The Voice of the Networks

Energy Networks Association

Open Networks Project

Curtailment Process and ANM Reliability Good Practice Guide

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Executive Summary

This Good Practice Guide considers both the methodology of how Distribution Network Operator's (DNO) should consider curtailment for Flexible Connections and which metrics should be considered while assessing installed Active Network Management (ANM) systems.

The information presented in this guide has been collected from parties involved in the Open Networks project through a set of questionnaires in WS1 P7 and WS2 P7, as well as a follow up workshop. This document was subsequently circulated for review to the respondents and attendees of above.

In general terms the DNOs current approaches can be categorised into three methodologies: the DIY assessment, the DNO curtailment assessment and the curtailment index. Most DNOs approach's already use half hourly based curtailment assessments so it was easy to assign this concept as Good Practice. The DNOs do have a variation on how and when the curtailment assessments are processed so we have documented a set of key assumptions that need to be stipulated. The purpose of this is to ensure that the curtailment assessments can be compared between DNOs by customers more easily. These assumptions are outlined in this document. It should be noted that the presentation of this data in the curtailment assessment is being captured in WS2 P7 and therefore has not been presented here.

Several DNOs have experience on running ANM systems and it is not always clear why an ANM system has responded in a certain way. This information should be interpreted in a consistent way by the DNO and then presented consistently to the customer. This is important to aid the comparison between differing system architecture and the facilitation of identifying component parts that are not operating well. It would also act as a basis to present a more granular breakdown of the performance to key stakeholders. This document presents the key performance criteria that should be considered.

1 DNO's current Approach

To understand the current approach, each DNO undertook to answer two questionnaires under WS1 P7 and WS2 P7. These questionnaires were used to inform the discussion at the subsequent workshop. The section below summarises the responses from both the questionnaire and discussions.

1.1 Electricity North West Limited

1.1.1 General process

Electricity North West offers managed connections to both existing and new customers for both demand and generation. Currently there are a small number of actively controlled customer connections predominantly made up of customers groups identified as part of the capacity to customers (C_2C) innovation project which has now been developed into a business as usual process. The C_2C project successfully proved that our industrial and commercial customers are willing to sign up to this kind of demand side response contract which rewards customers for being flexible with their demand for electricity and which can help us manage the network by releasing capacity in order to help manage the network during periods of system abnormality. This has now been successfully integrated into our business as usual processes, known as 'managed connections'; from 1 July 2016 all generators above 200kW applying for a new connection with Electricity North West are offered a managed connection.

Electricity North West also offers actively managed flexible connections to customers, however so far there has been limited need to offer actively managed flexible connections to customers within the Electricity North West network. Currently there are no actively managed zones within Electricity North West. The company are in the process of developing a full system wide control system at which point all zones will have a capability of being actively controlled. Whilst this centralised system is being developed any requirements for active network management will be resolved by establishing local active network managed regions, where required.

1.1.2 Pre-application publicly available information

Electricity North West has a series of constraint heat maps available to customers which indicate both thermal and fault level headroom at 33kV and 11kV. There is also information provided for network topology, demand and generation loading data, and network development proposals held within the Long Term Development Statement (LTDS).

To date there has been limited requirements for utilising flexible connections options within the Electricity North West network as there have been low numbers of identified network constraints that these services could address. Electricity North West is currently in the process of updating published information relating to flexible connections options.

Electricity North West connection teams endeavour to discuss with customers their individual requirements and identify the optimal connection option utilising all available connections options they have at their disposal.

The company is also currently in the process of updating and improving the way capacity heat maps are presented to stakeholders including information relating to DER levels.

1.1.3 Curtailment estimates during application

As of 4 December 2017, all Distributed Generation (DG) connection offers greater than 200kW, and non-firm demand connections greater than 200kW are provided with a curtailment index within their quotation. Electricity North West considers scenarios when the system is abnormal and unavailable, for instance during faults, construction and maintenance outages to determine the curtailment index.

Electricity North West publishes a curtailment index per voltage level. When a customer connects the company monitors the actual curtailment experienced by the customer, and if this level approaches or exceeds the index it will investigate and potentially seek to intervene.

A revised view of curtailment may be provided in the Connection Agreement where extended periods of time between quotation and energisation occur.

1.1.4 Post connection data

Customers with a curtailment index will receive an annual review letter, which will provide the curtailment experienced, looking back over the year. The ‘actual’ curtailment is calculated based on a six year rolling average.

At times of abnormal distribution system configuration generation export may need to be constrained at the instruction of the Electricity North West Control Centre. Where periods of constraint are identified for planned work Electricity North West will, so far as is reasonably practicable, provide as much notice of the restrictions as we are able. For unplanned events Electricity North West will use reasonable endeavours to request the generation be run down in a controlled manner, but reserve the right, depending upon system conditions prevailing on either Electricity North West or NGET’s network at the time, to undertake the constraint of the generation without notice.

1.1.5 Methodology to evaluate ANM system reliability

Currently there are no active network management systems in operation within ENWL’s network so no metrics are currently in operation for the monitoring of system reliability.

1.2 Northern Powergrid

1.2.1 General process

Northern Powergrid (NPg) has actively managed “flexible” connections in the following areas: Blyth B grid supply point (Northumberland); Driffield supply point (East Riding of Yorkshire) and Seal Sands supply point (Teeside). There are approximately 15 customers with this type of contract which manage capacity restrictions both system intact and under outage conditions. Only the Driffield scheme is open to new entrants.

Northern Powergrid publishes information on flexible connections in the FAQ section of its website, which includes an explanation of the types of flexible connections offered, the benefits and key contacts within Northern Powergrid.

As part of its flexible connections offerings Northern Powergrid provides information regarding queue position in the last in first out stack, other fuel types in the stack above the potential new connectee and capacity above the new connectee. It also provide details of the actual constraints whether they are thermal, reverse power and / or voltage constraints and any likely outages that may lead to a significant increase in curtailment. During our stakeholder engagement session customers have told Northern Power that they want an indication of the extent of curtailment that they are likely to encounter, and Northern Powergrid now provides this as part of the connection offer on the understanding that customers are responsible for undertaking their own due diligence to ascertain the financial viability of their project.

1.2.2 Pre-application publicly available information

Northern Powergrid's heat maps available on its website include a field identifying whether a substation is in an ANM area. Northern Powergrid are currently minded to extend the current Driffield ANM scheme to cover Hull and the East Riding of Yorkshire and are considering new ANM schemes at Saltend, Keadby and Grimsby West grid supply points, but these will all be dependent upon level of interest and acceptance of ANM offers. Again, an indication of the types of constraints that are to be managed by any new schemes will be published.

Northern Powergrid publishes some limited information regarding DER via its website heat maps, but does not publish any general information on fault rates, although may provide more specific failure rate information / potential future outage information upon request.

1.2.3 Curtailment estimates during application

For a customer connecting to an ANM area, if requested, Northern Powergrid provides historical half hourly network loading data on the key assets that are potentially constrained. Some customers also use the company's network modelling data (which is included in the LTDS) to build their own loadflow model.

Northern Powergrid provides a curtailment estimate with its ANM connection offer, which generally uses a loadflow model and typically a year's worth of historical loading data, coupled with either a profile from the customer or an estimated profile from Northern Powergrid amongst other inputs to inform the potential level of curtailment. The curtailment estimate generally follows the guidance provided by the ENA. Whilst loss of communications infrastructure will have implications for the level of curtailment it does not influence the curtailment estimate, rather this is discussed in a more general manner.

Northern Powergrid commercial engineers will explain the two potential options of either a standard connection offer or ANM offer, explain how ANM works and provide a budget estimate of the costs associated with a standard offer and an ANM offer so the customer can make a decision on which offer to pursue. If an ANM offer is required, Northern Powergrid will collate all the network data required by its external 3rd party support who will then to produce a curtailment estimate.

The effort required in producing a curtailment estimate depends on whether it is a new scheme for the 1st customer or whether it is an additional entrant to an existing scheme. The former requires more resource for data gathering and for building the curtailment model, carrying out the analysis and producing an appropriate report for the customer. For additional entrants to an existing scheme, the majority of the model is already built, only requiring the addition of the new customer and the running of the load flow simulation to ascertain the level of curtailment for the curtailment report. Once a model is built it typically takes around 3 weeks to produce a curtailment report for a new scheme, for new entrants to an existing scheme this time is significantly reduced although actual timings are dependent, amongst other factors, upon the level of complexity and likely outage scenarios.

Curtailment assessment itself can either be a simple spreadsheet model for a straightforward constraint; otherwise this is a half hourly annual load flow based calculation using load flow simulators and associated scripts. The network model is built using data taken from Northern Powergrid's in-house modelling tools. Half hourly data from PI (Plant Interface, our data historian) is used in the model for any substation, circuit or transformer demands. Customer half hourly metering data may be used for any existing generation sites. The new customer output can either be based on any existing fuel type profile in the area or run using customers expected output. An annual half hourly assessment is then made applying any credible network outages to produce the curtailment assessment.

Disclaimers accompanying our curtailment estimates include, but are not limited to the following factors that may influence the actual level of curtailment:

- Demand growth or contraction
- Growth in unmanaged micro-generation connected at lower voltage levels
- Changes in network configuration
- Behind the meter changes to existing customer connections e.g. changes in capacity factor due to generator changes that utilise an existing connection agreement.

Northern Powergrid always recommends that the customer undertakes their own due diligence with regards the financial viability of their connection.

1.2.4 Post connection data

The Driffield ANM system has not yet been commissioned so the format of the planned annual curtailment report has not yet been finalised. Northern Powergrid has identified planned future works when requested by customers but does not currently have any processes to annually provide this sort of information.

1.2.5 Methodology to evaluate ANM system reliability

Northern Powergrid is currently in the process of deploying its first "off the shelf" ANM scheme at Driffield and will be developing its approach to reliability metrics shortly. Network/communication failures are monitored separately and not just for ANM. There will be a service contract in place with the 3rd party ANM service provider to provide information on scheme performance that will be shared with the ANM customers. Northern Powergrid anticipate that customer specific ANM performance reporting will be undertaken periodically and provided to each customer routinely.

1.3 Scottish and Southern Energy

1.3.1 General process

SSEN offer a range of Flexible Connections including Active Network Management to generation customers to alleviate generation constraints and allow new non-firm connections which actively curtail export capacity. Across 4 ANM systems now under Business As Usual (BAU) control, SSEN has over 30 ANM enabled connections within it's two licence areas. Traditionally these systems have been utilised wholly to manage generation within system intact scenarios, with full curtailment occurring in fault scenarios, however in early 2018 the first successful N-1 export scenario was successfully completed within the Orkney system and this functionality is now being rolled out across the remaining ANM zones.

Information on the flexible connections available within SSEN and the connections process are available on our website, including contact details for the Active Solutions team allowing customers to discuss specific projects prior to application. The connections process followings the NOM connections process, i.e. application, quotation, acceptance and delivery. Alongside the ANM quote letter SSEN provides the customer an assessment data letter which includes details such as queue position, location, half hourly demand data, size and technology of generation about the generator in the stack. Location of constraints and the thresholds set at these constraints.

Details can be found here; https://www.ssepd.co.uk/GenerationConnectionsHome/

1.3.2 Pre-application publicly available information

SSEN does not perform the curtailment assessment for the customer, electing to provide all the necessary data to enable this assessment to be completed by the customer or their nominated agent. This decision follows previous challenge on the accuracy of curtailment assessments issued by SSEN. SSEN acknowledges and accepts that this decision has resulted in some negative feedback from connecting customers who feel the curtailment assessment should be completed by the DNO, in response to this planning is underway to assess the ability to alter this process. Should SSEN adopt the curtailment assessment process it is expected there will be internal resource impacts or additional time requirements

SSEN currently issues the following data for curtailment assessments;

- SEPD/SHEPD Long Term Development Statement (LTDS)
- Generation Table for location/BSP/GSP
- Network Connection & Constraints for the GSP/BSP (which Generator would be connected to) and the location of currently connected Generation within that area (which would affect their connection)
- Demand Data for the location/BSP/GSP, Historic - 1 Year
- Measurement Point (MP) Settings
- Historic Outage Data for Constraints
- ANM Contracted Generation, LIFO Stack Positions
- Communications Availability Data (TSAT)
- Estimated G83 & sub 50kW Generation

Where a customer is connecting to an existing ANM system, SSEN provide the customer with historical communications availability i.e. 99.98. As part of the EGCA we are covered in terms of caveats and clauses around application of curtailment due to failsafe mechanisms.

1.3.3 Curtailment estimates during application

Detail on existing and planned ANM zones is available on our website, plans are underway to extend this information and present on our heat maps. Heat maps already include detail on the nature of constraints which appear on our networks and the current capacities, both demand and generation, which are available down to 33kV level. Breakdowns of generation types and levels are also available through the heatmaps although the level of detail adheres to GDPR and is therefore basic. ANM reliability and fault issues are released to affected customers at request, they are also logged for reporting, however this detail is not currently released publicly.

SSEN runs an internal report on curtailment levels across each scheme for internal analysis, these figures are available on a monthly rolling basis but are formally prepared on an annual basis. The reports consider all modes of curtailment, planned system function (issue of set-points), system failures, generator failures and maintenance outages. While SSEN do not present this to the customer all system failures are monitored, logged and investigated with learning applied to avoid repeat issue. Generation availability which includes loss of system related curtailment is calculated on a system and individual generator perspective and released both annually and upon request.

1.3.4 Post connection data

Maintenance or planned outage notifications are issued to customer's in-line with standard PSI processes, Transmission and Extra High Voltage (EHV) level outages are often notified up to a year in advance. In terms of recognising communications failures and defined network faults (affecting supplies in an un-planned manner) SSEN agree with the comments made by other DNOs but would add the following justification.

As an example, a Transmission outage which impacts ANM generation capacity (IOW Case Study) is entirely outside of ANM control - the generation is curtailed for a period, but the system is not 'fault', indeed it could be operating at 100% reliability while constraining generation within pre-programmed parameters. The same can be argued for Distribution outages (faults/planned works) however as far as the customer is concerned their generation is curtailed and its route cause is a Distribution Network issue. From a communications perspective we could break down faults again, having both customer communications link and general ANM system related communications faults. If a customer owned communications link fails and this results in their curtailment, would this be considered as a system reliability issue, or an issue outside of the system affecting curtailment of the generator.

1.3.5 Methodology to evaluate ANM system reliability

SSEN would recommend that ANM system reliability should factor two elements in the aid of providing customers with clear, accessible information. ANM System Reliability should focus on system operation with focus on issues which restrict the normal operational parameters of the ANM system, such as communications failures and unplanned network outages resultant of bad weather/damage to assets. In this scenario a ANM system with 100% reliability has suffered no communications failures for example but may have responded to normal operational parameters resulting in generation being curtailed 8% of the year. Alongside this, the standard reporting already offered by SSEN enables generators to view those scenarios where 'trim' or 'trip' signals have resulted in constrained or curtailed generation, why and for how long, to allow analysis on the commercial impact of those scenarios. In short, the 'reliability' of a system should be measured on that systems availability to perform the desired function, not how often that function is in operation within pre-programmed and agreed parameters.

1.4 SP Energy Networks

1.4.1 General process

In areas of our networks where it is not possible to connect further amounts of generation, or energy storage, without the risk of breaching network limits, SP Energy Networks (SPEN) offer actively managed "flexible" connections as a means to accommodate non-firm connections.

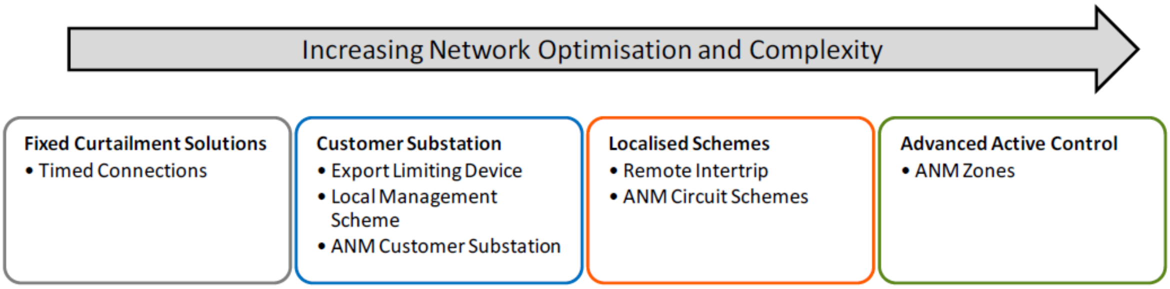
Following an application for connection from a User, DNOs must make an offer in accordance with Licence Condition 12 and Clause 16 of the Electricity Act 1989. To ensure equity, all Users may apply for a Firm connection to the network. This implies that the User will be able to access their Registered Capacity even during the outage of one distribution network component. Firm connections need alternative paths to the User's Connection Point and thus often have high cost and delivery time. Many Users therefore initially opt for a Non-Firm connection.

Where there are no network constraints (beyond the limited security of supply associated with the connection assets), a traditional Non-Firm connection offer can be made.

Where the network is constrained – either through specific localised constraints, or through multiple / distant constraints – Flexible Connection Solutions may be used to facilitate low cost timely connections. These Flexible Connections include a range of solutions including:

- Timed Capacity Connections;
- Export Limiting Devices;
- Local Management Schemes;
- Remote Intertrip Schemes; and
- Active Network Management (Zones, Circuits and Local Schemes).

The above techniques are arranged in order of increasing complexity (and network optimisation), although it is envisaged that, over time, much of the network will progress towards Flexible Connection zones involving ANM. In order to ensure equity, transparency and adequacy of information, Users are offered a Non-Firm connection with associated Principles Of Access. In areas where there are multiple or complex constraints affecting one or more customers, full Active Network Management systems may be implemented. These distributed control systems continually monitor the limits on the network and then allocate the maximum amount of capacity to customers in that area.



Flexible connections can be used to constrain capacity under System Intact conditions, or under First Circuit Outage Conditions as required and agreed within the Connection Agreement. To date, these have been limited to thermal and/or voltage constraints, however work is on-going to broaden the scope of network constraint management.

SPEN have 13 Projects / 143.48MW connected capacity to active network management schemes. In addition to this we have capacity connected on intertrips managing transmission constraints (9 projects / 200MW), other local management systems and export limiting devices.

1.4.2 Pre-application publicly available information

Our Flexible Connections and Principles of Access policy (ESDD-01-009) is publicly available. This outlines the process, covers the commercial principles and outlines the high-level technical arrangements and techniques used to achieve a range of Flexible Connection solutions.
https://www.spenergynetworks.co.uk/userfiles/file/ESDD-01-009.pdf

Where GSPs are already ANM enabled, or they are scheduled for ANM roll-out, this information along with the forecast year of roll-out is published:
https://www.spenergynetworks.co.uk/pages/distributed_generation.aspx

We will be deploying wide-area ANM in both Dumfries & Galloway and North Wales across 2019/20 with subsequent plans to roll-out across other GSPs. We provide reasonably detailed information about generation capacity opportunities though our interactive DG heatmaps. These give developers early indications of areas of the network which are approaching operational limits. Where GSPs are ANM enabled, this information is available through our heatmaps. In addition we provide information on our network and capacity availability through our annually published Long Term Development Statements (LTDS). Detailed information on the location and types of constraints is available upon request or as part of the formal offer process.

1.4.3 Curtailment estimates during application

All offers must enable prospective customers to understand the commercial proposition and the manner in which their connection will be managed. It is important that Applicants have both the technical and commercial information to forecast income projection and analyse their financial risk.

The ANM Flexible Connection Offer process is as follows:

- Initially, a Stage 1 Flexible Connection Offer will be issued. This high level offer outlines the ANM solution, and must be explicit on the Principles Of Access and detail those network conditions where capacity may temporarily be suspended, including whether these are System Intact constraints, or under FCO conditions. <u>This Stage 1 offer does not provide any estimate on likely levels of Curtailment.</u>

- Once an Applicant has accepted a Stage 1 Offer, detailed Curtailment Analysis can be undertaken, along with detailed design and specification of the ANM scheme and associated communications. The detailed designs form the basis of a Stage 2 Offer.
- The position in the LIFO Stack is governed by the Applicant's position in the Network Access Queue. Detailed Curtailment Analysis may be reassessed upon any changes to the Applicant's position in the LIFO Stack (this can happen if their connection is deemed to be stalled).

Constraint Analysis is of significant importance to the Applicant to be able to forecast MWh of output that the plant can expect to transit on an annualised basis. Once an Applicant has accepted a Stage 1 Offer, we complete full Curtailment Assessment for the customer and provide this in a standard template document used across SPEN. This provides information on:

- Forecast unconstrained MWh & capacity factor
- Forecast reduction of MWh and capacity factor based upon constraint impact.
- Max / Min / Average output
- Output and curtailment profiles

Constraint Analysis requires data to enable modelling of the technical characteristics of the network relevant to a constraint location and knowledge of the specified Principles Of Access to enable simulation of the level of Curtailment and/or network access that would be experienced by the Applicant.

To estimate the level of Curtailment, the analysis must consider:

- 17,520 hh/year (or 8,760 h/year) for a representative period (usually 24 months);
- profile assumptions relating to the Applicant's plant, agreed with the Applicant prior to Constraint Analysis being undertaken;
- the generation and Demand profiles of existing customers (historically measured where possible);
- profile data related to future plant (generic or historical output from similar plant may be used);
- the Principles Of Access for the particular Applicant, in particular the LIFO Stack;
- Curtailment quantification which should reflect the expected operation of the ANM scheme (this should reflect as closely as possible the operation of the ANM Curtailment Algorithms);
- the network operation which should reflect reality as closely as possible (for example, the model should include appropriate models for any AVC, load transfers, intertrips or special protection schemes or pertinent network responses);
- failure rates assumptions (which should be agreed and visible);
- planned outage schedules and network reinforcement plans (where these can be identified);

The complexities of the constraints, network, loading interactions and Principles of Access often dictate that the most appropriate method of undertaking these studies is through use of iterative load-flow analysis.

In some cases, developers may require some sensitivity impacts (for example, an agreed reduction in background Demand, or heavier than average generation profiles for entrants higher in the LIFO stack, or increased failure rates).

The following disclaimer is included within the curtailment report:

"This document has been prepared for the above named project or specified part thereof and should not be relied upon or used for any other project. We shall have no liability in the event that this document is used for any purpose other than that for which it was originally prepared. This document has been prepared for the sole and exclusive use of the party to whom it is addressed (the "Addressee"). Any other parties using any information contained in this document do so at their own risk and any duty of care to these parties is excluded.
To the extent that this report is based upon historical information and/or an assumed generation profile its validity is subject to changes out with the control of the Distributor, We make no

representation or warranty as to the accuracy or completeness of such information or accept any liability for any loss or damage suffered by the Addressee arising as a result of the Addressee's reliance on any such information supplied as part of this document."

1.4.4 Post connection data

Information is provided upon request. This contains the high level individual customer experience in terms of date, time off (duration) and event(s) which caused the fault. At present we do not provide any annual reporting of historical levels of curtailment activity, however we are developing a web based customer portal where the customer can log in to obtain detailed information on historical constraints.

We provide information to Stakeholders about works that could result in curtailment activity at various points throughout the year. This starts at the year ahead stage with Stakeholder Liaison Meetings where we let the Stakeholders know about Transmission or Distribution System outages, expected times and dates and high level details of the works. Where this is not possible, we provide information at the earliest opportunity. In addition we will contact the Stakeholders at several points prior to any works starting, up to the week ahead where we provide written notification of works that could impact them. We find that proactive communication is not only good customer service but equally reduces post event calls from customers.

1.4.5 Methodology to evaluate ANM system reliability

All ANM activity events are logged and can be reviewed when required. This includes both curtailment signals due to network capacity constraints, and actions taken due to comms failures.

A Stage 2 Flexible Connection Offer contains details of any communication (including the communications security level) and control requirements in sufficient detail to allow the Applicant to establish the level of risk associated with the loss of communications.

The Offer includes a clause limiting SPEN's liability for the consequences of loss of communication routes or devices. This outlines actions required to be undertaken in the event of communications failure. For example, a generator may be required to ramp down or tripped off.

1.5 UK Power Networks

1.5.1 General Process

UK Power Networks has got two live Active Network Management (ANM) systems, Norwich and March in EPN, hosting 200 MW of Flexible Distributed Generation (FDG) capacity with an additional 130 MW in the pipeline for Walpole. Over 20 generation sites have been connected to our distribution network through this connection offering, saving over £70m for the connectees in reinforcement costs. Following the success of Norwich, March and Walpole East Flexible Distributed Generation (FDG) zones. UK Power Networks can announce we are rolling out FDG connections in the South East of England. Flexible Distributed Generation – South East (FDG-SE) will incorporate the network in the Canterbury, Sellindge, Ninfield and Bolney Grid Supply Points (GSPs).

The FDG connections are managed against active constraints, most of the time under intact network condition, where a new FDG connections is in an area where there is already connected DG (FDG or non-FDG) and their combined export is such that it is above the network asset in intact conditions. Example overhead ringed circuits in rural parts of Eastern network.

The FDG schemes will be given annual energy curtailment estimates against the identified network constraints under a given Principle of Access. To date, UK Power Networks has used "Last-in, First-off" and "Prorata/Quota" as Principles of Access In addition, UK Power Networks provides the customer with a breakdown of energy curtailment per hourly period. These annual energy/time of curtailment estimates are aimed to provide customers with necessary information to evaluate their commercial investment cases.

UK Power Networks has also designed N-1 Logic Schemes for Norwich and March ANM systems. These N-1 Logic Schemes are activated during system maintenance, allowing the FDGs to operate under a new set of constraints and sensitivity factors managed by the ANM system.

1.5.2 Pre-application publicly available information

The FDG connection offering aims to provide a point of connection within the existing network without the need for/or ahead of reinforcement. The customer must be willing to accept temporary reduction to their export to ensure the network is kept within operational limits and the constraint is not breached.

In order to assist customers with their application, UK Power Networks have the following information is available in UKPN website:

- Curtailment Estimate Heatmaps for EPN: https://www.ukpowernetworks.co.uk/internet/en/our-services/documents/FDG_curtailment_heat_maps_v2.pdf

- Curtailment Estimates Heat maps for SPN: https://www.ukpowernetworks.co.uk/internet/en/our-services/documents/FDG_South_East_curtailment_heat_map(Jun-17).pdf

- Flexible Distributed Generation Zones: https://www.ukpowernetworks.co.uk/electricity/distribution-energy-resources/flexible-distributed-generation

- DG Mapping Tool - The DG map shows the approximate locations of our 33kV and 132kV overhead electricity network poles and towers. It also shows where our 11kV, 33kV and 132kV substations are approximately in the East of England and the South East. Please note the data provided is indicative only. Applicants will need to be registered with Companies House: https://www.ukpowernetworks.co.uk/internet/en/our-services/list-of-services/electricity-generation/find-out-where-our-overhead-network-is/

- General Information on alternative connections for DERs:

  https://www.ukpowernetworks.co.uk/electricity/distribution-energy-resources

Further DER information is available in various formats such as; LTDS, Contracted Connections Register, Regional Development Plans and alternative connection standards (ANM, Timed Connection and Inter-tripping) for each FDG zone.

1.5.3 Curtailment Estimates during Application

The ANM system deployed across UK Power Networks uses the escalating control actions philosophy. This is to ensure curtailment of FDGs are minimised whilst keeping the network within design limits. Position in the FDG queue is guaranteed when the area is operating under a LIFO principle. UK Power Networks also provides the FDG customers with the number of distribution constraints they are subject to under Intact and most credible N-1 scenarios. In addition, a detailed curtailment assessment report is issued to each customer with the following information:

- Introduction to the FDG Zone
- Description of technical constraints
- Description of ANM solutions
- FDG Commercial Arrangements

- Curtailment Assumption
- Curtailment Estimation
- Point of connection for a Flexible DG Connection
- Summary of Time Series Constraint Assessment studies
- Duration curves for uncurtailed and curtailed power output
- Time series chart for uncurtailed and curtailed power output

The curtailment assessment results are an estimate giving the customer the predicted (i.e. not guaranteed) level of curtailment subject to a series of assumptions. List of active constraints, Energy estimate before curtailment, Energy estimate after curtailment, capacity after curtailment (%), Reduction in energy produced to curtailment (%), duration curves for uncurtailed and curtailed power output, time series chart for uncurtailed and curtailed power outputs: yearly, monthly and time of day profile.

1.5.4 Post Connection Data

UK Power Networks currently provide historic curtailment and performance data on request from the customer. UK Power Networks currently have a basic web portal showing high level and real time status of the system. We are currently developing a web portal that can provide detailed historic information. If there are outages leading to confirmed and sustained impact to the generators, they will be informed but not for potential curtailment scenarios.

1.5.5 Evaluate volumes of energy curtailment

The following process describes the curtailment assessment process:

a) Determine DER's Point of Connection for Flexible Connection.
b) Collection of annual historical load and generation data.
c) Assumptions on network running arrangements, ratings, DER utilisation factors during summer, Winter and Autumn/ Spring.
d) Run full load flow in the loop time series curtailment assessment in DIgSILENT (using the assumptions and historical load and generation data).

The following process describes how the underpinning data is calculated for the curtailment assessment:

1. Annual historical load and generation data are obtained from PI Historian and then cleansed to ensure no erroneous value exists.
2. Practical assumptions are made on network running arrangements, ratings, DER utilisation factors during Summer, Winter and Autumn/Spring.
3. Time series curtailment assessment algorithm is developed in DIgSILENT which will minimise the curtailment of DERs according to a defined principle of access.

1.5.6 Methodology to evaluate ANM system reliability

Smart grid systems cause an additional strain on DNOs ancillary infrastructure. This is observed more in the telecommunications and IT system. Most distribution networks use low bandwidth, high latency telecommunications systems for the purposes of SCADA control systems. With the requirement for more granularity of data and higher polling rates, it can be understood that a significant step change had to be undertaken. These changes had to occur at all levels of the infrastructure since ANM generates more data and this also has an impact in other part of the shared infrastructure such as data historians, server processors, etc.

One of the complex issues was related to the ANM application handling of the communication failures. This was previously being masked as being caused by actual communication failures but it got diagnosed during an investigation of intermittent radio communications link that was unnecessarily closing TCP connection sockets between the central ANM and the local field devices.

This led to the ANM triggering the failsafe action with short duration but high frequency curtailment instructions to the generators. This type of events had a greater impact to rotating machine generation due to the inertia requirements to restore to the same pre-event generation output compared to generation such as solar farms.

The following metrics are currently used for reliability monitoring:

a) Availability of Communication
b) Availability of Equipment/hardware (including measurement equipment/sensors)
c) Availability of ANM software solution

Communication faults should be part of standard ANM outage (refer to answer to Q3) but network outages (including DG customer outages) should be classed as 'non-standard' ANM outages. (Assuming ANM system reliability is evaluated against standard ANM outages)
UK Power Networks have currently established a stable communication network for the two operational ANM schemes in EPN.

The future ANM system needs to be more flexible, integrated and coordinated with other smart systems. Following are the key areas of focus for the future;

- Continuation of business adoption of FDG.
- Review and sourcing effective smart technologies.
- ANM system in areas of Transmission constraints.
- Integration of storage, demand response and electric vehicles.
- Further development in commercial area such as curtailment using market mechanisms.

Having encountered a multitude of issues as described in this document, an end to end assessment of the overall solution was carried out in middle of 2016. This identified a number of improvement actions to stabilise the system and minimise unnecessary curtailment of the DGs, some of which are outlined below.

Measurement resilience
Loss of measurement data at the constraint location means failsafe curtailment of all associated DGs unnecessarily. There will be future logic based functionalities that allows the use of other measurement data in the network to derive an approximated measurement value at the constraint location preventing the failsafe action for certain period.

Communications resilience
Use of backup communication infrastructure would greatly increase the resilience of the ANM system. However, this will require this functionality to be developed at both the central software as well as the field devices.

Increased Intelligence
Further intelligence needs to be developed so that DGs are less curtailed due to system issues taking account of other data such as time of the day, generation profiles etc.
The ANM system is complex smart grid technology requiring integration with multiple components in the existing network. As the ANM concept is to utilise the latent capacity of the network assets without putting the network at risk, the system needs to evolve from a pre-configured logic based system to a more active and intelligence system that is able to take decisions based on dynamic power flow and real time system changes.

As UK Power Networks moves toward a Distribution System Operator, we should cater for continuous changes to network dynamics:

- Network Running Arrangements changes.
- Firm DG ramping.
- Sudden loss of demand.
- Bi-directional flows at GSP level.

- Dynamic Sensitivity factors.

To effectively manage the FDG connections as Business as Usual, the network operators need to build a new set of capabilities to support the new business functions from planning to operations. Due to its active nature, the system needs to be regularly assessed and optimized with a whole systems approach.

1.6 Western Power Distribution

1.6.1 General Process

Western Power Distribution (WPD) currently offer actively managed “flexible” connections to avoid significant reinforcement costs, broadly known as “alternative connections”, with the option of full active control for some connections. Currently there are in the region of 20-30 accepted and 10-20 connected sites, across all four licence areas.

While intertripping schemes are offered to some sites where constraints are only required under abnormal running, the “alternative connections” also operate under normal running. This is primarily as WPD’s ANM system works on a pre-event curtailment basis, which means we constrain to the N-1 system capacity in intact network conditions, and to the N-2 system capacity in N-1 conditions.

Information about the connection process is available on the WPD website and the Connection Offer contains some general details about alternative connections. A report of the anticipated curtailment is also included along with the offer, although it is caveated as no guarantee is provided on the level of curtailment. While customers find the report a helpful indication we have not had enough data back from our connected sites to compare the accuracy of the contents.

1.6.2 Pre-application publicly available information

Within the information on the website a list of the intended rollout of ANM zones is listed, but the specific constraints related to the zones are not shown as they are connection dependant. A Generator Capacity Register spreadsheet can also be found, which shows types and numbers of generators, in each stage of the connection process. The utilisation of the network is also demonstrated through the Network Capacity map, which is a heatmap showing areas of likely constraint.

1.6.3 Curtailment Estimates during Application

Customers are encouraged to carry out their own studies of likely curtailment. However, half hourly load flow data is not provided to the customer unless asked for and the complexity of the assessment means they are unlikely to be able to carry it out to a higher level of accuracy.

The data within the curtailment report is provided in MWh’s of curtailment, includes pictorial representation over a year and numbers of customers ahead in the LIFO stack at time of study. It is calculated using historic load flow data within a detailed power flow study process to account for the impact of multiple connections within parallel networks. The study is carried out on an intact system and over a two year period. While fault rates are not included or published the report is based on pre-event curtailment to the next outage.

The following disclaimer is stated at the bottom of the report provided:
“For the avoidance of doubt, WPD does not guarantee any level of duration or frequency of curtailment or constraints. The Customer is strongly encouraged to conduct their own assessment of the potential curtailments/ constraints and risk associated with an alternative connection.”

The reports are currently produced in conjunction with a third party and the time required to produce the report between the two parties is in the region of 10-15 man hours over 3-5 days to account for simulation time.

Customers vary on their optimism around the data in the report but have suggested upper limits of curtailment between 5-15%.

1.6.4 Post Connection Data

Currently data on actual curtailment is not provided to customers. However, WPD are planning to implement a means to provide metrics to customers on the state of their connection. For planned outages customers are able to access a web portal which gives information on upcoming outages. This provides a means for continued communication and a means for getting further updates on how long they will be constrained for.

1.6.5 Evaluate volumes of energy curtailment

WPD uses a curtailment assessment tool developed with SGS. The inputs to the tool include: a network model (from PSSE or IPSA) including locations of demand and generation, half hourly demands for each relevant substation in the model covering a two year period, sizes and types of generation, pre-set generation profiles for types of generation, and the LIFO stack. These are put in place prior to any ANM being opened for offers. When a customer makes an ANM application, their generation details will be added and the curtailment tool run. Ideally, a number of generators are batched together before the curtailment tool is run, but this is not always possible. It typically takes 14 hours for the computer simulation to run, and the process is generally quite labour intensive. The output from the curtailment tool is a two page document which we include with the customer's connection offer.

We are further developing this process and are planning to move towards using representative days (12 days, representing a typical winter, spring/autumn and summer day), rather than using actual data for a two year period, which will significantly cut down on computing time, and speed up response time for customers.

Substation half-hourly demand data is collected from our SCADA system for a two year period and then cleansed to remove abnormal conditions and data errors. Generation profiles for different technology types are created by taking an average of the output of a number of sites, again having accounted for data errors.

1.6.6 Methodology to evaluate ANM system reliability

We currently do not assess the reliability of our ANM systems. Whilst we have information on times that ANM systems or communications are not working, we don't compile this into a number to present to a customer.

Curtailment to customers from communications faults associated with ANM systems should be reported separately from curtailment caused by the normal operation of an ANM system. Equally, curtailment caused by outages to assets the customer is connected to should also be reported separately, as this would not be curtailment due to ANM operation. However, certain network outages would lead to greater curtailment action from an ANM system so would need to be included.

1.7 National Grid - Electricity System Operator

1.7.1 Summary of generation connection classes and types of connection

To understand the flexibility requirements at transmission level, an understanding of generation connections categories is required, which are summarised below. Where generators are required to apply directly to National Grid Electricity System Operator (NGESO), more detailed information can be found at: [Applying for a connection | National Grid ESO](#).

For those generators / Distributed Energy Resources (DER) only required to apply for a connection with the Distribution Network Operator (DNO), please consult the DNO for further information, including more detail on the locations of managed zones.

1. A direct connection to the transmission system always has requirements for flexibility. Generally,[1] that flexibility will be manually applied and will require the user to become signatories to the Balancing Mechanism (BM), which provides the visibility and control required to operate the transmission system.

2. A large[3] embedded generator is required to apply to the host DNO for their connection and are also obliged to apply to (NGESO) for a "Use of Transmission System Agreement". That requirement will usually[2] involve entering into a Bilateral Embedded Generator Agreement (BEGA) which also compels becoming a Balancing Mechanism (BM) signatory and provides the visibility and control to give flexibility in the same way as a directly transmission – connected party.

3. A small[3] or medium[3] embedded generator or DER is required to apply to the host DNO for their connection; in this case, there is generally no compulsion to have any agreement with NGESO, although as the examples below illustrate where there can now be exceptions to this. Historically there were no requirements for transmission flexibility on this type of generator however, that is changing owing to the current trend towards volumes of generation in this class displacing larger generation with traditional control via the BM. It has been recognised that provision of visibility and control on this class of generation is an economic way of connecting generation to the network, and can be used to provide early connection ahead of transmission reinforcements works via the transmission Connect and Manage arrangements. It is therefore becoming increasingly common to compel transmission flexibility as a condition of connection in defined zones of the network. There are various ways of applying the control requirements to small and medium generators, though these generally will depend on the availability of Active Network Management (ANM) in the host DNO area and the ability of the host Transmission Owner (TO) to interface their network to the DNO equipment.

1.7.2 Flexibility required on small and medium generation for transmission reasons

As stated in the previous section, there is a growing requirement for small and medium generators to provide flexibility in order to receive an economic & efficient and / or timely connection, together with ensuring costs to consumers are minimised. This is currently a developing area so new examples in addition to those listed below will emerge to meet this goal. Generally, the technical control will be consistent with requirements detailed in the European Code (Requirements for Generators) and associated UK code G99.

1. Where no other flexibility mechanism exists to control a limited transmission infrastructure capacity network, a small or medium generator / DER could apply for a BEGA and associated BM membership as a means providing the flexibility to get connected in the limited capacity area. Unless part of a non-firm connection agreement (see item 4 below) flexibility via a BEGA will normally be compensated at the generators submitted price. Where flexibility is

[1] Automatic dispatch of transmission connected generation is currently being developed as an economic solution to capacity issues in the Dumfries and Galloway area of SW Scotland.

[2] For certain generation in Scotland, a generator can request a Bilateral Embedded Licence Exemptible Large Power Station Agreement (BELLA) instead of a BEGA - this does not include a flexibility requirement. NGESO will only agree to a BELLA request if it is in an area that does not require active control of generation.

[3]

Host TO	Small	Medium	Large
National Grid Electricity Transmission (England + Wales)	50 <	50 to 99.9	≥ 100
Scottish Power Energy Networks (Southern Scotland)	30 <	N/A	≥ 30
Scottish and Southern Energy Networks (Northern Scotland)	10 <	N/A	≥10

compensated in this way, no curtailment assessment will be provided. Control is by manual instruction.

2. Where there is limited capacity on the local transmission connection assets that are fully funded by the host DNO, it is common practice to offer what is in effect an extension of distribution ANM onto those assets. Under this arrangement, the host DNO avoids transmission reinforcement costs that they would normally pass onto the developer. In exchange for avoiding these costs the developer is required to offer curtailment, usually controlled by ANM. In this case the curtailment is normally not compensated and any curtailment assessment will be provided by the host DNO in line with their policy on distribution constraints.

3. The Security and Quality of Supply Standards (SQSS) requires a higher standard of security to ensure regional stability of the transmission network for consumers than is required to provide a connection to small and medium generators / DER. In regions with an excess of generation, it may be possible to allow more generators to connect, on condition they are automatically removed from the system following a fault on transmission equipment that is more onerous than the generator/ DER are entitled to stay connected for. To achieve this, the host TO will link its' intertrip equipment to the host DNO's ANM equipment. This fault event is beyond the required standard for which a small or medium generator is entitled to stay connected thus is not compensated. A curtailment assessment will be provided in the form of a probability and likely duration of a typical fault event. E.g. a 1 in 100-year event, with an average restoration time of 8 hours, typically in the range of 1 minute to 2 weeks.

4. To satisfy the SQSS for transmission infrastructure requirements, the host TO are obliged to build infrastructure assets for the network to remain operable against defined deterministic criteria, together with associated economic levels of dispatch agreed with NGESO. The SQSS can also be satisfied at a lower standard than this where a developer choses to do so and where this is not to the detriment of any other user. An example of where a developer may wish to accept a lower technical security of connection is to get a connection date ahead of completion of lengthy transmission reinforcement works, hence avoiding delays to the energisation of their project. This type of connection is often known by various terms such as; user choice, non-firm, or customer choice - design variation. The host TO (via NGESO and the local DNO) should explain to the developer the options for a fully firm connection, together with any non-firm options. The specific restrictions for which the connection is 'not firm' for will be listed in the NGESO to DNO connection agreement (usually referred to as the 'Bilateral Connection Agreement') who, in turn, will make them available to the developer. Curtailment against these specific non-firm restrictions will not be compensated and could be applied manually, or automatically, via a ANM or Load Management Scheme (LMS).

5. Emergency Disconnection: Where conditions on the transmission system are beyond those that the TO or NGESO are required to design and plan for, in order to limit risks to, or the actual disconnection of consumer demand, NGESO will instruct the local DNO to disconnect generation that is contributing to adverse network conditions. Such events are unplanned and extremely rare, so no curtailment assessment is possible. NGESO is obliged to use all applicable commercial options for managing the network before emergency disconnection. Emergency disconnection is uncompensated.

6. Managed Zones: In a managed zone, all new generation / DER (usually of 1MW and above) is required to provide visibility and control of their generation / DER output to NGESO.
   A developer can do this by joining a BM product. This could be full BM membership or one of the new, more cost-effective products that are under development for small generators / DER. Note - for managed zones, transmission constraint management services via commercial arrogation will be restricted not to aggregate above Grid Supply Point (GSP) level. As an alternative to BM membership, in most managed zones, it is possible to provide flexibility via the local DNO ANM scheme. This option will be more suited to small players who otherwise would not be active in the provision of regular balancing services to NGESO. The NGESO generation dispatch system will interface the DNO ANM scheme which will then control the generation. All the elements in items 1 to 5 above could be present in a managed zone, in which case the commercial arrangement / curtailment assessment for that part of the managed zone will apply. Flexibility for the remainder of the zone will be compensated at submitted prices and no curtailment assessment will be provided. Where payment is applicable and the developer has submitted a price, this will be via a backstop pricing arrangement settled by NGESO. The location and further details for a particular zone, will be available from the local DNO.

7. Automatically Managed Zones: All new generation / DER output is obliged to be routinely controlled automatically by a network management scheme. These schemes are currently under development and it is envisaged that pricing and payment will follow a BM route or backstop price as per section 6 above. Actual control will be by a transmission level Active Management Scheme, which will interface to small and medium generation via the local DNO ANM scheme. Again, all requirements of 1 to 5 could apply, otherwise curtailment will be settled at a submitted price with no curtailment assessment.

1.7.3 Reliability of Automatic Network Management Equipment

Each host TO will have its own reliability standards for equipment located on the Transmission Network. In order to ensure a high standard of security, this tends to have dual redundancy and high availability. Where that equipment interfaces to DNO equipment, the TO's standard will be reflected onto the local DNO via the Bilateral Connection Agreement. Generally, this will refer to the common elements of the scheme and will not reflect the communication requirements to individual small generators, where a failsafe policy will be agreed with the local DNO.

2 Curtailment Assessments

This section outlines the key areas where there is consistency with the DNO's approach and those that have been considered as good practice. It also puts forward the key assumptions that should be included in curtailment assessments to ensure easier comparison between the DNO's approaches.

2.1 Key Observations

2.1.1 General Process

All DNOs offer Flexible Connections which manage both system intact and outage conditions. There is information available which covers information about these connections ahead of connection application.

There is a range of information provided:

1. explanation of ANM solution and network conditions where capacity may be temporarily suspended.
2. information regarding position in the Queue and the Queue Management Process.
3. half hourly demand data, size and technology of generation about the generator in the stack.
4. location of constraints and the thresholds set at these constraints.
5. general details about alternative connections and assessment of predicted curtailment

Customers feedback on the provided information has been mixed, with come customers being happy with the provided report output and assumptions while others feeling that more detail or tweaks to the assumptions would be preferable.

2.1.2 Pre-application publicly available information

Each of the DNOs offer a range of background information such as heat maps pointing to ANM enabled areas and ANM roll out plans. This are supplemented by network overview information and customer fora. However, information about the specific constraints are not typically shared. There various sources of information that indicate the level of DER which include embedded generation register, heat maps and regional development plans.

2.1.3 Curtailment estimates during the application

The time that information is provided to customers about the forecast of curtailment varies between DNOs during the application timeline. This ranges from not being provided, through to at feasibility stage, at connection offer stage or at post application stage.

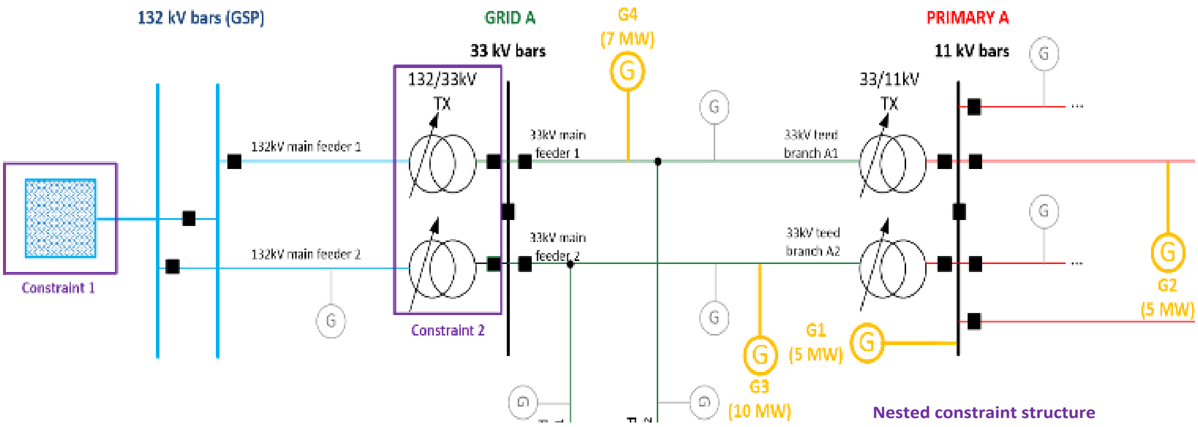
Between the DNOs there are three main approaches to curtailment assessment:

1. The predominant approach, uses half hourly analysis to calculate a curtailment assessment.
2. Some DNOs provides data to allow the customer to produce the curtailment assessment themselves. One DNO offers only this approach.
3. Finally, one DNO uses an approach that calculates an index to represents a typical level of curtailment across the network for the various voltage levels.

The input data used in all three approaches are fairly consistent based around half hourly generation and demand data, details of an impedance model, information on running arrangements and the configuration of the ANM system. Some companies also incorporate fault and outage information into their assessments. This data is used by most of the companies preform a loadflow based curtailment assessments, or for simple networks a spreadsheet based assessment. The demand data used is historical, usually 1 or 2 years while the generation data is either based around idealised profiles or uses customer generation profiles.

Fundamentally the curtailment assessment needs to emulate the behaviour of the ANM system.
An example from UKPN of the technical considerations, where constraints may be classified by their reach as global or local. Global constraints are relevant to all connections in the ANM system. Local constraints are only relevant to a subset of the connections in the ANM system. The possibility of constraints occurring simultaneously is considered in the ANM system design. This is required in order to ensure a consistent approach to constraint elimination and facilitate post-curtailment log analysis.

The example below illustrates how two constraints that are triggered simultaneously by four generators could be managed (see figure 1): Constraint 1 at the Grid Supply Point (132kV); Constraint 2 at Grid A (132/33kV substation).



Arrangements for Management of Multiple constraints.

Generator	Relevant to constrain
G1	Constraint 1
G2	Constraint 1
G3	Constraint 1, Constraint 2
G4	Constraint 1, Constraint 2

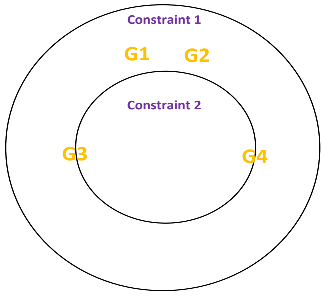


Figure 1 ANM managing multiple constraints

Generators G1 and G2 were connected first and did not trigger Constraint 2 (at Grid A). Therefore, they are only liable for curtailment for Constraint 1. Generators G3 and G4 were connected later and are thus liable for curtailment for both Constraint 1 and Constraint 2. The management of multiple constraints will then follow a "nested" structure: if both constraints are triggered, the "most local" constraint is managed first as a convention. G3 and G4 are curtailed to eliminate Constraint 2 and then, if Constraint 1 still persists, all four generators are curtailed.

It is worth noting that DNOs do not typically publish faults rates however some DNOs either provides these on request or indicate asset type outage durations. Some of the DNOs also give supplementary information about the communications reliability, this is either historical performance or a description of how the ANM system caters for the loss of communications which invariable lead to generator curtailment. The curtailment assessments are typically provided with a disclaimer.

The process of creating curtailment assessments is reasonably time consuming and is significantly affected by the complexity of network and ANM system. This is typically between 2-6 man days, or in the case for a third party provider up to 2 and half weeks. Particularly complex scheme could take longer. The minimum acceptable amount of information for the customers is not well understood.

2.1.4 Post connection data

There is less consistency on the data shared post connection with two companies share historical curtailment data on request but are developing web portals to detail information on historical curtailment. The other companies do not share this information.
To supplement this customer information all DNOs provide information about upcoming planned works that may impact curtailment although the approaches vary from the information on request to annual processes to flag planned works to an annual process like above plus more detailed updates nearer the time.

2.1.5 Evaluating volumes of energy curtailment

All companies have incorporated ANM/flexible connections offers to some degree into their options for customers and have incorporated them into their connections process. The transmission companies have not substantially changed their processes however some of the principles they use could help inform the ANM connection offer process. As discussed already many of the companies use a half hourly based analysis for their curtailment assessment. Almost all DNOs highlighted the criticality of good quality data and challenges they have had cleansing the data.

An example from UKPN of curtailment assessment results for 17520 iterations (i.e. 1 year, every half hour) is provided below:

DG name	**FDG1**	
Capacity (MW)	**15**	**Capacity of FDG**
PoA	**LIFO**	**Principle of Access**
Uncurtailed energy (MWh) generated before curtailment used for the curtailment assessment	**18057**	**Sum the energy (MWh) before curtailment for the total duration of the study**
Uncurtailed utilisation factor (%) before curtailment used for the curtailment assessment	**13.74 %**	**= Uncurtailed energy (MWh)/(17520/2*15)**
Estimated energy (MWh) generated after curtailment	**17326**	**Sum the energy (MWh) after curtailment for the total duration of the study**
Estimated utilisation factor (%) after curtailment	**13.19 %**	**= Estimated curtailed energy (MWh)/(17520/2*15)**
Estimated energy (MWh) of curtailment	**731**	**= Uncurtailed energy - Estimated curtailed energy**
Reduction in output due to curtailment (%)	**4.05%**	**= Uncurtailed energy/ Estimated energy (MWh) of curtailment**

Arrangements for *Management of Multiple constraints.* results

Also sum the curtailment Due to each Constraint in (MWh) and present the results.

2.2 Calculation principles

The purpose of this Good Practice Guide is to help inform each of the DNOs of key principles and assumptions that can be stated that that underpin the analysis. For curtailment, the assessments the process should be documented as clearly as possible. The process should also be quantitative, with the input data clearly outlined in the supporting information. Also, the specific assumptions below should be documented to ensure the customer understands any differences in DNO approach.

Fundamentally the analysis should give every customer participating in a specific ANM area a comparable analysis based using the same analysis parameters. The key assumptions should be stated to enable easier comparison between the DNOs. However, as the DNOs will use conservative assumptions to limit the likelihood for overestimations and aid the ability for initial comparison between DNOs. Therefore if a customer required more detailed analysis this can be carried out by the customer themselves using provided data or as a paid for service if the DNO offered this.

Good Practice should be built on consistent, clear and open assumptions which allows for easy comparison between curtailment assessments.

Good Practice should be built on consistent, clear and open assumptions which allows for easy comparison between curtailment assessments.

2.3 Key assumptions

This section outlines the key assumptions that should be stated to enable a more informed comparison between the analysis carried out by DNOs.

2.3.1 Use of Half Hourly Analysis

Most DNOs use half hourly analysis through either a simple spreadsheet for simple radial networks or a load flow analysis for more complex networks. Either are effective however any non-radial networks should use a load flow analysis to ensure the best results.

While carrying out load flow based analysis, it is important to ensure that each time step converges correctly. If there is a significant number of non-convergent timesteps the model should be reviewed. It should be noted that this becomes increasingly more challenging as the number of customer grows in a complex topology zone.

The running arrangements must be stated, it should be clear if the analysis includes abnormal running or communication outages in the analysis.

Approach	Pros	Cons
Load flow based	Detailed analysis capable of producing precise results	Complex, time consuming and resource intensive
Spreadsheet based	Simplified approach for radial networks	Cannot be applied to meshed networks

Table 2 Pros and cons HH analysis methods

Both approached are considered Good Practice depending on the complexity of the network. There are potential future options discussed below.

2.3.2 Demand Data

Half hourly demand data used in the analysis is often historical, it should be made clear to the customer what data is being used. This is likely to be a future network configuration with historical (or assumed) data. This gives the customer an indication of if they were connected during the historical year in question, what their curtailment would have been. Efforts should be made to ensure that all historical data is aligned in time, to ensure all macro affects are captured. It should be made clear to the customer that this demand data is subject to change which should make the curtailment better or worse.

For all historical data appropriate data cleansing should be carried out to identify potentially erroneous data. If the data is so bad that it needs to be interpolated this should be done to the best of the DNO's ability to ensure the analysis is still representative. Identified data issues should be corrected in the DNO's core systems to enable good ongoing data quality.

Good Practice entails care when preparing demand data using the considerations above to ensure the most representative and accurate input data.

2.3.3 Generation Profiles

The generation profiles used are split into two main approaches, an idealised (or assumed) profile or real historical profile. Idealised profiles will need to be used for all new generation which has not yet connected or does not have a full year's data. One advantage of using idealised profiles is that it gives a more conservative result by removing any generation of a specific type's diversity. It also allows for the DNO to use a relatively high capacity factor in this idealised profile. Both of these reduce the risk of under estimating curtailment. Using historical data would give more realistic results however this would increase the amount of data cleaning required. Just like with historical demand data, all the data needs to be aligned in time. Whichever assumptions are used, they should be clearly stated.

Approach	Pros	Cons
Profile	Easy to derive and incorporates a level of conservatism	Is not truly representative
Historical	The most representative data	Require more resource to extract and cleanse

Table 3 Differences in generation data

Good Practice is considered to use historical data to give the customer the most representative results, however using profile generation data is still a valid approach.

2.3.4 Principles of Access

The principles of access should be clearly stated in the offer and the curtailment assessment. Most DNOs use Last In First Off (LIFO) as this simplifies the commercial proposition. This may not be a strict LIFO as the impact of the generator on the constraint may be considered using a sensitivity factor. Generators which do not impact a specific constraint may not be curtailed ensuring an efficient use of the network. It is worth noting that is pro-rata or vintaging (groups of pro-rata generators) are used, the upfront curtailment calculations are conservative as the mix of generation is unknown at this point, however once this is known a more accurate curtailment figure could be derived.

It is important that the customers understand who is ahead of them in the stack impacting their curtailment. Unlike conventional connection offers, if the analysis is done at the time of offer the assessment considers all customers who have received an offer. This is makes it significantly more likely that customers could pull out of the stack ahead of them, improving their curtailment. The assumption of what type of generation is considered in the stack should be stated. It is also important to understand the type of generation and the collective size of each type generator ahead of them too. As similar generators will have comparable profiles, this will drive more curtailment particularly if there is a large volume ahead of them in the stack. This should be made clear in the curtailment assessment.

Good Practice includes detailed information of the generators ahead of them in the stack as detailed above.

2.3.5 Key outputs

There are various formats of output provided by all DNOs and this is a focus for WS2 P7. The particular format and the specific suggestions can be found in this product's report. However, some key pieces of information ought to be included in a curtailment assessment:

1. Energy volume before curtailment (the assumed generation profile)
2. Energy volume after curtailment
3. And/or, the curtailed volume of energy
4. Indication (probably visually) of the volume of curtailment throughout the year and throughout a day
5. Indication of any abnormal running considered
6. Outline of the assumptions in the previous sections in the supporting information

Good Practice should include all of the above.

2.4 Suggested improvements

The time and computer resource to calculate curtailment assessments are significant with involve complex runs taking over 20 hours to compute. There is also a significant amount of upfront data cleansing for the larger data sets. Once a zone is established it could be possible to use different approaches for some aspects of the analysis including probabilistic analysis, stochastic analysis or using indicative days. Taking the indicative days for example, the number of daily profiles could be reduced to 12, one a month, from 365 for the entire year. This would make the analysis significantly less computationally intensive to run however significantly less granular. There would need to be periodic sensitivity analysis to ensure that the simplified results are still representative.

Secondly, by the nature of the significant time for processing the data, budget estimates do not include any indication of curtailment. One way to give a prospective customer more upfront information could be using a web-based curtailment assessment tool which allows a customer to identify a point of connection and an indicative curtailment assessment could be calculated using the current LIFO stack. This would allow customers to get a high level indication on where curtailment could be high for their type of generation.

It is also worth noting that several DNOs are exploring ANM connections for demand and more comprehensive consideration for energy storage schemes. The principles are similar however the analysis will need to be running using a demand biased (worst case) model, the practicalities of running a mixed demand and generation model are challenging.

3 ANM Reliability

3.1 Key Observations

Long term experience of the reliability of ANM is still emerging so the collective knowledge and breadth on ANM reliability is less detailed. All DNOs who have live systems monitor a number of metrics through the DNO's core systems or directly in the ANM system itself. These are, as a minimum, typically communications integrity, the actions the ANM system as undertaken and each generators export. This information is not shared with third parties, or in some cases, on request.

3.2 Proposed Metrics

As curtailment can be caused by a variety of reasons it is appropriate to categorise the mechanisms into key categories. This allows easier comparison between systems and DNOs to help identify potential system issues or configuration errors.

3.2.1 Curtailment

This is curtailment driven by normal operation of the ANM system. Within these metrics, they should include the level of curtailed output of the generator. It is worth noting that the system cannot directly derive what the generator would have been exporting had not been curtailed. This could be derived from weather data for renewable generation subsequently however this is out of scope of this product. The system should also indicate which constraint point or points are driving the curtailment and the power flow, voltage or current at the time. Equally it should have the generators in the stack that are being curtailed, ideally with the sensitivity factor that was being used at the time. Documentation or direct indication of any optimisation procedures the ANM system is employing is also important as still could explain transitionary behaviours more easily.

With the above information, it should be possible to determine if the action is legitimate or if there is an issue. It is worth noting that any data logging will need to be stored with high granularity of between 1 and 10 seconds, so that the transitional states are effectively captured. This can have scalability, ICT and storage implications.

In Good Practice, details of all curtailment actions should be logged with sufficient detail to enable identification of key cause(s).

3.2.2 Communications

Communication failures can be broadly categorised into two types of systems, either the internal generally resilient ICT system communications and the external last hop communications required to reach the generator or measurement point. The former will be discussed in the next section.

There are a variety of communications options and models operated by the DNOs including customer owned, DNO owned and third party owned communications links across scanned telemetry, radio communication, mobile communication, microwave links, optic fibre and even satellite communication. All of these have vastly different reliability and accountabilities however this is not the focus here, moreover how a failure is logged.
By the nature of remote communications this information can only be fully assembles once the communication link is restored. Typically for a generator the remote end identifies that there is a communication failure through a lack of an acknowledgment, heartbeat or last gasp, at this point the generation is curtailed until communication is restored. This information about the length of time and the nature of the communications failure should be sent back to the central system and logged.

In Good Practice the length of time of a communications outage should be logged with which communication leg caused the issue.

3.2.3 System Integrity

System integrity can include an electrical network fault, an ICT system fault, an ICT internal communications fault or a software bug that could all impact the curtailment of a customer. An electrical fault should be logged in the DNO's Network Management System (NMS) so if this drives any curtailment directly or from subsequent fault switching these actions are logged by the NMS, however appropriate data will need to be shared between the NMS and ANM system to derive the full impact and causality.

Both ICT type faults should be accommodated in any failure over procedures within the DNO's ICT estate. Appropriate logging of systems and internal communications links will be required to quantify the impact. By the nature of this type of system either it would be imperceivably to the customer through fast failure over procedures operate or fairly catastrophic if they do not operate correctly. Data logging of the actions should be cross referenced with the impact to the customers.

Finally, the most difficult to identify is software bugs or misconfiguration. They are best avoided all together with through prototyping and trailing of the systems and configurations. It is recommended that any newly installed ANM system is integrated frequently after any changes and that there is a regular check of live systems to ensure it is operating correctly.

In Good Practice the central systems should be redundant and covered by detailed SLAs. In the event of a fault this should be logged, resolved and communicated effectively.

Appendix 1: Glossary

The following terms are used throughout this document:

ANM – Active Network Management
BAU – Business As Usual
BEGA - Bilateral Embedded Generator Agreement
BELLA – Bilateral Embedded Licence Exemptible Large Power Station Agreement
BM – Balancing Mechanism
DER – Distributed Energy Resource
DNO – Distribution Network Operator
EGCA – Embedded Generation Connection Agreement
ENA – Energy Networks Association
ENWL- Electricity North West Limited
ESO – Electricity System Operator
GDPR - General Data Protection Regulation
LIFO - Last In First Off
LMS – Load Management Scheme
MWh – Mega Watt hour
NGESO – National Grid Electricity System Operator
NOM – Normal Operating Model (connections process)
NPg – Northern Powergrid
PSI – Planned Supply Interruption
SPEN – Scottish Power Energy Networks
SQSS – Security and Quality of Supply Standards
SSEN – Scottish and Southern Electricity Networks
TO – Transmission Owner
UKPN – UK Power Networks
WPD – Western Power Distribution
WS1 P7 – Workstream 1 Product 7
WS2 P7 - Workstream 2 Product 7

Appendix 2: List of Questionnaire Questions

General Process

1. Do you offer actively managed “flexible” connections as a means to accommodate non-firm connections by actively constraining customer capacity? How many have been accepted/connected?
2. Do these connections manage capacity in the system intact network?
3. Do you publish information on your connections process regarding flexible connections?
4. "What information do you provide to customers as part of their formal offer and/or connection agreement about the nature of the constraint(s) which will be managed?
5. For example: Only whether it is Intact/N-1 or more detailed info such as thermal on particular circuit under particular outage.
6. Also, what contractual data such as position in queue etc.)"
7. Has any feedback been received from customers with regards to the information provided?

Pre-application publicly available information

8. Do you publish information on what areas are already flexible connection/ANM enabled or when they are scheduled to be ANM enabled? (This could include which types of flexible connections are available in which areas of network?)
9. Does this information include what types of constraints the ANM enabled zones presently manage (e.g. thermal on transformers, thermal on circuits, voltage etc) and what they could manage if required?
10. Do you publish information on levels of DER by district/area within your license? How frequently are these updated? (Does this feed into your published DG heatmaps?)
11. Do you publish information on typical fault rates (GB wide, License wide)?

Curtailment Estimates during Application

12. What information do you provide to customers to enable them to undertake curtailment estimates themselves?
13. "What information about forecasted curtailment do you calculate and subsequently provide to applicant? (e.g. MWh, Frequency of curtailment; what granularity - monthly/yearly)"
14. "At what point(s) in your connections process do you estimate curtailment? (e.g. Within the Offer / only after the offer has been accepted / only on request etc)"
15. What method(s) do you use to estimate the level of curtailment? (e.g. calculated based on generic failure rates / based on historic loading data and queue / determined from detailed power flow studies and queue)
16. Do you publish information on typical fault rates (GB wide, License wide)?
17. Do you provide asset specific failure rate / outage forecast pertaining to individual connections (e.g. transformer has experienced X outages in the last 5 years? Of which X were planned. Altogether these resulted in X hours of outage.)?
18. Do you provide information to allow the Applicant to understand the level of risk associated with loss of communications?
19. What disclaimers do you use in conjunction with the curtailment estimate?
20. How would you grade the effort required to provide the curtailment information that you currently provide to customers? (man-hours per connection)
21. What is the acceptable minimum for customers?

Post Connection Data

22. What information do you provide to customers to enable them to understand their curtailment history?
23. Do you provide any information on upcoming planned works which may increase likelihood of curtailment?

Evaluating volumes of energy curtailment

24. What is your current curtailment assessment process? I.e. collation of source data, time to assess, when is the assessment issued (a process map would be ideal).
25. Please outline how the underpinning data is calculated for the curtailment assessment

Methodology to evaluate ANM system reliability

26. What metrics do you currently use for reliability monitoring? (availability? Inclusive of network/communication failures or are these separated?)
27. How is this information circulated? (If at all publicly? If by request, how?)
28. Do you agree with the initial Product assumption that communication faults and network outages should be classed as 'non-standard' ANM outages and thus calculated separately and not part of this Product's focus?