EPRI

MANAGING FLEXIBILITY ON THE DISTRIBUTION SYSTEM WITH DYNAMIC OPERATING ENVELOPES

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Transitioning to a Flexible Distribution System

The interconnection of distributed energy resources (DER) that can inject and absorb power to and from the distribution system, such as distributed generation and electric energy storage systems, is expected to increase in support of societal goals and as technologies mature. The cost to interconnect new DER will tend to increase as hosting capacity is consumed and grid infrastructure enhancements are needed to maintain safety and reliability.

At low levels of DER penetration, the hosting capacity of the local electric power system is commonly represented as a static value that is determined considering conservative "worst case" conditions. However, hosting capacity is not a static value as it is dependent on the coincidence of several factors that vary over the course of a day, season and/or year. As the remaining hosting capacity shrinks with rising DER penetrations there is interest in utilizing the additional hosting capacity that is available outside of those worst-case conditions. Capabilities to utilize more "flexible" DER interconnections[1] (for both generation and demand resources) that can be managed in concert and controlled dynamically[2] will likely become a viable means to maximize the use of DER within the operating limits of the grid.

It will be the responsibility of distribution management systems to evaluate and monitor these constraints - managing the resources of a few while maintaining power quality and reliability for all customers. Developing a means to limit the injection/consumption of power from select DER during the limited periods of time that hosting capacity may be exceeded can become an economic means to maximize DER energy production over time. The application of Dynamic Operating Envelopes, which combine novel analytics and pragmatic coordination, not only support flexible interconnections but will also be a key element to enable the optimization of DER.

A dynamic operating envelope establishes the upper and lower operational bounds for a controlled resource over a given time period.

A Shifting Paradigm

Today, utilities review DER interconnections under "worst-case" conditions evaluating the impact of the requests on the electric system with a focus on maintaining safety, power quality, and reliability. In these evaluations a fixed upper capacity limit is allotted to individual DER in what is coined a "firm interconnection". With a firm interconnection agreement, DER producing power may inject up to their allotted limit throughout the year and not expect to be curtailed under normal operating conditions.[3] The static operating limit of a firm interconnection agreement requires minimal oversite of distribution operators to monitor and control DER behavior. However, reliance on static operating limits ultimately restricts how

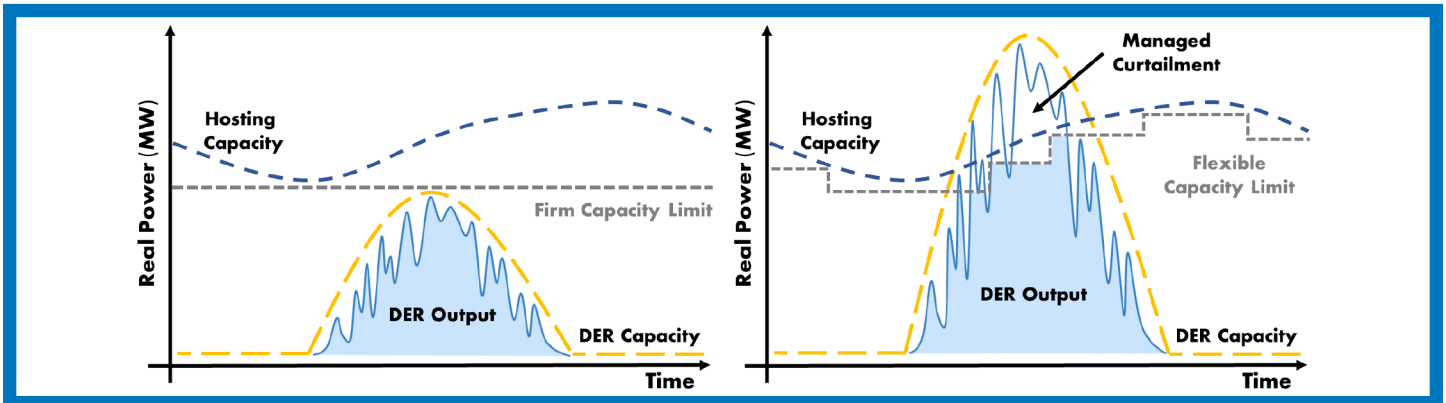


Figure 1 –Flexible interconnection strategies can increase DER capacity

1 *Understanding Flexible Interconnections.* EPRI, Palo Alto, CA: 2018. 3002014475.
2 As the grid changes over minute to yearly time-scales
3 Interconnection agreements generally allow the disconnection of DER as necessary to maintain the safety and reliability of the electric power system

much DER capacity can be installed on, and how much energy can be transmitted across, the distribution system.

In Figure 1, the area between the line representing the firm capacity limit and the curve representing the time-varying hosting capacity quantifies the marginal hosting capacity that can be leveraged through the active management of DER. In the future, the distribution system will need to be more flexible to enable increased integration of generation while also serving more dynamic loads – a point underscored by the impeding adoption of electric vehicles at residential and commercial scales. To support this transition, planners may utilize more "flexible" DER interconnections (for both generation and demand resources) with the expectation that those resources will be managed or controlled dynamically within grid constraints.

To manage the more dynamic distribution system, distribution operators will need new capabilities and tools to forecast constraints and manage resources in a fashion that avoids adverse impacts to the grid. One such capability may be the application of dynamic operating envelopes to guide flexible resources to operate within the system constraints that change with time.

This level of active resource management requires a paradigm shift in the roles and responsibilities of distribution planning and operations departments.[4] ***So, how will distribution utilities manage these flexible resources?***

Dynamic Operating Envelopes

Put simply, a **dynamic operating envelope** establishes the bounds within which a controlled resource (load or generation) can operate for a given period of time and avoid adverse grid impacts. The operating envelope is created by allocating the grid's marginal hosting capacity amongst the flexible resources. Allocation of the marginal hosting capacity may utilize a uniform, proportional, or economic based approach.

New tools will be needed in the distribution control centers to develop the dynamic operating envelopes over multiple time horizons (spanning near real-time (just in time) to day- and week-ahead, and even seasonal projections). The envelopes will be communicated directly to resource owners or their device controllers. The dynamic operating envelopes, shown in Figure 2, identify the forward looking generation/consumption limits that each resource must operate within for the applicable system conditions over a specified time period. These limits

4 *Evolving Analytics and Tools for Distribution Operations and Planning: An EPRI FO2222 Phase 1.* EPRI, Palo Alto, CA: 2021. 3002020590.

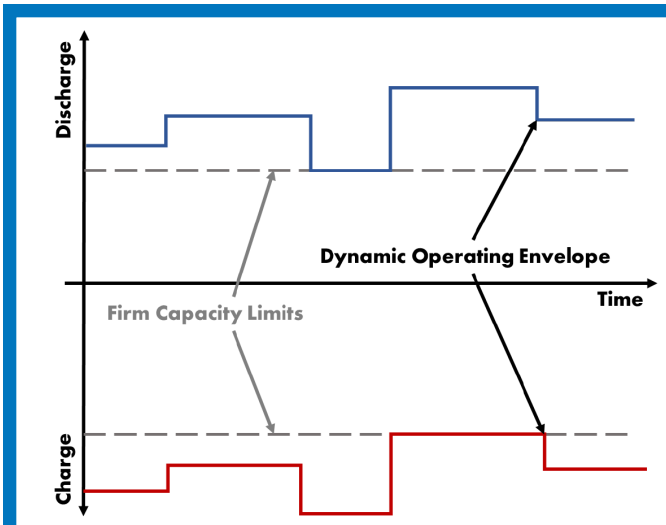


Figure 2. Dynamic Operating Envelopes can allow greater DER capacity than firm limits at certain times

What's In An Envelope? Moving Beyond Hosting Capacity

Calculating distribution system constraints is nothing new. Utilities have been using analytics like hosting capacity to understand the amount of load or generation the distribution system can accommodate without causing adverse impacts for years. In planning applications these analytics are used to interconnect DER such that they do not cause reliability and power quality issues in the operating timeframe. Moving forward, these same types of analytics will be needed in the control center to identify near-term constraints.

Time-based hosting capacity will be a critical assessment to make operating envelopes a reality. Additional capabilities are needed to *translate grid constraints* into operating limits for individual DER. To do this, utilities will need transparent processes for allocating the grid's marginal hosting capacity among multiple flexible resources.[5] Curtailment mechanisms will need to be non-discriminatory and impose the least possible restrictions (and therefore financial impacts) necessary to avoid adverse grid impacts. Moreover, the analytics used in the development of dynamic operating envelopes must consider the uncertainty of end use behavior. In these ways, the creating of dynamic operating envelopes will require significantly more advanced analytics than are incorporated into most of today's hosting capacity assessments.

5 *Implementing DERMS to Manage Grid Constraints.* EPRI, Palo Alto, CA: 2021. 3002022194.

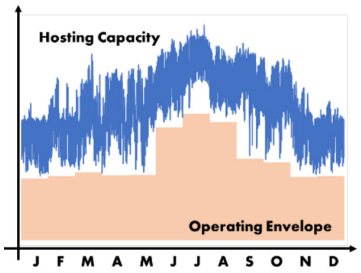
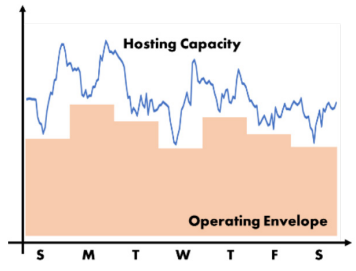
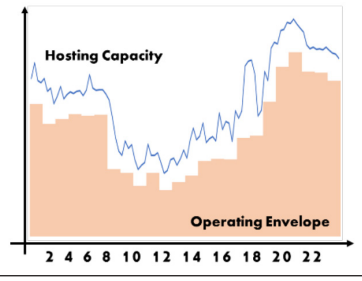
can then be used to guide the dispatch of flexible devices by aggregators in the market and to optimize the management of all resources on the system. Resource owners maintain the flexibility to operate their resources within the bounds of the current operating envelope. Operating envelopes can be an essential tool to achieve future energy goals – allowing utilities to integrate greater amounts of DER in a least-cost manner – balancing infrastructure improvements with the ability to manage infrequent conditions.

Dynamic operating envelopes can be developed in different ways depending on 1) insight to grid visibility, 2) analytical methods available, and 3) the temporal and geographic resolution of the envelope. Creating and using dynamic operating envelopes is essential to improving overall resource management and enables utilities to maximize the use of existing assets by leveraging the marginal hosting capacity on the system.

Example Application of Dynamic Operating Envelopes

Dynamic Operating Envelopes may be adopted for various timeframes and used for multiple applications, illustrated in Table 1. These forward-looking timeframes span from long term for use in outage scheduling and planning applications, near-term for use in market participation and switch order writing, and real-time for use in management and operations. For each timeframe considered, a range in visibility requirements will also be needed to improve the end-use application. Several of these applications are described below:

Table 1. Applications and data requirements for dynamic operating envelopes in different timeframes

Timeframe	Applications	Data Requirements	Example
Long Term (1 week – 1 year)	• Maintenance and outage scheduling • DER planning and interconnection • Informing customers	• Local area long term load forecast • As built system model • Connected DER capacity	
Near Term (1 day – 1 week)	• Creating short term action plans • Scheduling NWA dispatches • Informing markets • Planning curtailments	• Local area near-term load and DER forecasts • As switched grid configuration • Planned switching	
Short Term (1 minute – 1 day)	• Constraint management • Dispatch override • System restoration	• Real-time visibility • As switched system model • Planned dispatches	

Implementing Operating Envelopes in California

Late in 2020 the California Public Utilities Commission (CPUC) approved a proposed decision related to Electric Tariff Rule 21, which governs, among other things, the interconnection of DERs on the state's distribution grid. One of the notable issues discussed was allowing customers to follow a Limited Generation Profile (LGP) or operational envelope instead of the traditional fixed limit. The new changes dictate that customers may submit an LGP with values corresponding to the monthly minimum hosting capacity value (called Integration Capacity Analysis or ICA in California) published by the utility at the time of the application. A 10% buffer to the published ICA values was agreed upon as a means of mitigating the uncertainty contained within the ICA values, as was a provision to allow utilities to limit a customer's LGP when needed to maintain safety and reliability. In essence this decision established the creation and use of dynamic operating envelopes for DER interconnections that traditionally relied on fixed capacity agreements. As of the writing of this document, implementation is pending on several technical hurdles, one of which is UL certification of inverter power control systems that comply with the use and modification of LGPs. Meanwhile, utilities in California continue to investigate tools and processes for integrating these changes into their planning and operations departments.

Source: Proposed Decision 20-09-035 "Order Instituting Rulemaking to Consider Streamlining Interconnection of Distributed Energy Resources and Improvements to Rule 21." https://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M347/K953/347953769.pdf

Tools to the Transition

In order to transition to a state where dynamic operating envelopes can be developed within operational timeframes, real-time to months ahead, it will require new and improved data and tools in the control center:

- ***Distribution System Model.*** This model must be up to date, representing new construction and the as-operated state of the distribution system. Access to high fidelity models at all times is needed in the control center, where suspected model errors often lead to costly delays and inefficient use of field crews. The grid model must also represent both firm and flexible DER, with information about the location, type, and size of DER supplied by the customer information system (CIS). Ensuring the appropriate data and processes are in place to have up to date models readily available is an ongoing area of improvement for utilities during the digital transformation.
- ***Load and DER Forecasts.*** Unlike planning studies which rely on worst case conditions, dynamic operating envelopes depend on time-based forecasts of gross load and generation output. The shorter the time horizon, the greater the accuracy and spatial resolution of the forecasts must be to minimize uncertainty in operational decisions. Historical SCADA and AMI data combined with weather normalization was previously sufficient to accurately forecast distribution load levels but growing behind the meter DER penetration and changing customer behaviors are driving the need for new tools and capabilities.
- ***Analytical Tools.*** The power flow solvers (planning) and DMS (operations) utilities use today will need to evolve in order to support the development and application of dynamic operating envelopes. Not only will this entail incorporating new data streams and computational capabilities, but it will also involve establishing new processes, roles and responsibilities within the control center. Applicable systems must be DER aware, support the ability to quantify marginal hosting capacity and develop dynamic operating envelopes for each flexible DER in a manner that can be efficiently applied within operational time frames.
- ***Communication and Control.*** Creating and communicating dynamic operational envelopes will require a structured data exchange between the control center and asset owners/operators. At some utilities the control center will communicate operating envelopes and rely on asset owners to operate their resources accordingly. In other locations the utility may have full control of individual resources and will send the operating envelopes directly to customer resources. In either case, managing flexible resources will require some type of communication between the control center and end use devices.

Where Do We Start

Distribution utilities are at varying stages of readiness for implementation of dynamic operating envelopes. Today, many distribution utilities lack visibility and granular communication with DER such that distribution operators may not have the situational awareness to understand how DER is operating at any given time. DER

management systems (DERMS) are continually evolving but do not yet have the capabilities to create dynamic operating envelopes with sufficient precision. DER control may also be limited – large scale DER may be equipped with a recloser at the interface with the distribution system, with control of the DER limited to on/off switching under severe unplanned circumstances. For behind the meter installations, the vast majority of distribution utilities have no technical or legal pathway for communicating with or controlling the DER. When it comes to the tools available within the control center, many utilities are in the midst of deploying a DMS, with plans to use traditional applications like FLISR and VVO and an eye towards advanced capabilities likes DERMS to manage DER. Additionally modernization is still underway to improve grid-edge visibility through additional measurement points. To achieve the benefits of a dynamic operating envelope, utilities must have enhanced grid and DER monitoring, as well as capabilities that enable efficient communication with DER owners and coordinated control of grid and DER devices.

This is not to say that distribution utilities cannot begin implementing dynamic operating envelopes with the tools and data available today. Today's interconnection practices create static operational limits for DER. In some cases, utilities have begun analyzing conditions more granularly to give DER owners additional flexibility in their operation. Fixed agreements ranging from seasonal to time-of-day limits are the first step in creating dynamic operating envelopes. Control center staff responsible for writing switching orders currently take note of impacted DER, and notify owners accordingly, demonstrating a manual version of coordination and control using operating envelopes.

In the meantime, operational planners can use emerging analytics like time-based hosting capacity to identify grid constraints in near-term even though the tools are not designed for real-time use. Distribution utilities can also work towards adopting communication protocols like IEEE 2030.5 to communicate constraints and operating limits to end use devices themselves. Without such communication and control, a flexible DER future may be unreliable and unattainable.

As hosting capacity is consumed by the interconnection of new DER, transitioning to flexible interconnection agreements is one option for avoiding cost increases associated with grid infrastructure enhancements. The operating system's ability to determine dynamic operating envelopes and to dispatch these resources (both regulatory and technical) is a pre-requisite to this change.

Where Are We Now

Dynamic operating envelopes have the potential to become a powerful mechanism in maintaining power quality and reliability during the operation of a DER prolific grid. Developing these envelopes properly will require thoughtful consideration and careful design. Addressing these challenges is critical and will take time to refine technical solutions and support their implementation. Therefore, EPRI continues to engage in research to address the data, analytics, and implementation considerations to make this a reality. Examples of ongoing and planned research initiatives include:

1. Enhancing a framework for effective grid model data management to enable high fidelity grid models to be available for operational and planning tools alike
2. Improving local area DER and load forecasting methods and defining the accuracy and resolution needed to drive the development of dynamic operating envelopes
3. Reshaping hosting capacity analytics to deliver dynamic operating envelopes at both the group and device level
4. Creating intuitive displays, interfaces, and dashboards for operators that clearly communicate current and forecasted conditions as well as the grid's ability to accommodate DER dispatch
5. Documenting the flow of data and communications between distribution and bulk system operators, as well as customers and DER aggregators in support of flexible DER interconnection and operation

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About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

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