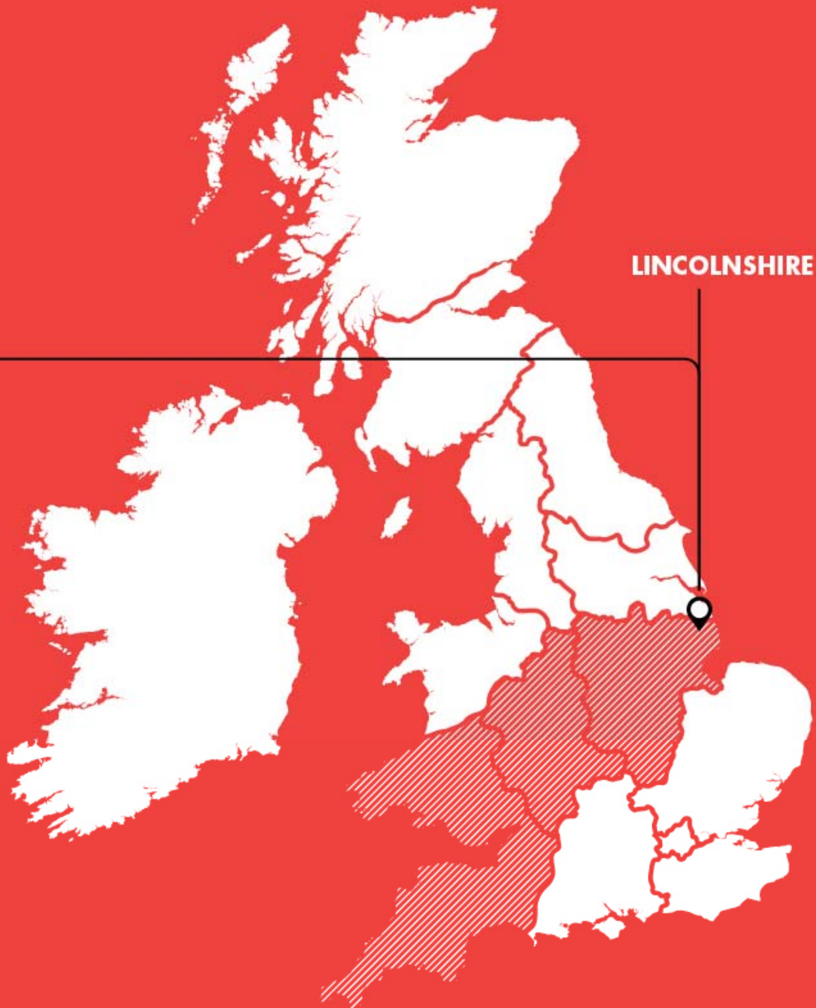
WESTERN POWER DISTRIBUTION

LOW CARBON HUB

CONNECTING RENEWABLE ENERGY IN LINCOLNSHIRE



SDRC

DISSEMINATE KNOWLEDGE AND EVALUATE THE POTENTIAL FOR SIMILAR PROJECTS THROUGHOUT THE UK.

LCN Fund
Low Carbon Networks

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Prepared by:	Philip Bale	27.01.2015
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Contents

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Glossary

Term	Definition
ANM	Active Network Management
AIS	Air Insulated Switchgear
ADDS	All-Dielectric Self Supporting cable
ACSR	Aluminium Conductor Steel Reinforced
BSP	Bulk Supply Point
CB	Circuit Breaker
CAD	Computer Aided Design
CAF	Cost Apportionment Factor
CT	Current Transformer
DG	Distributed Generator
DNO	Distribution Network Operator
DPCR	Distribution Price Control Review
DLR	Dynamic Line Ratings
DVC	Dynamic Voltage Control
ENTSO-e	European Network of Transmission System Operators
FAT	Factory Acceptance Test
FACTS	Flexible AC Transmission System
GIS	Gas Insulated Switchgear
GB	Great Britain
GSP	Grid Supply Point
GT	Grid Transformer
GoS	Guarantees of Standards
HDA	Hard Drawn Aluminium
IFI	Innovation Funding Incentive
ITT	Invitation To Tender
kV	Kilo Volts
LIFO	Last In, First Out
LCH	Low Carbon Hub
MCP	Max Conductor Pressure
MCT	Max Conductor Tension
MCW	Max Conductor Weight

MVA	Mega Volt Amperes
MWh	Mega Watt hour
NMS	Network Management Systems
OPPC	Optical Phase Conductor
OPV	Optimised Protection Variant
OHL	Overhead Line
PV	Photo Voltaic
RPZ	Registered Power Zone
RTU	Remote Telemetry Unit
SGS	Smarter Grid Solutions
SDRC	Successful Delivery Reward Criteria
SCADA	Supervisory Control And Data Acquisition
T1 & T2	Transformer 1 & Transformer 2
TNO	Transmission Network Operator
UHF	Ultra High Frequency
VVT	Virtual Voltage Transformer
VT	Voltage Transformer
WPD	Western Power Distribution

1 Introduction to the report

This report summarises the techniques demonstrated as part of Western Power Distribution's (WPD) Lincolnshire Low Carbon Hub, and as detailed in the Successful Delivery Reward Criteria (SDRC) 8, the project will disseminate the knowledge generated and evaluate the potential for future roll out throughout the UK based on the learning to date.

The knowledge generated has been categorised into the design, construction, operation and commercial aspects for each of the techniques. Further information associated with the project, including how the methods were designed, will be included in the Ofgem Project close down report which will be submitted to the authority before 1st May 2015

2 An Introduction to the Lincolnshire Low Carbon Hub

The Low Carbon Hub (LCH) for East Lincolnshire has been designed to test a variety of new and innovative techniques for integrating significant amounts of low carbon generation on to electricity networks, in an effort to avoid the costs that would normally be associated with more conventional methods.

The East Lincolnshire electricity network is typical of most rural areas across the East Midlands and large sections of Great Britain making it an ideal location to demonstrate how new technologies, operating procedures and commercial arrangements could be used by a Distribution Network Operator (DNO). The substation at Skegness has two 90MVA transformers, stepping the voltage down from 132kV to 33kV. Skegness supplies East Lincolnshire through seven 33kV feeders and under normal running arrangements supplies eight primary substations.

The project received £3m of funding from Ofgem's Low Carbon Networks Fund Tier 2. In this project, we are seeking to explore how the existing electricity network can be developed ahead of need and thus deliver low carbon electricity to customers at a significantly reduced cost in comparison to conventional reinforcement.

Lincolnshire, being on the East coast it is suitable for a wide range of renewable generation types, these include onshore and offshore wind farms, large scale solar Photo Voltaic (PV) and energy from bio crops. Many generators could not connect to the distribution network closest to them due to the effects the connection would have on the network operation. These connections tend to result in installing new underground cable to the Skegness grid substation where the connection will have less of an effect on the network, meaning it could operate within its design and operation limits. This can be very expensive and prevented generation connections. We received a high volume of connection enquiries from developers which made it ideal for this project.

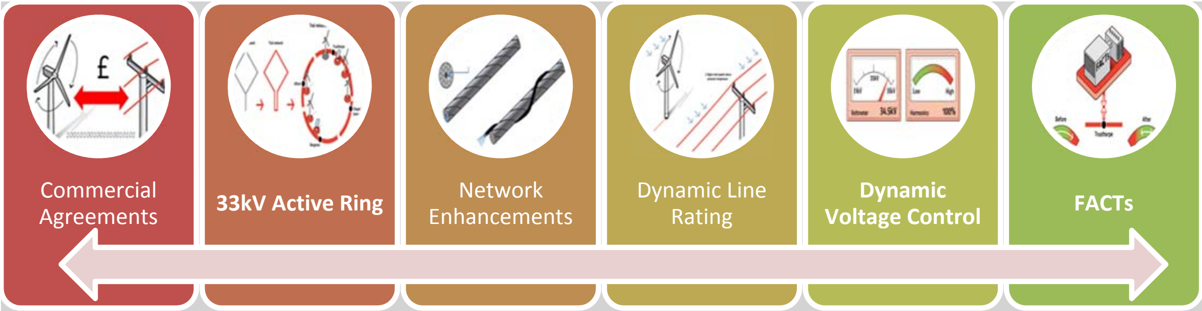


Figure 1 – LCH Methods

The project has developed the six project techniques detailed in Figure 1, demonstrating them in East Lincolnshire to increase network capacity and facilitate additional generation connections.

New commercial agreements – Innovative agreements have been negotiated with Distributed Generator (DG) customers to optimise their output and mitigate network issues (e.g. to deliver reactive power service) using real time network measurements. Potential limitations of the current regulatory framework have been identified.

33kV active network ring – The active ring allows increased control of the 33kV system and network reconfiguration based on real time power flows. Construction of the ring involved the installation of an additional circuit breakers, disconnectors and smart grid protection and control.

Network enhancements – Sections of existing overhead lines have been upgraded within the demonstration area with higher rated and lower impedance conductors to increase the network's capacity to connect DG. This work is in addition to investment already funded through the Distribution Price Control Review (DPCR) 5 settlement. For the purposes of disseminating learning, the communications required for a range of the methods above have been reported as part of this method.

Dynamic system ratings – The Skegness Registered Power Zone delivered innovative connections to offshore wind farms based on dynamic rating of overhead lines. These components have been further developed and the new techniques tested at 33kV to calculate the network capacity and operating limits based on real time asset data.

Dynamic voltage control – Building on the principles of an existing Innovation Funding Incentive (IFI) project, the 33kV target voltage has been actively varied. This was done dynamically based on real time measurements of demand and generation. Dynamic voltage control increases network utilisation whilst maintaining the system voltage within the statutory limits.

Flexible AC Transmission System (FACTs) Device –A Flexible AC Transmission system device has enabled us to control both network voltage and system harmonics of the active ring. This equipment is not normally deployed on Distribution networks for this purpose. Shunt compensation has been used to generate or absorb reactive power. This highly technical solution has been designed to increase the amount of distributed generation that can be connected.

3 Overview of the Commercial Arrangements methods

New commercial agreements – Innovative agreements have been negotiated with Distributed Generator (DG) customers to optimise their output and mitigate network issues (e.g. to deliver reactive power service) using real time network measurements. Potential limitations of the current regulatory framework have been identified

3.1 Background to existing Distributed Generation Connections

The majority of generation developers looking at new developments request a non-firm (teed connection). These connections can be made at any network voltage, from 400V (Low Voltage) to 132kV (EHV), they are not actively controlled by the DNO and often operate with a fixed power factor. A non-firm connection is a single circuit connection which operates without constraints under normal healthy, intact network conditions. However, with a non-firm connection there is an increased risk of the DG connection being restricted or disconnected from the network for certain faults or asset maintenance. In the worst case, this can result in a DG site being constrained off for the repair time after a network fault or during certain planned maintenance outages.

DG developers can also request a firm connection (looped connection). This has two separate supplies and is designed to avoid constraints during faults or asset maintenance. The high cost associated with the two separate supplies and infrequent abnormal network operation means a firm connection is rarely installed for new generation connections.

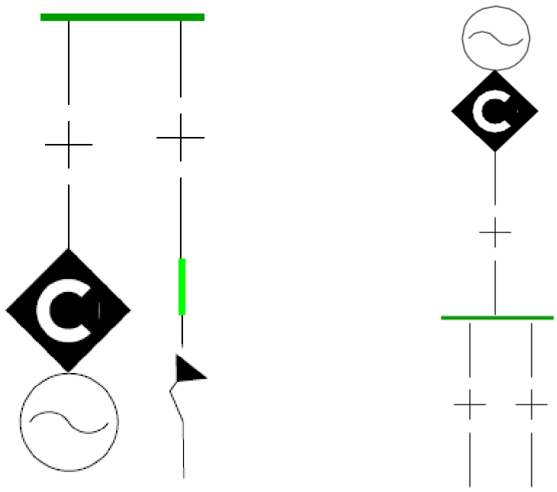


Figure 2 – Teed and looped connections

Whilst the network is intact, Non-firm Generation connections are designed to be fit and forget arrangement, the network modelling takes into account the most onerous, but credible scenarios that can occur on the network:

- The connected and proposed DG are operating at their full outputs, simultaneously;
- The demands across the distribution network are at their lowest, and
- The distribution network voltage is at the top of its operating bandwidth.

When the network is due to be rearranged as a result of planned maintenance and where the generation will cause any network asset to operate outside of its design or statutory limits, the DNO contacts the operator of the distributed generator. The site is either constrained down to a set maximum export level or disconnected from the network dependent on the severity of the constraint.

When the network operates abnormally as a result of a fault, if the generation causes the network to operate outside of its design or statutory limits, either protection relays at the substation or WPD's control room operates the DNO circuit breaker using SCADA telemetry, disconnecting the generator from the network.

This connection philosophy ensures that under normal operating conditions the network remains within its design and statutory limits and generator can operates in an unconstrained mode of operation. A fit and forget design and operation often leads to spare capacity in the system which is not utilised, as the most onerous credible scenarios detailed above do not occur regularly. The most onerous credible scenarios become even more infrequent when different intermittent generation sources are connected to the same network as they seldom operate at maximum output, at the same time.

The commercial arrangements method of the Low Carbon Hub has assessed how capacity can be unlocked effectively within networks whilst ensuring networks remain inside of the design and statutory limits at all times.

3.2 Low Carbon Hub – Commercial arrangements

The Low Carbon Hub project has demonstrated how DNOs and Generation developer can enter into new innovative commercial arrangements. These agreements can unlock additional generation capacity if the generator is willing to operate in suitable reactive power control mode and constrain active power output. Western Power Distribution (WPD) has been offering HV and EHV alternative connections in East Lincolnshire since February 2014 as an alternative to the high cost of conventional network reinforcement.

3.2.1 Contracts and Agreements

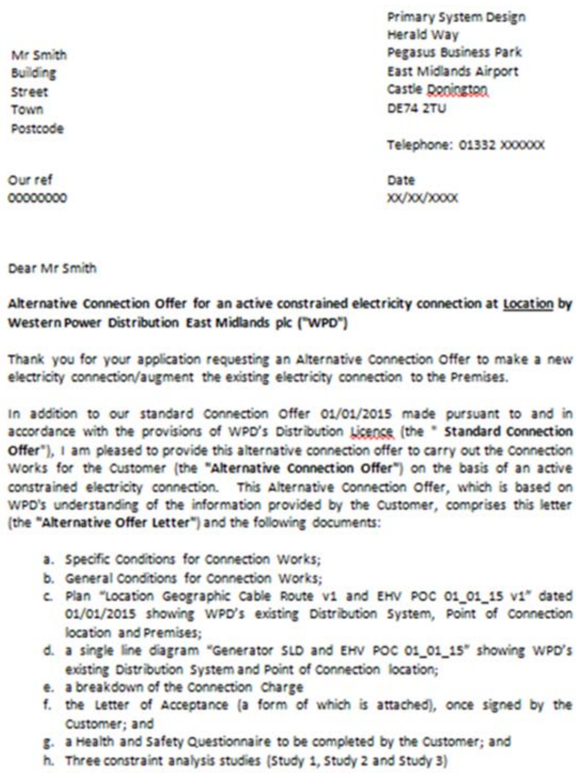
In order to offer new commercial arrangements, the project has created new Alternative Connection Documentation after researching constraint methodologies, engaging with customers and making amendments to the standard connection agreements creating a suite of Alternative Connection documents. To date, the project has offered 29 alternative connections in East Lincolnshire at the time of publication.

3.2.2 Learning Summary

Area	Knowledge Generated
Commercial	There has been and remains a strong appetite for Alternative Connections, with a large number of Generation Developers requesting and accepted by offers in East Lincolnshire as a way of unlocking capacity in areas otherwise considered constrained. Customers also expressed an interest in other geographical locations which often trigger prohibitive connection costs.
Design & Commercial	It has been shown that Last In First Out (LIFO) the best compromise when releasing capacity. LIFO was used for the method of constraining generation due to a number of factors: • The relative simplicity and clarity of the method both for the DNO and for the customer. • The broad acceptance of LIFO by our stakeholders, including generators and some financing institutions. • Our wish to protect existing generators from any impact of later-connecting generators; and • The efficiency of the underlying economic signals
Commercial	Alternative Connections are not the right choice for all new generation developers. In the same way developers evaluate the increased costs of a firm connection over the risk and consequence of constraints with a non-firm connection when the network is operating abnormally. With an alternative connection a generation developers must also evaluate the capital cost savings from an alternative connection over the potential longer term reduction in revenue from an alternative connection.
Operational & Commercial	The newly released capacity available within a network is not fixed; it is dependent on, the diversity between the generation sources, the location of new and existing generation and the willingness of generation developers to accept increasing levels of risk. This makes it very difficult to share upstream network reinforcement through a Cost Apportionment Factor (CAF) methodology.
Commercial	Any generation development will have a maximum acceptable financial cost for a network connection and associated upstream reinforcement. The maximum cost is driven by a number of other factors including other site costs, potential capacity factor and risk. Alternative Connections can offer a lower capital cost of connection but often increases the risk associated with the site.
Commercial	The location of new renewable developments is dependent on a number of factors, availability of resource, land, costs, planning risk. As such, not all generation developers are interested in developing sites in East Lincolnshire and have requested other areas they would prefer WPD offer alternative connections.
Operational	In creating alternative connection agreements, it has increased the workload in maintaining a suit of additional documents (33kV Alternative Connection Offer – Section 16, 33kV Alternative Connection Offer – Section 15, 33kV Alternative Connection Offer – Section 16 & 15 Combined, 11kV

	Alternative Connection Offer – Section 16, 11kV Alternative Connection Offer – Section 15, 11kV Alternative Connection Offer – Section 16 & 15 Combined, Alternative Connection Agreement). There is a requirement to ensure these documents are developed at the same time as the standard connection agreements and ensuring any changes to either document does not result in conflicts.
Build	WPD's asset database, Crown, was modified to facilitate offering new Alternative Connection agreements. However the process of incorporate Alternative Connections into Crown was made more difficult owing to the subtle differences to standard connections such as the importance of the LIFO queue.
Design	Throughout the project there have been conflicting terms and language to describe Alternative Connections. To avoid confusing customers, the project sought to avoid terms already being used in the National Terms for Conventional connections and to standardise the language being used in connection offers and agreements.
Design	Stakeholders fed back that the alternative connection agreement should be as similar to the standard connection agreement as possible. This is helpful to both those gaining internal sign on and acceptance from their financing institutions.
Operational	Most generation developers required a meeting to discuss the finer points of the Alternative Connection offer and to discuss the three constraint analysis studies and the assumptions used within.
Design	Both the Alternative Connection Offer and Alternative Connection Agreement generated a number of difficult choices. The following decisions at the time of this report have been made: 1) Alternative Connection Offers are not interactive with each other 2) Generation developers do not need planning permission before they can apply for an Alternative connection, 3) WPD does not offer budget Alternative connections owing to the information required and the time to run the network studies; instead we use the online constraint analysis tool to provide the customer with an indication of constraints. 4) A generation developer can only secure their place on the LIFO queue after they have made a formal application and supplied all of the minimum information, 5) WPD has always aimed to provide an Alternative Connection offer within the industry Guarantees of Standards (GoS) for the respective connection. 6) WPD is not charging Design and Estimation fees for Alternative Connections 7) A Generation developer has the acceptance period of the Offer where their position in the queue is fixed. If the generation developer does not accept the connection or the offer lapses, their LIFO position is relinquished and generators further down the queue effectively move up.

	8) If a generator requests to increase their capacity, the new capacity is modelled as a new connection and is issued a new LIFO number at the bottom of the queue. 9) An Alternative Connections can transfer to a standard firm or non-firm connection at any time by the customer funding the required upstream network reinforcement.
Operational	At the trialling stage, offering Alternative Connection offers substantially increase the connections workload as the studies are more comprehensive and many aspects of the offer letters cannot be automated. It was a difficult to process to offer both Alternative connections whilst maintaining all standard GOS without additional resource. The Future Networks Team offered all Alternative connections until a handover to the Primary and 11kV planners could be achieved.
Operation	The level of risk DG developers appeared to accept was higher than WPD initially forecast, resulting in a higher ANM capacity.
Commercial	To help both WPD staff and DG developers gain a clearer understanding of Alternative Connections a summary page and list of FAQ's have been produced and are available on the WPD website for review.



Primary System Design
Herald Way
Pegasus Business Park
East Midlands Airport
Castle Donington
DE74 2TU

Telephone: 01332 XXXXXX

Mr Smith
Building
Street
Town
Postcode

Our ref
00000000

Date
XX/XX/XXXX

Dear Mr Smith

Alternative Connection Offer for an active constrained electricity connection at Location by Western Power Distribution East Midlands plc ("WPD")

Thank you for your application requesting an Alternative Connection Offer to make a new electricity connection/augment the existing electricity connection to the Premises.

In addition to our standard Connection Offer 01/01/2015 made pursuant to and in accordance with the provisions of WPD's Distribution Licence (the " **Standard Connection Offer**"), I am pleased to provide this alternative connection offer to carry out the Connection Works for the Customer (the "**Alternative Connection Offer**") on the basis of an active constrained electricity connection. This Alternative Connection Offer, which is based on WPD's understanding of the information provided by the Customer, comprises this letter (the "**Alternative Offer Letter**") and the following documents:

a. Specific Conditions for Connection Works;
b. General Conditions for Connection Works;
c. Plan "Location Geographic Cable Route v1 and EHV POC 01_01_15 v1" dated 01/01/2015 showing WPD's existing Distribution System, Point of Connection location and Premises;
d. a single line diagram "Generator SLD and EHV POC 01_01_15" showing WPD's existing Distribution System and Point of Connection location;
e. a breakdown of the Connection Charge
f. the Letter of Acceptance (a form of which is attached), once signed by the Customer; and
g. a Health and Safety Questionnaire to be completed by the Customer; and
h. Three constraint analysis studies (Study 1, Study 2 and Study 3)

Figure 3 – Alternative Connection example document

3.3 Active Network Management Hardware

3.3.1 Background

The project required an Active Network Management scheme to monitor key network points and control the output of Alternative DG connections to stop the network operating outside of its design and statutory limits. The functional specification for an Active Network Management was completed with a scheme being tendered, procured, supporting policies written and installed in East Lincolnshire. The ANM scheme is capable of constraining the power output from Distributed Generators during periods when the network cannot absorb the excess generation. .The ANM software was integrated into WPD's Network Management Software (NMS).

Figure 4 – Active Network Management installed at Skegness Grid Substation

The ANM system for Skegness was required to use the current and voltage measurement points across the East Lincolnshire network to measures the following constraints:

- Thermal constraints on the 132kV double circuit from Skegness – Boston – Bicker Fen.
- Skegness GT1 & GT2 (132kV/33kV) Transformer constraints,
- Selected East Lincolnshire 33kV voltage and thermal constraints, and
- Selected East Lincolnshire 11kV voltage and thermal constraints.

3.3.2 Knowledge Generated

Area	Knowledge Generated
Design	At the time of tendering, three companies responded to WPD's ITT, with Smarter Grid Solutions representing the most economically advantageous tender based upon evaluation criteria.
Design	The connection of an ANM scheme requires an impact assessment, understanding the impact of an ANM failure scenario including communications failure. A Global trip of an ANM scheme could result in large amounts of generators being disconnected at the same time, creating a transient disturbance on the system.
Design	When assessing the installation of Active Network Management in a constrained area, consideration should include how future constraints may

	evolve across the network being studies, the adjacent distribution networks and the transmission network due to potential changes in demand and generation over the next 25 year period.
Design and Operational	The ANM equipment was installed at Skegness Grid substation to prove the concept. The ANM equipment is more suited to a temperature controlled server room then an operational substation. The communications infrastructure between Skegness grid substation and the core network is very strong. The ANM equipment will be subsequently moved to the server room.
Build	A flexible approach was required when incorporating measurement points into ANM systems. It was not possible to use a standard approach. As an example, the Skegness 132kV feeder current is being measured through an optical link to the feeder protection Relay.
Build	The ANM system has been integrated into WPD's NMS; at the request from Network Control Engineers only relatively basic controls have been enabled.
Design	The ANM communications has been built around WPD's standard communications options, however future testing and evaluation is underway to provide a range of flexible communications options which can be installed at future DG locations.
Commercial	WPD is continuing to discuss interoperable standards with ANM manufacturers. This is highly likely to result in flexible ANM specifications for ANM Areas.
Build	From the signing of contracts with Smarter Grid Solutions (SGS) to having a commissioned unit on site, the process took approximately 4 months.
Design	Significant detailed studies are required for the settings for the different measurement point thresholds and the time a generator needs to respond to ensure the system has the time to respond to transients that will occur in the system.
Build	The ANM operation and measurement set points need to be fully understood and incorporated into the constraint analysis software discussed in the next section.

3.4 Constrain Analysis Software development

3.4.1 Background

The project required WPD planners to understand the impact of Alternative Connections on the network under both normal and abnormal network conditions. DG developers also needed to understanding if an alternative connection was suitable for them before performing their own due diligence on the connection and likely future constraints. Two new constraint analysis software tools were specified, designed, tested and used as part of the project.

3.4.2 Web based tool

A simple constraint analysis tool was built for Generation Developers to estimate at a high level the number of constraints a new connection might expect in a particular location. The constraints analysis tool is hosted at www.lincolnshirelowcarbonhub.co.uk and uses a simple graphical interface and does not require any knowledge of primary system design or power flow analysis software.

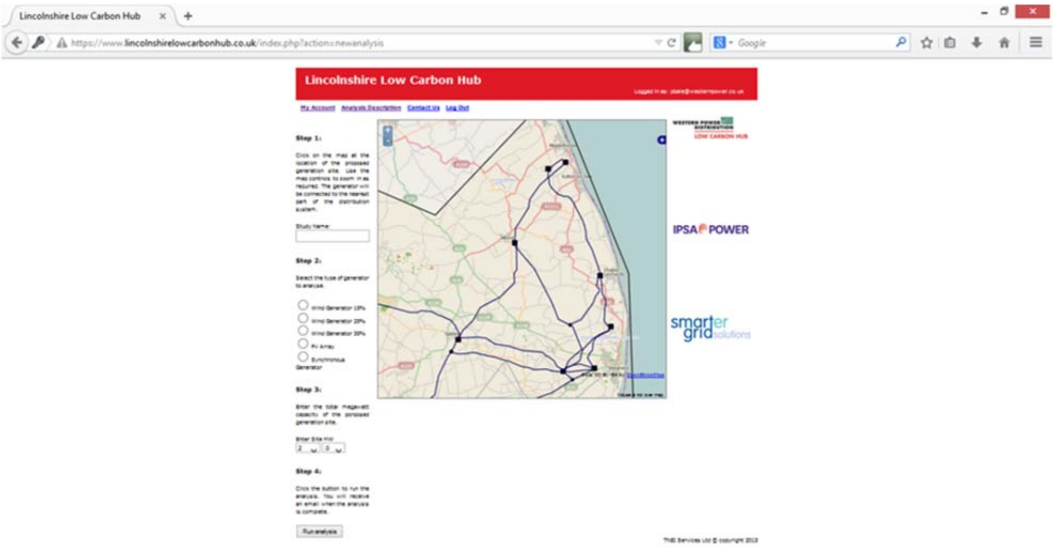


Figure 5 – Web based constraint analysis tool (screen shot)

3.4.3 Desktop tool

A version of the constraint analysis tool built for Western Power Distribution’s Primary network planning team uses the same data and algorithms. The spreadsheet tool requires the planner to specify the new point of coupling for the generator and cable distance between the generator and the existing network. The tool also allows primary system designers to modify different factors such as generation export, network demand profiles and the network running arrangements, showing the constraints under different network outages.

The tool estimates what the power flows and voltages would have been across the distribution network if the Active Network Management scheme and generation was in operation using historical data. The historical data and studies were manipulated to provide DG developers with three studies and an understanding of how the constraints may change for a number of different sensitivities including demand changes and the successful operation of the LCH innovative techniques.

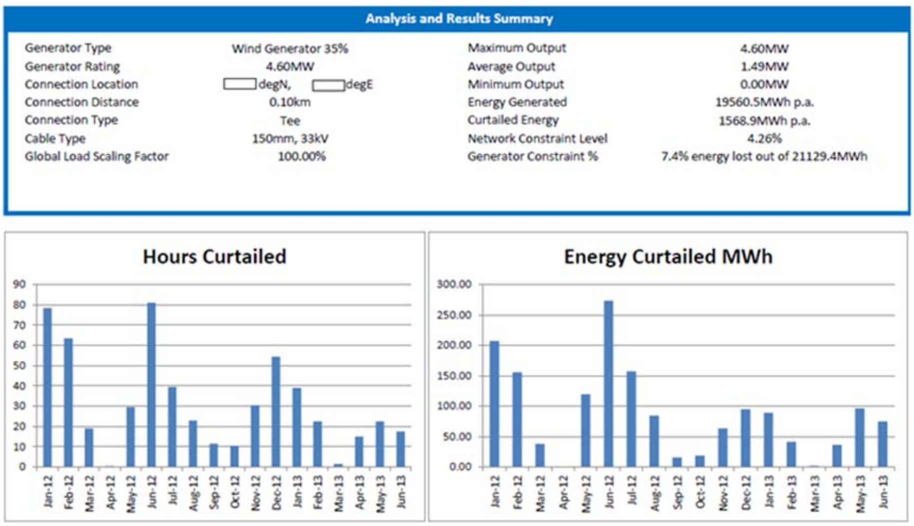


Figure 6 - Desktop tool (output screen shot)

3.4.4 Knowledge Generated

Area	Knowledge Generated
Design	A constraint estimation tools is an essential aspect of Alternative Connections. Western Power Distribution would not have been comfortable allowing a third party to run this analysis on their behalf due to the complexities encountered in the debugging stage of the software development. The tool allows the DNO to study how the network operates with Alternative Connections under both normal and abnormal network configurations understanding how power flows and voltage profiles will change at different times of the year. The Constraints analysis tool allows a generation developer to understand which areas are likely to experience both, lower and higher constraints and understand the risk of accepting an alternative connection.
Design	It is not possible for a DNO to provide an estimation of future constraints or guarantee network availability based on LIFO as there are a number of factors that are outside of a DNOs control which could either increase or decrease the constraints a generator may experience. Instead WPD has advised customers of the likely constraints based on historical network operation and run a number of scenarios using this data. **Developments which could decrease constraints:** ▪ Existing Generation with a reduced Capacity Factor. This could be due to generator maintenance or outages, weather conditions, derogation of output over time or a site being decommissioned. ▪ Existing or new Demand connections increasing their demand ▪ Network reinforcement **Developments which could increase constraints:** ▪ Connection of increasing levels of micro-generation. ▪ Existing Generation with a higher output / capacity factor. This could be due to favourable weather conditions or replanting with more efficient components. ▪ Existing demand connections reducing their demand
Design	In order for Generation developers to understand the risks associated with a connection and carry out their own due diligence, it requires the DNO to be very clear with the assumptions it made in undertaking the analysis. WPD provided customers with details of the East Lincolnshire network components, load data, network configuration data and the capacity and type of generation ahead of them in the LIFO queue. The majority of generation developers are not willing to share their basic connection application information (Capacity, generation type & point of common coupling) with other generation developers to aid their constraint analysis connections. Not having the alternative generation locations makes it more difficult for the customer to conduct their own detailed constraint analysis studies.

Operational	WPD ran three different scenarios based on the historical network data and weather data. These were intended to provide an understanding for a generation developer as how likely the constraint can change with the reduction of demand and the successful operation of the LCH smart grid technologies. The majority of parties, especially solar PV developers did not believe study one to be particularly helpful as it assumed 100% sustained output. Further studies following this route should probably consider a bell curve for Solar PV as this would provide more meaningful results.
Build	At the time of the project, it was not possible to purchase an off the shelf constraints analysis tool. Whilst the analysis could be run by a number of companies, the software was not user-friendly and could not be packaged for use by a DNO. The Low Carbon Hub Constraints Analysis tool successfully showed the software could be designed and packaged for a DNO to operate constraints analysis themselves. Developing the tool in Excel for the proof of concept tool was the best options owing to the flexibility developing the tool, solving the bugs encountered quickly and effectively.
Build	The tool was independently evaluated by Smarter Grid Solutions, a third party with their constraint analysis tool. This built confidence that the constraint analysis software was performing as expected.
Operation	If the Constraints Analysis tool had the functionality to identify limiting factors and to step through the time series data, issuing Alternative Connections would have been an easier process. Identifying the limiting factors would have allow the planning teams to understand how the network constraint points' change throughout the year, depending on the demand profiles at each primary substation and the generation profiles for each site. Stepping through the desktop tool time series data would have made debugging the tool much easier and allowed a better understanding at to how the power flows can change throughout the years and with different generation outputs. The LCH tool has this functionality, however this is currently a resource intense and time consuming process to carry out.
Commercial	It is possible to analyses networks to the granularity of ½ hourly time periods for a long duration. This assesses all nodes will remain within the design and statutory parameters from the 11kV bus bars to the 400kV super grid transformers. Conducting ½ hourly analysis is computationally heavy and can take several hours if carried out on a high specification laptop. A more effective method of nodal analysis would be to group time periods and run computational studies based on these groups, significantly reducing the amount of computational studies required. Using 1/2 hourly demand profiles is suitable when conducting analysis on one BSP, however when expanded up to one GSP the time to complete the analysis created delays in offering alternative connections.
Design	Adding any new generators to the network required all new generators to be remodelled to maintain an accurate estimation of constraints. By connecting

	a new generator the network impedance and reactive power flows change due to the additional cable installed. This can result in changes to the voltage profiles and power flows, but the decision was taken for the analysis to be re-run for all generators further up the queue to ensure the results are accurate.
Design	The tool was designed to study 33kV connections between 2-30MVA, in reality, it should have been developed for 11kV and 33kV connections between 150kVA – 30 MVA. As such the constraint analysis software that has been written which constrains generation by 10% output is not very effective for small generation sizes. Any further tool should consider how both large and small generation can be studies in the same tool.
Design	It would have been possible to use a simpler constraints analysis tool without using time series nodal analysis studies if the networks are radial and the constraints were only thermal. However if a network will develop voltage constraints or could be developed to operate meshed, It is believed a nodal analysis tool is required to provide the levels of accuracy and certainty a DNO and Generation Developer requires.
Design	The East Lincolnshire Network was a very suitable network to test constraint analysis owing to its relatively simple design with few alternative infeed. Whilst it took a considerable amount of time to debug with several iterations to the code and analysis, it was clear when the toll was producing accurate results. As the tool was fully tested, it became clear that the tool would need to conduct a very high number of sequential nodal analysis studies to calculate constraints, sometimes in excess of 4,500,000 studies. The result of this high number of studies was memory issues. These were identified and fixed. It is essential that the constraint analysis tool produces results are reliable and repeatable. If constraint analysis tool is required for a more complex network, sufficient time should be allowed to ascertain if the results from the tool are credible, and if the constraints are accurate representations of the actual level of constraints.
Operation	WPD's Internal planning staff were very receptive to the development of tools using time series data to improve the understanding of how the network operates. A full business wide training programme was rolled out to 200+ planning staff that will need to regularly conduct constraint analysis studies to ensure they are comfortable with the process. The Desktop tool requires a number of steps to be followed; making sure the required information is inputted. Failure to input all the information can result in the Constraint analysis tool not using the correct information and producing misleading results.
Design	The constraint analysis study documentation displays the estimated generation MWh output per month and the estimated MWh constrained per month for three different study scenarios. Generation developers have often requested additional information to understand what assumptions have been made and why. A number of Generation Developers have provided feedback that they would prefer to have one number to compare rather than all of the constraint

	information. The decision to provide monthly data was a conscious decision to ensure DG developers could see how the constraints changed overtime.
Design	The online tool estimates the cable distance as 130% of the straight line to the nearest 33kV asset. This accounts for the additional distance for the installation of cables in roads. The online tool provides a simple way to identify more optimal locations for future DG locations that will be less susceptible to future constraints.
Design	One of the key parameters within an ANM system is the setting of suitable limits for each measurement point, imposed to constrain and release generation within the ANM scheme, whilst ensuring all sections of the network remain within their design and statutory parameters. The trim, Trip, Sequential trip and Global trip, control generator output for critical network positions. If these settings are too low, DG sites would be constrained off prematurely and the capacity within the network will not all be released. If the settings are too high, the generation could lead to cascade trips and global trips. Artificial constraints need to be inserted to compensate for the n-1 scenarios, e.g. what are the resultant voltage profiles and power flows when a circuit or transformer trips. The network limits needed to be carefully calculated to avoid further cascade trips. There is a requirement to have the constraint analysis software matching the ANM equipment set up. Installing Active Network Management can reduce the capacity of a network, as a tolerance is required for ramp down time and communications latency.
Build	The anticipated time to write and debug the software programme was underestimated both by TNEI and WPD as the tool continued to 'fall over' in the early stages. These issues were solved over a period of a month with considerable learning generated to solve the nodal analysis issues associated with running approximately 4.5 million nodal analysis studies sequentially.

3.5 Alternative Connections - Potential for replication

3.5.1 Areas to Replicate

There are significant opportunities to be replicated beyond WPD's network areas in areas of high levels of intermittent generation as a method of unlocking further generation capacity.

Alongside the development of alternative connections as part of the Low Carbon Hub and demonstration in East Lincolnshire, the ANM policies have been written for offering alternative connections as a BaU process, WPD's 200+ planners have been trained how to offer alternative connection offers and WPD has changed its core database to facilitate the alternative connections.

WPD has already committed to rolling out the technique across all four WPD licence areas with 11 new zones opened by 2023. Each will use the Alternative Commercial agreements developed as part of this project. Further information is available on www.westernpower.co.uk/connections.aspx.
WPD will develop a constraints analysis tool for all ANM areas using the learning generated from this project (as detailed above) to build a tool that is more suitable for rollout across the business by Primary and 11kV planners.

Generation customers can now register their interest in Alternative Connections through the connections section of the WPD website. Customer feedback helps WPD to priorities the areas that Alternative connections should be offered next.

Two new simpler alternative connection offers - Timed connections and soft intertrip connections are also being offered using the same principles developed as part of the LCH.
A key requirement to Alternative Connections is the creation of robust, flexible constraint analysis software. This is essential for network with voltage constraints.

It is expected that the alternative connections will continue to evolve taking into account the learning from both East Lincolnshire and the future roll out of ANM.

3.5.2 Areas that require further work

Further work is required to understand how a standard firm or non-firm connection could be made in an ANM area requires a change in methodology to ensure the connection does not have a negative impact on the alternative DG connections, but the minimum cost scheme is offered to the customer.

WPD prefers to have at least two options for equipment and services, WPD is continuing to discuss our ANM plans with a number of manufacturers looking to developing and demonstrate ANM solutions so WPD has at least two Active Network Management providers and solutions for future applications.

Designing a network to operate with Active Network Management requires careful considerations, especially the effect on the existing protection settings. The protection philosophy was originally set up to protect demand driven networks, often with levels of redundancy built into networks.

Future Constraints analysis software would be more suitable running on a dedicated server system or in the cloud rather than a desktop PC or Laptop.
A standalone test server would have produced quicker results, reduced the time associated with fixing bugs and made it easier to ultimately adopt the final software back onto WPD's systems when it has passed all operational trials.

4 Overview of the Ring Method

33kV active network ring – The active ring allows increased control of the 33kV system and network reconfiguration based on real time power flows. Construction of the ring involved the installation of an additional circuit breakers, disconnectors and smart grid protection and control.

4.1 Background to Network Design

The 33kV or primary network, in rural areas, is largely made up of radial feeders supplying primary substations with either one or two transformers. The existing primary network in the LLCH area is made up of two radial feeders, two transformers and 33kV normally open points at Trusthorpe, Chapel St Leonards and Ingoldmells substations. This radial network configuration is relatively simple to operate and maintain; power can only flow along one path. However these like most radial networks have presented a number of barriers to the connection of additional distributed generation. This is mainly due to voltage rise outside of statutory limits and thermal constraints across the system.

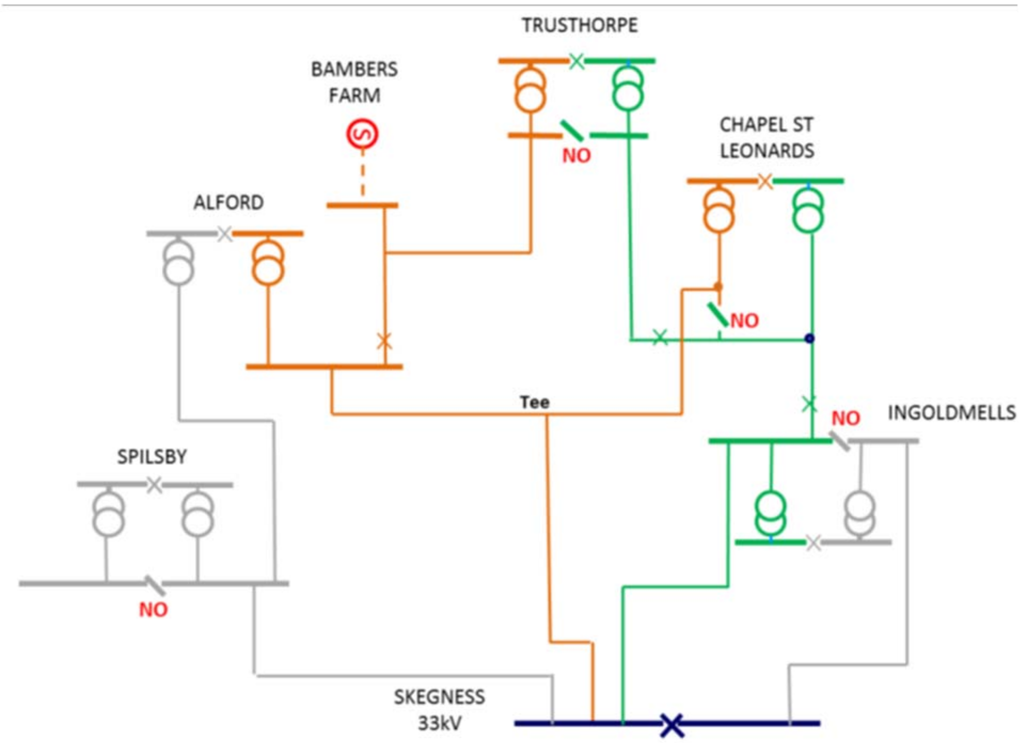


Figure 7 – Existing radial feeders

Voltage rise occurs when the Distributed Generation (DG) exceeds the network demand, causing power to flow in the opposite way it is intended and thus the voltage increases rather than decreases. This tends to be the limiting factor if increasing levels of generation requesting connection to relatively high impedance circuits. The network design solution is to reduce the network impedance; this is often solved by installing new high capacity, lower impedance cables connecting to the network closer to the grid substation.

Thermal issues occur when either a large generation sites or a number of smaller generators connect to the same piece of network, often where the circuit impedance is relatively low. The output of the combined DG can exceed the static ratings of overhead line (OHL), cables or transformers. The network design solution is often to install larger cables and transformers or to add new circuits, switchgear or transformers.

A method of network reinforcement to alleviate both voltage rise and thermal limits is modifying an existing radial network to operate meshed or in parallel. This historically has not been used; the Low Carbon Hub has demonstrated how it could be applied in the LLCH area to increase network capacity.

4.2 Low Carbon Hub – Ring Network

The creation of the 'active network ring' involved installing additional switchgear, disconnectors, cable sections, Current Transformers (CT's), Voltage Transformers (VT's), replacement batteries, new telecommunication links and new protection relays.

The following work was carried out at each substation to facilitate the meshing of two network feeders.

Skegness

- Transposed feeders 08 (Alford T1 / Chapel St Leonards T2) and 07 (Spilsby T1 / Alford T2),
- Installing a new three ended current differential protection scheme on CB07 (Alford T1 / Chapel St Leonards T2),
- Installing a new two ended current differential protection scheme on CB04 (Ingoldmells / Chapel St Leonards),
- Replacing existing 110V batteries.

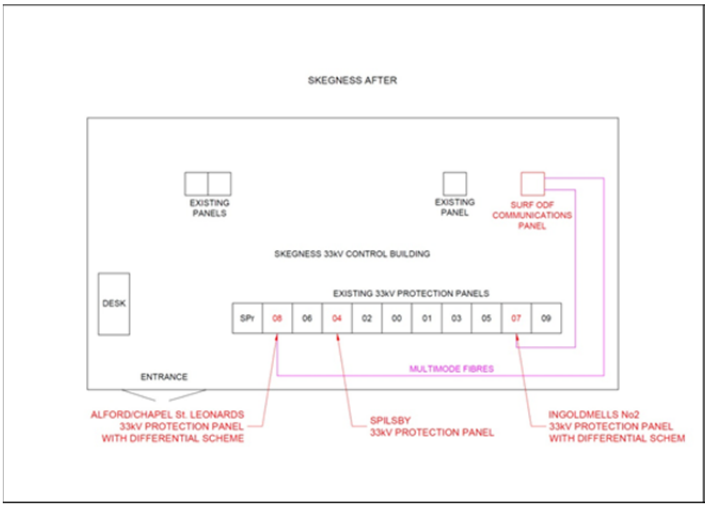


Figure 8 – Skegness Installation

Alford

- Replace the existing outdoor 33kV outdoor oil circuit breaker (CB) at Alford with an outdoor 33kV SF6 circuit breaker,
- Replace the two existing line disconnectors; with new disconnectors that have auxiliary contacts fitted,
- Post CTs were installed on T2 to summate the transformer load and the CTs within the CB bushing,
- A three ended current differential protection scheme was installed on the Alford / Chapel St Leonards circuit with distance protection backup,
- A three ended current differential protection scheme was installed on the Trusthorpe /Bambers Farm circuit with distance protection backup,
- Three phase VTs were retrofitted to both line disconnectors for use with distance protection and check synchronisation

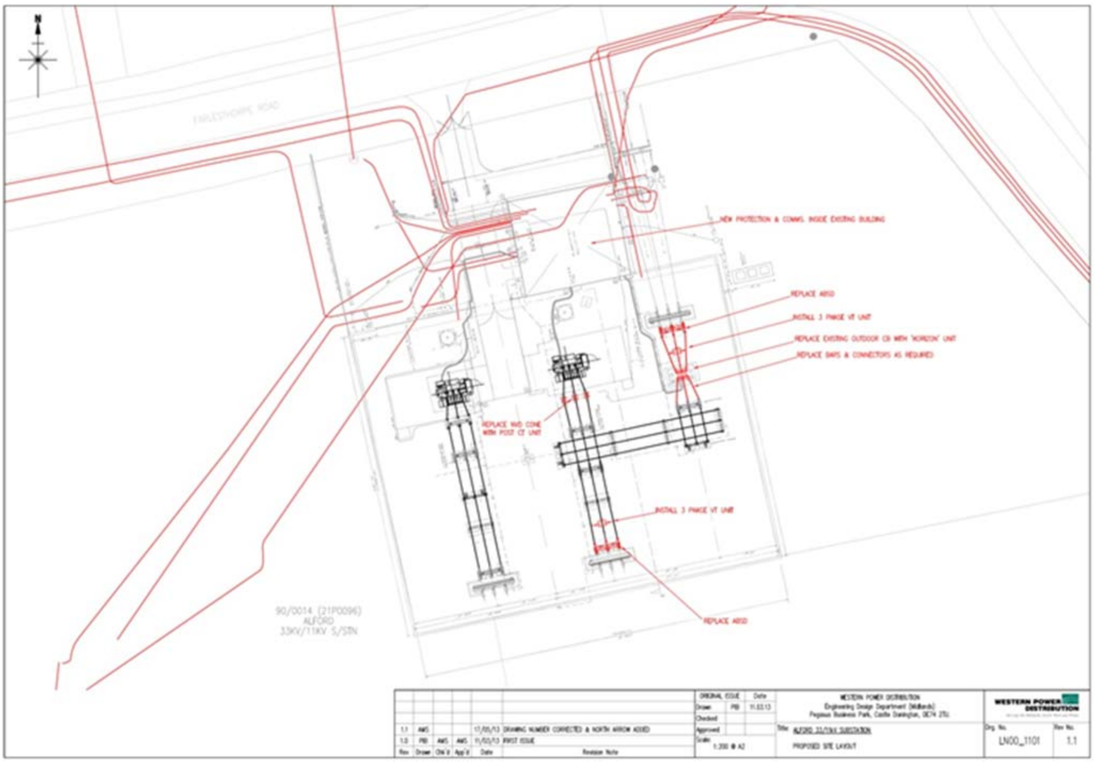


Figure 9 – Alford Installation

Bambers Wind Farm

- Installation of a three ended current differential scheme on the Trusthorpe / Alford circuit with distance protection backup,
- Retrofit appropriate CTs to the Bambers Wind Farm Ormazabal 33kV circuit Breaker.

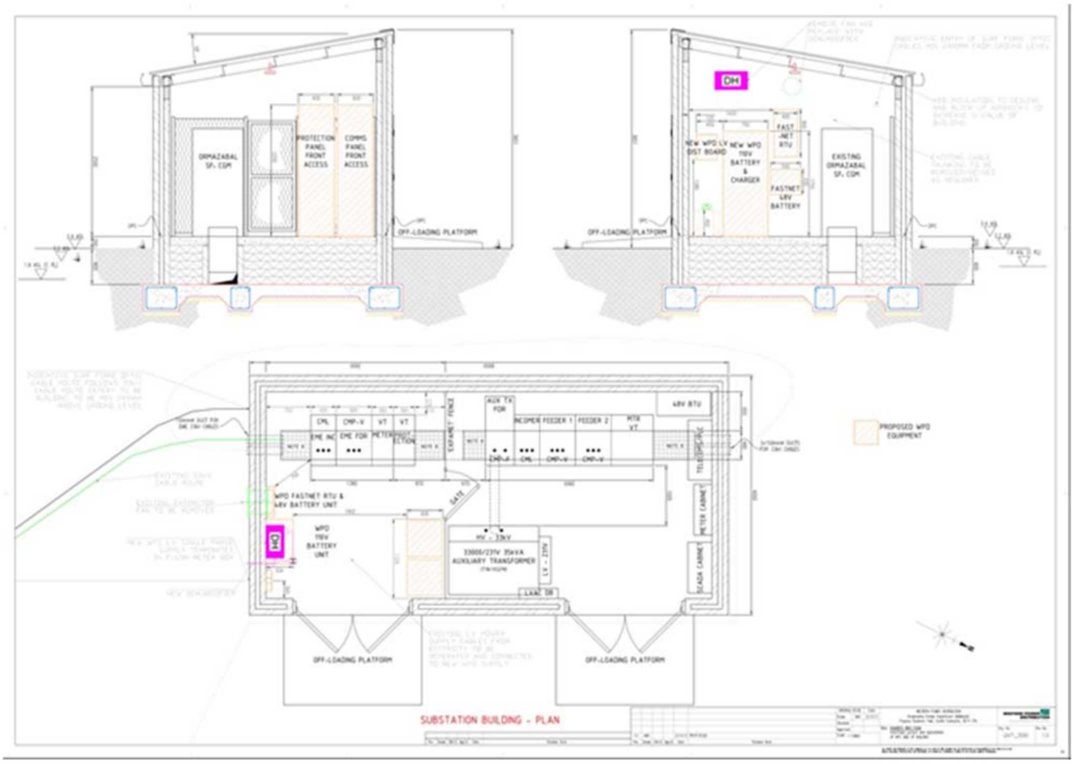


Figure 10 – Bambers Wind Farm Installation

Trusthorpe

- Install a 33kV 7 panel switchboard as part of the Trusthorpe primary substation transformer change and LLCH project. 2 x feeder circuit breakers, 3 x transformer circuit breakers (2 x primary transformers and a FACTs transformer) and 2 x bus sections,
- Installation of a three ended current differential scheme on the Trusthorpe / Alford / Bambers Farm circuit with distance protection backup,
- Installation of a two ended current differential scheme on the Trusthorpe / Chapel St Leonards circuit with distance protection backup

Figure 11 – Trusthorpe Installation

Chapel St Leonards

- Installation of a 3 circuit breakers board,
- Reinstatement of the T1 line disconnector, cable connecting the Skegness/Alford circuit toT1 Line disconnector,
- Removal of over sailing Ingoldmells/Trusthorpe OHL span and line disconnector,
- Three phase VTs were retrofitted to both line disconnectors for both distance protection and check synchronisation,
- Cable connect the new ring main unit to both T1 and T2 disconnectors and Trusthorpe OHL,
- A three ended current differential protection scheme was installed on the Chapel St Leonards / Alford / Bambers Farm circuit with distance protection backup,
- A two ended current differential protection scheme was installed on the Trusthorpe / Chapel St Leonards circuit with distance protection backup to provide adequate protection for this network.

Figure 12 – Chapel St Leonards Installation

Ingoldmells

- Installation of a new bay including terminal structure, Horizon 33kV circuit breaker, disconnector, cable sealing end structure, VT, disconnector and cable sealing structure,
- Modification to the existing cross bay, installing a new Horizon 33kV circuit breaker and post insulator,
- Three phase VTs were retrofitted to both line disconnectors for both distance protection and check synchronisation,
- The Skegness circuit existing line disconnectors has been be replaced with disconnectors including auxiliary contacts,
- A two ended current differential protection scheme was installed on the Chapel St Leonards circuit with distance protection backup,
- A two ended current differential protection scheme was installed on the Skegness circuit with distance protection backup will provide adequate protection for this network.

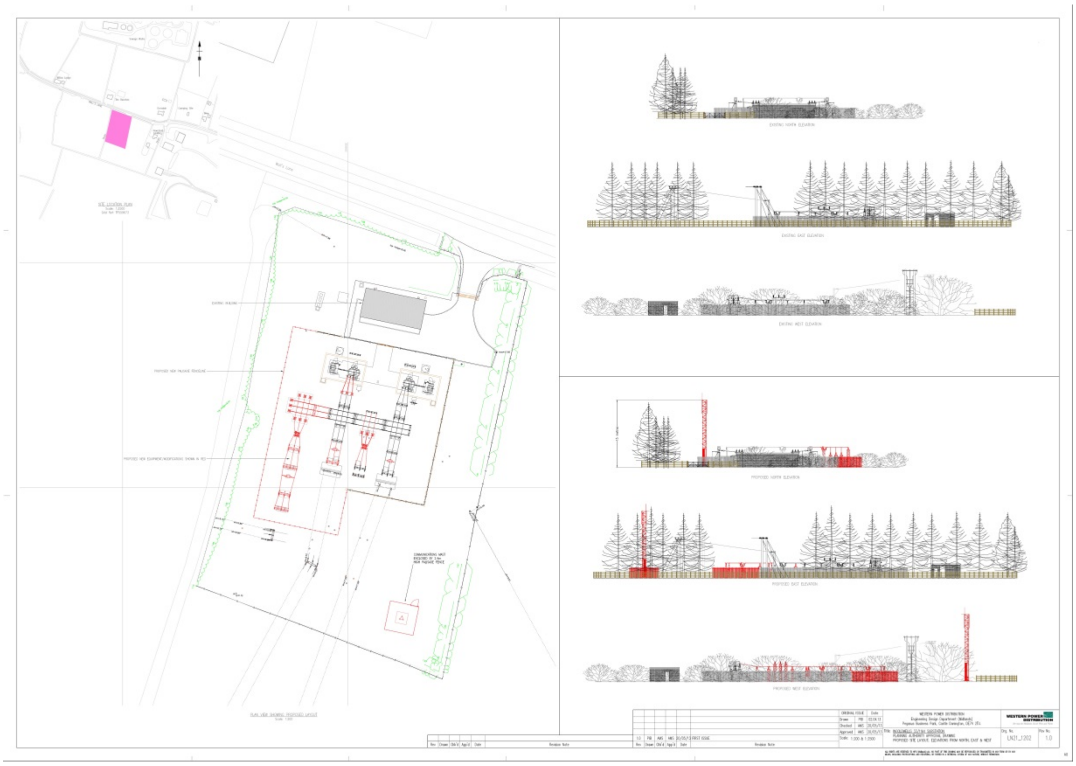


Figure 13 – Ingoldmells Installation

The installation at all sites allows the network to run as a closed ring with greater controllability enabled by increased visibility of power flows and voltage profiles. This arrangement allows WPD to reconfigure the system based on the real time status of the network. The protection scheme operates under normal conditions using a new communication network described in Section 5. The backup protection, when the communications are not operational is distance protection. A technical description of the ring network will be included in the Project Close Down report.

4.3 Knowledge Generated

Area	Knowledge Generated
Design	To create an active ring network the original project design included an additional 4.5 km of new 33kV OHL and the closing of the existing normally open point at Chapel St Leonards. This new OHL in combination with the active ring network would have created an increase in the potential capacity to connect generation. However due to local opposition, largely linked to possible new wind farms, the wayleave process became increasingly difficult. Speaking to local groups it became clear that the proposal to build the new OHL was unfeasible. Although further steps could have been taken to secure permissions (compulsory wayleaves etc.), this was deemed inappropriate for an ahead of need investment or a LCNF demonstration project. Subsequently an alternative network layout was developed that sought to maximise the potential operational capacity of the existing assets. While this did not adversely affect the majority of elements of the project, it has had a significant bearing on the design of the active ring network, and resulted in a redesign of the network layout.
Design	The public perception of new renewable generation in the area changed very quickly in-between the final submission and the detailed design of the project. The change in public opinion had a considerable impact on the ability to secure agreements.
Design	The Low Carbon Hub design was largely completed using desktop planning; learning from this project has shown that for a project of this complexity, further design works at the bid or pre project stage would have resulted in a better understanding of the project requirements. If WPD was to repeat the process, the design work & permissions for higher dependency delivery plans would be carried out prior to committing to the ring method. Where suitable alternatives do not exist, the ring network would not be expected to be selected as a suitable method. It is a requirement that any works to the network should result in the network being the same or better after completing works. This ruled out a large number of options for the ring network as the options would have reduced certain flexible elements that already existed in the network. As such, it isn't a particularly flexible technique and should be fully considered before committing to modifying an existing radial network to a ring operation.
Design	It was possible to deliver the ring network using only the existing distribution network assets by including Ingoldmells substation. Due to the new 4.5km interconnector not being built, the capacity unlock by the ring method was reduced, but the ring network has facilitated three additional generation connections.
Operation	The delivered of ring network has provided considerably more network security for both demand and generation customers after a fault due to a fault being cleared in the
Design	The decision to include Ingoldmells substations and the associated OHL's required a number of complex decisions to be made. The inclusion of

	Ingoldmells significantly increased the number permutations and complexity for both normal and abnormal running arrangements leading to delays in selecting an acceptable Low Carbon Hub design that can be adequately protected. The learning from this method was that a more robust mitigation plan should have been in place in the event the new OHL could not receive wayleaves or planning permission. There is also a much higher risk associated with building Overhead Lines for renewable generation.
Design	The time taken to plan, design, carry out the works and commission new schemes is significant. Even if looking to replicate this technique again in a new area, it would be sensible to allow at a minimum of 3 months for design works per substation and 6 – 12 months for construction per substation depending on the length of the works. This means that technique is more suitable to an ahead of need network reinforcement scheme rather than reacting to a generation connection enquiry.
Design	Within the East Midlands, meshed circuits tends to be associated with 132kV urban circuits, one of the key elements of the project was required to ensure that the meshed network design was suitable for a rural 33kV schemes and not a replication of the schemes used on 132kV urban networks. Some UK rural distribution networks were designed to operate as a meshed ring, often with distance protection. Part of the Low Carbon Hub ring method was to work with the design and delivery teams when assessing how meshed network solution can be retrofitted to an existing network to increase capacity.
Design	The project aimed to show how the existing network could be altered rather than rebuilt to enhance capacity. With the project delays associated with not receiving permission for the new OHL line, it is now conceived that the use of 33kV switchboards at a number of sites would have been an economical advantageous alternative to an AIS or hybrid Air Insulated Switchgear (AIS) solution accounting for the reduced network risk during an offline build, a quicker construction phase and the result of a simpler network to operate. The learning has shown that if the delivery timescales are short and significant works are required on site, the quickest solution is the construction of an offline build as demonstrated at Trusthorpe primary substation. This approach also reduces network risk as the majority of the construction can be carried out whilst the existing network is still in service. The use of a hybrid of existing air insulated assets and new gas insulated switchboards connected with cables can lead to the operation of sites being more complex. This was carefully managed to WPD's existing design policies.
Design	The learning from the project showed that having the right current and voltage transformers in the right locations, with the correct accuracy is often a limitation to smarter solutions. Both the ring network and the DVC method has shown how additional CT's can be incorporated into existing networks (Alford, Chapel St Leonards and Ingoldmells), how additional VT's are best incorporated into AIS sites (Alford & Ingoldmells), how additional VT's are best incorporated into GIS sites (Trusthorpe) and how additional VT's are best

	incorporated into hybrid AIS/GIS sites (Chapel St Leonards). At Alford, Chapel St Leonards and Ingoldmells there was no space within the existing transformer bushing to install the matched CT's required as part of a current differential scheme. This issue was overcome by installing Post CT's. The two options available were to install slipover CT's over the transformer. This was discounted due to the reduced clearance and potential maintenance issues in the future if there is a build-up of debris between the CT and the bushing. The use of post CT's was selected, however no post CT at 33kV was rated to support any length of bus bar. As such, 66kV insulation posts were installed on both sides of the Post CT to facilitate their use whilst still maintaining the equipment rating.
Design	Both operational compounds and switch rooms do not have an abundance of space to add additional assets, if space is available careful consideration is required into how modifications can be made safely, how the entire site can be maintained and how this impacts on future works. The design of an active ring using sites with additional circuits retrofitted to them is more complex due to additional space constrains when trying to connect new switchgear. All designed were vetted to ensuring that primary substations were not sterilised by the work being completed under this project.
Operation	Meshed networks can cause particular protection issues with very rural networks and the associated low fault levels. With high levels of inverter driven generation, making differentiating between a network fault and high steady state output from the connected generation very difficult. A two and three ended current differential scheme with distance backup was selected as the best way method of protecting the network. The connection of new generation to the current differential network will be made, ensuring the network will operate with no more than three ends. This has required several new generation connections to be made as a looped connection to maintain no more than three ends.
Build	Due to the alternative nature of the Low Carbon Hub ring method rather than following standard designs resulted in the onsite team taking a much more active role in addressing issues with input from the designer rather than decisions being made by the designers and disseminated to site. Whilst the project was successfully delivered all the works within the truncated timescales safely and effectively, a longer delivery timetable would have allowed for better allocate of resources and a lower risk delivery.
Operational	The Current Differential schemes have shown to be effective method of protection the network; several links have required further investigation as a result of current imbalance alarms occurring, especially during low demand periods. The current differential relays have been adapted to account for current imbalance present on the rural 33kV network at times of minimum demand.

4.4 Ring Network - Potential for replication

This technique has shown to increase network capacity and improve network security, but it is very dependent on the existing network infrastructure. This means it will not be a suitable method in all locations owing to the available space.

A simple meshing operating using PMAR could be achieved if the resultant power flows are maintained within the equipment ratings and the voltage and current transformers required for the protection scheme can be incorporated into the network

The process of re designing an existing radial overcurrent protected network technique does take a considerable amount of time and effort owing to the complex design works, long lead time items and the requirement for network outages. This means the techniques is more likely to be used for a long term investment ahead of need to increase network capacity rather than responding to a particular generation connection

There are often quicker, more cost effective methods of unlocking additional capacity which may limit the potential for replications across GB. If the meshing of feeders is applied across future wider areas, Future replications in Western Power Distribution would use more offline rebuilds rather than modifying an existing network to enhance capacity.

5 Overview of the Network Enhancements methods

Network enhancements – Sections of existing overhead lines have been upgraded within the demonstration area with higher rated and lower impedance conductors to increase the network's capacity to connect DG. This work is in addition to investment already funded through the Distribution Price Control Review (DPCR) 5 settlement. For the purposes of disseminating learning, the communications required for a range of the methods above have been reported as part of this method.

5.1 Over Head Line Network Enhancement

5.1.1 Background to 33kV OHL asset replacement

The design of the primary network and asset replacement programme is influenced by a number of factors:

- The current and future demand a network area will support when operating both normally and abnormally for maintenance or after credible faults on the network,
- the thermal capacity, often matching the standard transformer capacity installed across the network,
- voltage profile analysis, ensuring the network will stays within the required limits across the network, when operating both normally and abnormally,
- the thermal capacity sharing across the network under abnormal network operation, and
- the changing of the network design standards over time.

When network assets are due to be replaced either due to condition or load related reasons, a DNO is incentivised under the regulatory performance measures to install the minimum cost scheme that fits the current and credible future functional requirements such as demand growth. This ensures that assets are not over invested and subsequently stranded. However, it can also result in the replacement not being fit for an evolving, unknown future.

5.1.2 Low Carbon Hub – Network Enhancements

One of the LCH techniques was to ascertain what additional functionality should be either designed or built into networks to make them more suitable for future generation connection. The Distribution Price Control Review 5 (DPCR5) overhead line replacement programme for both load and condition reasons were routinely evaluated to ascertain if the most suitable asset for the future was being proposed. Sections of 33kV overhead lines were being replaced between Alford to Trusthorpe and between Chapel St Leonards to Trusthorpe. There were identified as key circuits which, if the impedance was reduced, would unlock additional generation capacity for both conventional and alternative connections.

In East Lincolnshire, nodal analysis modelling showed that even with the connection of relatively small new distributed generation sites near Trusthorpe, the relatively high existing network impedance and existing generation connections resulted in the network operating above upper statutory limit of 35,000V during periods of minimum demand. At the time the OHL replacement was being planned, there were no new generation applications in this area that would benefit from a larger conductor being installed.

The standard design manual for replacing rural 33kV Overhead lines is with 150mm2 Aluminium Conductor Steal Reinforced (ACSR). The circuits being replaced in the LLCH area were designed to have 300mm2 Hard Drawn Aluminium (HDA) installed with the provision for optical fibre both at the construction phase and as a retrofit activity. This conductor cross sectional area was double in size, and had half the network resistance. 10.2km of 33kV network was rebuilt with the larger design standard.


Figure 15 – Rebuilt line with fibre wrap

5.1.3 Knowledge Generated

Area	Knowledge Generated
Design	It became clear that securing wayleaves for replacement Overhead Line that the process would be longer and more protracted then planned. Engagement with Arable land owners revealed they were not willing to accept shorter span lengths, i.e. the closer spacing of overhead line poles. The circuits being replaced were constructed in the 1950's; they have a typical span length of 150 – 160m. Following WPD standard 43-40 design philosophy, 150mm^2 conductors on a single wood pole design would have an average span length of approximately 120m and 300mm^2 conductors on a single wood pole design would have an average span length of approximately 85m.

	This feedback from land owners resulted in WPD requiring a replacement line maintaining similar span lengths. WPD designed a new H pole construction with an equivalent span of 160m for similar future scenarios. The pole positions of the Overhead Lines were discussed with Landowners and residents so as to not obstruct farming practices and to reduce the visual amenity. The necessary wayleave permissions were secured on this basis.
Commercial	The additional uplift associated with rebuilding the 10.1km of overhead line to the Low Carbon Hub standard was calculated as £80,000, this increased the summer capacity from 16MVA to 41MVA and has been modelled to reduce voltage rise by 24% compared to the existing circuit during maximum reverse power flows. This could either connect an additional 12MW of distributed generation under conventional connections.
Design	The wrap causes an impact on the MCT (Max Conductor Tension), MCW (Max Conductor Weight) and MCP (Max Conductor Pressure). However the impact is only marginal it does affect the design slightly. At a maximum span length of 190m at maximum design temp the sag increases from 7.02m to 7.29m, this was taken into account to ensure clearances were still maintained, the maximum clashing span was reduced from 190m to 178m.
Design	The two OHL rebuilds received all the required wayleaves from landowners in February 2103. Local Authority permission, Flood Defence Consent from the Environment Agency, Land Drainage Consent from Lindsey Marsh Drainage Board and DECC Section 37 consent were all received by August 2013, taking approximately six months to secure.
Design	The design of the larger conductor rebuilds was studied to understand the impact on the network under both intact and plausible non-intact scenarios to ascertain what impact it will have on the resultant power flows. This also included adding different levels of generation at different points on the network to ensure the rebuilding of the circuits with a larger conductor did not present unbalanced power flows that could limit the future` capacity of the network system.
Operation	The installation of a larger conductor reduces the resistance of the circuit; the reactance of the replacement circuit was similar to the original circuit. The replacement conductor reduced the effects of voltage drop when the network is demand driven, reduces the effects of voltage rise when the network is generation driven and reduces the network losses.
Design	WPD's OHL design software models conductor sag based on tension, adding fibre wrap to an overhead line will increases the weight rather than the tension. The resultant design based on tension is more conservative but will ensure that statutory clearances are maintained.
Build	The build of the overhead line was completed in sections. After the section were completed, the optical fibre team following behind to wrap the new line. This increased the duration of the wrapping the line but reduced the disturbance on landowners.

5.2 Telecoms

5.2.1 Background to Telecommunications within Primary Substations

The requirement for advanced telecoms was identified as an enabler for a number of LCH techniques, such as part of Dynamic Line ratings, the current differential protection traffic for the ring network and the backhaul of data for the Advanced Voltage Control. Existing communications for SCADA traffic is UHF (Ultra High Frequency) radio; this has a relatively low latency and bandwidth and operates in a hub and spoke design between substations and the base. It is not suitable for the high speed and bandwidth data requirements for current differential protection traffic between primary substations. It could be a limitation for other methods where network data is required to support network operational decisions.

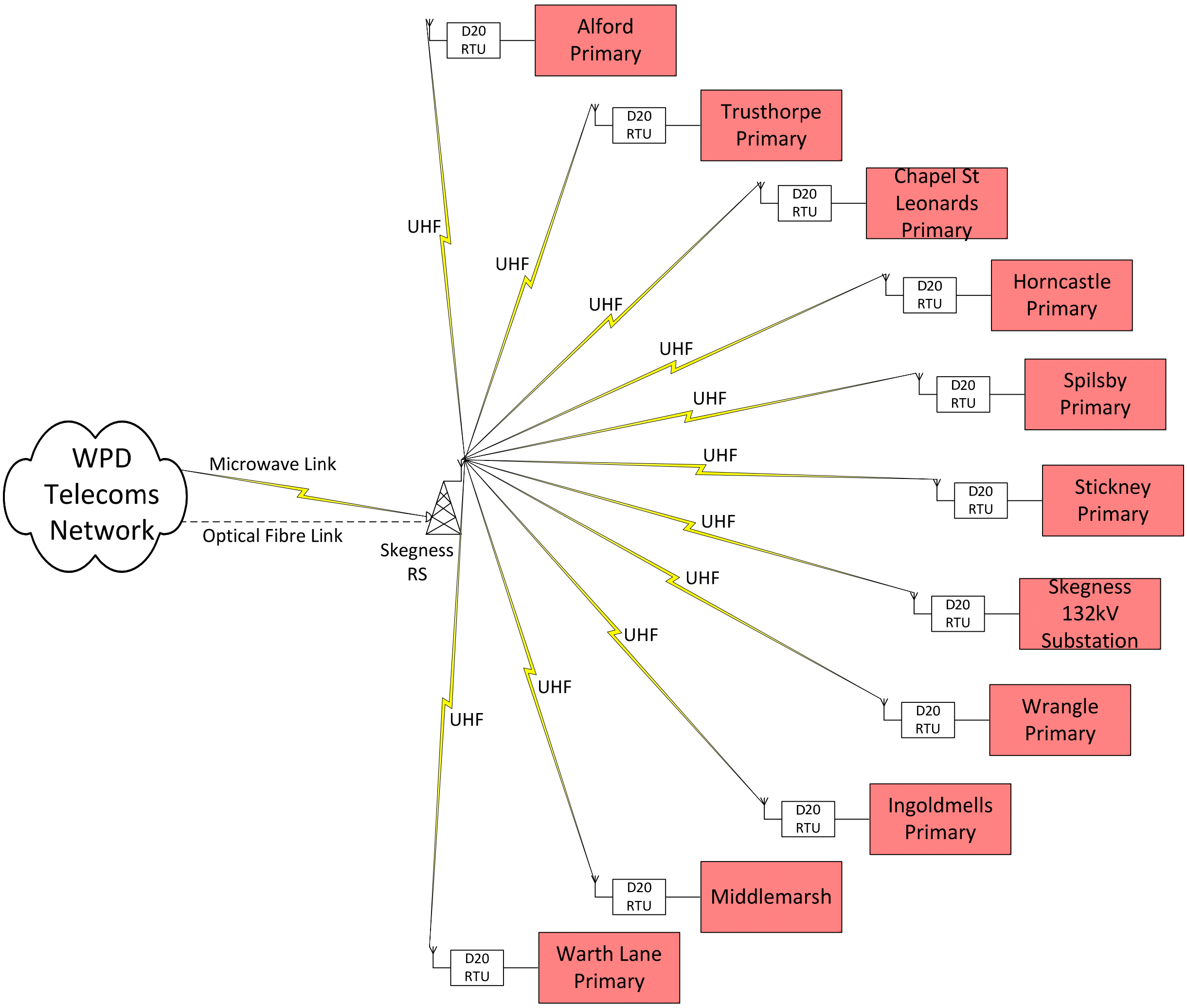


Figure 16 – Hub and spoke SCADA communications

5.2.2 Low Carbon Hub - Telecoms

A key requirement of the project was to investigate what would make a suitable telecommunications links between primary substations for network protection and other data requirements. The protection requirements for the Low Carbon Hub and advanced network operation require a reliable, low latency communications media for protection purposes.

Fitting optical fibre and microwave communication links for primary substation current differential protection schemes was a new area to WPD. As such there was a low level of risk with any new technology, the decision was made to trial both wired and wireless communications channels as part of the project to further reduce the impact of any one communication technology not operating effectively. A review of the available wired and wireless communications communication media was conducted and a report published on www.westernpowerinnovation.co.uk/documents.aspx. both wired and wireless communications.

The project installed 96 fibre SkyWrap to new and existing lines between Skegness to Alford and Alford to Trusthorpe. The project installed three microwave towers and three microwave links installed between Skegness to Ingoldmells, Ingoldmells to Chapel St Leonards and Chapel St Leonards to Trusthorpe

Figure 17 – WPD Microwave tower and link

5.2.3 Knowledge Generated

Design	There are three main options for attaching fibre to wood pole overhead lines 1) Optical Phase Conductor (OPPC) can be used, however this requires the re stringing of the centre phase, this is a high cost installation for retrofit. This also requires sufficient spare conductor to be strategically stored for repairs. The use of OPPC could lead to extended periods of time when the optical fibre is not available for protection traffic. Therefore OPPC was not considered for the project or WPD's fibre standard.

	2) All-Dielectric Self Supporting cable (ADDS) is WPD's the first choice for adding fibre to an existing line wood pole line as it can be installed below the overhead line. However, on the existing OHL's where fibre was required on in East Lincolnshire, the ADSS could not be installed without either reducing the ground clearance which would have caused issues with the very large farm machinery or causing an unacceptable risk of clashing or increasing the height of a number of poles along this circuit. Therefore, ADSS was not an appropriate choice for the surveyed east Lincolnshire lines. 3) Optical Fibre Wrap is applied to the centre phase of the existing overhead line, the conductor provides the mechanical strength of supporting the fibre. WPD selected fibre wrap to provide communications between Skegness – Alford and Alford – Trusthorpe, installing on both new and existing OHL's. Studies showed that one of the implications of the wrap was increased sag under certain conditions, three existing spans would no longer meeting WPD's OHL policy for clearances, the issue at these locations was increasing the line height.
Operation	As a result of adding optical fibre to 33kV OHL in the East Midlands, a new policy was written for all WPD areas. Some of the key points focus on: installation, labelling, clearances, access to fibre optic equipment, subsequent work on the OH network, operational earthing, repairs / maintenance of overhead line, handling fibre optic cables, system bonding and additional loading on the Overhead Line.
Build	Microwave links were required between Trusthorpe, Chapel St Leonards, Ingoldmells and Skegness primary substations. Desktop studies showed that towers at 15 meters would allow a clear line of sight between all substations. However, line of sight tests were performed and showed issues at several sites due to obstacles preventing a clear line of sight. Further work was required to relocate the microwave towers to different locations within the substation boundaries to facilitate line of sight communications. Permitted development rights were used to secure the installation of new towers at Trusthorpe, Chapel St Leonards and Ingoldmells primary substations. 15m is the maximum height for permitted development. If the project required taller towers planning permission would have been required. Securing planning permissions for a microwave tower would have been an increased risk. There was a number of mitigation plans in the event the WPD could not have secured permission for the necessary microwave towers and links.
Operation	Whilst the use of microwave links for current differential protection has been used by other DNOs within the UK, WPD has limited operational experience of operating microwave links as the primary communication channel for current differential protection data. The links have remained stable since the installation.
Design	The use of the optimised protection variant (OPV) Mimo Max equipment

	was considered for the project, however the bandwidth was significantly lower than microwave links, a much higher latency meant several links could not be used in series whilst still maintaining a sub 6ms response required for the current differential protection.
Commercial	The cost associates with the telecoms infrastructure was much higher than forecast, the foundations for the microwave towers and the installation of 96 fibres also exceeded the project budget.
Design & Operational	There was originally concern that as a result of the Optical fibre wrap would have a negative impact on the aesthetics of the overhead line. The effects of wrapping the overhead line is not significant and would not prevent further OHL's from being wrapped.
Design & Operational	Careful consideration at the design stage is required for the application of temporary earths and the location of earthing of splicing canisters. Failure to do so can result in reduced operational functionality.
Build	Due to a UK shortage in the exterior jacket material which protects the optical fibre, the fibre installer for the project used an alternative product. This caused issues in the installation phase as the material was less pliable then the normal jacket. During the installation process the fibres became damaged and when tested, they failed the tests. This required the manufacturer to re wrap approximately 10km at their expense. The lessons learnt from this installation were captured and processes have been put in place to ensure that the same issue cannot occur again. The subsequent re wrapped circuit showed all 96 fibres passed the tests.

5.3 Network Enhancements - Potential for replication

In areas where there are clear indications Distributed Generation will be connected, the enhancement of assets should be considered as assets are due for replacement. This may include installing a lower capacity circuit or a circuit designed for fibre to be retrofitted

In areas of Active Network Management, the circuit utilisation will be very high. The replacement of assets with a lower impedance and large capacity will reduce the constraints seen by DG customers and reduce network losses. The design and build costs associated with Enhancing OHL's is relatively modest and should be applied in ANM areas if appropriate.

The rebuilding of an overhead line is a relatively quick process if the ground remains dry during the installation. The process can be delayed significantly if sections of the new overhead line are built more than 30m from the original line, the securing the necessary permissions can result in a long and protracted process.

If an overhead line is being rebuilt to increase the capacity of a line or reduce the impedance as a result of a DG connection, there is a risk that the permissions create delays in network reinforcement being carried out ahead of the generation connection.

5.4 Telecomms - Potential for replication

Further work is required to assess the long term performance of the microwave communication links to ascertain if they should be used in other locations as the primary current differential communications link.

Fibre can be retrofitted onto existing 33kV lines to facilitate increased communications between primary substations. The current high cost associated with installing fibre on wood pole is likely to prevent its extensive use across the rest of GB.

6 Overview of the Dynamic Line Ratings methods

Dynamic system ratings – The Skegness Registered Power Zone delivered innovative connections to offshore wind farms based on dynamic rating of overhead lines. These components have been further developed and the new techniques tested at 33kV to calculate the network capacity and operating limits based on real time asset data.

6.1 Background to Overhead Line Ratings

Within the UK, Overhead conductors have specific static current ratings based on seasonal weather patterns dictated by ENA Engineering Recommendation P27.

The P27 ratings determine the maximum current rating to maintain the conductor below the maximum design temperature. With increasing current flowing through an overhead line, the temperature of the conductor increases, which can either damage the overhead line and/or cause the conductor to expand reducing the proximity to the ground.

OHL static ratings assume certain conservative static environmental factors such as:

- Ambient air temperature (°C)
- Wind speed (m/s)
- Wind direction (°)
- Incident solar radiation (W/m^2)

The Engineering Recommendations is based on probabilistic ratings and ensure the overhead lines operating at the maximum current loading will operate below the maximum design temperature except for short excursions in extreme environmental conditions. The actual operating temperature of a conductor varies considerably depending on the external environmental factors and the current (A) flowing through the line.

Previous innovation projects have shown that overhead line ratings can be dynamically increased when the environmental conditions allow, i.e. during cold, windy conditions perpendicular to the Line. Dynamic Line Ratings projects previously, at the time of the bid, have shown how fixed weather stations can measure wind speed, wind direction and temperature accurately to accurately to achieve large increases in an overhead lines capacity. However weather stations were shown to be unreliable at times and whilst the OHL rating is often the first limit on a circuits capacity, other assets cannot be dynamically rated prevent and significant increases in capacity.

6.2 Low Carbon Hub – Dynamic Line Ratings

The Low Carbon Hub built on the work of the Skegness 132kV Registered Power Zone (RPZ) which delivered cheaper connections to offshore wind farms, giving Western Power Distribution Policy for 132kV tower lines. The LCH has developed a method of dynamically rated 33kV overhead lines within the NMS, calculating new maximum operating limits based on real time electrical output from Wind Farms instead of using multiple weather stations.

The method converts the Electrical Output from multiple turbines into the wind speed at the nacelle height using turbine manufacturer's data, estimates the wind speed at the overhead line height using the wind power law, and incorporates the wind speed data into the Dynamic Line rating algorithm to better estimate the actual maximum circuit rating making best use of all the available information.

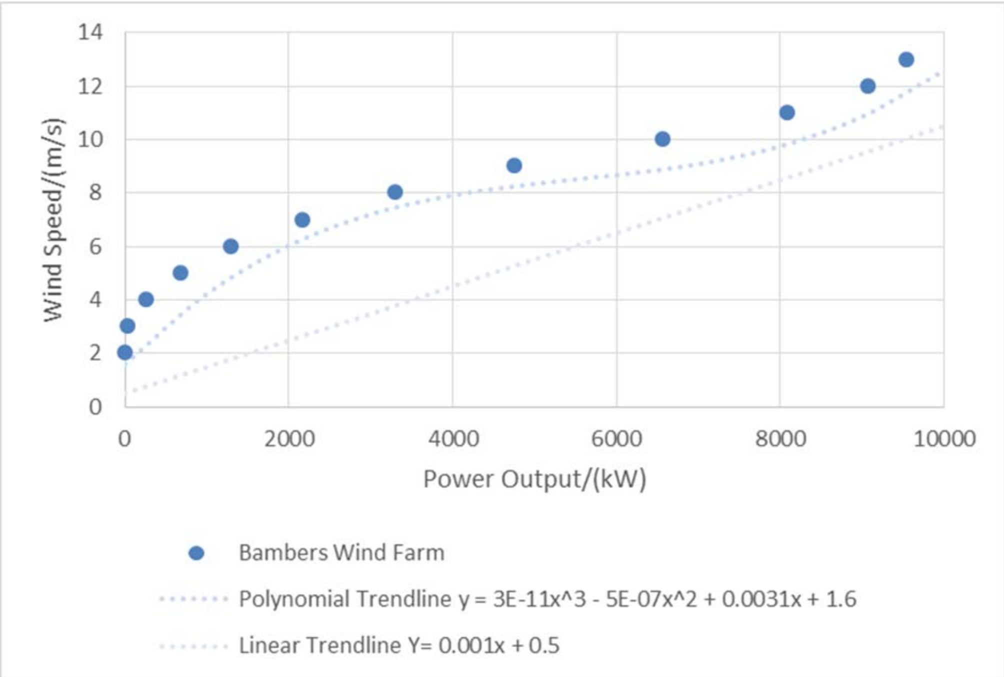


Figure 18 – Algorithm to calculate wind speed from electrical output

6.3 Knowledge Generated

Area	Knowledge generated
Design	In most rural networks, the overhead line rating is often the limiting factor when assessing the capacity of a circuit. The Low Carbon Hub project has shown that using dynamic line ratings, it is possible to dynamically calculate and increase the rating of the Overhead line where the wind speed is high and the ambient temperature is low. However there are a number of assets in a circuit such as cables, circuit breakers, disconnectors and current transformers which cannot be dynamically rated based on weather conditions, their ratings are fixed. In

	East Lincolnshire, the 33kV OHL's can typically be dynamically rated up to 113% of the static rating before the OHL is no longer the limiting component. Operating the circuit above the rating of the cables, disconnectors and current transformers could lead to premature aging and asset failure.
Design	LCH Dynamic ratings are based on enhancement the existing static ratings using the P27 fixed temperature data and calculating the wind speed data using a number of safety factors including a pessimistic direction. Whilst it is possible to measure weather conditions accurately, by installing weather stations to maximise the rating of the OHL, the large increases are not required as the circuits are also limited by the fixed asset ratings of cable sections, current transformers and circuit breaker ratings and often the statutory voltage limitations prevent the full asset ratings from being reached. This project has shown that the use of wind farm data could facilitate the modest increases in capacity available due to the other fixed asset ratings. The project has also shown that where the fixed asset ratings are not the limiting factor, wind farm data could be used in conjunction with weather stations and/or Met Office data to make the use of dynamic line ratings technique more flexible, reliable and reduce the potential points of failure in DLR techniques.
Design	At 33kV safety factors are required to account for how the line is sheltered and how this could change in the future. Sheltering can change over a relatively short period of time as both natural and manmade structures evolve. A line survey of the feeders being dynamically rated identified a new industrial building had recently been erected very close to an overhead line, this caused the line to have to be diverted due to horizontal statutory clearance issues. Even with the relocated OHL, the building still has a sheltering effect on the OHL.
Build & Operation	The algorithm was scripted within WPD's NMS and displayed as an analogue value alongside the relevant overhead circuits. The circuits have not been operating within the dynamic capacity as the current generation does not exceed the static ratings.
Commercial	There is an opportunities to incorporate the dynamic line ratings within the ANM scheme if the thermal ratings of the circuits become a constraining factor. The current accepted generation does not have any 33kV thermal constraints that can be solved with Dynamic Line Ratings.
Commercial	Dynamic Line ratings using Wind Farm data will be used most where clusters of wind farms occur close to the grid substation or when a network is being run abnormally.

6.4 Dynamic Line Rating- Potential for replication

The current generation connections show at the time of writing the report, Dynamic Line Ratings are not required in East Lincolnshire due to the locations of current and proposed Distributed Generation.

Dynamic line ratings are most likely to be replicated in rural locations where high levels of generation are causing thermal constraints. Dynamic Line Ratings can be used to increase the capacity of the line under certain conditions, however the risk and consequence of sheltering must be considered on a circuit by circuit basis.

The greatest potential for replication will be combining the electrical output from wind farms with either met office data or weather stations to calculate the dynamic rating of a line. This method is most suited to either Active Network Management areas with high levels of wind generation.

7 Overview of the Active Voltage Control method

Dynamic voltage control – Building on the principles of an existing Innovation Funding Incentive (IFI) project, Dynamic Ratings, the 33kV target voltage has been actively varied. This was done dynamically based on real time measurements of demand and generation. Dynamic voltage control increases network utilisation whilst maintaining the system voltage within the statutory limits.

7.1 Background to voltage control at Grid substations

A typical UK Grid substation arrangement will have two Grid transformers, stepping the voltage down from 132kV to a nominal 33kV, supplying a number of the primary substations where the voltage is further stepped down to a nominal 11kV. Each Grid and Primary transformer has an Automatic Voltage Control (AVC) relays at the substation which autonomously corrects for circulating current and controls the network voltage within its defined limits.

The 33kV and 11kV network voltage profiles are controlled by AVC relays with static set point voltages. These voltage set points are derived by network analysis for the creditable worst case network scenario, i.e. configuring the network for maximum voltage drop across the overhead lines, cables and transformers with no contribution from intermittent embedded generation.

7.1.1 Low Carbon Hub – Dynamic Voltage Control

The Dynamic Voltage Control scheme has demonstrated the concept of optimising AVC voltage set points in real time. The method is more effectively utilising the available analogue network data, created an algorithm to calculate a more optimal set point and has modified the existing AVC hardware and communications so the Skegness AVC’s can accept new set points remotely.

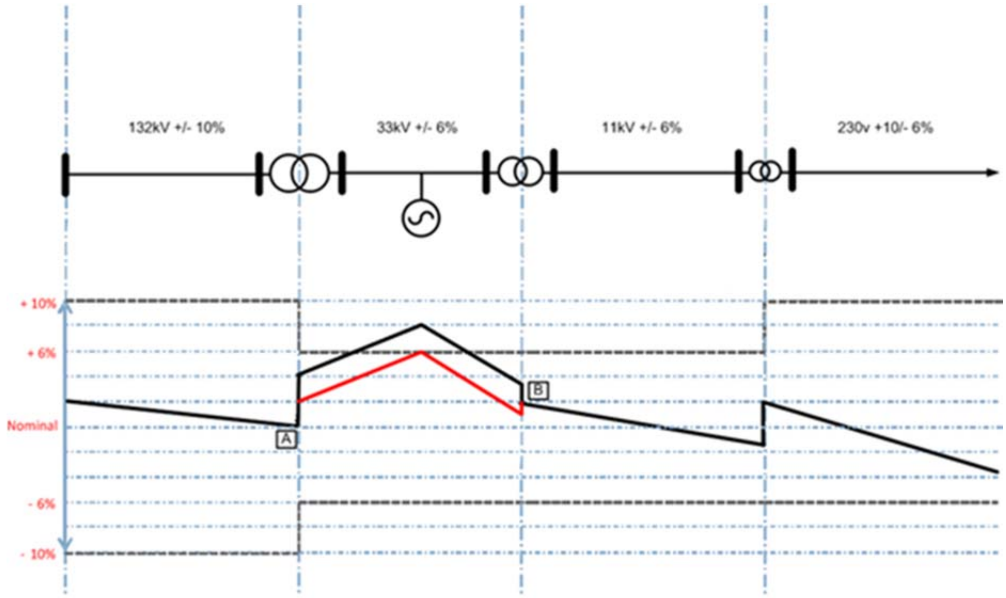


Figure 20 – showing simple network design with DVC

7.1.2 Better calculate voltages at key locations

As shown above, the majority of primary substations do not measure and recover the voltage on the primary side. It hasn't been a key requirement as most distribution networks are predominately supplying demand. However in networks where the generation can exceed the demand, without accurate voltage sensors at key points of the network, it is very difficult to further optimise the voltage profile across the networks whilst maintaining the statutory limits. Retrofitting new Voltage Transformers and associated equipment to an existing primary substation can often be relatively difficult and expensive.

At Horncastle Primary substation, the primary voltage is being derived using the 11kV Voltage Transformer, the measured Real Power (P) through the transformer, the measured Reactive Power (Q) through the transformer, the tap position and the physical characteristics of the transformer. The recovered data is used to calculate the primary network voltage.

7.1.3 Knowledge Generated

Area	Knowledge Generated
Design	The original design was for the AVC relay to calculate the primary network voltage as a Virtual Voltage Transformer (VVT); however limitations with the processing power of the current SuperTAPP n+ AVC meant an alternative solution was required. The planed upgrade of the SuperTAPP n+ AVC is released later in 2015 will have this functionality allowing the data will be presented to the RTU as an analogue signal.
Design	The VVT data has been hosted on Fundamentals system called iHost to prove the concept After testing, the VVT will be transferred onto WPD's iHost server.
Build	The installation of VVT can now be built into an existing standard SuperTAPP

	n+ scheme for approximately £4,000. The associated cost of installed a fixed outdoor VT is approximately £40k, although this varies at each location. This includes the purchase and installation of the 33kV VT, structure, plinth and multicores back to the RTU.
Operation	The Virtual VT through the iHost system has allowed primary system design to better understand how the primary network is operating in areas where transducers have not been available. This has confirmed the voltage profiles corresponds to the nodal analysis models and has been used to optimise the existing fixed AVC settings at Sleaford as well as Skegness.
Commercial	The data associated with the VVT is approximately 4MB per day being transmitted using GPRS. In the future the VVT data could be backhauled through the SCADA network.

7.2 Creation of an Algorithm and integration into software

Fundamentals Ltd have created an Algorithm which check the network configuration / running arrangement and voltage profiles at key locations in the a network. If appropriate, the algorithm has been designed to optimise the voltage in two ways. It can either calculate a more appropriate target voltage setting, sending the analogue set points it over WPD's SCADA network to the AVC relays at Skegness or it can determine if the AVC scheme should switch between standard and alternative settings.

7.2.1 Knowledge Generated

<table>
<tr><th>Area</th><th>Knowledge Generated</th></tr>
<tr><td>Design</td><td>Dynamic Voltage Control could either analyse additional information locally at the grid substation or centrally within the Network Management System. Both have advantages and disadvantages. As part of the Low Caron Hub design, both methods were evaluates with the Centralised Control option being progressed.

<table>
<tr><td>Local Control</td><td>Centralised control</td></tr>
<tr><td>✓ Local Control avoids the high level of information to be backhauled to a central location.</td><td>✗ Requires high levels of data to be backhauled to a central location. Recognising both GPRS and existing UHF radio links is not an ideal solution.</td></tr>
<tr><td>✗ High cost additional communications links would be required to enable the communications to all locations,</td><td>✓ Can utilise existing communications links or low cost communications links to be utilised</td></tr>
<tr><td>✗ Additional intelligence would need to be installed in the Grid substation,</td><td>✓ Allows existing Network Management Systems (NMS) to be utilised to understand</td></tr>
</table>
</td></tr>
</table>

		when the network is operating abnormally	
	✗ *The ability to understand when the network is operating abnormally is very difficult, requiring all switches and breakers to have status indication to be retrofitted with communications linking to the Grid substation intelligence.*		
	Or		
	✓ *This requires the solution to be switched off when the network is operating abnormally.*		
	✓ *Avoids the high level of information to be backhauled to a central location.*		
Design	There is a requirement to understand if each voltage measurement points are being influenced by the AVC being optimised. If the system is not aware if the network is operating abnormally, there is a possibility that abnormal network configuration the voltage optimisation takes into account unrelated information and incorrectly calculate the target voltage settings.		
Design	The algorithm has been configured to turn off in the event the network is working abnormally or if the communications is not available, the relay defaults to the nominal settings to ensure the voltage will stay within statutory limits if the outage is prolonged.		
Design	The DVC has been designed to maintain statutory limits after credible n-1 scenarios, taking into account and calculating the voltage profiles after a fault when calculating and setting a more optimal voltage profile.		
Design	The DVC has been designed and configured to optimise the voltage no more than twice a day. This will allow the voltage profile to optimise for long term steady state power flows rather than short term transients in load or generation.		
Build	The way the algorithm interrogates non tele controlled isolators has been modified, allowing the open or closed state to be shown within WPD's NMS to ensure the Algorithm can detect if the network is operating abnormally.		
Build	The scripting of the algorithm has been carried out by WPD's staff as they have the detailed knowledge of how WPD's NMS is configured and interfaces with AVC's. It would have been very difficult for an independent company without significant NMS experience to carry out the final centralised scripting.		
Operation	Due to the significant change to the control of the AVC Hardware, the algorithm has been tested with bench equipment for several months before		

	to test how the algorithm interfaces with the modified hardware. This has been essential to de bug performance issues.
Operation	The algorithm can operate in the test server taking live information and the decisions it would take analysed, further de risking the operation of the network until the algorithm can be shown to be predictable and stable.
Commercial	This technique has been designed to operate independently with the ANM scheme installed at Skegness. If the DVC is operating with a more optimal voltage target, the voltage headroom across the network will be increased, reducing the impact of generation being constrained for voltage issues. If the DVC is not operational or cannot optimise the voltage profile based on abnormal operation or the voltage profiles across the network do not allow the voltage target to be amended, if any voltage violations are seen, the ANM scheme will constrain generation to reduce the effect on the network.
Design	The full AVC functionality can still be maintained at Skegness by the control engineer, including tap lock 3% and 6% voltage reduction.
Design	When the NMS issues a command over SCADA such as tap lock or voltage reduction, the NMS can only issue one instruction at a time. For existing hardwired schemes when this instruction is issued it is applied to both AVC's at Skegness.

7.3 Hardware modifications to allow remote set points

Like most AVC relays, at Skegness Grid substation, they operate autonomously, sending digital and analogue outputs to the Network Management Software. Through the NMS a Control engineer also has some basic control functions over SCADA such as locking the tap changer, manually tapping the transformer, and applying a 3% or 6% reduction in the target voltage.

As part of the Low Carbon Hub, all existing functionality has been transferred from Hardwired communications to DNP3 and further functionality such as applying new analogue target voltages manually or automatically. The project installed a new D400 RTU from G.E to allow the DNP3 functionality.

7.3.1 Knowledge Generated

Area	**Knowledge Generated**
Design	Skegness has two AVC schemes per transformer – as part of a previous innovation project. Due to the more complex AVC arrangement, There has been a requirement to keep detailed description of the trial with associated drawings; this is especially required for an innovation project as the installation is non-standard. Work has also considered a plan for the next stage, adopting the solution if successful or decommissioning if not successful.
Design & Operation	Due to the significant change to the control of the AVC Hardware, a relay was bench tested with DNP3 control through a D400 RTU for several months to show how the hardware interfaced with the NMS and the DVC Algorithm. This has been essential to de bug performance issues.

Design	There has been a reluctance to transfer away from hardwired control to DNP3. Hardwired controls are very established, well understood and easy for the local engineers to test and debug issues between the RTU and the AVC relays. However Hardwired communications is expensive to install and will limit the control and future functionality of the relay. There is a requirement for a number of design decisions to be made when incorporating Dynamic Voltage Control at a substation, including what should happen when the scheme is turned from Remote to Local control. Should the algorithm in the NMS be turned off before the AVC scheme is transferred to Local Control, should the AVC retain the dynamic target voltage, should the AVC switch back to the default target voltage.
Design and Operation	As detailed above, the NMS can only issue one command at a time over SCADA, two commands cannot be issued at the same time. A tap lock or voltage reduction instruction must be sent and carried out by both AVC relays at the same time. To operate with DNP3, A further algorithm is required within the Envoy or the SuperTAPP n+ relay so the DVC can be applied to both transformers at the same time.
Operation	The transfer away from hardwired communications will requires a different diagnostic team to respond to site in the event of a potential relay or communications fault. This will see the communications team operating closer to the protection relays or additional training for the project engineers.

7.4 Dynamic Voltage Control - Potential for replication

This technique has shown there are substantial opportunities to optimise target voltage settings by using an Algorithm to review the voltage profiles and power flows across the network. The technique has the highest potential for replication in locations where there is a significant difference between maximum and minimum demands, where there are different demand profiles across the network, when the feeders are of a similar length or have similar voltage profiles and large levels of intermittent generation connected.

The solution requires further work to find a solution that will unlock capacity for non-firm generation connections. This will require DVC to optimise the network in the event the network is operating abnormally or if the communications are not available as to unlock DG capacity the relay cannot default to the nominal settings.

The solution demonstrated in the Low Carbon Hub could be incorporated into Active Network Management scheme areas. This method would unlock capacity when the DVC is operating by optimising the voltage profile and reducing the voltage constraints. When the DVC is not operating due to Abnormal network operation or communications outages, the ANM scheme will ensure that the network remains within the statutory limits by curtailing Alternative Generation in the event the network would operate outside of the statutory limits.
The use of DNP3 for AVC control is still requires longer term testing before being considered for rollout.

8 Overview of the FACTs methods

Flexible AC Transmission System (FACT) Device –A Flexible AC Transmission system device will enable us to control both network voltage and system harmonics of the active ring. This equipment is not normally deployed on Distribution networks for this purpose. Shunt compensation will be used to generate or absorb reactive power. These highly technical solutions have been designed to increase the amount of distributed generation that can be connected.

8.1 Introduction to voltage regulation Problem

As detailed above in the Dynamic Voltage Control sections, both 11kV and 33kV the networks have been designed where the voltage is regulated at the Grid and Primary substations. The network impedance, connection of demand and generation are all managed to ensure that the voltage profiles across all feeders remain within statutory limits. Maintaining the voltage profiles within the statutory limits becomes more of an issue when network feeders have relatively high impedance and trying to support large demands or generation connected.

The use of a FACTs device is being demonstrated as an alternative to traditional network reinforcement where both steady state voltage profiles and step changes in voltage is a problem.

Using this methodology, new demand or generation connections to relatively week networks require the existing circuits to be rebuilt with a lower impedance conductor or new large capacity circuits to be installed at locations where the effect will be reduced.

As part of the Low Carbon Hub, it has created an active network with multiple in feeds from generation, the high degree of variability (both in terms of demand and generation) can result in unwanted voltage fluctuations which the traditional voltage control of a On Load Tap Changer (OLTC) is not best suited to correct due to their slow operation.

8.2 Low Carbon Hub – DStatcom

As identified at the bid stage, Flexible AC Transmission (FACTs) system comprises of a family of technologies which can be used to rectify a number of issues automatically. The project reviewed the most appropriate device and size in the FACTs family, working with TNEI it was confirmed that a Shunt Thyristor valve or Voltage Source Converter device would best regulate the steady state and transient network voltages. The technical report covering the FACTs device was published 30th July 2014 and is available on the project website www.westernpowerinnovation.co.uk website in the documents section.

WPD issued an ITT (Invitation to Tender) for a Shunt connected device required to meet the functional specification EE/200 – 36kV Static Synchronous Compensator for the Lincolnshire Low Carbon Hub. The tender received 4 responses, the S&C 3.75MVAr DStatcom was procured as the most advantageous economical tender.

The DStatcom was connected in parallel with the electricity network at Trusthorpe to operate as a controllable current source (an arrangement often referred to as 'shunt compensation'). This allows reactive power to be generated or absorbed by altering the capacitance or inductance and is a means of controlling power factor or network voltage. The solution will be designed in such a way to maximise the amount of generation that can be connected.

Figure 21 - DStatcom at Trusthorpe primary substation

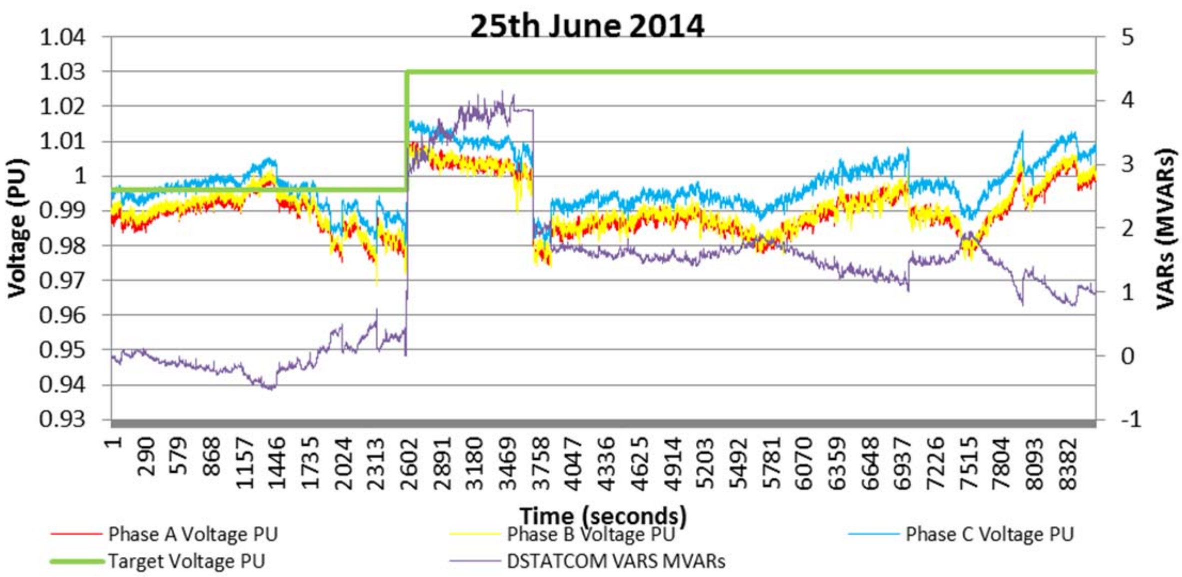
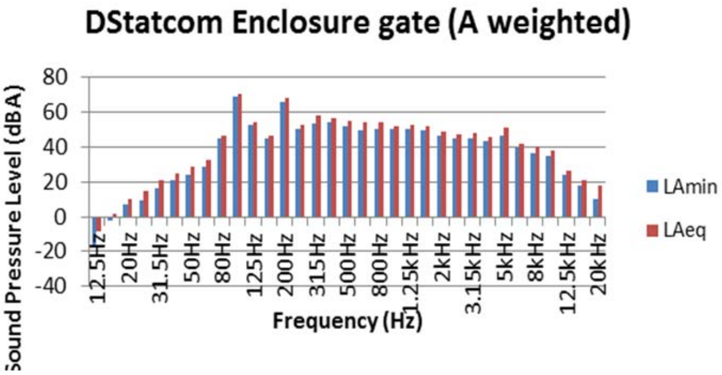
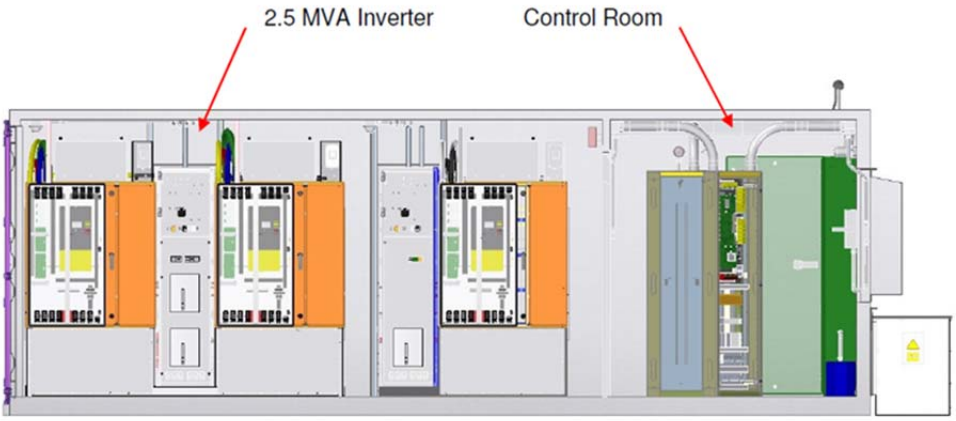
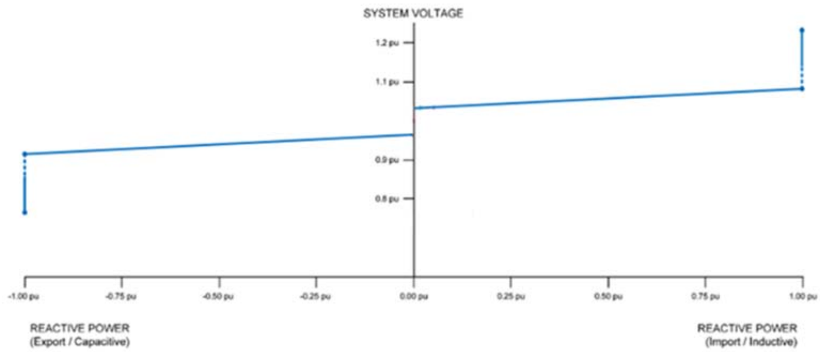


Figure 22 - DStatcom performance

8.3 Knowledge Generated

Area	Knowledge Generated
Design	The DStatcom being a high value asset sensitive to flood water damage and Trusthorpe being in a flood zone required the device to be elevated by 800mm to ensure if a flood occurred the device would not be affected.
Build	Integration of new technology such as the DStatcom has required WPD to be make amendments to other areas of the business such as the use of alternative RTU's to handle 32 bit analogue DNP3 signals.
Operation	There was a number of difficulties experiences during the design and build stages surrounding delivery of drawings and response to technical queries. To overcome this issue it is recommended that the design and build occurs earlier in any future project to reduce the dependencies. It is also recommended a future contract would stipulate earlier receipt of drawings and diagrams linked to financial payments. This may have overcome the issues encountered on the Low Carbon Hub.
Commercial	DNO substations are often in relatively close proximity to customers, as such DNOs have worked with manufacturers over many years to minimise the audible noise produced from equipment such as transformers. The DStatcom is often installed in areas much further from customers; where the noise has attenuation and is not an issue.
Operation	The WPD DStatcom complies WPD's noise policies, however unless additional noise mitigations are put in place - the audible noise generated by the DStatcom installed in Trusthorpe is likely to limit their use in substations in close proximity to customers. The additional noise generated by the DStatcom is both around the 150Hz, generated by fan the cooling fans, and at the 5kHz generated by the power electronics. The higher frequency noise is very noticeable close to the device but attenuates before the boundary of the substation. The 150Hz noise generated by the cooling fans will be the limiting the installation of these devices within close proximity of customers.  Figure 23 - Noise performance whilst at 100% electrical output

	S&C have explored with an expert what passive noise attenuation filters could be installed to reduce the noise within the container. It has been estimated that the noise could be reduced by approximately 10dB.
	The impedance characteristics of the DStatcom transformer used to couple the LV device to the 33kV network was a special design and manufactured to very tight tolerance. This ensures that the DStatcom has the required reactive power capacity at the required network voltage. WPD would only consider purchasing both the DStatcom and the associate transformer together, with the contract specifying the required reactive power performance at the point of common coupling.
	A DStatcom is very effective at boosting voltage during network outages to maintain statutory limits during periods of low generation if installed on a relatively weak network at the ends of feeders, relatively long electrical distances from the voltage controlling substation. • When the DStatcom is operating at 100% capacitive mode (exporting reactive power) the voltage is boosted by 3%. • When the DStatcom is operating at 100% reactive mode (importing reactive power) the voltage is reduced by 5%. • The DStatcom can operate at 263% of the nominal output (3.75MVAr) for two seconds in the event of a network disturbance.
	DStatcom have predominately been designed around the incorporation into large wind farms. In their containerised form the DStatcom is substantially smaller and lighter than many other assets being installed on the site, meaning access and lifting is rarely going to be an issue. In a UK substation the DStatcom is likely to be the largest and heaviest piece of equipment that needs to be lifted in a primary substation. Access to some of the most rural sites may require different solution to be progressed to overcome difficulties for delivery and installation of the DSTATCOM & associated Transformer
	The DStatcom is a relatively complex item that will likely require long term service plans and access to spare parts. This is unlikely to be a function a DNO could perform themselves.
	The DStatcom purchased was designed and built in America; it has been designed to different design standards then the UK. A refit of the control room has been arranged to make better use of the space and rectify an issue identified at the Factory Acceptance Test (FAT).

	 Figure 24 – DStatcom enclosure
	The use of a Voltage control mode with a dead band would allow the DStatcom to regulate the voltage only when it exceeds pre-defined limits, reducing the running time of the power electronics and regulating the network voltage only when it approached the statutory limits. This mode would also reduce network losses. An example of a voltage control mode with a dead band is shown in figure 25.  Figure 25 – DStatcom PV mode with a dead band

8.4 FACTS - Potential for replication

8.4.1 Areas to replicate

There is a significant opportunity to replicate the DStatcom installing in locations where either steads state or transient voltage control is an issue. WPD have supported Scottish Power and shared learning to help them assess where DStatcom could be used to solve network issues.

When using a Statcom for voltage control, the device will be much more effective in weaker network locations, the further electrically from the transformers controlling the network voltage the greater the effect the Statcom will have.

The design of Statcoms will need to evolve to make them more suitable for inclusion into a DNO substation, especially when there are being installed in close proximity to customers and audible noise could be an issue.

In the future it is likely that the DStatcom could be used for a number of purposes at different times, including voltage stability, reducing network losses and controlling the flow or reactive power between the DNO and TNO, helping the DNO to comply with the new ENTSO-e regulations.

8.4.2 Areas that require further work

Software tools to configure Voltage Target & Slope settings - The installation of a DStatcom requires the operator to understand how the voltage profiles changes over a range of different demand and generation sensitivities to appropriately configure the target voltage setting and slope settings. A software tool, such as the constraints analysis tool using historic demand and generation data may be required to support the configuration of devices such as a DStatcom.

9 Conclusion

The Low Carbon Hub has answered all the key questions identified at the bid stage and resulted in significant new learning for GB DNOs. The project has identified where and how the techniques could be applied to unlock capacity for future generation connections and where further work is required. The project will result in a number of innovative techniques that can be replicated by WPD and other DNOs to aid the quicker and more cost effective connection of new generation to the network.

9.1 Learning for future projects

Aspects we would repeat

- Designing and delivering innovative solutions alongside the main business teams has resulted in a better project with an improved level of engagement from the rest of the business,
- Where applicable, WPD will continue to quickly roll out solutions developed through innovations projects for use across the network, and
- WPD will continue to design and deliver ambitious innovation projects to generate the required learning for roll out of innovative solutions.

Aspects we would do differently

- When designing future bids, a more detailed design would be completed ahead of a bid submission or an increased level of contingency would be included so the project had the required funds and time to deliver the project, and
- Future innovation projects would not aim to deliver as many methods / techniques in the same area, at the same time.

9.2 Summary of key LCH learning

1. Active Network Management will be replicated and rolled out in areas where distribution network voltage and thermal constraints limit the connection of future Distributed Generation. Most other DNOs have included Active Network Management in their innovation plan,
2. A constraint analysis software package that is suitable for rolling out and adoption by planning teams need to be developed, taking the lessons learnt already learnt from the LCH demonstration. The Low Carbon Hub tool has proven the concept and that any future constraint analysis software will have a trade-off between the accuracy of the results and performance,
3. The project has shown the 33kV active ring method is less appropriate for roll-out due to the high costs and effort associated with delivery. It is expected that in simple meshing scenarios could be achieved by adapting the existing network and for more complex meshing scenarios, an offline rebuild would be most appropriate solution. Further work is required to understand when it is appropriate to mesh simple 33kV sections,
4. Certain assets, such as 33kV OHLs in ANM areas, should be enhanced ahead of need where there is a clear indication the functionality will be utilised in the future,

5. Dynamic line ratings are less suitable for 33kV and 11kV networks due to the lower height of the conductors and the risks associated with sheltering,
6. Dynamic Voltage Control requires future work before it will be ready for wider area deployment without Active Network Management. The Low Carbon Hub has proven the concept and how it could be incorporated into an ANM enabled area,
7. Statcoms will increasingly be used in key distribution locations to improve voltage control and to facilitate further generation connections, and
8. A range of suitable communication solutions continues to be a barrier to wide scale rollout of innovation projects.

Documents such as policies mentioned in this report are available on the project website www.westernpowerinnovation.co.uk or by request through WPDinnovation@westernpower.co.uk.