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PNNL-33053

Small Hydropower Interconnections: Best Practices

August 2022

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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1.0 Introduction

Small hydropower projects have been the predominant source of capacity growth of U.S. hydropower for more than a decade, and they present the most cost-effective and environmentally permissible avenues for hydropower growth (DOE 2016; Johnson et al. 2018). However, interconnection to electricity distribution and transmission grids is a persistent barrier due to cost surprises and schedule overruns. As a culmination to research into the status and requirements of small hydropower interconnection across the United States, this paper presents the best practices for setting interconnection standards that can improve the process for small hydropower developers. As part of the analysis, the interconnection costs are compared between small hydropower, solar, and wind.

The analysis of the small hydropower interconnection landscape across the United States was carried out by Pacific Northwest National Laboratory (PNNL) and Oak Ridge National Laboratory (ORNL) with support from the U.S. Department of Energy Water Power Technologies Office. The research team was guided by a Technical Advisory Group (TAG) and gleaned data from publicly available sources, such as the HydroSource database (ORNL 2020) and interconnection queues hosted by utilities, balancing authorities, independent system operators (ISOs), and regional transmission organizations (RTOs).

The results of this work are shared in a series of papers detailing the state of small hydropower in the United States ("Small Hydropower Interconnections: Small Hydropower in the United States"), the variety of state interconnection processes to connect power generators with the grid ("Small Hydropower Interconnections: State Interconnection Processes"), and an analysis of the interconnection processes ("Small Hydropower Interconnections: Analysis of Interconnection Processes"). In this, the final paper in the series, best practices for interconnection processes ("Small Hydropower Interconnections: Best Practices") are identified from the solar energy and distributed wind energy industries that are transferrable to small hydropower development. This information will help overcome barriers to future small hydropower development.

2.0 Best Interconnection Practices from the Solar Photovoltaic and Distributed Wind Industries

A literature review was conducted of grid interconnection in the solar photovoltaic (PV) and distributed wind industries to transfer knowledge about the best practices for interconnecting small hydropower below 20 MW. Parallels to small hydropower generation and grid interconnections were highlighted in three main areas: policies and procedures, cost, and associated upgrade components. In addition, interconnection costs associated with hydropower projects were compared to the solar PV and distributed wind industries.

2.1 Best Interconnection Practices from the Solar PV Industry

In 2020, 19 GW of solar PV was installed in the United States, with 4 GW installed for residential, commercial, and industrial customers, and the remaining 15 GW at utility scale (Feldman et al. 2021). Cumulatively, the United States operates 93 GW of solar capacity (Feldman et al. 2021). The proliferation of new solar PV capacity has driven many of the procedural and technologic improvements for distributed generation interconnection due to popularity, capacity, and volume of interconnection requests. As utilities and developers have improved processes to facilitate grid interconnection, processes which are not specific to the generator technology, best practices from the solar industry can be used to inform small hydropower generators.

2.1.1 Policies and Procedures

Improvements in policies and procedures to better facilitate solar PV interconnection can be grouped into categories of 1) cost certainty, 2) cost allocation of system upgrades, 3) early access to distribution system information, and 4) application process simplification.

Uncertainty about utility required interconnection costs makes it difficult for developers to accurately understand the economic viability of projects. Oftentimes, developers may not be made aware of expected costs until they have progressed well into the interconnection request process. Providing cost certainty earlier in the process can set developers expectations about costs and limit their financial risk.

If interconnection of a solar project triggers system upgrades, the project that pushes the distribution circuit beyond capacity limits is often liable for the costs. This method of cost allocation can place the financial burden for upgrades on a single project that happens to push the network over its hosting capacity. Under this system, one project pays for upgrades that provide benefits to other projects and customers. In response, FERC has issued an Advance Notice of Proposed Rulemaking on this subject, which targets the participant funding model for interconnection-related network upgrades (FERC 2021). Such an approach can help spread the costs for system upgrades across a wider number of new generators that will be using the circuits.

Information about the local grid hosting capacity, voltage, and substation equipment can help developers determine if a particular POI is suitable for their project. Pre-application reports summarize existing information from the utility and are available at a low cost from many utilities or authorities to help prospective developers evaluate a POI. Another useful tool is hosting capacity maps that provide developers easy access to information about the distribution lines and available capacity for interconnection. Hosting capacity maps are provided in a few areas across the country, including investor-owned utilities in California and by the Midwestern Independent System Operator.

Interconnection applications are the gateway transaction between the customer and the utility or authority who reviews and approves interconnection requests. A 2016 survey showed that solar developers find applications to be unclear, the process lacks enforceable timelines, and the authorities provide little supporting information about the interconnection process (Barnes et al. 2016). Best practices include having a central webpage with all relevant interconnection information, standardized application forms, application checklists, and additional reference materials. Online applications also improve the processing time, with 50 percent of online applications being processed in less than 2 weeks compared to 28 percent of manual applications (Makhyoun et al. 2014).

2.1.2 Interconnection Costs

Interconnection cost per installed capacity for solar projects is lower than small hydropower projects. Bird et al. (2018) surveyed 92 solar interconnection reports in the Western Interconnect and found the median cost to be $306,000 and the median nameplate capacity (rated output of the generator) to be 5–10 MW. In Section 4.0 of the previous report in this series (“Small Hydropower Interconnections: Analysis of Interconnection Processes”), a median cost of $200,000 for a median nameplate capacity of 2.45 MW was reported in a survey of 151 small hydropower projects across the United States.

2.1.3 Components and Infrastructure Upgrades

Analysis of solar interconnection requests by Sena et al. (2014) and Bird et al. (2018) found that 56 percent and 43 percent of applications, respectively, had effects on the distribution system that required system upgrades. Network expansion was the most common upgrade request (Bird et al. 2018), which requires building new circuits to connect the solar project to the distribution network. Other required upgrades are attributed to voltage impacts, grid protection impacts, or thermal impacts. Voltage impacts were common among the states reviewed in the reports—Arizona, California, New Mexico, and Colorado—but thermal and protection impacts were more commonly identified in California and New Mexico (Bird et al. 2018). See Appendix A for a description of voltage, thermal, and protection impacts from PV interconnection.

2.2 Best Interconnection Practices from the Distributed Wind Industry

Distributed wind typically consists of a small number of wind turbines deployed at residential, commercial, or industrial sites. They are often used to offset power consumption.

In the search for general best practices and interconnection documentation for distributed wind projects, a limited subset of interconnection information was available compared to small hydropower projects. Data were available from a single utility in the Northwest and another in New York. According to the data, wind projects under 5 MW are distributed and contain a comparatively small number of turbines. Most projects over this size are unlikely to be associated directly with end use and, thus, are classified as centralized wind farms. For projects with only one or two turbines, being able to connect at the distribution level and qualify for small generator interconnection criteria will substantially decrease the time and expense for interconnection (Daniels 2007).

A cursory review of available distributed wind system studies revealed that, similar to small hydropower projects, upgrades were largely dependent on capacity of the distributed generator, configuration of the distribution system, protection and control requirements, and data telemetry and control requirements. Table 1 contains upgrades and associated cost data for a set of distributed wind projects in the Pacific Northwest. More analysis of the distributed wind interconnection data is provided in 0.

Table 1. Interconnection Costs and Upgrade Categories for In-Service and Withdrawn Distributed Wind Projects in PacifiCorp Territory

	Capacity Size (MW)	0.0358	0.10	0.11	0.65	1.0	1.56	1.715	2.6	4.5	5.0
Upgrades Required	New/Upgrade Metering	✓	✓	✓					✓	✓	
	New/Upgrade Communications							✓	✓	✓	✓
	Relay Settings at POI	✓	✓					✓			
	Protective Device Equipment						✓				
	New Substation						✓				
	Substation Upgrades									✓	
	New Structures						✓				
	New Breaker										✓
	Disconnect switch/ reclosers								✓		
	Reconductoring								✓		
	Upgrade Line Equipment								✓		
Total Upgrade Cost (thousands)		**$7.50**	**$15**	**$12.70**	**$0**	**$0**	**$1,477**	**$92**	**$3,161**	**$1,072**	**$70.78**
Total Upgrade Cost ($Thousand/MW)		**$209**	**$150**	**$115**	**$0**	**$0**	**$947**	**$54**	**$1,216**	**$238**	**$14**

2.3 Interconnection Cost Comparison

Figure 1 highlights the cost findings. Although wind costs appear to be dramatically less overall, there were limited data available—from one utility in New York and one in the Pacific Northwest. The solar PV search yielded more interconnection cost data in addition to more lessons learned and best practices than that of distributed wind.

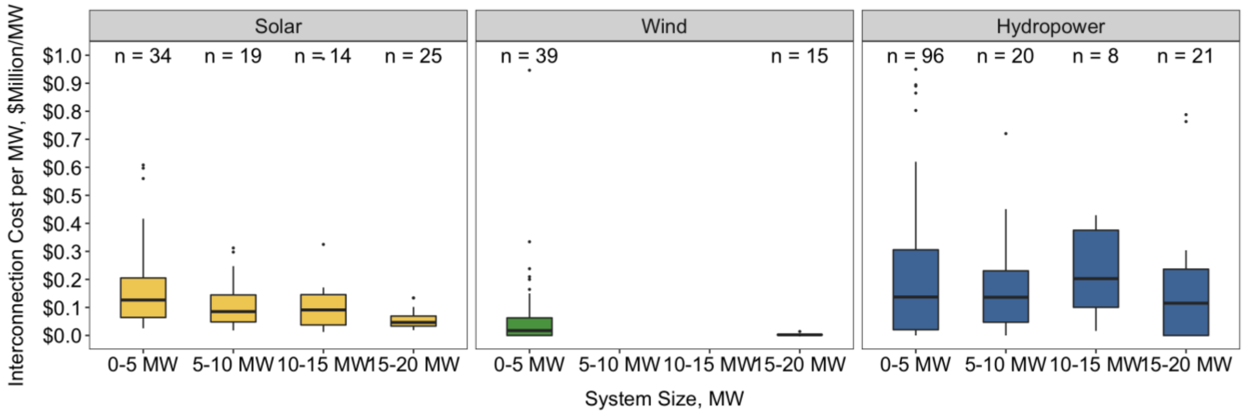

Figure 1. Total Interconnection Cost ($Million per MW) for Solar, Distributed Wind, and Small Hydropower Projects. Solar cost data from Bird et al. 2018; wind cost data from New York and PacifiCorp interconnection reports, not including reports with $0 estimated cost upgrades; hydro cost data from this analysis.

3.0 Summary

Despite the potential of small hydropower for clean energy production and minimal environmental impacts, interconnection to electricity distribution and transmission grids has persisted as a barrier to growth. This report summarizes research in which specific barriers to small hydropower interconnection were investigated, including unclear processes, unpredictable study results, prohibitive network upgrade costs, unreliable timelines, and ineffective mitigations.

First, the state of small hydropower projects under 20 MW in capacity was characterized ("Small Hydropower Interconnections: Small Hydropower in the United States"). Both development activity and resource potential were found to concentrate in the non-power dam (NPD) and conduit market segments, and geographically in the extended Appalachian region and in the Mountain West, Pacific Northwest, and California. Second, interconnection processes were reviewed in all 50 states ("Small Hydropower Interconnections: State Interconnection Proceses"). Common trends in these processes were distilled. However, significant variation in distribution scale interconnection guidelines were observed between states, which undoubtedly constrains development at a national scale.

Next, and as the primary focus of this effort, the sourcing of interconnection information and benchmarking of study findings was completed ("Small Hydropower Interconnections: Analysis of Interconnection Processess"). From that analysis, an Interconnection Benchmarking Database (IBdb) was assembled from publicly accessible sources. In total, 290 projects were found, 151 of which were examined in greater detail through interconnection reports. A mixture of queue owners of 14 utilities and four balancing authorities/system operators were included in the database. Geographic coverage was strong in the Pacific Northwest, Mountain West, East, and Northeast, but lacking in Texas and the Southeast. This database was then analyzed for common upgrade types, key trends and differences in study findings, network upgrade costs, and timelines based on project information, location, and system ownership. The cost the replace or install new conductors (or transmission cables) were shown to be significantly higher in the West than in other regions on a per MW basis. Higher POI voltages in the East than in the Pacific Northwest were correlated with higher new conductor costs per mile between the two regions. New substation costs clustered around 10 MW. There were some differences in costs by queue owner, mostly restricted to conductoring and new substations. Many other costs were comparable across regions, as were timelines for interconnection review. For the most part, timelines appeared to be consistent with project expectations.

In this paper, best practices for interconnection processes were gleaned from the solar energy and distributed wind energy industries. Comparing interconnection costs, PV and distributed wind showed a marked diminished cost compared to small hydropower, with more consistent cost spreads for similar capacity classes. This could be attributed to the geographical siting flexibility found in PV and wind projects as compared to small hydropower projects. Efforts in these adjacent industries to share additional system information, improve cost certainty to developers, and leverage power electronics could facilitate small hydropower interconnections.

3.1 Next Steps

The next steps for this work are to target the most costly and time-consuming upgrades, such as substation modifications and conductoring, to identify any potential contributions that may be attainable through (1) enhanced transparency of distribution and transmission system data and (2) power electronics such as power converters and smart inverters. Tools and templates may also be built from these analyses to facilitate interconnections for the project developer and interconnecting authority.

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Appendix A – Solar Photovoltaic Interconnection

In 2020, 19 gigawatts (GW) of solar photovoltaic (PV) was installed in the United States, with 4 GW installed for residential, commercial, and industrial customers, and the remaining 15 GW at utility scale (Feldman et al. 2021). Cumulatively, the United States operated 93 GW of solar capacity (Feldman et al. 2021). Solar projects have driven many of the procedural and technologic improvements for distributed generation interconnection due to popularity, large capacity, and volume of interconnection requests. As utilities and developers have improved processes to facilitate grid interconnection (and these processes are not generator technology-specific), best practices from the solar industry can be used as best practices and lessons learned for small hydropower generators. Details about voltage, thermal, and protection impacts that were caused by PV interconnection are described in this appendix.

A.1 Voltage Impacts

Voltage impacts can be classified as having adverse effects to system voltage. Overvoltage impacts are more common and can be mitigated with inverter power factor correction, modification of voltage regulation equipment, or new regulation equipment (Sena et al. 2014). Voltage deviation can be mitigated with inverter power factor correction or conductor upgrades (Sena et al. 2014). Using PV inverter capabilities to modify the power factor provides a lower cost alternative compared to new voltage regulators to mitigate voltage impacts that were recommended at solar plants <10 MW and interconnection voltages <13.8 kV. New or modified voltage regulator equipment can mitigate voltage impacts with costs ranging from $3,500 to $98,500. Conductor upgrades are required in some cases to mitigate both thermal and voltage impacts. Conductor upgrades are a more expensive mitigation measure, with costs exceeding $100,000 per project (Sena et al. 2014).

A.2 Thermal Impacts

Thermal impacts are most commonly mitigated by upgrading conductors to higher current ratings (15 of the 20 projects with thermal impacts identified by Sena et al. [2014]. Conductor upgrade costs range from $50,000 to $2,400,000. Other mitigation approaches included transformer upgrades, new voltage regulation equipment, and, in one case, facility curtailment. Curtailment provided a no-cost mitigation measure that would deenergize the solar generator’s output when a contingency occurred on the distribution circuit.

A.3 Protection Impacts

Protection impacts occur when protection and control equipment do not meet the current or power requirements after adding a new generator to the circuit. Protection impacts can be mitigated with upgrades at the interconnection substation or upgrading reclosers. Substation protection upgrades were more commonly identified as mitigation measures (37 of 43 projects with protection impacts identified by Sena et al. 2014). Mitigation measures can include relay modifications (low cost, <$5,000), relay upgrades ($500,000), or advanced protection schemes, including deadline checking, DTT, and high-side fault protection. Implementing advanced protection schemes increases the upgrade costs significantly, with costs ranging from $125,000 to $1,300,000 (Sena et al. 2014). Some protection impacts were mitigated with recloser modification (costs ranging from $45,000 to $179,000) (Sena et al. 2014).

Appendix B – Distributed Wind Interconnection

Distributed wind typically consists of a small number of wind turbines deployed at residential, commercial, or industrial sites. They are often used to offset power consumption. The general theory of operations of distributed wind holds many similarities to small hydropower and may allow parallels to be drawn between the interconnection processes and required upgrades. Both systems are generally smaller and more dispersed assets compared to centralized power plants; both utilize rotating turbine generators, which generate AC power; and both may also require unique and/or costly upgrades given interconnections to weak or isolated grid topologies resulting from siting constraints.

The installed capacity of distributed wind in the United States as of 2018 was 1,127 MW, produced from over 83,000 turbines, averaging approximately 10 kW per turbine. In 2018 alone, however, 50.5 MW of distributed wind was added across 12 states and mostly came from projects with turbines greater than 1 MW in size. Very small distributed wind projects (i.e., microturbines, which offer a capacity of less than 1 kW) are typically used in off-grid and isolated applications and are used to power wells, pipelines, and other isolated infrastructure (Orrell et al. 2019). Therefore, the range of capacities that are relevant to small hydropower turbines may offer insight into interconnection processes but are limited to a small set of wind turbines overall.

B.1 Policies & Procedures

In the search for general best practices and interconnection documentation for distributed wind projects, a limited subset of interconnection information was available compared to small hydropower projects. It was found that total transportation and installation costs for a distributed wind project, which can include labor, equipment, metering, wiring, interconnection with the utility, and other components, can often be a considerable amount of the overall cost of a project (10–35 percent). This is found to be even more true for projects located in more remote sites or difficult terrain, and is higher for commercial systems over residential (Kwartin 2010; Orrell and Poehlman 2017). For projects with only one or two turbines, being able to connect at the distribution level and qualify for small generator interconnection criteria will substantially decrease the time and expense for interconnection (Daniels 2007).

B.2 Interconnection Costs

Interconnection queues were examined for wind projects less than 5 MW to obtain information on utility interconnection costs and patterns for smaller distributed wind technology. It is assumed that projects under 5 MW are distributed and contain a comparatively small number of turbines; most projects over this size are less likely to be associated directly with end-use and thus are classified as centralized wind farms. This search revealed a small number of results in a limited number of areas, namely the states of Massachusetts, New York, and PacifiCorp's service territory in the Pacific Northwest.

For small wind in Massachusetts, high level information was found on 16 projects. Of those, the average size was 400 kW with only two projects greater than 1 MW. Eleven of the projects were submitted under the standard application process, meaning only five qualified for the expedited process despite having small capacities. Half of the projects in the queue ultimately required impact studies as part of their interconnection process. Limited data were available regarding whether system modifications were required for these projects, but for those that did have data, it is worth noting that nearly all were for projects under the standard application process. Only one project requiring system modifications was for an expedited application and was associated with a 65 kW project. No other information on the specific upgrades or the overall interconnection costs for these projects was available.

The New York dataset had a larger number of projects under 5 MW, but with limited cost data available. The New York dataset totaled 490 small wind projects, of which 48 were not interconnected and only 35 required upgrade costs. Of the projects that required upgrade costs, only 9 were ultimately interconnected to the grid. The average total cost to the customer was found to be just over $11,300 and the highest cost was $42,400, revealing a comparatively low-cost range. The vast majority (92 percent) of projects not interconnected were applications for community distributed generation, with only one withdrawn project for net metering and two for remote net metering. Projects that incurred costs, but were interconnected, had a smaller capacity (257 kW on average), compared to those that were withdrawn (3.34 MW). A plot of all projects with coordinated electric system interconnection review (CESIR) costs is shown in Figure B. and Figure B..

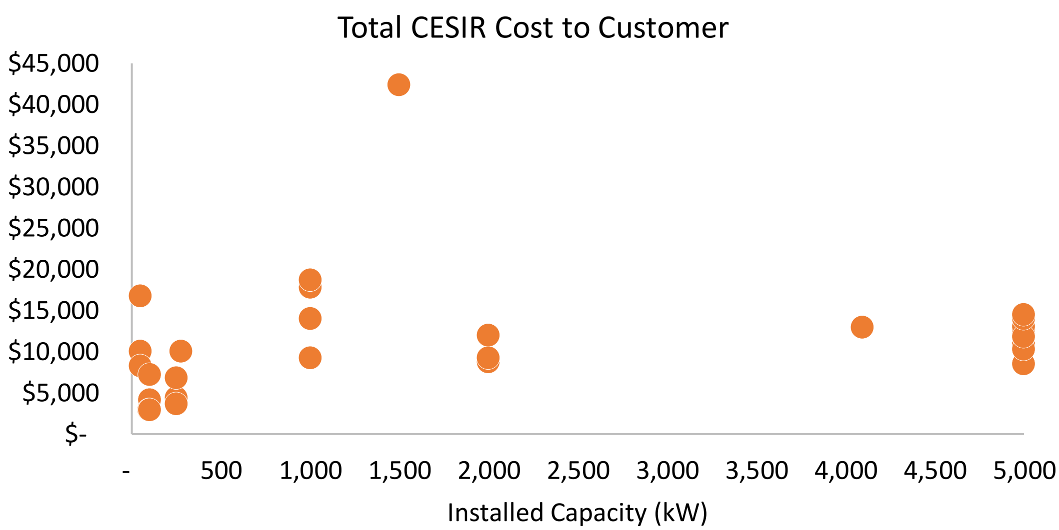

Figure B.1. CESIR Cost to Customer by Installed Capacity, New York Wind Projects <5 MW

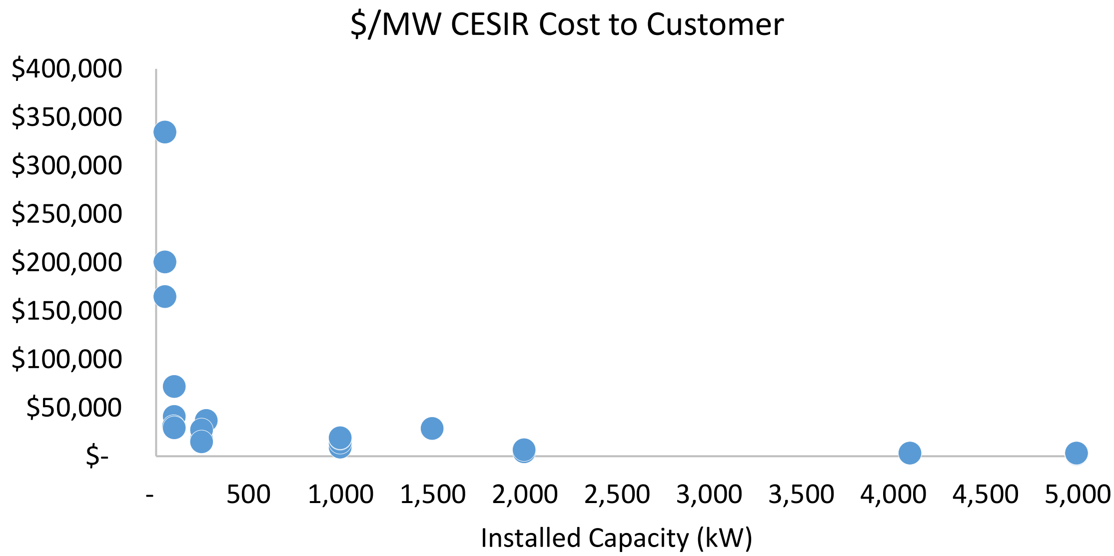

Figure B.2. $/MW CESIR Cost to Customer by Installed Capacity, New York Wind Projects <5 MW

Though the number of datapoints is limited, comparing the $/MW cost of distributed wind interconnection to that of small hydropower yields some takeaways and opportunities for comparison. The overall range of costs for distributed wind are substantially lower compared to hydropower, with the max being just under $350,000/MW compared to nearly $3 million/MW for small hydropower. However, given the data available, it is unclear whether characteristics of the distribution system, particularly in New York state, or the distributed wind technology are the source for the difference in cost of network upgrades for distributed wind as compared to the small hydropower dataset discovered in this project.

B.3 Components and Infrastructure Upgrades

B.3.1 Upgrade Costs and Requirements for Interconnection

Reports were studied for several distributed wind projects in various states across the Pacific Northwest by identifying the required upgrades and their relative costs for parallels that might be drawn between distributed wind and small hydropower interconnections. Limited availability of small wind reports reduced the area of coverage for comparison, and no detailed reports were found in areas outside the Pacific Northwest. Nineteen small wind projects were found in the PacifiCorp queue across Utah, Wyoming, and Oregon. The average size of the projects was just over 1.9 MW. Only seven of the 19 projects were ultimately interconnected. Of all the projects, only 10 had study reports available with additional information. Interconnection costs and the upgrade categories applicable to the various projects are provided in Table B.1.

Only two projects required no costs to interconnect after no impacts were found following their studies, both of which were 1 MW or smaller in size. It was specified for these projects, however, that a relay capable of disconnecting the generator from the electric power network if the frequency or voltage moves outside an acceptable range would still be required for interconnection. Of the projects that did require costs, projects with costs under $15,000 only required metering or relay settings at the POI. Three of the projects had substantial interconnection costs greater than $1,000,000. The high costs associated with these projects were due to new substations, substation upgrades, and/or rebuilding multiple miles of transmission lines.

Table B.1. Interconnection Costs and Upgrade Categories for In-Service and Withdrawn Distributed Wind Projects in PacifiCorp Territory

	Capacity Size (MW)	0.0358	0.10	0.11	0.65	1.0	1.56	1.715	2.6	4.5	5.0
Upgrades Required	New/Upgrade Metering	✓	✓	✓					✓	✓	
	New/Upgrade Communications							✓	✓	✓	✓
	Relay Settings at POI	✓	✓					✓			
	Protective Device Equipment						✓				
	New Substation						✓				
	Substation Upgrades									✓	
	New Structures						✓				
	New Breaker										✓
	Disconnect switch/ reclosers								✓		
	Reconductoring								✓		
	Upgrade Line Equipment								✓		
Total Upgrade Cost (thousands)		**$7.50**	**$15**	**$12.70**	**$0**	**$0**	**$1,477**	**$92**	**$3,161**	**$1,072**	**$70.78**
Total Upgrade Cost ($Thousand/MW)		**$209**	**$150**	**$115**	**$0**	**$0**	**$947**	**$54**	**$1,216**	**$238**	**$14**

A cursory review of available distributed wind system studies revealed that, similar to small hydropower projects, upgrades were largely dependent on capacity of the distributed generator, configuration of the distribution system, protection and control requirements, and data telemetry and control requirements.

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