

CURTAILMENT ASSESSMENT

Methodology and Assumptions

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Glossary

DERMS	Distributed Energy Resources Management System
DOC	Directional Overcurrent
FCO	First Circuit Outage
GSP	Grid Supply Point
LIFO	Last In First Out
ODP	Open Data Portal
PoA	Principle of Access
Sum Constraint	A constraint that is made of individual circuits and protects for the N-1 capacity

1. Introduction

1.1. Background

Since 2019, UK Power Networks has been offering Flexible/Curtailable Connection solution to allow customers triggering network constraints to connect to the network, avoiding high reinforcement costs and accelerating the time the connection can be made by up to a decade in some cases. Flexible Connections have become an essential strategy for effectively managing grid capacity and facilitating the shift towards low carbon technologies.

This is achieved by operationally controlling the real time generation output of the site through UK Power Networks' Distributed Energy Resources Management System (DERMS) at times when the network is congested to ensure the network is operated within its admissible limits.

Since the start of the Flexible Connection offering in 2019, UK Power Networks has been issuing Curtailment assessment reports at the connection offer stage to provide a view on the expected level of curtailment a site might be subject to whilst in operation.

UK Power Networks has updated the tool used to produce curtailment estimates to facilitate an open and transparent approach to providing curtailment information. This document details the methodology and summarises the assumptions taken as part of the curtailment assessment studies.

1.2. Enhanced Curtailment Reports and Data Provision

To help customers better understand the level of curtailment issued in offer letters, the curtailment information now included in the curtailment reports have significantly been enhanced compared to those that have historically been issued.

The enhanced curtailment reports not only include the estimated level of curtailment, but also provide a breakdown of the curtailment per constraint and includes information on the constraints triggered by the site and their limits.

To provide full transparency on the drivers for curtailment, for each of the constraints triggered, a graph showing the constraint loading before and after curtailment, is included in the curtailment report.

The report now also provides visibility on the connection queue above the site being studied, including capacity, technology and application date.

To ensure transparency and replicability of the results, the curtailment half hourly data are also being issued at connection offer stage, including the half hourly curtailed and uncurtailed profile and the breakdown of curtailment per constraint.

Other data sets required to carry out third party curtailment assessment are now available on UK Power Networks' [Open the Open Data Portal \(ODP\)](#) and details of the datasets are available in Section 5.

1.3. Curtailment Estimate vs Curtailment Limit

The curtailment assessment is carried out outside of Distribution Connection and Use of System Agreement (DCUSA) Schedule 2D and has no contractual implications. For clarity, differences between the curtailment estimate and the curtailment limit are captured below.

Curtailment Limit sets a contractual cap on curtailment (% of hours per year) that a site can be subject to, which if exceeded, will need to be compensated by the DNO at a published set price. This is a regulatory requirement and is calculated through the DCP 404 spreadsheet.

Curtailment Estimate is the estimated energy reduction (kWh) that a site is expected to be subject to due to distribution and/or transmission constraints and sits outside of DCUSA Schedule 2D.

2. Key Concepts

This section describes the key concepts used within the curtailment assessment studies, including Principle of Access (PoA), Sensitivity Factor (SF), pre/post fault constraint management, constraint thresholds and technology specific profiles.

2.1. Principles of Access

Access to the network capacity is managed based on a Last-In-First-Out (LIFO) principle of access determined by the site's application date. Under LIFO, each flexible DER (generator and electricity storage) is assigned a position within a global priority stack. When a constraint is breached, the DERs at the bottom of the priority stack that have a contribution to the constraint, will be curtailed first and DERs at the top of the priority stack will be curtailed last.

The Grid Supply Point (GSP) LIFO is automatically determined based on the DER's application date. Sites with earlier application date are placed at the top of the stack, whereas sites with later application date are placed at the bottom of the stack.

For each of the constraints, an individual constraint LIFO stack is then generated based on the GSP LIFO stack and based on the relative sensitivity factor of sites in the stack to the constraint. If a site doesn't have an association to a constraint (a sensitivity factor threshold of 5% is used), it will not be included in the constraint LIFO stack.

During a constraint breach event, customers at the bottom of the stack are curtailed first and customers at the top of the stack are curtailed last.

2.2. Sensitivity Factor

UK Power Networks' DERMS uses sensitivity factors to establish a relationship between a constraint location and a customer. Sensitivity factors are a result of linearizing load flow equations around an operating point, applying marginal changes in active power on the node of interest and calculating the impact on the constraints.

Thermal sensitivity factors define the contribution that the active power (MW) of a DER has on the power flow (MW) at the constraint. For example, if a generator output is decreased by 1MW and the power flow at the constraint location decreases by 0.4 MW, the sensitivity factor of the generator at that point is +0.4 MW/MW.

Comparing sites with the same characteristics (LIFO stack, capacity, technology etc), the higher the sensitivity factor, the lower the curtailment will be (comparing other parameters being . In the example of 1MW overload at the constraint, a DER that has a 100% SF on the constraint will be reduced by 1MW, whereas a DER that has a 10% sensitivity factor on the constraint will be reduced by 10MW.

UK Power Networks has set a threshold sensitivity factor of 5% below which a customer is not considered to be associated to a constraint.

2.3. Pre-fault Constraint Management

Constraints that are active post-fault (e.g. after losing a transformer, overhead line, etc) are designed to be managed pre-fault to secure for the N-1 capacity of the asset, and to ensure that there are no short-term overloads immediately after the fault. The N-1 short-term rating is used when available. Pre-fault constraint management is required due to the timescales for DERMS system to operate and for customers to respond to a curtailment instruction being minutes rather than milliseconds; the allowed post-fault capacity for the duration of the overloads, needs to be taken into account when setting the curtailment threshold.

This is achieved through the Sum Constraint concept, which summates the power flow of the individual assets and ensures it stays below the N-1 capacity of the site.

For a two grid transformer site, the Sum Constraint summates the power flow on the two transformers and ensures it stays below the N-1 capacity of the site, as shown in Figure X. Curtailment is initiated when the power flow on the Sum Constraint exceeds the N-1 capacity of the site. For a 3 circuits site, the Sum Constraints summates the power flow on the three circuits and ensures it stays below the N-1 capacity, as shown in Figure 1. Curtailment is initiated when the power flow on the Sum Constraint exceeds the N-1 capacity of the site.

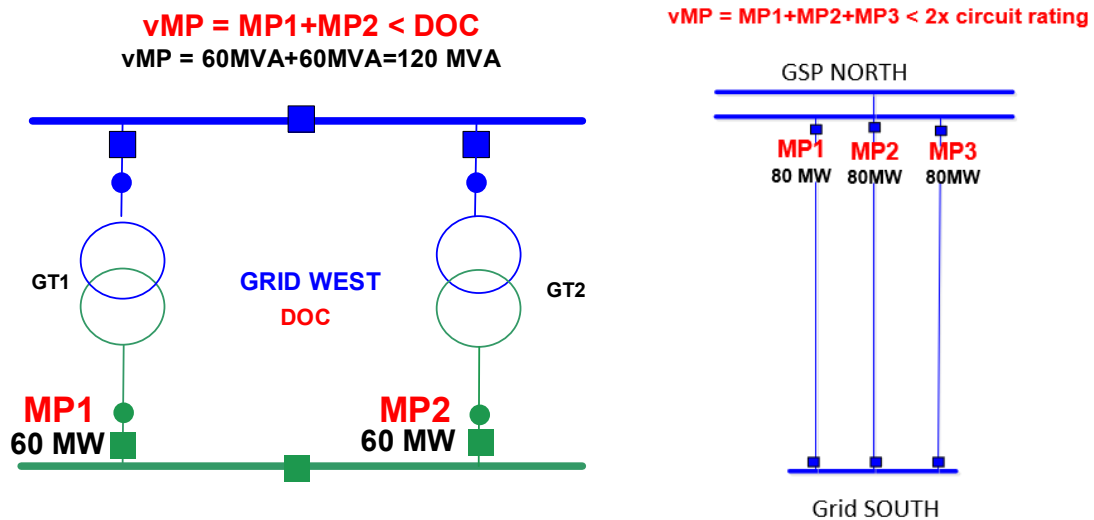


Figure 1: Sum Constraint examples: 2xtransformer Sum Constraints (left); 3xcircuits Sum Constraints (right).

2.4. Operational Settings

The points at which DERMS starts curtailing are normally set below the asset’s rating. A potential power flow increase can occur between the time the constraint is breached and the time a curtailment instruction is fully actioned (approximately 3 minutes). This power flow increase needs to be considered to ensure the power flow stays below the constraint limit. At curtailment assessment stage, a standard operating margin of 90% is used (i.e., the threshold for curtailment is 90% of the rating of the constraint). Closer to the time the site goes live, operating margins are calculated based on a standard methodology and are configured operationally in DERMS.

The power flow ramp-rate at a constraint (in MW/s), in combination with the time allocated to the DERMS system to react to a breach of a particular threshold (in seconds), represent the potential power increase at the constraint (in MW) before any curtailment action is initiated and before the constraint is removed. The faster the ramp-up rates, the larger the separation between two thresholds need to be, as shown in Figure 2.

This power flow ramp rate at the constraint is driven by the combined variability of individual DERs (both firm and flexible) as well as the contribution of demand reduction, this represents the worst-case ramp rate that can be experienced at the constraint.

For example, for a constraint at a Grid site driven by the directional over-current (DOC) protection rating, where firm and flexible DERs downstream could ramp up by 10MW by the time DERMS takes action, DERMS must start curtailing at least 10 MW below the DOC setting. This would ensure that DOC is not exceeded ahead of DERMS taking actions and sites responding to a curtailment instruction. Failure to do so might result in the whole site being disconnected affecting final demand customers.

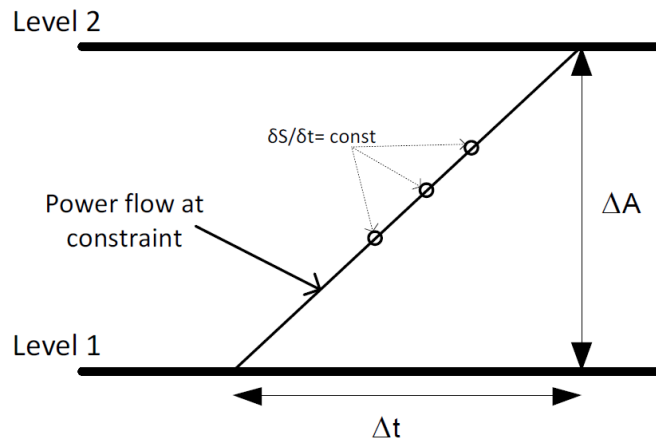


Figure 2: Constraint Operating Margin

2.5. Technology Specific Profiles

As the future operational profile of accepted but not yet connected sites is not known at the connection offer stage, UK Power Networks models these sites based on technology specific profiles. Once the sites are operational, their historical observed profiles are used to model their impact on the network.

Technology specific profiles are available in the Open Data Portal (ODP) (here) and are illustrated for a sample summer day in figure 3 below.

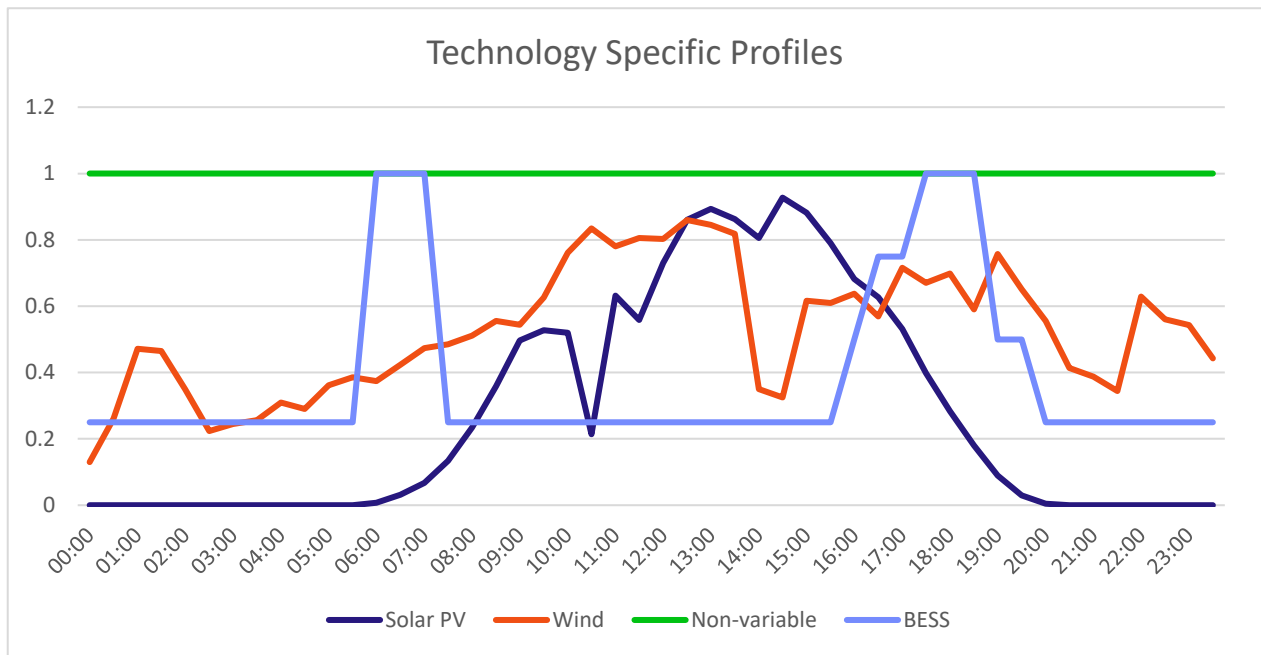


Figure 3: Technology Specific profile during a summer day.

3. Curtailment Methodology

This section describes the curtailment methodology used in the curtailment studies carried out by UK Power Networks to generate curtailment estimate reports, issued at connection offer stage.

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A high-level overview of the process is shown in Figure 4. The next subsections provides further detail of each of the steps.

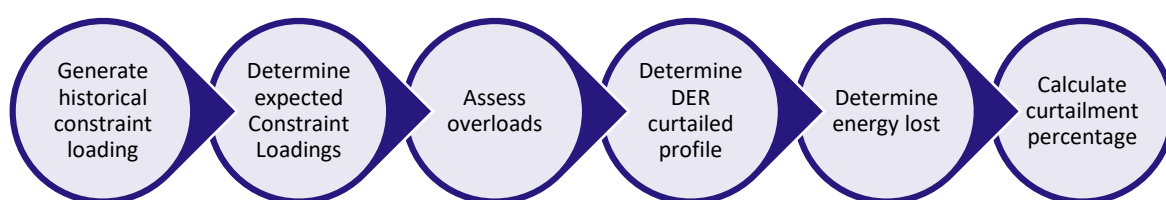


Figure 4: Curtailment methodology high level overview.

3.1. Historical Constraints Power Flow

The historical constraint power flow data is retrieved from PowerFactory simulation software, by running load flow studies for each half hour of the year, for the whole year, by setting up the network model as described in Figure 1 below.

Table 1: Network model set up summary.

Network Element	Modelling setup
Demand Data	The latest year of half hourly observed demand data is used for Primary Substation loads and EHV connected loads.
Connected Generators (and electricity storage)	Only EHV-connected generators are modelled (the export from 11kV connected generators is already included in the primary substation load data). EHV-connected generators connected for more than 2 years are modelled based on their historical output (Technology specific profiles are no longer used).
Accepted and In Delivery generators	Accepted and in-delivery generators are excluded from the PowerFactory model. Their contribution is subsequently added in the DSO Curtailment tool using technology-specific standard profiles.
Micro generators uptake (G83/ G98)	Future G83 and G98 connection forecast are not included in the background power flow.
Network	The whole network is run as intact. No outages are considered. No reinforcement in the future should be considered.

3.2. Expected Constraint Loading

Accepted but not yet connected sites are modelled based on their technology specific profiles and based on their relative sensitivity to the constraint.

The Curtailment Assessment Tool then calculates the expected ‘uncurtailed’ loading at the constraints triggered by the connections. This is calculated by adding the profiles of the accepted and in delivery applications, to the original background power flow (historical constraint loading) exported from PowerFactory. The technology specific profiles and the maximum capacities of the accepted and in delivery applications, scaled by their sensitivity factors with respect to the constraints, are considered when calculating the expected ‘uncurtailed’ loading at the constraint, as shown in the equation below.

$$P_{expected} = P_{original} + \sum_{DER} capacity \times SF \times tech\ specific\ profile$$

3.3. Assess Overloads

Once the accepted and inflight offers have been added to the background power flow, creating the expected uncurtailed constraint loading at the constraint, the Curtailment Assessment Tool compares the uncurtailed loading at the constraint, for each timestamp (half hour), against the constraint rating scaled by an operating margin.

The default operating margin used in the DSO curtailment tool is 90% of the rating. If any of the constraints is breached, the tool calculates the excess power (i.e., the power above the rating) required to bring the loading of the constraint below its rating. The following formula is used to calculate the overload in terms of excess power, for each of the constraints, for each half hour:

$$P_{excess} = P_{Constraint} - Rating_{Constraint \times Operating\ Margin}$$

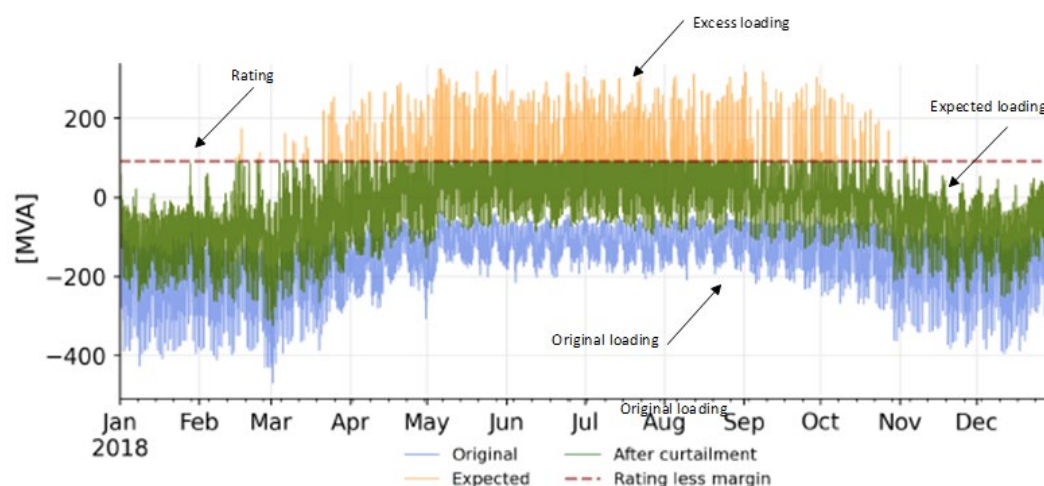


Figure 5: Calculated constraint overload.

3.4. Determine DER Curtailed Profile

For each timestamp where the excess power is greater than zero, the Curtailment Assessment Tool gathers the list of DERs which can be curtailed to resolve the constraint based on a LIFO principle of access per constraint and based on the firm/flexible attribute.

The following formula is used to calculate the amount of curtailment required to alleviate the constraint for each DER in the stack, based on the DER sensitivity factor with respect to the constraint. This is capped by the amount of power being produced by the DER at any given time.

$$P_{DER_curt_required} = \max(P_{DER_original}, P_{excess} \times SF_{DER}^{Constraint})$$

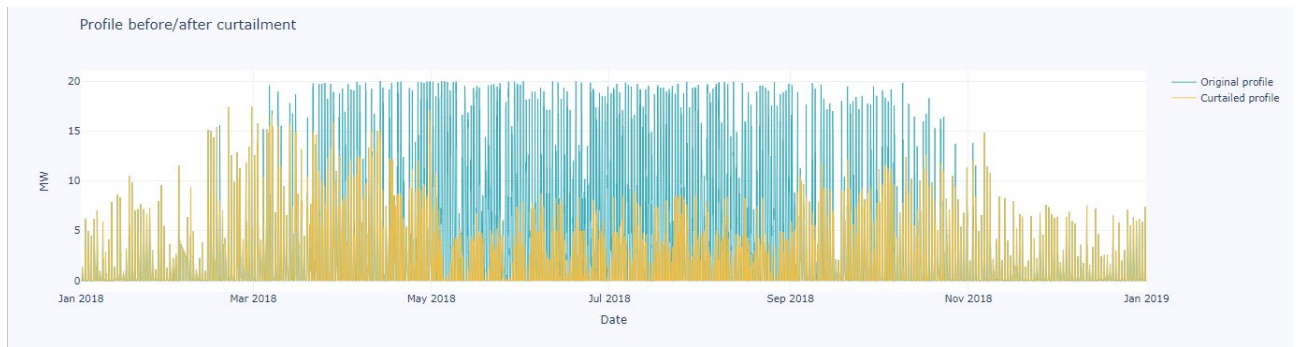


Figure 6: Curtailed and uncurtailed profile

3.4.1. Detailed Curtailment Methodology

If multiple nested constraints (e.g. circuit, grid site, 132kV circuit, SGT) are active at the same time, the tool resolves the constraints starting with the constraints at lower voltages and then moving to constraints at higher voltages. It resolves Sum Constraints first, then transformers and finally circuits. When there are two assets of the same type and voltage level (e.g., two grid transformers), it resolves the most onerous constraint first (e.g., the grid transformer with the highest overload at that timestamp will be resolved first).

The Curtailment Assessment Tool then updates the power flow of the given constraint and the power flow of all other constraints affected by the DER (based on the sensitivity factor). By ensuring that all constraints are updated, the Curtailment Assessment Tool considers how curtailing a DER affects each constraint. This prevents the need to curtail the same DER multiple times within the same half hour due to different constraints. After this, the Curtailment Assessment Tool proceeds with the next set of active constraints for that given timestamp, curtailing DERs as required, if no other constraints are active, or if the DERs cannot be curtailed further (i.e., the DER output has been curtailed to zero), it proceeds with the next timestamp.

Once all timestamps are completed, the Curtailment Assessment Tool calculates the final curtailed profile for each of the DERs. A detailed curtailment methodology is shown in

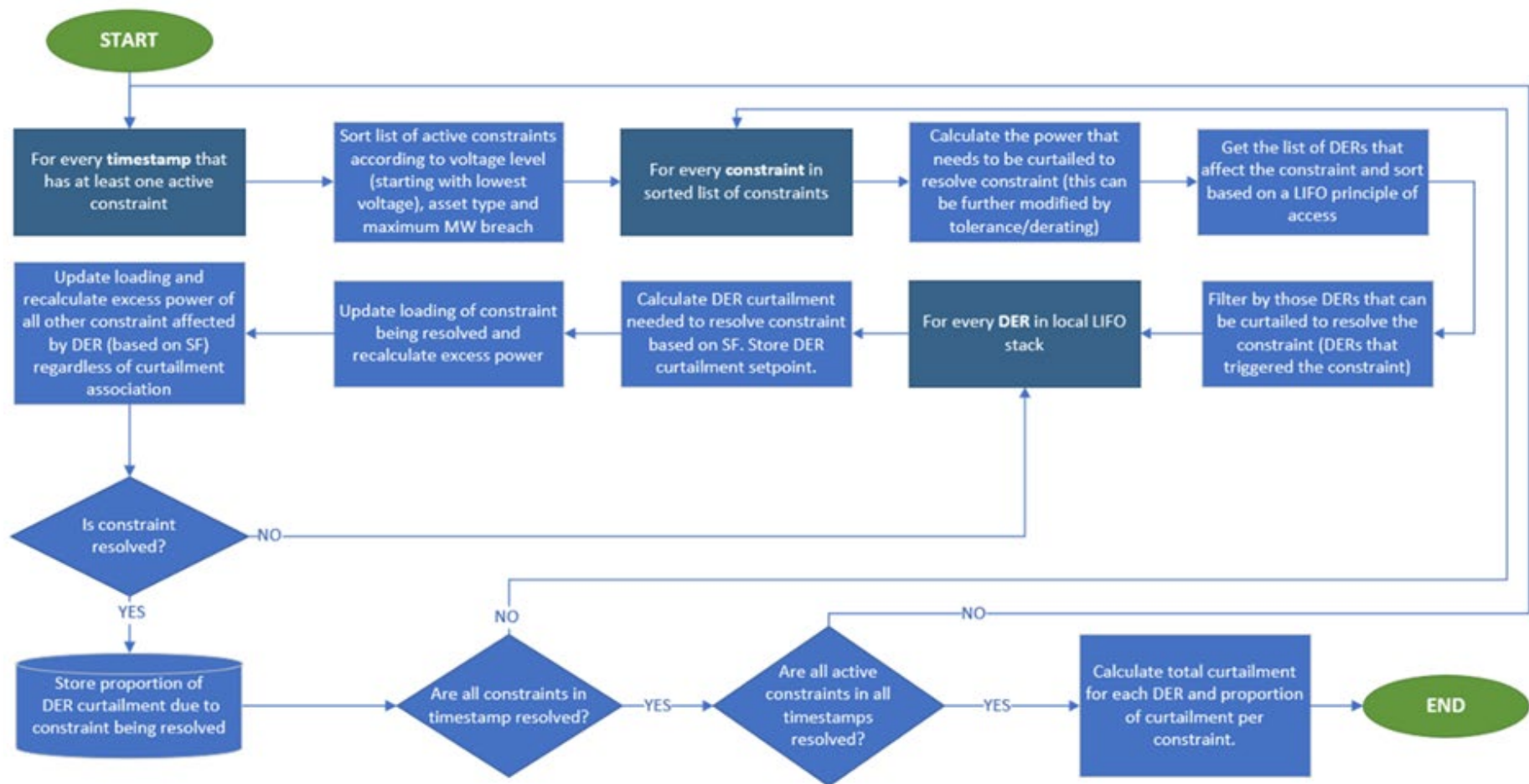


Figure 7: detailed curtailment methodology flowchart.

3.5. Energy Lost Curtailment

The Curtailment Assessment Tool then determines the energy lost (kWh) due to curtailment by comparing the uncurtailed profile i.e. the output of the DER if it was not curtailed, which comes from the technology specific profiles, to the curtailed profile that has just been calculated, as shown in the equation below.

$$\text{Energy Lost (kWh)} = \sum_{\substack{\text{for each} \\ \text{timestamp} \\ \text{in the year}}} \text{uncurtailed output} - \text{curtailed output}$$

Finally, the percentage of curtailment is calculated as the energy lost divided by the uncurtailed output [kWh].

$$\% \text{ Energy curtailed} = \frac{\text{Energy lost (kWh)}}{\text{Uncurtailed energy (kWh)}}$$

3.6. Curtailment per Constraint

The curtailment tool stores the amount of curtailment driven by each constraint for each timestamp (i.e., each half hour of the year) and it then generates a breakdown of curtailment per constraint as percentage of the total curtailment (in MWh), as shown Figure 8.

When the site is subject to multiple nested constraints, the curtailment breakdown per constraint might show that most, or all, of the curtailment at the site is driven by the most dominant constraint. However, this doesn't necessarily mean that the other constraints are never going to be breached as they might then become active if the most dominant constraint is lifted.

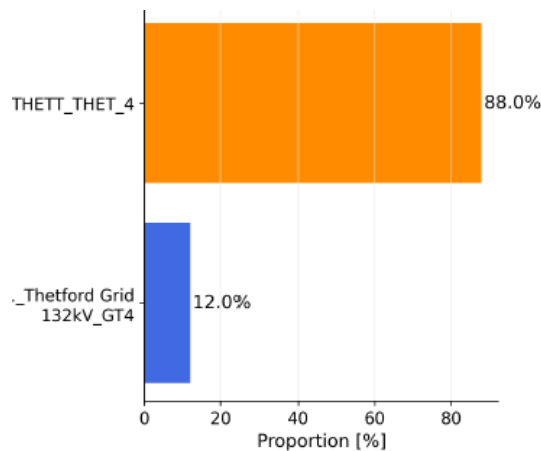
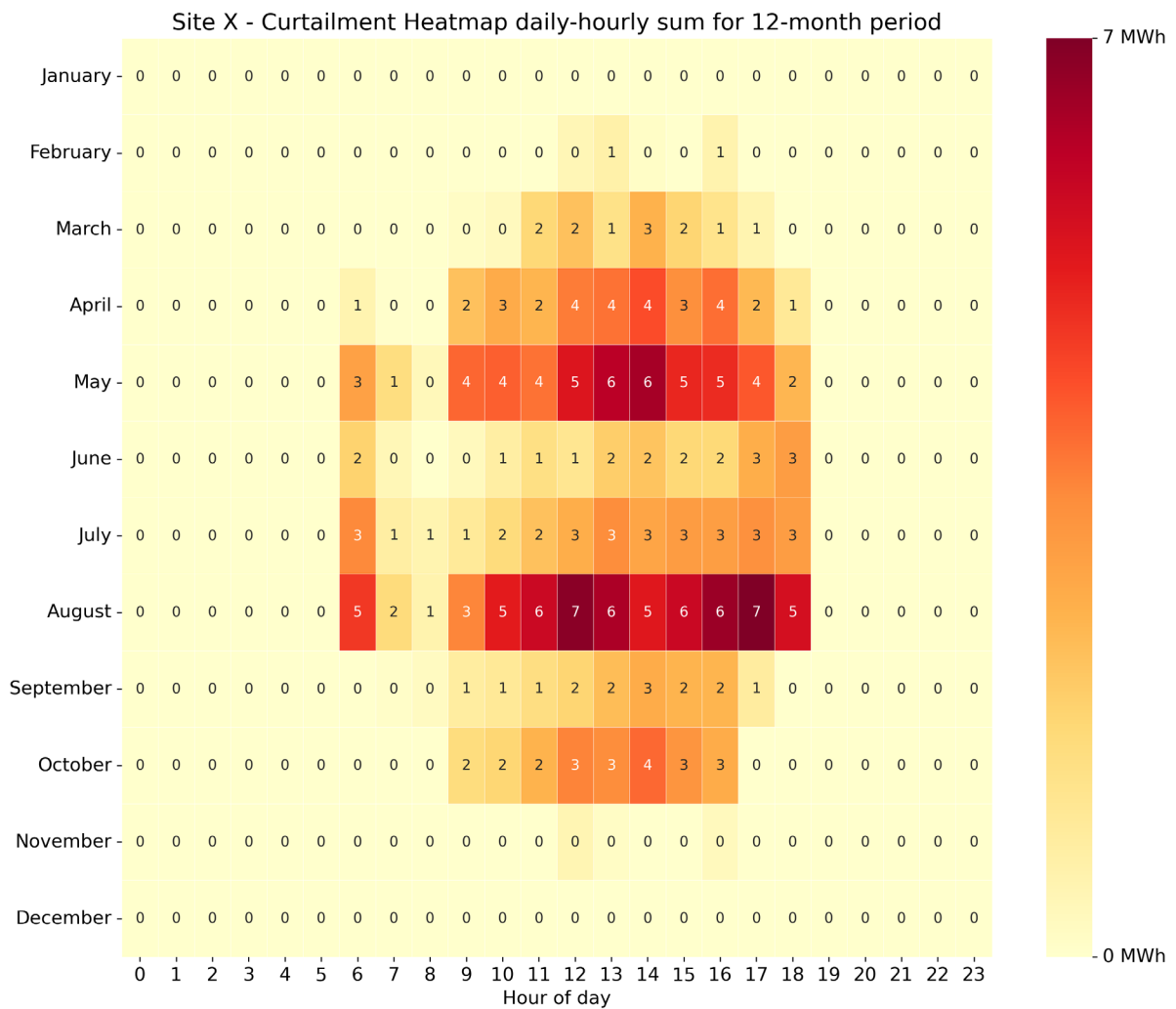


Figure 8: breakdown of curtailment per constraint.

3.7. Curtailment Heatmap

The curtailment tool then generates a curtailment heatmap which illustrates the estimated curtailment for one year of operation. Each cell represents the aggregated estimated curtailment (i.e., the sum) for a specific hour of the day (x-axis) and month of the year (y-axis) in MWh.

This is done by summing the curtailment (MWh) amount for each half an hour of the day for each month of the year (e.g. the sum of the energy curtailed between 1-2pm for each day in January, February, March etc). Summing up all the cells in the heatmap results in the total energy (MWh) lost throughout the year, which is equivalent to the energy lost (kWh) due to curtailment, discussed in the previous section.



4. Summary of Curtailment Assumptions

The main assumptions that have been used in the curtailment studies are summarised in Table 1.

Table 2: Summary of assumptions

Area	Assumption
a) Network Configuration	<ul style="list-style-type: none"> • Curtailment studies are carried out for 12 months of intact running arrangement. Abnormal running arrangements including planned and unplanned network outages are not considered in the study. • In areas where significant reinforcement is due to be delivered (past Gate C), the future running arrangement is used in the curtailment study.
b) Network Boundary	<ul style="list-style-type: none"> • If a GSP is running in isolation (e.g. Burwell) curtailment is run for the individual GSP; if multiple GSP running in parallel (e.g. Braintree and Rayleigh) curtailment is run for the group of GSP running in parallel.
c) Constraint ratings	<ul style="list-style-type: none"> • Seasonal cable and overhead line ratings are used in the study and come from PowerFactory. • Transformer ratings from PowerFactory are used in the study and are applied where the nature of the constraint is thermal. If the limiting factor is the DOC or tap changer reverse power flow, these limits are used in the curtailment studies. • Continuous seasonal ratings (if available) are used both for intact and post fault network constraints (managed pre-fault) Limits on the Grid Supply Points applied by National Grid through the Appendix G / F process are considered in the study, including Technical Limits.
d) Curtailment thresholds	<ul style="list-style-type: none"> • If the identified constraint is active post fault i.e. following the loss of a circuit or a transformer, UK Power Networks' DERMS system secures in anticipation of the fault to avoid short term overloads on the network occurring. This is reflected in the curtailment studies where the asset limit is considered to be the N-1 capacity of the asset. • The curtailment threshold is calculated applying an operational margin of 10% on the constraint rating to cater for power flow swings at the constraint and reflects the real-life implementations of DERMS.
e) Principle of Access	<ul style="list-style-type: none"> • Last In First Out (LIFO) principle of access adopted, based on the application date.
f) Connected load and generators	<ul style="list-style-type: none"> • Load are modelled in PowerFactory based on observed demand in the latest calendar year. • Generators connected for more than 2 years are modelled in PowerFactory based on their historical profiles. Once the site under study is operational, if the sites above in the stack operates than how they have operated in the past, this might cause curtailment of the site under study to increase or decrease. • Generators that have been energised less than 2 years ago, a technology specific profile is used. • Half Hourly load flows are then executed with 30 minutes resolution for the most recent year of demand data available, to produce the background power flow.

g) Demand and small-scale generation growth	<ul style="list-style-type: none"> No demand growth is assumed in the studies. No small-scale generation growth (G83/G98 and sub-200kVA G99) is assumed in the studies.
h) Acceptances and in-flight offers	<ul style="list-style-type: none"> The contribution of acceptances and in-flight offers are added on top of the background power flow previously calculated. All Acceptances and in-flight offers are considered to materialise. Acceptances and in-flight offers are modelled based on their technology specific profile.
i) Uncurtailed profile of the site being studied	<ul style="list-style-type: none"> The site being studied is modelled based on its technology specific profile (in per unit) and multiplied for the export capacity of the site. Technology Specific profiles are available here and have the following capacity factor. <ul style="list-style-type: none"> solar - 14.20% capacity factor wind - 30.14% capacity factor non-variable - 100% capacity factor energy storage - 52.05% capacity factor energy storage + solar - 54.61% capacity factor The sites are modelled at unity power factor, no reactive power contribution is considered for curtailment studies. For this reason, active power (MW) can be considered equal to the apparent power (MVA).
j) Sensitivity Factor	<ul style="list-style-type: none"> DERMS uses sensitivity factors to establish a relationship between a constraint location and a DER. Sensitivity Factors are used to determine the volume of curtailment required to remove the network constraints. UK Power Networks has set a threshold sensitivity factor of 5% below which a customer is not considered to have a contribution to the constraint and will not be associated to it.

5. Curtailment Data in the Open Data Portal

Most of the data required to carry out curtailment studies by third parties are now available in UK Power Networks' Open Data Portal. To find out more about our datasets or to raise any questions, please contact our dedicated DSO Data Team at: dso.data@ukpowernetworks.co.uk

Historical Power Flow

- SGT: [Super Grid Transformer Power Flow Historic — UK Power Networks \(opendatasoft.com\)](#)
- 132kV Circuits: [132kV Circuit Operational Data Half Hourly — UK Power Networks \(opendatasoft.com\)](#)
- Grid Transformers: [Grid Transformer Power Flow Historic Half Hourly — UK Power Networks \(opendatasoft.com\)](#)

Ratings/Limits

- Technical limits: [Network Operational Data Dashboard — UK Power Networks \(opendatasoft.com\)](#)
- circuits: [Long Term Development Statement \(LTDS\) Table 1 Circuit data — UK Power Networks \(opendatasoft.com\)](#)
- transformers: [Long Term Development Statement \(LTDS\) Table 2a Transformer Data - 2W — UK Power Networks \(opendatasoft.com\)](#)

DER

- above 1MVA: [Embedded Capacity Register 2 - 1MW and above — UK Power Networks \(opendatasoft.com\)](#)
- below 1 MVA: [Embedded Capacity Register 1 - under 1MW — UK Power Networks \(opendatasoft.com\)](#)
- standard technology specific profiles: [Standard profiles UK Power Networks uses for electricity generation — UK Power Networks \(opendatasoft.com\)](#)

Outage data: [EHV Network Outages — UK Power Networks \(opendatasoft.com\)](#)

Curtailment history: [Constraint Breaches History — UK Power Networks \(opendatasoft.com\)](#)

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UK Power Networks (Operations) Limited

DSO

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