Conditional grid connections

A literature review

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High demand for electrification and intermittent generation lead to new challenges for grid operators. Conditional connections can serve as a tool to increase the value of existing grid infrastructure and postpone or even prevent the need for grid reinforcement. It can help as a tool for TSOs and DSOs to connect their customers faster before eventually moving to firm connections. For some users, a permanent non-firm connection in return for lower grid tariffs might even present a business opportunity.

The report contains an overview of existing literature about economic and technical consequences of conditional connections. Complemented by case studies of countries that use or are planning to use non-firm connection arrangements, we give a broad overview about different design choices for conditional connection agreements, their implications and experiences.

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SAMMANDRAG PÅ SVENSKA

Bakgrund och syfte

Efterfrågan på nätkapacitet ökar framöver. Energiomställningen innebär dels att mer distribuerad och väderberoende produktion (DG) ansluts till nätet, dels att efterfrågan på effekt ökar mer än efterfrågan på energi. Mot denna bakgrund kan villkorade avtal underlätta problem i elnätet och därmed ge samhällsekonomiska vinster.

- Öka kapacitetsutnyttjandet: Användning av villkorade avtal kan bidra till att nätkapaciteten utnyttjas bättre och att det samlade behovet av investeringar i nätet reduceras.
- Möjliggöra tidigare anslutning: Användning av villkorade avtal kan göra det möjligt att ansluta fler kunder tidigare, innan nätbolagen hinner att utöka nätkapaciteten.

Målet med litteraturstudien är att ge ett grundligt faktaunderlag for Ei:s vidare arbete om villkorade avtal. Studien omfatta de samhällsekonomiska och tekniska konsekvenserna av att införa villkorade avtal och bygger på akademisk litteratur, erfarenheter från hur andra länders tillsynsmyndigheter har arbetat med temat och synpunkter hämtat från berörda intressenter.

Sammanfattning av insikter från den akademiska litteraturen

Allmänna iakttagelser

Den akademiska litteraturen fokuserar nästan uteslutande på villkorad anslutning av så kallade distribuerad produktion (DG) som en åtgärd för att underlätta tidigare anslutning till nätet, och därmed som en tillfällig åtgärd. Sådana avtal är frivilliga för producenten. Alternativet är att vänta på nätutbyggnad som möjliggör en s.k prima anslutning. En mellanväg där villkorad anslutning tillämpas tills anslutningsavgifterna kan delas mellan flera DG:er, nämns också.

Avkortningsstrategier

Allokeringsprinciper eller avkortningsstrategier som avgör hur den begränsade kapaciteten ska fördelas mellan producenterna måste beskrivas i de villkorade avtalen. En betydande del av litteraturen fokuserar på effektiviteten av olika avkortningsstrategier, eller principer för tillgång. En rad avkortningsstrategier nämns i litteraturen, men LIFO och pro-rata är de mest använda principerna och analyseras därför mer ingående.

DSO:erna bestämmer principen och valet av en begränsningsstrategi kan påverkas av faktorer som befintliga nätförhållanden eller tariffstruktur. Vägledande principer eller kriterier för utvärdering av olika avkortningsstrategier inkluderar transparens, förutsägbarhet, enkelhet, rättvisa, effektivitet och kostnadseffektivitet.

Litteraturen identifierar dock inte tydligt en enda optimal avkortningsstrategi. Dels finns det avvägningar att göra mellan komplexitet och optimalitet. Dessutom beror det på den specifika situationen i nätet och sammansättningen av produktionen, utformningen av villkorade avtal och viktningen av andra principer såsom rättvisa och hållbarhet.

Incitamenten för DG:erna

Litteraturen diskuterar hur olika modeller och principer påverkar fördelningen av kostnader och risker, och följaktligen DG:ernas incitament att välja villkorade avtal. Följande designelement spelar en roll:

- Kompensationssystemet (kompensation för minskad energiproduktion)
- Hur många och vilka andra som har villkorade avtal
- Den maximala avkortningsgraden, hur den bestäms, om den är fast eller begränsad osv.
- Avtalets längd
- Fördelning av specifika anslutningskostnader
- DG:ens kapacitet (storlek)
- Diskonteringsräntan

Krav på DSO:erna

Ett annat återkommande tema i litteraturen är vad som krävs av DSO:erna för att de ska kunna använda villkorade avtal effektivt som ett alternativ till nätinvesteringar. Å ena sidan måste nätägaren bedöma kostnaderna av villkorade avtal kontra nätinvesteringar. Å andra sidan måste hen ha system på plats för att avkorta produktionen vid risk för överbelastning i nätet. Nödvändiga system och verktyg som identifieras i litteraturen inkluderar optimal flödesanalys, aktiv nätverkshantering, effektiv nätverkskontroll och utformning av villkoren i avtalet om avkortning.

Fallstudier

Den akademiska litteraturen innehåller också en hel del fallstudier och jämför fall från olika länder. Här nämns det bredare regelverket och policyramen som en faktor som spelar en roll i utformningen och användningen av villkorade avtal, inklusive tariffstruktur och mål och subventioner för förnybar produktion. Utformningen av flexibilitetsmarknader och samordning mellan TSO och DSO nämns också, men analyseras inte vidare.

Beräknade kostnadsbesparingar

För det mesta uppskattas inte kostnadsbesparingar, med några anmärkningsvärda exempel. De få uppskattningar som presenteras tyder på att besparingarna genom att implementera villkorade avtal kan bli avsevärda.

Sammanfattning av regulatoriska erfarenheter

Villkorliga avtal vid anslutning av nya kunder har först nyligen ansetts mer allmänt som ett verktyg för att hantera kapacitetsutmaningar i distributionsnät, främst relaterade till tillväxten i distribuerad produktion. Därför är införandet av villkorade avtal till största delen i ett tidigt skede i de länder som omfattas av vår undersökning. Vår kartläggning täcker, såvitt vi vet, de länderna som har kommit längst i införandet av sådana system. Vissa länder har implementerat system för villkorade avtal och redan skördat viss erfarenhet. Andra har nyligen implementerat systemet eller håller på att utvärdera dess införande.

Förutom diskussioner om samma designelement som omfattas av den akademiska litteraturen, fokuserar regleringsprocesserna också på:

- Inverkan av villkorade avtal i distributionsnätet på högre nätnivåer och behovet av samordning mellan nätnivåer
- Användning av villkorade avtal på TSO-nivå
- I vilken utsträckning aktörer på villkorade avtal kan delta på balans- och flexibilitetsmarknader
- Inkludering av villkorade avtal vid anslutning av laster (förbrukning)
- Möjligheten att erbjuda blandade prima/sekunda avtal eller tillfälliga sekunda arrangemang
- Regler för uppsägning av avtalen
- Ersättning i form av reducerad nättariff, dvs. ersättning inte begränsat till lägre anslutningsavgifter

I Storbritannien, ett land med stor erfarenhet av villkorade avtal, fokuserar den senaste nätanslutningsreformen på förenkling, att reducera bördan för små nätkunder och att stärka DSO:ernas incitament att kontinuerlig investera i nätet, även om de har möjlighet att använda villkorade avtal. Reformen är delvis relaterad till behovet av att påskynda anslutning av DG för att uppnå landets netto noll-mål.

Irland, som introducerade sekunda avtal för mer än två decennier sedan, tittar å andra sidan nu på att implementera en mer sofistikerad modell för villkorade avtal. På TSO-nivå ska en årlig översyn hjälpa till att flytta nätanvändare från villkorade till prima avtal snabbare, medan på DSO-nivå kommer nuvarande, enkla villkorade avtal gradvis att utökas mot full aktiv nätverksdrift under det kommande decenniet.

Medan många länder har implementerat detaljerade regler och standarder, har Norge valt rambestämmelser som överlåter utformningen och detaljerna i villkorade avtal till de enskilda nätägarna och nätanvändare som vill ingå ett avtal.

Reformen är ganska ny och erfarenheter av olika system har ännu inte kartlagts.

Nederländerna tycks gå en annan väg genom att främja utvecklingen av marknadsbaserad flexibilitetsupphandling som det instrument med vilket DSO:er kan hantera överbelastningar, i stället för villkorade avtal.

SUMMARY AND CONCLUSIONS

Background and objectives

The demand for network capacity is set to increase. The energy transition means that more distributed and weather-dependent generation (DG) is connected to the grid, and that the demand for power capacity increases more than the demand for energy. Against this background, conditional connection agreements can alleviate challenges in the grid and provide significant socio-economic gains:

- Increase capacity utilization: Conditional connections can contribute to better utilization of the grid capacity and to reduce or defer the need for grid investments.
- Enable earlier connection: Conditional connections can make it possible to connect more customers earlier, before the grid companies have time to expand the network capacity.

The aim of the literature study is to provide a thorough factual basis for Ei's further work on conditional connection agreements. The survey covers the socio-economic and technical consequences of introducing conditional connections, and is based on academic literature, experiences from other countries' regulators work with the theme, and views from other stakeholders.

Summary of insights from the academic literature

General observations

The academic literature focuses almost exclusively on conditional connection of distributed generators (DGs) as a measure to facilitate earlier connection to the grid, and consequently as a temporary measure. Such agreements are voluntary for the DGs, and the alternative is to wait for grid expansion that allows for firm connection. An intermediate solution, where conditional connection is applied until connection charges can be shared among several DGs, is also mentioned.

Curtailment strategies

Allocation principles or curtailment strategies determining how the constrained capacity should be allocated among generators need to be outlined in the conditional connection agreements. A significant share of the literature focuses on the efficiency of different curtailment strategies, or principles of access. A range of curtailment strategies are mentioned in the literature, but LIFO and pro-rata are the most frequently used principles and are therefore analysed more thoroughly.

The DSOs determine the principle, and the selection of a curtailment strategy may be influenced by factors such as the existing grid conditions or tariff structure. Guiding principles or criteria for the evaluation of different curtailment strategies include transparency, predictability, simplicity, fairness, efficiency and cost-effectiveness.

However, the literature does not clearly identify a single optimal curtailment strategy. Partly, there are trade-offs to be made between complexity and optimality. Moreover, it depends on the particular grid situation and generation mix, the design of the connection agreement and weighting of other principles such as fairness and sustainability.

DG incentives

The literature discusses how different models and principles affect the allocation of costs and risks, and consequently, the incentives to opt for conditional connection by DGs. The following design elements play a role for DGs:

- The compensation scheme (compensation for curtailed energy)
- The stack of conditional connection agreements
- The maximum curtailment rate, how it is determined, whether it is fixed or capped, etc.
- The length of the agreement
- The allocation of reinforcement costs
- The capacity of the DG (size)
- The discount rate

What is required of DSOs

Another recurring theme in the literature is what is required of the DSOs in order for them to use conditional connection agreements efficiently as an alternative to grid investments. On the one hand, the DSO must assess the efficiency of conditional connection versus grid investment. On the other hand, it must have systems in place for curtailing of DGs in case of congestions in the grid. Necessary systems and tools identified in the literature include optimal flow analysis, active network management, effective network control, and contractual arrangements.

Case studies

The academic literature also contains quite a few case studies and compares cases from different countries. Here, the wider regulatory and policy framework is mentioned as a factor that plays a role in the design and use of conditional connections, including network tariff structures and renewable generation targets and support schemes. The design of flexibility markets and TSO/DSO coordination is also mentioned, but not further analysed.

Estimated cost savings

For the most part, cost savings are not estimated, with a few noteworthy examples. The few estimates that are presented, indicate that savings from implementing conditional connections may be substantial.

Summary of insights from regulatory experiences

Conditional connection schemes have only recently been more broadly considered as a tool to manage capacity challenges in distribution grids, mainly related to the growth in distributed generation. Therefore, the introduction of conditional connections is for the most part in early stages in the countries that are covered in our survey. Our survey covers, to our knowledge, the most advanced approaches available. Some countries have implemented conditional connection schemes and already reaped some experience. Others have just recently implemented such a scheme or are in the process of assessing its implementation.

Apart from discussions of the same design elements that are covered by the academic literature, the regulatory processes also focus on:

- The impact of conditional connections in the distribution grid on higher grid levels and the need for coordination between grid levels
- The use of conditional connection on the TSO level
- The extent to which actors on conditional connection agreements can participate in balancing and flexibility markets
- The inclusion of loads as eligible for conditional connection
- The option to offer mixed firm/non-firm connection agreements or temporary non-firm arrangements
- Exit conditions
- Compensation in the form of grid tariff reduction, not limited to solely connection charges

In the United Kingdom, a country with considerable experience with non-firm access agreements, the most recent grid access reform focuses on simplification, shielding small grid customers and strengthening the incentives for continuous grid reinforcement for DSOs, also in the presence of curtailable connections. The reform is partly related to the need to accelerate connection processes to achieve the country's net zero targets.

Ireland on the other hand, who introduced non-firm connections more than two decades ago, is now looking at implementing a more sophisticated non-firm connection model. On the TSO level, an annual review shall help to move grid users from non-firm to firm connections faster, while on the DSO level, current, simple conditional connection arrangements will be gradually expanded towards full active network management in the coming decade.

While some countries have implemented detailed regulations and standards, Norway has opted for framework regulations that leave the design and details of conditional connection agreements to the individual DSOs and grid users that want to enter into an agreement. The reform is fairly new, and experience with different schemes has not yet been collected.

The Netherlands seems to pursue a different route by favouring the development of market-based flexibility procurement as the instrument by which DSOs manage congestions, instead of conditional connection agreements.

1 INTRODUCTION

1.1 Background

The demand for grid capacity in Sweden is increasing due to connection of more distributed and weather-dependent generation in distribution grids. The structure of electricity consumption is also changing, with demand for capacity is growing faster than the demand for energy.

In view of this situation, the Swedish energy market regulator, Energimarknadsinspektionen (Ei), is considering to what extent conditional or non-firm grid connection can be used to increase the efficiency of grid connection and investments.

There are three main reasons why increased utilization of flexibility in grid operation could be economically beneficial:

- The utilization rate is decreasing, and thus, the risk that the cost of new capacity exceeds the value of the capacity increases.
- The lead-times for build-out of new grid capacity are longer than the lead-times for small-scale distributed generation and new demand. By utilizing flexibility, new demand can be connected earlier.
- Technology development of control and management systems as well as storage solutions such as batteries, has made more flexibility available for utilization, and has reduced the cost of flexibility.

Flexibility can be used as a *temporary* arrangement to connect new generation or loads earlier than what would otherwise be possible for technical reasons or due to uncertainty about the future demand for capacity. Flexibility can also be used as a *permanent* arrangement as an alternative to investments in grid capacity.

Solutions for the use of flexibility in grid operation may be designed in different ways and with different levels of sophistication. The choice of solution depends on factors such as the network challenge, the magnitude of the problem and the underlying flexibility potential. In general, if the grid companies are to utilize flexibility, the flexibility needs to have the right characteristics and the right location.

1.2 Overview of the report

The challenges and discussions about conditional connection agreements are not specific to Sweden. As a basis for the assessment of whether, to what extent and how conditional connection can be used in the Swedish context, we have been awarded the assignment to survey the literature on conditional connections, including academic work, reports assigned by or carried out by regulatory authorities elsewhere, and reports documenting the experiences and concerns published by other stakeholders.

This report summarizes our findings from the literature study, focussing on the following main issues:

- What challenge or problem is the conditional connection agreements designed to handle?
- What are the specific design elements of the conditional connection agreements that have been assessed or implemented?

2 ACADEMIC LITERATURE

2.1 Background

The academic literature on conditional connections is limited. We have surveyed 13 relevant and publicly available academic papers and white papers. The papers almost exclusively consider conditional connection of distributed renewable generation to distribution networks. A large share of the literature also relies on case data from the UK which has been one of the leading countries trialing and implementing conditional connection agreements.

Some of the papers provide extensive insights on factors and terms of conditional connection, whereas other papers focus on a few or a single aspect relating to such agreements.

2.2 Overview of the surveyed literature

The main challenge for conditional connections in the literature is the expansion and integration of distributed generation into distribution networks not accommodated to the connection of (variable) generation. Conditional connection solutions and agreements are motivated by faster and more cost-effective expansion of distributed generation, particularly renewables.

The papers reviewed consider financial, technical and contractual aspects of conditional connections. The methods applied to examine conditional connections include CBAs, theoretical analyses of contractual arrangements including comparison of Principles of Access (PoA), comparisons of experiences from different countries, and technical studies based on trials. The previous literature reviewed in some of the articles include studies of the impact of renewable integration on the grid, trade-offs of deferring grid investments, the impact of different rules and comments on some trials and schemes in various countries.

The papers cover a wide variety of aspects using different methodologies, so creating a common framework for comparison of the papers is challenging. An overview of the main aspects covered in the articles is in included in Table 1.

Further insights provided by the academic articles are explored in more detail in sections 2.2.1-2.2.13 reviewing each article in depth. Section 2.3 provides an overview of important design features of conditional connection agreements.

Table 1 Overview of surveyed academic papers

Study	Challenge	Considered alternatives	Eligible parties	Main design features	Case studies	Assessment criteria	Focussed issues
Anaya & Pollitt (2014)	Integration of generation to power grids using smart solutions.	Conditional connections (PoA)	DGs	Optional Various curtailment principles Various compensation schemes Various connection and reinforcement costs	GB, Ireland, Northern Ireland, USA	Cost-effectiveness for DNOs and generators. Economic and social efficiency.	Social optimality of PoA approaches and allocation of risk regarding curtailment and investment
Anaya & Pollitt (2015)	Encourage cost-effective expansion of renewable DG to meet growing electricity demand whilst avoiding/ reducing grid investment costs.	Conditional connection and non-conditional connection	DGs	Optional Pro rata curtailment No compensation for curtailed electricity Various connection and reinforcement costs	UK (Flexible Plug and Play)	Benefits for DG projects based on NPV	How to connect more DGs more efficiently, and what affects the DGs economic incentive to opt for interruptible connection
Anaya & Pollitt (2017)	Growth in DG generation Distribution networks not accommodated for generation.	Conditional connection,	DGs	Optional Pro rata curtailment No compensation for curtailed electricity	UK (Flexible Plug and Play)	NPV for different parties, distribution between parties	The effect of different connection scenarios on the benefits of interruptible connection
Anaya & Pollitt (2021)	Managing fluctuations from intermittent renewable generation on local distribution systems	Potential sources of flexibility services (markets, tariffs, connection arrangements)	DGs	N/A	Austria, France, Germany, GB, Japan, Netherlands and Norway		The role of regulation to promote the use of flexibility in distribution networks, survey of seven countries
Andoni et al. (2017)	Rising penetration of DG, handling curtailment.	Conditional connections (PoA)	DGs	Optional Various curtailment principles Compensation scheme and connection costs not specified	UK	Capacity factor	Comparison of the efficiency and fairness of different curtailment rules
Boehme et al. (2010)	Method for estimating/ predicting advantages/ disadvantages of non-firm connections	Conditional connections	DGs	Optional Last-in-first-out type curtailment principle	Scotland, Orkney Islands	Efficiency of dispatch	The challenges and opportunities offered by non-firm connections A methodology to analyze the need for curtailment in grid operation

Study	Challenge	Considered alternatives	Eligible parties	Main design features	Case studies	Assessment criteria	Focussed issues
Currie et al. (2011)	Identifying PoAs that can be implemented in an ANM scheme.	Conditional connections (Principle of Access - PoA)	DGs	Various curtailment principles		Multi-criteria assessment (technical, commercial & regulatory)	Evaluation of PoA and recommendations about their potential in rolling out ANM technology
Foote et al. (2013)	Connection of new wind capacity to a full network and improving ANM scheme	Active network management	DGs		Scotland, Orkney Islands	Efficiency of ANM scheme	Evaluation of the use of active network management (ANM) when connecting new wind capacity to a full network
Furusawa et al. (2019)	Rapid DG expansion	Conditional connection and non-conditional connection	DGs	Temporary Optional Various curtailment principles Various compensation schemes. Various connection costs	Germany France/ Belgium UK	Acceptability by DGs Practicability for DSOs	Evaluation of models for constrained connection in four countries: What are the feasibility and effectiveness of different approaches?
Plecas et al. (2017)	DG expansion in distribution networks	Voltage management strategies	DGs	Alternative 1: Raising point-of-connection voltage limit Alternative 2: Increased demand Alternative 3: Non-firm connection	Scotland, Orkney Islands		The application of voltage management profiles and integration of DG into voltage-constrained feeders
Electric Power Research Institute (2018)	Increase distribution system utilization, allowing more DG, lowering the cost of DG integration	Conditional connections and non-conditional connections	DGs	Voluntary New connections	N/A	Hosting capacity of network	Explaining the concept of flexible interconnection and potential implications for utility processes
Electric Power Research Institute (2020a)	Rising penetration of DG, avoiding traditional infrastructure upgrades, securing a commercial environment conditional for connections	Conditional connections	DGs	Voluntary LIFO and pro rata curtailment principles Various connection and reinforcement costs	Not specified, based on experiences of early adopter utilities.	Capacity factors and curtailment levels for DGs, upgrade incentives	Principles of access and different rules of curtailment

Study	Challenge	Considered alternatives	Eligible parties	Main design features	Case studies	Assessment criteria	Focussed issues
Electric Power Research Institute (2020b)	Rising penetration of DG, avoiding traditional infrastructure upgrades, securing a commercial environment for conditional connections	Conditional connections	DGs	Voluntary LIFO and pro rata curtailment principles Various connection and reinforcement costs	Not specified, based on experiences of early adopter utilities.	Allocation of costs and incentives for reinforcement	Principles of access and cost allocation mechanisms for grid upgrades

2.2.1 Anaya and Pollitt (2014)

Anaya, K. L. & Pollitt, M. G. (2014). Experience with smarter commercial arrangements for distributed wind generation.

Challenge

- Accelerating the integration of generation to power grids using smart solutions.
- Identifying arrangements that are cost-effective for DNOs and generators and economically and socially efficient.

Increasing such connections can influence the grid negatively in terms of voltage fluctuation and regulation, thermal capacity congestion, power factor correction, frequency variation and regulation and harmonics.

With interruptible connections, network reinforcement can be avoided or deferred.

Smart solutions help reduce curtailment levels and can be particularly useful for the integration of intermittent generation. Smart solutions make it possible to determine the exact available capacity at a node in real time and allocate the curtailment to meet the available capacity.

Methodology

Comparison and evaluation of the implementation of different curtailment strategies, LIFO, Pro-rata and Market based, in Great Britain, Ireland, Northern Ireland and the USA.

The evaluation considers the social optimality of the approaches, and how curtailment and investment risks are allocated between the DSO, generators and customers.

Criteria for case selection

1) Maturity of wind generation market, more mature markets indicate a more mature regulatory framework that has promoted renewables.
2) Experiences with relevance to DSOs wishing to promote the connection of small-scale wind. Preference given to studies using smart solutions and practice of curtailment methods.

Main insights

If risk is ignored

- the market-based approach is superior to LIFO and Pro-rata because it signals the true cost of curtailment, and
- LIFO is superior to Pro-rata because LIFO exposes the DGs to marginal rather than average connection costs.

However, as private risk may be higher than the true social risk of connection, it may be a good idea to reduce the risk of the marginal generator.

The allocation of curtailment risk differs across the case studies depending on several specific design elements such as the compensation scheme, the stack of non-firm connection agreements, and how the maximum hours of curtailment are determined.

Incentives for participation

The risk allocation of curtailment depends on the curtailment rules.

Requirements

- Optimisation and control of the network.
- Smart commercial arrangements to manage the amount and frequency of curtailment events and to attract investment in distributed generation.

General assessment of curtailment approaches

Last-in-first-out (LIFO)

Approach: Generators are curtailed in a specific order e.g., based on connection date. The last generator on the ranking is curtailed first. No regulatory or technological changes are needed to apply these changes.

Risk allocation: Risk is transferred to the marginal/ last generator.

Social optimality: Best because the last generator faces the marginal costs. Each generator is exposed to their marginal curtailment cost to the system and includes the rising curtailment cost.

Pro-rata

Approach: The curtailment is equally allocated among generators. The allocation can be based on installed or availably capacity, or another parameter.

Risk allocation: Equitable allocation among generators.

Social optimality: Each generator is exposed to the average cost of curtailment; the generator faces the average connection cost and sets this equal to marginal benefit (ignoring risk) which is not the social optimum because the connection imposes costs on other generators which are not taken into account.

Market-based

Approach: Generators bid for curtailment by offering a price. A barrier to establishing this approach can be the scale and complexity of distribution networks.

Risk allocation: Risk is transferred to the generator bidding and winning offers for being curtailed. Thereby the least-cost dispatch is selected.

Generators can pay the expected loss, pay more than expected loss to compensate for risk aversion or less than expected loss to reflect the avoided internal costs.

Social optimality: Provides a better signal of the true curtailment costs and is the most optimal allocation similarly to optimal dispatch. Considerable transaction costs and requires optimal market conditions. Moreover, generators are exposed to the uncertainty of and risk from other generators bidding behind the same constraint

Case studies Great Britain

Two case studies are considered, the Orkney ANM project and the National Grid Connect and Manage regime.

Design features

Orkney ANM

ANM was implemented on the Orkney Isles to make better use of the existing grid and for releasing capacity and allow for the connection of new generation.

- DSO has real time control of power output
- Only non-firm connections with specific ANM conditions. Offered to generators larger than 50 kW.
- Curtailment allocation based on Last-in first-out. Conditions for queuing: proof of planning consent and paid deposit as part of the commercial agreement.
- No reinforcement costs, but generators have to pay for communications and control equipment for the ANM scheme.
- No compensation mechanism for curtailed energy, risk is transferred to generation.

- Individual projects and program
- Encourages connection of renewables

Connect and Manage

- Implemented by system operator National Grid. Required changes to industry codes and license modifications.
- Full access right is the default option for connecting generation, but design variations can be considered to accelerate the connection date with non-firm access.
- Promoted faster connection of generation to the transmission network with firm access rights when local works were completed or planned.
- Generators are compensated and the curtailment costs are passed on and paid by all market participants.
- Market-based curtailment allocation. System operator tries to find the most cost-effective offers for system balancing.
- Encourages connection of renewables and non-renewables.

Expected gain

Orkney ANM

The ANM scheme implemented had a cost of £0.5 million whereas the reinforcement cost was estimated to £30 million.

Smart solutions have expanded the economic curtailment boundary from 15 MW to 25 MW.

Reduced waiting time.

Connect and Manage

Two-stage approach mitigates stranding risk to consumers due to the mechanism with minor reinforcements followed by major reinforcements.

Integration of generation to the transmission network.

Case studies Ireland and Northern Ireland

Design features

- The transmission system operator offers alternatives to turn down wind generation
- Pro-rata with removal of dispatch balancing costs for curtailment.
- No compensation for curtailment. Cheaper connection costs.
- Offering different levels of firmness:
  Fully firm access – after the completion of Associated Transmission Reinforcement (ATR).
  Non-firm basis access – given after the completion of Site Related Connection Equipment and safety ATRs.
  Partially firm access – intermediate approach, limiting export capacity to specific percentages based on maximum exporting capacity. (Mainly Ireland)
- Encourages connection of renewables

Expected gain

- Quicker connection and expansion of wind generation.

Case study USA

Design features

- Innovative procurement method, the Renewable Auction Mechanism (RAM), which is an attempt to combine generation and network costs in the allocation of subsidies
- Firm access
- Market-based procurement mechanism
- Encourages connection of renewables to distribution and transmission grid, generators up to 20 MW.
- Generators determine price based on time of delivery periods and allocation factors (peak/ off-peak periods). Least expensive projects are selected first up to the capacity limit of each conditional connection product. Three product categories: firm, non-firm peaking and non-

firm non-peaking. Transmission upgrade costs are also added to the cost of the bids and ranking.

Expected gain

- Incentivises fast connection of distributed generation which has to be within two years after the utility commission approval.

DSO take-aways

- Provide more transparency on network status so that generators can select the best connection points and allow the DSOs to better evaluate the network.
- Stakeholder involvement and engagement has been an important factor contributing the success and confidence in non-firm grid connections.

The connection agreement should:

- Include an optimal amount of generation capacity at each distribution node, but the challenge is to determine how to increase generation capacity without triggering incremental reinforcement in the network.
- Trade off the amount of compensation paid for curtailment, the reinforcement costs and the value of the distributed generation. Arrangements should minimize curtailment to reduce compensation payments.

2.2.2 Anaya and Pollitt (2015)

Anaya, K. L. & Pollitt, M. G. (2015): Options for allocating and releasing distribution system capacity: Deciding between interruptible connections and firm DG connections.

Challenge

- Increasing connection of renewable generation to distribution networks to achieve the energy targets of the EU Renewable Energy Directive from 2009.
- Innovative commercial and technical solutions are needed to meet growing electricity demand whilst keeping investment costs down.
- Approaches by the DSO to release capacity and connecting more DG cost-effectively and the financial effect on DG.

Definition of conditional connection

No specific definition.

Methodology

- Cost benefit analysis comparing the benefits of offering interruptible connection versus non-interruptible connections for DGs.
- Comparison of four scenarios for new DG connection

The scenarios capture different aspects such as connection size, number and type of generation plant, and the total volume of interruptible capacity, and how these aspects affect the decision to select the conditional connection option by an individual DG. Demand is fixed in all scenarios, and the estimated curtailment levels for the scenarios take into account the total interruptible capacity and type of generation technology.

The analysis is based on Flexible Plug and Play trial in the UK for a specific constrained area with a particular network configuration. The study does not quantify the benefits DSOs can capture by connecting more DG.

Main Insights

Operational and contractual issues facing a DG customer when deciding on interruptible and non-interruptible connections:

- The profitability of conditional connections compared to firm connections depends on the curtailment level – the more curtailment, the lower the NPV when lost energy generation is not compensated.
- How the reinforcement costs are allocated among DGs can affect the choice between firm and non-firm connection. If reinforcement costs are shared among several DGs, the threshold for choosing firm connection is lower.

- The threshold is lower for small DGs if costs are allocated according to installed capacity.

Context

- Only interruptible connections are possible in an area without major network reinforcement.

Incentives

- DSO: More and faster connection of DG customers with lower grid investments.
- DG: Lower connection tariff by avoiding system reinforcement or paying for longer sole use connection (impacts project viability).

Requirements

DSOs must employ Active network management (ANM) and apply innovative commercial arrangements:

- Determine rules for curtailment (PoA).
- Determine capacity quota for interruptible capacity, i.e., the maximum capacity that can be connected with conditional connections.
- Inform existing and new customers about control and management of new connection.

Case study: UK - Flexible Plug and Play

Design features

Three connection options are available:

- *Interruptible connection:* DGs pay connection costs, but no reinforcement costs and receive no compensation for revenue losses due to curtailment (sale of electricity, subsidies, incentives, embedded benefits).
- *Firm connection*: Connections costs, reinforcement costs shared across all DG customers at the same connection point, and full power exports, i.e., no curtailment.
- *Business as usual (BAU)*: Firm connection where each DG project is pays individual reinforcement costs (sole use grid asset).

Principle of access: Pro-rata. All DGs with interruptible connection are equally curtailed based on their proportion of total connected capacity (across all DG customers with the same technology and same generation profile).

Other methodological considerations

A capacity quota to limit total interruptible capacity is set to a maximum of 33.5 MW.

Three renewable DG technologies are considered: Wind, solar PV, and Anaerobic Digestion Combined Heat and Power.

The relevant costs and benefits for the DGs are:

- Costs: Curtailed generation, connection and (potentially) reinforcement costs. DG customer connection costs – cost associated with sole use grid asset and potentially a proportion of grid reinforcement costs up to one voltage level above the connection point, referred to as a "shallowish" connection policy. Use of system charges depending on voltage level. Additional costs if connection impacts National Electricity Transmission System.
- Benefits for each DG customer: Electricity revenues, subsidies and incentive schemes, embedded benefits and savings for auto consumption (only relevant for solar PV). Embedded benefits are the costs that generators and suppliers may save when they connect directly to the distribution network instead of the transmission network.

Scenario 1: 100% wind and partial interruptible connection capacity

Only 18 MW of the 33.5 MW capacity quota is used, connecting five DGs with capacity ranging from 0.5 MW to 10 MW. The curtailment level per annum is 0.33%.

Interruptible connection clearly yields the highest NPV across all DG projects.

Net present value of set of projects under different connection regimes (£m/MW)		
Interruptible	Firm (shared reinforcement)	BAU (individual reinforcement)
0.96	0.77	0.50

Comparing only connection and reinforcement costs, the interruptible and firm shared reinforcement options save £0.54 m/MW and £0.32 m/MW respectively, compared to the BAU option.

Scenario 2: 100% wind and full interruptible connection capacity

The full interruptible connection capacity quota of 33.5 MW is utilized. This yields more efficient use of the distribution network.

The number of interruptible DG customers is seven (two in addition to scenario 1), with the same capacity range as in scenario 1. The maximum curtailment level is 5.33% per annum.

In this case, firm reinforcement is the option with the highest NPV. The increase in the total interruptible capacity connected increases curtailment levels, but also reduces the share of reinforcement costs across all customers.

Net present value of the set of projects under different connection regimes (£m/MW)		
Interruptible	Firm (shared reinforcement)	BAU (individual reinforcement)
0.69	0.71	0.40

The preference between interruptible and firm connection with shared reinforcement is sensitive to changes in the discount rate. With a higher discount rate of 10%, small generators still prefer the firm option whereas the larger generators prefer the interruptible option.

Comparing only connection costs, interruptible and firm shared reinforcement options compared to the BAU option save £0.49 m/MW and £0.36 m/MW respectively.

Scenario 3: Mix of wind, solar and bioenergy and full interruptible connection capacity

The full interruptible connection capacity of 33.5 MW is utilized. A total of 11 DGs are connected: 6 wind farms (27.75 MW), 1 solar PV (4.5 MW) and three bioenergy CHP (1.25 MW). The maximum curtailment level per annum depends on the type of generation technology: wind - 5.33%, solar PV – 2.57% and bioenergy CHP – 1.73%.

Distributed energy customers prefer firm connections due to the relatively low individual reinforcement costs when they are shared. The total NVP is higher compared to Scenario 2 with only wind projects. The different technologies have different generation patterns and solar PV and bioenergy CHP also have lower curtailment levels.

Net present value of the set of projects under different connection regimes (£m/MW)		
Interruptible	Firm (shared reinforcement)	BAU (individual reinforcement)
0.73	0.74	0.40

Solar PV generators have the lowest NPV, even if they have the lowest technology specific discount rate of 6.2%. With a higher discount rate of 10%, project NPV becomes negative. The energy export rate also negatively affects the profitability. Similar to Scenario 2, smaller generators prefer the reinforcement connection option and larger generators the interruptible connection.

Comparing only connection costs, the interruptible and firm shared reinforcement options save £0.7 m/MW and £0.6 m/MW respectively compared to the BAU option.

Scenario 4: 100% wind and full interruptible connected capacity with network reinforcement option

The first 7 DGs that are connected are the same as in Scenario 2, i.e., the interruptible capacity quota is full, but an additional 13 projects want to connect. In order for all to get connected, the network needs to be reinforced by 56.5 MW to a total capacity of 90 MW. The scenario considers the effect of accelerating the reinforcement by a year. For the 7 wind DGs already on interruptible connections, the reinforcement would take place 5 or 6 years after connection. It is assumed that the reinforcement cost is borne by demand and the baseline network reinforcement costs do not affect the DGs.

Accelerating network upgrades by a year yields a higher total NPV for all the DGs, but it also increases the discounted cost of network reinforcement. The DGs realizes a net benefit because the reinforcement costs are borne by demand. The capacity increase reduces curtailment and the benefit of accelerating the network reinforcements by one year outweighs the cost.

Net present value of set of projects with network reinforcement in 2019 or 2020 (£m/MW)	
2019	2020
0.74	0.71

Small DGs connecting earlier benefit disproportionately and have a higher project NPV relative to other similar sized projects connected at a later time. The opposite is true for larger generators. The discount factor has a greater impact on larger generators because the connection costs are higher.

Evaluation of the attractiveness of interruptible connection

- BAU always has the lowest NPV.
- The share of interruptible capacity increases curtailment and makes interruptible connection less attractive. When full interruptible connected capacity is assumed, the firm connection option with shared reinforcement costs has a slightly higher total NPV.
- Size matters: The higher the standard deviation in generator size the higher the losses for large DG customers. Higher share of reinforcement costs faced by larger DG customers compared to small DG customers (Pro-rata distribution based on the MW size of the generator).
- Results are sensitive to the assumed discount rate.
- Network reinforcement due to demand growth results in less curtailment and increases the value of non-firm connection.

2.2.3 Anaya and Pollitt (2017)

Anaya, K. L. & Pollitt, M. G. (2017): Going smarter in the connection of distributed generation.

Challenge

- Growth in distributed generation and integration into distribution networks not accommodated for generation.
- Expansion of DG benefits different parties, what is the effect of different connection scenarios (with and without smart solutions) on the most relevant benefits?

Definition of conditional connection

Non-firm connection involves restricting the ability of generators to export power in a constrained part of the network in return for reduced connection cost.

Methodology

- Cost benefit analysis illustrating allocation of benefits across DSOs, generators and wider society represented by energy suppliers or demand customers for firm and non-firm connections.
- Same CBA methodology as applied in 2.2.1

Main Insights

- DGs benefit the most from non-firm connections.
- A smart connection incentive can be implemented to allocate the benefits of increased DG connection more efficiently.
- The incentive consists of a payment by DGs to DSOs and may also contribute to a reduction in network reinforcement costs.

Context

- Based on GB market, Flexible Plug and Play (March grid – constrained area)
- Low DG penetration

Requirements

Active networks applying innovative commercial arrangements that might include the following specifications:

- Maximum level of curtailment for generators
- Appropriate principle of access
- Maximum capacity that can be reserved for interruptible connections (set capacity quota)
- Potential compensation schemes and scenarios associated with demand growth
- Network reinforcement criteria
- Consideration of generation mix at the same connection points

These arrangements typically require smart solutions, such as:

- Smart technical tools: Active network management, dynamic line rating, quadrature booster.
- Smart regulatory tools: Funding schemes, competitive mechanisms, lower socialization costs, prices reflecting the time and location-specific value of real energy, reactive power and reserves, etc.
- Smart engagement initiatives: Interruptible capacity, lower connection costs, quicker DG connections, PoA.

Case study: Allocation of benefits of non-firm connections in the UK

Main issue

Quantification of benefits from connecting more DG to a constrained grid under different generation circumstances (DG technology, partial/full interruptible capacity quota).

Scenarios

Scenario 1: Only wind generation, partially utilized interruptible capacity quota of 14.5 MW (Max quota 33.5 MW).

Scenario 2: Mix of wind, solar and bioenergy CHP generation, partially utilized interruptible capacity quota of 27.6 MW (Max quota 33.5 MW).

Scenario 3: Mix of wind, solar and bioenergy CHP generation, full interruptible capacity quota of 33.5 MW utilized.

DSO benefits

The DSO benefit consists of so-called "DG incentives" the DSO might be entitled to. The DG incentives are revenues received for connecting DG and are included in the estimation of the total allowed distribution network revenue. Total benefits from DG incentives are an annual operation and maintenance allowance and an annual DG capacity allowance.

Scenario insights

The DG incentives for DSOs depend only on installed capacity, thus the benefits are highest for the scenarios with the highest installed capacity, scenario 2 and 3.

Generator benefits

The generators' benefits are equal to the profits from connecting DG units. The benefits consist of energy revenues from electricity sales, subsidies and incentives, embedded benefits and energy savings for auto producers. The costs include generation costs (capital and operational) and connection costs.

Scenario insights

The results show greater benefits with non-firm connection across all scenarios, in Scenario 3 because of the low maximum annual curtailment limit (max 2.3%) for solar PV. In Scenario 1, with the lowest curtailment limit, the benefits of non-firm connection compared to firm connection is the highest.

Wider society benefits

The wider society benefits include only supplier embedded benefits since all other benefits are assumed to be reflected in subsidies paid to DG. The embedded benefits stem from supplier avoidance of balancing system charges, a reduction in transmissions losses and distribution line losses.

Scenario insights

Supply embedded benefits correspond on average to around half of the total embedded benefits across all scenarios. Total embedded benefits are comprised of generation and supply embedded benefits.

Initial evaluation of practicability

Acceptability of DG

- DG benefits the most in the scenarios.

Ease of curtailment by DSO

- Short/ medium term issue: Internalize and incorporate innovative commercial arrangements into normal practice, offering non-firm connections to potential or existing customers.

Overall assessment of acceptability

- Wider society benefits the least.

Evaluation of the effectiveness of conditional connection

The paper refers to important savings (reduced reinforcement needs, quicker connection and lower connections costs) due to the application of ANM in other trials by DSOs in UK.

Paper suggests a *smart connection incentive*, to be paid by DGs to DSOs, to allocate the benefits from increased DG capacity connection more efficiently. The proposed incentive should also reduce reinforcement costs, particularly in areas with low DG penetration. This result might not be true for high penetration areas due to increases in energy losses and surplus generation.

2.2.4 Anaya and Pollitt (2021)

Anaya, K. L. & Pollitt, M. G. (2021): The Role of Regulators in Promoting the Procurement of Flexibility Services within the Electricity Distribution System: A Survey of Seven Leading Countries.

Challenge

- Managing fluctuations from higher shares of intermittent renewable electricity connected to distribution networks, ensuring network capacity constraints are not violated and power quality requirements are met.
- Expanding the literature one the role of regulation in promoting the use of more flexibility in distribution networks, specifically the regulatory changes that may be required to incentivize the use of flexibility in distribution networks.

Definition of conditional connection

N/A

Methodology

Questionnaires to capture insights on regulatory issues that may have an impact on the use of flexibility solutions by DSOs, including distribution utilities, energy regulators, energy marketplaces and experts in Australia, France, Germany, Great Britain, Japan, the Netherlands and Norway.

The survey covers the countries' activities related to several regulatory options relevant for the use of flexibility solutions in general:

- Changes to utilities' revenue incentives
- Changes to the network tariff structure
- Changes to definition of products/service and standardization
- Specification of market design rules for local flexibility markets
- Specification of rules for peer-to-peer trading of flexibility
- Changes to smart meter rules framework
- Changes to rules for independent aggregators
- Encouragement of better coordination between DSOs and TSOs
- New rules that allow DSOs to procure flexibility on behalf of TSOs
- Changes in feed-in regulation
- Improvements to customer data access and management

- Creation of standard CBA methodology for the evaluation of flexibility services at DSO level

Main Insights and findings

- Flexibility markets: Even where flexibility markets are highly developed, it is unclear to what extent they are cost effective and whether current regulation is fit for purpose. The market design of flexibility markets is a work in progress.
- Network tariffs: More dynamic network tariffs are considered, but the practicality of implementation is uncertain. (The authors do not expect network tariffs to deter provision of flexibility.)
- DSO/TSO coordination: Work to facilitate increased coordination is ongoing in most of the countries.
- CBA methodology: Most of the countries are working on a common methodology, which there is clearly a need of.

2.2.5 Andoni et al. (2017)

M. Andoni, V. Robu, W.G. Früh & D. Flynn (2017): Game-theoretic modeling of curtailment rules and network investments with distributed generation.

Challenge

- Grid infrastructure inadequate to support increased renewable or distributed generation, especially in distribution networks.
- Developing flexible services ensuring safe operations and power systems stability, for example forecasting techniques for RES output prediction, demand response, energy storage and generation curtailment.
- Propose a new 'fair' curtailment rule reducing curtailment events per generator and guaranteeing approximately equal share of curtailment to generators of unequal rated capacity.

Definition of conditional connection

Interruptible or non-firm connections are offered to generators along with rules about the order they are dispatched or curtailed. The type of connection is preferred in many cases to avoid high costs or long waiting time.

Methodology

- Simulation of the effect of three curtailment rules on capacity factor of wind generators and the effect of spatial wind speed correlation. The three curtailment rules are
  - LIFO: Last-in-first-out
  - Rota: Rotational curtailment
  - Pro-rata/Shared percentage
- Game-theoretical model to bridge knowledge gap of incentivizing privately developed grid infrastructure. (Not further described here.)[1]

Main Insights

- Effect of curtailment principles and special correlation on capacity factors: LIFO is unfair, Rota yields the lowest curtailment events and Pro-rata is fair but yields a high number of curtailment events.
- A new curtailment rule, Fractional Round Robin (FRR), that is fair and also reduces the number of curtailment events, is proposed.
- Increased spatial correlation can reduce the average capacity factor.

[1] The game-theoretical approach models incentives for private grid investments, which we do not regard as relevant for the Swedish setting.

Context

High spatial correlation between generation output, i.e., wind generation in the grid area.

Requirements

- Rules for curtailment specified in the legally binding agreement between renewable energy generator and system operator.
- Active network management scheme.

Case study: Curtailment principles and spatial correlation

Main issue

The effect of curtailment principles and spatial correlation on the capacity factor of generators.

Design features

- *LIFO:* The last connected generator is curtailed first. Early connectors have an advantage. Simple, transparent, and new connections do not affect existing DGs connected. However, new connections might be disincentivized and the available transmission capacity used inefficiently.
- *Rota:* Generators are curtailed on a rotational basis or according to a predetermined rotation specified by the system operator. The generator size and contribution to network constraints is not taken into account, resulting in disproportionate revenue losses, especially for smaller DGs.
- *Pro-rata/ Shared percentage:* Curtailment is shared equally (and fair) between all non-firm generators in proportion to power output or capacity. Used in the Flexible Plug and Play project because it allows for connection of larger volumes and enhanced network utilization. However, all generators are curtailed each time, which might be frequently and require that the DG is adjustable.
- *Fractional Round Robin:* The power is curtailed sequentially and on a rotational basis according to the rated capacity installed. Larger generators are thereby chosen proportionally more times.

Other methodological considerations

Wind speed modelling for three wind generators (2-7 MW) based on UK data, taking into account spatial correlation. No power exports and constant demand is assumed.

Results

LIFO: The third and last generator experiences a reduction in the capacity factor of 67.4%. LIFO has the lowest average number of curtailment events, but high variance in capacity factors for participating stations which is “unfair”.

Rota: Smaller generators can be disadvantaged, but the variance in capacity factor for the generators is smaller compared to LIFO. Rota is the scheme with lowest number of curtailment events.

Pro-rata: Equal reduction in capacity factor for all generators, and scores highly on fairness with an average capacity factor variance of 0. However, it requires the highest number of curtailment events,

Fractional Round Robin: Equal reduction in capacity factor for all generators. Similarly fair to Pro-rata but reduces the average number of curtailment events significantly. Knowledge of curtailment in advance reduces uncertainty for short term power output prediction. For long periods of time – many years – the level of curtailment under this scheme will converge to the proportional curtailment rate with Pro-rata.

A further finding is that regardless of the curtailment strategy, as correlation between the generators increases, the capacity factor of the generators decreases.

2.2.6 Boehme et al. (2010)

Boehme, T., Harrisson, Gareth P., & Wallace, A. Robin (2010): Assessment of Distribution Network Limits for Non-firm Connection of Renewable Generation.

Challenge

- Integration of intermittent renewable electricity in areas with weak electricity grid.
- Evaluation of the potential impact of new renewable generation on the electricity network prior to connection, and the challenges and opportunities offered by non-firm connections.
- Need to develop methodology to analyze the need for curtailment in grid operation.

Definition of conditional connection

Agreement where DSO reserves the right to reduce the output of the renewable farm by means of an Active network management system.

Methodology

The paper focuses on the methodological application of optimal power flow analysis to the maximum power flows and curtailment levels. A probabilistic approach based on previously recorded data and demand series applied to the Orkney Islands (wind, tidal and wave power).

Main Insights

- Optimal power flow analysis can be used to determine curtailment levels for non-firm grid connections.
- The connection point of DG and other DG producing into the same grid is highly relevant for the level of curtailment and financial viability of the projects.

Requirements

- Active network management system
- Within network within thermal and voltage limits

Design features

Proposes a dispatch system based on optimal power flow (OPF) analysis.

Last-in first-out (LIFO) was to some extent demonstrated in this model because the wind farm was prioritised by assigning it a lower generation cost.

Evaluation

- Connection point of DG is highly relevant, can result in very high curtailment losses due to spatial correlation.
- For non-firm connections, the installed capacity of the renewable generator is highly relevant for financial viability. It is difficult to determine the optimal capacity to install because the production depends on the output of other generators connected and subsequent connections.

2.2.7 Currie et al. (2011)

Currie, R., O'Neill, B., Foote, C., Gooding, A., Ferris, R., and Douglas, J. (2011): Commercial arrangements to facilitate active network management.

Challenge

Identifying principle of access options that can be used in ANM scheme.

Definition of conditional connection

Principle of access are defined as part of the terms of interruptible contracts.

Methodology

Multi-criteria assessment of principle of access based on technical, commercial and regulatory criteria. Recommendations based on assessment and dialogue with industry partners.

Main insights and recommendations

- LIFO and shared percentage are recommended in the short-term and can be implemented without new technology or changes in the regulatory environment.
- Market-based approach is recommended in the medium term. It will require considerable effort to implement, the scope and operations need to be defined. The approach

is more suited to transmission system constraints because more generators can partake.
- The Greatest Carbon Benefit is recommended in the long term if the goal is to decarbonise electricity. Implementing this PoA is complex and would require large market and regulatory changes.

Assessment of curtailment approaches

The paper considers the following PoAs: Last-in-first-out (LIFO), Generator Size, Greatest Carbon Benefit, Shared Percentage, Market-based, Technical Best and Most Convenient.[2]

The following are considered more in depth based on the passing of an initial evaluation of equitability and transparency.

Last-in-first-out (LIFO)

- Transparent to stakeholders
- Does not impact existing connections, reduces uncertainty of interruptible connections to investors.
- In line with existing regulation and legal compliance.
- Might limit the technical utilization of the distribution network.

Shared Percentage (Pro-rata)

- Favored by the majority of the stakeholders.
- No changes in regulation required.
- Even division of curtailment ensures fair access to the network capacity.
- Existing customers are impacted by the connection of new interruptible generation, and the uncertainty can influence the business proposition. Can be addressed by a constraint payment.

Greatest Carbon Benefit

- Promotes European energy policy.
- Easy to implement from a technical perspective but challenging to determine carbon footprint of different technologies in a fair and transparent manner given the commercial implications.
- Regulatory action needed to implement this approach, can be lengthy.

Market-based

- Requires a proper market to be set up, requires considerable effort, needs to establish market clearing and settlement system.
- Does not impact existing connections.
- Can be extended to generators already connected to the network.
- More suited for transmission system constraints because distribution network constraints are highly localized.

2.2.8 Foote et al. (2013)

Foote, C., Johnston, R., Watson, F., Currie, R., Macleman, D., and Urquhart, A. (2013): Second Generation Active Network Management on Orkney.

Challenge

Connection of new wind capacity to a full network by deploying active network management (ANM) scheme.

Definition of conditional connection

Active network management scheme implements a power flow application controlling the power output of several generators to resolve thermal constraints.

[2] An overview and summary of PoAs is provided in section 2.3.

Methodology

Findings from studying the first generation ANM deployed on the Orkney Islands. Elaboration on the second-generation developments for communications, real time ratings and voltage management, storage, platform upgrade, demand side management, small scale generators and distribution state estimation.

Main Insights

- Effective and reliable communications between the central ANM controller and the local ANM controller, and the measurement points at critical constraint locations in the network reduces curtailment from fail-safe actions.
- Extending real-time management and ANM software to include monitoring of voltage at critical constraint locations and curtailment, if necessary, may increase efficiency further.

Requirements

- ANM scheme: trial of dynamic line rating device and real time thermal ratings application.
- Fail-safe actions in case of communication failure.

Initial evaluation of practicability and acceptability

Communications performance review of 2011/12 found that communications with generators had a total average availability of 98.89%. There were 174 communication failures with a mean downtime of 6h 14 mins. The communications with MPs were more reliable with a total average availability of 99.89% and 53 communication failures.

SGS (Smart Grid Solutions) experience from previous ANM projects indicates that communication is often a primary problem source in new projects and a considerable portion of total cost of smart grid innovations.

Several of the generators are community owned. Demand side management is considered as an alternative to curtailment of generators.

When making use of the increased real-time current carrying capacity of the network, real-time voltage management of the network will be necessary.

Another tool that is considered implemented into the ANM-scheme is the establishment of an energy storage park where third-party organisations can test storage to offset generator curtailment.

The next move is to test storage to offset curtailment as another tool in the ANM scheme. It is also considered to include smaller generators into the scheme. Initially only generators larger than 50 kW were allowed to join the ANM scheme because smaller generators have a smaller impact, but higher communications and integration costs. However, the combination of smaller generators impacts the grid and adds additional curtailment to generators already part of the ANM scheme.

2.2.9 Furusawa et al. (2019)

Furusawa, K., G. Brunekreeft, and T. Hattori (2019): Connection for distributed generation by DSOs in European Countries.

Challenge

- European distribution networks experience capacity challenges due to the obligation to connect increasing *small-scale renewable generation capacity*.
- In order to *defer grid investments*, different models for “constrained connection” were implemented, while at the same time reduce connection fees for DGs, and network tariffs for customers.
- What are the feasibility and effectiveness of different approaches?
    - What are the pros and cons of different models?
    - Are the European approaches applicable to other countries, such as Japan?

Definition of conditional connection

The constrained connection is defined as a generation connection to the network with the possibility of curtailment of the output; the owners of DG accept the curtailment if the network constraint is binding.

Methodology

- *Case studies* of different European approaches for constrained connection by which DG is connected conditional on curtailment.

Main insights

- Relative acceptability of distributed generation and the ease of curtailment differ depending on the energy policy background and available technologies.
- The acceptability by DGs depends on the compensation received when curtailed and the benefits of early connection.
- Flexible connection and direct and dynamic control of DG is the easiest option for DSOs.
- There is no one-size-fits-all solution: The energy policy context (RES support, connection tariffs) and the available control technology must be taken into account.
- Effective use of conditional connection requires detailed assessment of curtailment costs and network investment costs, allocation of the curtailment volume, and impact on network tariff structure.

Incentives

Win-win solution

- DSO: Possible to defer grid investments
- DG: Lower connection tariff and shorter waiting time
- Other network users: Lower usage tariff

Requirements

Information before the agreement is made: DSO informs the DG investors about the connection costs and expected (rough estimate) curtailment for constrained connection, and the connection cost of unconstrained connection.

Active DSO network management: Requires active DSOs that apply a probabilistic approach to network management, have the option to curtail DG output, monitor and control power flow in real time, and use mixed tariffs, and an interrelated approach to these activities.

Acceptance of DG owners: Constrained connection must be *optional* for the DG

Case study: Germany

Main issue

- Reduce network costs

Design features

- Permanent curtailment rule: The DSO has the option to make investment plans conditional on a 3% curtailment of output from DG plants.
- DSOs can curtail DG output more if it is necessary in grid operation, considering power flow, compensation cost, communication methodology, and impact on heat supply.
- Such “feed-in management is planned D-1, H-1, and can be adjusted 1 minute before delivery.
- The DGs get full compensation for the curtailed output (i.e., the feed-in-tariff, FIT).
- DG does not pay any network charges, i.e., lower network charges cannot be used to incentivize conditional connection.

Expected gain

BMWi estimated that the three-percent rule saves at least 15% of network investment costs (2014). At the time the paper was published, the impact of the rule on each individual DSO’s investment costs were under investigation.

Case study: France and Belgium

Main issue France

- High connection costs for individual DGs, reform to coordinate multiple connection to reduce costs

- Did not reduce queues and high connection costs remained an issue. Risk of inefficient connection order and free riding.

Main issue Belgium

- Large amount of DG supported by priority policy

Design features France

- DSO offers smart connection as option
- Smart connection implies acceptance of possible curtailment, reduced connection fee and earlier connection.
- DSO can request curtailment of the DG D-1 and in the IDM period. If the DG does not respond to the request, the DSO can disconnect it in the worst case.
- Two types of curtailment methodologies:
    - Warranted capacity: The DG is guaranteed a minimum instant load, i.e., a maximum curtailment level.
    - Warranted energy: The DG is guaranteed a minimum injected level of input, injection above this level can be curtailed by the DSO.
- No compensation for curtailment

At the time the paper was published, smart connection was in an experimental stage for a period of two years (2017-2019) and only in a specified area.

Design features Belgium

- Warranted capacity
- Curtailment methodology: Pro-rata in the experimental phase; Subsequently prioritized curtailment is planned, subject to acceptability
- No compensation for curtailment

Expected gain France

It is expected to realize a net gain of 65 million EUR for the connection of 720 MW of additional production to the existing feeders at a national level (Enedis, 2017).

Case study: UK

Main issue

- DSOs apply Active Network Management to provide cheaper and faster distribution connection.
- Initially tested timed/profiled connection, implying informing DGS of possible planned curtailment. The DSO could curtail DG output by a fixed volume within the planning period.
- DGs pay connection costs above a threshold and a network usage tariff

Design features

- Flexible connection as optional procedure
- Allows curtailment without specifying the time period
- The DSOs selects the type of curtailment methodology, i.e., LIFO or pro-rata.

Initial evaluation of practicability

Acceptability of DG

- Risk of reduced DG income.
    - France and UK: Benefit of connection must outweigh the expected loss of revenue by curtailment
    - Germany: No loss due to compensation
- Curtailment method
    - Warranted energy guarantees a minimum income
    - UK curtailment based on LIFO or pro-rata least acceptable, similar to warranted capacity

Ease of curtailment by DSO

- The share that the DSO can control directly for congestion management
    - Currently only possible in the UK
- Warranted energy and the 3% rule
    - More difficult for DSOs, planning becomes an issue

Overall assessment of acceptability

No single best approach is identified. The appropriate approach depends on the energy policy background in promoting DG and the technology to control DG.

Evaluation of the effectiveness of constrained connection

Relationship between investment and curtailment cost

- Constrained connection generally regarded as temporary measure by DSOs
- Effectiveness depends on the cost to be saved relative to curtailment costs
- For low levels of DG connection, investment costs are high and curtailment costs low, the reverse is true for high DG connection.
- The network investment cost for connection cannot always be distinguished clearly, however. And an investment can improve reliability (for all) and support economic development.
- The curtailment methodology may be important for the DG owner, in order to estimate the curtailment cost. Compensation and the length of the constrained connection period is also important.

Relationship between curtailment period and network usage tariff structure

Need to consider how the network usage tariff is charged under constrained connection. Changes from volumetric tariffs to capacity or fixed tariffs bring new issues, as to how the degree of curtailment should impact the tariff paid.

2.2.10 Plecas et al. (2017)

Plecas, M., Gill, S., Kockar, I., and Anderson, R. (2017): Evaluation of New Voltage Operating Strategies for Integration of Distributed Generation into Distribution Networks.

Definition of conditional connection

Non-firm connections do not guarantee network access at all times and the generators would need to curtail output on instruction by the DSO in order to stay within network limits.

Challenge

- The increasing number of distributed generation connections to distribution networks not designed for bi-directional power flows.
- Cheaper and more timely connections for DGs within network limits.
- Limited real-world application of voltage management profiles and integration of distributed generation into voltage-constrained feeders.

Methodology

Case study of three adjustments to existing management of an 11 kV feeder to increase its capacity in the UK. The three strategies for adjusting the voltage profiles are:

- Increased operational upper-voltage levels
- Simple demand-management
- Non-firm connections to manage local voltage constraints

The three strategies can be implemented individually or in combination.

Main Insights

- Active network management (ANM) schemes have used non-firm connections to manage thermal limits, the same principles can also be applied to voltage limits.
- Increasing operational upper-voltage levels allows greater capacity to connect to any substation that is voltage constrained.

- Increasing demand allows for an increase in connected capacity, but the location of demand increase influences whether the potential capacity increase is 1:1 or less.
- Non-firm connections combined with curtailment can increase the capacity and energy yield from DG, the greatest potential is in the middle region of the feeder.

Requirements

- Connection of DG at 11 kV level is currently limited to firm connection agreements - total firm capacity should not exceed the total generation that can be fed into the network under minimum demand conditions.
- Network voltage statutory limits for 11 kV networks are +/- 6%. Usually more stringent rules are applied. If the point-of-connection voltage exceeds 11.25, the generator is not allowed to connect.

Case study: Orkney Islands

Main issue

Manging voltage profiles of one 11 kV feeder to allow for more DG connection capacities, exploring the effects of three strategies.

Design features

Strategy 1: Raising the point-of-connection voltage limit

The point-of-connection limit is raised from 11.25 kV to 11.4kV with steps of 0.5kV. Requires studies to makes sure that all unmonitored points of the feeders are within limits and that it is a safe policy.

Strategy 2: Increasing demand

By converting non-electric demand or demand-side management. Increase in demand by 100 kW at different substations.

Strategy 3: Non-firm connection agreements

Based on wind profiles and historic network demand and voltage data. Identifying DG capacity available for connection at each location whilst experiencing potential different levels of curtailment.

Estimated gain

Strategy 1: An increase in the operational voltage limit at the point-of-connection allows greater capacity to connect to any substation that is voltage constrained. Substations originally thermally constrained are still constrained. Raising the point-of-connection allows for increases in DG connections, whilst remaining within the statutory limits of 11.66 kV.

Strategy 2: If located in the same area, an increase in demand is a 1:1 increase in DG capacity, but demand is often located elsewhere in the feeder or across multiple secondary substations. For thermally constrained substations, additional demand anywhere on the feeder reduces reverse power flows from the feeder to the primary substation about 1:1. If the DG capacity is voltage constrained, then additional demand located closer to the primary substation than the particular DG, every additional unit demand creates less than one unit of extra DG capacity. On the other hand, if the additional demand is located further from the primary than the DG unit, the additional demand results in about a 1:1 increase in DG capacity.

Strategy 3: The greatest opportunity for non-firm capacity is in the middle regions of the feeder. Non-firm connections close to the primary substation are limited by the large firm capacities combined with relative proximity to the voltage-controlled bus. At the end of the feeder, there is less available capacity because of the distance to the nearest point of voltage control. A 10% curtailment level is commensurable with a doubling of capacity in the middle regions of the feeder.

About the Orkney Islands-project.

Maximum network DG capacity of 28 MW under traditional network planning, and an additional 20 MW acquired under first round of non-firm connections by applying a system stripping off additional generation in case of faults on one of the undersea cables. Further capacity would require additional subsea cable or implementation of ANM scheme.

ANM scheme estimated to cost £0.5 million compared to an additional subsea cable of £30 million.

The scheme enabled an additional capacity of distributed wind energy of around 24 MW.

2.2.11 Electrical Power Research Institute (2018)

Electrical Power Research Institute (2018): Understanding flexible interconnection

Challenge

- Increase distribution system utilization allowing more distributed energy resources (DER).
- Lowering the cost of integrating DER through flexible interconnection.

Definition of conditional connection

Flexible interconnection refers to the number of options that are available for DER interconnections, particularly options involving real-power control.

Methodology

Explanatory paper on the concept of flexible interconnections and potential implications for utility processes.

Main Insights

- Conditional connections can enable utilities to maximize capacity, but it can be challenging to implement network control and to determine contractual arrangements.
- For DER developers, conditional connections can allow for connections of larger units of DER or avoid costs of grid upgrades.
- The communications and control technologies to implement conditional connections are emerging technologies not yet applied on a larger scale.

Context

- Applicable for grid connection of equipment for generating or storing energy.
- Options available to utilities strongly depend on the availability of communication and control systems.

Requirements

Interconnection rules to ensure distribution system performance and reliability are maintained at acceptable levels. Includes technical screenings, studies and inspections.

DER perspective

An alternative to traditional options limiting the size of DER or upgrading the grid. Larger DER units benefit from economies of scale and may be permitted in more locations. Flexible connection can be more appealing than firm connection even if the power is curtailed and additional control costs apply.

Utility perspective

- Reduce power delivery costs by maximizing the quantities of power within the grid capacity.

Flexible capacity can be realised by DER control options, for example:

- Activating the autonomous Volt-Watt function of the DER to avoid local overvoltage constraints.
- Connecting DER units to management system that limits power output to avoid thermal or other constraints.

Ease of curtailment

- Technically challenging to reliably control power output, failsafe mechanisms need to be developed.
- Communication and control applications enabling flexible connection are emerging technologies not deployed at large scale by most utilities.
- Contractual arrangements and tariff structures to support flexible interconnection at the distribution level have yet to be determined.

«Other concerns involve the permanence, or lack thereof, of grid support coming from non-utility assets and the question of how planning and operations could take into account the possibilities of DER plants that are unexpectedly taken offline for maintenance or closed/shutdown permanently"

Requirements

To enable more and large-scale DER and real-power management, the utilities will require the following capabilities:

- Advanced two-way communication systems that are more frequent and interactive
- Distributed Energy Resource Management computing and transmitting time-varying request to devices.
- Cyber security
- Updated planning and interconnection processes

2.2.12 Electrical Power Research Institute (2020a)

Electrical Power Research Institute (2020a): Principles of access for flexible interconnection solutions – Rules of Curtailment.

Challenge

- Increased integration of DGs into the grid whilst avoiding traditional infrastructure upgrades.
- The time varying nature of power exports from DGs that distribution systems can accommodate due to the underlying load, generation, temperature, control settings, circuit configuration and other parameters fluctuating over time.
- Creating commercial environment and arrangements amenable to flexible grid solutions.

Definition of conditional connection

A distributed energy resources control strategy used to defer or avoid system upgrades and/ or increase distribution system utilization.

Main issue

Curtailment approaches to minimize curtailment levels in complex network constraint scenarios when simple approaches can lead to non-viable economic levels of curtailment.

Methodology

Analysis of pros and cons of different curtailment strategies to different stakeholders based on experiences of early-adopter utilities. The paper mainly focuses last-in-first-out (LIFO) and Pro-rata strategies.

Main Insights

- LIFO provides higher curtailment and financial certainty for DER developers.
- Pro-rata can lead to higher network utilization, distributes the curtailment more equally and provides similar incentives for co-financing upgrades. However, additional flexible agreement customers may increase the level of curtailment and create financial uncertainty.

Context

Flexible interconnection agreements define the grid conditions triggering curtailment and the curtailment logic determines the power output limitations imposed on participating distributed energy resources (DERs).

Requirements

Monitoring and telemetry to support the strategies

Assessment of curtailment approaches

Last-in-first-out (LIFO)

- Evolving grid conditions require that curtailment levels are regularly adjusted, they can be increased or decreased.
- Differences in DER technologies and production schedules can influence curtailment levels. Example – curtailing last connected solar generator at night when

demand is low is not possible and the wind generator might more frequently get curtailed even if it is in a better position in the stack.

- Early connecters get curtailed less often. New customers connecting under the flexible agreement do not affect the existing customers negatively in terms of curtailment. Measures might need to be taken to avoid gaming of LIFO priority rules.
- Incentives to upgrade to fixed capacity arrangements when the total cost of curtailed power across all DER customers is greater than network reinforcement costs depend on the customer position in the queue. The last connected customer gets curtailed more often and receives a greater benefit from the upgrades. The asymmetry in the willingness to pay for an upgrade might have to be included in an arrangement where upgrade costs are allocated asymmetrically.

Pro-rata

Active power curtailment is shared across the DERs in proportion to a reference parameter. Maximum active power available for export or present active power exports are examples of reference parameters.

The proportion factor is the same across all DERs, but the factor may change over time as grid conditions evolve.

- Most of todays' commercial PV systems are not capable of calculating and reporting their maximum solar power available to an upstream DER managing entity when executing curtailment commands.
- A greater number of units may be able to connect under pro-rata because the curtailment is spread evenly, and the projects can a achieve a capacity factor above the minimum to be financially viable. However, new flexible agreement customers connecting can increase the curtailment levels of existing customers. This might impact the long-term financial viability of the projects and create uncertainty for DER customers. To reduce the uncertainty, the flexible agreement can include a quota on connected DER capacity or maximum threshold of curtailment for new connections.
- Incentives to upgrade to fixed capacity arrangements when the total cost of curtailed power across all DER customers is greater than network reinforcement costs might depend on the production technologies. Otherwise, all customers are curtailed similarly, and they should have similar incentives to co-finance network upgrades.

2.2.13 Electrical Power Research Institute (2020b)

Electrical power research institute (2020b): Principles of access for flexible interconnection. Cost allocation mechanisms and financial risk management.

Challenge

- Increased integration of DGs into the grid whilst avoiding traditional infrastructure upgrades.
- Time varying nature of power exports from DGs that can be accommodated for by distribution systems due to the underlying load, generation, temperature, control settings, circuit configuration and other parameters fluctuating over time.
- Clear rules for governing the allocation of grid upgrade costs and financial risk management in order to secure a commercial environment for flexible connections.

Definition of conditional connection

A distributed energy resources control strategy used to defer or avoid system upgrades and/ or increase distribution system utilization.

Methodology

Review of cost allocation and financial risk management considerations for conditional connections based on experiences of early-adopter utilities.

Main Insights

Principles defining how future upgrades will impact flexible interconnection customers and financial risk to involved parties:

- Applying the traditional cost causation principle to network upgrades (see below) can be challenging for conditional connections because there are multiple customers contributing to the constraint and their incentives to contribute can be influenced by factors such as principles of access (PoA).
- Under LIFO, the last generator, who gets curtailed the most, has a stronger incentive to pay for upgrades than the first customer. With pro-rata, the generators should have an equal incentive to co-finance the reinforcement, especially if they use the same generation technology.
- Voluntary payment for upgrades can result in free rider problems whereas with mandatory payment, it is difficult to determine a common economically efficient threshold for the DGs.
- For the DSO it is inherently difficult to plan the amount of headroom when reinforcing the grid. Existing customers do not wish to pay extra for additional headroom, but the cost of large upgrades is strongly correlated with the number rather than the size of the upgrades.

Context

Three main motivations to upgrade the network in areas with flexible interconnection agreement customers.

Case 1: Flexible interconnections are a temporary solution that allows for quick connection of DER whilst the network is being upgraded and eventually allows for fixed agreements.

Case 2: Network upgrades are triggered by a standard planning process not related to DER growth. The planning process can be caused by load growth or other reliability considerations.

Case 3: Flexible interconnection customers reach a certain threshold where the costs of collectively financing the network reinforcements is less than the lost revenues from curtailment.

Requirements

The authority having jurisdiction (presumably the regulator) has to establish the principles on how to allocate the costs of network reinforcements across the customers. The principles have to be established upfront because of their potential effect on long-term financial project variability.

Assessment of cost allocation approaches

Principle of cost causation

Case 1: Clearly identifiable customers causing the need for an upgrade.

Case 2: Identification of cost causers and beneficiaries is less clear. The upgrade may benefit flexible interconnection customers even if they were not the source of the network upgrades. In some cases, the flexible interconnection customers might try to influence the DSO in its planning process to oversize the upgraded capacity so that curtailment is further reduced, or firm export capacity is offered.

Case 3: Multiple flexible interconnection customers contribute to the economic justification of a network upgrade. An emerging challenge is to set the principles to determine who triggers the upgrade and how the costs should be allocated amongst the flexible DER customers.

- Flexible interconnection customers may make an arrangement with the DSO to *voluntarily* pay for reinforcements and upgrades to a fixed agreement. However, free riding might be an issue.
- Flexible interconnection customers may be *required* by the DSO to upgrade to a fixed connection capacity agreement once the collective curtailment costs outweigh the costs of network upgrades. This principle avoids the free rider problem and aims to maximize DER production. However, it is challenging to determine a collective economic threshold for upgrades agreeable to all parties.

Regardless of a voluntary or mandatory policy, the DSO can contribute to determining the economic threshold for upgrades by coordinating bids (voluntary) or by providing data on curtailment.

Amount of headroom to include in an upgrade

The amount of headroom to include when upgrading the network roughly corresponds to the upgrade costs. Determining the level of headroom can therefore influence the threshold for determining whether an upgrade is economic.

Flexible interconnection customers have little incentive to pay for headroom beyond their connections, yet additional headroom can be economic since the cost of large upgrades are strongly correlated with the number rather than the size of the upgrades. Again, an issue might be that other parties benefit from the additional headroom, for instance customers who are not distributed energy resources. In addition, it is difficult for the DSO to predict DER or load growth. A primary challenge for the regulator is thus to assign the responsibility for the determination of the acceptable amount of headroom.

Influence of curtailment logic

Pro-rata: In theory the curtailment is shared equally amongst the flexible interconnection customers and so the incentives are similar. The primary consideration is whether to make participation in upgrades voluntary or mandatory.

LIFO: The last connected flexible customers benefit more from network upgrades because they are more frequently curtailed. Cost allocation options under LIFO:

- Allocation in proportion to the expected gains of the customer facilitates equal financial gain across the customers, yet it lacks economic efficient outcomes because the costs are mainly allocated based on the date of connection.
- Allocation in proportion to the customers' contribution to the constraint. The allocation promotes economically efficient outcomes, but the financial gains are unequal to the customers.

The curtailment principles and logic are elaborated in Electrical Power Research Institute (2020a).

Contribution to future upgrade costs

Voluntary: Flexible interconnections are an alternative to grid upgrades and the future costs of upgrades should only be made voluntary if in the best interest of the customer.

- Allows for customer choice, takes into account that each DER project is unique with different risk preferences and willingness to pay.
- Requires that all parties agree, but also provides an incentive for free riding.

Mandatory: Flexible interconnections defer cost obligations to connect to the grid and if enough customers connect so that grid investment becomes economic for the group, customers should be required to pay their apportioned amount.

Assessment of financial risk

Risk and uncertainty associated with accuracy of curtailment estimates:

- Accuracy of power system models
- Repeatability of historic data
- Correlation of load and generation given the disparity in data sources

The customer bears the additional risk when entering flexible interconnection agreements. Key success factors from early adopters on managing risk:

- Transparency into methods used for determining curtailment levels.
- Logging and auditing constraints triggering curtailment.
- Utility sets maximum curtailment level for the customer and might involve compensation if the maximum level is exceeded. Reversed, the customer might have to pay the utility if actual curtailment is less than the estimate.

2.3 Summary of insights from the academic literature

2.3.1 General observations

The academic literature focusses to almost exclusively on conditional connection of DGs as a measure to facilitate earlier connection to the grid, and thus, as a temporary measure. Such agreements are voluntary options for the DGs, and the alternative is to wait for grid expansion that allows for firm connection.

An intermediate solution, where conditional connection is applied until connection charges can be shared among several DGs, is also discussed.

A significant share of the literature focusses on the efficiency of different curtailment strategies, or principles of access, i.e., how curtailment is allocated between customers with non-firm connection. The literature discusses how different models and principles affect the allocation of costs and risks, and consequently, the incentives to opt for conditional connection by DGs. The overall efficiency of the mechanisms in terms curtailment efficiency is also discussed. Table 3 provides an overview and short assessment of the curtailment strategies. The literature does however not clearly conclude as to what is the optimal curtailment strategy. Partly, there are trade-offs to be made when it comes to complexity vs. optimality, and partly, it depends on the particular situation and design of the connection agreement.

It is also discussed whether other criteria, such as sustainability, should be weighted in the curtailment allocation.

The following design elements play a role for DGs:

- The compensation scheme (compensation for curtailed energy)
- The stack of conditional connection agreements
- The maximum curtailment rate, how it is determined, whether it is fixed or capped, etc.
- The length of the agreement
- The allocation of reinforcement costs
- The capacity of the DG (size)
- The discount rate

Another recurring theme in the literature is what is required by DSOs to use conditional connection agreements efficiently as an alternative to grid investments. On the one hand, the DSO needs to assess the efficiency of conditional connection versus grid investment, and on the other hand, have systems in place for the curtailment in case of congestions in the grid. Instruments such as optimal flow analysis, automatic network management, effective network control and contractual arrangements are discussed.

The academic literature also contains quite a few case studies and compares cases from different countries. On a general basis, the wider regulatory and policy framework is mentioned as a factor, such as network tariff structures and renewable generation targets and support schemes. The design of flexibility markets and TSO/DSO coordination is also mentioned, but not analysed.

For the most part, the cost savings are not estimated, with a few noteworthy examples. The estimates that are presented, indicate that the savings may be substantial.

An overview of the main insights per article is provided in Table 2.

Table 2: Overview of main insights from the academic literature

Paper	Focus	Main insights
Anaya and Pollitt (2014)	The influence of allocation rules on risk allocation and social optimality, and the terms and conditions of interruptible connections in case studies.	If risk is ignored, • the market-based approach is superior to LIFO and Pro-rata because it signals the true cost of curtailment, and • LIFO is superior to Pro-rata because LIFO exposes the DGs to marginal rather than average connection costs. However, as private risk may be higher than the social risk of connection, it may be a good idea to reduce the risk of the marginal generator. The allocation of curtailment risk differs across the case studies depending on a number of specific design elements such as the compensation scheme, the stack of non-firm connection agreements, and how the maximum hours of curtailment are determined.
Anaya and Pollitt (2015)	How to connect more DGs more efficiently, and what affects the DGs economic incentive to opt for interruptible connection	The profitability of interruptible connection for DGs depends on: • The curtailment level, which is affected by the share of interruptible capacity in the network, • How reinforcement costs are allocated among DGs, • The size of the DG, • The assumed discount rate, and • Network reinforcement caused by demand.
Anaya and Pollitt (2017)	The effect of different connection scenarios on the benefits of interruptible connection	DGs benefit the most. A smart connection incentive, to be paid by DGs to DSOs, would allocate the benefits more efficiently and may reduce network reinforcement costs.
Anaya and Pollitt (2021)	The role of regulation to promote the use of flexibility in distribution networks, survey of seven countries	Several regulatory options are relevant for the use of flexibility solutions in distributed networks, including grid revenue incentives, network tariff structure, flexibility market design, coordination between DSOs and TSO, feed-in regulation, etc. The market design of flexibility markets is work in progress, and their cost effectiveness still uncertain Network tariffs probably do not deter provision of flexibility Most countries work on DSO/TSO coordination There is a need for a common CBA methodology
Andoni et al. (2017)	Comparison of the efficiency and fairness of different curtailment rules	LIFO is unfair. Rota yields the lowest curtailment events Pro-rata is fair but yields a high number of curtailment events. Fractional Round Robin, implying an equal reduction in the capacity factor for all DGs, is fair and reduces the number of curtailment events.
Boehme et al. (2010)	The challenges and opportunities offered by non-firm connections A methodology to analyze the need for curtailment in grid operation	Optimal power flow analysis can be used to determine curtailment levels. The connection point is highly relevant for the level of curtailment and financial viability of DG projects (due to spatial correlation).
Currie et al. (2011)	Assessment of and recommendations for Principles of Access that can be implemented in an ANM scheme.	LIFO and shared percentage are recommended in the short-term and can be implemented without new technology or regulatory changes. Market Based approach is recommended in the medium term. Requires considerable effort to implement, scope and operations need to be defined. Greatest Carbon Benefit is recommended in long term for decarbonisation. Complex implementation and large market and regulatory changes required.

Paper	Focus	Main insights
Foote et al. (2013)	Evaluation of the use of active network management (ANM) when connecting new wind capacity to a full network	Effective and reliable communication and measurement at critical constraint locations reduces curtailment from fail-safe actions. Extension to monitoring of voltage at critical constraint locations necessary for real-time voltage management.
Furusawa et al. (2019)	Evaluation of models for constrained connection in four countries: What are the feasibility and effectiveness of different approaches?	The relative acceptability of DGs differs depending on the energy policy background and available technologies. The acceptability of DGs depend on the compensation and benefit of early connection. Flexible connection and direct dynamic control easiest option for DSOs. There is no one-size-fits-all solution: The energy policy context matters Effective use of conditional connection requires detailed assessment of curtailment costs, network costs, the curtailment volume and allocation and impact on the network tariff structure. Network investment costs cannot always be clearly distinguished. The curtailment methodology, compensation and length of the constrained connection period is important for the DG owner.
Plecas et al. (2017)	The application of voltage management profiles and integration of DG into voltage-constrained feeders	The ANM principles for management according to thermal limits can also be applied to voltage limits. Increasing operational upper-voltage limits allows greater capacity to connect. The impact of increased demand on connection capacity depends on the location of demand. The potential for increased capacity due to non-firm connection and curtailment is greatest in the middle region of the feeder.
EPRI (2018)	Explaining the concept of flexible interconnection and potential implications for utility processes	Conditional connection enables network capacity utilization, but implementation of network control and determination of contractual arrangements can be challenging. Conditional connection allows for connection of larger DER units and deterred grid upgrade costs. Necessary communication and control technologies are emerging technologies.
EPRI (2020a)	Principles of access and different rules of curtailment	LIFO ensures higher curtailment for late connectors, but financial certainty for DER developers. Pro-rata can lead to higher network utilization, more equal curtailment, and incentives to co-finance upgrades, but more uncertainty about the level of curtailment.
EPRI (2020b)	Principles of access and cost allocation mechanisms for grid upgrades	Traditional cost causation principle can be challenging as the incentives to contribute may vary among customers due to the PoA. Voluntary payment for upgrades may create free rider problems. With mandatory payment it is difficult to determine a common efficient threshold. It is difficult for DSOs to plan the right headroom for network investments. Regulator should establish the principles for the allocation of network reinforcement costs up front and assign the responsibility for the determination of the acceptable headroom.

2.3.2 Curtailment strategies

Allocation principles or curtailment strategies determining how the constrained capacity should be allocated among generators need to be outlined in the conditional connection agreements. The DSOs determine the principle, and the selection of a curtailment strategy may be influenced by factors such as the existing grid conditions or tariff structure. Guiding principles or considerations taken into account by the literature when proposing or evaluating different curtailment strategies include transparency, predictability, simplicity, fairness, efficiency and cost-effectiveness. A range of curtailment strategies are mentioned in the literature, but LIFO and Pro-rata are the most frequently used examples and are analyzed more thoroughly.

Below we provide an overview and summary of the different strategies mentioned in the literature and some of the implications and potential advantages and drawbacks.

Table 3: Overview and description of curtailment strategies in the academic and other literature

Curtailment strategy	**Curtailment logic**	**Assessment of advantages and drawbacks**
LIFO	Last to connect will be curtailed first, discrimination in order of connection.	Unequal incentives for upgrades. Provides certainty for already connected customers but might disincentivise new connections if a high curtailment level is expected. Require clear guidelines to avoid strategic stacking.
Pro-rata	Curtailment shared equally proportionally to rated capacity, active power output or some other factor.	Curtailment is shared equally, fair and maintains competitiveness. A greater number of DGs might be able to reach capacity factor above minimum economic capacity factor. Over time with new connections, curtailment may increase for all customers and provide uncertainty for DG developers. Solutions might be to set a quota on connected DG capacity for system. More similar incentives to co-finance network upgrades. High number of curtailment events and requires that generators are technically equipped to be curtailed frequently.
Rota	Rotational restriction, does not consider size/ time.	Does not take into account generator size and contribution to curtailment reduction. A disproportionately larger revenue impact for smaller generators. Predictable power output.
Fractional Round Robin	Power curtailed is distributed sequentially on rotational basis according to the number of units installed.	Larger generators are chosen proportionally more times in direct relation to their size. Similar results to pro-rata over time, but fewer curtailment events per generator.
Curtailment Index	Customers forecasted an index value and max cap of expected curtailment in year. Percentage of time that the network is unavailable per site. Index assigned used to rank curtailment stack of sites.	Curtailment index value set by DSO compared to actual curtailment. Sites with the lowest the index value will have imports/ exports restricted first, then when their curtailment levels rise the index value and position in the stack will be adjusted and they will be less curtailed.
Carbon emissions	Generators with highest emissions are curtailed first.	Easy technical implementation but challenging to determine carbon footprint of different technologies in a fair and transparent manner is challenging given the commercial implications. Requires regulatory action to implement.
Market based	Bidding for grid access or curtailment (lowest bids required to curtail).	Makes use of private information on financial contracts and generation performance. Incentivises generator investment in flexibility and remote storage. Most optimal allocation role, but with considerable transaction costs. Requires optimal market conditions.
Generator size	Larger generators are curtailed first (power output or capacity).	Removes constraint by curtailing fewer generators. but can potentially discourage connection of larger generators.
Most convenient	Generators most likely to respond to curtailment signal are curtailed first.	Easy to implement, but DSO or operator preference is discriminatory. Difficult to precisely determine the parameters for selection.

Curtailment strategy	**Curtailment logic**	**Assessment of advantages and drawbacks**
Technical best	Technical suitability to address the constraint.	Constraints and grid configurations influence what type of response characteristics of generators is relevant to address the curtailment. DSO encouragement for grid reinforcement, but location dependable.

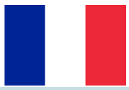
3 EXPERIENCE FROM REGULATORY PROCESSES IN OTHER COUNTRIES

In addition to reviewing the academic literature, we have looked for insights from regulatory experience in eight European countries where conditional connection has been discussed, evaluated and/or implemented. In understanding with Ei, we decided to focus on Norway, Denmark, Germany, the UK, Ireland, France, the Netherlands and Italy. In addition, we have looked at two examples from overseas, Australia (Queensland) and New York. Generally, we relied on available sources and documents from the regulators, as well as studies performed to explore new non-firm connection schemes in the different countries. These were complimented by interviews with regulators from Norway, Denmark, Germany and the Netherlands as well as an exchange with a British DNO, written correspondence with the Italian regulator and an Australian DSO. For the US example, we had to consult a study and several news reports.

While conditional, flexible or non-firm connections are a long-known tool for DSOs in the British and Irish power markets, many of the above-mentioned countries only recently took a decision towards implementing flexible connections or are in the process of assessing the benefits and downsides of a possible introduction of alternative grid access mechanisms. A potential outlier are the Netherlands, where the regulator cautions against conditional connections, stressing the downsides of the instrument with regard to the responsibilities of grid operators to ensure sufficient grid capacity for users wishing to connect. The Dutch regulator suggested its congestion management reform to be more a suitable tool to efficiently deal with grid bottlenecks instead. Still, a consultation is planned for autumn 2022 in which market participants will be asked to give their views on the introduction of non-firm access rights going forward.

The table below gives an overview of the status of conditional connections in the surveyed countries.

Table 4: Overview of conditional connection regulation in selected countries

					
Regulator	NVE	Forsyningstilsynet	BNetzA	Ofgem	CRE
Non-firm connections exist?	Yes	Yes	No	Yes	Yes
Voluntary/ obligatory	Voluntary	Voluntary	N.A. (obligation considered)	Voluntary	Voluntary
Permanent/ temporary	Both (based on contract)	Both	N.A. (permanent considered)	Temporary (unless desired)	Temporary
Plan to introduce? (nationally)	Introduced	Introduced	BNetzA works on framework	Introduced	Introduced
Term for conditional connection scheme	"Tilknytning med vilkår om begrensning»	«Begrænset netadgang»	«bedingter Netzanschluss», «Spitzen-glättung»	«flexible connection», «curtailable connection»	"Opérations de raccordement alternatives"

Regulator	CRU	ACM	ARERA	AER	FERC
Non-firm connections exist?	Yes	No	No	Yes (rule change proposal)	Pilot(s)
Voluntary/ obligatory	Temporarily obligatory	N.A.	N.A.	Voluntary	N.A.
Permanent/ temporary	Temporary	N.A.	N.A.	Uncertain	Permanent (Active Network Mgmt)
Plan to introduce? (nationally)	Introduced	No (but survey planned)	Likely (next regulatory period)	Likely (country-wide)	Uncertain (but FERC currently lays basis)
Term for conditional connection scheme	«Non-firm grid access»	N.A.	N.A.	«dynamic connections»	«flexible interconnections»

Source: Various literature, public information and interviews

3.1 Norway

In the face of an additional need for electrification of transport and industry, the Norwegian regulator has opened up for conditional connections ("tilknytning med vilkår om utkobling") for both generation and load. The regulation provides a high-level framework, stating that all users and generators have the right to use their entire grid capacity at any moment. Non-firm connection agreements are voluntary for both DSOs and grid customers.

3.1.1 Regulatory context and process

The Norwegian Energy Act ("energiloven") constitutes the regulatory basis for the definition of connection processes. Paragraph 3 of the NEM regulation ("Forskrift om nettregulering og energimarkedet" – Grid regulation and energy market regulation), more precisely 3-1, 3-2 and 3-3, outlines that a grid company and a consumer, as well as a generator can enter into a **voluntary agreement** about conditional connection at all grid levels[3]. It must state in which concrete cases such limitations, i.e., disconnection of or reduction in consumption, can take place. A contract about non-firm connections can only be entered if both sides agree to it as grid customers in Norway have the right to full connection.

The conditional connection arrangement was introduced to give network companies and generators the opportunity to defer expensive network investments and corresponding connection charges to cover a need for capacity that will only arise for a few hours annually. In November 2019, the option was first introduced for the supply side[4], and in April 2021

[3] Forskrift om nettregulering og energimarkedet (NEM). Last changed in August 2021.

[4] OED (2019). Høringsnotat. Forslag til ny forskrift om nettregulering og energimarkedet.

expanded to also include demand[5]. The conditional connection arrangement was introduced to give network companies and generators the opportunity to defer expensive network investments and corresponding connection charges to cover a need for capacity that will only arise for a few hours annually.

The mechanism was expanded to new load because of the increasing demand for connection from data centres, electric ferries and offshore petroleum and gas installations. End-users typically need to quickly resolve whether connection is possible, often have their own reserve capacity, and are usually willing to accept restrictions on their network use if a connection charge can be avoided or reduced. Socio-economic costs can therefore be reduced by giving these grid users (including generators) faster access while not having to reinforce the existing grid.

Since the law states that reduced tariffs in exchange for entering such an access agreement are not allowed, grid companies can only offer reduced connection charges. In Norway, connection charges are relatively deep (they may cover a share of investments in the meshed grid).

Alternatively, DSOs can still offer a reduced tariff instead of reduced connection fees when they enter a contract for interruptible consumption ("utkoblbart forbruk", UKT). This instrument has been introduced to curtail demand (from existing connections) on short notice in return for lower grid tariffs in constrained areas on all grid levels. While it is not mandatory for grid companies to offer such agreements anymore, they are still widely available and used. Compared to conditional connections, interruptible consumption tariffs are mainly used as an operational measure, rather than to alleviate structural grid issues. The role of the UKT has changed over time and is expected to be offered mostly in addition to agreements about a permanently conditional connection going forward. Grid companies and users have to judge themselves which option is most suited to their needs. For example, Elvia offers two UKT tariffs, one for instantaneous automated activation, and one with a 2-hour notification deadline before automated activation.

The grid operators are obliged to connect all parties asking for grid access. If the grid capacity is not sufficient, the DSO must invest to ensure that connection is possible. Exemptions apply for generation, subject to the connection not being deemed to be rational from a societal perspective, and for consumers only in extraordinary circumstances (see Ot.prp. nr. 62 [2008-2009]).

NVE has given the network companies the discretionary power to handle connections in their own grids, provided the general principles of the Energy Act with respect to economic efficiency, transparency and non-discrimination are fulfilled. The regulator does not specify the details of the agreement, such as, e.g., whether there is a limit to curtailment or a minimum size of the connection.

As the contracts are completely voluntary, there is also no expectation on the regulator's side to limit the agreement to a temporary solution. It expects that the parties will agree to a certain duration of the contract that allows a re-negotiation or cancellation period in case one party wants to step back from the contract.

According to NVE, it is very improbable that grid companies would allow small grid users to enter such an agreement, since it would not be beneficial to them. This factually prevents "uninformed" users from entering a conditional

[5] OED (2021). Høringsnotat. Endringer i forskrift om nettregulering og energimarkedet (tilknytning av uttak med vilkår om utkobling eller redusert strømforsyning).

connection agreement with the grid operator that would leave them worse off.

3.1.2 Relevance of flexible connections

Generally, the regulator stresses that conditional connections are not widely used, and it is not the objective to let them become part of the "new normal". The flexibility in connecting new customers is mainly needed due to new grid investments taking on average 7-8 years to materialise, i.e., to allow earlier connection.

But the option of non-firm connections is in demand, especially for wind generators but also for facilities that have some flexibility regarding their power use, e.g., soon-to-be-electrified oil and gas platforms.[6] In case of unforeseen events or maintenance work, the petroleum installations can be disconnected from the grid.

3.1.3 Considered alternatives in regulatory process

Currently, the regulator does not plan to introduce alternative access right regulation, such as auctioning of network capacity or local market arrangements for network access including connect and manage schemes that utilise local flexibility.

However, there is increasing R&D activity on local flexibility mechanisms and similar arrangements that touch upon the topic of access rights, and NVE is monitoring these projects closely. Recently, NVE has introduced a regulatory sandbox where network companies can apply for time-limited exemptions from their ordinary (budgetary) obligations to test new mechanisms, including for grid connection and operation.

3.1.4 Arguments for the current model

Conditional connection agreements might be advantageous for grid users in a short timeframe rather than having to wait for a full connection. Due to the saved connection fees, projects that previously could not be carried out due to high costs will now likely be able to be realised. The advantages from the grid operator's perspective are better grid capacity utilization and faster and/or cheaper connection solutions.

NVE considers that the complete freedom of contractual obligations provides a good basis for a more standardised framework in the future. No volume restrictions, time limits, or principles of access apply, and no secondary regulation further specifies details of the application of conditional connections. As the tool is relatively new, it might thus serve to gain useful experience with different approaches and in different circumstances.

The DSOs need to employ new infrastructure to monitor the grid and automatically give curtailment signals to the respective users. The rather open regulation thus helps in establishing best practices when it comes to improving the detailed oversight of grids.

3.1.5 Experiences with implementation of conditional connections

Due to the rather recent introduction and the wide application that the regulation allows, NVE has not yet collected enough information or drawn any conclusions about the conditional connection regime. Statnett (TSO) has not yet offered any conditional contracts on the transmission level but has announced they may do so in the future. The TSO requires that DSOs that offer conditional connections coordinate with higher voltage grid operators to ensure operational safety.

[6] See OKEA's «konsekvensutreding» regarding the grid connection of the Draugen and Njord O&G platform. 40 MW are offered without restrictions, with 40 additional MW under a conditional connection agreement that can be activated in case of grid constraints (N-0 connection that stops in case of a failure).

For lower voltage grid operators, the TSO voiced the following recommendations:

- Restrictions in the grid should be followed up by the grid owner and the necessary steps taken to manage grid constraints in the case of an intact network or if outages should occur.
- The TSO should not be forced to make interventions in the grid that occur as a consequence of the (new) connection.
- Statnett wants to be involved in sufficient time before the conclusion of an agreement so that the TSO's assessment can influence the content of the agreement, any technical solutions needed, and whether the agreement makes the connection operationally sound.
- Conditional connection agreements should be simple at the start. Grid constraints in the area of use should be easy to handle for the grid company offering the agreement.
- Especially if automatic curtailment is considered, the effects have to be estimated in planning, operation and in case of error correction in the grid.

Generally, the regulator has stressed the need for further coordination with grid companies that are faced with the implementation of conditional connection schemes to potentially standardise and develop the mechanism in the future. Grid companies need to be closely integrated in the consultation process before a new regulation is being decided on.

3.2 Denmark

In Denmark, the development of non-firm grid connection agreements started in 2012 with the first offers of limited grid access at the DSO level. In 2014, the energy industry association took the initiative to standardise the new limited grid access agreements to reduce connection queues. The guideline covered the distribution grid but also served as an inspiration to the TSO to come up with its own scheme. Ultimately responsible for the introduction of these schemes is the Danish Utility Regulator "Forsyningstilsynet".

3.2.1 Limited connection at DSO level

Regulatory context and process

In 2014, Dansk Energi (now Green Power Denmark), the country's energy industry organisation, published a proposal for restricted grid access ("begrænset netadgang") targeted at larger scale heat pumps in cogeneration plants, electric boilers and district heating. The scheme was based on Art. 73b in the Energy Supply Law[7] that gives industry organisation the right to make suggestions about standardised grid tariff agreements.

The scheme was approved by Forsyningstilsynet, the relevant regulator for electricity and network tariffs, in April 2015, and it was subsequently introduced by some DSOs (after approval of the individual tariff proposal by the regulator).

In 2020, Forsyningstilsynet gave the green light to extend the scheme[8] to demand connected at 10-60 kV (medium voltage). The regulator allowed the new grid access design as price differentiation is permitted if it improves efficient grid use and increases security of supply.

The scheme was not extended to household users as they are regarded too small to benefit from the implementation and to provide a cost-effective way to reduce bottlenecks. Furthermore, a large number of small customers on limited connection agreements would require very detailed control

[7] Elforsyningsloven § 73 b

[8] Dansk Energi. (2019). Vilkår og betingelser for tilslutning med begrænset netadgang

and metering at lower grid levels, which would be too advanced to implement at this point.

The latest version of the industry association's limited grid access standards was handed to Forsyningstilsynet in April 2022[9] and was approved in June. It aims to expand the scheme to generation facilities. The standard includes fully limited and partly limited grid access, where for the latter, only a percentage of the feed-in capacity is limited. With political targets to quadruple renewable power capacity in Denmark by 2030, it is necessary to be able to connect new generation without long delays. The new arrangement is expected to be offered to grid users from January 2023.

Principles and requirements

Limited grid access is given in return for a reduction of the connection fee and can be requested by both new and expanding connections.

Some of the main principles include:

- The customer pays the costs associated with connection, so that no costs are passed on to other customer groups.
- The new/expanded conditional grid connection should not trigger grid reinforcements in the local or overlying grid that go beyond the costs for establishing the individual connection and necessary automation/control devices.
- The grid operator has the right to disconnect/ downregulate the given consumption facility automatically or manually when the local grid is strained.
- The customer cannot, against payment, demand additional reinforcement in the transformer or the meshed network without changing to a fully firm connection. The customer can only pay for reinforcement up to its point of delivery.
- If limited network access is not sufficient from the grid user's perspective, the customer has the option to revert to a connection with full network access (in due time or against retroactive payment).
- Limited access can be given even in areas without constraints. Users with limited connections then bear the full economic risk if future demand increases and curtailment is needed (including imbalance costs, delivery of reserve power in case of participation in the market). The grid company can inform about possible restrictions but does not have to guarantee permanent grid access.
- The grid company is expected to provide an estimate of curtailed hours per year but has no responsibility to adhere to those numbers.
- The grid company should carry out a thorough calculation of costs and possible operating patterns to get an overview of each individual network connection. With this data, the customer must be oriented about the uncertainty of network access now and in the future and written into the network connection agreement. This serves only for orientation and is not binding for the DSO in any way.

The new standard limited grid access agreement for generators contains the following principles:

- The customer pays the full standard connection fee for the part that is connected to the grid with full access, and a reduced connection fee for what is connected to the grid under limited grid access.
- The customer must decrease his grid use when notified by the grid operator.

[9] Green Power Denmark. (2022). Vilkår og betingelser for tilslutning med begrænset netadgang for produktionsanlæg

- Limited grid access is only offered to generators connected to medium and high voltage distribution grids, as these are the ones potentially affecting grid bottlenecks due to their size.
- Available for plants at a rated capacity of 1 MW and higher.
- The grid company should be able to control generation with its existing SCADA system.
- It must be possible to downregulate/curtail the plant manually if signals from the grid company cannot be transmitted.
- The limited grid connection agreement must be notified and approved by Forsyningstilsynet.

3.2.2 Limited connection agreements at TSO level

Regulatory context and process

Energinet gave input to the public consultation phase on the new DSO standard on August 8, 2022[10]. Generally, the TSO did not see the introduction of conditional connection in the distribution grid as too problematic. They did however warn that conditional connections in the distribution grid implies an increased need for reserve capacity for upregulation, costs for which will have to be covered via grid tariffs.

Furthermore, they noted that an introduction of limited grid access for generators on the transmission level might prove difficult as this will entail the need for counterbalancing measures on the other side of grid bottlenecks. Counter-balancing might be hard to procure in cases with already existing deficits in power generation on that side of the grid.

While the arrangements discussed above were all aimed at the distribution system level, Energinet took inspiration from Dansk Energi's limited grid access scheme and in 2019 suggested a limited access methodology for *load* connected to the transmission grid.[11] Energinet subsequently stopped the process after the consultation period. An updated version that included feedback was sent to the authority in June 2022.[12] Energinet wants to introduce the proposed connection agreement by January 2023 or as soon as it is approved by Forsyningstilsynet.

In the separate public consultation on Energinet's proposal, broad interest was expressed in Energinet offering limited network access even to new generation facilities. For the moment, however, Energinet will not consider this option further.

Principles and requirements

The Energinet proposal differentiates between a limited connection and a temporarily limited connection. The purpose of limited network access is to deal with large network connection requests in a fair and appropriate way.

Limited connections

For users that can accommodate for an indefinite restriction, a higher tariff reduction is foreseen due to their limited effect on grid costs. The new method expands the toolbox of the TSO and can lead to quicker connection processes. Access to available capacity is granted on a "first come, first served" basis, depending on the signing of the network connection agreement.

A significant difference to the DSO scheme is that Energinet offers a reduction in the grid tariff instead of an exemption from the connection fee. Energinet estimates that the cost of a user with a permanently limited connection represents only

[10] Energinet. (2022). Høringssvar til fsts vedr. Green Power Denmarks metode for begrænset netadgang for elproduktionsanlæg

[11] Energinet. (2019). Vilkår for begrænset netadgang

[12] Energinet (2022). Begrænset netadgang for forbrugsanlæg i transmissionsnettet samt midlertidig begrænset netadgang for forbrugsanlæg i transmissionsnettet

one third of that of a user with firm connection (CAPEX needs, interest, depreciation, O&M). Therefore, including other parts of the grid tariff than connection charges, e.g., grid losses, a limited connection user would pay a tariff that is 53% lower than the standard transmission grid tariff.

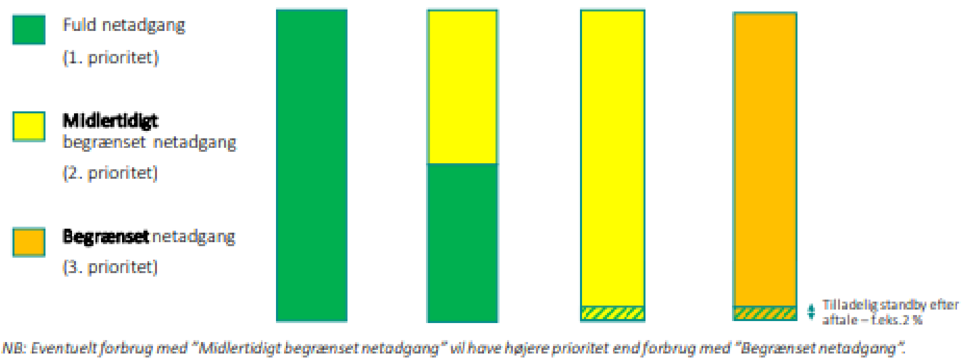
In addition to the tariff reduction, the interruptibility of the limited connection gives a geographical incentive, where the lower risk of interruption in a supply-dominated area both provides an additional incentive to place new flexible consumption in precisely those areas and, all else being equal, to consume more power there due to the lower tariff. Energinet thus expects that the agreements will reduce the need to transport energy away from areas with a large production surplus and thereby also reduce the requirements for network expansion.

Temporarily limited connection

For users not willing to enter a permanently limited agreement, the TSO wants to introduce a temporarily limited tariff product that allows them to connect faster but transition to a normal, firm connection as soon as the grid circumstances allow. For temporary agreements, the tariff is based on the weighted average in the use of the standard and the limited grid tariff. The weighting takes into consideration the user's consumption between 1st of July and 1st of July of the last year and takes effect from January 1st. When full grid access is established, the tariff changes back to the standard fee. Furthermore, a waiting period should prevent customers from gaming for the more advantageous connection. It is not possible to change from temporarily limited grid access to limited grid access for a duration of five years after the grid user transitions to full access. This restriction shall ensure that other customers do not have to carry the costs for grid expansion after the network has been expanded to make room for new, unrestricted connections. It is also the same period that Energinet must adhere to when it unilaterally wants to cancel limited grid access agreements.

With both types of agreements, Energinet obtains the right to curtail or restrict consumption whenever it is necessary for the secure operation of the grid *within the bidding area*. Whether failures, operational events, planned maintenance, safety interruptions or prolonged breakdowns cause the grid constraints does not matter. However, bottlenecks between bidding areas and the need for system balancing are not valid reasons for restricting grid access. If possible, the TSO will inform the counterparty of planned curtailments as soon as they are known to the system operator.

Figure 1: Prioritisation of demand with different access rights



Source: Energinet (2022)

In curtailment situations, customers with limited grid access are curtailed before market-based mechanisms such as balancing or redispatch come into effect (cf.). Limited connections are disconnected according to the pro rata principle. For users with temporarily limited agreements, the LIFO principle applies.

Energinet aims to notify companies about curtailments under the agreements as soon as the next day's schedules are available but reserves the right to announce them without notice. The curtailment then has to be applied in a 15-minute timeframe.

Further development and evaluation process

The TSO aims to evaluate the proposed tariff reduction percentage as well as the general method four years after its introduction. A main objective is to use it for the connection of large, flexible Power-to-X facilities or district heating facilities that are expected to come online in the future. These would likely lead to significant grid congestion if handled via standard grid access. According to Energinet's analysis, the introduction of limited grid access would substantially reduce the need for wide-ranging grid reinforcements.

The value for Energinet in offering interruptibility agreements lies in the cost savings that a long-term and secure arrangement creates, by not having to expand network capacity to accommodate customers who prefers a lower tariff to very high supply security.

3.2.3 Participation in balancing power markets

Neither DSO or TSO arrangements take away the customers' rights to – at their own risk – participate in the spot and balancing power markets. However, customers with restricted grid access on the TSO level cannot participate in local flexibility markets or offer upregulation (reduced demand). On the other hand, they are allowed to offer up- or downregulation in the balancing markets for the entire bidding area and all capacity bidding markets, as well as to the local flexibility market for downregulation (increase demand).

Customers with a limited grid access agreement at the DSO level can participate in TSO flexibility and balancing markets, but not in DSO flexibility markets. Similar to the rules on the TSO level, the right to upregulate has been transferred to the DSO (but does not affect actions on the TSO level).

3.3 Germany

No conditional connection regime is implemented, although a law for its introduction was prepared but not adopted. Responsibility for development of a new non-firm access regime has been assigned to the regulator. A study commissioned by the former government laid out a detailed design for mandatory curtailment of flexible loads, which was met with strong resistance. In early 2023, a consultation process regarding a new design can be expected.

3.3.1 Regulatory context and process

Germany has not implemented a conditional connection regime yet. Large changes to grid access were discussed in January 2021 but postponed due to public and political resistance. However, new incentives for market-based flexibility procurement were promised by the government to deal with the grid issues that accompany the *Energiewende*. Currently, a new attempt is made to find a suitable conditional connection model.

The prepared, but not introduced, SteuVerG (Steuerbare-Verbrauchs¬einrichtungen-Gesetz – Steerable load law) contained a mechanism to allow grid companies to use a method called "Spitzenglättung" (peak shaving) to curtail flexible loads, e.g., EV charging or heat pumps, to reduce the need for grid reinforcements. The mechanism would have allowed grid companies to adjust loads via flexible connections two months after its introduction.

After the proposal was shelved due to heavy resistance, especially from the automotive sector, the new government assigned the responsibility to develop a new flexible connection design to BNetzA (Federal Network Agency – Regulator), following a recent ECJ ruling imposed on the German government to give BNetzA more independence in setting grid tariffs.

The decision in the 2022 amendment to Art. 14a EnWG (Energiewirtschaftsgesetz – Energy Act)[13] now gives the regulator the task of developing uniform national rules for grid-oriented management and the connection of steerable loads in return for reduced grid tariffs. The background is that the new EU net zero and “Fit for 55” legislation make it necessary for grid operators to take a wider system perspective. This wider perspective includes the development of flexibility mechanisms for new loads from heat pumps and EVs (with high power use and simultaneity) to support the uptake of distributed generation. Due to its importance for the distribution grids, the Article 14a remains part of the high-level legal EnWG as a “lex specialis” and is not included in the more detailed grid connection and access regulations.

The 14a-paragraph specifies that grid-oriented control and steering by the DSO will only be possible based on a bilateral agreement between the network operator and the respective user, or on economic incentives to act independently. This implies that participation will not be obligatory. While this must be respected, BNetzA now has the sole responsibility to specify the conditions under which fully or partially limited connection can be agreed. The objective of the new regulation and a design criterion is to minimise the utilisation of such a tool and rather count on the development of market-based flexibility solutions.

Furthermore, old contracts that were concluded under Art. 14a in the past should not be affected by the new rules. The regulator will also be able to make it obligatory for grid companies to offer conditional access tariffs. The legal text mentions the installation of smart meters as a precondition to offering the curtailable connection arrangement.

According to BNetzA, it aims to publish a consultation document in the beginning of 2023, outlining the proposed design of a new scheme. Incentives should be given via reduced grid tariffs mainly, but also lower connection fees.

3.3.2 Report: Design of a mandatory mechanism

The contents of the initially proposed law were based on a study by BET[14] commissioned by the “intelligent grids” working group of the German Ministry for Economic Affairs and Energy in 2018. As the Ministry expects large additional connections requests due to new loads, conditional connections may help to optimise grid use and resolve constraints. The study differentiates between classic, partly flexible and fully flexible (household) consumers. While the authors advocate not to restrict conventional uses, they deem that flexible loads (EVs, heat pumps) can potentially be made conditional. New requests should therefore also face connection fees that can be differentiated, and where users can choose the share of conditional access themselves. As this can be difficult for individual users, a standardised option should be developed.

More curtailable load should lead to lower grid tariffs. With conventional, existing consumers not being touched, no large redistribution effects would materialise while strong signals for efficient grid use would be given to flexible connections. The study suggests restricting the use of the tool only to the most strained grid use peaks.

The proposal implies mandatory participation for users with EVs and heat pumps, unless they opt to pay extra for

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[13] Deutscher Bundestag. (2022). Beschlussempfehlung zu dem Gesetzentwurf der Bundesregierung: Entwurf eines Gesetzes zu Sofortmaßnahmen für einen beschleunigten Ausbau der erneuerbaren Energien und weiteren Maßnahmen im Stromsektor

[14] BMWK (2018). Gutachten Digitalisierung der Energiewende. Topthema 2: Regulierung Flexibilisierung und Sektorkopplung

unconditional access. Generally low tariffs for conditional grid use would provide an even stronger incentive for participation. This can be achieved due to the very low costs such loads impose on grid investment and operations. At the same time, the curtailable assets should be allowed to offer their flexibility for market-based schemes under certain restrictions to manage the risk.

3.4 United Kingdom

As an early mover regarding non-firm grid access arrangements, the UK has recently taken extra steps to adapt its regulatory framework to the needs of a net zero future. In 2022, it published its Access Significant Code Review decision, that on the one hand reduces grid connection fees and on the other hand clearly defines how flexible connections can be handled by DSOs. This is aimed at reducing connection lead times and increase RES uptake. The reform should enable DNOs to take a wider system perspective by giving more flexibility with their budget when it comes to establishing connections and grid reinforcements, as well as keeping them responsible to expand the grid according to the needs of its users. To achieve that, the regulation now prescribes not to offer non-firm arrangements to small users, to require a curtailment limit for parties seeking connection, and to set an explicit end date of the curtailable connections. The final Access SCR decision seeks to simplify the flexible connection model and focus on helping DNOs anticipate system needs.

3.4.1 Regulatory context

The United Kingdom was one of the first European countries to consider non-firm access rights in 2006, when Ofgem and National Grid started to think about alternative solutions to solving grid issues. The introduction of feed-in tariffs and other incentives for the build-out of renewable energy led to a much faster take-up as expected by the grid operators. The power networks quickly became overstrained with the new reverse power flows materialising. As a remedy, DNOs started to refuse new connections of distributed generation and the regulator had to scurry for solutions to alleviate the issue.

From 2012 onward, the Flexible Plug and Play Pilot scheme allowed market participants to collect information about how to best design such arrangements. To this day, experience from the trials provides a foundation for theoretical assessments and studies of practical use cases (see references in Chapter 2).

3.4.2 The use of flexible connections

By 2018, most of the distribution network operators (DNOs) have offered flexible connections to renewable generators or consumers. When opting for a flexible connection, generators do not have to pay reinforcement costs in the wider network (same voltage level and the one above, called "shallowish" connection charges). If further connections make reinforcements necessary, grid users are required to pay a share of these costs through a claw-back mechanism.

The LIFO principle is often (but not always, as the curtailment rule is not strictly regulated) used when curtailment occurs. However, in a document published by the Energy Networks Association, the organisation coordinating DNOs' approaches in the UK, the pro rata method and curtailment according to a "curtailment index" are also described.[15] The curtailment index However, in a document published by the Energy Networks Association, the organisation coordinating DNOs' approaches in the UK, the pro rata method and curtailment

[15] Energy Networks Association (2021). Flexibility Connections: Explainer and Q&A

according to a "curtailment index" are also described. The curtailment index method caps curtailment according to an estimate of the need for curtailment over the course of a year. The estimate considers historical network power flows, typical load, generation profiles and the grid user's position in the LIFO ranking (if used by the grid operator). The tool is used to rank curtailable connections and when they will be constrained by the DNO. Those with the lowest curtailment index are placed at the top of the stack and have a higher likelihood of curtailment in the future. When they are curtailed, their position in the Curtailment Index will be reassessed and they might move lower in the ranking.

Grid users always have the right to request a standard connection but will have to pay the associated costs. By now, DNOs offer several non-firm connection products for demand and generation units:

- Active network management is the most sophisticated product. It requires good monitoring capabilities of the lower voltage grids and passes real-time data on to the DNO. This allows the grid operator to allocate the maximum amount of available capacity to the existing users in the grid area. The LIFO principle is applied in case of grid congestion. Automated curtailment signals are then sent to customers.
- Contractual flexibility is offered with e.g., special conditions in the contract that could entail temporarily limited grid access until full capacity is available.
- Intertrip options abstain from the 2-circuit connection system planning standard and will lead to curtailment if one circuit fails.
- Timed connections restrict export capacity at certain peak grid usage times.
- Other options include shared capacity, demand management by the customer or export limitations that are strictly enforced through systems installed by the DNO.[16]

A problem that was identified with these schemes is that the Distribution Use of System charges (DUoS), i.e., all network tariffs that are not paid on a per kWh basis, might not be spent on grid reinforcements but also on implementing solutions for flexible connections customers.

3.4.3 Significant Code Review of Network Access

Recently, net zero targets and the associated need to integrate an even higher share of renewables became an important driver to amend and elaborate the scheme. To this end, Ofgem launched a Significant Code Review (SCR) of network access and forward-looking charge arrangements in 2018.[17] The aim was to enable DNOs to take a wider system perspective when weighing new connection of demand under flexible conditions, versus grid reinforcements.

The regulator initially defined several standard models for flexible connections[18]:

- *Different levels of firmness:* Providing access with lower levels of firmness (connection capacity), where access to connection is capped or completely curtailed depending on different grid circumstances.
- *Shared access:* Several users can share connection capacity but must coordinate their use to ensure that contractual limits are not breached.

[16] The flexible connection alternatives can be found on DNOs' websites, e.g. Scottish and Southern Electricity Networks

[17] Ofgem. (2018). Electricity Network Access and Forward-Looking Charging Review - Significant Code Review launch and wider decision

[18] Ofgem. (2021). Access SCR – Consultation on Minded to Positions

- *Static time-profiled non-firm access:* Access rights are conditional on peak/off-peak periods over fixed time intervals (hourly, daily, weekly, monthly, seasonally).
- *Dynamic time-profiled non-firm access:* Certain events trigger non-firm access rights, e.g., PV or wind feed-in exceeding a certain threshold.

With these considerations, Ofgem wanted to give new grid users a range of connection options to choose from when subjected to the risk of curtailment. This way, business cases for non-firm connection would be offered to a wider range of individual market players. The non-firm access option is also considered necessary to give generators who do not have the willingness to pay for expensive grid reinforcement the possibility to connect.

Three main criteria were suggested to assess the value of new non-firm connection options:

1. The scheme should foster efficient grid use and development.
2. It should reflect the consumers' needs appropriately.
3. Changes to the current system should be practical and proportionate

Flexibility markets are seen as a logical complement to non-firm access rights by the regulator. They are treated distinctly from flexible connections however, as they are considered as a service to the DSO, while flexible connections are until now seen as a risk for the grid user side. The Access SCR aims to change this perception. Ofgem is of the opinion that *"the benefit perceived by users depends on the design of the connection charges; under deep connection charges, users can directly reduce their one-off payments, whereas under shallow connection charges, they could mainly benefit from a faster connection or direct compensation."*

In May 2022, the final decision on the Access SCR was released by the regulator[19]. A significant part of the decision is a reduction in distribution connection charges. Grid reinforcement charges are reduced for generation (only costs for investments needed on the same voltage level apply) and completely removed for consumers. Ofgem expects these changes to be a core driver for the handling of flexible connections going forward. More users might for example opt for firm connections as connection fees become lower. This aspect should incentivise DNOs to take a wider system perspective and carry out reinforcements ahead of need. A main objective is to reduce the time it takes to connect and thereby incentivise more renewables in the grid.

In the course of several consultation rounds during the last years, the regulator came to the conclusion that the options for flexible access outlined above were too complicated, impractical to implement and without large-scale benefits to the grid. That is why the final decision is to simplify the access rules: to not offer non-firm arrangements to small users, to require a curtailment limit for parties seeking connection, and to set an explicit end date of the curtailable connection (unless the grid user specifically requests to prolong the non-firm connection agreement).

Flexible connections can be very complex and difficult to understand for individual consumers. Moreover, the access to energy is considered an essential need that could be jeopardised if flexible connections are available to domestic end-users. Flexible connections are thus not considered suitable for this consumer group.

Due to the potential benefits to both grid and users, larger grid users should however always be able to opt for a curtailable connection. The agreement should also give some certainty about the curtailment that can be expected. Therefore, DNOs will be required to publish limits in the

[19] Ofgem. (2022). Access SCR – Final decision

offers to the grid users, either as hours per year or as a percentage. Strict requirements will be put in place to disincentivise the grid companies from exceeding these limits. If larger amounts of curtailment are necessary, the DNOs will have to procure curtailment on the market.

Fixed end dates for curtailable connections are introduced to reduce investment uncertainty and give an impetus for forward-looking grid expansion by the distribution grid operators. Ofgem stresses the danger of relieving DNOs from their responsibility to solve grid constraints over the mid- to long-term and expects an end date to counteract that. This does not necessarily have to result in investments in grid reinforcements but could alternatively be resolved through flexibility procurement.

With this step, the regulator wants to give more power to the customer and to shift some of the risk back to the grid company. At the same time, the DNOs are given tools to take more strategic investment decisions and tackle grid reinforcement ahead of need through a more flexible budgeting approach. Business plans that need to be approved by Ofgem can be expanded by an uncertainty mechanism to also include planned connection needs that need to be adjusted to include heat pumps, EVs etc.

Before its expected entry into force in April 2023 (also the start of a new regulatory period, ED2), no commonly defined curtailment limits have been introduced by DNOs, and the application of flexible connections varies widely in practice. The modified framework should lead to more standardisation and will be further developed in industry work groups ahead of finalising the reforms.

Ofgem also stated that it has not made a quantitative assessment of the impact of the new curtailable connection framework due to the low costs of implementing it and the strong alignment with other SCR principles.

3.5 Ireland

Ireland also has a long history with non-firm access arrangements. Non-firm connection agreements were already established in 2001 as a transitory measure but became more sophisticated over time. In response to new regulations (ECP-1 and ECP-2), a new firm access methodology has been developed on the transmission level. It is based on Firm Access Quantities and depends on a yearly review of the status of non-firm connections and a comparison with the Transmission Network Development Plan. This approach should reduce the time it takes to move from non-firm arrangements to a firm connection. Similarly, the DSO has published plans to gradually introduce more sophisticated non-firm access arrangements from 2021 onward.

3.5.1 Early introduction of non-firm access rights

In Ireland, the volume of new requests for grid access led to a long queue and many potentially viable RES projects not being realised. To enable faster connections, the transmission grid operator obtained the right to offer non-firm connections as a transitory measure already from 2001.[20] If generation had to be capped due to grid constraints or outages, no financial compensation would be given until the necessary reinforcements were put in place (termed as Deemed Firm Date). This first approach to non-firm access was considered a simplified solution that would not interfere with the introduction of more sophisticated schemes over time. The regulator came close to abolishing the regulation in 2003 as new firm connection capacity would anyways be

[20] CRU (2001). Firm and Non-Firm Access to the Transmission System. A direction.

needed in the upcoming years to ensure security of supply but decided to let it continue until further notice[21]. That decision was made because the non-firm access could still provide value for DG that would not secure firm access in Ireland's regularly held generation capacity competitions.

From 2011, the concept of Firm Access Quantity (FAQ) was developed by the TSO EirGrid. FAQ forecasts where in the grid firm access is expected to be available and posts schedules of potential constraints ahead of time. Generators with firm access receive compensation if they are scheduled to run but curtailed due to grid constraints, while a unit with non-firm access is not compensated if curtailed. The system is implemented through balancing and imbalance arrangements. The system incentivises new projects to locate outside of areas where connection is not considered feasible without grid reinforcements. In congested grid areas, only non-firm connections for an extended period of time will be offered.

To fully secure FAQs in areas with grid constraints, generators are assigned Associated Transmission Reinforcements (ATRs), i.e., new or upgraded transmission infrastructure projects. To forego the risk of being curtailed without compensation, a project must be connected via its permanent connection and completed ATRs. EirGrid publishes quarterly updates on the status and progress of ATRs on its website.

Figure 2. The backward-looking part is based on this annual review. The forward-looking feature focuses on local

3.5.2 Enduring Connection Policies to handle large connection request volume from 2018

In 2017, CRU published a new Enduring Connection Policy (ECP-1), applicable on both TSO and DSO level from 2018. [22] Its aim was to reduce the timeframe for connecting new generation to the grid by cutting down speculative applications for grid connections by DG projects. The ECP-1 also aimed at increasing the efficiency of connection request reviews through batch processing. Non-firm offers with fixed timescales were also introduced to help set up connections more quickly. Incentives were given to the grid operator to deliver firm access in due time.

In June 2020, CRU updated the ECP and published a framework for a second application window, ECP-2.[23] EirGrid was asked to develop a new firm access methodology based on transmission network development plans. Connection offers continue to be issued on a non-firm basis, but applicants will receive scheduled FAQs under the new methodology. More weight is given to locational factors when making firm access available to generation and storage.

3.5.3 New firm access methodology for transmission grid

A backward- and a forward-looking element are featured in the new firm access methodology. From 2022 onwards, EirGrid will conduct access reviews[24] where all connected non-firm generators will be assessed according to the methodology outlined in

bottlenecks, but the assessment also considers flows between regions that might affect the allocation of firm

[21] CRU. (2003). Commission Decision on Future of Direction on Firm and Non Firm Access to the Transmission System

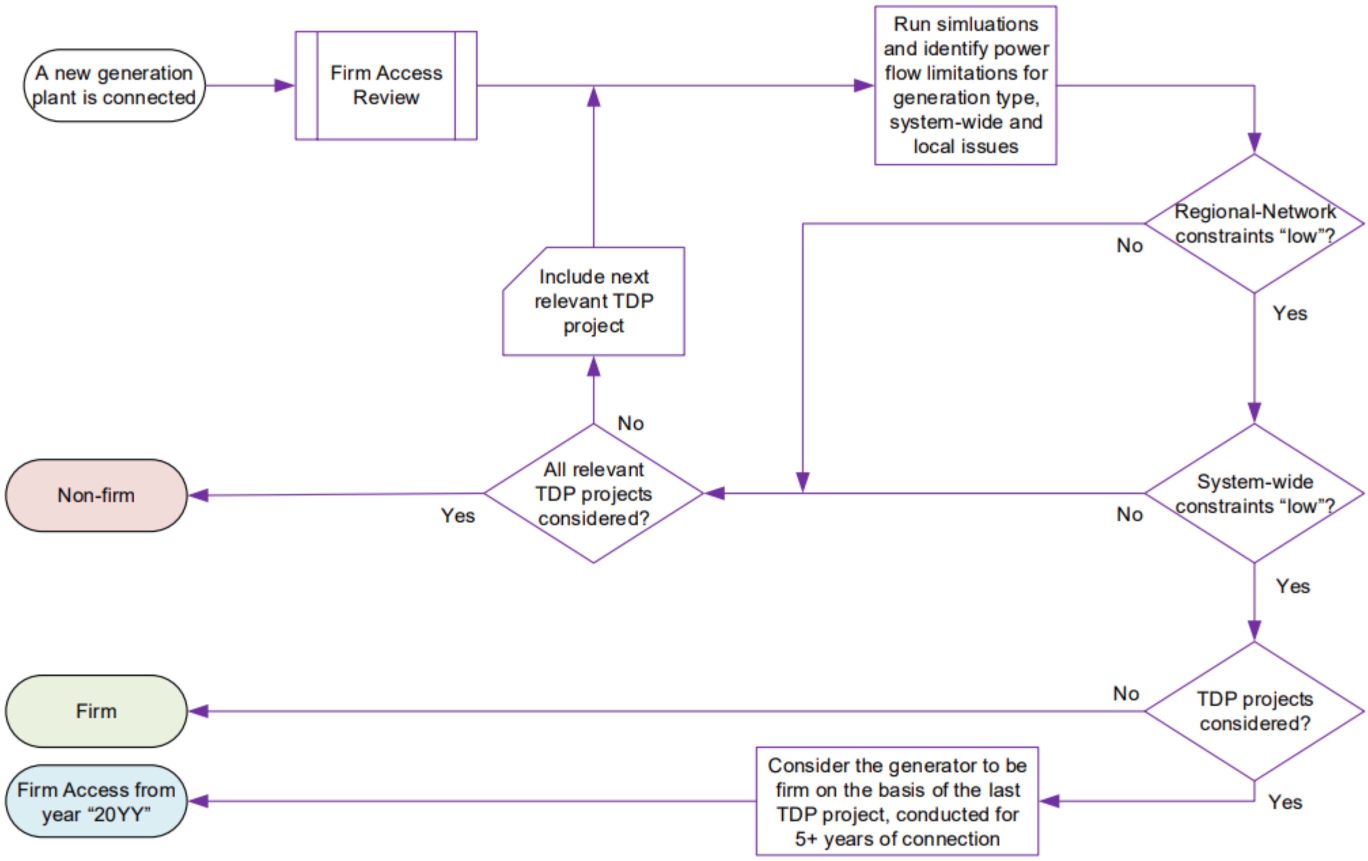
[22] CRU (2017). Enduring Connection Policy Stage 1 (ECP-1) Decision.

[23] CRU (2020). Enduring Connection Policy Stage 2 (ECP-2) Decision

[24] EirGrid (2021). Firm Access Methodology Review

access rights. This is based on the Transmission Grid Development plan. Generators will have the right to feed in with a Minimum Export Capacity of 1 MW (essentially making it only applicable to larger generators).

Figure 2: EirGrid methodology for annual firm access review



Source: EirGrid (2021)

3.5.4 Non-firm access schemes introduced at DSO level

In reaction to ECP-2, ESB Networks, Ireland's main DSO, also laid out plans for the gradual introduction of non-firm access (NFA) concepts at the DSO level over the regulatory period 2021-2025 in early 2021.[25] From Q1 2021, a simple non-secure access offer for generators was offered in the form of a hard inter-trip connection for transformer capacity in the distribution grid.

Further steps are planned from 2022/23 onwards:

- New devices and tools to signal and communicate with distributed generation, e.g., an agreed reduced Maximum Export Capacity (MEC) in case of faults, rather than full curtailment, shall be developed and trialled.
- Variable MEC shall be trialled for specified planned or fault-related outages.

[25] ESB Networks (2021). Non-Firm Access Connections for Distribution Connected Distributed Generators Guide.

- New active network management practices and automated responses shall be developed in the regulatory period 2026-2030.

These new arrangements are not to unduly infringe the operations of active generators or those with already signed connection agreements. Moreover, the NFA concepts should be simple, automated, rather than centrally controlled, and applied at higher voltage levels. No costs should be carried by consumers or generators that do not fall under the NFA scheme.

3.6 France

While the country's largest DSO started trials of conditional connections for DG in areas with a high demand for connections from RES in 2017, first, only locally available alternative connections were offered for generators from 2018. The French regulator then signed off on rules for alternative connections in 2021. The new regulatory basis enabled the implementation on a wider scale for MV customers at the DSO level, albeit with strict boundaries for how much curtailment can be performed by the grid operator. Enedis estimate fee savings of up to 90 kEUR/MW for generators. The TSO currently works on its own conditional connection scheme on the request of the regulator.

3.6.1 Local introduction on the DSO level after pilots

In 2018, after a pilot phase, Enedis, the main DSO in France, started to offer curtailable connections in some of the more constrained grid areas. The main purpose was to allow renewable energy generators to connect faster and at a lower cost. Later, connection of storage and charging infrastructure also became important drivers for the mechanism.

3.6.2 Regulatory basis was defined in 2020 and entered into effect in 2021

In 2020, a draft decree to set up a regulatory framework for conditional connections was sent to the High Energy Council (CSE), a coordination body set up by the French government to collaborate on new laws and regulation in the energy sector. CSE was to ensure that investments in the grid were not reduced while at the same time promote the connection of distributed generation that would not be built under the standard framework. Grid operators were officially given the right to introduce alternative connection schemes.[26]

In July 2021, the regulation for the introduction of "Opérations de raccordement alternatives", or alternative connections, was adopted.[27] With this, RES producers connecting at medium voltage level could request an alternative connection offer from Enedis. If the grid operator implements an alternative connection solution on its own initiative, it bears the resulting additional costs compared to the reference solution. If it does so on the initiative of the connection applicant, the latter bears the additional costs. Some boundaries have been introduced (for grid operators with more than 100 000 customers):

- Curtailed energy may not exceed 5% of the annual production of the generator.
- The firm connection capacity cannot be lower than 70% of the requested connection capacity, i.e., a maximum of 30% of the connection capacity can be curtailed.

The DSO can only offer a conditional connection if:

[26] Gouvernement de France. (2020). Code de l'energie. Article D342-23

[27] Ministère de la transition écologique. (2021). Arrêté du 12 juillet 2021 d'application de l'article D. 342-23 du code de l'énergie

- The non-firm connection capacity under the scheme does not exceed 1% of the total renewable capacity in the grid area.
- The energy that can be curtailed under the scheme does not exceed 0.1% of RES generation in the grid over the course of the previous year.

Still, the rules were adopted in the regulation without major changes. The regulator, CRE, first criticised these suggested limitations as too restrictive, as they could prevent or delay RES projects and would thus defy the purpose of the introduction of conditional connections. According to CRE, a capacity cap would prevent resolving one-off constraints for which a significant curtailment over a short period would be necessary. The actual impact on the energy fed into the grid would in such a case be minor. Still, the rules were adopted in the regulation without major changes.[28]

In an economic evaluation of the smart connection, Enedis calculated that MV generators could benefit from connection fee reductions of ca. 90 kEUR/MW.[29]

In November 2021, CRE demanded that within 6 months, RTE should deliver a proposal for an alternative connection framework at the TSO level. RTE has not yet published such a proposal.

3.7 Netherlands

The Netherlands do not have conditional connection arrangements. While ACM prepares a consultation in autumn 2022 about the benefits of flexible connections, the regulator alludes to its recently implemented congestion management reform as the main tool to deal with grid constraints. The new rules are designed to incentivise market-based flexibility mechanisms to emerge. Compared to other countries, the regulator sees the introduction of flexible connections as potentially counteracting the objectives of the congestion management reform, as they might take responsibility away from grid operators to reinforce the grid.

3.7.1 Regulatory context

In recent years, the Netherlands have started to experience and are expecting further capacity shortages and long queues for connecting RES projects or increasing transmission capacity. In principle, there is an unconditional obligation to connect customers to the grid for anyone who makes a request. A connection can only be refused where no grid capacity is reasonably available which does not apply to contractual congestion, only to physical congestion (i.e. only when the actual volume that flows through the grid causes congestion, and the capacity is not just exceeded by the capacity that could hypothetically be expected if the contractually set capacities are fully accessed). This is handled quite strictly by the energy regulator ACM: A grid operator is expected to undertake far-reaching efforts to fulfil grid connection tasks and to use all possible means to deliver the requested electricity. Exceptions are rare.[30] Furthermore, grid operators are not allowed to discriminate between customers. That implies that they cannot distinguish between existing and new customers in the allocation of available grid capacity. The allocation of scarce transport capacity on the basis of a "first come first serve" principle would violate this principle.

The regulator states that when connecting new wind and solar parks, grid operators must start from the transmission

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[28] CRE. (2021). Délibération n° 2021-326 du 21 octobre 2021 portant décision d'approbation de la procédure de traitement des demandes de raccordement des installations de production d'électricité au réseau public de transport d'électricité

[29] Enedis. (2019). Les flexibilités au service de la transition énergétique et de la performance du réseau de distribution

[30] cf. to Schenkefeld vs. Liander (2018).

capacity that is actually used instead of the maximum transmission capacity that has been contractually agreed. However, ACM has not considered non-firm connections up to now. It only allows grid operators to experiment with flexibility under strict conditions, including that pilots do not disrupt the market.

In autumn 2022, a consultation process will begin to determine a reasonable limit for supplying or refusing transmission capacity, and if there is a need for non-firm connection agreement options.

3.7.2 Reform of congestion management rules as an alternative to non-firm grid access

In the meantime, ACM has published new congestion management rules that aim to solve grid issues.[31] Article 9.1 states that "grid operators [may] enable connected parties, voluntarily under pre-agreed conditions with the grid operator (...) to contribute to solving physical congestion, by temporarily or otherwise (partially) waiving the use of the right to grid transport".

This should primarily be achieved by giving DSOs and TSOs incentives to procure flexibility on market terms. The objective is to increase flexibility by temporarily restricting the use of grid by existing consumers.

The rules aim to incentivise local flexibility in areas where the grid has reached its maximum capacity. In addition to large demand sources, distributed generation can also participate in congestion management in return for financial compensation. If the power supply or demand in an area exceeds the grid capacity, the TSO or DSO can request bids from market parties go use or generate more or less electricity. A common market platform, GOPACS, collects the bids that the grid operator can subsequently accept.

With the new rules, grid operators will soon be able to conclude long-term contracts with large consumers and producers for an agreed fee. The changes introduce remunerations for grid users that can alter their consumption/ generation after day-ahead market closure and thereby support the grid operator. While in-house expertise is needed to take part in the redispatch market, the new congestion management rules facilitate the participation of a wider selection of players to alleviate grid issues.

Consumers and producers with a transmission capacity of more than 60 MW are obliged to contribute to solving physical congestion on conditions agreed in advance with the TSO. In case of congestions, the system operator can oblige consumers and producers with a transmission capacity of more than 1 MW to make curtailment offers under conditions to be agreed with the grid operator. It will also be possible for consumers and producers with smaller connections to participate jointly in congestion management through aggregated bids.

In the event of imminent large-scale disruptions, the grid operator is authorized to switch off loads or to instruct the increase or reduction in generation, or to oblige a connected regional grid operator to reduce the amount of active power or reactive power that is transported. A network operator must first deploy all market-based resources before non-market-based resources are used.

Instead of using non-firm connections, the decree introduces a capacity limitation product. The product implies that a grid operator can conclude agreements with grid users in its service area by which he can request, subject to pre-agreed

[31] ACM. (2022). Besluit van de Autoriteit Consument en Markt van 24 mei 2022 kenmerk ACM/UIT/577139 tot wijziging van de voorwaarden als bedoeld in artikel 31 van de Elektriciteitswet 1998 betreffende regels rondom transportschaarste en congestiemanagement

conditions, them not to make full use of their contracted transmission capacity against payment. Such bilateral agreements are considered as market-based because the network operator and the connected party agree on the conditions voluntarily. For all capacity-limitation-based products, the grid operator aims to publish whether curtailment is required the day before.

The rules are expected to be applied from 2023. According to ACM, the costs for congestion management incurred from the publication date of the decision (from 24 May 2022 to 31 December 2023) will be reimbursed via ex-post calculation of tariff decisions for the regional grid operators.

In July 2022, ACM also published deadlines for new connections to the distribution grid that should help speed up connection processes and alleviate queues that have been forming over recent years.[32] ACM will also examine the extent to which system operators, when refusing or allocating transport capacity, will be able to give priority on the basis of sustainability criteria.

3.7.3 Relevance of flexible connections

With these changes in mind, the regulator is mindful of the parallel introduction of non-firm connections as they might be counterproductive to the chosen pathway. ACM is of the opinion that conditional connections would have a small effect on relieving congestions as they are only interesting for a very small share of grid users and might also come with certain disadvantages.

One downside is that grid companies might lose the incentive to procure market-based flexibility, as their responsibility to take care of grid shortages could be alleviated by resorting to non-firm connections.

Non-firm connections are only relevant and interesting for specific parties that represent only a minority of grid users, e.g., batteries or electrolysers. The focus on non-firm connections could entail the risk that capacity shortages are glossed over, and that slow planning of grid extensions would lead to more severe issues later in time.

According to ACM, it is ultimately the responsibility of the grid operator to estimate when new connections can be made. This is especially relevant for the connection of intermittent renewable energy sources. If more details on the reason for structural congestions are given by the system operator, and it can notify market players about its needs for flexibility, new services that offer such flexibility will emerge.

Generally, however, non-firm connections are not expected to inhibit such market-based tools that can exist in parallel with other available tools. The non-discrimination principle, however, has to be kept in mind when drawing on curtailable grid access.

Still, the Dutch regulator plans a public consultation about non-firm connections in September 2022 with a hearing period of ca. 1 month. After that, it gives itself some months to assess flexibility solutions for lower network levels, supplemented by data from DSO trials in 2023. A decision as to whether introducing non-firm connections as another instrument in the toolbox of grid operators will be made subsequently.

3.8 Italy

For the time being, Italy does not have any non-firm connection agreements in its regulatory repertoire but plans a consultation in autumn 2022.

[32] ACM. (2022). Ontwerp codebesluit aansluittermijnen elektriciteit

As conditional connection arrangements do not exist in the country, the regulator does not have insights or recommendations to share. However, the subject is under assessment and a consultation process is planned, starting in September 2022. The uptake of EVs and heat pumps, etc. require new solutions to avoid grid congestion.

Conditional connections, or a different flexibility mechanism, might then be considered for the next regulatory period starting in 2024 and the consultation document will serve as preparation for a potential introduction. Earlier pilots or similar initiatives could also be considered, according to the Italian regulator, ARERA.

3.9 Australia

Preparations are being made to introduce flexible connection arrangements in Australia. While there are no schemes on national level to date, first dynamic connection tariffs that were introduced in Queensland should serve as inspiration to standardise a contract design across the country. The utilities plan to introduce conditional connections to every low voltage customer by mid-2023. The schemes are urgently needed as DG uptake on the LV grid in the country is among the highest globally.

3.9.1 National rule change in preparation for more flexible connection arrangements

Due to record behind-the-meter generation at household level in Australia, non-firm, or "dynamic", connections constitute a hot topic in the country. On the national level, the AEMO (Australian Energy Market Operator - TSO) submitted a rule change request in May 2022, calling for the introduction of a new flexible trader model[33]. The request came after the Energy Security Board (ESB) published a consultation paper on transmission access reform. The proposed regulation should allow for controllable resources (EVs, batteries, solar systems) to be separated from passively connected resources (appliances, lighting), and allow customers to connect these new usages without the need for a second connection point. The step should enable increased flexibility for new (conditional) connection designs.

While the rule change request does not per se constitute a call for the introduction of a flexible connection regime, it prepares for additional flexibility of DSOs in their connection design. It also introduces a category of grid use that can be steered without major inconvenience for the end-user, thus expanding the tools available to grid operators in case of grid constraints. This should maximise the uptake of distributed energy resources and improve the timeliness of new connections, while at the same time keeping costs for establishing new connections down.

Grid congestions have also led investors to call for national reforms of grid access. A detailed proposal for changes to the network access regime on national level is expected to be published by December 2022.

3.9.2 Queensland's DSOs introduce dynamic connections from 2022

On a regional level, several DSOs are starting to offer dynamic connections, some as new offerings, others still in trials. South Australia Power Networks, for example, imposed zero or near-zero power export limits in a 12-month field trial to relieve congestion in an area with many solar rooftop customers. This is done to avoid that early PV adopters prevent late movers from using the available grid capacity. Smart inverters are allowed to automatically adjust the exported electricity to the available capacity in the grid at

[33] AEMO. (2022). Flexible trading arrangements and metering of minor energy flows in the NEM

peak times. A pro rata approach keeps incentives for new-builds to enter the market. If the trial is deemed successful, a new standard connection agreement for PV users could emerge that might be used across Australia.

Queensland DSOs Ergon Energy and Energex decided to introduce dynamic connection in 2022. The region has one of the highest rooftop PV penetration levels in the world, at almost 40%. To accommodate for the continuation of the booming market, the DSOs developed dynamic connection agreements to replace current firm access contracts. Standards for conditional connections were published in December 2021 and first contract options were made available for grid users in July 2022. The Queensland-based utilities expect to move to a product that can be elevated to serve as a national standard by July 2023. For now, this only covers negotiated contracts between the grid operator and the user, although the ambition is to introduce dynamic connections to every LV customer by mid-2023 and optimise performance from 2023-25. The new connection standard will apply only to new connections and in case of connection modifications of small, distributed generation with a capacity <30 kVA capable of responding to signals by the DSO.

It is important for the functioning of the dynamic connection agreements to improve data quality in the grid, and to increased LV monitoring and visibility. Opening up dynamic connection opportunities for early adopters gives the industry time to adapt to the new standards and the DSOs time to improve their offerings according to the needs that materialise. Overall, the grid operators expect to increase export hosting capacity for DG on their grids, streamline connections processes, improve network operations management, reliability and invest more efficiently in their grids.

3.10 USA - New York FICS pilot

In the US, there is currently no regulatory framework for conditional connection arrangements. First steps towards an implementation are made, with FERC establishing national rules for faster connection of distributed generation and different independent system operators conducting pilots for flexible interconnections. The FICS project in New York uses active network management, similar to the UK, to increase the grid's hosting capacity for RES generation. Curtailment rates of 5-10% can double DG feed-in, according to the findings.

Federal regulation is being established step by step

The US power market structure differs in many ways from the one in Europe. However, the core issues for grid companies are the same. The rapid uptake of distributed generation leads to high costs and long connection queues. New policy initiatives instated by the Biden administration actively try to tackle the issue by investing large sums in grid expansion projects. At the same time, innovative projects are conducted throughout the country to improve network management and the relieve grid scarcity.

In response to initiatives by PJM and other ISOs, the Federal Energy Regulatory Commission (FERC), responsible for electricity transmission and wholesale market regulation, is to implement a first-ready, first-served interconnection requirement to speed up connection processes in the US.[34] Bulk or clustered processing of connection requests and larger financial commitments of developers should drastically improve the logjam brought about by speculative projects with little chances of being built.

[34] FERC. (2022). FERC Proposes Interconnection Reforms to Address Queue Backlogs

New York pilot shows value of flexible connections

In the NYISO area, Avangrid conducts a pilot on flexible interconnection methods, where active network management and automation are used to increase grid hosting capacity and reduce CAPEX needed for new power lines. The FICS (Flexible Interconnected Capacity Solution) project[35] uses a DERMS platform to increase the hosting capacity of the local grid for the connection of three 5 MW PV plants.

While the connection of the plants would have been rejected without the pilot setup, the active network management approach and the ensuing non-firm grid access allow for their operation without engendering the need for grid expansion. New PV capacity is prevented from overloading the grid, and thus the developers forego the requirement to fortify the grid. Often, the substantial sums needed for that leads to otherwise viable projects not being built.

To achieve the technical requirements for active network management, new grid sensor and control technologies have to be implemented. Continuous real time data measurements are used to maintain grid reliability and safety in the face of potentially challenging DG operations. As grid capacity approach potentially dangerous levels, steering signals are sent to the PV plants and network assets to restore the network to operation within the limits of the safety standards. That means that DG power output needs to be reduced when generators receive a signal from the grid company. Curtailment is only used as a means of last resort.

According to Avangrid, similar experiences with FICS systems show that ca. twice as much distributed generation can be connected to the grid if 5-10% of the output is actively reduced by the network management system.

3.11 Summary of insights from regulatory experiences

Non-firm connection schemes have only recently been more broadly discovered as a tool to manage difficulties stemming from the dynamics of decarbonising the power sector in different countries. Therefore, the introduction of conditional connections is for the most part in early stages in the countries that are covered in our survey. Still, we tried to select the most advanced approaches available. Some countries have implemented conditional connection schemes and already reaped some experience. Others have just recently implemented such a scheme or are in the process of assessing its implementation.

Apart from discussions on the same design elements that are covered by the academic literature, the regulatory processes also focus on:

- The impact of conditional connections in the distribution grid on higher grid levels and the need for coordination between grid levels
- The use of conditional connection on the TSO level
- The extent to which actors on conditional connection agreements can participate in balancing and flexibility markets
- The inclusion of loads as eligible for conditional connection
- The option to offer mixed firm/non-firm connection agreements or temporary non-firm arrangements
- Exit conditions
- Compensation in the form of grid tariff reduction, not limited to solely connection charges

In the United Kingdom, a country with considerable experience with non-firm access agreements, the most recent

[35] Brattle. (2021). Initial report on New York Power Grid Study

grid access reform focuses on simplification, shielding small grid customers and strengthening the incentives for continuous grid reinforcement for DSOs in the presence of curtailable connections. This is partly related to the need to accelerate connection processes to achieve the country's net zero targets. Ireland on the other hand, has introduced non-firm connections more than two decades ago but is now looking at implementing a more sophisticated non-firm connection model. On the TSO level, an annual review shall help to move grid users from non-firm to firm connections faster, while on the DSO level, current, simple conditional connection arrangements will be gradually expanded towards full active network management in the coming decade.

While some countries have implemented detailed regulations and standards, Norway has opted for framework regulations that leave the design and details of conditional connection agreements to the individual DSOs and grid users that want to enter into an agreement.

The Netherlands seems to pursue a different route by favouring the development of market-based flexibility procurement for DSOs to handle congestion management instead of conditional connection agreements.

TERMS AND ABBREVATIONS

Active network management – A smart tool to integrate system control components for real time control of energy producing and consuming devices to increase grid utilization and ensure electricity networks operate within acceptable parameters. (Based on Currie et al., 2011 and Anaya and Pollitt, 2017.

Dynamic line rating – A tool that measures the atmospheric conditions such as temperature which makes it possible to increase distribution utility capacity. (Based on Anaya and Pollitt, 2017)

Quadrature booster – A tool that helps balance power flows across parallel circuits and increasing capacity headroom with the help of a type of transformer. (Based on Anaya and Pollitt, 2017)

Embedded benefits - Embedded benefits are costs which generators and suppliers can save when connecting directly to the distribution network instead of the transmission network. (Based on Anaya and Pollitt, 2015)

Principle of Access - Commercial principle or rule for allocating constrained capacity.

Abbreviations

ACM – Autoriteit Consument & Markt (Dutch regulator)

AEMO – Australian Energy Market Operator (Australian TSO)

ANM – Active network management

ARERA – Autorità di Regolazione per Energia Reti e Ambiente (Italian regulator)

ATR – Associated Transmission Rights

BNetzA – Bundesnetzagentur (German regulator)

CAPEX – capital expenditure

CRE – Commission de régulation de l'énergie (French regulator)

CRU – Commission for Regulation of Utilities (Irish regulator)

DER – distributed energy resources

DERMS – distributed energy resources management system

DG – distributed generation

DNO – distribution network operator (used mainly in UK)

DSO – distribution system operator

DUoS – Distribution Use of System (UK term for distribution grid tariffs)

ECJ – European Court of Justice

ECP – Enduring Connection Policy (Ireland)

EV – electric vehicle

FAQ – Firm Access Quantities

FERC – Federal Energy Regulatory Commission (US regulator)

FICS – Flexible Interconnected Capacity Solution

ISO – independent system operator (TSO in US, UK)

LIFO – Last-in First-out

LV – low voltage

O&M – operations and maintenance

MEC – Maximum Export Capacity

MV – medium voltage

NFA – non-firm access

NVE – Norges vassdrags- og energidirektorat (Norwegian regulator)

NYISO – ISO for New York area

PJM – US ISO in Pennsylvania, New Jersey, Maryland, and surrounding states

PoA – Principle of Access

PV - photovoltaic

RES – renewable energy sources

RIIO-ED2 – “Revenue=Incentives+Innovation+Outputs” Edition 2 (2nd electricity distribution price control period (2023-2028))

RTE – Réseau de Transport d'Électricité (French TSO)

R&D – research and development

SCADA - Supervisory control and data acquisition

SCR – Significant Code Review (regulatory reform in the UK)

TSO – transmission system operator

Terms used to describe conditional connections

Non-firm connection

Non-firm access

Flexible connection

Interruptible connection

Conditional connection

Constrained connection

Flexible interconnection capacity solutions

Smart connections

Curtailable connections

Dynamic connections

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About THEMA

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