



Use of Operating Agreements and Energy Storage to Reduce Photovoltaic Interconnection Costs: Conceptual Framework

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1 Rhode Island Office of Energy Resources

2 National Grid

3 National Renewable Energy Laboratory

4 Rocky Mountain Institute

5 Lawrence Berkley National Laboratory

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Foreword

This analysis was conducted as part of the Solar Energy Innovation Network (SEIN). SEIN is a collaborative research effort led by the National Renewable Energy Laboratory and supported by the U.S. Department of Energy's Solar Energy Technologies Office. SEIN supports teams across the United States that are pursuing novel applications of solar and other distributed energy resources by providing critical technical expertise and facilitated stakeholder engagement, giving them the wide range of tools necessary to realize their innovations in real-world contexts. Teams are composed of diverse stakeholders to ensure all perspectives are heard, key barriers are identified, and the resulting solutions are robust and ready for replication in other contexts.

The writing of this report was initiated and led by a team from Rhode Island that participated in Round 2 of SEIN. The team was led by the Office of Energy Resources, which was joined in the effort by National Grid (Rhode Island) and the Clean Energy States Alliance. The team sought to elucidate the potential value of adding battery energy storage to solar projects to reduce distribution upgrade costs and optimize solar hosting capacity.

This report is supported by analysis conducted by the National Renewable Energy Laboratory and Lawrence Berkley National Laboratory, which is detailed in a companion report, *Use of Operating Agreements and Energy Storage to Reduce Photovoltaic Interconnection Costs: Technical and Economic Analysis* (McLaren et al. 2022).

Acknowledgments

The Project Team thanks the Clean Energy States Alliance for their contributions, the developers who participated in our focus group, participants who provided feedback from SEIN Teams and Staff, participants from the SEIN Symposium, and all of the reviewers who provided input on this report. Reviewers included representatives from the U.S. Department of Energy, the Clean Energy States Alliance and Clean Energy Group, the Northeast Clean Energy Council, the Interstate Renewable Energy Council and the National Renewable Energy Laboratory, among others. Thank you!

List of Acronyms

ANSI	American National Standards Institute
BESS	battery energy storage system
DER	distributed energy resources
DERMS	distributed energy resource management systems
FICS	Flexible Interconnection Standards
ISA	interconnection service agreement
MW	megawatts
OEA	Operating Envelope Agreement
PV	photovoltaics
RUG	recorder under glass
SEIN	Solar Energy Innovation Network
UL	Underwriter Laboratories

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1 Introduction

State decarbonization goals and visions for large-scale electrification of the thermal and transportation sectors necessitate increased and accelerated deployment of renewable and distributed energy resources (DERs). The existing electrical infrastructure and supporting interconnection and permitting processes will need to be updated to support efficient and cost-effective renewable energy deployment at scale. Common challenges that increase the cost of integrating renewables include mismatches in timing between renewable energy production and peak electricity consumption, as well as the physical distance between large renewable energy systems and electric load centers.

This report (and its companion technical report, McLaren et al. 2022) explores one integrated technical and process concept designed to manage interconnection costs and streamline interconnection timelines to support near-term renewable energy deployment. We describe a new agreement between renewable energy developers and utilities, informed by the technical analysis. The agreement defines the operational parameters for a renewable energy system, with the goal of reducing risk and cost to all parties. This work provides a foundation upon which other states and utilities may build proof of concept.

We limit our scope to distribution system-connected solar photovoltaic (PV) systems with installed capacity roughly between 1 and 5 megawatts (MW) that are not associated with load. However, the concept may be applied to a range of solar PV project sizes, use cases, projects interconnected at the utility substation, and/or other renewable energy technologies. The applicability of the concept to other situations is a recommended area for future research.

1.1 Problem Statement

Solar PV systems that are sufficiently large or located on a portion of the electric grid with limited hosting capacity can necessitate costly and time-consuming upgrades to grid infrastructure as a prerequisite of interconnection. These grid upgrades serve the purpose of mitigating or avoiding grid violations that might result from the PV system, which could adversely affect neighboring customers.¹ Faced with grid upgrade costs, developers of solar projects have several options: (1) maintain the PV system size and pay the cost of the grid upgrades, delaying construction and interconnection; (2) downsize the PV system to eliminate the risk of violations and reduce interconnection costs; or (3) control the amount of generation from the PV system that is exported to the electric grid at critical hours to eliminate the risk of grid violations² and reduce interconnection costs. The first two options—maintaining system size at high cost or downsizing the system—are common choices. The third option—controlling the

¹ For more technical background on issues regarding the integration of distributed energy resources on the distribution system, the role of smart inverter features, and related planning activities and the IEEE 1547 standard, see Appendix D of (Enayati 2020).

² A grid violation is any instance where actual grid conditions are not within predefined operating parameters. For example, a thermal violation occurs when the temperature of a conductor exceeds a range specified by the American National Standards Institute (ANSI).

generation exported to the grid—may be achieved through either curtailment (e.g., using inverter settings) or the addition of equipment (e.g., a battery energy storage system).

In an effort to minimize time from project conception to operation, developers often downsize the PV system size (option 2) in order to maintain proper voltage and power quality requirements on a feeder. An abundance of available land on which to site renewable energy systems has led some developers to a strategy of building “small but quick” to get PV projects in operation. However, due to decreasing land availability and increasing public concern over the visual impact of many small PV systems, there may be benefit to a shift in strategy. Instead of maximizing the number of PV systems, there may be future emphasis on maximizing the revenues (and perhaps grid benefit) of each PV system by providing electrons during expensive hours and near large load centers. In addition, instead of increasing hosting capacity³ on an as-needed, project-by-project basis, focus could shift to using advanced controls and storage technology at the point of interconnection to increase the hosting capacity for distributed resources. It is in this light that our work examines how to bring option 3—controlling the exported generation from the PV system to the electric grid at critical hours—into play as a viable alternative to PV system downsizing.

1.2 Proposed Solution: Operating Envelope Agreement

One technology that can control the exported generation of solar PV systems is energy storage. Paired solar PV and storage systems use power control systems that can control specific characteristics of renewable electricity export on a specified operating schedule. The first component of our work analyzes the technical viability of paired energy storage’s control to mitigate the PV system’s grid violations and to estimate the economic feasibility of pairing energy storage for this purpose. Details of these analyses are described in the companion analysis (McLaren et al. 2022). The second component of our work is the development of a conceptual framework for a contractual agreement between the PV system owner and the electric utility, which is necessary to establish rules for how to operate the paired solar PV and storage system. This conceptual framework is the focus of this report, where we describe the concept, considerations for implementation, and provide example language.

This report discusses one possible contractual agreement, referred to as an Operating Envelope Agreement (OEA). The objective of an OEA is to identify a mutually agreeable set of technical operating requirements for a PV and storage system (including hours of enforcement, called an “Operating Envelope”) that limits risk to neighboring customers and the utility’s electric infrastructure, as well as providing certainty to both the utility and PV system owner. From the perspective of the system owner, this contractual agreement can unlock revenue while preserving the system owner’s control over the paired PV and energy storage system and providing certainty required for project financing.

³ Hosting capacity is the amount of PV that can be added to the distribution system before control changes or system upgrades are required to safely and reliably integrate additional PV.



Operating Envelope Agreement (OEA): A contractual agreement between the utility and the system owner that defines a mutually agreeable set of time-based technical operating requirements (an “Operating Envelope”) for a PV and storage system that limits risk to neighboring customers and the utility’s infrastructure and provides certainty to both the utility and PV system owner.

The OEA exists between an electric utility (referred to as “utility” throughout this report) and an authorized agent controlling a renewable energy project through a utility-approved control scheme (referred to as “system owner”). The system owner may be the renewable energy developer, project owner, project operator or manager, or customer, which may change throughout the life of the PV system.⁴ Critically, the system owner must have legal authority to make decisions about the operation of the renewable energy system to ensure that operations comply with the OEA.

The OEA contains predefined operating parameters and a set of terms and conditions. It may layer onto an interconnection service agreement (ISA), such as by inclusion as a “Special Operating Conditions” attachment, with the ISA providing a foundation for the OEA. In this report, however, we distinguish the OEA and ISA as two separate agreements. This helps

⁴ Initially, the PV system owner is the developer, who applies for interconnection with the utility. After project completion, the PV system owner may be a developer-owner, transition to a third-party operator, or become a customer off-taker. In some cases, the system owner may be different from the system operator, but for simplicity we refer only to the system owner with the assumption that the system owner and system operator will communicate and coordinate accordingly. See Section 3.4 for additional considerations about changes to system owners.

distinguish the considerations that may render the terms and conditions of an OEA different from those of an ISA.

Under the envisioned contractual agreement (OEA), the system owner maintains control of the operation of the distributed energy resources (DERs). Advances in real-time communications, control technologies, and protocols may support some degree of utility control of third-party systems connected to their electricity grids; for example, using distributed energy resource management systems (DERMS). However, the OEA we envision does not provide for utility control of the paired solar and storage system. The availability and use of DERMS technology is currently limited. In addition, there is often reluctance on the part of system owners to allow a utility control of assets, and reluctance on the part of utilities to take on that responsibility. Utility control would likely require different terms and conditions than we discuss in this report due to the different risks parties would experience. Our envisioned OEA arrangement may pose an alternate solution to utility control of third-party systems if specific measures for enforcing the OEA are in place (e.g., monetary penalties).

Pairing energy storage with renewable energy projects to control export is not a novel idea; however, implementing a contractual relationship that preserves the developer's agency over the system is an innovation over current practice. Indeed, so-called Flexible Interconnection Standards (FICS) have been implemented in several utility jurisdictions, but rely on pre-set inverter settings to curtail renewable energy systems with the utility monitoring system output.⁵ Furthermore, there has been relatively little historic uptake of paired energy storage and renewable energy for the express purpose of reducing interconnection costs or streamlining interconnection time.⁶ Reasons likely include unclear regulatory processes, vague tariff language, and lack of feasible methodologies for distribution system analyses.⁷ This report makes significant strides in smoothing these barriers and advancing the frontier of utility-developer contractual relationships.

1.3 Our Process for Developing the OEA Concept

The concept of an OEA is informed by both technical analysis and stakeholder engagement. Technical analysis of a case study shows how to pinpoint the critical hours in which exports from a DER system may contribute to grid violations and how to define operating parameters to mitigate the risk of violations, without the need for costly and time-consuming grid upgrades

⁵ See Horowitz et al. 2019. Essentially, the Operating Envelope is a principle of access in addition to those mentioned by Horowitz et al., which dictates export over time rather than specifying when generators will be curtailed. There seem to be two key benefits of the Operating Envelope principle of access: granularity and predictability. An Operating Envelope is more specific than a pro-rata principle of access and will allow developers to optimize their revenues within existing grid constraints. An Operating Envelope is more predictable than a last-in/first-out principle of access (the last project to interconnect is the first to be curtailed) because the chance of curtailment is not dependent on other systems coming online.

⁶ No such examples exist in Rhode Island to the authors' knowledge.

⁷ Some utilities (e.g., in California and Nevada) offer publicly accessible hosting capacity analyses that provide a 24-hour hosting capacity profile for each month of the year for each feeder or feeder segment. Developers in these jurisdictions may use this data to infer and propose operating parameters. Our report and its companion analysis provide additional methodological guidance for utilities to conduct these analyses on a project-by-project basis as projects proceed through the interconnection queue, thus resulting in utility-validated up-to-date operating parameters.

prior to interconnection (McLaren et al. 2022). The predefined operating parameters allow the system owner operational flexibility to maximize revenue, in compliance with applicable rates and regulations. The insights from this technical analysis are summarized more below, and in detail in the companion report.

Engagement with utilities and developers has provided key insights into the terms and conditions to be considered in an OEA. Stakeholder engagement revealed four important issues, which helped guide our work:

1. Project developers need a reasonable degree of certainty about the annual cash flow potential of their projects, in order to secure project financing.
2. Utilities need assurance that the DER system will operate as expected, to reduce risk to the electricity system.
3. Simple and straightforward agreements are crucial because both utilities and system developers are resource constrained.
4. Identifying the addition of energy storage as an alternative to paying for grid upgrades—as an integral part of the interconnection study and application process—could streamline project timelines for both the utility and system owner.

As such, the terms and conditions detailed later in this report aim to provide certainty, reduce risk, and specify protocols for developing and enforcing an OEA.

1.4 Scope and Audience for This Report

This report discusses the general framework of an OEA, including key decision points for customizing the OEA to a particular project or for a specific utility jurisdiction. The report also discusses some considerations for integrating the concept of an OEA into a utility's interconnection service agreement.⁸ Although the concept of an OEA may also extend to other technology combinations and interconnection configurations, the scope of this report only considers the OEA as applied to solar PV paired with energy storage connected directly to a distribution grid. The report is organized into three sections that discuss the: (1) Operating Envelope requirements, (2) terms and conditions, and (3) considerations for development and integration into an interconnection tariff.

The intended audience for this report includes developers, utilities, and policy and regulatory officials.

- Developers may use this report to understand the value of paired solar and storage systems in managing interconnection costs and timelines.

⁸ This report describes considerations for an OEA as part of an interconnection service agreement. Any entity aiming to adopt the concept of an OEA should conduct their own legal review as appropriate.

- Utilities may use this report as a starting point for developing contractual agreements with developers that provide the needed assurances for system reliability and safety.
- Policy and regulatory officials may use this report to provide guidance for updating interconnection protocols and processes that allow for the scale of DER deployment necessary for deep decarbonization.

2 Operating Envelope Agreement: Technical Requirements

As discussed above, the OEA is composed of two primary components: the Operating Envelope and the terms and conditions. The Operating Envelope is a set of technical requirements for operating the system over the course of a year. These requirements are determined through a technical analysis that uses power flow simulations to identify the potential for grid violations, given expected solar generation and grid loading. An example analysis is detailed in a separate document that describes a methodology used to define the Operating Envelope that would be specified in an OEA. The report also provides an economic analysis of the impact of the Operating Envelope for the example case (McLaren et al. 2022). We find that limiting the export of DERs (either by curtailment or the use of battery storage) mitigates grid violations triggered by the injection of solar generation.

Operating Envelopes are likely to differ significantly across regions, across different distribution circuits and substations, and potentially between locations on the same distribution circuit or feeder. While solar production profiles are relatively similar across the country, load patterns exhibit substantial regional variation due to prevailing climates and weather patterns, and distribution feeders vary significantly in their ability to host DERs based on many factors. A thorough analysis would need to be conducted to account for the local conditions and evolving technological capabilities, including those of inverters and DER controllers.

Although there is unlikely to be a “one-size-fits-all” set of OEA technical requirements, we can discuss some general conditions that may trigger grid violations; how to identify those violations through a technical analysis; and how to translate the results of that analysis into technical specifications for an OEA.

2.1 Conditions That Influence the Technical Requirements

Many factors drive the timing and magnitude of potential violations, and hence the necessary hours of enforcement and type of restrictions defined within the OEA. These include the number and capacity of existing DER systems, the configuration of the distribution feeder, the placement of the new solar system on the distribution circuit, and the demand pattern (loading) of the circuit.

Larger capacity renewable energy systems, while being modeled and prior to any construction, may point to more hours of violations or violations with higher magnitudes, relative to smaller

capacity systems.⁹ PV systems located further from substations may trigger more violations than those near the equipment designed to provide load balancing functions. Demand patterns and how consumption aligns with production will influence the specific timeframes during which export will be restricted (e.g., time of day, days of week, months of year).

Figure 1 through Figure 4 provide a simplified illustration of how these variables interact to cause modeled grid violations. Figure 1 shows the anticipated solar generation from a proposed PV system for each month of the year. The line represents the electricity load of the feeder where the proposed PV system would be interconnected. High levels of solar generation in the spring and fall and contemporaneous low local electricity loads present a potential for grid violations during certain times of the day.

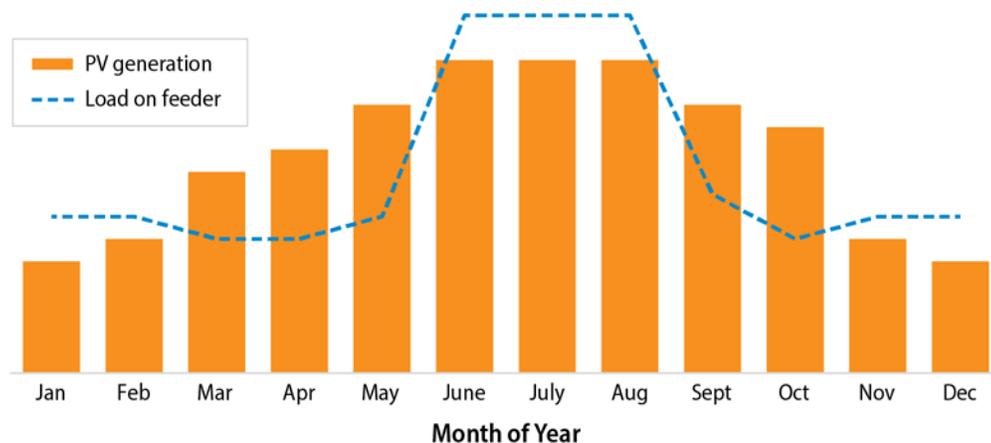


Figure 1. Illustration of monthly solar generation overlaid with a feeder load profile that is characterized by a high summer peak, due to air-conditioning demand.

The vertical axis represents power (e.g., MW). In this example, there is high solar generation but low electricity demand in the spring and fall. This mismatch can trigger grid violations during modeling.

Figure 2 illustrates a day during a month in the spring or fall. Solar generation is high in the middle of the day when load on the feeder is low. These are the hours in which the solar generation is most likely to cause grid violations. Figure 3 illustrates how OEA technical requirements might be implemented to mitigate potential grid violations. The PV system owner could curtail or store solar generation in a battery energy storage system (BESS) during the hours of enforcement (in this example 12 p.m. to 3 p.m.) and then discharge the BESS outside of the hours of enforcement. Note that the technical analysis must also inform specifications that ensure that battery storage discharge will not trigger additional violations.

⁹ Note that multiple smaller capacity systems can also trigger grid violations, similar to a larger capacity system. That circumstance is out of scope for this analysis and discussion of development of an OEA.

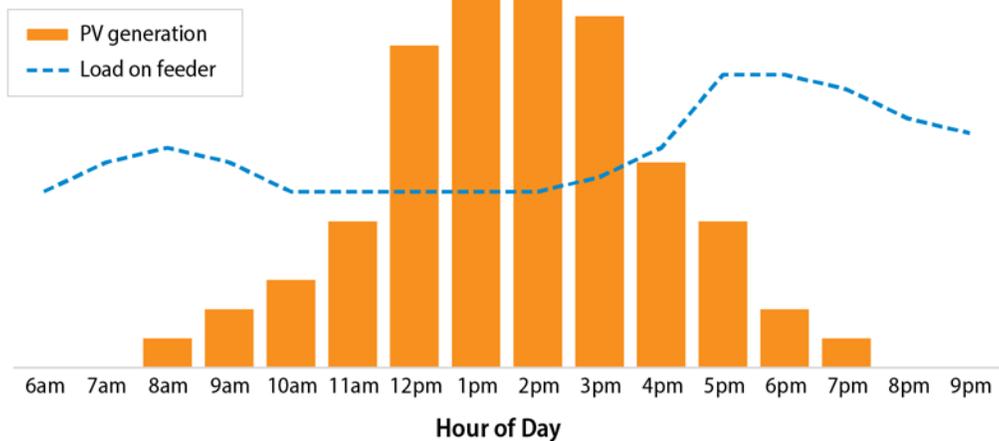


Figure 2. Hourly solar generation and load (MW) during daytime hours in a spring or fall month.
 The vertical axis represents power (e.g., MW). During midday, solar generation is relatively high, and the electricity demand is low. In this example, injecting solar onto the grid in the midday hours may trigger grid violations.

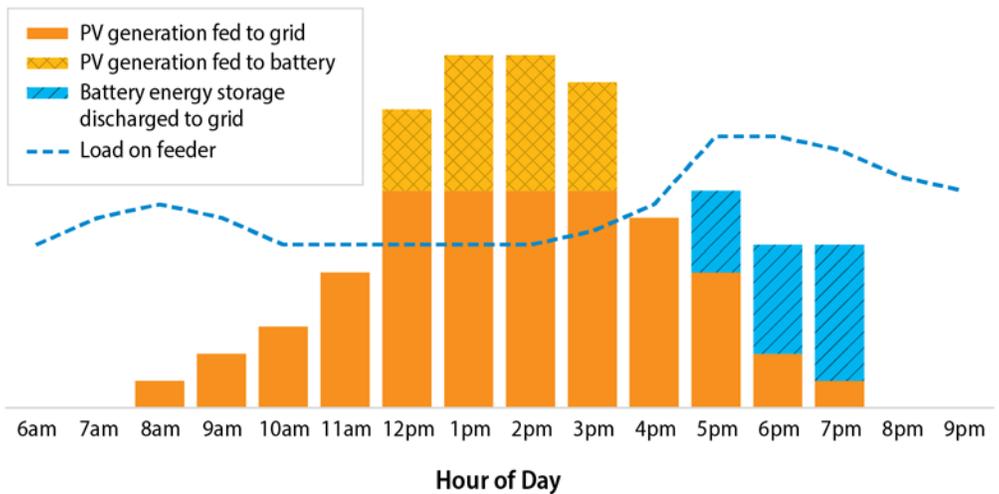


Figure 3. During midday, solar may be curtailed or stored and discharged during hours when such discharge will not induce violations.

The vertical axis represents power (e.g., MW). In this example, OEA operating parameters would specify the maximum allowable level of injection during each hour.

The technical requirements (i.e., the Operating Envelope) of an OEA are constructed based on the months of the year and hours of the day in which violations occur, as well as the magnitude

of those violations. In most cases, the requirements will dictate maximum export allowances from the DER system. Most grid violations are likely to be in the form of overvoltages, undervoltages, line overloads, and transformer thermal overloads. Other technical requirements may entail specified ramp rates, fixed power factor lag, power factor correction, and voltage levels at the inverter bus. Figure 4 details how the results of an analysis inform the construction of the OEA requirements.

Variables Influencing the Technical Requirements of the Operating Envelope Agreement

	Simple OEA		→	Complex OEA	
Month of Violation	Enforcement during entire year	Enforcement during certain season(s)		Enforcement during specific months	
<i>Analysis Indicators</i>	<i>Violations occur in most months</i>	<i>Violations occur regularly during certain seasons</i>		<i>Violations are clustered in a few months</i>	
Hours of Violation	Enforcement 24-hours/day	Enforcement sunrise to sunset		Enforcement during specific hours of day	
<i>Analysis Indicators</i>	<i>Violations occur in most months</i>	<i>Violations occur throughout day</i>		<i>Violations are clustered during specific hours</i>	
Magnitude of Violation	Zero export to grid during enforcement	Single maximum export during enforcement		Maximum export limits may vary over the year	
<i>Analysis Indicators</i>	<i>Violations are large in magnitude</i>	<i>Violations are consistent in magnitude</i>		<i>Violations vary predictably in magnitude across the seasons</i>	

Figure 4. Three analysis outputs that shape the technical requirements of an OEA.

The variables that shape the technical requirements of the OEA include (1) the months of the year that a DER causes grid violations, (2) the hours of the day that violations occur, and (3) the magnitude of the violations. The columns represent the range of technical requirements for the continuum of potential OEAs, ranging from most simple to most complex.

2.2 Getting the Right Balance: Simplicity, Flexibility, and Risk Tolerance

Another factor that may shape the technical parameters within an OEA is the desired balance between simplicity and detail. At a minimum, the operating requirements must eliminate the risk of violations to ensure system reliability across the full range of possible system load scenarios. If this foundational criterion is met, the requirements may be written in general terms that maximize simplicity or with more granularity to minimize restrictions. Simplicity facilitates monitoring and reporting, but if the operating requirements are too restrictive, system developers cannot take advantage of market opportunities to earn sufficient revenue. For example, a power flow analysis (or detailed impact study) may reveal potential violations during peak hours over 10 months of the year, but the developer and utility may agree to simplify the agreement to limit exports during peak hours for the entire year.

As the use of real-time communications equipment and protocols and advanced control capabilities (such as those specified in IEEE 1547) become more widespread, operating requirements may evolve to be more precise and, potentially, able to be adjusted automatically according to grid conditions. Any such evolution should be considered with the dual objective of, first, maintaining safety and reliability of the electric grid and, second, increasing economic and environmental benefits of DERs. Communication options are dependent on technological

capabilities as well as the preferences of the utility and system owner. Examples of communication options include software to software (e.g., utility software sends a call to inverter software), software to human (e.g., utility software generates an email to the system owner), human to software (e.g., a utility distribution system engineer sends a call to inverter software such as DERMS might provide), human to human (e.g., a utility distribution system engineer emails the system owner), or external to software/human (e.g., a peak event called by utility software is delivered to either the inverter software or to the system owner). Utilities and system owners may want to strive for automating the communication process over time.¹⁰

2.3 Revisiting Technical Requirements Over Time

Under current practice, an ISA is issued based on a DER's expected operating profile, and remains unchanged for the lifetime of the system. Once the technical requirements for the OEA are determined, it may be set for the life of the project or revisited over time. There are pros and cons to each approach. A static OEA offers simplicity and predictability, for both the DER operator, their financier, and the utility. However, there is the potential for suboptimal system operation over time because the grid is constantly changing. Allowing for the requirements to be revisited would maximize flexibility and could optimize use of the electric grid. While project developers typically need a high level of certainty regarding expected revenues over a system lifetime to ensure that the project can be financed, they may be open to changes in the OEA requirements if there is a guarantee that changes would only be made if it was to their financial benefit. Utilities may need bounds on how often an OEA can be revisited and who pays for new studies, to avoid burdening utility resources.

One potential compromise between a static OEA and a holistic revisit is to agree to a maximum number of hours over the course of a year that restrictions on export to the grid will be enforced and allow those hours to change over time. By doing so, the system owner can estimate minimum expected system cash flow by assuming OEA restrictions would apply to the most profitable hours. Any reduction in the number of hours actually enforced each year or changes in the timing of those hours of enforcement would potentially increase revenues. From the utility's perspective, specifying only a maximum number of hours of enforcement each year provides the greatest degree of flexibility, allowing the utility to adjust the Operating Envelope as evolving grid conditions and load patterns change over decades. All such conditions, including maximum hours and protocol for enforcement, must be clearly specified during contracting.

Changes may also be indicated by relevant policy or regulatory changes over time. To the extent possible, future changes should be contemplated and planned for at the time the OEA is executed. For example, evolving IEEE 1547 advanced inverter standard specifications and options for the interconnection and interoperability between utility electric power systems and DERs could overlap with certain OEA requirements (IEEE Standard Association 2018)¹¹.

¹⁰ Utilities and system owners should ensure proper performance validation checks are in place instead of relying on automated (involving software) or manual (involving humans) communication channels. See Section 3.1 for additional considerations.

¹¹ For educational materials on IEEE 1547 see NREL's resource page at: <https://www.nrel.gov/grid/ieee-standard-1547/>.

Likewise, a jurisdiction that already requires energy storage systems to limit grid export at peak hours may deem an OEA that includes restrictions on energy storage redundant.

2.4 Future Research

Future research should explore how relaxing co-location impacts grid violations. In other words, if the Operating Envelope is relatively insensitive to system location (within a sufficiently small neighborhood of interconnection points), then it is possible that the solar PV system and the energy storage system may not need to be co-located to produce the same grid benefits if operating equivalently to the Operating Envelope for the paired system.

3 Operating Envelope Agreement: Terms and Conditions

The second main component of the OEA is the set of terms and conditions. The purpose of the terms and conditions is to clarify processes and procedures, thereby reducing risk of unknown consequences for each party.

This report describes several terms and conditions that may be considered in adopting an OEA. We describe the general concept for each term or condition as well as highlight considerations that might help jurisdictions or parties customize an OEA. The terms and conditions included here, and their considerations, are all informed by conversations with stakeholders, including utilities and developers. We offer four categories of terms and conditions: (1) performance validation and data reporting, (2) term of the agreement and changes to the agreement, (3) non-compliance, enforcement, liability for damages, and dispute resolution, and (4) changes in ownership.

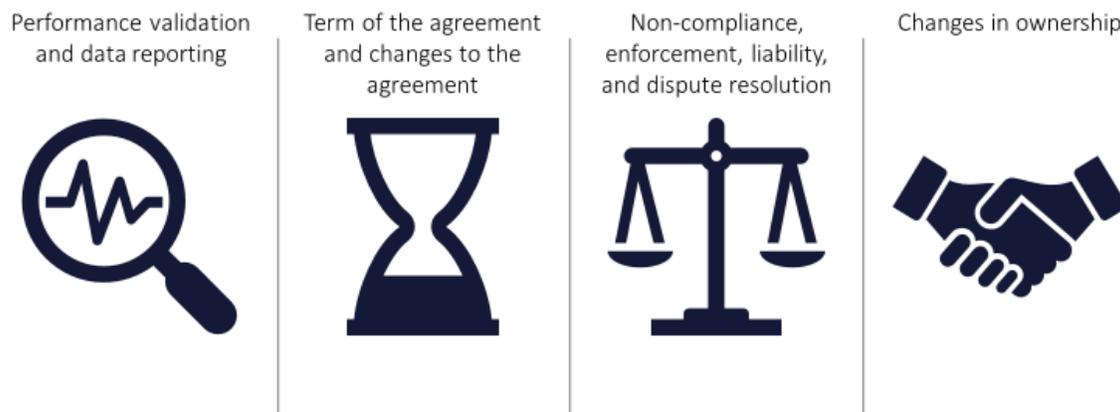


Figure 5. Four categories of terms and conditions

Utilities and system owners may seek to standardize OEAs across jurisdictional and operational boundaries for simplicity and streamlined administrative burdens. If OEAs become a common tool, standardization and best practices may be a fruitful area for future research.

The terms and conditions described herein do not constitute a comprehensive list. These terms and conditions have not undergone any legal or regulatory review and are presented in concept only. Any jurisdiction adopting an OEA and any party entering into an OEA should do a thorough legal review of the terms and conditions, as well as the contract as a whole.

3.1 Performance Validation and Data Reporting

The OEA must detail how performance will be verified. Performance is defined as adherence to the Operating Envelope, defined by the technical requirements on operating parameters and hours of enforcement. Because one key function of the OEA is to build assurance that the system owner will operate the system in a manner that mitigates grid violations and avoids grid upgrades, utilities will need to be able to verify that performance is as agreed. From the developer's perspective, routine data reporting will provide an evidentiary basis for compliance with the OEA and reduce risk of allegations of non-performance.

The primary driver for performance validation methods is the risk and severity of consequences of non-compliance. A small system may have limited impact on the grid if it operates outside of the agreed-upon Operating Envelope, whereas a large system may risk area reliability for neighboring customers and/or substantial damage to the grid if operated incorrectly. While the OEA is designed to reduce risk, the utility may still perceive risk (or compounding risk) to grid reliability as more systems are built in the same electrical area, even with OEAs in place. All systems must have some level of performance validation, with the protocol potentially being different depending on system size relative to feeder capacity, risk or severity of consequences, and number of systems interconnected. These determinants should be clearly defined in advance, such as in the interconnection system impact study within the interconnection tariff, so that developers and system owners can understand why, when, and how systems will be treated differently.

At minimum, all systems must be able to positively demonstrate compliance. This demonstration may occur at the "witness test," a standard requirement for interconnection where a utility staff confirms correct operation of the system in person. Specifically, the system owner should verify that the inverter set points are correct and demonstrate that their control system will indeed control the site in compliance with the OEA. If the Operating Envelope is time-based (i.e., export to the grid is limited during predefined hours and days) then the control system¹² should show that there is a time-based control scheme by simulating operations during restricted hours.

Incidental reports from utilities indicate that some PV systems may export higher than expected levels of electricity, relative to amounts modeled in system impact studies and specified in interconnection service agreements. While there are multiple methods for controlling export, no standardization has been in place, which has likely contributed to utility scrutiny of inverter controls and desire for additional technological backstops to ensure compliance. System developers and the utility need to consider current and anticipated standards and certifications

¹² A data recorder such as a RUG (recorder under glass), DR87 recorder (interval data recorder), or smart meter can ensure no unwanted export.

during the development of an OEA. For example, IEEE 1547 (2018) compliant UL-certified smart inverters are expected to become available in 2022.

For larger systems, or for systems that have higher risk or severity of consequences for non-compliance, additional technological measures (either on-site or in a utility control center) will likely be required to backstop compliant performance. These measures may include, but are not limited to, technology controls, routine system testing throughout the life of the system, and enhanced technological standards.

The utility may also require use of software that allows the utility to mirror the system owner's data monitoring and control system interface to provide real-time system monitoring. A relay system can also be set up to report back to the utility only when exceptions occur. In the event of non-compliance, these systems would allow the utility to take action to prevent adverse grid impacts.

Near-term backstops and verification can enable the concept of an OEA by providing both technical and stated assurances that the system will operate as expected. As more systems come online, utilities and system owners will be able to better estimate risk of non-compliance using actual data. If the likelihood of risk is deemed to be sufficiently small, then utilities may consider relaxing real-time monitoring and foregoing some backstops for certain low-risk systems. Future research is needed to not only hone processes for predicting and modeling PV system output, but also for ensuring proper functioning and precision of control systems and technological backstops.

3.2 Term of Agreement and Changes to Agreement

The term of agreement specifies the length of the OEA contract and the resulting Operating Envelope of the paired system. There is a key parallel between the term of the OEA and the term of an ISA. An ISA is an agreement between a utility and a system owner that describes the system to be interconnected (e.g., production and export profiles). ISAs are typically in place for the life of the system, and are only modified if the system itself is modified or does not operate as expected.¹³ Importantly the ISA prevents system modifications beyond what was studied and deemed safe and reliable in interconnection studies. Once the ISA is in place, the system can effectively be considered as static, and future changes to the electric grid, such as the addition of new systems, can be studied as incremental.

In this same vein, the OEA describes a system that operates in a certain predetermined, approved, and expected manner. In the absence of changes to the paired system, the OEA should be in place for the life of the paired system. One complexity is the difference in expected lifetimes of PV systems and storage systems, with PV systems typically having longer lifetimes. Only if the system owner replaces the system with a system that is technically and operationally equivalent to the original is the OEA able to remain in place. If the replaced or modified system is technically or operationally different, the utility will require a new system impact study that may in turn result in amendments to the OEA. For example, the OEA may need to be amended if

¹³ For example, an ISA will no longer be valid if a system owner adds panels to an existing solar PV system; a new ISA will need to be drawn up before the modified PV system can export production to the grid.

the system owner chooses to not replace the storage system at the end of its life. Possible modifications may include curtailing the PV system such that the Operating Envelope is maintained or restudying the PV system alone and investing in required grid upgrades. Once the paired solar and storage system is decommissioned, the OEA will expire.

The OEA should be in force at all times throughout the life of the PV system but may need to be modified if there is any planned, unplanned, or desired change to the overall operating profile of the system either in hours of enforcement or unrestricted hours. As with an ISA, if the system owner wants to add renewable energy generation, request a change in operation, or change energy storage capacity, then the system will need to be restudied, which may result in changes to the Operating Envelope's technical requirements or hours of enforcement. If the addition of renewable energy generation is large, the utility may also require additional grid modifications or larger energy storage. As energy storage costs drop and market value streams increase, system owners may also choose to increase the size of energy storage. This will trigger a restudy to determine whether a new Operating Envelope or grid upgrade is needed to accommodate the larger system, similar to existing practices with updating ISAs. If the paired system appears to be functioning differently than studied, such as discovered through repeat grid violations or analysis of performance data, then the utility may work with the system owner to identify and fix problems, require a revision to the OEA, or terminate the underlying ISA and disconnection of the system.¹⁴

The system owner may initiate a change to the OEA if market conditions suggest it may enable additional revenue streams. This would require restudy of the system by the utility, for which the cost may be borne by the system owner, depending on the utility's existing policies. The restudy may result in a different set of technical restrictions on operating parameters or hours of enforcement, which may or may not be divergent from the original OEA by the system owner. The original OEA must remain in force as a default so that the system owner can choose to forego changes if the new operating parameters are deemed unfavorable. Allowing developers to maintain the original operating parameters, and reject a new set of operating parameters, is essential for ensuring the original economic assumptions under which the project was financed are upheld; otherwise, system owners may not be able to finance new projects.

On the other hand, a utility may choose to restudy systems on a constrained feeder to understand whether operating parameters can be modified in a way that provides grid benefits. If the restudy results in a mutually beneficial change to the operating parameters (e.g., provides incremental grid benefits and increases expected revenues for the system owner), then the utility may propose a modified OEA. A utility may choose to conduct a periodic restudy (e.g., every 5 years) or may choose to restudy systems based on local load growth, changes in DER penetration, or other factors. The cost of restudies that were not envisioned in the original OEA or initiated by the system owner would likely be borne by the utility. In all cases, the costs and timelines associated with restudies associated with changes to the OEA should be specified in the interconnection tariff.

¹⁴ See Section 3.3 for more information about non-compliance.

Finally, the OEA may also be amended or modified if changes to technology, staffing, or processes suggest a mutually beneficial or necessary change to performance validation, data reporting, or other terms and conditions. In this instance, either party may propose amendments or modifications, and both parties must agree to the changes.

3.3 Non-Compliance, Enforcement, Liability for Damages, and Dispute Resolution

A system may be deemed non-compliant if it is operating differently than specified by the Operating Envelope. Non-compliance may be discovered via investigation of a grid violation or through performance validation and may be uncovered by either the utility or the system owner. Non-compliance should be defined in the OEA.

Here, we consider two examples of non-compliance. The first example is non-compliance due to misoperation, such as programming the inverter settings in a way that is inconsistent with the technical requirements or hours of enforcement. The second example is through inadvertent export exceeding predefined tolerances onto the grid.¹⁵ As discussed in the performance validation section, these examples may or may not manifest as grid violations. The OEA may treat non-compliance of the two examples differently, or utilities may choose to specify additional standards of performance that allow for minimal non-compliance.¹⁶

Ideally, the utility and system owner collaborate to identify, diagnose, and solve any problems or issues that arise. However, as a last resort for severe, repeated, and unexplained violations, a utility can enforce the OEA by forced disconnection of the paired system from the electric grid, similar to their authority to disconnect problematical loads. Disconnection may occur if the local electric grid experiences a grid violation causing or necessitating an outage for safety and reliability, the paired system is found to be non-compliant either through investigation of a grid violation or through performance validation by either the utility or the system owner, or if the system presents a real risk to safety and reliability as specified in the ISA. Disconnection may be immediate, such as in an emergency situation, or planned, such as after discovering non-compliance through performance validation. Disconnection may be remote or manual, depending on available technological capabilities. The duration of the disconnection may extend until there is no longer a risk to safety and reliability, or until the system owner can demonstrate compliance with the OEA. There are likely similarities in disconnection policies with ISAs and in existing interconnection tariffs, and utilities may prefer to maintain the same processes across ISAs and OEAs.

This enforcement is likely to be a sufficiently significant deterrent to system operators allowing the system to perform differently from the OEA due to the resulting loss of production and revenues. However, regulators and utilities may consider imposing more substantial penalties for gross violations that result in material or monetary damage. As is common in regional bulk supply procurement processes, additional monetary penalties may be assessed for non-

¹⁵ OEAs may allow predefined levels of inadvertent export, for example when using a power control system. The level of allowed export must be defined in the OEA.

¹⁶ For example, a utility may specify a maximum number of times that inadvertent export can occur annually before the system is considered to be non-compliant.

compliance with expected performance beyond loss of market revenue caused by system disconnection. Regulators play an important role in approving and assessing disconnection policies and imposing penalties because they are more likely to be viewed as an independent third party without bias for or against renewable energy systems. Regulatory review of disconnection and penalty policies opens an opportunity for stakeholder engagement and ensures those policies are clear and understood. A utility may then petition the local regulatory jurisdiction having authority to impose a monetary penalty, revoke an OEA or ISA, or permanently disconnect a system if that system is repeatedly non-compliant. All processes, including evidentiary standards for compliance and enforcement should be detailed, transparent, and allow for stakeholder input.

In many cases, planned or emergency disconnection may prevent damages from occurring. However, the OEA should specify how liability for damages will be assessed and compensated. This language may be similar to language from an ISA if deemed appropriate by the utility. In some cases, the utility may require the system owner to have liability insurance to cover harm to humans and property. In other cases, the utility may pass along the cost of financial penalties the utility is issued by a public utilities commission. Any consequences of non-compliance and resulting damages as well as the process for determining causality should be specified in either the OEA, ISA, or other contract between the utility and system owner.

In case non-compliance or liability is contested, the OEA should describe a process for dispute resolution, which may be similar to dispute resolution processes already described in a utility's ISA. An existing dispute resolution process may need to be reviewed for relevance to paired system applications. If a modification to an existing dispute resolution process is deemed necessary, the utility should confer with legal and regulatory teams to understand whether that modification can be housed within an OEA or if the interconnection tariff itself needs to be updated. Ideally, the dispute resolution process will be flexible enough to also handle unknown unknowns, in case unexpected and novel disputes or situations arise.

3.4 Change in Ownership

The OEA is an agreement between the utility and the system owner. The OEA may be initially entered into by the developer. From project conception to decommission, the system owner is likely to change at least once, if not multiple times. Likewise, the OEA must provide equivalent contact information for system owners to contact utility representatives—at minimum, the contact information for a utility representative capable of responding to inquiries about the OEA and ISA. Accurate tracking of system owner information and other key contacts is important to ensure communication between the utility and owner in case of an emergency, grid violation, or required disconnection.

The OEA must include a clause that describes the expectations and process for a change in system ownership. Such details may include a deadline of notification (e.g., no more than 10 business days following system sale, or at minimum 14 days before sale is completed), how the change is made (e.g., via an online portal, via letter signed by both original and new system owners), and what information is required (e.g., administrative contact information, information required for tax purposes, operations contact in case of emergency, affirmation that the new system owner understands and agrees to the OEA). Similarly, the OEA must detail how the utility will notify the system owner if there is a change in points of contact at the utility. The

OEA may also describe enforcement protocols in the event of a lapse in accurate contact information. For example, the utility may disconnect systems or impose a financial penalty on systems for which system owner information is no longer valid.¹⁷

Utilities may already have a process in place for tracking changes in ownership related to ISAs for stand-alone systems. However, tracking changes in ownership is likely more critical for a paired system with an OEA because these systems can operate in a manner that is known to cause grid violations if not in compliance with the Operating Envelope. A utility may choose to implement similar protocols for a change in ownership related to an ISA, enhanced protocols, or may simply require a single notification for both agreements.¹⁸ The easier the process to update contact information, the more likely system owner information will be updated when there is a change and the less burden there will be on utility staff to manage contact information across numerous projects, especially as the DER penetration increases. Similarly, the OEA should describe a clear protocol that defines the primary point of contact within the utility and system owner under different circumstances¹⁹ and the expectations regarding follow-up communications.

The OEA should also specify the expectation that the OEA continues in force even if the system owner changes and notification is not made properly, as well as consequences of the new system owner declining to agree to the OEA. Such consequences may include disconnection, restudy, and/or mandatory grid upgrades to mitigate violations caused by the system operating in a manner different from the Operating Envelope.

3.5 Other Terms and Conditions

A utility or system owner may decide to include additional terms and conditions as appropriate and advised by legal and regulatory teams. These may include contingencies, severability, discerning operational interactions with markets or other revenue streams, mandating site checks or other operations and maintenance requirements, among others.

¹⁷ Imposition of a financial penalty would likely need to be included in an interconnection tariff. An additional consideration is whether the proposed enforcement mechanism may adversely affect project financing, and whether those costs would be borne by customers supporting renewable energy programs.

¹⁸ It may be helpful for a utility implementing OEAs for the first time to take the opportunity to build out a streamlined or improved process for updating contact information as a sort of pilot to improve the process across all system integration platforms if needed.

¹⁹ For example, the business contact for the system owner should not be called for operational issues; a utility's interconnection representative should not be called for billing issues; etc.

4 Integration With an Interconnection Tariff

4.1 Interconnection Tariff Considerations

Regulatory and legal staff will require the concept of an OEA be included explicitly in an ISA. Doing so may provide two important benefits. First, regulatory proceedings may allow for stakeholder collaboration in developing an OEA, which may result in improvements to the contract that benefit all parties. Second, increasing transparency of the OEA and associated processes may reduce risk and streamline interconnection for system owners.

Building out a process to consider the value of energy storage in managing PV interconnection costs may also necessitate changes to process sections of an interconnection tariff. Paired energy storage as an alternative solution to interconnect is likely only to be preferred by system owners if it does not add time, cost, or uncertainty to project development. Therefore, utilities may consider providing three options for each interconnection study: option 1 is the cost and timeline of interconnecting the full PV system size with necessary grid upgrades, option 2 is the cost and timeline of interconnecting a downsized PV system, perhaps with limited or no grid upgrades, and option 3 is the cost, timeline, and operating parameters for interconnecting the proposed PV system size with limited or no system upgrades. Note that option 3 could be realized through paired energy storage or curtailment of excess solar via advanced inverter controls. Providing all three options upfront will reduce the number of iterations on system characteristics, reduce the number of studies required, and speed up timelines for the utility, the system owner, and all other subsequent system owners in the interconnection queue.

The utility or other stakeholders may also find it helpful to develop a tool and provide adequate data for system owners and developers to preemptively sketch out the value proposition for each of the three interconnection options outlined in the previous paragraph. Such a tool may take economic factors as inputs, including costs and projected cash flows, and provide a net present value output. The tool may include simple default parameters, such as lifetime of system components, which may be refined by developers. As the value case for energy storage in supporting interconnection becomes better understood, it is likely that developers will build out their own internal capabilities and models for choosing the best interconnection option for their particular business.

The interconnection tariff modifications outlined above along with a model OEA would provide the information and transparency needed for system owners to make the best choices for themselves, while continuing to advance state clean energy and decarbonization policies.

4.2 Developing an OEA

Developing the final OEA involves combining the results of the technical analysis with negotiations regarding communication protocols and the terms and conditions. The technical analysis is conducted by a utility distribution system engineer in which the initial modeling investigates the proposed PV system size at the specified location on a feeder. If grid violations occur, the engineer conducts two alternative scenarios. The first determines the largest size PV

system at that location that does not result in a grid violation.²⁰ The second analysis pairs the originally proposed PV size with an energy storage system sized to mitigate the grid violations discovered in the original analysis and confirms that the energy storage does mitigate all violations. The analysis also determines whether there must be any restrictions on the hours or level that storage can be discharged to the grid to avoid additional violations. Note that curtailing solar during certain periods, in place of battery energy storage, would be an equally viable alternative to mitigate violations. The results of these analyses inform the technical requirements specified in the OEA (McLaren et al. 2022).

Using these required operating parameters, the developer can select their preferred option based on their own economic analysis, and either downsize the PV system with no operating restrictions required, curtail PV generation according to the export restrictions identified by the analysis, or add energy storage and operate according to the requirements identified by the analysis.

After the developer has selected their preferred system size and configuration, the second task in developing the OEA language is to negotiate the terms and conditions. In Section 4.1, we suggest including model language for an OEA's terms and conditions directly in the interconnection tariff so that it may be informed by a stakeholder process. The utility and developer can work from the model language to negotiate terms and conditions. All terms and conditions should be thoroughly reviewed by legal representatives acting on behalf of both the utility and the system owner.

4.3 Additional Caveats and Considerations

Throughout this report, we frame the OEA as a separate agreement that is an addition to an ISA. However, if the OEA is part of the ISA, such as in a “Special Operating Conditions” attachment, then the terms and conditions are necessarily governed by those already present in the ISA. Care should be taken to review the ISA terms and conditions to make sure they are appropriate, applicable, and comprehensive for a system that has an OEA.

The OEA language should also consider the eligibility and participation of the system in other relevant programs, incentives, or tariffs. The operating parameters specified in the OEA could negate eligibility to certain programs. On the other hand, the OEA should not be dependent on the existence of or participation in other programs. A best practice is for the OEA to contain all system operation parameters required to ensure system reliability. While participation in a particular program may appear to override the need for an OEA, the consequences of that program disappearing should be considered.

²⁰ This analysis may be completed through a routine Hosting Capacity Analysis but should use the most up-to-date data.

5 Conclusions

The conceptual framework for an OEA is one integrated technical and process concept designed to manage interconnection costs and streamline interconnection timelines to support near-term renewable energy deployment in furtherance of long-term climate mitigation solutions. In the future, the project team hopes to produce a follow-on report with real-world examples of OEAs, or interconnection service agreements that include OEA concepts.

We encourage utilities or others that are considering implementation of the OEA concept to reach out to the project team, using the contact emails below. By sharing the results of stakeholder discussion, legal reviews, and regulatory scrutiny, we can distill best practices and facilitate implementation of the OEA concept, to the benefit of all parties.

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