW limit imposed on the generator connection by the NGET SoW process.

During the pre-design phase and engagement with the customer a number of alternative connection options were explored. One suggestion of the Estate was to install a new private cable across their land, linking the generation export to the demand sites thus avoiding the need for an export limitation as identified through the SoW process. This option would have required significant capital investment and ongoing operation and maintenance costs, while SP Energy Networks apparatus was already in situ around the Estate and which provided a supported distribution network across the Estate.

By facilitating the managed connection, the Estate has been able to reduce their overall energy costs and further benefits are being realised as power directly from the AD plant is being used to heat the large residence that form the main demand of the Estate. In addition, the farm itself has used the AD plant to improve efficiency by using the renewable heat to dry waste cattle manure which is then used as animal bedding, saving around £70k per annum by avoiding the purchase of additional bedding straw. Without use of onsite generation, the heating was limited to some key areas of the house.

In addition to the implementation of monitoring equipment on the existing 11kV network which is used to ensure that export from the entire Estate does not spill onto the wider network above the agreed export limit, SP Energy Networks reconfigured the existing network to ensure that the new generation could supply all the Estate's local demand. The Estate residence itself was connected on the opposite side of the normally open point of the existing 11kV network that meant it could not benefit directly from use of the generation export following the installation of the AD plant. Finally a monitoring system was also installed in and around the Estate to ensure that demand can be flexed to absorb the export from the generation as required.

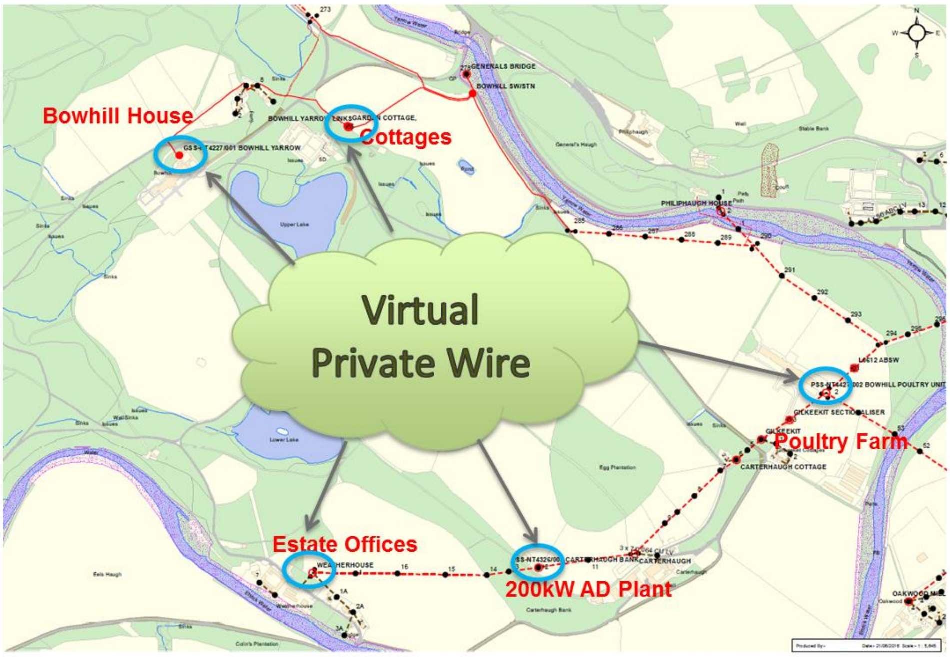


Figure 16: Coupling of Demand and Generation using VPW

4.3. LV: Facilitating Connections for Residential Customers

Individual small scale residential DG connections do not cause any significant impact on the network. However, network issues do arise when their penetration levels are high and clustered together. This can result in local voltage rise, phase imbalance and potential circuit overloading.

The network operator manages connections at LV according to either ER G59/3 or ER G83/2[1]. The former covers DG connections above 16A per phase and the latter covers small-scale DG connections (up to 16A per phase). Single small-scale DG installations up to 16A per phase can be made under G83 Stage 1. In this case, there is no need for network changes and the installer should inform the DNO within 28 days that the unit is installed and commissioned in order to allow SP Energy Networks to record the unit location on data records.

Alternatively multiple or clustered installations by the same applicant, such as a Housing Association or Local Authority, require consent from the local DNO before they can connect. After the developer submits an application under G83/2 Stage 2, generation assessment by the DNO is required in order to ensure that the cumulative effect of multiple connections will not cause the distribution network to operate outside its statutory voltage or thermal design limits. These include: (I) at periods of low demand a distributed generator must not overload the thermal limits of the feeder; and (ii) under all expected operating conditions, voltage limits across the feeder must be maintained within operational limits.

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[1] Distributed Generation Connection Requirements, SPEN, ESDD-01-005, Issue No 1.
[2] Strathclyde University BHA PV Analysis, Final Issue

If the assessment identifies a constraint related to voltage rise, thermal capacity of the existing network or a reverse power flow issue, the developer can either request the network reinforcement or reduce the scale of the proposed generation.

In order to identify the capacity available for G83/2 connections, an understanding of the specific LV network is essential. Changes to network voltage and phase imbalance affect the capacity that is available. Factors such as looped services and legacy feeding arrangements must also be taken into consideration. LV networks differ from networks at higher voltage levels with regards to the lack of availability of network data, including current and voltage information. It is also well documented that registered G83 and G59 connections don't necessarily reflect the reality of what has already been connected to the network, within the trial area alone we determined through street survey that the DNO had not been informed of at least 70% of all the G83 connections already installed.

The key innovation we have investigated as part of ARC is a smarter approach to design and the process of connecting G83/2 projects. Our case study with Berwickshire Housing Association (BHA) highlights the methodology we used to achieve this. Further information is also available through our report developed in conjunction with the University of Strathclyde which provides further details of the analysis and methodology.

Working with the customer, BHA, and using their housing stock data for their proposed G83/2 connections, we created network configuration maps from our existing GIS system and developed design principles to classify an individual connection as red, amber or green. Red being can't connect, amber being possible however further in-depth analysis would be required, green was able to be connected with immediate effect.

Based on this classification coding, we were able to release 24% of proposed connections (green) without in-depth network analysis, using engineering judgement and network knowledge. Further analysis and network monitoring was then conducted to assess and release further connections that were originally classified as amber or red.

Our case study illustrates how this more staged approach to design allowed us to accelerate connections and how availability and use of real-time network data is again key in the decision making process. It details how data from monitoring and modelling was used to then release more capacity.

4.3.1. LV Voltage Control

Almost all 11kV/415V transformers operate with a fixed ratio between the primary and secondary windings and with no on-load tap changer. In most network designs this ratio is set so that at minimum load the voltage across the secondary windings is close to the statutory maximum. This approach increases the acceptable length of the LV circuit, accounting for voltage drop along it during the maximum loading condition, meaning more customers can be reached with fewer secondary substations.

Unfortunately this configuration, whilst suited to passive unidirectional electricity flows, limits capacity for new generation. A moderate cluster of small generators exporting onto an LV feeder can cause local voltage rise that exceeds the statutory limit, as there is little headroom between the actual voltage and the statutory voltage limit.

In contrast, transformers at higher voltage levels are equipped with On Load Tap Changers (OLTC) and control relays that regulate voltage through automatically changing the windings ratio when the voltage varies by a certain amount from a voltage target. Installing this technology at LV as part of a generator connection creates significant opportunity to increase capacity for new generation on both HV and LV circuits. The LV OLTC equipment supplied by MR Reinhausen has been used to manage voltage in areas with high penetration of small scale PV. Data gathered from the implementation of these transformers will be used to inform future standard specification and recommend where this type of solution may be able to be deployed in future. The OLTCs are installed are located at substations with the highest volume of BHA PV properties and have been used to facilitate a greater availability of network capacity.

Markle Mains Farm – Installed On-Load Tap Changing Secondary Transformer

4.3.2. Dynamic Voltage Control

Advanced AVC can make use of additional current inputs to select a target voltage at the transformer which results in better regulation of voltage on the downstream network. Modelling of the network, with careful selection of settings, and coordination with generators with a voltage control limiting function can increase generation hosting capacity whilst not adversely affecting voltage for load customers.

Advanced AVC functions can account for the impact of generation teed into the incoming feeders, the effect of generation on the power factor seen by parallel transformers, and influence how the reactive load should be shared. This is important to avoid high circulating current through parallel transformers.

In order that the complete AVC function can accommodate reverse power flows from embedded generation, consideration must be given to the capability and operational health of the tap changer. Many of the transformers and tap changers in service were manufactured before reverse power became an issue due to the advent and penetration of distributed generation. Some tap changers of a certain vintage have since been declared as having reduced or no reverse power capability. However, it is possible by calculation, inspection and consultation of the original manufacturer's data to assign specific limits of reverse power for some tap changers which can then increase allowable generation connections.

In addition to the AVC relays themselves, voltage control schemes contain many components which can fail over time and lead to a non-operational situation (fixed-tap). Contactors, limit switches, stepping relays are all examples of components that can fail without adequate maintenance. These components often reside in the tap changer drive mechanism compartment or a marshalling kiosk and can be difficult to replace due to their age. AVC scheme upgrades can be achieved using more modern components and are an important consideration in realisation of a fully-operational Advanced AVC scheme.

The SuperTAPP SG is an Advanced AVC relay which is designed to meet the requirements of distribution networks with generation. It has functions to handle parallel transformers, remotely embedded generation, dynamically changing substation and network switch configuration, variable load power factors, and dynamic changes to voltage targets.

Using these functions, SuperTAPP SG can autonomously handle regulation for a variety of local scenarios, as described in section 5.2.4. Furthermore it can receive inputs from an ANM scheme or existing Network Management Systems of the Distribution network operator to adjust its target voltage levels to meet the needs of area constraints.

Two SuperTAPP SG units were installed at Ayton and Eyemouth primary substations to enable accommodation of the greatest level of connected PV capacity.

Ayton Primary installed SuperTapp+ AVC Scheme

4.3.3. Case Study: BHA PV Scheme

In October 2014, with the aim of reducing energy costs for residents and using income generated from the PV to facilitate improvements in housing stock, social landlord Berwickshire Housing Association (BHA) formed a partnership with Oakapple Renewable Energy and Edison Energy. This investigated the potential benefits associated with installing a solar scheme with 749 G89 roof-mounted solar PV systems to BHA owned properties. Each PV installation ranged from 2kW to 4 kW, with a total proposed installation capacity of around 2,200kW. The proposed PV systems were to be installed on terraced and semi-detached properties located across Berwickshire, including Duns, Eyemouth and Coldstream[3]. This covered 59 secondary substations under the Berwick, Dunbar and Eccles GSP's with majority of proposed connections heavily clustered along LV feeders. The proposed installations represented multiple new connections onto an already constrained network area due to the penetration of private G89 PV installations since the introduction of the Feed-in-Tariff mechanism (FiT). The connection application was subject to G83/2 Stage 2 analysis whereby a study of network impact was required in order to ensure that the distribution network would continue to operate within design limits.

BHA engaged with SP Energy Networks to determine if this could be facilitated under the ARC project and in turn University of Strathclyde (UoS) were asked, as project partners, to investigate the impact on the surrounding network area of new PV connections through the use of power system modelling. Following a programme of strategic network monitoring and analysis, a better understanding of our LV network operation allowed SP Energy Networks to release around 95% of the homes originally considered for PV installation.

To determine the impact on the network, the BHA housing stock was mapped onto SP Energy Networks GIS system based on the postcode address. This data enabled UoS to identify the specific secondary substation and LV feeders potentially affected by the proposed PV scheme. Heat mapping was undertaken to establish primary and secondary substation clustering and proved a robust means in which to determine where further enhanced network monitoring needed to be installed prior to any determination being made as to the best alternative connection solutions, as shown in figure 17.

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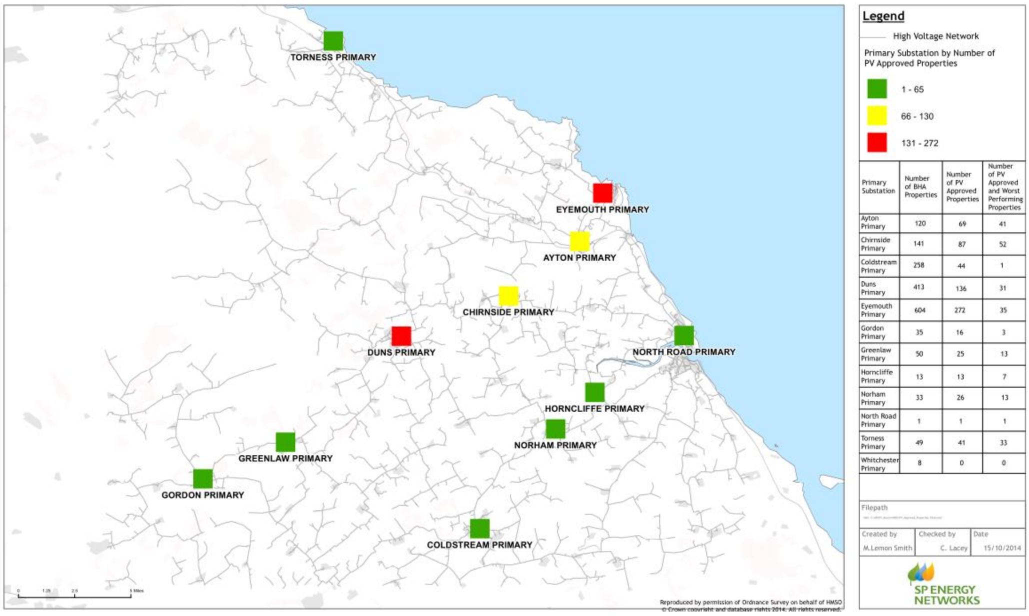
[3] Berwickshire Housing Association PV scheme: http://www.edisonenergy.co.uk/case-studies/berwickshire-housing-association



Primary Substation	Number of BHA Properties	Number of PV Approved Properties	Number of PV Approved and Worst Performing Properties
Ayton Primary	120	69	41
Chirnside Primary	141	87	52
Coldstream Primary	258	44	1
Duns Primary	413	136	31
Eyemouth Primary	604	272	35
Gordon Primary	35	16	3
Greenlaw Primary	50	25	13
Horncliffe Primary	13	13	7
Norham Primary	33	26	13
North Road Primary	1	1	1
Torness Primary	49	41	33
Whitchester Primary	8	0	0

Figure 17: Number of PV Approved Properties Aggregated to Primary Substations

Site surveys were conducted as part of the study where network staff manually surveyed the area as part of the ARC project. During this survey, it was identified that only 30% of current G83 PV connections had been notified to and recorded by SP Energy Networks. This serves to highlight a failing of the current FiT notification process, as DNOs across the country are not being notified of significant numbers of G83 installation being installed on their network.

Now with an accurate understanding of the existing network, each circuit cluster was studied to determine if new PV connected generation would exceed voltage or thermal limits. A process was created to access the level of constraint and this is shown in Figure 19.

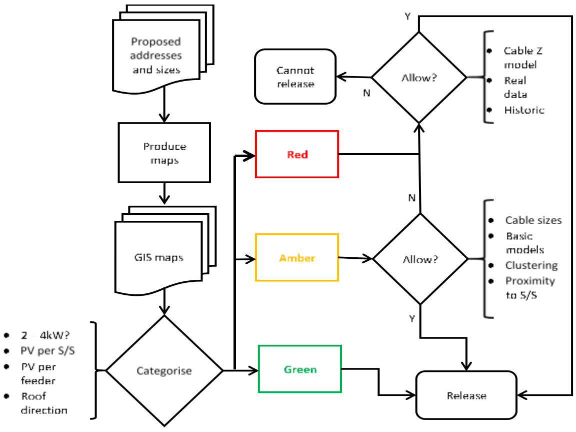


Figure 18: The Flowchart of the Analysis4

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[4] A. Park, “Delivering Community Energy” Presented at Low Carbon Networks & Innovation (LCNI) Conference, Liverpool, Nov 2015.

During the project all proposed PV installations within the green group of properties were permitted to connect immediately as it was found that they would not have any adverse impact upon the network. Installation at these properties began in February 2015 and was completed in July 2015.

The properties in the amber group were subject to further analysis. The cable sizes, distance from secondary substation and real-time voltage monitoring were considered. After this additional analysis, these properties were either marked as green and released, or moved to the red group.

The red group of properties were the most clustered and as such could potentially have the greatest impact on the local network. More detailed analysis was carried out by UoS to quantify this. In addition to the installation of monitoring equipment at the secondary substation, this analysis included detailed power systems modelling of each highly clustered substation, including accurate modelling of LV feeders and the 11 kV circuits that were potentially affected. Using all this information time series load flow analysis was undertaken based on real and historic data to establish the risk of any voltage or thermal limit being reached, see figure 19 & 20.

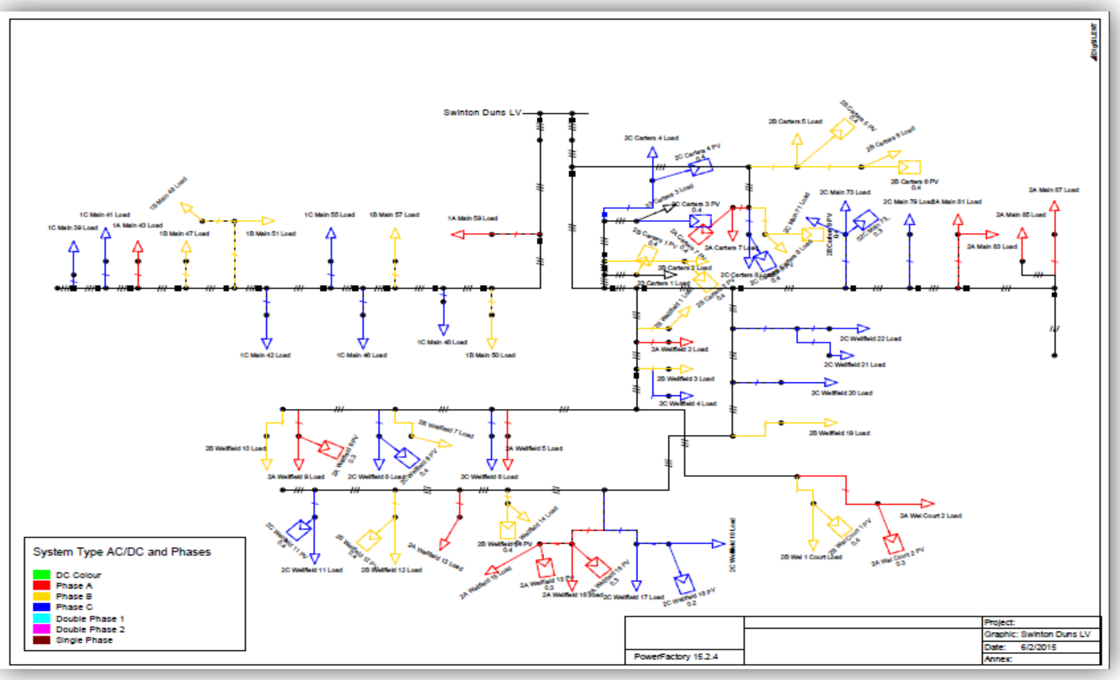

Figure 19: UoS LV Feeder Modelling

Figure 20: LV Secondary Substation Monitor

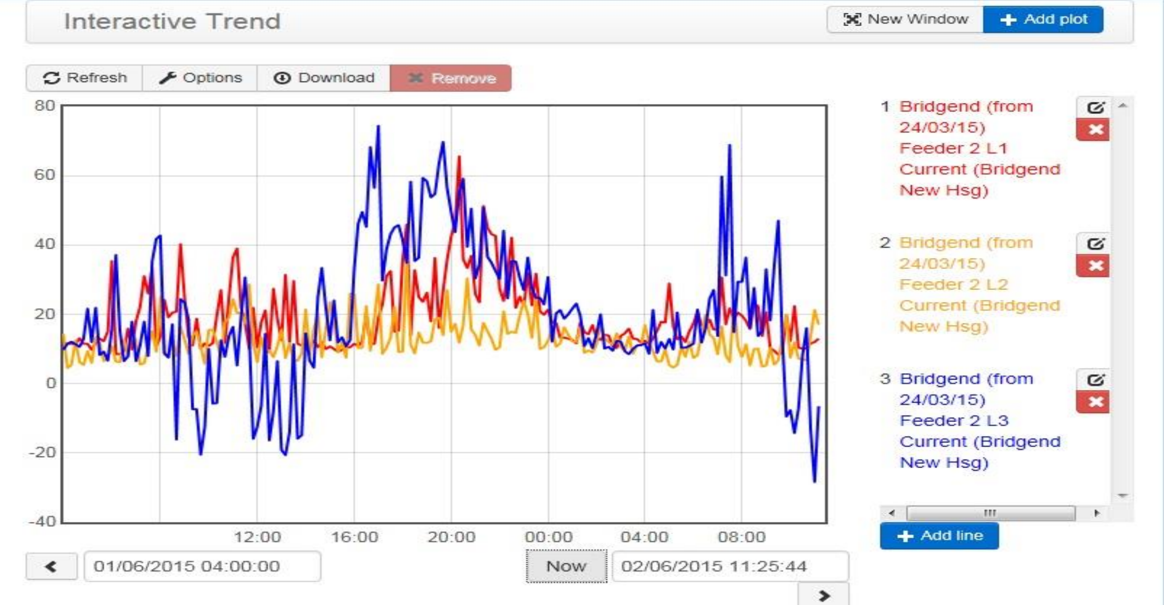

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Figure 21: LV Feeder Profile via Enhanced Network Monitoring

Revised network design applying the data made available via the installed network monitoring permitted advancement of network modelling from the traditional design processes, which differed significantly from the traditional desktop network modelling through the availability of improved network data. Working closely with the customer and agreeing to invest more time into the design process can release more capacity from existing network assets.

Throughout the process, we provided ongoing customer engagement and facilitated discussions with stakeholders. We provided regular updates to the analysis based on BHA feedback regarding installation progress and any tenant consent issues. In some cases this created additional headroom on the network to enable us to permit further connections at different properties. The success of this process resulted in all proposed installations being completed by January 2016. Further benefits have also been accrued from the installation of these 749 PV systems as the Housing Association estimates that over the lifetime of the installation of the PV arrays, tenants will see a combined benefit of a £1.9m reduction in energy costs. This promotes the value to customers of investing more time into the design process.

The deployment of monitoring will remain in place following the end of the project in order to provide SP Energy Networks with a minimum of 2 years' worth of data around the behaviour of the system throughout high solar irradiance and lower demand periods of spring, summer and early autumn. For secondary substations identified as 'Red' and at higher risk of voltage excursion, the project has mitigated any perceived risk by installing secondary OLTC transformers to help regulate secondary voltage levels and avoid potential high volts on the system during daytime summer month periods as detailed in section 4.3.1.

5. Customer Service Innovations

In any change process, such as changing the nature of DG connections and offering provided to customers, regular and transparent stakeholder engagement and communication has been critical to success.

Taking the original ARC project problem statement – how to reduce aborted connection applications – this is particularly true. While huge strides have been made over the years to provide DG customers with more and more information to let them self-serve, problems remain in the extent and frequency by which this can be provided. The challenge being that the connected, contracted and offered position and the interactivity of connections is a constantly changing picture and often the easiest way for developers to find viable connections is simply to submit a number of speculative connection applications. This section provides information on the customer experience during the project and new methods employed through the project to improve the customer experience for both new and existing DG customers.

5.1. Stakeholders

In any connections process, there are a number of stakeholders involved. The level of engagement required for the process is likely to vary on a case by case basis, and this was true of a number of cases in the ARC project. For example, smaller community generators required more interaction and engagement to guide customers through the connection process than perhaps a larger organisation who has experience of developing a number of generation sites in the past.

Figure 22: provides an outline of the stakeholders in the connections process.

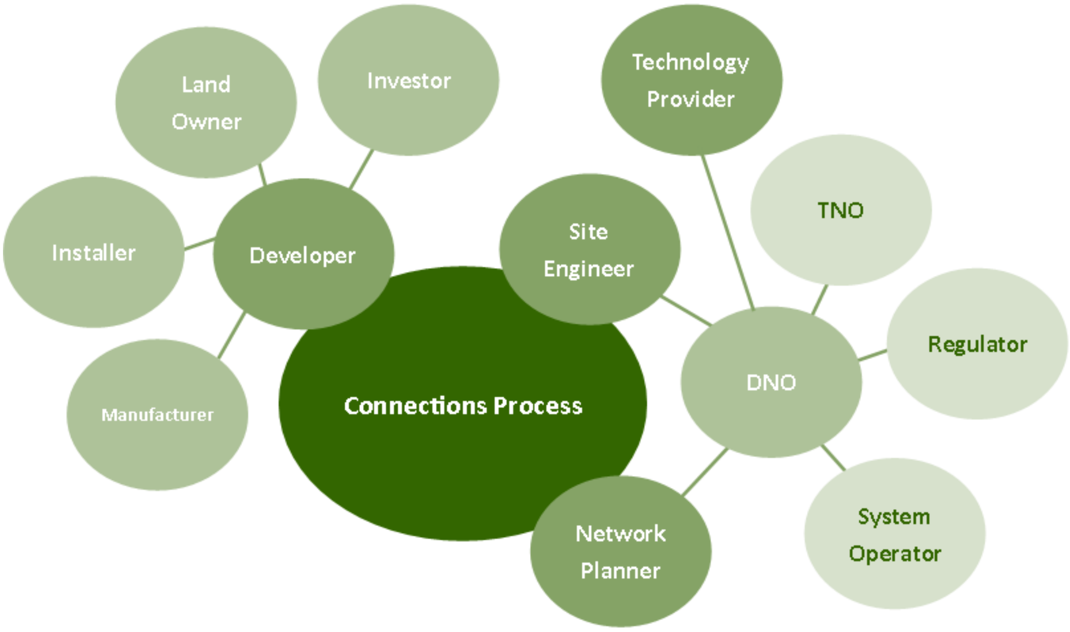


Figure 22: Stakeholders Involved in the Connection Process

The DNO and developer sit on opposite sides of the connections process. The main point of contact between the DNO and the developer is the network designer/planner who is responsible for running the connection studies and issuing a connection offer to the customer, as well as coordinating the commercial principles of access via commercial teams.

The DNO must also interact with the Transmission Network and System Operator to be able to identify any SoW requirements. The regulator has an input in a less direct manner by setting out guidance and standards for granting and reporting on connections performance and when a customer can expect to receive a connection offer following initial submission of a competent connection application.

Developers must engage with a number of stakeholders working with them to ensure delivery of a successful project. This includes the technology manufacturer (for example, the turbine or PV manufacturer) and their investors or financial institutions that are being asked to fund the development. The investor requires the ability to model the expected revenue from the project and associated risks against the cost of the project to ensure that an appropriate rate of return can be achieved. Where developments are connecting via managed connections, such as those delivered through the ARC project, non-contractually binding curtailment assessments and reports become important documentation and a key aspect of the connections process and final connection offer/agreement.

The land owner may also be the same company or person as the developer, but often there are Wayleave issues to solve not only for the development site, but also in respect of the proposed connection route for either a new overhead line or cabling works. Wayleave issues, particularly for the construction of power lines, can cause lengthy delays and high costs to a project, as was the case for a number of the ARC project participants.

5.2. ARC Customer Service

The ARC project team has put the customer at the heart of the process throughout the project. We recognised from the project's inception that providing an enhanced level of customer service to connection customers participating in trials was essential and complemented our wider customer service approach to getting closer to our customer by moving towards a geographical delivery model.

While all participants received the normal level of service as all existing DG connection applicants, DG customers facing barriers to connection in the ARC project area (through either cost, timescales or lack of local network capacity or transmission delays) and who had successfully gained planning permission were invited into an 'optioneering' process with the project team to understand how an alternative smart solution and commercial innovation could be used to resolve the barriers to connection and allow them to realise access to the network.

Core to the 'optioneering' process was the development of a deeper understanding of the connection barriers. In a number of cases, new generation was being connected to provide energy to local demand in the area – and in some cases new local demand. Due to limitations in the standard connection design process, this was on most occasions overlooked or simply never considered and therefore alternative connection solutions had not been offered to customers. In other examples, more detailed analysis or support by monitoring of network flows and voltages was required, which increased the time before a robust connection offer could be provided or managed connections considered. Throughout the ARC project, we offered a tailored rather than a 'one size fits all' approach to customer service. We consider that our approach has been very successful. This is evidenced by 100% of customers who received an alternative connection offer, accepted the connection terms and have now connected or are in the process of developing their projects to connect to the network.

By entering into discussions, and learning more about the site, the technology, the generation profile and demand of a development, the ARC project deployed robust innovative designs and efficiently implement smart technology or alternative connection solutions to facilitate connections.

All DG applications participating in the 'optioneering' process were provided with a traditional firm connection offer, and where applicable were also offered 'smart' alternatives such as an actively managed connection or voltage reduction techniques. Each option had costs and timescales associated with them and it was then the customer's choice, with agreement of the relevant stakeholders, to consider the option that best suited them.

The case study below demonstrates that there are proven benefits of early engagement between the DNO and those customers seeking to connect supported by clear and transparent dialogue. In addition, the DNO has to become a key stakeholder and project partner as early as possible in order to enable a true understanding of the customer's connection requirements and in some cases how this relates to existing demand, community ambitions or future business diversity. Greater engagement is required for managed connections and there is a need to understand the true impact the generation may have on the network rather than a static deterministic approach. This attitude toward customer engagement is not only true for generation connections but as more Low Carbon Technologies seek to connect to the network a similar approach is required for future flexible demand and storage customers.

5.2.1. Case Study: Hoprigshiels Wind Farm

Hoprigshiels Wind Farm development **(**https://hoprigshielswindfarm.wordpress.com/**)** is a 7.5 MW 33 kV connected wind farm that has connected to the distribution network under the Dunbar GSP ANM scheme.

As part of the Dunbar GSP ANM network solution, we engaged early with the developers of Hoprigshiels Wind Farm to facilitate a connection implementing the developed two-staged Connection Agreement. As one of three new generators seeking to connect into the Dunbar GSP scheme, it was important that each developer was provided with an enhanced level of customer engagement and service to take the customer through the new process, connection arrangements and implications for the overall delivery of this major project step-by-step. The original offer had stated that due to transmission reinforcements, a connection date prior to 2021 would not be possible. Furthermore, the costs to complete the transmission works were estimated at £20 million, ~£6 million of which would be funded directly by the developer with the remaining costs to complete wider transmission works underwritten by the developer during the construction phase.

To enable the connection to take place the ARC project engaged significantly during 2014 with National Grid who initially had reservations to our proposal. It had not been able to agree the concept of using an ANM solution; the connection would have been unable to be accelerated. Through detailed dialogue with National Grid and provision of a variety of technical and commercial information, it was agreed that additional generation could be connected under Dunbar GSP through the development of ANM control. It was agreed however that due to the nature of existing generation and lack of network capacity the ANM scheme proposed would form Stage 1 of a two-staged connection agreement. This effectively means that, under Stage 1 of the agreement, Hoprigshiels are able to connect to the network in 2017, 5 years ahead of the original offered for the connection, via ANM control. In parallel, the developer will pay a contribution towards the necessary costs to upgrade the transmission network and, upon completion in 2021, Stage 2 of their agreement will come into effect and they will have unrestricted access to both the transmission and distribution network.

Due to the innovative nature of this new commercial agreement, significant engagement has taken place with the developer, their consultants, and those institutions providing the funding for the construction of the project, to enable them to understand the nature of the connection and the implications of ANM during Stage 1. This required a significant effort in providing robust curtailment assessments, which are non-contractually binding but are a key consideration in the decision to progress with the development in order for them to understand and calculate overall risk to the project.

In addition to Hoprigshiels, two additional developers have also contracted to connect under Dunbar GSP via the newly developed two-stage agreement. This facilitates an additional 50 MW of generation capacity by 2017, which has been or is in the process of connecting to the network via ANM control that would otherwise have been delayed until 2021 at the earliest. This has only been made possible due to the level of engagement undertaken with all stakeholders seeking to connect and by all developers working together as a collective group to bring forward a network solution that was beneficial to all parties.
Further examples of enhanced levels of customer service are described below:

- ✓ Initial curtailment assessments provided by the ARC project team as part of the initial connection offer was deemed to be overly conservative, therefore we arranged for additional curtailment assessments to be undertaken. These considered a number of different network scenarios, and provided a wider understanding of the reality of how the network operated and how this was likely to be impacted in future by existing and future DG export.
- ✓ We facilitated discussions between Hoprigshiels and the other two developers connecting in the area – Kinegar and Viridor. As a community group, Hoprigshiels did not have the financial resources to be able to absorb all the reinforcement costs. However as they were the initial contracting party and therefore the project initiating the requirement for the transmission reinforcement, they required reassurance that the other generators were committed to the process and in due course would proceed and sign their proposed connection offers. Discussions with other developers allowed each to gain mutual understanding of the other respective projects, impacts of routing and timescales for delivery and ultimately when each would be in a position to commit to the transmission investment as a collective group.
- ✓ Following the engagement with the customers financial investors we held a dedicated Stakeholder Workshop in Edinburgh that was focussed on the commercial and financial impact on projects of alternative connection solutions and where delegates were able to

hear views from Financiers, Developers, as well as staff from the ARC team and representatives from SP Energy Networks Commercial team.

5.3. Customer Service Tool Box

In addition to the technical and commercial tools demonstrated throughout the ARC project, there has been a number of Customer Service tools trialled to support customers and in some cases, allow them to self-serve at certain parts of the connections process more of which is detailed below.

5.3.1. Online Curtailment Assessment Tool

The Online Curtailment Assessment Tool (OCAT) was developed as part of the ARC project to provide DG connection customers with a real-time view of hosting capacity reflecting connected, contracted and offered generation. The portal has been developed and designed to provide customers with an open and transparent online portal for estimating of time and cost to connect both under a firm and a managed connection. The managed connection offer also includes an estimate of likely curtailment in MWh's.

OCAT has been developed with the aim of allowing users to choose their technology (for example, wind or PV), identify the location of the development in relation to the existing distribution network, explore options around preferred POC locations and optimise the size of the development based around network capacity. Figure 23 provides a screenshot of the tool.

The importance of selecting the specific technology that is seeking to connect means that the calculation tool uses an appropriate energy profile and follows the same logic as per our smarter design process whereby the energy contribution of the generation is considered as opposed to the maximum export capacity that the generation project is capable of as per the current maximum generation/minimum demand philosophy.

This approach to self-service has received very positive feedback from the DG development community and Stakeholders at our regular workshops. Innovation funding via ARC has allowed SP Energy Networks to capture learning around some of the initial benefits but also the potential longer term applications associated with online network modelling, such as,

- ✓ Successful demonstration of network model creation from GIS databases;
- ✓ Maximises use of networks resources;
- ✓ Identify areas for future reinforcement through the tracking of DG requests;
- ✓ Support for ANM systems as BaU.

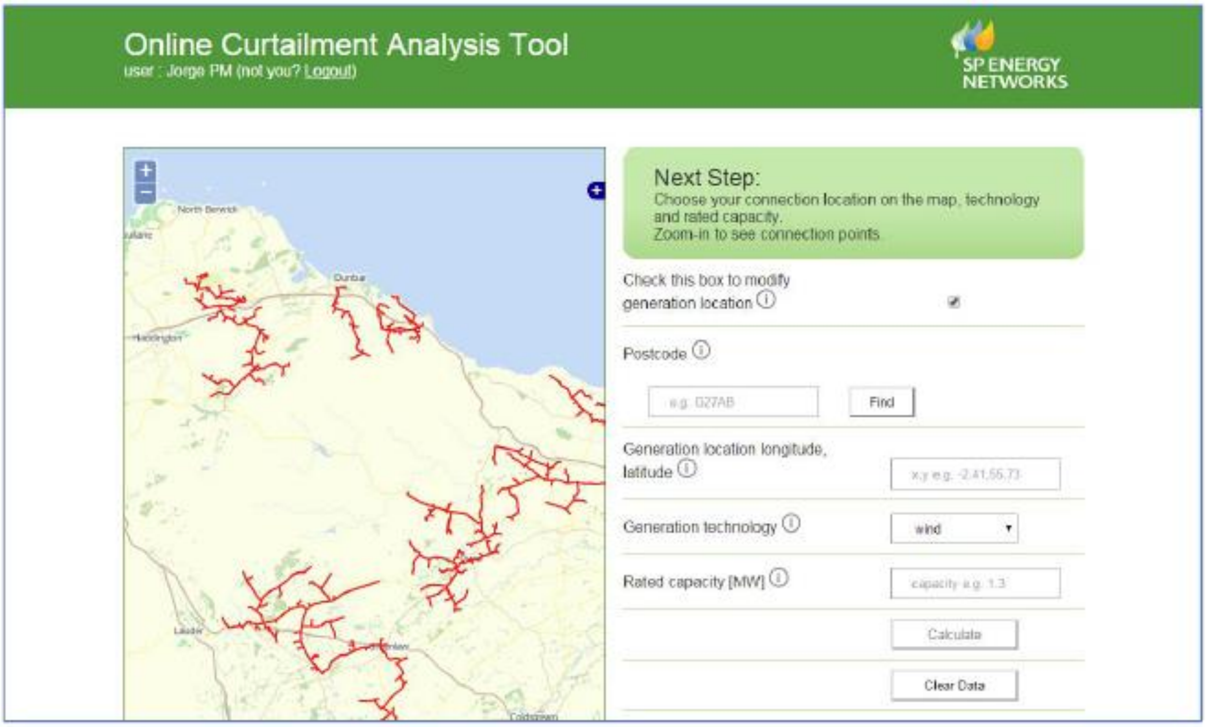
But also challenges exist in implementing such a self-service tool applicable by a DNO, challenges include but are not limited to;

- ✓ Accurate Network Modelling and Connectivity with GIS database;
- ✓ Integration of Network Monitoring Data;
- ✓ Queue Management;
- ✓ Interactivity with New Connections and Asset Modernisation Projects;

- ✓ DG Operating Profiles.
- ✓ Overall cost vs. customer benefit

With the development of OCAT many of the benefits have been captured and wider applications identified;

- ✓ Successful demonstration of network model creation from GIS databases;
- ✓ Maximise use of networks resources;
- ✓ Identify areas for future reinforcement through the tracking of DG requests;
- ✓ Support for ANM systems as BaU;
- ✓ Opportunity to explore new technologies in the trial area.



Online Curtailment Analysis Tool
user : Jorge PM (not you? Logout)

Next Step:
Choose your connection location on the map, technology and rated capacity.
Zoom-in to see connection points

Check this box to modify generation location ⓘ ☑

Postcode ⓘ e.g. D27AB

Generation location longitude, latitude ⓘ x,y e.g. -2.41,55.73

Generation technology ⓘ wind

Rated capacity [MW] ⓘ capacity e.g. 1.3

Figure 23: OCAT Web Portal

5.4. Connections customer engagement going forward

The level of customer service provided during the ARC project has been greater than typically granted to those customers seeking a connection under BAU. It is recognised however that in order to facilitate future Alternative or Actively Managed Connections, a commitment to an enhanced level of customer engagement and service is a minimum pre-requisite and any DNO or Network Operator must commit and plan for such activity as appropriate.

The Innovation funding mechanism provides the opportunity for additional engagement with stakeholders to provide detailed studies and explore alternative solutions to the connection issue. In order to take this forward into the business on a daily basis, a balance must be struck between what is practical to implement as part of BAU, and what should be automated in order to facilitate better customer engagement and allow increased time for network planners to engage with customers as appropriate to facility their connection.

Provision by the customer on the purpose of the connection particularly when coupled with new or existing on-site dement is essential to being able to provide additional information to the planner. This can be facilitated by adding one or two additional questions as part of the connection application. For example:

- ✓ Has planning consent been granted for the proposed development?
- ✓ Will this generation used to supply an existing or future on site demand?
- ✓ Have you submitted any additional connection applications recently in relation to this site?
- ✓ Are there any site specific issues that planners should be aware of e.g. water courses, way leave issues with neighbouring land owners whose land should be avoided when developing the connection route?

In other cases, automating the process through the use of tools, such as OCAT, can help customers to self-serve during the pre-application process, and reduce the number of speculative applications which take time and effort to process, the costs of which are passed onto the general consumers through Distribution Use of System charges.

The development of our OCAT tool means that for the trial area we hope to have this live on the SP Energy Networks website during the first quarter of 2017. The tool has been developed to date so that it can complement existing heat-maps data already available and as new Actively Network Managed zones are identified the OCAT tool will be further developed to include a greater number of circuits across our distribution network.

6. Recommendations/Key Points

This report has talked through some of the technical, commercial and customer service elements of designing and operating new connection solutions across the different voltage levels on the network.

The report has demonstrated the technical aspects of the project and the methods applied to accelerate customer connections. Explanation of the existing methods, tools and policies used in the connection of distribution generation customers sets the scene against which ARC and other innovation projects are operating.

Innovation has led to new methods and approaches to the connection of generation at 33 kV, 11 kV and LV networks. However the first part of any innovative approach remains clear and transparent customer engagement. By engaging with customers at an early stage, visiting the site of their proposed development and understanding the drivers behind the connection and its impact upon the wider network, a better solution for the connection can be designed and which will be accepted by the customer.

The next phase is development and greater availability of real-time network data that will allow enhanced network design and modelled based upon more realistic network operating characteristics. Through the use of smart grid enablers such as enhanced monitoring and coordinated modelling, the designer must have the opportunity to make use of enhanced information on the network and understand how it is operating in reality – as compared to the conservative, deterministic designs typically applied to connections to date.

Finally, new tools can be developed and deployed on the network. This comes in the form of technology for monitoring and controlling the network objects, as well as new commercial mechanisms which must go hand in hand with technology innovation. As network operators continue to transition towards local Distribution System Operators, this can and will only be achieved through real-time visibility and control of assets connected to their network.

At SP Energy Networks the learning from the ARC Project has facilitated the advancement in company policy towards alternative connections through the creation of a Flexible Connection and Principles of Access Policy. Whereby a customer wishing to connect the SP Energy Networks, can request access to these techniques to realise a connection to the distribution system with consideration given to the following;

- ✓ Need for Flexible Connections
- ✓ When to use a Flexible Connection Offer
- ✓ Customer Groups for Whom a Flexible Connection Offer is Applicable
- ✓ Stakeholder Engagement
- ✓ Commercial Arrangements;
    - Offer and Connection Agreements
    - Principles of Access

    - Transparency and Records
    - Managing the Network Access Queue
- ✓ Technical Arrangements;
    - Communication Infrastructure
    - Cyber Security
- ✓ Techniques to Achieve Flexible Connections;
    - Timed Capacity Connections
    - Export Limited Devices
    - Local Management Schemes
    - Remote Intertrip Schemes
    - Active Network Management

6.1. Learning

New approaches and tools in this project have been demonstrated through the following:

- Successfully deployed of ANM at the T-D interface including the retrofitting of an ANM system to an existing generator
- The data and tools needed to accelerate the connection of renewable generation have been explained and linked to relevant case studies across all voltage levels.
- OCAT was developed and deployed as a means for customers to self-serve and appreciate levels of connected generation already on the network.
- A VPW arrangement was developed and implemented at the Power Networks Demonstration Centre in Cumbernauld.

6.2. Key Findings:

- Additional monitoring, communications, data and new design tools are key enablers to smart solutions and note that they can be solutions in their own right. Providing network planners with an ability to understand the true available capacity on the existing network is essential to provide DG customers with viable and alternative connection solutions

- Smarter network design – moving away from conservative and deterministic studies to a probabilistic view of available capacity – requires data sets and tools to analyse the actual implications of any new connection proposal.

- Working in partnership with developers and groups of developers provides a means of bringing customers together to fund grid investments that could never be taken on by any individual developer.

- Enhanced customer service by providing easily accessible real-time available capacity for customers to self-serve, and by ‘optioneering’ solutions can dramatically reduce the volume of aborted connections and overall improve customer satisfaction.

- Managing connections for transmission constraints by controlling distribution connected generation is acceptable and provides benefits to existing customers by overcoming the shortcomings of generation intertrip schemes.

6.3. Recommendations:

- Investment in additional monitoring, communications, data and new design tools is a pre-requisite for any smart solution and must form part of the core infrastructure of a modern network to complement conventional assets.
- Network design policies and standards need to evolve to reflect the changing nature of the distribution network from passive to active, and should be updated to allow a process for evaluating new options as part of the modern planner's toolbox.
- Customer engagement and service tools are essential to maximise the opportunity for self-service and to ensure that the correct smart solutions are identified as 'options' for all DG customers. Managed connections can provide a suitable alternative to traditional distribution connections which may be subject to high costs and/or lengthy time delays for connection.