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Regulatory and Technical Challenges and Barriers to Adoption of Distributed Wind Energy in Agricultural Settings

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ABSTRACT

Distributed wind (DW) energy development can benefit agricultural landowners through the possibility of improved resilience of electrical service from onsite generation and associated economic benefits. DW development currently faces technical and regulatory challenges related to interconnection of projects with distribution or transmission equipment on the main electrical grid. A review was conducted of barriers to adoption for agricultural DW projects and potential roles of various stakeholders in addressing them. One major barrier is that the unique characteristics of wind energy generation such as its variability and intermittency, may require upgrades for the whole power line, which can lead to prohibitive cost burdens on individual interconnection customers. Another barrier is compliance with federal, state, or utility-level regulations that require technology-agnostic, industry-standard equipment that is often not technically realistic for DW projects. DW developers, grid infrastructure owner-operators, regulators, and standards publishers can work together to address these challenges and facilitate DW development.

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EXECUTIVE SUMMARY

Distributed wind (DW) energy development in agricultural areas can be attractive because of its potential to provide onsite energy generation, improved electrical service resilience and reliability, and economic benefits of selling excess generation to the main grid. However, developing DW projects is logistically challenging, largely because of technical and regulatory needs when interconnecting DW projects to distribution or transmission lines on the main grid. In practice, the current typical procedures and requirements for interconnecting distributed energy resources (DERs) and DWs can stall or even prevent project development.

Wind energy has specific technical challenges that may be affected by, or have an impact on, agricultural DW developers. For example, wind energy has unique characteristics such as variability in power output over time that may contribute to adverse electrical outcomes like backfeeding and unintentional islanding that can be dangerous for operators and damaging to grid infrastructure. Wind turbine generators are also uniquely susceptible to electrical or mechanical damage by various extreme weather or natural disaster conditions, and repair and replacement of components may have long lead times, resulting in long energy generation downtimes, for projects in rural areas. There are solutions to these challenges; backfeeding and unintentional islanding can be prevented through upgrades on the electrical grid (e.g., anti-islanding device and/or smart inverter installation at points of interconnection) and wind turbine equipment can be hardened against natural disasters specific to the project location. The grid upgrades in particular have often historically been cost-prohibitive for projects, especially in areas where the utility or other grid infrastructure owner-operator has passed the entire upgrade cost to an individual interconnection customer. These challenges are also exacerbated by the current state of the grid in rural locations, where there is often little redundancy in the electrical system and few resources to conduct the analytics needed to understand the impacts of these devices on the grid or to manage the consequences should the installation be unsuccessful.

Regulatorily, in conjunction with the need for upgrades, there is no standard method or procedure for sharing interconnection equipment upgrade costs amongst all interconnection customers, and costs are frequently passed to a single customer. If the customer is unable to justify or afford the cost, the upgrades are not made, and the challenge persists for subsequent interconnection project applicants; this outcome has been reported anecdotally in several DW interconnection reviews. Separately, many regulators impose compliance with industry-standard equipment that in many cases is difficult or even impossible for wind energy generators to comply with based on products currently available on the market, which can be costly, if upgrades are needed to support those devices, as well as logistically challenging. Development of DW-specific regulations, codes, and standards may improve these outcomes, which could require input, publication, and enforcement from the collaboration between stakeholders like DW developers, grid infrastructure owner-operators, publishing organizations for industry standards, and regulators at a federal, state, and utility-level. The relationship between these stakeholders may require clarification or shifting of responsibilities and purview, as well as focus on the impacts of current practices on wind energy generation in particular.

ACRONYMS AND TERMS

Acronym/Term	Definition
AC	alternating current
AGIR	Authority governing interconnection requirements
AHJ	authority having jurisdiction
ARC	all-requirements contract
CAISO	California Independent System Operator
CESIR	Coordinated Electric System Interconnection Review
CPUC	California Public Utilities Commission
DC	direct current
DER	distributed energy resource
DERMS	distributed energy resource management system
DTT	direct transfer trip
DW	distributed wind
EPS	electric power system
ERCOT	Electric Reliability Council of Texas
FERC	Federal Energy Regulatory Commission
G&T	generation and transmission
IC	interconnection customer
ICA	Integrated Capacity Analysis
IEEE	Institute of Electrical and Electronics Engineers
IOU	investor-owned utility
IREC	Interstate Renewable Energy Council
ISO	independent system operator
LADWP	Los Angeles Department of Water and Power
NERC	North American Electric Reliability Corporation
OEM	original equipment manufacturer
PG&E	Pacific Gas and Electric
PJM	Pennsylvania-New Jersey-Maryland Independent System Operator
POI	point of interconnection
PREPA	Puerto Rico Electric Power Authority
PUC	public utilities commission
RTO	regional transmission operator
SA/SB	Supplement A/B
SCADA	Supervisory Control and Data Acquisition
SCE	Southern California Edison

Acronym/Term	Definition
SIR	Standardized Interconnection Requirements
UI	unintentional islanding
UL	Underwriters' Laboratories
VSR	voltage supervisory reclosing

1. INTRODUCTION

Distributed wind (DW) energy presents an opportunity for agricultural landowners to improve onsite backup energy generation resilience and reliability through co-location of energy generation and usage on rural land, and may even have cross-cutting benefits relating to agricultural production [1]. However, current technical challenges and regulations relating to the interconnection of distributed energy resources (DERs) and specifically DW resources to the main grid present barriers to adoption of this technology, especially in agricultural contexts. This paper presents an overview of the current landscape of technical and regulatory challenges for interconnection of DW generation in agricultural contexts as well as potential solutions or mitigation strategies.

2. CHALLENGES AND BARRIERS

2.1. Stakeholder Roles and Responsibilities

One of the main documents with technical standards for grid interconnection, IEEE 1547-2018, defines two major stakeholders in DER interconnection projects; these stakeholders include authorities governing interconnection requirements (AGIRs) and authorities having jurisdiction (AHJs) [2]. In practice, the actual entities categorized as each of these types of governing bodies may vary based on location and interpretation. IEEE 1547-2018 provides examples of entities that may act as the AGIR, including regulatory agencies, public utility commissions (PUCs), municipalities, and cooperative boards of directors [2]. While examples of AHJs are not provided, in practice, there can be some overlap with stakeholders acting as AGIRs; for example, municipalities may act as either or both AGIRs and AHJs, with the responsibility of adopting and enforcing certain standards. In other circumstances, the AGIR and AHJ may be distinct, for example, if a utility serves as an AGIR for an electric power system (EPS) and adopts certain technical requirements and/or standards, but a local government body acts as the AHJ enforcing the standards and providing regulatory support in the form of permitting and licensing of projects. In any case, there is no prescriptive regulation, standard, or currently used best practice that distinctively defines these roles and responsibilities [3]. For the purpose of discussing stakeholder roles in this report, the major parties here are described more by operational activity rather than attempting to categorize by regulatory definition. These stakeholders include grid infrastructure owner-operators, DER developers, grid interconnection regulators, and standards organizations.

2.1.1. Grid Infrastructure Owner-Operators

The current managers and operators of existing electrical networks are major players in DER development and interconnection, since they are in charge of approving or denying interconnection requests for their system. These stakeholders can also be referred to as area electric power system (area EPS) operators [3].

DERs can be interconnected to the grid in front of the meter, on the transmission side, in which case transmission line managers and operators would be the responsible entity. These transmission network owner-operators tend to be larger regional utilities and authorities like independent system operators (ISOs) and regional transmission operators (RTOs); examples in the U.S. include the California ISO (CAISO), the Electric Reliability Council of Texas (ERCOT), and the Pennsylvania-New Jersey-Maryland Interconnection (PJM) [4]. DERs can also be interconnected to the grid, on the customer-facing side, in which case distribution or feeder line managers would be responsible for facilitating interconnection of new energy assets. These feeder network owner-operators tend to be smaller utilities or managers such as investor-owned utilities (IOUs), publicly owned utilities, and member-owned utilities. Major IOUs in the U.S. include Pacific Gas and Electric (PG&E) and Southern California Edison Company (SCE) in California [5]. The Puerto Rico Electric Power Authority (PREPA) and the Los Angeles Department of Water and Power (LADWP) are two examples of major publicly owned utilities in the country [5]. The Pedernales Electric Co-op in Texas and the Jackson Electric Member Corporation in Georgia are two examples of member-owned energy cooperatives [5]. In California, this distinction of which regulators are relevant to different interconnection customers (ICs) is broken down into three options: customers interconnecting to high-voltage, bulk power transmission lines follow CAISO regulations, while customers interconnecting to low-voltage, local distribution facilities and selling wholesale follow a wholesale distribution tariff (generally established by the utility), and customers interconnecting to

low-voltage, local distribution facilities and selling to a California load-serving entity (LSE) such as a utility follow Rule 21 as prescribed by both the state and the relevant utility [6].

The overall role of these grid infrastructure owner-operators is to serve their customers reliably and responsibly, meaning they must, to the best of their ability, prevent grid disturbances (e.g., outages, unacceptable voltage fluctuations) and prevent any sudden price increases or unfair price differences across their customer base [7]. This consideration is relevant to interconnection projects because the introduction of DERs at certain interconnection points and any associated subsidies may lead to shifting prices that disproportionately affect certain populations; transmission and distribution line owner-operators must explore fair pricing models that incorporate DERs [7].

Regulations and requirements may be implemented at the federal, state, or other level (e.g., at the level of the utility or other AHJs). Authorities that publish these regulations are responsible for regularly reviewing and updating these documents as needed, to ensure they align with the most current objectives and available knowledge and resources. There is also some amount of responsibility at each regulator's level to enforce these requirements; for example, the utilities reviewing interconnection projects must use compliance with these regulations as a requirement for approval.

2.1.2. DER Developers

DER developers have the responsibility to design their systems, which includes making decisions for DER system siting, capacity sizing, interconnection point, and electrical management (e.g., prevention of technical malfunctions). They are responsible for understanding the regulations with which they must comply and implementing the design and/or operational protocols that would enable compliance. The DER developer has the role of applying to the utility for an interconnection project.

2.1.3. Regulators

As mentioned, there are regulators at higher levels, such as federal and state agencies, that also mandate certain requirements for interconnection projects. Regulations tend to flow down; federal entities such as the Federal Energy Regulatory Commission (FERC) largely regulate interstate transmission line interconnection activities while state level entities like public utility commissions (PUCs) generally provide requirements for more local projects and regulations that must be followed by the smaller-scale utilities working to incorporate the interconnection projects. Like the utility regulators, these entities are also responsible for keeping interconnection requirements up-to-date and enforcing them. Regulators at local (e.g., municipal) levels may be considered the relevant AHJ responsible for enforcement of technical interconnection requirements. AHJs are often responsible for actions that cannot be conducted by utilities, such as allocation of permits [6].

2.1.4. Standards Organizations

Many of these regulators use widely accepted standards, such as those published by the Institute of Electrical and Electronics Engineers (IEEE) and Underwriters Laboratories (UL). The writers of these standards are responsible for regularly and consistently reviewing and updating these documents as needed, based on factors including technical advances in industry and evolving scientific understanding.

Higher-level regulators and standards organizations and their requirements have a large impact on the feasibility of interconnection project implementation. If these regulators are interested in

allowing DW resources to connect to the grid, then it is beneficial for them to understand the current state of existing barriers and challenges to interconnection customers (ICs) in the electrical grid system and, to the best of their ability, ensure that their requirements are not prohibitive.

2.2. Technical Considerations

2.2.1. Challenges Relating to Non-Dispatchable and Intermittent Energy Generation

Wind energy is susceptible to certain challenges due to its non-dispatchable and intermittent nature of energy generation. These characteristics can cause potential issues when DW resources are connected to the main grid, including sizing capacity unpredictability and unintentional islanding.

2.2.1.1. Capacity Sizing and Backfeeding

Even though rigorous wind resource assessments and site studies are industry-accepted best practices for determining effective DW development locations and design parameters, wind is still an intermittent resource with some level of forecasting uncertainty [8]. Even if DW system capacity sizing is optimized for the general wind patterns of the site, there may still be times of the day when the electricity generated by the DW resources exceeds the electricity demand. This situation can cause issues like backfeeding, which is a phenomenon during which electricity can flow bidirectionally along a power line rather than only in the direction from the source to the load, and it may occur when electricity generation exceeds demand at a given moment [9]. Bidirectional flow is expected for power systems with intermittent electricity generation sources, but many power systems, especially the lower-voltage feeder networks, are not designed for electricity flow in both directions, and could be damaged as a result [9], [10].

It is possible to upgrade grid lines and ancillary equipment to be able to support backfeeding, but these upgrades are costly. Currently, for some state and utility regulators, there is a precedent for passing the costs of making upgrades to distribution or transmission-level equipment to the first DER project applicant requesting interconnection with the grid [11]. Often, these costs end up being prohibitively high and prevent completion of the project. Another grid-level mitigation that could prevent backfeeding is the installation of anti-islanding devices like inverters at the point of interconnection (POI) [12]. However, this upgrade, as well as the upgrades of grid infrastructure that may be needed to support these devices, may also be costly and difficult or impossible for the developer to handle. Cost-sharing processes, which are discussed later in this report, can help make line upgrades for backfeeding protection more affordable.

Another option for preventing backfeeding is to incorporate energy storage into the DW system, which could provide arbitrage capabilities at times when energy generation and supply are misaligned [13]. From a technical standpoint, incorporation of energy storage by the DER developer could prevent backfeeding, but it is unclear whether doing so would acceptably comply with current interconnection regulations, which have yet to explicitly include energy storage technology requirements [14]. Management practices that incorporate curtailment into the operation of the DW system could also prevent backfeeding [10].

2.2.1.2. Unintentional Islanding

DER systems also have the potential to create unintentional islanding (UI) situations, which involve parts of the system remaining energized during a time of electrical isolation from the utility system [15]. Potential resulting fluctuations in voltage and frequency can be damaging to grid equipment

and harmful to system operators when the system is expected to be de-energized [7]. UI can degrade power quality within the energized island and prevent restoration of electrical service [16].

The risks of UI can be reduced through detection and mitigation actions. On the side of the DER generator, monitoring of voltage, current, frequency, and/or impedance through passive or active techniques can be used to detect UI so it can be managed properly [15], [17]. Anti-islanding devices and methods can be utilized to reduce UI risks [18], whether by deenergizing the island or by protecting the system equipment from damage from the island [19]. Anti-islanding devices and methods include direct transfer trips (DTTs), which prevents UI through isolation of the DER when the substation breaker is opened, voltage supervisory reclosing (VSR), which turns off electric power in a circuit when an energized island forms and tests the line voltage before allowing reclosing of the circuit, and extended time delay reclose, which provides a delay between formation of the energized island and reclosing of the circuit [19], [20].

2.2.2. Hardware and Infrastructure Challenges

2.2.2.1. Vulnerability to Extreme Weather

Wind turbines themselves can be vulnerable to extreme weather conditions and natural disasters, which can increase the risks for DW project developers in certain areas [21], [22]. For example, heavy precipitation could cause impacts including leading edge erosion and blade bending, and high winds could also result in erosion, as well as turbine blade throws or even structural collapse. Flooding could destabilize the foundation of the wind turbine. Extreme heat could cause reduced performance of the lubrication and hydraulic system, while extreme cold could result in icing and turbine blade breakage. Each of these mentioned impacts could lead to reduced performance and output, if not complete malfunction of the turbines. The risk of different natural disasters depends on the intended location for the DW system. Regardless of which extreme weather events are relevant to a certain project, agricultural areas tend to be isolated, and accessing resources like maintenance personnel or parts to repair the turbines after damage occurs is costly and time-consuming. DW system owner-operators may consider intentional design and/or operational procedures that can reduce the risk of wind turbine damage from natural disasters or extreme weather event. First, the siting assessment at the very beginning of the project, even before system design begins, should take into consideration the potential impacts from events such as flooding, landslides, sinkholes, and earthquakes [21]. Second, using wind turbine blade coatings, tapes, or shields can be used to prevent erosion while blade feathering and curtailment best practices should be incorporated into operations to prevent precipitation and wind impacts [21]. Finally, thermal management such as ventilation, cooling, deicing, and heating systems can prevent declined or performance or complete shutdown due to extreme heat, cold, and icing [21].

2.2.2.2. Infrastructure Status

In the cases of many rural feeder lines, there is currently insufficient real-time monitoring needed to generate the types of insights needed to plan the addition of DER energy injection into the grid [7]. This information is vital for development of a DER, for design choices such as capacity sizing, interconnection locations, and energy management plans.

Grid network infrastructure upgrades may also be needed when planning deployment of an interconnected DER system, including to enable safe electrical interconnection of the DW project to the grid and/or to comply with regulations. However, equipment and grid infrastructure upgrades may be specifically prohibitive to DW project applicants looking to develop in agricultural areas.

Agricultural areas tend to be rural, where the existing grid infrastructure is often not ideal for easy development of interconnected DERs. Many power lines in rural areas are long and nonredundant, which provides limited options for testing new types of interconnected equipment and still ensuring resilience and reliability of electrical service [7]. In general, the electrical infrastructure in rural areas tends not to be updated or compatible with the newest industry hardware that may be required to safely interconnect DW resources to the grid, or that may be required by regulatory entities. This hardware may include technologies enabling control of the system, such as DER management systems (DERMS) and smart inverters.

2.2.3. Workforce-Related Challenges

Some grid networks do have advanced equipment like smart meters installed, but are often unable glean any useful conclusions from the ample data because of a lack of access to tools and/or staff to perform the analytics [7]. Analyzing the current state of the electrical system is beyond the bandwidth of many operators because of resources needed, including training, technical expertise among the staff, and operational time to conduct the analyses [7], and adding a variable energy generation source adds even more analytical burden.

2.2.4. Challenges Relating to Information Availability

Basic information about the existing transmission and distribution line infrastructure is needed for DER developers to make informed decisions about their system designs, including considerations like interconnection points, capacity sizing, and cost, especially because wind energy generation has such unique impacts on the grid due to its variable and intermittent characteristics. Information like the distribution of existing interconnected projects along the grid and the sections of the grid that might require more updates to support DER interconnection could help make these decisions, but this information is often not disclosed to the public or even to DER developers applying for interconnection projects [14]. Generally, utilities are not required to disclose this information, but state or federal regulators could help require the release of relevant information such as substation generation capacities, currently scheduled upgrades, and potential constraints, either to the general public or to DER applicants [14].

2.3. Regulatory Considerations

As mentioned, there are several standards publishers and regulatory stakeholders in charge of maintaining, updating, and enforcing requirements for projects with grid interconnections. Implementing these requirements may be difficult or in some cases even prohibitive to DW projects, especially in rural contexts.

2.3.1. Regulations Adoptable by Authorities Having Jurisdiction

2.3.1.1. IEEE 1547-2018: IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces

IEEE 1547-2018 sets industry standards for interconnection and interoperability of DERs with existing EPS for distribution systems (DER interconnection to transmission or networked sub-transmission systems is under the purview of IEEE 2800-2022) [2]. A large part of IEEE 1547-2018 is the requirement for UI protection – the DER must have the capability to detect and trip any UI events within 2 seconds and then intentionally stay disconnected for a 5-minute return-to-service

delay time [15]. Type testing of the devices that perform the tripping capabilities is also required. Other technical requirements in IEEE 1547-2018 include voltage regulation, area EPS grounding integration, regulated response to abnormal conditions in the area EPS (e.g., voltage or frequency disturbances or faults), power quality requirements, islanding standards, interoperability protocols, and testing and verification requirements [2].

IEEE 1547-2018 is technology-agnostic and applies broadly to DERs, so the applicability of some of the specifications and requirements to different technologies is based on specified performance categories. The intent of the document is to provide interconnection standards inclusive to many DER types. However, in practice, some DW developers have reported that the non-specificity of technologies that end up requiring compliance with this standard causes wind to somewhat be overlooked compared to other technologies like solar, for which compliance tends to be logistically simpler [23]. For example, IEEE 1547-2018 power support requirements are specifically difficult to comply with for DW because of the intermittent, variable, and reactive power output [23].

2.3.1.2. IEEE 1547.1-2020: Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces

IEEE 1547.1 provides testing requirements for devices to verify compliance with IEEE 1547 standards [24]. These tests include ambient condition testing (e.g., temperature stability) as well as electrical testing (e.g., response to voltage and frequency disturbance or abnormality, interconnection integrity, limitation of DC injection, overvoltage contribution limitation, information monitoring) [25]. Some of these tests are used to verify UI functionality of anti-islanding devices [15].

Like IEEE 1547, the tests in IEEE 1547.1 are written to be technology-agnostic, but, again, some of the tests are specifically difficult for DW to comply with. Because the test is not technology-specific, the testing experiments do not incorporate DER power sources or their associated dynamics [23]. For example, IEEE 1547.1 testing for out-of-range frequency and voltage requires tripping within 10 seconds, but the intermittency and variability of wind resources would require advanced converter capabilities to achieve this standard [23]. Thus, when AHJs adopt IEEE 1547 standards, DW development may be stalled by the time it takes for industry original equipment manufacturers (OEMs) to develop compliant devices and get them to market. Having a subset of IEEE 1547 and 1547.1 recommendations specific to wind energy generation could provide more realistic metrics for DW while upholding reasonable and safe standards [23].

2.3.1.3. UL 1741: Standard for Safety – Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources

UL 1741 is meant to supplement IEEE 1547 with for project aspects including construction, electrical design and performance, and risk mitigation and personnel protection [26]. The document includes testing for electrical devices such as charge controllers, AC modules and their integrated electronics, and shutdown systems [26].

Supplements A and B to this document (also referred to as UL 1741 SA and UL 1741 SB, respectively) provide standards for grid support utility-interactive components, namely inverters and converters. The UL 1741 supplements are sometimes specifically required by regulators or AHJs. UL 1741 SA includes test procedures and requirements for anti-islanding protection devices, low and high voltage ride-through, low and high voltage frequency ride-through, ramp rate, power factor, and volt/var mode [26]. UL 1741 SB explicitly builds on the IEEE 1547-2018 and IEEE

1547.1-2020 standards for inverters and converters. The testing used in UL 1741 includes testing in manufacturing, production line, and type testing contexts [26].

2.3.1.4. IEEE 2800-2022: IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems

As mentioned, IEEE 2800-2022 is relevant to interconnection of projects with transmission and network sub-transmission infrastructure. Many of the general characteristics and tests discussed in this document are similar to those discussed in the aforementioned standards; IEEE 2800-2022 is also used to test inverter-based resources and their capabilities for aspects like voltage and frequency ride-through, and active and reactive power control, for a different system capacity than the IEEE 1547 suite [27].

2.3.1.5. Takeaways of Standards to Agricultural Contexts

Compliance of grid equipment with IEEE, UL, and other industry standards is challenging for DW, largely because DW is treated like other generation equipment and therefore the unique challenges and operating conditions are not necessarily practically addressed in industry standards. For example, the IEEE 1547 testing standards were not developed using a specific power source, and compliance for wind energy projects tends to be disproportionately prohibited by these test requirements because wind energy is variable than most other generation sources. Therefore, there is often a large time delay between AHJ adoption of a testing standard and the time at which a DW developer has access to compliant equipment from an original equipment manufacturer (OEM). Therefore, development of device standards in terms of performance and testing requirements may benefit from research into more realistic and practical DW-specific standards, which would be the responsibility of standards authors and publishers, although individual AHJs that adopt the IEEE and UL requirements as they currently may also be able to customize regulations and deviate from these standards.

2.3.2. Federal Regulations

2.3.2.1. FERC Standard Interconnection Agreements for Small Generators

This FERC document covers terms and conditions for interconnection of small generating facilities (capacities up to 20 MW) with a main transmission system, including requirements for equipment inspection and testing, operational dates for the generator, cost responsibilities for interconnection facilities, distribution upgrades, and network upgrades, billing frameworks, and liability information [28].

2.3.2.2. FERC Standard Interconnection Agreements for Large Generators

This document covers terms and conditions for interconnection of large generating facilities (capacities over 20 MW). Some of the agreements are similar to the ones used in the small generator agreements. The agreement, described in Appendix 6, includes project aspects such as the term limit for the interconnection agreement, regulatory filing, construction options, equipment procurement options, permits, taxes, testing and inspection, metering, communications, operations, maintenance, performance requirements, legal considerations, and information access [29]. This document classified projects based on the end use of the generated power; in this context, DW would count as an energy resource interconnection service, which would allow delivery of power from the generator to the transmission system as it is generated and energy needs arise [29].

Appendix 5 of this document is also referred to as the Standard Interconnection Agreements for Wind Energy and Other Alternative Technologies. Appendix G described interconnection requirements for a wind generating plant, including low voltage ride-through capability, compliance with reactive power design criteria, and supervisory control and data acquisition (SCADA) capability [30].

2.3.2.3. FERC Order 2222: Participation of Distributed Energy Resource Aggregations in Markets Operated by Regional Transmission Organizations and Independent System Operators

FERC Order 2222 is largely an economically driven order meant to support market competition [31]. The document establishes DER aggregators, who have a role to aggregate DERs for participation in regional transmission markets. This order allows these DER aggregations to directly participate in wholesale markets [31].

2.3.2.4. FERC Final Rule

The FERC Final Rule was established in 2023 to streamline interconnection application processes [32]. One of the major proposed changes was to implement cluster studies, which are studies of multiple ICs applying for interconnection at the same point; cluster studies make projects more attainable cost-wise and timing-wise because costs can be shared among developers rather than having the first applicant at an interconnection point be responsible for all the costs, and because cluster studies can reduce waiting time for other interconnection projects in the queue [32].

These FERC-published best practices are meant to facilitate and streamline interconnection processes, which is also a goal of state-level, municipal-level, and utility-level regulators. This rule explicitly states that it “is not intended to divert or slow the potential progress represented by [transmission provider efforts working towards addressing interconnection queue management challenges]” and that this rule is not meant to contradict or ignore efforts of transmission operators in relation to previous interconnection queue challenges [32]. The inclusion of this discussion in the Final Rule shows that, though the overlap between different regulator roles and responsibilities can be confusing, overall, the relationship between regulators at different levels is meant to be synergistic rather than competitive, and the multiple documents at various regulatory levels that exist tend to repeat similar requirements rather than contradictory ones.

2.3.2.5. Takeaways of Federal Regulations for DW in Agricultural Contexts

The federal regulations discussed here are largely related to the application process and economic outcomes of interconnection projects rather than regulatory or technical aspects. These federally published documents describe best practices and regulations for the sale of electricity. Both wholesale markets and utilities are possible customers for agricultural DW, which can be a range of capacity sizes and in a range of locations. Similarly, DW in agricultural contexts may be classified by FERC as small or large generators.

2.3.3. State-Level Regulations

Many states’ PUCs establish some form of state-level grid interconnection regulation. In this report, the established guidelines for grid interconnection regulation are described for California and New York. Interstate interconnection procedures are also discussed.

2.3.3.1. California

California Electric Rule 21 (Generating Facility Interconnections), originally published in 1982 and updated periodically since then, is the main interconnection requirement enforced by the California Public Utilities Commission (CPUC) [33]. One of the major updates to this document was Decision 14-12-035, which requires the installation of smart inverters compliant with UL 1741 SA [34]. Decision 19-03-013 recommends but does not require the use of smart inverters to replace existing inverters that have reached the end of their lifetime [35]. Decision 20-09-035 discussed the recommendations of one working group related to using Integration Capacity Analysis (ICA) capabilities to gather information about the grid that could be released to the public to inform decisions about interconnection points (e.g., current capacities for new DERs at different interconnection points, planned upgrades) [36].

As mentioned in the discussion about stakeholder roles and responsibilities, there is no generalized way that regulatory entities at different levels interact, but specific cases can help provide context. In California, the CPUC established Rule 21 as a broad regulatory framework for grid interconnection projects but largely confers responsibility for application-specific interpretation to the IOUs, who are given the flexibility to establish utility-level interconnection procedures and requirements within this framework. For example, the IOUs are responsible for releasing updated and publicly accessible ICA maps of the grid infrastructure under their purview [36] and responsible for determining other interconnection logistics like fair cost-sharing of grid-level upgrades [37].

The CPUC is responsible for ensuring that the IOUs are carrying out Rule 21 as was intended. One example of this role is evident in Decision 20-03-035, when the CPUC found that the implementation of Rule 21 by one of the IOUs was inconsistent with the CPUC intention, and required a change in the utility's documentation of its version of Rule 21 [36].

Additionally, the CPUC organizes working groups to address the gaps, interconnection barriers, and needs brought up by utilities, who are closer to the customer and understand interconnection challenges in practice. For example, current and past working groups have been tasked with researching topics such as UI and ICAs to inform Rule 21. The CPUC also mobilizes the utilities to conduct certain actions required to update the overall Rule 21 requirements. For example, in Decision 21-06-002, the challenge of conferring upgrade costs and burdens for distribution-level interconnection to the interconnection applicant was brought up to the CPUC, which concluded with the utilities being given the responsibility of conducting cost upgrade studies that would be needed to address this change at the level of CPUC [38].

California Rule 21 also includes a Fast Track application process for certain customers with small nameplate capacities (maximum 3 MW when interconnecting to SCE and PG&E and maximum 1.5 MW when interconnecting to SDG&E) or for net-metered and non-exporting generating facilities, to streamline the process when more complex reviews or studies are not needed [39]. This option can greatly reduce the time between application and operation of the DER – SDG&E estimates that fast track applications in its service territory are expected to take between several months up to a year or two, while other applications are expected to take several years, especially if upgrades are needed [6].

2.3.3.2. New York

Interconnection projects in New York State are mainly beholden to the requirements set forth in the Standardized Interconnection Requirements (SIRs) developed by the New York State Public Service Commission; one example of these requirements is the New York State Standardized

Interconnection Requirements and Application Process for New Distributed Generators and/or Energy Storage Systems 5 MW or Less Connected in Parallel with Utility Distribution Systems [11]. This document requires inverter-based systems with capacities of 50 kW to 300 kW to be certified and tested in accordance with the most recent versions of UL 1741 and UL 1741 SB [11].

The New York State SIRs also establish cost-sharing models for infrastructure upgrades required for interconnection of a project being proposed. For example, for transformers and other general safety equipment, costs are allocated based the type and capacity of the energy generation source planned for interconnection with the grid, and whether the customer requesting interconnection is a residential or non-residential customer. For example, if shared infrastructure upgrades are required to accommodate the interconnection of a wind energy generator with a total rated capacity up to 25 kW, any customer, whether residential or non-residential, can be charged up to \$750 [11]. The costs for larger-scale wind energy projects between 25 kW and 2 MW are determined by the utility [11].

For farm wind projects with rated capacities between 25 and 500 kW, there is a \$5,000 maximum cost to the IC [11]. The DW developer may be required to bear more of the costs related to the upgrades for the feeder infrastructure, depending on the project's rated capacity in comparison to the feeder capacity. For example, if feeder line upgrades are required, farm wind customers must pay half or all of the costs if their generation equipment nameplate rating is less or greater than 20% of the feeder rated capacity, respectively [11]. This rule also applies to residential and non-farm non-residential customers. The utility may require that a Coordinated Electric System Interconnection Review (CESIR) be conducted to determine whether the interconnection project is allowable. The CESIR can include a review of required transmission and safety equipment as well as necessary feeder upgrades. The CESIR costs related to transmission and safety equipment counts towards the \$5,000 maximum cost, but the IC must pay half or all of the CESIR costs related to the feeder upgrades depending on whether the generation equipment nameplate rating is less or greater than 20% of the rated capacity of the feeder [11].

In terms of sharing costs between different interconnection project developers, the NYS SIRs stipulate that, for upgrades costing over \$250,000, the first project that requires an eligible upgrade pays the whole cost upfront, and subsequent projects that also need and benefit from that upgrade will reimburse the developer of the initial project and earlier projects that have already paid a reimbursement, to distribute costs evenly among the ICs over time [11].

2.3.3.3. Interstate Model Interconnection Procedures

The Interstate Renewable Energy Council (IREC) has published best practices for state-level DER interconnection rules and procedures, as a compilation of current state interconnection application processes and recommendation for streamlined application review and project completion [40].

The IREC Model Interconnection Procedures include the ability of interconnection applicants to request a pre-application report with information, including substation or bus capacity, export capacity interconnected to the substation or bus, queued export capacity, available capacity, substation voltage, circuit distance between the proposed site and the substation, peak line load, protective device characteristics along the line, electrical dependencies or past issues that have occurred at the POI [40]. For the application process itself, the recommended procedures involve, first, the application by the IC. Then the regulator is responsible for the review of the application via either a screening process for smaller-capacity DERs, a fast-track process for medium-sized DERs, or a detailed study process for large or complex DERs [40]. Notable recommended best practices in

this document include adoption of IEEE 1547-2018 inverter requirements and UL 1741 SB test performance [40].

While the best practices and procedures described in this document are discussed at the state-level, the procedures seem mostly standardized among regulators, whether they are at the state-level or the utility-level.

2.3.3.4. Takeaways of State Regulations for DW in Agricultural Contexts

Elements of the interconnection requirements from state regulators in California and New York, as well as the relationship between the state regulators and utilities, can provide valuable lessons learned when attempting to apply a more comprehensive regulatory framework for DW interconnection in agricultural contexts.

Both California and New York have requirements for devices like inverters to be compliant with industry standards, which can be logistically challenging in agricultural contexts for aforementioned reasons, including the lack of redundancy in infrastructure that could be used for testing inverter implementation without compromising service to grid customers, or the lack of resources and operator availability to add on installation and testing tasks [7]. Recommendations, such as the one in Rule 21 regarding the optional replacement of existing inverters with smart inverters, can help provide guidance to grid operators working on interconnection projects while not imposing potentially prohibitive requirements.

The cost-sharing models described in the New York State SIRs can also provide a foundation and starting point for improving the affordability of interconnection projects for DW developers. Cost-sharing models based on project attributes like generator technology, capacity, and application (e.g., small-scale, large-scale, farm) can help relieve burden from the first individual IC. Nonetheless, the first developer applying for interconnection at a specific point must pay needed upgrade costs upfront, which could still be prohibitive to the project.

Fast track application options for smaller or non-exporting generators, such as the one provided in California through Rule 21, can help improve approval times and reduce waiting time in the interconnection queue, which is another observation that ICs have made.

Finally, both California and New York demonstrate how state-level regulators can work with utilities to establish and enforce interconnection rules. Having the state regulator work closely with a utility can help bring attention to compliance challenges, since the utility can see which barriers are in place in practice. Having a model where the state regulations are broad and the utilities are responsible for writing requirements most relevant to their needs can help ensure that the requirements are being maintained reasonably, partially based on real-world feedback and observations. When state regulators mandate that utilities are responsible for determining certain project aspects such as cost-sharing rates, more flexibility in costs is possible and utilities who are having direct conversations with the customer can be informed when setting electricity rates.

2.3.4. Grid Infrastructure Operator Regulations

Grid infrastructure operators such as utilities play a role in developing and conducting application procedures, as well as creating specific technical requirements for interconnection, which may include interpreting regulations flowed down from the state or federal level (e.g., California utilities such as PG&E and SCE each have their own version of California Rule 21).

2.3.4.1. San Diego Gas and Electric (SDG&E)

SDG&E is a utility located in California, so it implements its own version of Rule 21. Accordingly, the utility provides ICA maps to the public as well as the ability to purchase more detailed information about an interconnection point of interest through a pre-application report, which may include information like substation bus capacity, numbers of voltage-regulating devices on the line between the proposed site for the project and the substation, and the peak line load estimates [6]. These details may help project applicants make more informed decisions about project siting, interconnection location, generation capacity, and other design aspects.

In accordance with California Rule 21 application decisions, SDG&E has different application options for smaller-scale projects that can be reviewed more quickly through a fast-track process, and larger-scale or more complex projects that may require further study and/or upgrades. For non-fast-tracked projects, SDG&E clusters project applications for the same interconnection point into a single study [6], which can reduce waiting time in the interconnection queue for many applicants, and allows customers to share upgrade costs that might otherwise be the responsibility of the first interconnection applicant [14].

SDG&E requires inverter-based generation projects like wind generators to be compliant with standards including IEEE 1547, IEEE 2800-2022, and UL 1741 [41].

2.3.4.2. Pacific Gas and Electric (PG&E)

PG&E is also a California-based utility, so its requirements are very similar to those of SDG&E, since both have their own versions of Rule 21. PG&E also has options for fast-track and group study applications and provides a pre-application report at the request of the applicant [42].

PG&E also specifies requirements for standardized equipment. For example, projects at a POI with a voltage lower than 50 kV are required to have equipment certified to IEEE 1547-2018, whereas projects at a POI with any higher voltages are beholden to requirements specified by the North American Electric Reliability Corporation (NERC) and CAISO in the Distribution Provider's Interconnection Handbook [42]. Different tests (e.g., harmonic distortion, anti-islanding, and constant reactive power) are required to follow different standards, including UL 1741, UL 1741 SA, UL 1741 SB, and IEEE 1547.1 [42].

2.3.4.3. National Grid

National Grid is a utility based in New York State and Massachusetts; its Supplement to Specifications for Electrical Installations is relevant for electrical distribution systems in Upstate New York and Massachusetts as well as transmission systems in Upstate New York, Massachusetts, New Hampshire, and Vermont [43]. These guidelines, like the ones published by the aforementioned utilities, include compliance, testing, and certification standards for interconnected DER equipment. For example, National Grid requires inverter systems to be compliant with IEEE 1547 and certified and tested by UL 1741 SB, partially to provide anti-islanding protection [43]. This utility also stipulates additional anti-islanding requirements for DER ICs, such as screenings, recloser implementation, and risk of islanding (ROI) studies, depending on generation capacity [43].

Like the California-based IOUs, National Grid offers a pre-application process to provide information to an interconnection applicant about the utility system and its relationship to the proposed project site [43].

2.3.4.4. Generation and Transmission Line Operators

Generation and transmission (G&T) providers also work with the distribution operators, and on occasion will require all-requirements contracts (ARCs) for those distribution operators and energy cooperatives. Often, these requirements are long-term (on the order of several decades) and may prevent individual customers, whether residential or non-residential, from developing their own DER projects [7]. Removing ARCs or making requirements more supportive of DER development by distribution line owner-operators could help facilitate development of DW, but these changes would take time since ARCs must be observed until the contract period is over, and G&T operators with existing ARCs may not have reason from a business standpoint to change those requirements as contracts expire. Possibly, regulators at state, federal, or regional levels who may have an interest in DW development to further other goals like energy resilience and generation technology diversification may be able to impose rules regarding ARCs to make them more amenable to DER development.

2.3.4.5. Takeaways of Utility-Level Regulations for DW in Utility-Level Case Studies to Agricultural Contexts

Utilities are responsible for providing pathways for project applicants to receive information about the electrical system that can help inform the design and operation of the project, including selection of a reasonable interconnection point and realistic generation capacities, as well as an idea of potential upgrades that might be needed that could affect the cost and timing of the project. This information is valuable to interconnection projects in all contexts, including agricultural DERs.

As described, some of the standardized certification and testing requirements specified here can be difficult to conduct in agricultural contexts because of a lack of resources, little margin for error because of a lack of equipment redundancy, and installation and upgrade costs. Utility practices that include cost-sharing schemes like clustered or grouped interconnection studies can help distribute upgrade costs among DER applicants who would all benefit from implementation of the grid upgrades and can make it more feasible for compliant devices to be installed at interconnection points to enable further DER development at that POI.

In addition, some contracts at the level of electrical infrastructure owner-operators, such as ARCs between G&T and distribution operators, can make it difficult to develop DW or other DERs. ARCs are not used everywhere across the country, so they may not be financially necessary for G&T operators; however, there may be no motivation for G&T operators with existing ARCs to change the requirements. Thus, governmental regulations may play a role in shaping future contracts between owner-operators of generation, transmission, and distribution systems and making them less prohibitive to DER development.

3. CONCLUSIONS

The development of DW in rural contexts currently faces some technical and regulatory challenges that may be addressed by various stakeholders currently involved in electrical grid infrastructure ownership, operation, and regulation. One major concern is that interconnection of DW to current utility distribution and/or transmission lines may require costly and time-consuming upgrades of grid infrastructure due to both the variable and intermittent characteristics of wind energy generation and the need for compliance with various industry standards. Currently, stakeholders who oversee interconnection applications and upgrades (typically utilities) have different models for charging ICs for these costs, including having the first IC pay for the whole upgrade, having the first IC pay for part of the upgrade, or having the first IC pay for the whole upgrade but get reimbursed by subsequent ICs. In many cases, these costs have been prohibitive for the responsible IC and have prevented the development of the DER project as well as implementation of grid infrastructure upgrades necessary to interconnect any future DER project.

Grid infrastructure owner-operators and regulatory entities may have the information available and the needed expertise to identify and address the discussed barriers to DW interconnection and development. For example, utilities and G&T operators create their own cost-sharing models for DER development and integration with their equipment. Regulators, including grid infrastructure owner-operators (e.g., utilities) and state or federal entities (e.g., PUCs, FERC) may also continue to have a role in DER development and interconnection through their regulatory purview.

Additionally, many regulators and AHJs require compliance with technology-agnostic industry standards, which may require substantial financial, technical, and time resources. Standards organizations such as IEEE and UL, as well as regulators like PUCs, can form working groups to understand technical needs and specifications of wind energy generation with the purpose of creating subsets of standards that can reduce barriers to implementation. State, federal, and utility-level regulators who currently require compliance with these industry standards can also review their regulations with a focus on DW and address barriers to entry using these requirements.

A general summary of stakeholder roles and responsibilities and an overview of the barriers to DW adoption discussed in this report are provided in the following tables.

Table 3-1. Summary of Stakeholder Roles and Responsibilities in DER Development

Stakeholder	Examples	General Roles and Responsibilities
Grid Infrastructure Owner-Operators	<ul style="list-style-type: none"> • ISOs/RTOs • IOUs • Member-owned utilities / energy cooperatives 	<ul style="list-style-type: none"> • Regular updating of regulations / requirements • Enforcement of compliance with regulations • Review and approval/denial of interconnection project applications
Regulators / AHJs	<ul style="list-style-type: none"> • FERC (federal) • PUCs (state) 	<ul style="list-style-type: none"> • Regular updating of regulations / requirements • Enforcement of compliance with regulations • Physical/electrical system design
Standards Publishers	<ul style="list-style-type: none"> • IEEE • UL 	<ul style="list-style-type: none"> • Regular updating of standards to ensure implementation of safe systems

Stakeholder	Examples	General Roles and Responsibilities
DER Developer	<ul style="list-style-type: none"> Private companies Non-profits 	<ul style="list-style-type: none"> Physical/electrical system design Operational protocol establishment Application for interconnection Compliance with regulations (particularly utility regulations)

Table 3-2. Summary of Technical and Regulatory Challenges in DER Development.

Challenge or Barrier to Adoption	Impacts	Suggestions	Involved Stakeholders
TECHNICAL CHALLENGES			
Sizing capacity uncertainty	<ul style="list-style-type: none"> Backfeeding Damage to power lines not meant to convey bidirectional power flow 	Upgrade relevant power lines to handle bidirectional flow	DW system owner-operator, grid infrastructure owner-operator
		Incorporate anti-islanding devices at POI	DW system owner-operator, grid infrastructure owner-operator
		Incorporate energy storage into DW systems	DW system owner-operator
		Incorporate curtailment scenarios related to energy generation and usage into DW management	DW system owner-operator
Unintentional islanding	<ul style="list-style-type: none"> Fluctuating frequency and voltage Safety hazards for workers Grid equipment damage 	Incorporate anti-islanding devices at POI	DW system owner-operator, grid infrastructure owner-operator
Natural disasters or extreme weather	<ul style="list-style-type: none"> Damage to wind turbines, resulting in both downtime in energy generation and additional costs for repair 	Harden wind turbine components based on expected extreme weather events at the site	DW system owner-operator
		Incorporate curtailment scenarios related to high-wind, precipitation, and other storm scenarios into DW management	DW system owner-operator
Aging transmission and distribution infrastructure and costliness of upgrades	<ul style="list-style-type: none"> Grid infrastructure upgrade costs are often passed to the DW project applicant and can be prohibitively high 	Plan grid infrastructure upgrades proactively to distribute costs among utility ratepayers and/or future DER applicants	Grid infrastructure owner-operator, DW system applicant

Challenge or Barrier to Adoption	Impacts	Suggestions	Involved Stakeholders
Nondisclosure of critical grid information to the public or project applicants	<ul style="list-style-type: none"> Project applicants often select grid interconnection points that may not be optimal for their project, which can result in high costs or other nonoptimal project parameters 	Improve transparency of grid parameters relevant to interconnected DW projects	Grid infrastructure owner-operator, state government
REGULATORY CHALLENGES			
Some standards and regulations require grid power system equipment upgrades or installation of specific devices (e.g., anti-islanding devices, smart inverters)	<ul style="list-style-type: none"> Grid infrastructure may not be upgraded enough to support newer standardized equipment Costs of grid upgrades are currently often passed to the DW project applicant and can be prohibitively high 	Plan grid infrastructure upgrades proactively to distribute costs among utility ratepayers and/or future DER applicants	Grid infrastructure owner-operator, DW system applicant
		Re-evaluate requirements for compliance with certain standards	Regulatory bodies (e.g., federal and state governments), IOUs
		Re-evaluate inclusion of recommendations that are prohibitive or difficult to comply with in existing standards, based on DW developer feedback	Standards organizations (e.g., IEEE, UL), DW system owner-operators
All-requirements contracts are required by some generation and transmission providers	<ul style="list-style-type: none"> Contracts may prohibit generation on the distribution side, which may limit DW or general DER development 	Re-evaluate needs for all-requirements contracts	Generation and transmission operators
		Provide regulatory guidance or requirements for contracts between G&T organizations and distribution line owner-operators that are more inclusive of DER development	Regulatory bodies (e.g., federal and state governments)
Interconnection processes are not streamlined in all states	<ul style="list-style-type: none"> Interconnection application process is time consuming 	Identify bottlenecks and use applicant feedback and regulatory design to streamline processes	State governments, DW system applicant

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