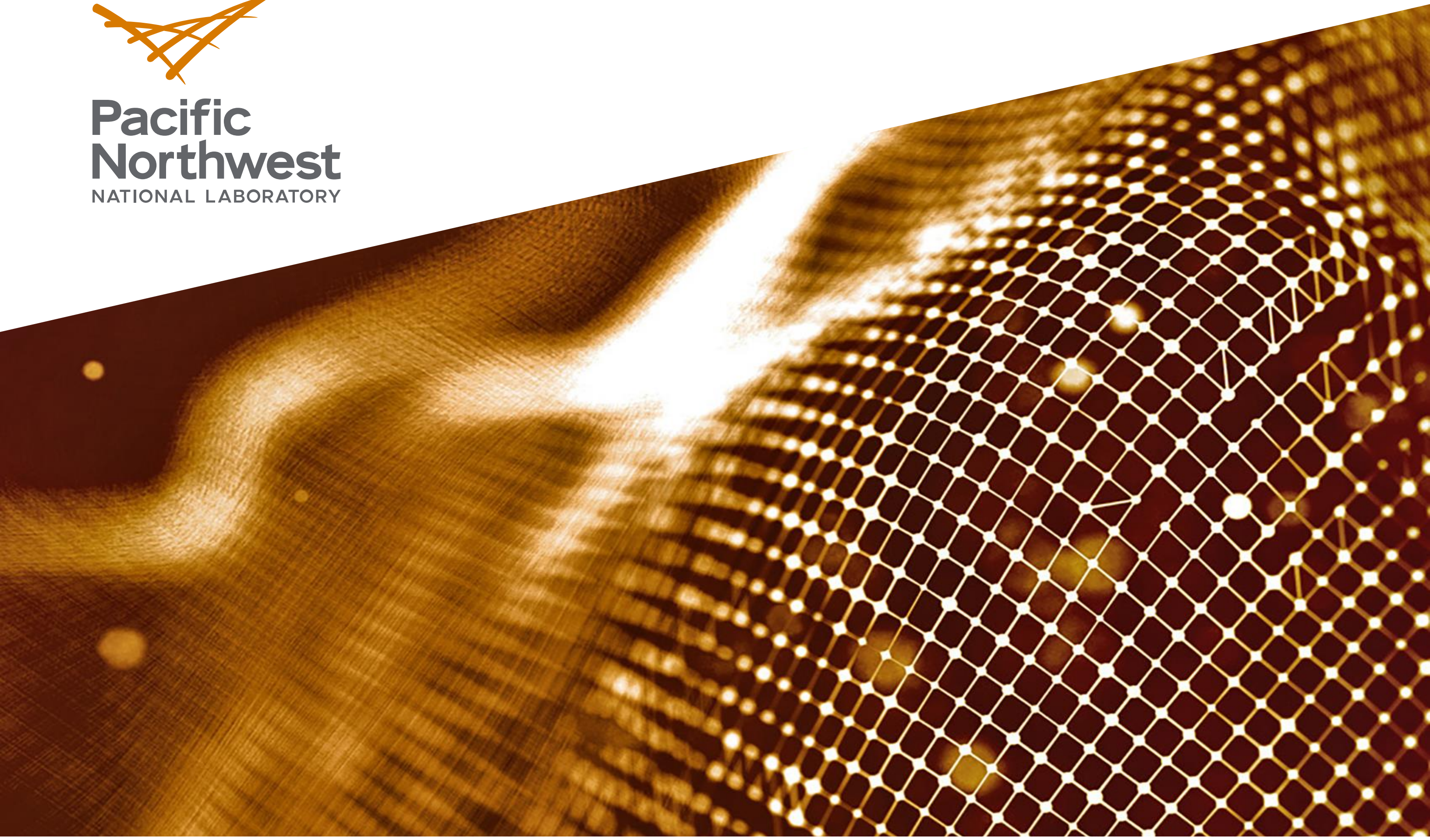

PNNL-33302

IRES Microgrid Energy Integration Report Version 1.0

September 2022

Jaime Kolln, Power System Engineer
Charlie Vartanian, Senior Technical Advisor
Matt Paiss, Technical Advisor
Scott Maple, Project Manager

Pacific Northwest National Laboratory

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Richland, Washington 99354

Abstract

This report presents technical information and guidance for the planned Integrated Renewable Energy System (IRES) microgrid project. This deployment of the microgrid and its associated assets was initiated in the beginning of 2022 at the Pacific Northwest National Laboratory (PNNL)-Sequim, Washington.

The information in the report is organized under two main focus areas:

- electrical power interface, or interconnection, information of planned IRES assets; and
- communication and control interface, or interoperability, information of the planned IRES assets.

The information is provided as technical input for the development of the IRES microgrid controller technical specification, and also provide input for PNNL's evaluation of adequacy of the electrical service infrastructure at PNNL-Sequim to support the IRES project and help identify any gaps that will require facility-based upgrades.

From an R&D aspect, this study and report will build on PNNL's research and development work relating to energy storage (ES) codes and standards (C&Ss), including hybrid systems, performed on behalf of the Department of Energy (DOE) Office of Electricity (OE) ES. The current state of C&Ss for advanced technologies and their application, including microgrid-based technology is limited. For cases where formal standards issued by recognized Standards Developing Organizations do not yet exist, guidance is provided based on emerging best practices, including industry-group references that can be leveraged for microgrid technology which is in its early stages of development and use.

Summary

This report summarizes the attributes of the various assets that will be used in Pacific Northwest National Laboratory's (PNNL's) Integrated Renewable Energy System (IRES) microgrid project. The asset attributes summarized in this report are organized into two main categories—electrical and communications. At this early stage of the IRES project, some assets have been defined and specified (e.g., the battery energy storage system [BESS]), but other assets have not. The goal of this report is to capture key technical assumptions for those assets that have been defined, and also recommend the performance requirements and associated standards to inform technical requirements of the IRES assets that have yet to be specified. Additionally, this report will provide insight into the electrical upgrades of facilities required to serve IRES project's ultimate resource plan.

The first part of the report characterizes the assets planned for IRES and key operating principles including no negative impacts to the electrical service or to other PNNL-Sequim connected loads.

The second part of this report addresses considerations that will drive overall microgrid control design and operations. These include interconnections (power interfaces), interoperability (communications interface), technical standards, and emerging best practices. Safety considerations specific to the BESS (another Department of Energy [DOE] funded Grid Integrated Marine Renewables [GIMRE] project) being used for IRES have also been included in this report.

The report concludes with guidance on performance testing that could be applied during equipment factory acceptance testing, or field commissioning tests for IRES assets and the microgrid as a total system.

The reference section of the report includes links to the various codes and standards (C&Ss) cited in the report. Additionally, the reference list also includes details of other C&Ss that may be useful as planning and operational details are further developed and finalized for the IRES project.

Acknowledgments

This project was supported by funding from the Washington State Department of Commerce Clean Energy Transition Program, and the Department of Energy (DOE), Office of Electricity, Energy Storage Program. The authors of this report would like to thank Vince Sprinkle (PNNL), and Imre Gyuk (DOE) for their support.

Acronyms and Abbreviations

AC	alternating current
ANSI	American National Standards Institute
AWG	American wire gauge
BESS	battery energy storage system
C&S	codes and standards
CRABEE	Cable Research Array for the Blue Economy and Energy
DC	direct current
DER	distributed energy resource
DOD	Department of Defense
DOE	Department of Energy
EES	electrical energy storage
ES	energy storage
ESS	energy storage systems
EV	electric vehicle
EVSE	electric vehicle service equipment
GIMRE	Grid Integrated Marine Renewables
ICT	information and communication technologies
IEEE	Institute of Electrical and Electronics Engineers
IRES	Integrated Renewable Energy System
MESA	modular energy system architecture
NRTL	Nationally Recognized Testing Laboratory
PCC	point of common coupling
PNNL	Pacific Northwest National Laboratory
POC	point of connection
PQ	power quality
PV	photovoltaic
TCP/IP	transmission control protocol/internet protocol

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1.0 Introduction

The primary aim of the Integrated Renewable Energy System (IRES) project is to design and construct a renewable energy demonstration test bed at the Pacific Northwest National Laboratory (PNNL) Sequim campus located in Sequim Washington. This test bed will consist of a battery energy storage system (BESS), which will be connected to multiple renewable energy input resources via the PNNL-Sequim alternating current (AC) electrical system. The BESS will be able to provide electrical energy management services for various IRES demonstration equipment both onshore and offshore over the life of the test bed. Technical and performance specification studies needed for design and procurement of necessary equipment, battery, and power management systems are also a part of the IRES project. This IRES energy integration report is a part of the early design-stage studies scope of the IRES project.

The IRES asset attributes summarized in this report are organized into two main categories, electrical interconnections and communications interoperability. Even though the IRES project is still in its nascent stages, some assets have been defined and specified (e.g., the BESS), while other assets have not. The goal of this report is to capture key technical assumptions for those assets that have been defined, recommend technical requirements, identify associated standards to inform the design of the IRES assets that are yet to be specified, and to make provisions for PNNL- Sequim electrical plant upgrades that will be necessary to support IRES project's ultimate resource plan.

The information will provide technical input for the development of the IRES microgrid controller technical specification, provide input for assessing adequacy of the electrical service infrastructure at PNNL-Sequim to support the IRES project, and identify gaps that may require facility-based upgrades. This report's information also provides general guidance to microgrid project planning and design.

1.1 Project Overview

PNNL is a leading research institute in the domain of blue economy and marine energy applications successfully establishing collaborative efforts between the Department of Energy (DOE) and multiple partners including the state of Washington. With support from Washington State Department of Commerce[1], the IRES demonstration testbed will advance research by developing and testing renewable energy production, management, and use for multiple marine applications (e.g., ocean observations, vehicles, aquaculture). It will also advance energy resiliency for coastal communities by developing an integrated renewable energy test platform that will model how multiple renewable energy resources could power shoreline businesses or communities. The IRES will provide an R&D testbed to demonstrate how a variety of renewable systems can be integrated to reduce carbon emissions which will contribute to a net zero site as well as provide an interoperability testbed for controls and communication protocols that will help expand energy options for shoreline and maritime businesses.

Consistent with its designation as an R&D project, this is a complex undertaking to design and build a system with no similar counterpart elsewhere. It will result in operating guidelines for others contemplating integration of multiple types of renewable energy with energy storage for increased flexibility and reduced emissions.

[1] Contract executed 4/19/2022 between PNNL and WA State Dept. of Commerce, CRADA No 557

1.2 Planned Assets

The IRES project plans to deploy the following supply resources that will be monitored and controlled to operate as an integrated microgrid within the PNNL-Sequim campus:

- BESS rated 125 kVA 208 kWh, but operated at 50 kVA maximum charge/discharge;
- onshore (rooftop) solar photovoltaics (PV) generation, up to 10 kW;
- floating solar PV generation, up to 10 kW;
- tidal generation rated up to 40 kW; and
- wind generator (future capability), up to 10 kW.

Several loads that will be monitored and controlled are also included in the microgrid design and operations are enumerated below:

- Two EV charging stations, up to 7.2 kW each, capable of smart-charging control, e.g. 'V1G' capable. These will be operated as controlled loads.
- One shore-power supply for eVessel charging, supporting up to 20 kW peak charge load. This will initially be a monitored-only microgrid load.
- Various electrical outlets for up to 4 kW of service to IRES project test and monitoring equipment loads.

The IRES project is leveraging two other projects planned for deployment at PNNL-Sequim. These are two separately DOE funded projects to deploy a BESS for Grid Integrated Marine Renewables (GIMRE)[1] and a Cable Research Array for the Blue Economy and Energy (CRABEE)[2]. These projects will work together to provide the connection and integration of tidal generators and other offshore assets. At this early stage of the IRES design, these are the only two 'fixed' capacities among the several planned IRES microgrid assets. As shown in Figure 1-1, the BESS will now be used to supplement renewable energy generation and other microgrid assets.

[1] https://doepeerreview.sandia.gov/index.php?gf-download=2021%2F10%2FKolln_Jaime_Safety-and-Reliability.pdf&form-id=2&field-id=13&hash=9f18e607f2e2a8b4c787072ae7908cb5c1cd3ebbc1af7f1e8497eff196bce80a

[2] Per Rob Cavagnaro, "The system will consist of a 12x 6 mm^2 core trunk cable that is broken out into 4 extensions comprised of 4x 6 mm^2 cores in a subsea node. Each of the cores of the trunk cable is rated for 33 A and 54 A in the extensions. As currently specified, connectors are the limiting factor for the system. Each cable will have a connector or bulkhead termination with 20 A rating per pin/core."

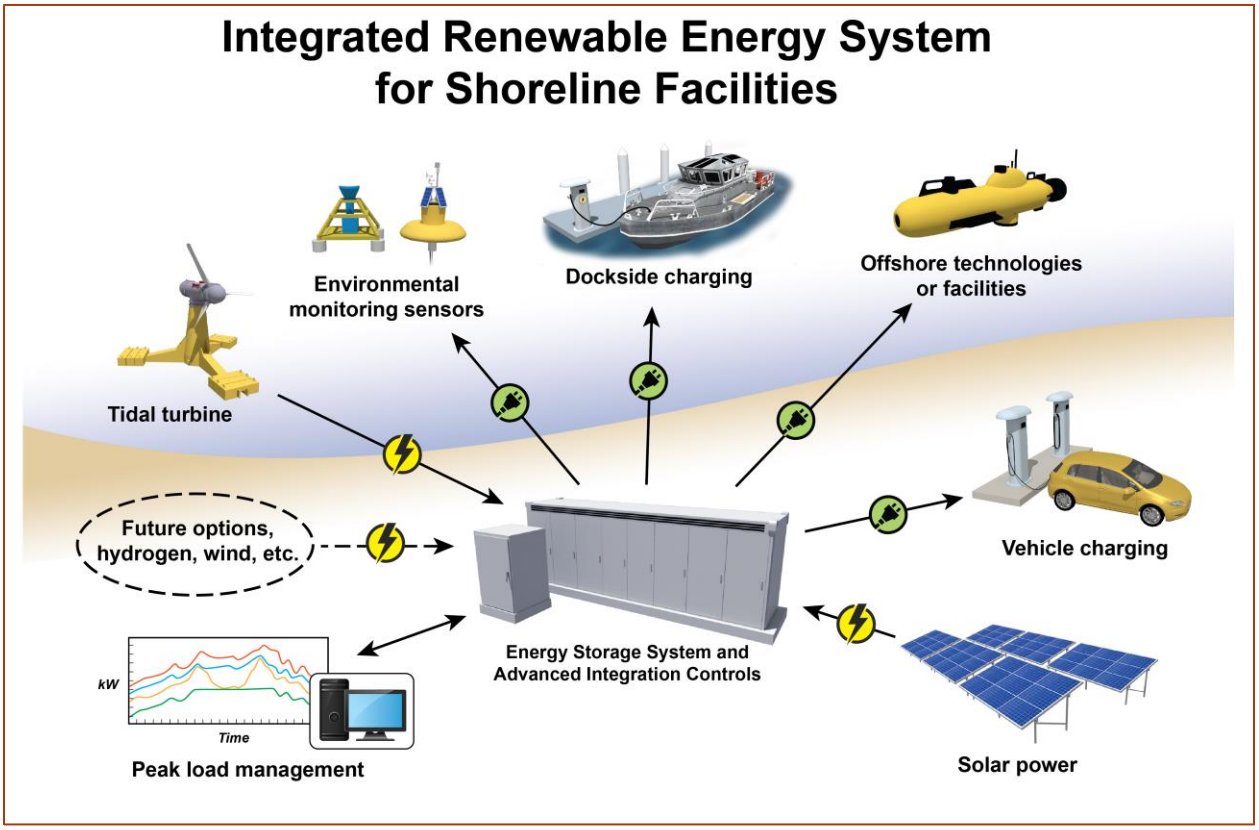

Figure 1-1. High-Level Overview Of The IRES Microgrid.

The GIMRE project is purchasing and installing a 125 kVA 208 kWh rated Li-ion based BESS at PNNL-Sequim. However, this system will be control-limited to have a maximum power charge/discharge of 50 kVA. This BESS power limitation is due to constraints imposed by the current PNNL-Sequim electrical plant capacity. The GIMRE project is a prior-approved DOE Office of Electricity Energy Storage program BESS demonstration. The primary use case demonstrates that BESS is able to meet the Institute of Electrical and Electronics Engineers (IEEE) 1547-2018 (IEEE 2018a) compliant grid interconnection performance requirements (e.g., ride through and volt/VAR control) when integrated with future tidal generators and renewable resources that will be installed and operated at PNNL-Sequim. In addition, the infrastructure supporting the BESS can be configured to electrically isolate operating tidal generators from the campus' electrical plant through 480 V AC switching.

The CRABEE project is a separate DOE Water Technology Office funded project that will deploy an array of undersea cables offshore of the PNNL-Sequim campus. This array will be connected to a single shore-side fixed electrical termination point. The rating of CRABEE will have capacity to host four individual 10 kW assets (e.g., tidal generators) or can be combined to support larger assets. Thus, the electrical integration plan for IRES is based on a maximum tidal generation peak output of 40 kW.

The following graphic illustrates the conceptual AC electrical plan to tie the BESS, tidal generator(s), and load bank via AC-coupling to the PNNL-Sequim electrical plant. This conceptual single line also shows metering points that will provide data to the IRES microgrid controller.

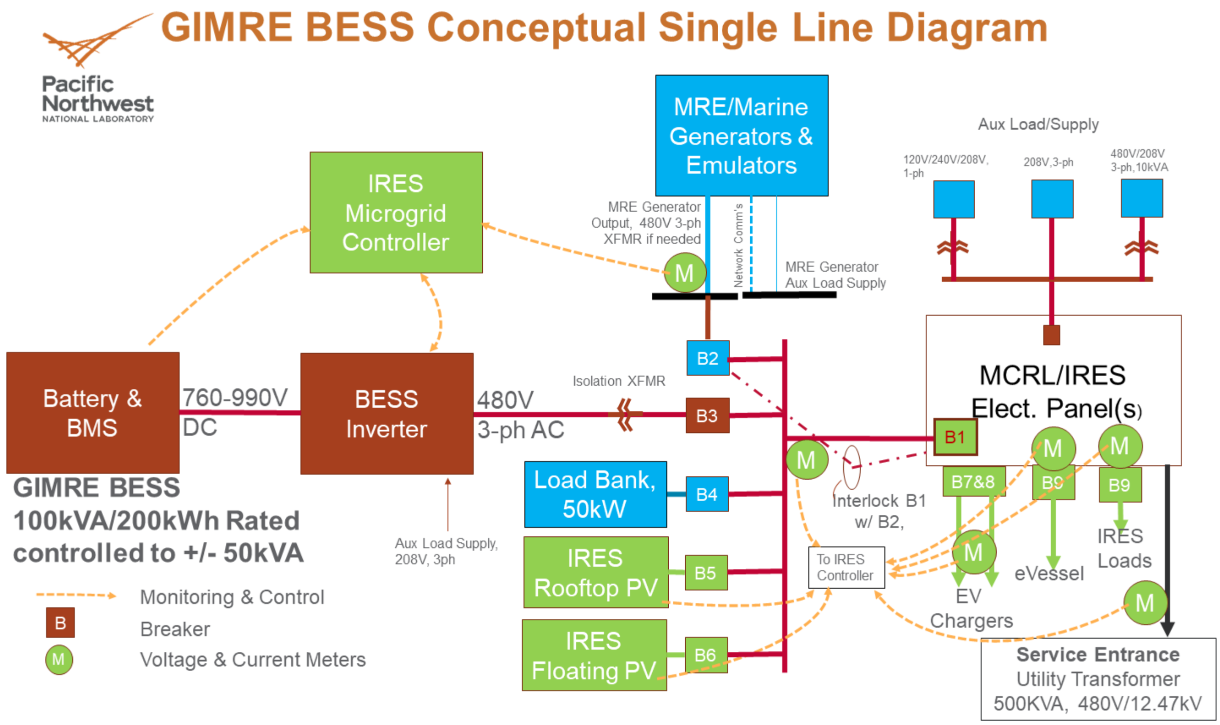

Figure 1-2. Conceptual Overview of BESS and Tidal Generation Electrical Connections

As shown in Figure 1-2 above, the two known capacities for IRES are the 125 kVA rated BESS which will initially be control-limited to operate at 50 kVA maximum charge or discharge, and the 40 kW aggregate tidal generation power. Table 1-1 below lists assets with known ratings represented in black text color. The other asset capacities are assumed maximums. The assumed capacities are represented in blue text in Table 1-1. These capacities are the basis for: 1) designing of the PNNL-Sequim electrical plant upgrades needed to host the IRES project and 2) specifying and designing the IRES microgrid controller. ***<u>Thus, these assumed capacities will need to be bounding metrics as individual assets are procured.</u>***

Table 1-1. Overview Of The IRES Microgrid With Estimated Values In Blue. Standards Indicated Are Some Of The Common Communication Protocols For Those Assets.

IRES MICROGRID ELECTRICAL RATINGS SUMMARY									
Asset Description		Power Interface/Interconnection Spec's				Communications Interface/Interoperability Spec's			
Microgrid Asset	**Asset Type**	**kW/kVA**	**Voltage (V), Phases**	**Breaker Rating (A)**	**Codes & Standards**	**Protocols**	**Transport**	**Metering Location**	**Controls (Y/N)**
Shore PV	Resource	*10**	*208, 3-ph* *480, 3-ph*	*30* *15*	IEEE 1547-2018 UL-1741-SA/SB listed	*DNP3, Sunspec, 2030.5*	*TCP/IP*	From PV inverter	Y
Floating PV	Resource	*10*	*208, 3-ph* *480, 3-ph*	*30* *15*	IEEE 1547-2018 UL-1741-SA/SB listed	*DNP3, Sunspec, 2030.5*	*TCP/IP*	From PV inverter	Y
Tidal Generator	Resource	40 (4X10)	480, 3-ph	50	1547-2003 UL-1741 compliant	*DNP3, Sunspec, 2030.5*	*TCP/IP*	From/at CRABEE?	N
Wind Generator	Resource	*10*	*208, 3-ph* *480, 3-ph*	*30* *15*	1547-2003 UL-1741 compliant	*DNP3, Sunspec, 2030.5, Modbus RTU*	*TCP/IP*	At generator	N
BESS	Energy storage	125 max/ 50 limit	480, 3-ph	75A	1547-2018 UL-1741-SA/SB compliant	DNP3 and Sunspec	TCP/IP	From BESS inverter	Y
Dockside Charging	Monitored load	20	208, 3-ph	50	SAE J2953, SAE J1772 SAE J2847/1	*2030.5*	*TCP/IP*	At breaker	N

EV Charging 1	Controlled load	*7.2*	*240 1-ph*	*40*	IEEE 1547-2018, UL-1741-SC, IEEE 2030.5, SAE J3072,	*2030.5, OCPP*	*TCP/IP*	From EVSE	Y
EV Charging 2	Controlled load	*7.2*	*240 1-ph*	*40*	IEEE 1547-2018, UL-1741-SC, IEEE 2030.5, SAE J3072,	*2030.5, OCPP*	*TCP/IP*	From EVSE	Y
IRES Test and Monitoring Equip.	Monitored load	*4*	*120 1-ph/ 240 1-ph/ 208 3-ph*	*20*	UL listed equip	*SunSpec Modbus, 2030.5*	*TCP/IP*	At panel breaker	Y
Grid Interface	Resource	Net zero	480v 3-ph	Net zero	UL listed equip	*DNP3, SunSpec Modbus, 2030.5*	*TCP/IP*	At revenue meter	N

1.3 Microgrid Design Drivers

The IRES microgrid will be installed and operated within an existing R&D operational environment that includes sensitive test equipment. An overall overarching design driver for IRES is to not interfere with the electrical power quality (PQ) or reliability of PNNL-Sequim electrical service. In lieu of measuring or otherwise determining baseline PQ and reliability of the PNNL-Sequim campus, IRES project assets will rely on IEEE Standards that set minimum impacts that a compliant resource can have to the receiving electric system's PQ and reliability. All IRES assets must comply with IEEE 519 (IEEE 2022) limits on harmonic injection and IEEE 1547 performance requirements including maxing voltage deviation impact when connecting or disconnecting. In the case of equipment that is not listed in UL1741 (UL 2021) or can't otherwise prove compliance with IEEE 519 and IEEE1547, it must have the ability to be connected to the portion of the IRES electrical connection that can be isolated (i.e., behind breaker B1 as shown in Figure 1-2). The BESS and photovoltaic (PV) inverters are mature products and are able to meet the noted IEEE Standards. Tidal generation as an asset class is less mature and will be connected such that they can be isolated from the rest of PNNL-Sequim's electrical plant.

While the primary driver of IEEE 1547 is 'no negative impact' to PNNL-Sequim electrical service (the interconnection point), the secondary design driver is meeting the functional needs of the several use cases that IRES will perform. These are simply listed by name below to exercise caution in the evaluation of all electrical and controls designs for both individual IRES assets as well as integrating scope of the IRES microgrid controller. The electrical connectivity and capacities (interconnections) must support the use cases and the communications and controls (interoperability) must also support the project's use cases as listed below:

- Self-supply of a portion of the total PNNL-Sequim site's electrical load with carbon-free marine and terrestrial renewable energy.
- Meet the ride through portion of the IEEE 1547-2018 Distributed Energy Resource (DER) grid interconnection standard requirements—To be met by the BESS individually and for overall microgrid as measured at point of common coupling with the local electric utility.
- Meet the VAR capacity and voltage control portion of the IEEE 1547-2018 DER grid interconnection standard requirements—To be met by the BESS individually and for overall microgrid as measured at point of common coupling with the local electric utility.
- Blackstart and islanded operation of BESS and tidal generation as an electrically isolated system. Wherein the BESS will act as both sink and source for the tidal generator's electrical load and output during limited periods of tidal generation demonstration operations. Period of isolated BESS-supported tidal generator operation may range from days to weeks depending on power capacities (auxiliary load and output) of the tidal generator.
- Local site PQ improvement, via voltage sag mitigation with the BESS inverter.
- Renewable energy output smoothing (sub-hourly output leveling, PV, tidal, and/or wind) with BESS.
- Renewable energy output shifting (multi-hour output shifting, PV, tidal, and/or wind) with BESS.
- Electric vehicle (EV) charge management—Controlled EV charge-rate (power) reduction and/or charge interruption via microgrid controller dispatched signals.

The IRES and related DOE energy storage (ES) and microgrid R&D projects will explore relatively more aggressive microgrid use case scenarios through modeling and simulation of the IRES microgrid. Examples of additional questions that can be addressed through use of digital simulation include:

- What total capacity (power and energy) would be needed from the IRES resources to meet 100% of peak site load for (a) temporary 1-'X' hour emergency load service, and (b) continuous load service?
- What PNNL-Sequim electrical plant upgrades would be needed to avoid thermal overload of conductors and/or unacceptable bus voltages (e.g., exceed American National Standards Institute (ANSI 2020) voltage range limits) at very high level (>50%) of self-supply?
- What inverter characteristics (e.g., grid forming vs grid following, active voltage regulation ranges) are needed to support 'blackstart' of a portion (25%, 50%) through all (100%) of PNNL-Sequim site electrical load?
- What would be the net economic impact from shifting various levels, 10% up to 100% of site load from utility supply to self-supply. What percentage of self-supply of electrical power and energy would be optimal in terms of net benefit/cost from customer perspective, and utility perspective?

These examples of extended use case analysis will require development of an electrical load flow and dynamic simulation model of the IRES power system, and asset and load characterization for economic production modeling. Digital tools that will support this enhanced level of R&D investigation through simulation include PNNL's Grid-Apps-D for power system modeling and simulation[1], and PNNL's Energy Storage Evaluation Tool for microgrid economic production cost modeling[2].

[1] https://gridapps-d.org/about
[2] https://eset.pnnl.gov/overview

2.0 Interconnection Guidance

2.1 Interconnection Overview

Interconnection includes an evaluation and approval process for the connection of resources (generators and ES systems) to electric power systems. This established industry practice will be applied to IRES resources. The process of interconnection evaluates the proposed resource in terms of impact to the receiving power system's performance to assure that the power system's performance will be adequately maintained with the addition and operation of the new interconnected resource. The following generalized definition of interconnection adapted from IEEE 1547provides a concise definition,

> **Interconnection:** The result of the process of adding a resource to an electric power system.

While the physical and measured reference point for DER impacts to power systems is normally the connection point with the utility distribution system (point of common coupling or PCC), the IRES project will extend interconnection practices and principles to the point of connection (POC) of IRES resources with the PNNL-Sequim electrical plant. Figure 2-1 below provides an illustration of the POC vs. PCC. Overall, the minimum acceptable impacts will be implemented at POC, but reflected all the way up to the PCC with the utility.

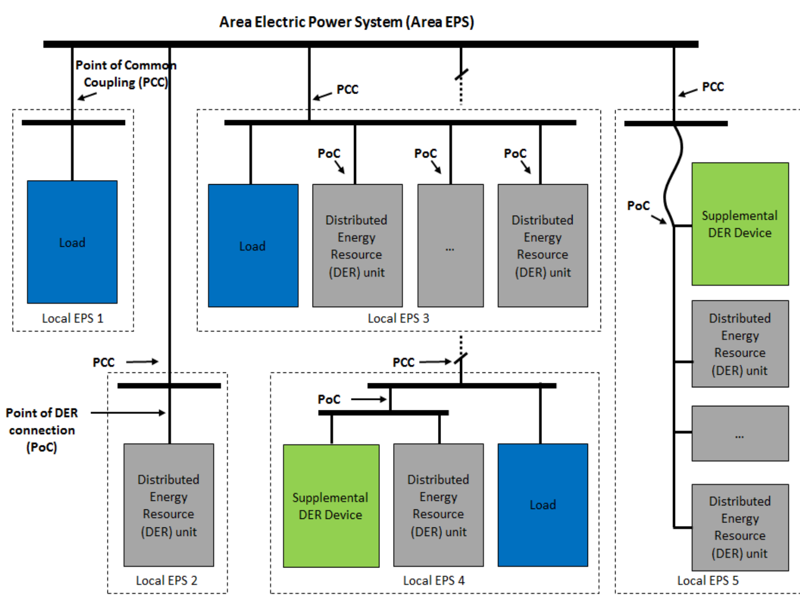

Figure 2-1. IEEE 1547 Interconnection Point of Connection vs Point of Common Coupling

For the relatively more mature resource types (PV and BESS), the IRES Project will require the newer extended level of performance capability per IEEE 1547-2018 vs. IEEE 1547-2003. The extended set of performance capabilities described in IEEE 1547-2018 include grid supportive capabilities including short-term ride event through, minimum VAR capacity, and voltage control. The relatively less mature technologies deployed by IRES including tidal generation will require listing (UL 1741) or must otherwise show compatibility with IEEE 1547-2003. IEEE 1537-2003 sets the minimum safety standard for all DER — do not energize a faulted power system. This is implemented through 1547-compliant anti-islanding controls. IEEE 1547-2018 also requires this minimum safety requirement — albeit coordinated with short (<2 second) ride through for brief grid disturbances.

Another major difference between IEEE 1547-2003 and 1547-2018 is the addition of minimum interoperability capability. Table 2-1 shows three standards, which is the main interoperability requirement. Compliant DER must have the capability to use the communication protocols outlined in Table 2-1.

Table 2-1. IEEE 1547-2018 Required Communications Protocols

Protocol	Transport	Physical Layer
IEEE Std 2030.5™ (SEP2)	TCP/IP	Ethernet
IEEE Std 1815 (DNP3)	TCP/IP	Ethernet
SunSpec Modbus	N/A	Rs-485

While these are minimum required interoperability capabilities for an individual DER connecting to a power system, this minimum for DER is not adequate for assuring interoperability within a microgrid operating environment.

3.0 IRES Interoperability Guidance

Interoperability is "the ability of two or more systems or applications to exchange information and to mutually use the information that has been exchanged"[1]. The IRES project requires the integration and coordinated operation of the various systems and assets through a microgrid controller. The interoperability of such equipment depends on the reliability of communication signals and the ability to understand the signals in order to apply the appropriate controls and interactions.

3.1 Physical Connectivity of Devices

Due to the length of wire that will be required and the proximity of various cables that will exist in parallel, communications wiring between microgrid assets and the microgrid control platform will include shielded category 6 cable. Amplifiers or network switches may be necessary for distances over 100 m to prevent degradation of the said signals. Wireless communications may be used on non-critical devices such as research metering however, this is not recommended for systems which will require communication with the microgrid controller for power management.

Safety systems, such as those used by PNNL-Sequim building fire panels and alarms, may require other alternative communication wires. This type of signal wire is typically 16 American wire gauge (AWG) non-shielded, twisted pair, and fire-rated. The AWG, shielding, and color code-based requirements vary depending on the application. Each asset procurement should consider the safety communication interfaces as needed and must be verified with PNNL fire protection engineers.

3.2 Cybersecurity

PNNL cybersecurity is critical since the National Laboratory is working on cutting edge technologies for the DOE and Department of Defense (DOD). PNNL cybersecurity subject matter experts (SMEs) must be engaged early and often, as well as engaged in the procurement processes to ensure that there is a clear integration path forward. Considerations for cybersecurity include isolated networks, access control, and security software. Other considerations may include abnormal communication or behavior detection. This guidance is not comprehensive and the cybersecurity SMEs of PNNL along with the PNNL information technology (IT) SMEs will aid the development of risk assessments and guidance according to the asset's communication requirements to meet third party monitoring requirements that may be necessary for warranty support, data sharing, utility coordination, or billing (as is the case with personal use EVs and electric vehicle supply equipment [EVSE]).

3.3 Communications

The IRES microgrid controller must have the ability to communicate with all of the monitored and controllable assets and meters. The coordination of these systems will require multiple information and communication technologies (ICT) standards and protocols. Common protocols for each microgrid asset have been described in Table 1-1. As a research facility, the PNNL-Sequim microgrid should have as much flexibility with the standards being implemented in order to meet the diverse needs associated with the variety of research projects and users.

---

[1] ISO/IEC 17788:2014, 3.1.5 (ISO/IEC 2014)

Additionally, since assets are not being procured simultaneously, the microgrid controller should have the capability to be updated as assets are added and improvements are made to the standards and protocols. For the purpose of this document, the most prominent, flexible, and secure ICT standards and protocols are identified but these may require reassessment during the procurement phase based on the capabilities identified with the support of vendors.

All of the IRES microgrid assets described in this report have some form of monitoring which requires at least one-way communication for reporting. Some of them will also have control capabilities. The variety of assets, both commercial and research, with equally diverse electrical and communication requirements have been described briefly in Table1-1above.

3.3.1 Photovoltaics

The PV or “solar” panels themselves do not contain ICT technologies. The intelligence lies in the power conversion system that converts direct current (DC) power, usually from multiple panels, to more commonly used AC power. These inverters communicate with the microgrid controller in order to determine the electric output characteristics. While these assets are capable of a multitude of different protocols and standards, but per IEEE 1547-2018 Standard for Interconnection of DER, the mandatory communication protocols are IEEE Std. 2030.5 (IEEE 2018b), SunSpec Modbus (Alliance), or IEEE Std. 1815 (Distributed Network Protocol3 [DNP3]) (IEEE 2012). To ease integration, it is recommended that all PV inverters use the same communication protocol.

3.3.2 Tidal Generator

As a research asset supporting a variety of tidal generation, the CRABEE may use any number of communication protocols. The cable specified for communication in this case is a fiber optic with switchgear located at a shore station. This will allow the systems to connect via a diverse number of transmission control protocol/internet protocol (TCP/IP) protocols. As these generators will likely have power conversion systems such as inverters. It is recommended that they adopt the same protocols as the PV inverters. These assets could also opt to use other protocols or even proprietary communications means such as application programming interface. These integrations will be ongoing and have varying operational periods, therefore each procurement team will require their own discussion with SMEs to explore interoperability requirements and capabilities. If using a vendor specific or proprietary protocol or information model the vendor should be required to provide technical documents and demonstrate alignment with existing standards. This may include documentation of mapping and semantics.

3.3.3 Wind Generator

Wind energy is generated as AC power but in order to manage frequency variability, this power is converted to DC and then back to AC at the frequency, phase angle, and voltage required for stable electric grid operations. The last step in this power conversion from DC to AC power is performed by an inverter. While this inverter is often integrated into the wind generator system and may be proprietary, efforts should be made to align communication protocols with those employed in inverters for PV and BESS. This includes, but is not limited to, information models, semantics, and use cases. If using a vendor specific or proprietary protocol or information model, the vendor should be required to provide technical documents and demonstrate alignment with existing standards. This may include documentation of mapping and semantics.

3.3.4 Battery Energy Storage System

Similar to a PV plant, the energy storage electrical output for BESS is converted from DC power to AC power through an inverter. The same communication protocols would apply, however there are additional information requirements attributed to the equipment and bi-directional nature of energy storage's ability to import power, which need to be taken into consideration. Additional equipment includes metering and battery management systems . It is expected that the SunSpec Modbus (SunSpec/modular energy system architecture [MESA]-Device (MESA), IEEE Std 2030.5 (IEEE 2018b), or DNP3 (MESA-DER (MESA 2018)) would apply to microgrid BESS. The additional information is described in a relatively complete manner in MESA de facto standards for energy storage, SunSpec/MESA-Device and MESA-DER. This procurement is already in progress and the vendor will provide the MESA defined protocols.

3.3.5 Electric Vehicle Service Equipment

While the electric vehicles being charged will vary, the charging equipment will be stationary. PNNL has already identified a vendor, ChargePoint, which can support our campus EVSE needs. Since PNNL has already identified ChargePoint CT4000 series level 2 commercial charging stations to be optimal, the need for interoperability is somewhat bounded by the capabilities of those EVSE. These assets include an integral long-term evolution modem for communication with ChargePoint and managed charging will likely require the microgrid controller to have access to their cloud application programming interface.

3.3.6 Dockside Charging

This is a nascent application for a microgrid managed asset. As such there is no standardization It is expected that the same standards that apply to EVSE and EVs would also apply to marine vessel charging equipment. Every effort should be made to align the dockside charging communication protocols with EVSE protocols including, but not limited to, information models, semantics, and use cases. If using a vendor specific or proprietary protocol or information model the vendor should be required to provide technical documentation and demonstrate alignment with existing standards. This may include documentation of mapping and semantics.

3.3.7 Test and Monitoring Equipment

Testing and monitoring equipment will need to be procured based on the individual circuits or assets being tested. These may include individual monitor and testing components or systems used to monitor multiple data points, devices, and systems. In order to provide the quality of data necessary for researchers, the researchers considered to be SMEs must be involved in specifying both the data requirements and the communication protocols necessary. For example, simple Bluetooth sensors may be adequate in some cases more stringent requirements for sensors may require them to be ANSI or NRTL (Nationally Recognized Testing Laboratory) certified. This variety of requirements is expected to be diverse but suggested metering protocols that can apply to microgrid control SunSpec Modbus (200 series information model) or IEEE Std. 2030.5.

3.3.8 Electric Grid Interface

Interfacing with the electrical grid per IEEE 1547-2018 requires that the inverters or microgrid controller use either SunSpec Modbus, IEEE Std. 2030.5, or DNP3. Typically, the controls must meet the testing requirements specified in IEEE 1547.1, which is certified by a NRTL's UL 1741-

SB testing process. In the case of a microgrid, the requirements are rather unique. It is still recommended that the certification be provided however, it is sufficient that they attest to the capability to meet the requirements. Alternatively, the vendor can demonstrate that the inverter-based resources each meet the requirement and the microgrid controller will coordinate but not hinder these operations. Additionally, documentation should be requested describing the operational aspects that relate to a “do no harm” approach to the microgrid and the grid at the point of common coupling i.e., electric service entrance. This review is expected to be complicated and should include SMEs from Facilities and Operations, researcher staff, and the electrical power system operators. All of these SMEs should have in-depth understanding of IEEE 1547-2018, its intent, and the operational parameters necessary to meet the standard’s requirements. Test tools from the MESA Alliance will likely be available to aid in testing the functions associated with the requirements. Note, these will be BETA tools and should not be seen as complete or “certified” to meet IEEE 1547.

4.0 BESS Safety Considerations

Common elements related to safety include fire safety, electrical safety, and hazardous material safety. The C&Ss include those standards instituted nationally, locally, and those particular to PNNL' s campuses. PNNL employs SMEs and engineers with intimate knowledge of these requirements many of which also help to develop those safety standards pertinent to their particular area of expertise. These SMEs must be engaged early and often during the design phase and also during the procurement (including requests for information/requests for proposals [RFI/RFP]) of each asset in order to avoid potential delays, change orders, and hazards. Additionally, since tightly coupled DERs and control systems are still being developed, safety C&Ss are constantly evolving. The SMEs at PNNL working to develop them will be able to assist in identifying challenges associated with these new technologies and systems during the procurement and design phases in order to proactively work towards the safest microgrid implementation possible.

Figure 4-1 is a graphical example of the relevant C&Ss for stationary energy storage systems (ESSs) deployed in the US[1].

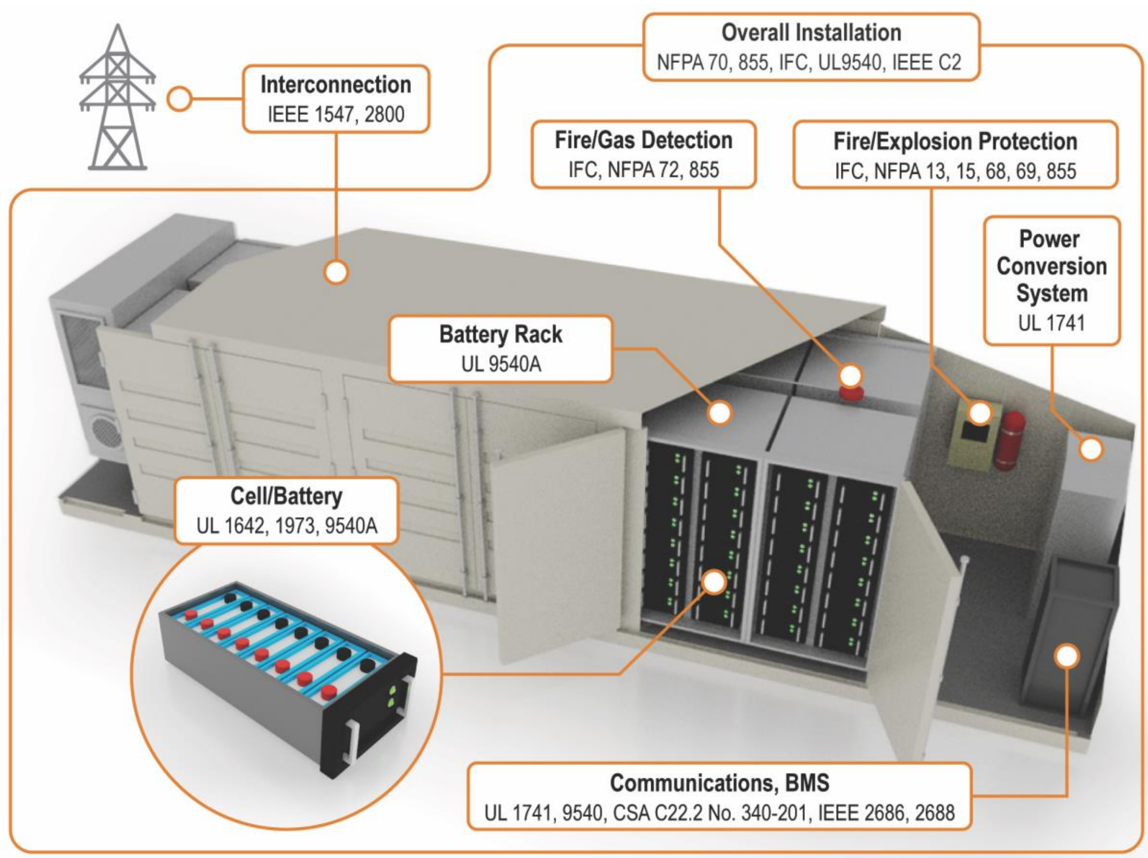

Figure 4-1. Standards Applicable To Stationary BESS Including The Related Safety Standards

[1] UL 9540 (UL 2016), NFPA 72 (NFPA 2022), NFPA 855 (NFPA 2020)

5.0 Performance Testing Guidance

This section provides an overview of common tests and verification steps performed in context of relevant C&Ss. While all may not be needed for commissioning and acceptance testing of the specific IRES assets, this information can help in the development of specific tests for IRES assets individually, and as an integrated microgrid.

Furthermore, this section provides an overview of the common stationary grid applications for energy storage and evaluates whether the existing C&Ss are enough to perform testing and performance verifications for such applications. Please note that these tests are representative, and the most common test performed for each category but may not reflect the complete list of tests which will be performed.

Table 5-1. Common Tests And Performance Verification For Energy Storage

	Unit Performance	Grid Integration	Safety
Purpose	Compliance and performance verification of energy storage	Compliance with grid integration and storage performance for grid applications	Safe operation and maintenance of energy storage
Tests	• Stored energy capacity • Round-trip energy efficiency • Ramp rate • Standby energy loss rate • Self-discharge rate • Input/output power	• Peak shaving • Frequency regulation • Voltage regulation • Intermittency smoothing • Backup power • Microgrid	• Components • Installation • Maintenance • Operation • Safety for grid events

In order to evaluate whether the existing C&Ss are adequate to perform testing and performance verification of the ES, it is important to know the application. For instance, the performance requirement and associated performance verification tests for ES to provide frequency regulation can be different from that of the performance requirement and associated tests for energy arbitrage. The evaluation in this study is done based on the testing protocols presented in Figure 1-1.

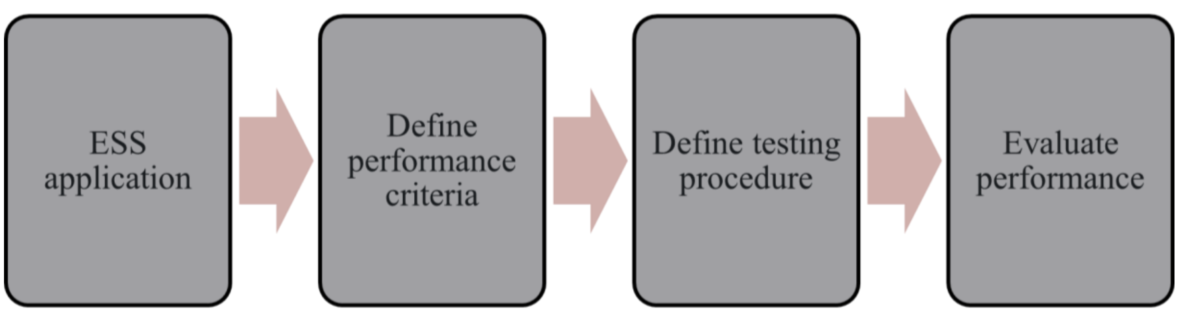

Figure 5-1. A Generic Protocol For Energy Storage Testing

First, the type of tests to be performed are identified based on the stationary grid applications. Next, the criteria for performance evaluations are defined. If the battery is to be used for frequency regulation, the performance criteria to evaluate its response time and ramping capability are more important whereas if it is to be used for energy arbitrage, performance criteria based on energy capacity will be more important. Once the application and its associated (case specific) performance metrics are defined, steps for performing the actual tests are defined. Finally, the evaluation is performed to compare the value of the performance metrics with the minimum threshold the end user has for these metrics, which varies with location and return of investment required for the project.

Table 5-2 below is oriented towards ES, and is illustrative only. As specific IRES assets are identified, specified, and then deployed – case specific asset tests should be developed.

Table 5-2. Stationary Grid Applications Covered By Existing C&Ss

Standard	Application	Metrics Considered	Remarks
IEC 62933-2-1	1. Frequency regulation 2. Voltage regulation 3. Peak shaving/peak shifting 4. Back-up power	1. Actual energy capacity 2. Input/output power rating 3. Round trip energy efficiency 4. Expected service life, 5. System response 6. Auxiliary power consumption 7. Self-discharge of the ESS system 8. Voltage range 9. Frequency range	1. Performance and acceptance criteria are not defined 2. Generic tests are defined instead of application-specific IEC 62932-2-2, currently approved for Draft Technical Specification, has application-specific tests
IEEE 1547	1. Tests for response to voltage disturbance, 2. Tests for response to frequency disturbance, 3. Synchronization 4. Voltage regulation, 5. Frequency support, 6. fault current tests	Not specific to ESS. It is generally applicable to any DER integration to the distribution system A. Type Tests B. Interoperability Tests C. Production Tests D. DER Evaluations and Commission Tests	Mostly focused on grid integration and less on-grid application. It covers a few grid applications such as frequency regulation, voltage regulation, but many application-specific tests are not explicitly covered. Moreover, those tests are not specific to ESS
UL 1741	1. Anti-islanding, 2. Low/high voltage ride through, 3. Low/high-frequency ride through, 4. Must trip tests 5. Ramp rate (normal and soft start) 6. Specified power factor, 7. Volt/VAR mode, 8. Frequency watt, 9. Volt watt	Advanced Inverter Testing only Nonspecific to ESS	Specific to inverter/converter for an islanded or grid-connected mode of testing

PNNL-22010	1. Peak shaving/management, 2. Frequency regulation, 3. Volt/VAR, 4. Renewables Firming, 5. Islanded Microgrids, 6. Power Quality, 7. PV Smoothing, 8. Frequency Control	**A. Reference Performance:** 1. Stored energy capacity 2. Round-trip energy efficiency 3. response time and ramp rate 4. Standby energy loss rate 5. Self-discharge rate **B. Application-Specific Duty-Cycle Performance Tests**	Selected examples: • IEC 62932-2-1 is standard that incorporates these performance metrics. • IEC TR (Tech Report) 62933-2-200:2021 also uses these metrics to develop test methods for EES systems located in EV charging station with PV. • IEC TS (Tech Specifications) 62933-3-1:2018 (Electrical energy storage (EES) systems - Part 3-1: Planning and performance assessment of electrical energy storage systems - General specification) has used these metrics and our duty cycles for each application.

IEC 62933 (IEC 2017) provides a generic test procedure for various grid applications, but application-specific tests are not defined explicitly. While those generic tests provide some insights about the type of tests to be performed and serve as a necessary set of tests, those generic tests will not serve as sufficient set of tests for accepting the ES for the given application. Moreover, IEC 62933 does not provide any acceptance criteria.

Similarly, IEEE 1547 standard is focused on grid integration of distributed energy resources, and it is focused less on the specific grid applications. It covers a few grid integrations tests to provide frequency regulation and voltage regulation, but the majority of these tests are not specific to the most of the grid applications. Since IEEE 1547 defines the grid integration tests for DERs as opposed to energy storage, the defined test procedures may not be specific enough to the storage.

UL 1741 provides several tests to ensure safe operations of ES in grid-connected modes. The test types it covers are primarily based on ensuring safe operation, ride though, or tripping of the energy storage for various types of grid events.

Even though IEC 62933, IEEE 1547, and UL-1741 cover a large set of grids applications from module performance, grid integration, and safety perspective, those standards still lack in terms of defining the acceptance criteria and application-specific duty-cycle tests. To fill this knowledge gap, PNNL_22010 provides a comprehensive set of stationary grid applications, performance criteria for each application, and application-specific duty cycle tests to evaluate the suitability of the energy storage for a given application.

6.0 Conclusions

This report presented a summary of technical attributes of the IRES microgrid projects planned resources. The resource plan includes generation (e.g., PV), ES (e.g., BESS) and controlled loads (e.g., V1G EV chargers). The summarized technical attribute will inform the specifications of the overall microgrid controller capabilities and specifications for the IRES project. The information will also inform the execution of PNNL-Sequim facility upgrade plans with the IRES microgrid having operational flexibility to execute its intended use cases.

The IRES project is a valuable industry reference point and learning opportunity. All markets have significant challenges and opportunities in terms of development and application of C&S specific to microgrids and DERs that support microgrids, e.g., BESS. This report provides a baseline to evaluate IRES project-specific needs and also attempts to inform general industry efforts for development of C&S to support the adoption and use of microgrid and clean/advanced energy technologies, products, and systems.

7.0 References

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