Flexible DER & EV Connections

July 2024

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

Disclaimer

Acknowledgments

This work was prepared by Rosalie Dahyeon Yu of ICF and Paul De Martini of Newport Consulting with project team reviews by Surhud Vaidya, Darren Murtaugh, Dale Murdock, Saumil Patel of ICF, and Andrew De Martini of Newport Consulting. Development of the paper benefited from discussions with Pacific Gas and Electric, Southern California Edison, and Rhythmos.

The DOE Office of Electricity sponsored this report as part of a broader ongoing effort to advance market and operational coordination of distributed energy resources, especially their evolving use as virtual power plants. DOE Office of Electricity Program Manager Joseph Paladino oversees this work.

Contents

Introduction 3
Flexible Connections 4
Planning and Operating Parameters 4
Hosting Capacity 5
Dynamic Operating Envelope 5
Flexible Interconnections/Service Connection Approaches 7
Customer Controlled Solutions 7
Flexible Solar and Storage Interconnection Example 8
Flexible EV Service Connections Example 11
Utility Direct Controlled Solutions 13
Flexible Solar and Storage Interconnection Examples 13
Flexible EV Service Connections Example 14
Utility Curtailment Determination Methods 15
International Insights 17
Conclusion 20

Introduction

The United States is actively integrating Distributed Energy Resources (DER) into its energy framework, marking a transformative approach to energy production, distribution, and consumption. This shift towards decentralized grid networks, where a mix of dispersed power sources are integrated into the electric grid, contrasts sharply with traditional distribution networks designed for one-way power flow from large-scale power plants to consumers. The modern grid must evolve to accommodate dynamic two-way electricity flows, essential for integrating and unlocking the full potential of DERs while maintaining system safety and reliability.

Currently, distributed solar photovoltaic (PV) and battery energy storage projects in several states are encountering significant challenges in interconnecting with the distribution grid. This is primarily due to capacity constraints that can result in costly infrastructure upgrades needed to accommodate the interconnection request. Also, new service connections for electric vehicle (EV) fleet charging and large public charging centers are challenged with distribution capacity constraints.

Thus, it is important to explore new grid designs, and operating methods, and establish supportive regulatory frameworks to guide the evolution of distribution networks and facilitate the interconnection of DERs. This whitepaper introduces and elaborates on three key concepts: dynamic operating envelopes, flexible interconnection, and flexible service connections. This paper aims to inform regulatory decision-making processes by presenting emerging flexible connection strategies and case examples. Additionally, this paper provides a strategic framework for managing distribution networks to enhance DER integration and electrification, ultimately moving towards a more complete orchestration of DER and EV charging.[1]

Key Definitions

- Dynamic Operating Envelope is a more granular engineering method to determine capacity availability due to time-sensitive variations in export energy, customer demand, and grid conditions (including circuit reconfigurations).
- Flexible Interconnections are control approaches to enable more DER interconnections based on dynamic operating envelop parameters.
- Flexible Service Connections are control approaches to enable customer service connections for larger loads such as EV fleet charging and data centers based on dynamic operating envelope parameters.

The structure of this paper is as follows:

- Planning and Operating Parameters: This section discusses the foundational concepts of hosting capacity and dynamic operating envelopes.
- Flexible Connections Methods: This section covers various techniques and control mechanisms for flexible connections. It presents use case examples for solar and storage projects and EV charging. The discussion encompasses both customer-controlled solutions and utility-controlled approaches, including various curtailment methods such as pro-rata and Last-In-First-Out. Also, use case examples of flexible connections for solar and storage projects and EV charging are presented, with insights from both the US and international contexts.
- International Insights: This section provides a global perspective on the development of flexible DER interconnections and EV charging service connections. It focuses on the advancements in Australia, the United Kingdom (UK), and across Europe addressing distribution capacity constraints

[1] DER orchestration refers to the coordinated dispatch/response of DERs, including behind-the-meter DERs, flexible loads, smart inverters, and front-of-the-meter DERs.

in line with their policy objectives.

- Conclusion: Summarizes key regulatory and business takeaways and provides context for further discussions on DER Orchestration Model and DER Market Evolution.[2]

Flexible Connections

Flexible connections are methods to improve distribution system utilization allowing more DER interconnections and service connections for EV charging while lowering the cost of integration. Flexible connection strategies involve shaping DER and EV charging exports and imports to remain within distribution system operating parameters (e.g., capacity limits, voltage limits) during periods when distribution systems are constrained (Figure 1).

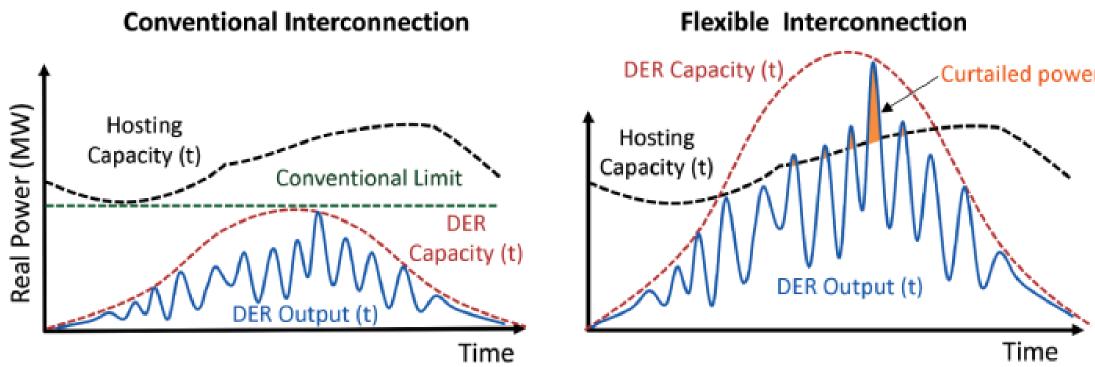

Figure 1. Conventional Interconnection Versus Flexible Interconnection (Source: EPRI)

The potential benefits of flexible connections include increasing facilitates higher DER and EV adoption, lowering connection costs, and/or deferring infrastructure upgrades.[3] Flexible connection methods can be applied in various scenarios, serving as a temporary or a more permanent solution. In a temporary context, flexible connections enable distributed generation, battery projects, and large EV charging centers (e.g., fleet charging and public charging locations) to connect more quickly, bridging the gap until scheduled distribution reinforcements are completed. Alternatively, it can be a longer-term solution until other proposed DER/EV charging loads create the need for an upgrade.

Planning and Operating Parameters

The reference point for flexible connections is identifying distribution grid constraints in distribution planning and subsequent hosting capacity analysis. However, hosting capacity analysis alone does not fully account for more dynamic operational conditions of a distribution feeder that may allow for sufficient increased capacity to enable the connection of distributed generation and battery storage and service connections for electric vehicle charging without grid infrastructure upgrades. Hosting capacity analysis and assessing dynamic operating conditions are prerequisites for implementing flexible connections.

[2] These papers are scheduled to be uploaded on the US DOE Operational Coordination website upon completion in FY 2024. https://www.energy.gov/oe/operational-coordination

[3] Electric Power Research Institute (EPRI), Active Resource Integration Project Techno-Economic Analysis of Flexible Interconnection, October 2022. Available online: https://www.epri.com/research/programs/067418/results/3002025504

Hosting Capacity

Hosting capacity refers to the amount of DER/EV charging energy that can be integrated into a distribution system before requiring control adjustments of DERs or distribution infrastructure upgrades to maintain safety and reliability.[4] Hosting capacity is based on three key operating parameters:[5, 6]

- Thermal Capacity – The maximum current that a conductor can carry continuously under the conditions of use without exceeding its temperature rating. This is referred to as the ampacity. The ampacity of a conductor depends on its ability to dissipate heat without damage to the conductor or its insulation. Increases in electrical current flowing on the grid can cause conductors to exceed their ampacity limits, which can lead to heat-related damage and safety issues.
- Voltage – Electrical lines must maintain voltage within the required customer service standard.[7] Voltage considerations include over and under voltages (on primary and secondary conductors), voltage regulation, and changes to equipment operation (e.g., load tap changers, line regulators, and switched capacitor banks).
- Protection Coordination – Bidirectional power flows and altered fault currents introduced by inverter-based resources can desensitize relays, cause sympathetic tripping, and increase fault duty, all of which can compromise system reliability and safety. Hosting capacity is influenced by several factors, including the current equipment on a distribution system including substations, primary circuits, and secondary lines. Importantly, available capacity within the hosting capacity limits can increase due to a reduction in the export/import of energy and/or distribution upgrades.

HCA typically provides a static assessment that considers steady-state conditions such as peak load scenarios for DER integration. This has led to the development of a dynamic operating envelope method to reflect a more granular, time-sensitive representation of capacity availability due to variations in export energy, customer demand, and grid conditions (including circuit reconfigurations). Dynamic operating envelopes offer a more effective understanding of hosting capacity limitations based on time-varying import/export limits that can guide near real-time dispatch and control of DERs.[8]

Hosting capacity limits can increase due to a reduction in the export/import of energy and/or distribution upgrades

Dynamic Operating Envelope

A dynamic operating envelope establishes the upper and lower bounds for a given time interval for allowable import or export power at a point of interconnection. These upper and lower bounds can change from one time interval to the next, based on system conditions and anticipated constraints, allowing for

[4] National Renewable Energy Laboratory (NREL), Advanced Hosting Capacity Analysis website. Available online: https://www.nrel.gov/solar/market-research-analysis/advanced-hosting-capacity-analysis.html#:~:text=Hosting%20capacity%20is%20the%20amount,added%20to%20the%20distribution%20system

[5] Maryland Department of Natural Resources, Hosting Capacity FAQ website. Available online: https://dnr.maryland.gov/pprp/Pages/hosting-capacity-faq.aspx#a

[6] EPRI, Distribution Feeder Hosting Capacity: What Matters When Planning for DER?, April 2015. Available online: https://restservice.epri.com/publicdownload/000000003002004777/0/Product

[7] The national standard, ANSI C84.1-2020 establishes nominal voltage ratings and operating tolerances for 60 Hz electric power systems above 100 volts, up to a maximum system voltage of 1200 kV. For example, for a nominal operating voltage of 120 V, the acceptable operating voltage range is 114 V – 126 V.

[8] Australian Renewable Energy Agency (ARENA), On the calculation and use of dynamic operating envelopes, 2023. Available online: https://arena.gov.au/assets/2020/09/on-the-calculation-and-use-of-dynamic-operating-envelopes.pdf

more intelligent use of the hosting capacity.[9] Dynamic operating envelopes introduce a more sophisticated method to determine available energy export/import limits to connect new distributed generation, storage, and larger EV charging loads based on forecast and real-time grid conditions. Forecasted power flows are typically used since the availability of real-time granular distribution grid data is limited.

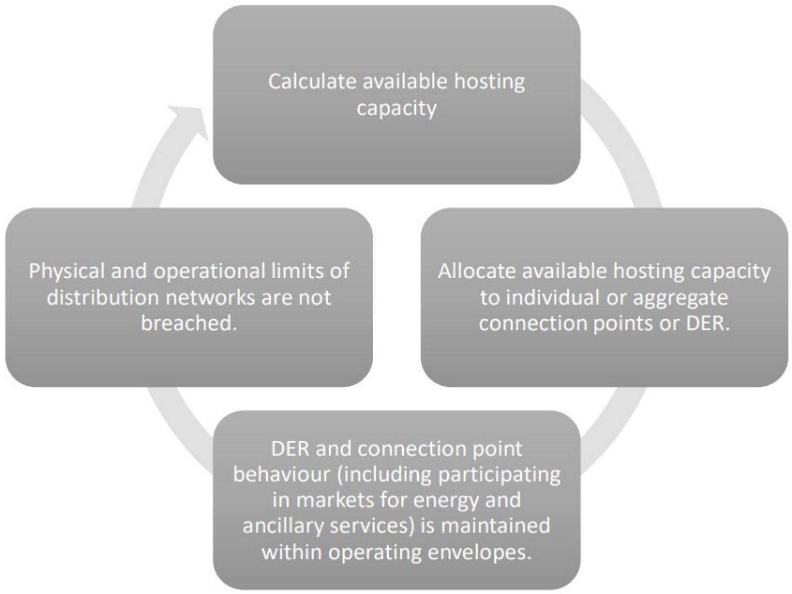

Figure 2. Operating Envelope Lifecycle in Each Time Interval (Source: ARENA[10])

The process of determining operating envelopes involves identifying the specific locations of DER assets or connection points within the network to understand how real and reactive power exports and/or imports at these points will affect the voltage, thermal, and protection constraints (Figure 2). The operating envelope for each DER export/EV charging load is calculated for each time interval typically by electric utilities. For example, operating envelopes for distribution systems in the US are currently forecasted hourly over a year. This results in seasonal, monthly, or daily time-specific operating limits for DER/EV charging based on available distribution capacity at each time interval. These variable operating limits for DER export/EV charging are the dynamic operating envelope.

The ultimate objective is to evolve from limits and curtailments to advanced and coordinated optimization of all types of DERs ("DER orchestration").

The integration of DER into modern distribution networks is increasingly reliant on shaping DER and customer loads through various methods, including behavioral-based time-varying pricing strategies, and flexible connections.

[9] Ibid.
[10] Ibid.

Figure 3. Spectrum of Flexible Interconnection Solutions (Source: NREL[11])

The ultimate objective is to evolve from limits and curtailments to advanced and coordinated optimization of all types of DER/EV charging ("DER orchestration") on distribution networks to allow greater adoption and use of distributed resources and expanded electrification and development and use of the DOE is a critical first step. This is illustrated in the spectrum of flexible connection solutions in Figure 3. DER orchestration aims to coordinate flexible DER and EV charging through various customer and utility mechanisms to optimize the utilization of distribution capacity.

Flexible Interconnections/Service Connection Approaches

The initial use of dynamic operating envelopes today is done prospectively through customer-controlled solutions employing time-based import/export limits or in real-time via utility direct-controlled curtailment and derates of DERs/EV charging. The following discussion provides an overview and examples of both approaches employed for solar and battery storage interconnections and service connections for EV fleets and large public EV charging facilities.

Customer Controlled Solutions

Customer-controlled solutions empower end-users to actively manage their DER in response to dynamic operating envelopes provided by the distribution utility. These solutions involve customer control systems that automatically adjust electricity consumption and energy exports to align with the dynamic operating envelope parameters. Key aspects of these solutions include:

- Advanced Inverter Settings: Advanced inverters play a crucial role in customer-controlled solutions by providing the capability to modulate power output dynamically. These inverters can adjust the electricity export and import for distributed generation and battery storage based on grid conditions, ensuring that DER systems operate within safe and allowable system parameters. Customers can leverage these settings to maximize their energy production while maintaining grid reliability.

- Export/Import Limits: Customers can utilize dynamic operating envelope export/import limits to manage the flow of electricity between their DER systems and the grid. By adhering to variable limits that reflect the grid's capacity at different times, customers can ensure that their energy

[11] NREL, Overview of TA Requests relative to I2X presentation, March 2024. Available online: https://www.energy.gov/sites/default/files/2024-03/Flexible Interconnection Strategies and Approaches Intro Webinar Slides 3.15.pdf

exports and imports are optimized to avoid overloading the grid.

Flexible Solar and Storage Interconnection Example

An example of customer-controlled export limits for solar and battery storage is California's Limited Generation Profiles (LGP). On March 21, 2024, the California Public Utilities Commission (CPUC) issued a decision allowing renewable energy systems to use LGP to flexibly interconnect to distribution grids. Under this decision, "Limited Generation Profiles specify the maximum amount of electric generation a [distributed energy resource] system will export to the grid at different times throughout the year, ensuring that the project is responsive to fluctuating grid constraints at different times.[12]" DER projects under the LGP will alter their grid injections by selecting one of three "24-value LGP configurations[13]" options to respond to grid conditions. The three types of 24-value LGP configurations are 24-hourly, Block, and 18-23-fixed[14].

24-Hourly Configuration
The 24-hourly configuration divides the day into 24 distinct hourly periods, leading to a maximum of 288 LGP values per year (24 hourly values per month for each of the 12 months), each with a specific export limit. This configuration allows DERs to adjust their power output every hour based on predefined limits, providing a high level of granularity and responsiveness to daily fluctuations in grid conditions. By aligning the export limits closely with the grid's hourly capacity and demand variations, this configuration optimizes the utilization of available hosting capacity (note: California refers to hosting capacity analysis as Integration Capacity Analysis – ICA).

Block Configuration
The Block configuration aggregates the 24-hourly values into several blocks, each block representing a period during which the export limit remains constant. For example, the day might be divided into six 4-hour blocks, each with its export limit. This approach simplifies the operational complexity while still offering significant flexibility. The block configuration is particularly useful for balancing ease of implementation with the need to respond to predictable patterns in grid usage and renewable energy generation.

18-23-Fixed Configuration
The 18-23-fixed configuration (i.e., two hourly blocks 6 pm-midnight and midnight-6 pm for each of 12 months) provides a hybrid approach, where the hourly values are fixed, and the remaining hours are aggregated into blocks or assigned different export limits. This method combines the granularity of hourly adjustments with the simplicity of block configurations. It allows for precise control during critical periods of the day when grid conditions are most variable while simplifying the management during less critical times.

---

[12] Interstate Renewable Energy Council (IREC), Milestone Decision by California Regulators Approves the Use of DER Schedules to Avoid Interconnection Upgrades, March 2024. Available online: https://irecusa.org/blog/irec-news/milestone-decision-by-california-regulators-approves-the-use-of-der-schedules-to-avoid-interconnection-upgrades/

[13] LGP Configurations: The number of unique LGP values (the maximum export limit of an LGP project for a specific hourly time period during a specific month or block of months) per year together with the hourly time periods and months or blocks of months that each LGP value represents.

[14] CPUC, Resolution E-5296, March 2024. Available online: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M526/K988/526988970.PDF

Figure 4 from the CPUC[15] provides a conceptual illustration of LGP configurations, comparing with one value per month versus an LGP with two values per month. The blue line depicts the maximum annual ICA-Static Grid (ICA-SG) value, the maximum amount of power generation calculated conservatively that can be installed without causing any thermal, voltage, or distribution protection violations. The yellow curve depicts the ICA-Operational Flexibility (ICA-OF) values that exist at the time of interconnection application. The red dashed line shows an exemplary LGP using monthly minimum ICA-SG values with the 10% buffer. With the 10% buffer, the export limit is 90% of the minimum ICA-SG value during a specific month. Lastly, the purple dashed line shows LGP using two values per month with the 10% buffer.

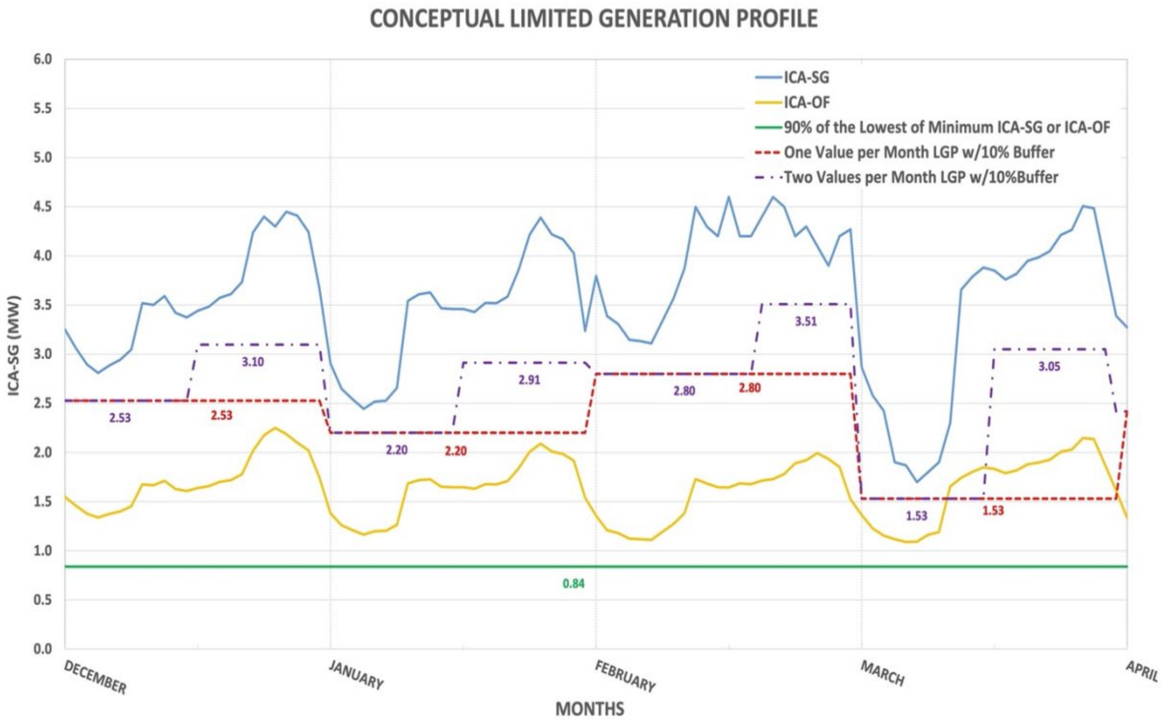

Figure 4. Conceptual Illustration of Four Specific Limited Generation Profiles Configurations (Source: CPUC[16])

As the granularity of the LGP increases, it more closely resembles the ICA-SG curve. An LGP with two values per month aligns better with the ICA-SG curve compared to an LGP with just one value per month. This increased alignment allows for greater utilization of the available hosting capacity within a month, thereby increasing a facility generator's export power. The CPUC decision was approved using a 24-value block configuration in which a system's export levels can vary up to 24 times per year. DER customers calculate the monthly LGP values to not exceed 90% of the monthly minimum ICA-SG values, and these values are submitted in a format that includes 288 data points (24-hourly export values through the year) as pre-determined export levels set in advance. Following an interconnection request, a technical evaluation will be conducted to ensure compliance. This approach will allow projects to design configurations that take advantage of the specific daily and seasonal peak periods that arise at the project's proposed location on the grid.

---

[15] California Public Utilities Commission (CPUC), Appendix A Illustrative LGP Figures, 2022. Available online: https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M527/K822/527822624.pdf

[16] Ibid.

In summary, the CPUC's 24-value LGP configurations offer a versatile and effective framework for integrating renewable energy into the grid, providing both high granularity and operational flexibility to meet the evolving demands of the energy landscape. For effective implementation, DER developers and customers need to have access to detailed grid data and hosting capacity analysis. Also, advanced control systems, such as Power Control Systems (PCS)[17], are essential for managing the dynamic adjustments required by these configurations. The CPUC ruled that customer PCS devices will be the primary option that developers can use to control the LGPs of interconnecting systems. Figure 5 from the CPUC[18] illustrates the method of controlling generation output at the Point of Common Coupling (PCC) using an Underwriters Laboratory (UL) certified[19] PCS.

A PCS with an integrated schedule will function as the main control mechanism to manage the amount of export, using profiles that detail permissible power levels for every hour of the year (up to 8760 set points: number of hours in a year). The device measures the actual export of electricity at the PCC and ensures it does not exceed the predetermined limits. If necessary, the PCS can send updated power limit commands to the inverters. The PCS plays a critical role as it can inform hourly adjustments to the export limits based on real-time operational conditions, by adjusting the power output to ensure it remains within the 90% ICA-SG threshold. If the PCS detects that the power output at the PCC exceeds the set hourly limit, the PCS will promptly communicate a reduced power output limit to the inverters. The inverters will then adjust their output downward to ensure that the power generation does not surpass the established limit.

National Grid in Massachusetts is launching a customer-oriented Local Power Controller (LPC) pilot for behind-the-meter DER to interconnect a DER with net-zero thermal impact on their distribution grid to mitigate constraints and/or the need for system modifications. This pilot is being used to explore the capabilities of customer-owned LPCs to provide a more robust local energy management approach beyond that currently afforded by solely using utility-grade relays. The LPC system design and architecture are currently being developed by National Grid, but applications are being accepted. Under the pilot, a customer is responsible for assuring operations and compliance with the LPC requirements, which includes ensuring the DER has net-zero thermal impact on the distribution grid. National Grid will monitor compliance and address any non-compliance.[20]

---

[17] Power Control Systems (PCS) are systems or devices that electronically control the power output of one or more generating facility. PCS limit the Alternating Current (AC) or Direct Current (DC) and loading on the grid supplied by the power production sources. CPUC Resolution E-5296, March 2024. https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M527/K828/527828811.pdf#:~:text=15%20Normally%20this%20is%20accomplished%20using%20Power,(PCS).%20PCS%20are%20systems%20or%20devices%20that&text=34%20On%20June%2027%2C%202023%2C%20the%20CPUC%20Energy

[18] CPUC, Smart Inverter Working Group, February 2023. https://webproda.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/rule21/limited-generation-profiles/siwg-iou-slides---20230216.pdf

[19] The CPUC decision requires PCS certification to a “standard for UL PCS with integrated schedule,” referring to a future version of UL 3141 (Outline of Investigation for Power Control Systems) that includes PCS scheduling functionality able to accommodate the three LGP configurations adopted.

[20] National Grid, Massachusetts Local Power Controller Pilot, February 2024. Available online: https://gridforce.my.site.com/servlet/servlet.FileDownload?file=0156T00000GztUc

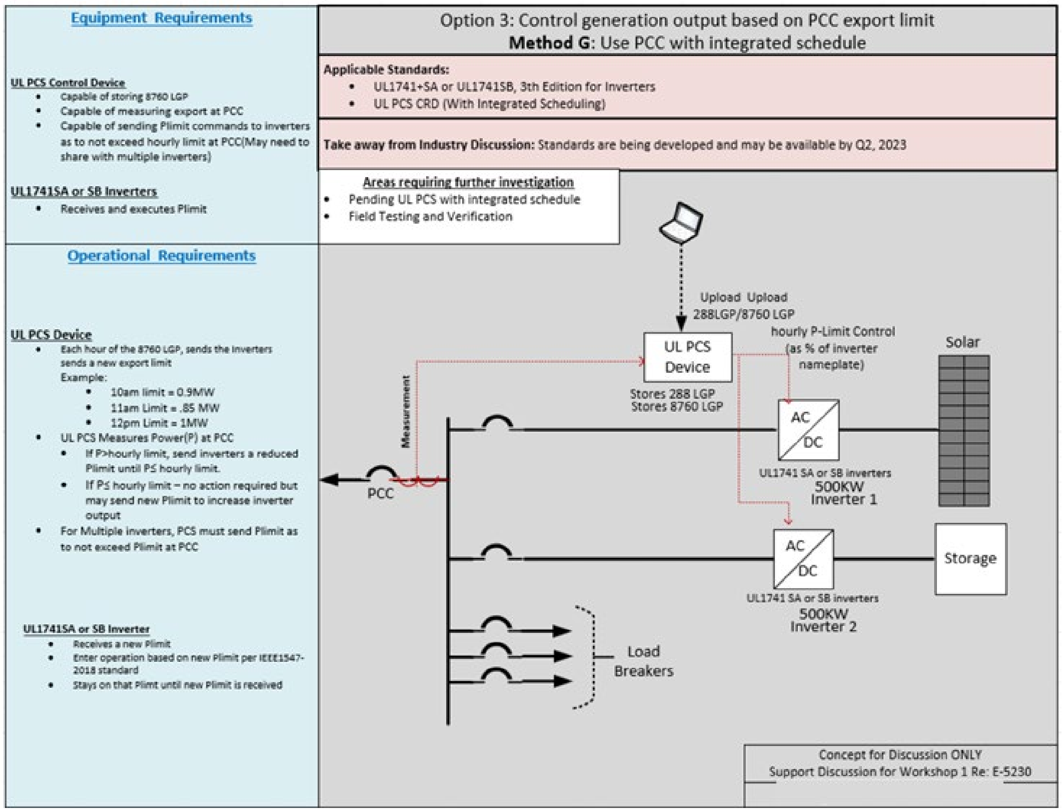

Figure 5. CPUC Selected Customer-Controlled Method (Source: CPUC)

Flexible EV Service Connections Example

Flexible service connection refers to an arrangement between customers and utilities that optimizes the magnitude and timing of customer loads in response to grid conditions. Rather than paying interconnection costs, a customer operates their loads flexibly. This means they increase load when the network is less constrained and automatically reduce loads upon the utility's direction. Flexible EV fleet charging solutions are designed to address distribution capacity constraints by optimizing the timing and magnitude of EV charging loads. These solutions leverage advanced technologies and strategic management practices to ensure that EV fleet charging integrates seamlessly with the existing grid infrastructure without overloading it.

Customer-managed charging systems utilize advanced software and control technologies to adjust the charging rate and timing dynamically based on real-time grid conditions. These systems can prioritize charging sessions to delay or reduce charging power during peak demand periods and may increase charging activity when grid capacity is available. This can enable faster and lower-cost service connections, particularly for EV fleet operators and large public charging facilities.

Southern California Edison Load Control Management Systems (LCMS) Pilot[21]

Southern California Edison (SCE) has implemented a two-year Automated LCMS Pilot, designed to allow customers to receive electrical service connection based on the currently available grid capacity as

[21] SCE, Establishment of Southern California Edison Company's Customer-Side, Third Party Owned, Automated Load Control Management Systems Pilot (Advice Letter 5138-E and 5138-E-A), January 2023. Available online: https://www.sce.com/regulatory/advice-letters

opposed to delaying the customer EV charging interconnection until required grid upgrades are completed to support full capacity charging.

The customer's LCMS can reduce charging levels, disconnect specific devices, or stop charging at specific chargers to remain within distribution grid operating limits. Customers are responsible for purchasing, installing, and operating their LCMS. The customer LCMS technology requires certification from Nationally Recognized Testing Laboratories (NRTLs) for performance validation. This is like the CPUC's requirement for an LGP system. This allows customers to manage their electrical demand and EV charging stations within specific parameters set by SCE. Two approaches may be employed at the customer's option:

- Localized Autonomous LCMS: Operates independently without real-time external communication, using pre-programmed limits to manage power usage.
- Utility Communication-Based LCMS: Receives power limits in real-time or day-ahead from SCE through communication protocols, which informs a customer's LCMS.

Under the localized autonomous option, authorized personnel can program the customer's LCMS locally to implement the SCE-provided limits, or it can be programmed remotely via approved communications. Under the utility communications-based option, the LCMS receives power limits From SCE through communication channels utilizing protocols such as IEEE 2030.5. Communications can be implemented either via cloud-based services or through direct communication gateways at the customer's facility. Communication between SCE and the customer's LCMS is accomplished using utility-specified cybersecurity protocols to protect against unauthorized access and potential cyber threats. SCE's conceptual architecture for the Utility Communications-Based LCMS pilot is illustrated in Figure 6.

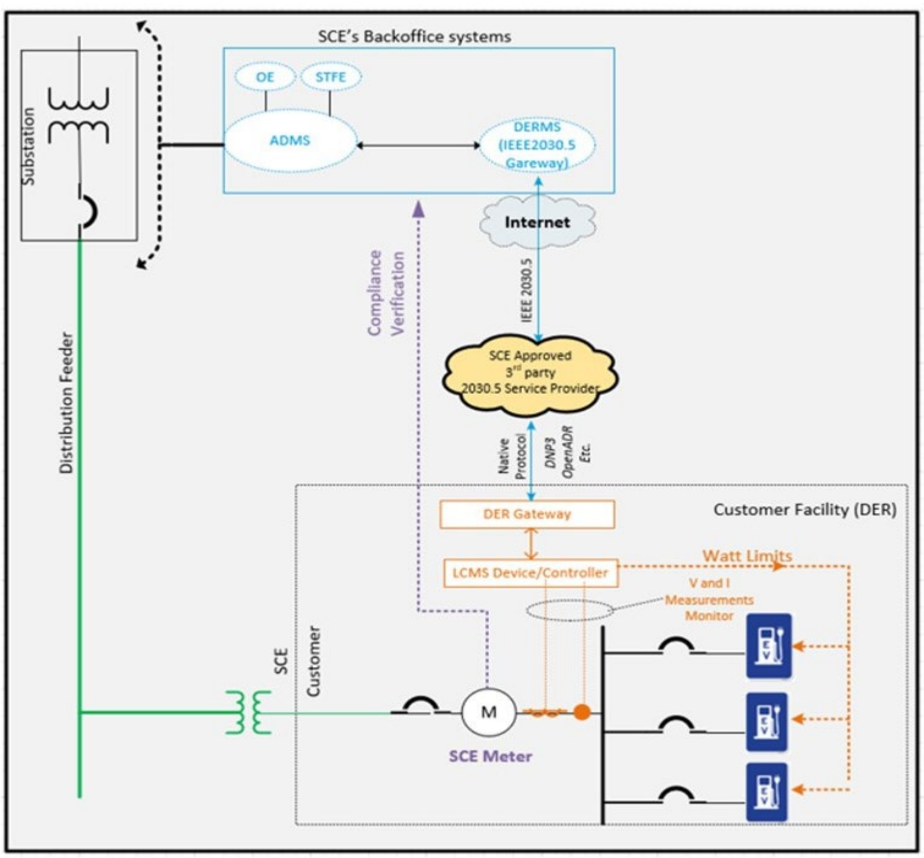

Figure 6. Customer Controlled Utility Communication-Based LCMS Conceptual Architecture (Source: SCE)

SCE will collect data on the performance and impact of LCMS, providing biannual updates to the California Public Utilities Commission (CPUC).

Utility Direct Controlled Solutions

Utility-controlled flexible interconnection and EV flexible service connections involve the use of utility operational system analytics and control capability to interface with customers' smart inverters, PCS systems, EV telematics, and smart chargers. In addition to the technology, DER/EV charging will occasionally require curtailment based on the grid's capacity. This necessitates a methodology to determine how much reduction (in charging or energy export) is needed and from which DER/EV charger. The following discussion highlights emerging architecture for utility-controlled DER/EV charging and two common curtailment methods.

Flexible Solar and Storage Interconnection Examples

Avangrid Demonstration

In 2015, the New York State Public Service Commission mandated the state's six major investor-owned electric utilities to initiate flexible community solar interconnection demonstration projects.[22] The first demonstration project was Avangrid's Flexible Interconnection Capacity Solution (FICS) in their NYSEG and RG&E service areas. The objective was to accommodate larger amounts of solar-generated electricity on the lower-voltage distribution electric delivery system without jeopardizing the safe and reliable operation of the distribution grid. Avangrid employed a utility-controlled approach to monitor and control the output from intermittent renewable resources. For this demonstration, Avangrid used an ADMS, including supervisory control and data acquisition (SCADA) and DERMS, along with sufficient distribution network sensing and secure communications.

Table 1. Avangrid Flexible Interconnection Capacity Solution Demonstration (Source: Avangrid)

Project #*	Location	Size (MW) and Type	Interconnecting Utility	Constraint
Robinson PV (DER #1)	Chaplain, NY	5 MW Solar PV Generator	NYSEG	Overvoltage and Undervoltage
Spencerport PV (DER #5-#7, 3 sites)	Spencerport, NY	Each 5 MW Solar PV Generator for a total of 15 MW	RG&E	Substation Transformer Thermal

*Notes: The table shows four sites that completed FICS witness testing for the REV Demo project, out of nine initially considered. The others were removed due to inactivity, withdrawal, or selection of a standard interconnection.

Avangrid reported[23] that the FICS option reduced interconnection costs consistent with similar approaches employed in the UK (actual savings redacted in the report). Initial curtailment estimates for Spencerport DERs #5-7 predicted a 3% curtailment rate under full interconnection. Actual operational data showed an even lower overall curtailment rate of under 0.006% over 28 months after adjusting for curtailments resulting from control communications issues. The pilot project also demonstrated the need for highly reliable and resilient communications and information protocols to effectively link the utility operational systems with the solar PV inverter and its related control and information systems and achieve the full

[22] NY PSC, Case 14-M-0101, Reforming the Energy Vision, Order Adopting Regulatory Policy Framework, and Implementation Plan (Issued February 26, 2015) (Track One Order).

[23] Avangrid, Flexible Interconnection Solution, 2022. Available Online: https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7B007CA790-0000-C41D-A3EB-4A5832292DBD%7D

benefits of the FICS.

Commonwealth Edison's (ComEd) Mendota Demonstration
ComEd has implemented a utility-controlled solution in the Mendota demonstration to enable flexible interconnection for distributed renewable projects to address conventional hosting capacity limitations.[24] Without intervention, adding new DERs would risk thermal overload on the local substation transformer due to reverse power flow during high DER output and low load periods. The utility-controlled solution involves monitoring substation transformer power flow and curtailment of solar PV output using a tiered curtailment strategy based on specific criteria, ensuring transformer loading remains within safe limits.

ComEd's first step was building an accurate model of DERs individually or in aggregate, considering grid constraints, DER locations, installation characteristics, and any programmatic limitations affecting dispatch capabilities. Secondly, a detailed end-use forecast mechanism is used. This forecasting considers locational attributes and estimates DER output and required curtailments to support real-time grid operations, compensating for the inability to monitor every DER in real-time.

Thirdly, this utility solution leveraged ComEd's DERMS and ADMS to assess grid conditions and dispatch DER for real and/or reactive power control. Smart inverter dispatches are coordinated with ComEd's existing Volt-Var Optimization (VVO) implementation.

National Grid (Massachusetts) Active Resource Integration Pilot
National Grid has recently launched Active Resource Integration (ARI), a utility-controlled flexible interconnection pilot. ARI involves a utility-DER control system that will monitor thermal loading conditions of the grid and initiate automated commands to a customer's distributed solar or battery storage facility to adjust the DER operating conditions as needed to mitigate specific distribution constraints. The ARI system design and architecture are currently being developed by National Grid; however, applications are being accepted.[25]

Flexible EV Service Connections Example

The National Grid EV demonstration referred to as the EV Charge Smart Plan,[26] aims to enhance the integration and management of EV charging on the grid. The program employs both active and passive managed charging strategies. Active managed charging involves real-time utility control over charging activities, while passive managed charging relies on time-of-use rates and customer behavior to shift charging to off-peak periods. This dual charging strategy approach was used to accommodate a wider range of EV models and customer preferences. A brief overview of the actively managed charging approach follows.

National Grid's EV Charge Smart Plan leverages advanced technology and a subscription-based model to manage and optimize EV charging. The architecture integrates telematics from EV manufacturers and networked Electric Vehicle Supply Equipment (EVSE) to provide real-time data and control over EV charging activities.

The architectural approach integrates National Grid's ADMS and DERMS systems with telematics from select EV manufacturers (e.g., BMW and Tesla) and specific networked customer EVSEs. This approach to

---

[24] Commonwealth Edison's (ComEd) Refiled Grid Plan – Chapter 5. Available online: https://icc.illinois.gov/downloads/public/edocket/607970.PDF
[25] National Grid, Active Resource Integration (ARI) Pilot, July 2024. Available online: https://gridforce.my.site.com/servlet/servlet.FileDownload?file=0156T00000GITS4
[26] National Grid, National Grid Petition Seeking Certain Modifications to EV Managed Charging Program, New York Public Service Commission, Case 18-E-0138, 2024. Available online: https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BF0D6798D-0000-CC11-BE20-7BC34F9C0DB1%7D

active utility direct-controlled EV charging is like the utility direct-controlled DER curtailment architecture described for DER curtailment. In this application, National Grid utilizes EV manufacturers' telematics systems to gather real-time data on EV charging sessions. This data allows for precise control over the charging process, enabling smart scheduling to maximize off-peak charging and minimize grid stress during peak hours. The program also supports networked EVSEs, which are connected to home Wi-Fi and can be controlled remotely by the utility. This connectivity allowed National Grid to send commands to the charger to start or stop charging based on grid conditions and predefined schedules.

National Grid's data management system collects and analyzes charging data to optimize performance and ensure reliability. This data is used to monitor the effectiveness of the charging schedules and make necessary adjustments to improve customer satisfaction and grid stability. The program also addresses data loss and quality issues to maintain accurate billing and customer engagement.

National Grid reported that the program has faced and continues to address several technical challenges, including data loss from EV telematics and EVSE integrations, telecommunications failures, inconsistent smart charging performance, and interoperability issues following over-the-air software updates from EV or EVSE manufacturers. However, the program has successfully demonstrated its technical capabilities and National Grid has proposed refinements to improve the program's effectiveness.

Utility Curtailment Determination Methods

Under flexible interconnection and EV flexible service connections, DER/EV charging will occasionally face curtailment based on the grid's capacity. For utility-controlled solutions, this requires the utility to determine how much reduction is needed and from which DER/EV charger that is under utility control. The most common curtailment decision methods today are Last-in-First-Out and Pro Rata. Both LIFO and Pro Rata can be automated, allowing utilities to make real-time, data-driven decisions on which DERs/EV chargers to curtail and by how much. These curtailment methods are the control logic governing the order in which DER/EV chargers are curtailed and the degree to which they are curtailed.

Last-in-first-out (LIFO)

DER that applies for interconnection first is curtailed last. This approach prioritizes DERs that have applied for interconnection earlier, affording them lower curtailment compared to those DERs that connect later. By reducing the risk of curtailment for early applicants, this policy encourages early investment in DER projects. However, as more DERs are added, the LIFO mechanism could disadvantage newer projects, potentially making them economically unfeasible and limiting network utilization. Figure 7 from EPRI[27] illustrates the LIFO curtailment approach.

[27] EPRI, Principles of Access for Flexible Interconnection Solution: Rules of Curtailment, July 2020. Available online: https://www.epri.com/research/products/000000003002018506

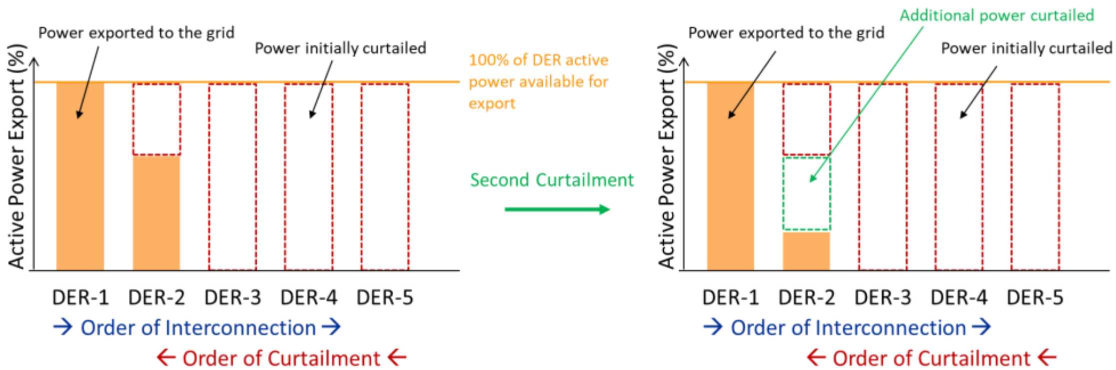

Figure 7. Last-In-First-Out Approach (Source: EPRI[28])

Pro-rata

In this approach, all DER in an area experience a proportionate reduction in their power export to the grid. The Pro Rata curtailment calculation is as follows:

$$\begin{aligned} &DER\ Active\ Power\ Curtailed \\ &\quad = Proportion\ Factor\ (\alpha)\ (same\ for\ all\ DERs) \\ &\quad \times\ Allocation\ Key\ Value\ (specific\ to\ each\ DER) \end{aligned}$$

$$\alpha = \frac{\Delta P}{\sum(Allocation\ Key\ Value)}$$

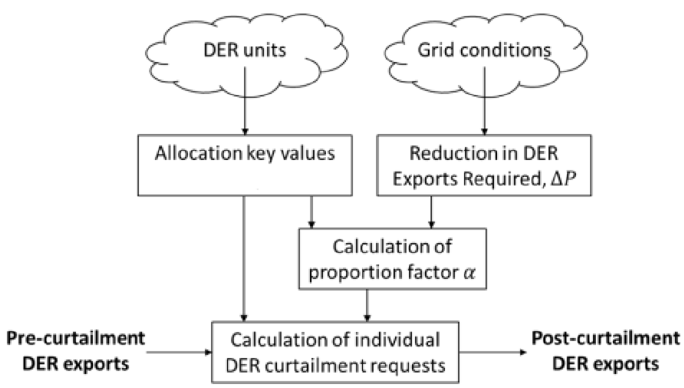

Figure 8. Overview of the Pro-rata Curtailment Process (Source: EPRI[29])

Proportion Factor (α) is a uniform scalar applied to all DERs to determine the percentage by which each unit's export is curtailed. The grid operator calculates the proportion factor based on the total reduction required (ΔP) for the grid's stability. The system operator adjusts α in response to changing grid conditions, ensuring the combined reduction in power export aligns with the grid's needs. On the other hand, the allocation key is the benchmark used to determine how much each DER should curtail its power export for a given group of DERs. It is a predetermined parameter as part of the flexible interconnection agreement that reflects the contribution of each DER to the grid. Two common types of allocation keys are:

[28] Ibid.
[29] Ibid.

- Present Active Power Export: It reflects the power currently being exported by each DER. Higher current exports lead to higher curtailment levels under this key.
- Maximum Active Power Available for Export: It reflects the maximum power each DER could potentially export, considering factors like local consumption and storage capacity. This key may lead to significant curtailment regardless of the actual power being exported.

For an illustrative example, refer to Figure 9. Each solar PV has different system nameplates (DER-1 at 2 MW, DER-2 at 1 MW, and DER-3 at 3 MW). Consider that each unit exports different amounts prior to curtailment (DER-1 at 1.2MW, DER-2 at 0.9MW, and DER-3 at 2.8MW). The grid operator needs to curtail 1 MW across all DERs based on the current grid condition. The right-hand side image of Figure 9 shows each DER's reduction in output, which is proportionately curtailed based on multiplying the present active power export (allocation key) by 0.2 (proportion factor).

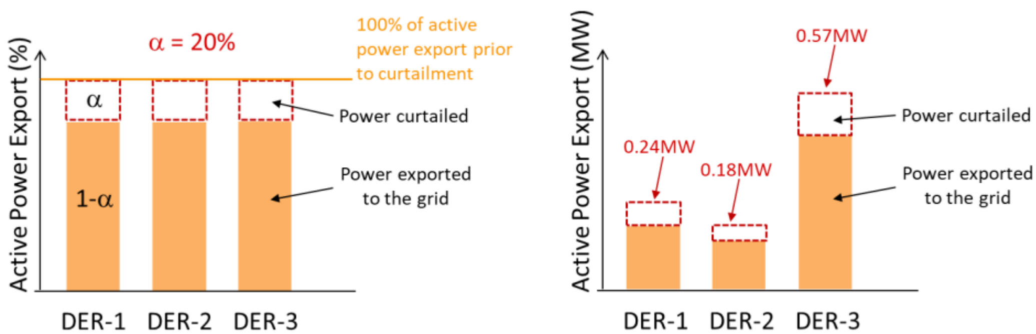

Figure 9. Pro-Rata Approach (Source: EPRI[30])

This approach can potentially enable DER to earn a viable financial return through power exports as compared to the LIFO approach. The downside is that as DER penetration rises, the frequency of grid congestion and curtailments may grow, and DER owners may have less confidence in the financial viability of their projects.

In summary, to adequately provide for a commercial environment that is amenable to flexible interconnection and service connection solutions it is important to establish clear curtailment methods. Also, effective communication with DER owners is crucial, ensuring they are informed about curtailment timings and processes through automated systems.

International Insights

Flexible DER interconnections and EV charging service connections are being explored in Australia, the United Kingdom (UK), and across Europe (EU). While Australia has been a global thought leader in the development of dynamic operating envelopes and pilots, developments in other parts of the world are following close behind. There is an urgent need to address distribution capacity constraints that may be hindering distributed renewable energy, battery storage, and EV charging development to achieve policy objectives.

Australia

In Australia, the concept of dynamic operating envelopes includes both the analysis to determine the

[30] Ibid.

variable grid constraints and the methodology to manage the DER, primarily distributed solar PV. Australia has extensively explored active solar PV curtailment to manage its integration into the electricity grid. The Dynamic Operating Envelope provides a dynamic range within which DERs can import or export power without exceeding the physical and operational limits of the distribution network. The distribution network service providers (DNSPs) are demonstrating DOEs through such as the Distributed Energy Integration Program (DEIP).[31] The primary goals include enhancing grid reliability, reducing interconnection costs, and supporting a higher penetration of distributed renewable resources and battery storage across the network.

As in the US, the DNSPs are implementing DOE through smart inverter functions and their utility ADMS and DERMS systems to facilitate real-time monitoring and control of DER outputs, ensuring grid stability and reliability. These efforts focus on calculating and communicating DOEs using standards-based communication protocols. Various pilot programs, such as the South Australia Power Networks (SAPN) Flexible Exports Trial,[32] are underway to test and refine DOE implementations, demonstrating significant improvements in DER integration and grid management.

United Kingdom (UK)

In the UK, the implementation of DER/EV flexibility is part of a broader strategy to orchestrate DERs and improve grid flexibility. Since 2019, the Office of Gas and Electricity Markets (Ofgem), the UK regulator for electricity and gas markets, has been pursuing local flexibility markets to source flexibility services as a non-wire alternative. This is like efforts in the US. However, as in the US, there is a recognition that flexible interconnections and service connections may also be needed to address existing constraints hindering DER development and electrification. Ofgem's The Future of Distributed Flexibility[33] initiative aims to further explore options to enable the dynamic management of distribution constraints through dynamic operating envelope-based curtailment services and ultimately toward DER orchestration via distributed market mechanisms (Figure 10). These efforts are important for supporting the UK's ambitious targets for decarbonization and renewable energy integration, ensuring that DERs can contribute to overall grid stability and mitigate distribution capacity constraints.

---

[31] ARENA, Distributed Energy Integration Program website. Available online: https://arena.gov.au/knowledge-innovation/distributed-energy-integration-program/

[32] ARENA, Flexible Exports for Solar PV Final Trial Report, October 2023. Available online: https://arena.gov.au/knowledge-bank/sa-power-networks-flexible-exports-for-solar-pv-trial-final-report/

[33] Ofgem, Future of Distributed Flexibility website. Available online: https://www.ofgem.gov.uk/call-for-input/call-input-future-distributed-flexibility

Alternatives to flex over time

Time →

	Planning **timescales** *(Services which are alternatives to procuring flexibility)*	Availability **timescales** *(Flexibility services provided ahead of operations)*	Operations **timescales** *(Flexibility services provided close to real-time)* Pre- t=0	Post- t=0
Energy balancing	**Contracts for Difference** • *Generators enter long-term contracts with Government and get paid a flat (indexed) rate*	**Capacity Market** • *Government procures pre-agreed flexibility, years in advance, to respond to system stress events* **Wholesale day-ahead/intra-day** • *Wholesale trading of generated electricity, day-ahead or intra-day* **Time of use tariffs** • *Supplier driven variable tariffs used for half-hourly settlement* **Local P2P** • *Trials only, enables producers and consumers to trade electricity directly* **Tx Locational marginal pricing** • *Possible modification of wholesale trading, with price dependent on location*	**Balancing mechanism** • *System operator procures flexibility close-to-real-time to manage energy imbalance (can also support constraint management)* **Tx frequency services** Dynamic Moderation • *System operator accesses flexibility to slowly correct small frequency deviations* Dynamic Regulation • *System operator access flexibility to provide rapid response to frequency deviations* Reserve services • *System operator accesses flexibility to manage energy imbalance at various timescales*	**Tx frequency services** Dynamic Containment • *System operator accesses flexibility post-fault to bring system back into balance* Reserve services • *System operator accesses flexibility to manage energy imbalance at various timescales*
Network constraints	**Dx flexible connections/active network management** • *Customer connections where curtailment is part of the terms of connection* **Dx reinforcement deferral** • *Conventional reinforcement where flexibility is non-economic solution*	**Local P2P[13]** • *Trials only, enables producers and consumers to trade capacity directly* **DNO flexibility products** Sustain • *System operator procures pre-agreed flexibility to prevent the network going beyond its firm capacity*	**Tx thermal services** Constraint Management Pathfinders • *System operator accessing flexibility to resolve constraints and reduce balancing costs*	**DNO flexibility products** Dynamic • *System operator accesses flexibility following network abnormality* Restore • *System operator accesses flexibility to support increased load restoration*

Figure 10. Ofgem Future of Distributed Flexibility Alternatives Over Time (Source: Ofgem)

Europe

Across Europe, there is a recognition that flexible DER interconnections and EV charging service connections are needed to mitigate the need for distribution capacity build-outs. This was identified by the Council of European Energy Regulators in their 2023 paper focused on flexible connections.[34]

> *"…to achieve efficient management of distribution networks, a different approach is needed. This involves a more active network management where network reinforcements are still a dominant mechanism but are no longer the only one. Over time, the mechanisms available to the DSO in efficiently managing its network have been extended and better specified. Examples of such are the implementation of specifications for flexibility procurement by DSOs in the Electricity Directive, and regulators and DSOs increasingly experimenting and implementing different time- and/or location-specific elements in the structure of network tariffs. The increasing interest in [flexible] connection agreements should be seen from this perspective."*

This was also identified as a key priority in the recent Wired for Tomorrow report[35] from Eurelectric, the association of European utilities.

In summary, flexible connections are recognized as an important tool for managing the integration of DERs into electricity grids in Australia, the UK, and Europe. They provide a flexible and efficient way to support

---

[34] Distribution Systems Working Group, CEER Paper on Alternative Connection Agreements, Council of European Energy Regulators, May 2023. Available online: https://www.ceer.eu/documents/104400/-/-/e473b6de-03c9-61aa-2c6a-86f2e3aa8f08

[35] Accenture, Wired for Tomorrow Report, Eurelectric, May 2024. Available online: https://powersummit2024.eurelectric.org/wired-for-tomorrow/

the transition to a more sustainable energy system. Each region is leveraging flexible connections tailored to their specific regulatory and operational contexts, but all share the common goal of optimizing grid performance and facilitating the growth of distribution resources and electrification.

Conclusion

Dynamic operating envelopes and flexible connection strategies are pivotal in the transition to a more distributed system, greater DER adoption, and expanded electrification given inherent distribution grid constraints. Unlike static hosting capacity, DOEs provide an advanced method for managing energy flows from variable distributed renewable energy generation and EV charging consumption. By setting upper and lower bounds on power exports and imports based on real-time and forecasted conditions, DOE enables flexible connections to optimize the utilization of existing grid infrastructure. This allows more DERs and EVs to connect without necessitating immediate upgrades. This can reduce costs and accelerate the adoption of renewable energy sources and EV charging infrastructure.

Regulators, utility planners, and DER developers should collaborate to create supportive regulatory frameworks that facilitate the adoption of flexible connection strategies.

At this early stage in the implementation of flexible connections, both customer-controlled and utility-controlled solutions are foundational to understanding the effectiveness of each approach. Customer-controlled solutions, such as advanced inverter settings, PCS, and managed charging systems, empower end-users to align their energy usage with grid conditions. Utility-controlled solutions leverage ADMS and DERMS to dynamically monitor the grid and control customer resources.

Flexible connections are a necessary step in the evolution toward comprehensive DER orchestration. This will involve a transition from limits and curtailments employed in flexible connections to more sophisticated, coordinated optimization of all DER types. As such, the technologies required for each flexible connection approach described previously should be viewed as an initial step toward more complete DER orchestration.

Globally, countries like Australia, the UK, and various European nations are adopting flexible connection strategies to manage grid constraints and support DER integration. These efforts provide valuable lessons and benchmarks for other regions looking to optimize their grid operations and support the integration of DERs and EV charging infrastructure. For example, Australia's extensive use of DOEs, the UK's local flexibility markets, and Europe's regulatory frameworks all highlight the critical role of flexible interconnection methods in achieving sustainable energy goals.

Regulators, utility planners, and DER developers should collaborate to create supportive regulatory frameworks that facilitate the adoption of flexible connection strategies. Policies should encourage innovation and investment in advanced grid technologies, ensuring that utilities and customers can collaboratively enhance grid reliability and efficiency. Policies that encourage innovation, such as those by the New York and California commissions and similar initiatives, provide a robust foundation for advancing DER integration and electrification. Key considerations include:

- Regulatory Support: Establishing clear guidelines and incentives for the adoption of DOEs and flexible connection methods.
- Data and Forecasting: Leveraging detailed grid data and predictive analytics to design dynamic operating envelopes that reflect real-time grid conditions.

- Technology Integration: Ensuring that advanced technologies like ADMS, DERMS, smart inverters, and related interoperability standards are implemented effectively.
- Customer Engagement: Educating and empowering customers to participate in managed charging and energy export schemes to optimize grid utilization.

In summary, flexible connections and dynamic operating envelopes are essential elements for managing the evolving energy landscape. By embracing these strategies, regulators, utility planners, DER developers, and other stakeholders can effectively address grid constraints, enhance reliability, and support the broader goals of decarbonization and electrification. This paper provides a foundational understanding of flexible connection strategies and their practical applications, offering the start of a roadmap for future developments.